ROCK MECHANICS IN JAPAN

VOLUME V

JAPANESE COMMITTEE FOR ISRM

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PREFACE

"Rock Mechanics in Japan, Volume V, 1987" was compiled by the Japanese Committee for ISRM in order to introduce the research activities on rock mechanics in Japan from 1982 to 1986 to researchers and engineers concerning rock mechanics in the world. This will be published every 4 years and time of publication will be the same of that of the Congress of International Society for Rock Mechanics.

The Japanese Committee for ISRM is organized under the cooperation of four societies; Japan Society of Civil Engineers, The Japanese Society of Soil Mechanics and Foundation Engineering, The Mining and Metallurgical Institute of Japan and The Society of Materials Science, Japan. This Committee is a representative organization in Japan for ISRM, established with the object of attaining the smooth communication of mutual research activities in Japan and abroad, and now consists of 276 personal members of ISRM and 66 supporting members.

The Rock Mechanics in Japan, Volume V, 1987 consists of three parts. In the first part are described the brief comments on the activities of the Japanese Committee for ISRM and on the research activities of the related four societies, the second part the abstracts of all the papers on rock mechanics appeared in the journals and proceedings of these societies. The third part is the list of literatures of the papers on rock mechanics appeared in the 28 publications issued by the four societies as well as the related societies and institutes in Japan. For convenience of citation, every paper is classified according to the International Geotechnical Classification System (I.G.C.).

The Rock Mechanics in Japan, Volume V, 1987 indicates some of the enthusiasm with which rock mechanics is approached in Japan. Quite a number of papers on rock mechanics and rock engineering have been published in Japanese every year. Unfortunately the language barrier often disturbs mutual understandings and data exchanges between rock engineers. It will be a great pleasure if this publication be of use to introduce Japanese research activities to the world and can contribute to the development of rock mechanics.

March 1987

K. akai

Koichi AKAI
Chairman of Japanese Committee
for ISRM

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I. RECENT ACTIVITIES

ON

ROCK MECHANICS IN JAPAN

1982—1985

RECENT ACTIVITIES ON ROCK MECHANICS IN JAPANESE COMMITTEE FOR ISRM

1. Recent Activities of the Committee.

In August, 1979, the Japan Joint Committee on Rock Mechanics of Japan Society of Civil Engineers (JSCE), the Mining and Metallurgical Institute of Japan (MMIJ), the Japan Society of Soil Mechanics and Foundation Enginnering (JSSMFE) and the Society of Materials Science, Japan (SMSJ) has been reorganized as the Japanese Committee for ISRM with 62 supporting members (companies) and 180 individual members.

Through the experiences on the successful organization of the International Symposium on Weak Rock, Tokyo, 1981 sponsored by ISRM, activities of the committee has grown up in quality as well as quantity. Since 1982, the committee has edited and published every year the classified list of the paper published in the field of rock mechanics in Japan. Furthermore since September, 1984, the committee publishes quarterly the news letter of the committee. At present, the committee has 69 supporting and 253 individual members, and hopes to host the 8th International Congress on Rock Mechanics in 1995.

The members of the committee supports the international cooperation of ISRM as members of the Commission on Computer Programs, the Commission on Rock Boreability, Cuttability and Drillability, the Commission on Rock Failure Mechanisms in Underground Openings, the Commission on Testing Methods, and so on.

Particularly, in the Commission on Testing Methods, Professor K. Sassa is in charge of coordinater of WG on Seismic testing within and between boreholes, and other individual members of the committee are working as the member of WG on Drilling and Boring Test, WG on Fracture Toughness Testing, WG on Surface seismic Methods, WG on Vibration and Blast Monitoring, and so on.

2. General Trend of Research Activities.

In December, 1984, the committee organized 6th Japan Symposium on Rock Mechanics, which was sponsored by JSCE, MMIJ, JSSMFE and SMSJ. The first through 5th sumposea had been organized every 3 years since 1964, by the Joint Committee on Rock Mechanics, the predecessor of the present committee. Although there has appeared a trend of increase of the presented papers as shown in Fig. 1, and the symposium had been organized after 7 years break, because the International Symposium on Weak Rock had

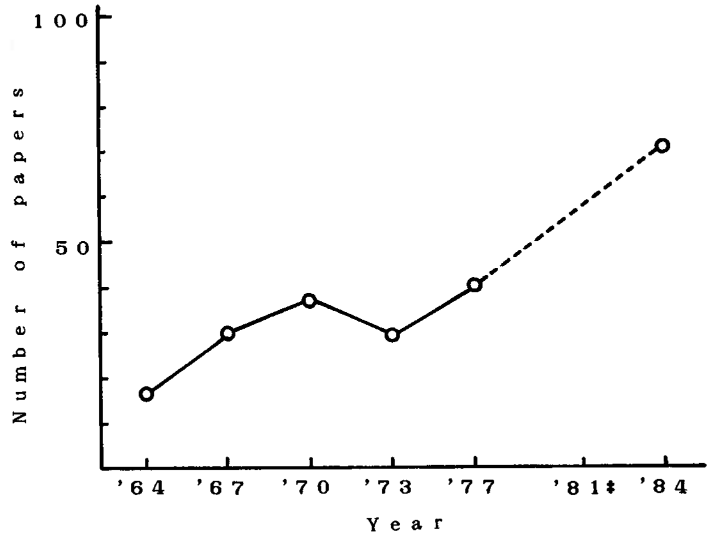


Fig.1: Increasing Trend of papers presented at Japan Symposium on Rock Mechanics
* In 1981, Int.Symp. Weak Rock had been held in Tokyo.

been organized in 1981, 70 papers had been presented in this Symposium held in Kyoto. They are classified into following 4 session themes;

Session 1: Properties of rock, rock mass and earth crust, consisted of 25 papers.

Session 2: In situ measurements, consisted of 9 papers.

Session 3: Structural foundation, excavation and rock slope stability, cosisted of 22 papers.

Session 4: New Fields in rock mechanics, consisted of 14 papers.

Table 1: Classification of papers on rock mechanics published in Japan

Subject	1982	1983	1984	1985	Total
General	2	0	0	2	4
Engineering geology and seismology	21	13	13	28	75
Site investigation	45	29	32	36	142
Engineering problems of weak rock	0	15	4	9	28
Rock propoerties	92	107	161	138	498
Analysis of rock engineering problems	103	100	145	86	434
Design, construction and behaviour of engineering works	61	81	120	67	329
Construction methods and equipment	31	31	30	35	127
Total	355	376	505	401	1637

Application of rock machanics covers various fields of engineering as well as science. However, general trend of research activities on rock mechanics would be reflected in the number of publications, and Table 1 shows a classification of papers on rock mechanics published in Japan from 1981 through 1985.

Y. Nishimatsu, Professor,
Chairman of Secretarial Board,
Japanese Committee for ISRM

RECENT ACTIVITIES ON ROCK MECHANICS
IN
JAPAN SOCIETY OF CIVIL ENGINEERS

1. Organization of Rock Mechanics Committee

The Rock Mechanics Committee of Japan Society of Civil Engineers (hereafter referred to as JSCE) is the chief executive body of JSCE on rock mechanics. The committee consists of forty four experts on rock mechanics from various fields such as universities, government organizations, consultants, contractors and other private sectors. The chairman of the committee is Dr. R. Iida, who is the executive director of Dam Engineering Center. The committee has four permanent subcommittees, i.e., the subcommittee on Dams, Tunnels and Caverns, Theory and Experiment, and Soft Rocks. The committee also has a temprary subcommittee on Education on Rock Mechanics. Each permanent subcommittee consists of thirty to thirty five members, and temporary subcommittee has seventeen members.

2. Activities of Subcommittee

The Subcommittee on Dams (Dr. K. Kikuchi, chairman) has been working on the revision of "Geologic Investigations on Dams" which was first published in 1977 from JSCE. The increase of the construction of embankment dams in the latest decade required the revision of the first edition of Geologic Investigations on Dams, which is mostly oriented to concrete dams. The Subcommittee has organized a working group on seepage problems in rocks to promote research works in this field.

The Subcommittee on Tunnels and Caverns (Mr. K. Yoshikawa, chairman) has been studying the evaluation and application of the results of investigations, tests and measurements in tunneling. The fruits of the study will be published in near future.

The Subcommittee on Theory and Experiments (Dr. S. Hibino, chairman) has been studying and compiling the bore hole testing method. The Subcommittee also has been working at the insitu stress measurement.

The Subcommittee on Soft Rocks (Prof. Dr. K. Kojima, chairman) has been making researches on the procedures of investigations and testing of soft rocks. The soft rock classification is another theme of this committee.

The Subcommittee on Education (Prof. Dr. Y. Nishimatsu, chairman) was established in 1984 to enhance the education on rock mechanics for undergraduate students. The committee has already collected and analyzed the curriculums on rock mechanics in all Japanese universities. The committee also has investigated the curriculum of rock mechanics to meet the demand of the industry.

3. Symposia and Work Shops in JSCE

(1) Symposia

The symposium on rock mechanics has been held every year by the Rock Mechanics Committee of JSCE. The following are the number of papers submitted and the participants attended. The rapid increase of the number of papers indicates the surge of the study on rock mechanics in Japan.

The 14 the Symposium in 1982 with 38 papers and 250 participants.
The 15 the Symposium in 1983 with 47 papers and 341 participants.
The 16 the Symposium in 1984 with 64 papers and 295 participants.
The 17 the Symposium in 1985 with 62 papers and 194 participants.

Among the various fields on rock mechanics, special interests have been attracting to the fields such as discontinuity problems in rock-masses, soft rocks, transfer of water, heat and air in rock-masses, vibration problems and behavior of rocks during and after excavation. Most of the increase of papers contributed to the Symposium fall under these subjects, which are closely related with the growing demand from the industry.

(2) Work shops

Work shops on specified topics have been held one to two times each year by the Rock Mechanics Committee. The topics of the work shops are 1 International Conference on Rock Store in Sweden, 2 Arhen Conference, 3 Foundation Treatment in Filldams in Japan, 4 Rock Mechanics in Tunneling, 5 In-situ Measurement Conference in Zurich, 6 Radio Active Wastes, 7 Discontinuity in Rocks, and 8 Field Measurements in Tunnels and Caverns.

(3) Publications

The major publications of the Rock Mechanics Committee of JSCE from 1982 to 1985 are listed as follows:

1 Mannuals for In-situ Deformation and Shear Tests for Rocks (1983).
2 Geologic Investigations and Field Measurements in Tunneling (1983).
3 Soft Rock Engineering (1984).
4 State-of-the-art of Borehole Jacking Test (1985).

N. Matsumoto, Secretary,
Committee on Rock Mechanics JSCE

RECENT ACTIVITIES ON ROCK MECHANICS IN THE JAPANESE SOCIETY OF SOIL MECHANICS AND FOUNDATION ENGINEERING

1. The Organization of the Society and its Activites

The Japanese Society of Soil Mechanics and Foundation Engineering (JSSMFE) was established in 1949, for the purpose of developing the theory and practice concerned to geotechnical engineerings. The JSSMFE has at present the individual members of 13,000, and they belong to the wide specialized fields such as civil, architectural, agricultural and geological engineerings.

The results of their activities have been published in the Journal of JSSMFE "Soils and Foundations", in book form edited by JSSMFE, and at the Japan National Conference on Soil Mechanics and Foundation Engineering, held every year. Last Conference of the 21th in 1986 had the participants of 1481 investigaters, and the presentations of 786 papers. Among them, the papers related to rock mechanics are as follows;

(a) Properties of rock and rockmass : 40

(b) Underground excavation : 14

(c) Dynamic properties and others : 10

The activities of the committee on rock mechanics at JSSMFE started in 1966. The results of them until 1982, have already been reported in "Rock Mechanics in Japan, Volume 1 ~ VI" published by the Japanese Committee for ISRM.

2. Recent Activity of the Committees on Rock Mechanics in JSSMFE

The recent activities of the committees at JSSMFE: the research committee on rock mechanics and the editorial committees, are summerized as follows;

2.1. The Research Committee on Rock Mechanics

(1) Main research subject: [Comparative study on the estimated and measured rock behaviors]

Up to the present, a large number of in-situ and laboratory rock testings have been performed all over the world for design and construction of various kinds of rock structures, such as dam, underground excavation and etc.

However, the very important and practical problem how to interpret the test results obtained from small scale of rock specimen/mass, and how to apply them to the actual problem by far the larger scale of rock structure, has not yet been enough solved. It can be said that this problem is one of the most important and fundamental subjects for rock engineering.

The powerful sourses of data for considering this problem shall be the case histories having both of the estimated and measured rock behaviors in actual works. So, the committee on rock mechanics of JSSMFE has collected these data and been discussing the problem based on them.

The collected data are of the representative case histories of Japan and of making set both of the estimated and measured rock behaviors. These are every two cases of dam, rock-slope and foundation of long-span suspension bridge, respectively, and every three cases of tunnel and underground opening.

The result of this research will be published in book form, from JSSMFE in a short time.

(2) Other subjects: [Interpretation and Application of the Results from Site-Investigation, Rock Testing and Monitering]

This subject is a research theme proposed after committee work for the main subject above mentioned has almost finished. The purpose of this subject is to make clear the advantages and disadvantages of investigation/testing methods generally used in rock engineering, based on the principle, accuracy, relationships between related other methods and etc.

The details of new subject are under discussing in the committee.

2.2. Editorial committees on rock mechanics

(1) The Editorial Committee for [Soft Rock]

The editorial committee started in 1983, and its task finished in 1986. The text titled "Sedimentary Soft Rocks in Geotechnical Engineering" is published in June 1987 from JSSMFE. Total pages are about 350. The contents of text are;

Chapter 1:	Geological Background of Sedimentary soft Rock
Chapter 2:	Physical Properties of Sedimentary soft Rocks
Chapter 3:	Mechanical Properties of Sedimentary soft Rocks
Chapter 4:	Time-dependant Properties of Sedimentary soft Rocks
Chapter 5:	Constitutive Relation and its Applicability
Chapter 6:	Tunneling in Sedimentary soft Rocks
Chapter 7:	Foundation on Sedimentary soft Rocks Dam / Bridge / Nuclear Power Plant
Chapter 8:	Slope Engineering in Sedimentary soft Rocks

(2) The Editorial Committee for [Manual for Rock Testing and Site Investigation (tentative)]

The editorial committee started in 1986. The editorial policy of this text are as follows;

The text is intended to be a guide to general engineers or design/construction enginners related to rock works. Many kinds of rock testing and site investigation methods are explained for their practical application.

R. Yoshinaka, Professor, Chairman,
Rock Mechanics Committee of JSSMFE

RECENT ACTIVITIES ON ROCK MECHANICS IN THE MINING AND METALLURGICAL INSTITUTE OF JAPAN

1. General Trend

Rising up money exchange rate of Yen as well as lowering down market price of coal and metals have brought severe economical difficulties to Japanese mining industry. In order to overcome this crisis, various technical developments and exploration of new fields of application are conducted in every field of mining. Particularly, in the field of rock mechanics, research activities on the extraction of geothermal energy, utilization of sub-surface space, and underground repository of nuclear waste have been promoted and conducted from various points of view.

The institute organizes every year several research committees on various subjects to promote research activities in the important and recent developing technical fields. Table 1 shows the research committees which have been organized and worked for the subjects related to rock mechanics in recent 5 years.

Table 1. Research Committees on the subject related to rock mechanics

Subject	Activity years					Publications	Publication year
	'82	'83	'84	'85	'86		
Standerdizationandapplication of rock test data sheet	o	o				Explanation of the rock test data sheet and collected test results On the data sheet and collected test results of the triaxial compression test	1982 1986
Design principles of roadway support	o	o	o			Design principles of roadway support	1985
Hydrofracturing for extraction of geothermal energy		o	o	o			
Classification and evaluation of the engineering peoperties of rock mass		o	o	o			
Prevention of water inflow in underground mines			o	o	o		
Field measurements of thermal peoperties of rock mass				o	o		
Development and utilization of sub-surface space				o	o		
Application of numerical analysis for the underground mines					o		
AE monitoring of the stability of rock cavern					o		
Measurement of the geometry of rock cavern with ultrasonic sensor					o		

The papers, reports and preprints in the field of rock mechanics form about 30% of total publications of the institute, and the classification of these publications in the field of rock mechanics is shown in Table 2.

Table 2. Papers and Reports Published in the field of Rock Mechanics

Study Subject	1982			1983			1984			1985			1986			Total
	J*	S*	A*	J	S	A**	J	S	A	J	S	A	J	S	A	
Mechanicalproperties and testing method of rock sample	4	26	10	6	22	0	9	22	8	6	16	1	9	6	1	146
Mechanical properties of rock mass and field measurements	1	2	0	5	6	1	0	7	7	3	9	4	2	8	5	60
Rock pressure and stoping methods in metal mines	2	8	4	1	2	1	0	1	0	1	0	1	1	2	2	26
Rock pressure and strata control in coal mines	9	17	2	15	15	2	4	14	9	5	12	3	4	15	4	130
Rock pressure and support techniques in roadway	3	3	1	5	3	2	2	4	2	1	3	3	1	2	3	38
Slope stability and surface subsidence	2	6	0	2	2	0	1	2	1	1	0	0	2	1	1	21
Excavation techniques and comminution	4	7	1	9	5	2	12	7	3	8	10	3	12	12	4	99
Permeability and thermal peoperties of rock and hydrofracturing	2	6	7	2	4	4	0	9	4	0	4	4	2	4	2	54
Total	27	75	25	45	59	12	28	66	34	25	54	19	33	50	22	574

* J: Journals, S: Spring meeting, A: Autumn meeting
** The Autumn meeting was held as the Joint-synposium of MMIJ and Aus. IMM, in 1983

2. Important Research Activities

In the coal mining in Japan, the most important problem in the field of rock mechanics is the prediction and prevention of coal and gas outburst, through recent decade.

In order to evaluate the danger of coal and gas outburst in an underground coal mine, microseismic activities have been monitored by a seismometer network located on the surface as well as underground. Furthermore, for the prediction of gas outburst which occurs after blasting, the AE has been observed in the borehole which had been drilled near to the driving face of cross-cut roadway.

The rock pressure has been measured by means of the door stopper type gauge, and monitored by the hydraulic pressure cell set in the borehole to evaluate the effect of large diameter boring (ϕ250mm) on the stress relief of coal seam.

In the metal mining, the most important problem concerning rock mechanics is the evaluation of engineering properties of rock mass and design principle of the stope as well as pillars.

In several mines, the ground movement around the roadway has been observed by means of various measuring devices during the term in which the driving face advances through the cross-section for measurements. The effect of conventional steel arch support is compared with the effect of rock bolt and sprayed concrete support by means of field measurements and theoretical analysis.

Various classification systems of engineering properties of rock mass have been compared and evaluated to be applied for design of mine pillars and stopes.

The rock stress has been measured in several mines for design and evaluation of stability of mine pillars. A hemispherical strain cell has been developed as a modification of the door stopper type strain cell, and realized the measurement of three-dimensional state of rock stress in a single borehole.

The dynamic behaviour of a blind raise boring machine has been analysed to increase the boring capacity. The effect of impact and mechanical vibration on the rock cutting are discussed.

In the field of development of geothermal energy, the principle and concept of linear fracture mechanics are applied for the design and evaluation of hydrofracturing cracks.

Y. Nishimatsu, Professor, Chairman,
Rock Mechanics Committee of MMIJ

RECENT ACTIVITIES ON ROCK MECHANICS IN THE SOCIETY OF MATERIALS SCIENCE, JAPAN

1. Committee on Rock Mechanics

This committee was established in 1963 to perform research activities regarding rock mechanics. It had held 99 regular meetings by the end of 1985.

The committee consists of about 60 researchers belonging to such departments as geology, mineralogy, geophysics, exploration engineering, civil engineering and mining engineering. The category of research subjects covers many fields. Therefore, the problems on rock mechanics are not only studied and discussed from various aspects, but mutual problems among different fields are also considered and much information can be exchanged among members. This is an outstanding feature of the Society of Materials Science, Japan.

The activities of this committee include holding about 4 regular meetings every year, the publication of a special issue of "Rock Mechanics" for the Journal of the Society of Materials Science, Japan (JSMS), and the holdings of lecture meetings, short courses and field inspections related to the rock mechanics. In addition, as an organized institute of the Japanese ISRM Committee, the committee sponsors various activities, such as conducting symposiums and conferences. At the committee's regular meeting, its activities are examined and various topics are introduced and discussed.

In this committee, a sub-committee was organized in 1971 to study the problems of grinding and crushing of materials. This sub-committee is also active, and it has held 6 symposiums to date.

2. Recent Activities

The topics taken up at the committee's regular meetings between 1982–1985 are as follows:

*** Geology and geophysics ***

1) The estimation of geophysical disturbance in the earth crust by tiltmeter and extensometer (proposed by I. Ozawa)
2) The geology in the plateau of Tibet (proposed by T. Nishiyama)
3) Materials in the earth's interior (proposed by I. Ozawa, S. Matsushima, H. Watanabe and N. Sumitomo)
4) Basemental terrains of the upper crust viewed from plate tectonics in Japan (proposed by K. Wadatsumi)

*** Exploration engineering ***

1) Safety monitoring of the roof rock of underground openings by elastic wave propagation (proposed by K. Sassa)
2) Remote sensing for the exploration of oil reservoir (proposed by M. Asada)
3) Earth radar (proposed by T. Hara)

*** Physical and mechanical properties of rocks ***

1) AE rate controlled compression tests of rock (proposed by M. Terada)
2) Physical properties of cracks in rocks under a high confining pressure (proposed by H. Yukitake)
3) The thermal conductivity of rock subjected to high pressure (proposed by H. Watanabe)
4) Engineering properties of crustal materials (proposed by T. Adachi)
5) The application of seismic computer tomography to rock mechanics (proposed by T. Yanagidani)
6) Landslides due to earthquakes in USGS (reported by Y. Kobayashi)

*** Numerical analysis and its application ***

1) The application of Cundall's model to gravity flow analysis of rock-like granular materials (proposed by H. Kiyama)
2) The 4th International Conference on Numerical Methods in Geomechanics and International Workshop on Constitutive Behavior of Soil (reported by T. Adachi)
3) The boundary element methods and their application to engineering (proposed by S. Kobayashi)
4) The back analysis of tunnel linings (proposed by M. Hisatake)

*** Engineering phenomena and their application to design ***

1) Gas burst at a coal mine in Japan (proposed by Y. Hiramatsu and T. Saito)
2) The International Symposium on Rock Mechanics Related to Caverns and Pressure Shafts held at Aachen, 26–28 May, 1982 (reported by T. Kawamoto)
3) Research activities in SMEC and CSIRO, Australia (reported by T. Kawamoto)
4) Dynamic properties and shaft resistance of a diatomaceous madstone (proposed by H. Sekiguchi)
5) Several features of rock burst in Japan (proposed by T. Saito)
6) The status of underground storage of radioactive waste in the world (reported by Y. Onishi)
7) Estimation of mechanical properties of rock mass and its approach to the design of rock structures (proposed by S. Sakurai)
8) Present studies of rock mechanics in U.S.A. (reported by C. Tanimoto)

A number of original papers on rock mechanics and their application have been published in regular issues of JSMS. One project of this committee was the publication of special issues of JSMS, Rock Mechanics No. 6 in Aug., 1982. Another was the lecture titled "Materials in the Earth" published serially in every issue of JSMS between Aug. and Nov., 1984. The contents of these issues are as follows:

*** Rock Mechanics No. 6 (5 reviews) *** JSMS, Vol. 31, No. 347, 1982

1) Engineering properties of geotechnical materials – especially soft rocks – (by S. Kobayashi and T. Adachi)
2) In-situ tests of rock masses and interpretation of the results (by S. Sakurai)
3) Mechanics of soft rocks and numerical analysis (by T. Kawamoto and Y. Ichikawa)
4) Design and construction in weak rock masses (by C. Tanimoto, Y. Onishi and T. Saito)
5) Research on dynamic properties of rock and tectonic problems (by Y. Kobayashi and H. Ito)

*** Lecture "Materials in the earth" *** JSMS, Vol. 33, Nos. 371–374, 1984

1) Materials in the earth's interior (I) (by I. Ozawa and S. Matsushima)
2) Materials in the earth's interior (II) (by H. Watanabe and N. Sumitomo)
3) Materials in the earthcrust (I) – Basemental terrains of the upper crust viewed from plate tectonics in Japan – (by K. Wadatsumi and K. Fujita)
4) Materials in the earth crust (II) – Engineering properties of crustal materials – (by S. Kobayashi and T. Adachi)

The committee also sponsored two short courses and a field inspection during the last 4 years:

*** Short Course: "Tendency in Research Related to Weak Rocks and its Problems" was held on 26 Nov., 1982. The applications to test, design and work for the construction of structures in/on weak rocks were discussed in this course.

*** Short Course: "Materials in the Earth" was held on 20 Nov., 1985. The utilization of earth materials was discussed from the aspects of geophysics, geology and engineering.

*** Field Inspection was held at the Abo Pass and the Kamioka Mine in central Japan, on 3 and 4 Oct., 1985. At the Abo Pass, two test tunnels had been constructed in hot rock masses with spring water. At the Kamioka Mine, zinc and lead ores had been mined from large ore deposits by sub-level stopping and cut-and-fill methods.

The sub-committee held the 6th symposium "New Techniques in Grinding and Crushing of Materials" on 14 and 15 Mar., 1984.

M. Terada, Professor, Chairman,
Committee on Rock Mechanics, SMS, J

II. ROCK MECHANICS ABSTRACTS

Rock mechanics abstracts consist of literatures on rock mechanics and related fields published in Journals and periodicals by Japanese Committee for ISRM and its organizing four societies; JSCE, JSSMFE, MMIJ and SMS, J.

The period for listing of this volume 5 is limited from the beginning of 1982 to the end of 1985.

The symbols, A–1, A–2, --- S–3 which can be seen at the end of each abstract correspond to I.G.C. classification symbols. The details are presented in Chapter III.

B. [Engineering Geology]

(1) Damages to Railway Tunnels Due to Earthquake

Yoshikawa, K.

Tsuchi-to-Kiso, JSSMFE, Vol. 30, No. 3, pp. 27–32, 1982,

This paper outlines the damages to the railway tunnels due to the past earthquakes, damages to the Tanna tunnel and Inatori tunnel due to earthquake faults which are respectively caused by Kitaizu earthquake in 1935 and Izu Ohshima kinkai earthquake in 1978 and the also presents prevention of earthquake disasters depend on operation system and Strenghening to tunnels by Japanese National Railways et al.

(B-4, H-5)

C. [Site Investigations]

(1) P Wave Velocities in Rock Mass with Water-Saturated Cracks

Sassa, K., Ryu, M. and Sugimoto, T.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 163–168, 1984,

In this study, it is clarified both experimentally and numerically that P wave velocities in rock mass with water-saturated cracks are not the time average velocity (Va) which is defined below:

$$\frac{L}{Va} = \frac{Lc}{Cw} + \frac{L-Lc}{Cr}$$

where, L; length of ray-path, Lc; sum of the thickness of the cracks across the ray-path, Vw; P wave velocity in the material filling up cracks, Vr: P wave velocity in rock with no cracks.

The reason why P wave velocities in the rock mass do not coincide with Va is as follows. The wave form of the P wave is formed by the superposition of the many waves having different ray-paths. The ray-path of the first one has no reflection at the contact plane between rock and the material in cracks. The ray-paths of many other waves except the first one have multiple reflections at the contact planes, then, the arrival times of these waves are delayed compared with that of the first one. The amplitude of the first one decreases with increase of the number of the cracks, while, the number of the waves having different ray-path with multiple reflections increases with increase of the number of the cracks through which P wave travels. In the field, propagation velocities are measured by using the wave of which wave length is much longer than the thickness of the cracks, therefore, the arrival time which can be detected from the records is mainly controlled by the superposition of the waves of which ray-paths have multiple reflections. Accordingly, P wave velocities in rock mass with water-saturated cracks decrease with increase of the number of the cracks even if the sum of the thickness of the cracks (Lc) remains constant. This means that the time average formula can not be applicable for P wave velocities in rock mass with water-saturated cracks.

(C-2)

(2) In-Situ Evaluation of Shear Strength of Rock by Borehole Shear Test

Tanaka, T., Funato, A. and Sone, Y.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 169–174, 1984,

The Rock Borehole Shear Test (RBST) apparatus is developed to determine shear strength parameters of the walls of a test borehole. The RBST showed to be a practical method for relatively rapid testing of the rock masses in situ.

The fundamental idea involved in RBST is performing a series of direct shear test on the side walls of a borehole. This is accomplished by forcing serrated plate against the wall of the hole and then pulling the plate axially along the borehole to induce shear(Fig. 1, Fig. 2). As in conventional direct shear testing, a sereis of tests with different applied normal stresses (σN) are performed, and the corresponding shear stresses (τ) are measured. The results are then plotted to define the Mohr-Coulomb failure envelope with internal friction angle (ϕ) and cohesion (C).

The RBST tests have been conducted in various sites and for different types of rock, soft to moderately hard rocks such as weathered granite, sandy silt stone, tuff, tuff breccia, sand stone, andesite and others. Some results obtained from these tests are as follows.

- On soft rocks, the RBST tends to give equivalent values of strength parameters to those of the former method such as in situ rock direct shear test.
- Strength anistoropy of rocks may be investigated by performing RBST in boreholes with different directions.
- The proposed method is effective to determine the shear strength characteristics of rock masses of broad area and also to use for engineering classification of rock masses.

(C-8, F-6)

(3) Determination of the C and ϕ In-Situ by the Result of Borehole Load Test

Takeuchi, T. and Ohhashi, T.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 175–180, 1984,

The method is proposed for determining the shear strength C and ϕ of uniform and clackless rock mass as soft rocks from the results of borehole load tests. This method is based on the fact that the yield stress, which is determined from the stress-deformation curve obtained from the borehole load test, is a function of the confining pressure in-situ.

Assuming an elasto-plastic model with the Mohr-Coulomb's criterion, the relationship between stress and displacement of borehole wall after yielding is obtained.

The confining pressure, Po, is determined as the stress, Po', at which the stress -deformation curve obtained from borehole load test begins to form a straight line.

In almost case, the stress, Po', is similar to the lateral pressure, which is calculated by use of the weight per unite volume, poisson's ratio, and depth, although exceptional cases may be exist.

The yield stress can be obtained from drawing a series of curves having yield stress, Py', as parameter and selecting one of the curves coincides with measured stress-deformation curve.

The test should be carried out at more than two points of different depth in the layer considered to have similar shear strength, i.e. cohesion C and angle of friction ϕ. C and ϕ can be obtained from the relationship between the yield stress, Py', and confining pressure, Po.

Then, evaluated values of C and ϕ are compared between the two cases; the one case is that a confining pressure is calculated, and the other case is that a confining pressure is defined as a stress at the point Po' on a stress-deformation curve. There are no significant difference in both cases.

(C-8, F-6)

(4) Ground Assessment Methods for Nuclear Power Plant

Ground Assessment Working Group, Ground Integrity Subcommittee, Committee of Civil Engineering of Nuclear Power Plant

Proceedings of the Japan Society of Civil Engineers, No. 358, pp. 11–26, 1985,

Standardization of seismic assessment of geotechnical property of foundation ground has been studied.

The national design criteria of whole structure of nuclear power plant has been authorized according to the seismic standard of Japanese Government.

Evaluation of geotechnical properties of foundation and slope have been studied based onthe several case studies of realistic sites of nuclear power plants in Japan.

The scope of this study involves preliminary site survey of potential active faults, rock classification and flow chart of geotechnical survey for the safety assessment on the strength, deformability, permeability for seismic assessment.

Evaluation of safety should be carried out by means to the preliminary pseudo-static analysis, subsequent detailed static analysis and the final dynamic analysis.

Degree of safety should be evaluated by the factor of safety depending upon the using methods of analysis. Required factors of safety are proposed based on the realistic and systematic case studies. (C-0)

(5) Application of Airborne MSS Data to Geomorphological and Geological Surveys for Road Construction in Mountainous Area

Gotoh, K., Setojima, M., Fukazu, N. and Koga, M.

Proceedings of the Japan Society of Civil Engineers, No. 358, pp. 53–60, 1985,

The construction of a new expressway in mountainous areas requires cutting off slopes and crossing over desolated valleys throughout the areas. For the purpose of rational design and performance of such a road, a considerable amount of information has to be acquired on the nature of the terrain through which the road will be built. This paper discusses the value of using the remote sensing technique for geomorphological and geological surveys recently undertaken for a highway in Kyushu district, southern part of Japan. Remote sensing data used for analysis were obtained with a multispectral scanner (MSS) on board an airplane. These data are analysed both analogly and digitally in comparison with results from interpretation of aerial photographs and direct reconnaissance surveys. (C-1)

(6) Preferred Orientation of Preexisting Microcracks in Granite Quarries

Kudo, Y., Hashimoto, K., Sano, O. and Nakagawa, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 290–294, 1984,

Granitic rocks have three mutually perpendicular planes along which they are most easily splitted. These planes are called, in quarryman's terminology, as rift, grain and hardway planes, in order of ease of splitting and sometimes called as bedding, rift and hardway planes. The phenomenon of rifting in granitic rocks have been known for a long time. Despite their importance in determining mechanical behavior of granitic rocks, these planes have not received the attention, especially in civil engineering devision.

Experimental results show that rifting depend on the preexisting microcrack behavior preferentially oriented along these planes. For example, the compressional wave velocity is the highest in the direction normal to hardway plane, the least in the direction normal to the rift plane. Furthermore, at high hydrostatic pressure, anisotropy of linear compressibility decrease and compressibility are equal to the intrinsic values. Microcracks with preferred orientation bring about the anisotropy in the mechanical properties of granitic rocks. Therefore, from technical point of view, it is important that we know the preferred orientation of microcracks in advance.

In this study, preferred orientations of the rift were surveyed at several granite quarries in Setouchi District. It became clear that most obvious preferred orientation of microcracks in this area was nearly horizontal without exception. (C-9)

(7) Data Base System for Laboratory Mechanical Properties of Rocks
Imazu, M.
Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 71–75, 1985,

In case of designing and constructing the structures, especially large scale rock cavernes, there have been many laboratory tests and in situ tests to determine mechanical properties of rock until now. But after construction, these test results has not been used effectively. In case of next construction near the location, where test results have already been obtained, there are many opportunities to use these data with relation to similar layers. Thus, it is hoped that these test results should be included in the data base system with the same format of collection and arrangement. There have been many data base systems for soil properties and layer data, but scarcely for mechanical properties of rock. Therefore, the data base system "ROCKBAN1" is developed to collect the laboratory test results of the rock's mechanical properties, that is, (a)density, (b)modulus of elasticity, (c)modulus of rigidity, (d)poisson's ratio, (e)compressive strength, (f)tensile strength. An example is shown in Fig-1.

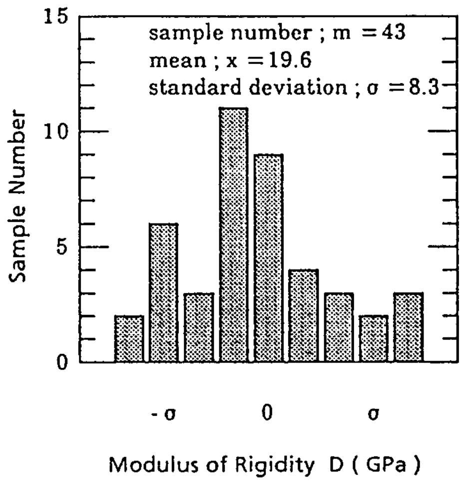


Fig - 1 Frequency Distribution of Rock Materials (GRANITE) --- Example --- (C-9)

(8) The Analysis of Pressure-Time Data by Hydraulic Fracturing to Determine the Stress State

Kuriyagawa, M., Kobayashi, H., Matsunaga, I. and Kosugi, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 96–100, 1985,

Hydraulic fracturing is often used for the determination of in-situ stress state. Recently, Mizuta proposed to measure the three-dimensional stress by hydraulic fracturing with the three boreholes which orients to the different direction.

In this paper, the problems arrising along with the three dimensional stress measurement are discussed. The stress concentration around the borehole arbitarily oriented to the principal stress directions with applyimg the hydraulic pressure is analysed.The orientation of hydraulic fracture is determined from the stress concentration. It is also shown that the problem can reduce to the two demensional situation of the plane perpendicular to the borehole axis, when the fracture parallel to the borehole axis initiates.

Then the basic procudure of our hydraulic fracturing test is shown. The fracture opening pressure is obtained by comparing 1st and 2nd cycle of pumping and instantaneous shut-in pressure (ISIP) is determined by the asymptotic method proposed by L.Aamodt.The interprepation of pressure-time data is also discribed with the relation to the fracture orientation.

(C-7)

(9) Study on Estimating Geostresses by Acoustic Emission

Murayama, S., Michihiro, K., Fujiwara, T. and Yoshioka, H.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 101–105, 1985,

Since a triaxial stress condition is common in rocks, the effects of stresses in defferent direction from the loading direction was investigated to interpret the Kaiser effect of AE. Cubic specimens with dimensions of 15cm x 15cm x 15cm were subjected to repeated stresses of fifty cycles in three principal directions. The stresses which were applied in the X, Y and Z directions one after another were 9.8, 14.7 and 19.6 MPa, respectively. And monotonous stress was given to applied to a specimen cored from X direction up to 11.8 MPa. As a result, the previous stress could be estimated without adverse effects of stresses in other directions by means of the Kaiser effect of AE.

Additionally, creep strains of rock under in-situ stress conditions are considered to have reached stready state, referred to as saturated strain state here. Cylindrical specimens in the saturated strain state were prepared at the laboratory under a constant stress of 14.7 MPa to achieve a constant rate of creep strain. After removal of the applied load, reloading stress of 16.7 MPa was gradually applied on the specimen to monitor its AE activities. Therefore, it is possible by means of the Kaiser effect of AE to find the previous stress which corresponds to the same strain as the maximum one for the previous unloading event.

It is crearly concluded from the results of the experimental studies described here that geostresses of granite in saturated-strain state can be estimated by means of Kaiser effect of AE even when there are different principal stresses. (C-7)

(10) Application of Computed Tomography to Geological Investigation
Sugawara, H., Tamada, A. and Namiki, H.
Tsuchi-to-Kiso, JSSMFE, Vol. 33, No. 7, pp. 53–56, 1985,

Geological investigations of a dam basement are usually conducted by utilizing bore holes and adits as well as seismic prospecting and geological survey. However, there are some cases where adequate geological investigations can not be carried out for various reasons, such as the limitation of a budget and time, and vast area remains uninvestigated. In such cases one may encounter serious problems while constructing dams. Computed tomography is one of the useful geological investigation methods for these situations.

The computed tomography was applied to the geological investigation of a dam site. It was found that the computed tomography could detect faults and other geological defects and was an effective method in improving the accuracy of evaluation of geological features of the above-mentioned uninvestigated area. (C-2)

(11) Photogeological Interpretation on Slope Failures Resulted from the Naganoken-Seibu Earthquake
Yajima, S. and Obara, K.
Tsuchi-to-Kiso, JSSMFE, Vol. 33, No. 11, pp. 13–17, 1985,

This report summarizes the result of photogeological interpretation on slope failures resulted from the earthquake for the purpose of data preparation for the engineering prevention works of disasters. The interpretation has revealed that the earthquake was responsible for occurrence of 265 slope failures. The largest one is located in an area which consists of the stage-III volcanic products of Mt. Ontake volcanics. Materials from it were accumulated along the Otaki River by dry avalanche and subsequent mud flows. The mud flow sediments appear to be relatively cohesive in view of their texture judged from the aerial photographs. (C-1)

(12) Disasters Due to the Naganoken-Seibu Earthquake and Their Relationships with Topography and Geology

Taga, N., Kobayashi, T. and Kochou, T.

Tsuchi-to-Kiso, JSSMFE, Vol. 33, No. 11, pp. 25–31, 1985,

Disasters due to the Naganoken-seibu Earthquake are discussed mainly based on the topographical and geotechnical engineering point of views. It is pointed out that the primary factors of these disaster are characterized by the relationships among volcanic topography, geology, and artificially cut and filled ground on the slope of mountain area, and structures (roads, tunnels, bridges, retaining walls, houses).

(C-9)

(13) Remote Sensing for a Large-Scale Slope Failure Triggered by the Western Nagano Prefecture Earthquake, 1984

Goto, K. and Aiko, T.

Tsuchi-to-Kiso, JSSMFE, Vol. 33, No. 11, pp. 33–38, 1985,

The western Nagano prefecture earthquake, 1984 was characterized by a large-scale slope failure and a subsequent gigantic debris flow. This paper investigates these natural disasters through the remote sensing technique and consists of two parts. The first part is concerned with the failure mechanism, and the origin of the failed slope is studied by the use of airborne MSS data obtained before the disaster. The study revealed the presence of weak portions in the origin. In the second part, the failed slope and the debris flow were identitied using MSS data obtained from the Landsat-4 satellite after the disaster.

(C-1)

(14) On the Slope Failure and Geological Features at Matukoshi District Due to Naganoken-Seibu Earthquake, 1984

Kondo, T., Takita, H. and Sakata, S.

Tsuchi-to-Kiso, JSSMFE, Vol. 33, No. 11, pp. 47–52, 1985,

On September 14, 1984, the magnitude 6.8 "the Naganoken-seibu Earthquake" occurred, with its epicenter under Otaki Village, Kiso County, Nagano Prefecture. The earthquake caused large scale slope failures of the southeast slope of Mt. Ontake and in the Matsukoshi and Takikoshi regions. In addition, there were numerous small scale slope failures.

Immediately following the earthquake, the authors conducted a survey of the main area of damage. The survey covered the state of damage and geological structure. It determined in detail the geological structure of the region where the slope failures occurred in the Matsukoshi region.

It was found that there is a buried valley along the upper surface of the paleozoic layer, which forms the foundation of the region where the slope failures occurred. Also, there is a large resorvoir of underground water among the volcanic conglomorate, and above it the soft tuff, ejecta from Mt. Ontake, has been accumulated in the buried valley. Finally, it was found that beneath this tuff, which collapsed during the earthquake, the underground water was supplied from the volcanic conglomerate, and the earthquake induced the pore water pressure build up in the ground.

This report covers the results of the survey and the factors leading to the slope failures in the Matsukoshi region.

(C-9)

(15) Mechanism of Slope Failures by the Naganoken-Seibu Earthquake 1984 and the Characteristics of Pumice

Kawakami, H., Konishi, J. and Saito, Y.

Tsuchi-to-Kiso, JSSMFE, Vol. 33, No. 11, pp. 53–58, 1985,

Slope failures at volcanic mountain Ontake and a slope failure at Matsukoshi district of Otaki village induced by a strong earthquake are discussed in some detail. A pumice stratum is suspected to have acted as the sliding surface in both slope failures.

Water contents of the pumice strata are higher than their liquid limits, so that the pumice strata would easily fluidize when they were sheared and remolded. The mechanical behavior of the pumice under repeated loading is described.

(C-9)

(16) Slope Failure at Matsukoshi by the Naganoken-Seibu Earthquake

Taniguchi, E., Kubota, T. and Kuwabara, T.

Tsuchi-to-Kiso, JSSMFE, Vol. 33, No. 11, pp. 59–65, 1985,

The paper describes slope stability analyses of a slope failure at Matsukoshi, Nagano Prefecture, which was due to the Naganoken-seibu Earthquake of September 14, 1984. The results of the analyses showed that the safety factor is less than 1 for a collapsed slope and over 1 for a non-collapsed slope. The analyses employed a dynamic soil strength which was determined from cyclic triaxial tests on undisturbed samples, and the equivalent seismic coefficient was determined from finite element analyses.

(C-9)

(17) Studies on Support Load and Deformations of Ring Supports Subjected to Heavy Pressure

Kobayashi, R., Yamashita, N., Takada, Y., Matsuki, K. and Takahashi, H.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 98, No. 1127, pp. 7–14, 1982,

In the Hokuroku District at Akita prefecture, overcoming the difficulties such as the road closure due to the heavy rock pressure is an important problem to decrease the maintenance cost of the drifts.

This paper reports the results of in situ measurements carried out for more than a year at Shakanai Mine as well as those of the laboratory investigations on the core specimen from the mine.

The hydraulic pressure cells shown in Fig. 9 are installed between the ring supports and the rock mass at the 220m level drift as shown in Fig. 3 and, at the same time the deformations of the ring supports both in the direction of the drift axis and in the plane of the ring supports are measured. The ring supports A and B are in the heavy rock pressure zone of the argillaneous tuff while the ring support E is in the gypsum zone where the rock mass is rather stable.

The laboratory investigations show that the strengths and the viscous constants of the tuff are much smaller than those of the gypsum and the larger water content appreciably decreases those constants as shown in Tables 1 and 2, and that the ratio of the uniaxial strength to the overburden pressure is 0.3 ~ 1.0 for the tuff and 1.9 ~ 2.1 for the gypsum. Accordingly, it can be said that the heavy rock pressure is caused mainly by the progressive failure and viscous flow of the tuff where the water plays an important role.

The ring supports A and B finally failed by the buckling apparently both in their planes and in the direction of drift axis as shown in Fig. 12 and the loads to them initially increase up to the maximum 6 ton and then gradually decreases as shown in

Fig. 11, while the load to the ring support E exceeds the capacity of 9 ton of the pressure cell and its deformation is very small. Fig. 13 shows the load bearing capacities of the two rock mass when the pressure cell penetrates them and this explains the decrease of the load to the ring supports A and B in the tuff zone.

Finally it is suggested that the main failure mechanism of the ring supports subjected to the heavy rock pressure seems to be the lateral buckling rather than the buckling in their planes since the critical load necessary to cause the lateral buckling is much smaller than that in their planes under the condition of the hydrostatic earth pressure.

(C-8)

(18) The Effectiveness of Bolt Support in Maintaining Mine Roadway — Fundamental Study on Roadway Closure (3rd Report) —

Ihara, M., Matsui, K. and Ichikawa, Y.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 98, No. 1128, pp. 73–79, 1982,

The effectiveness of rock bolting to regulate mine roadway deformation and failure condition is studied using finite element analyses and scale model tests. The results obtained in this study are as follows.

(1) The roof-side-floor bolting is the most effective support system of other bolting patterns in any strata conditions and ground pressures.

(2) The optimum bolt length is about 60% of roadway height or width. Further increases in bolt length beyond this value do not produce a proportional benefit in improving roadway conditions.

(3) The smaller the bolt spacing is, the better the roadway conditions are. It may be suggested to exsist a certain bolt spacing over which a sudden drop of the effectiveness of rock bolting occurs.

(4) The bolting in weaker rock shows higher effectiveness than in stronger one.

(C-8)

(19) In-Situ Measurement of the Extention of Hydraulically-Formed Fracture in Geothermal Well by Means of Acoustic Emission

Nakatsuka, K., Niitsuma, H., Tamagawa, K., Takahashi, H., Abe, H. and Takanohashi, M.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 98, No. 1129, pp. 209–214, 1982,

Hydraulic fracturing, which has been developed to stimulate oil reserviors, is recently noticed as a promising process to improve the productivity or injectivity of geothermal wells. In applying the hydraulic fracturing treatment to geothermal wells, the detection of fracture initiation and the mapping of extended fracture will be important for both optimizing fracturing operation and understanding the circulation mechanisms of subsurface geothermal fluid.

This paper describes a development of acoustic emission (AE) detection technique for hydraulic fracturing of geothermal wells, where an acceleration-sense measurement is employed to detect acoustic signals from discrete fracturing events as the hydraulic fracture extended. AE signals could be detected at the place about 1500 m far from expected fracture initiation point during hydraulic fracturing operation, which was carried out in Nigorikawa, Hokkaido, on May 1, 1980. It was suggested from the analysis of the data that AE provides an important insitu information on discrete extension of fracture during hydraulic fracturing.

(C-8)

(20) Development and Evaluation of Temperature Simulation Code for Geothermal Wells — Prediction of Temperature in and Around Geothermal Wells (1st Report) —

Morita, K., Yamaguchi, T., Karasawa, H. and Hayamizu, H.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 100, No. 1161, pp. 1045–1051, 1984,

A computer simulation code was developed to estimate the temperatures in and around a geothermal well.

This code is employing explicit solution method to solve finite difference equations on transient heat transfer problems, and is applicable for three types of fluid flow in the wellbore; injection, production and circulation.

A water circulation test was performed in HY-2 Well located in Yakedake area, Gifu Prefecture, to get field data for the evaluation of the computer simulation code.

Comparisons of computed results were made with the exact solution and field data obtained. These results showed that this simulation code can simulate the temperature in and around the borehole satisfactorily.

(C-7)

(21) The Determination of the Complete State of Stress in Rock by the Measurement of Strains on a Hemispherical Borehole-Bottom
— A Study on the In-Situ Measurement of the Stress Distribution in Rock (1st Report) —
Sugawara, K., Obara, Y., Okamura, H. and Wang, Y.
Journal of the Mining and Metallurgical Institute of Japan, Vol. 101, No. 1167, pp. 277–282, 1985,

This paper presents a new method to measure the complete state of stress, which is determined by the strains on the hemispherical bottom surface of a single borehole measured with the stress relief technique, and proposes an available arrangement of measurement points of strain to be used in practice.

The general observation equation of stress written with the strain coefficients on the bottom surface has been presented and the strain coefficients are analyzed concretely by FEM. The accuracy in the stress determined is discussed theoretically to be depends on the number of measurement points of strain and on those disposition. It is shown that the high accuracy can be obtained by the systematic arrangement, in which 16 strain gages, eight latitudinal and eight longitudinal, are located on a circle of 50 degrees in the zenithal angle from the center of hemi-spherical bottom, as shown in Fig. 10, and that the accuracy is higher than that expected in the conventional method which determines the stress from the nine strain components on a cross-section of a single borehole.

(C-7)

D. [Soil Properties: Laboratory and Field Determinations]

(1) An Experimental Study of the Laboratory Vans Shear Test
Yonezu, S.
Tsuchi-to-Kiso, JSSMFE, Vol. 31, No. 12, pp. 35–39, 1983,

The purpose of this paper is to clarify some uncertainties concerning shear strength measured using a triaxial vane apparatus.

Using artificially consolidated soils, the author obtained data on the vane shear strengths and the residual strengths of clays.

(D-6)

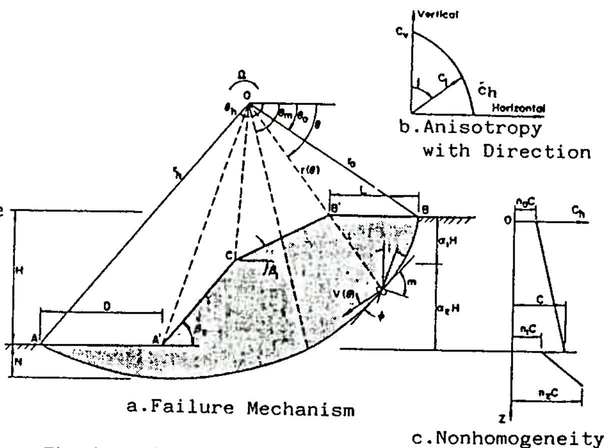
E. [Analysis of Soil-Engineering Problems]

(1) On Evaluation of the Yield Acceleration Factor Induced Earthquakes in Nonhomogeneous, Anisotropic Slopes by Limit Analysis
Sawada, T., Nomachi, S. and Chen, F.
Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 11–15, 198[illegible],

The upper bound techniqu of limit analysis has been previously applied to obtain the critical height and the yield acceleration factor of a homogeneous, isotropic slopes.

Now this paper establishes an expression for the evaluation of the yield acceleration factor for a slope induced eathquakes, based on the limit analysis of perfect placticity which yields a closed-formed solutions for sections in which the following conditions are considered:

(1) log-spiral failure-plane (Fig.a)
(2) nonhomogeneity and anisotropy of soil with respect to cohesion, C (Fig.b,c)
(3) general slope (Fig.a)



a.Failure Mechanism

b.Anisotropy with Direction

c.Nonhomogeneity with Depth

Fig. Log-spiral failure mechanism

In this work, the material of the slopes is assumed to obey the Coulomb yield condition and the associated stress-strain relations. The Coulomb yield condition is described by two parameters,namely: cohesion strength,C and apparent friction angle,Φ.

It is further assumed that only the cohesion strength,C is nonhomogeneous and anisotropic. A discussion will therfore be given of the types of nonhomogeneity and anisotropy to be used in the calculations. However, the apparent friction angle,Φ is assumed to be homogeneous and isotropic throughout the calculations,i.e. a constant value for a given type of slope. The cohesion strength C_i, with its major principal stress inclined at an angle i with the vertical direction(Fig.a,b) is given by

$$C_i = C_h + (C_v - C_h).\cos^2 i$$

in which C_h and C_v are the cohesion strength in the horizontal and vertical direction, respectively. The ratio of principal cohesion strength C_h/C_v denoted by κ, is assumed to be the same at all points in the medium. $C_i=C_h=C_v$ or $\kappa=1.0$ means an isotropic material. In Fig.a, the angle m is the angle between the failure-plane and the plane which is normal to the direction of the major principal cohesion strength kept at an angle i with the vertical direction. This angle, according to Lo's test(1965), is found to be independent of the angle of rotation of the major principal stress.

The upper bound theorem of limit analysis states that a cut in clay shown in Fig.a will be collapsed under its own weight, surcharge and each inertia force if, for any assumed failure mechanism, the rate of external work done by the soil weight,the surcharge and each inertia force exceed the rate of internal energy dissipation. The upper bound values of the yield acceleration factor can then be obtained by equating the external rate of work to the internal rate of energy dissipation for any such a mechanism.

We obtained as following $\quad K = F(\Theta_o, \Theta_h, D/r_o)$

The function F mentioned above has a minimum value and indicates a least upper bound, when Θ_o,Θ_h and D/r_o satisfy the following conditions. Thus,

$$\frac{\partial F}{\partial \Theta_o} = 0,\ \frac{\partial F}{\partial \Theta_h} = 0 \text{ and } \frac{\partial F}{\partial D/r_o} = 0 \quad \text{which yield} \quad K_c = \text{Min. } F(\Theta_o, \Theta_h, D/r_o)$$

The results of the upper bound limit analysis were found to be in good agreement with the results of the friction circle procedure(one of the limit equilibrium method) such as,the references according to Terzaghi(1948) and Lo(1965).

(E-6, E-8)

(2) The Deformation of Dam Abutment and Change of Permeability Due to the Fill Placement in Embankment Dams

Matsumoto, N. and Ikeda, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 300–304, 1984,

Foundation treatment to control seepage is one of the most important part in the construction of fill type dams. As the method of foundation treatment, grouting, i.e., injection of cement mix into the cracks of bedrock, is the most popular one. But soft rock, which is often observed in the foundation of dams recently, has low strength and shows extreme deformability, and it can be punctured at low injection pressure during grouting, so it is very difficult to attain watertightness in the bedrock by grouting, and to know the true permeability by water pressure test. For these reasons, it is often necessary to drill holes for curtain grouting from inspection gallery and to inject cement into these holes after dambody is filled at enough height for the purpose of using the weight of dambody to raise the allowable pressure of grouting.

This paper shows the results of measurement of deformation and permeability in the abutment of A Dam, whose foundation contains very weak rock in the right abutment, and the results of analysis of FEM by using two-dimentional model of A Dam. And three points are attained as conclusion,

1) The permeability of dam foundation which is composed of soft rock is decreased owing to the consolidation caused by the weight of dambody.

2) In the soft rock of dam foundation, permeability of bedrock nearly at the same level of the top of dambody is increased because of the tensile strain caused by the weight of dambody.
3) The deformation of foundation near the surface of abutment can be roughly assumed by using two-dimentional FEM.

(E-2, G-5, H-4)

(3) Analysis of Landslide during the 1978 Izu-Oshima-Kinkai Earthquake

Ishihara, K. and Nagao, A.
Journal of the Japanese Society of Soil Mechanics and Foundation Engineering, Vol. 23, No. 1, pp. 19–37, 1983,

Using the so-called pseudo-static method, a stability analysis was made for the mountain slide that took place at Mitaka-iriya village at the time of the Izu-Ohshima-Kinkai earthquake of January 14, 1978. Undisturbed samples of volcanic clay were obtained in blocks from the exposed surface of the deposit identified to have been the sliding surface. The partially saturated clay samples were tested under consolidated undrained conditions using the triaxial test equipment. Dynamic axial stresses with irregular time histories were applied to the specimens in combination with statically sustained axial stresses to determine the soil strength under the conditions simulating in-situ states of stress during the earthquake. The results of the tests were expressed in terms of the Mohr-Coulomb type failure criterion which showed that, while the angle of internal friction remained almost unchanged, the cohesion component in irregular loading increased above values obtained in the static loading. Using the strength parameters thus determined, a pseudo-static analysis was made to check the stability of the soil masses that had actually slid during the 1978 earthquake. The maximum horizontal acceleration required to cause the slide was computed. The computed accelerations were shown to cover a range between 400 and 500 gals which is consistent with the range estimated by other investigators on the basis of overturning of tombstones in the vicinity of the slide area.

(E-8)*

(4) An Iterative Method for Seismic Stability Analysis of Three Dimensional Earth Dams

Ohmachi, T. and Yokoyama, H.
Journal of the Japanese Society of Soil Mechanics and Foundation Engineering, Vol. 23, No. 2, pp. 155–164, 1983,

For an earth dam located in a narrow canyon, canyon restraint has significant influence on seismic stability of the dam. A numerical method is proposed for slope stability analysis of three dimensional earth dams subjected to horizontal seismic loading. The method is an extension of the simplified Bishop method, taking into account indeterminate shear force acting between vertical slices transverse to the dam axis. Due to the interslice shear force, limit equilibrium can be achieved at all points on a sliding surface. An iterative calculation procedure is presented to determine the magnitude of the interslice shear force and a critical seismic coefficient of the entire dam. Stability analysis by the proposed method is conducted for small-scale earth dam models used in failure experiments, and the analytical results are compared with the observations regarding the seismic coefficient and shape of failure surfaces. The comparison shows a fairly good agreement, demonstrating validity of the method and providing several useful findings concerning the slope stability.

(E-8)*

(5) Hydraulic Character of Discharge Hydrograph for Tunneling

Sato, K.
Journal of the Japanese Society of Soil Mechanics and Foundation Engineering, Vol. 23, No. 4, pp. 27–33, 1983,

Recently, several large-scale tunnels, such as the Seikan undersea tunnel and the Haruna-Nakayama tunnel, have been excavated for the Japanese railway system. One of the most important problems related to the tunneling projects concerns groundwater behavior and seepage around the tunnel. The intent of this paper is to clarify the fundamental character of tunnel discharge hydrograph by analyzing groundwater movement and water balance in terms of hydrology.

(E-7)*

F. [Rock Properties: Laboratory and Field Determinations]

(1) The Effect of Circumstantial Factors on Fracture Toughness of Rocks

Kobayashi, R., Matsuki, K. and Aoki, T.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 1–6, 1984,

In order to use fracture toughness of rocks for engineering purposes such as hydraulic fracturing in the geothermal fields, safety design of large underground openings or rock slope and rock blasting, etc., it is important to know the effect of circumstantial factors on fracture toughness of rocks. In-situ rock pressure, moisture content of rock mass, pore pressure and temperature of rock mass, etc. are included in these circumstantial factors.

This paper describes the effects of these factors on Mode I fracture toughness of rocks as well as the effect of confining pressure on Mode II fracture toughness of rocks. Four-point bending tests are conducted in the triaxial pressure cell for both sealed dry specimen and wet specimen without sealing. In the latter, water is used as the pressure medium to apply pore pressure in addition to confining pressure. Splitting tests are conducted in the oven to know the effect of temperature up to 300°C. For Mode II fracture toughness, so-called compact shear tests are conducted in the triaxial pressure cell.

Especially in the crystalline rocks such as granite and marble, it is well known that Young's modulus under tension is much lower than that under compression. To evaluate the effect of difference in Young's moduli, stress intensity factor is calculated for three-point and four-point bending tests using finite element method, and correction factor is proposed to compensate the effect of difference in Young's moduli.

(F-6)

(2) Fracture Toughness and Its Relation to Elastic Modulus

Wada, C. and Shoji, T.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 7–12, 1984,

This paper describes the relationship between fracture toughness and initial tangent modulus, i.e., Young's elastic modulus in tension, of granitic rock sample. ASTM standard specimens of notched three-point-bend and compact tension, containing various levels of water content or heat-treated at room temperature to 550°C, were tested to correlate fracture toughness to Young's Modulus. Furthermore fracture toughness tests were carried out at high temperature and in pressurized water environment to evaluate the fracture and deformation behavior under the simulated condition of geothermal reservoir.

Based on linear elastic fracture mechanics, elastic modulus was precisely measured for granitic rock sample by means of compliance calibration technique prior to fracture toughness test. Fracture toughness was determined by means of AE technique as an abrupt increasing point of AE activity.

The results obtained in this study indicate that a significant increase in fracture toughness (K_{iAE}) with increase in elastic modulus (E) was observed and fracture toughness has a single linear relationship with elastic modulus perpendicular to the crack direction. Theoretical consideration based on atomic scale fracture model by Gilman can give an adequate explanation to this relationship between K_{iAE} and E.

It is suggested that the effect of water content on the elastic modulus and fracture toughness can be interpreted as the result of internal friction on the micro-crack plane. Optical microscopic study leads to a conclusion that the decrease in elastic modulus and fracture toughness with increasing temperature is due to the increase in thermally-induced micro-crack in the rock sample. The result obtained at high temperature / pressurized water environment may be attributed to highly activated chemical reaction at the crack tip.

(F-6)

(3) Determination of Fracture Toughness of Rock by Nonlinear Fracture Mechanics

Hashida, T. and Takahashi, H.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 13–18, 1984,

This paper describes a recent development of evaluation procedure of fracture toughness K_{IC} of a granitic rock by nonlinear fracture mechanics (J-integral) and the stable crack growth characterized in terms of J-resistance curve. Various sized three point bend (1T-20T) and compact tension (1T-8T)specimens were tested, and the specimen size and configuration effects on fracture toughness were investigated. Acoustic emission(AE) measurements were made during the fracture toughness testing and the AE characteristics were examined through the observation of crack extension behavior from precrack tip. The relationship between the accumulated AE energy ΣE_{AE} and J-integral provided a good indication of the onset of a stable crack growth, denoted by J_{iAE}. A series of 1T compact tension specimens were tested to assess the effects of notch root acuity and fatigue precracking on the fracture thoughness J_{iAE}. The results showed that the J-integral approach provided a suitable evaluation of fracture toughness and stable crack growth behavior.

(F-6)

(4) Acoustic Emissions in Rock under Uniaxial Stresses

Hasegawa, T.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 19–23, 1984,

The stress drop distributions of acoustic emissions (AEs) in Westerly Granite and Sierra Granodiorite samples were studied from the view point of seismology. Experiments were performed under uniaxial compression by using a servo-controlled testing machine with constant stress increasing rate. The distribution of stress drop index defined by HASEGAWA (1982 a) for each AE-group fitted a Weibull's distribution function, and the parameter of uniformity m of this function on Westerly Granite was found to be high in the first running stage, and decreased by a factor 2 in the second stage. The parameter m on Sierra Granodiorite was lower than that of Westerly Granite.

(F-5)

(5) Discussion for Fracture Mechanism of Brittle Rock in Compression Tests – Acoustic Emission Activities and Simulation of Initiation and Propagation of Crack in the Fracture Process –

Yamashita, S., Amano, K., Otsuka, K. and Tsutsui, Y.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 25–30, 1984,

For clarifying a fracture process of rock, a few kinds of compression tests were carried out for cylindrical samples of several rocks with two types of slenderness ratios.

In these tests, it was revealed that at the stress level of the characteristic point B in the loading process up to the strength failure, non-linear strain behaviors were observed both in the stress-lateral strain curve and in the stress-volumetric strain curve, while the strain behavior in the stress-axial strain curve was still linear at that level, and that the non-linear strain behavior appeared in this curve if the stress level increased and reached the level of the characteristic point C.

Moreover, the levels of the stress-ratios of the above mentioned points from the stress-strain curve proved to be agreeable with those from the stress-AE activities curve.

And in order to clarify the fracture process of rock, the stress-strain behaviors associated with the fracture-initiation and -propagation from an initial crack were simulated in this study by the Finite Element Method.

The results of simulations indicated that at the characteristic point B, fracture was initiated and propagated in the direction of the loading axis by the tensile stress around the initial crack, and that beyond the stress level of the point C, the fracture was propagated as an extended crack by the shear stress in the direction across to the loading axis.

At the same time, cyclic-loading tests under uniaxial compression were carried out on rock specimens, and it was found that the stress-strain behaviors obtained from these tests coincided with those from the above simulations.

Furthermore, these behaviors were also confirmed by the behaviors of stress-AE count activities, such as "Kaiser Effect".

(F-6)

(6) Effect of Griffith Cracks and Inclusions on the Fracture Criteria under a General Triaxial Stress State

Koide, H., Takahashi, M., Kinoshita, S., Ishijima, Y. and Nakamura, A.
Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 31–36, 1984,

New cracks are formed in rock from Griffith cracks and Griffith inclusions with various aspect ratios and various characteritics.

The parabolic Griffith criteria and linear Coulomb criteria are derived from the ananysis of condition for formation of new cracks from the penny-shaped craks and inclusions.

However, the effect of intermediate principal stress is neglected in these conventional fracture criteria against the recent results of general tri-axial compression experiments of rocks

The statistical distribution of aspect ratio and orientation of Griffith cracks and Griffith inclusions is considered to explain the effect ofthe intermediate principal stress on the fracturing of rocks.

(F-6)

(7) Behavior of Elastic Wave Velocity in Rock under True Triaxial Compressional Stress

Takahashi, M., Koide, H., Nishizawa, O., Kinoshita, S., Ishijima, Y. and Nakamura, A.
Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 37–42, 1984,

Elastic wave velocities were measured in the rectangular prisms of Westerly granite and Yamaguchi fine grained marble under various true triaxial stress states. Measurements were carried out on the following four cases.

Case 1. Compressional velocities for the minimum and intermediate principal stress direction were measured in Westerly granite under confining pressure of 20MPa.

Case 2. Compressional velocities for the three principal stress directions and two polarized shear velocities for the minimum principal stress direction were measured in Westerly granite under confining pressure of 50MPa.

Case 3. Compressional velocities for the minimum and intermediate principal stress direction were measured in Yamaguchi fine grained marble under confining pressure of 20MPa.

Case 4. Compressional velocities for the three wave paths were measured in Yamaguchi fine grained marble under confining pressure of 20MPa at low strain rate ($1x10^{-6}$/sec).

The compressional wave velocity anisotropy between the intermediate and the minimum principal stress direction increased with increment of the intermediate principal stress for case 1, case 2 and case 3 . The velocity decrease of the two polarized transverse waves (SH and SV) in the minimum principal stress direction showed considerable difference under conventional triaxial experiment (confining pressure experiment) , while it became almost equal under the higher intermediate principal stress state (true triaxial experiment) for case 3. In case 4 , velocity recovery occured in the wave path through fracture plane after fault formation. The compressional and transverse wave velocity anisotropies were explained at the same time from volume changes of the two type of flat spheroidal cracks whose plane are perpendicular to the intermediate and the minimum principal stress directions. (F-6)

(8) On the Stress Loci by Strain Controlled Tests of Sandstone under Generalized Triaxial Stress

Nishida, T., Esaki, T., Aoki, K. and Kimura, T.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 43–48, 1984,

Stress rate and strain rate controlled tests of sandstone were carried out under generalized triaxial stress. In order to obtain the stress loci in the principal stress space, in the latter tests, octahedral shear strain was increased under conditions of uniaxial strain ($\alpha=-d\varepsilon v/d\varepsilon h=\infty$),constant mean principal strain ($\alpha=2$ except for plane strain) and proportional principal strain rate ($\alpha=3$ and 1) where $d\varepsilon v$ is the strain rate in the direction of one principal axis and $d\varepsilon h$ is that of other two principal axes

The results from the tests reveal that:-

(1) The failure curve of sandstone by stress rate controlled test is somewhat convex outward beyond that of Mohr-Coulomb. The failure curve agrees with the peak strengths by strain rate controlled tests.

(2) Under the condition of uniaxial strain , the stress states change toward the failure curve, with the decrease in the gradient of stress loci which depend on the stiffness of loading rod and Young's modulus and Poisson's ratio of the specimen,but the specimen does not fail.

(3) Under the condition of constant mean principal strain, the value of strain at the peak in differential stress-strain curves does not agree with that at the extreme value in stress-strain curves. The stress states deviate from the line perpendicular to hydrostatic axis, sharply change immediately before reaching the failure curve and go toward a certain point thereafter. For the condition of plane strain ($d\varepsilon_2=0$), σ_2 is not constant but decreases with the increase of octahedral shear strain. The difference in the relative value of ε_2 to ε_3 makes the distinct stress loci, which are expressed in terms of the normal and shear stresses on the fracture plane. (F-6)

(9) Friction of Silicate Rocks at High Confining Pressure

Cho, A., Shimada, M. and Yukutake, H.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 49–54, 1984,

Friction of two dry silicate rocks, Man-nari granite and Akaishi eclogite, was measured up to a confining pressure of 2.5 GPa at room temperature. A conventioal triaxial testing apparatus was used for the experiments up to 500 MPa, and a cubic press up to 2.5 GPa. A specimen was saw cut at an angle of 30° to the direction of the maximam compressive stress, and each pre-cut surface was ground with #320 emery. A cylindrical specimen of 8 mm in diameter and 16 mm in length was prepared by being jacketted with a teflon heat-shrink tube. The maximum compressive stress was applied with a rate of 20-100 MPa/min. The friction of Man-nari granite increased linearly up to normal stress of 1.5 GPa (corresponding to confining pressure of 1 GPa). Above 1 GPa of confining pressure, the friction had the same value as the shear strength of intact rock, and sliding occurred on the pre-cut surface without any other fracture plane and without any indication of ductility in intact parts. In Akaishi eclogite the friction also increased up to normal stress of 3.6 GPa (coresponding to confining pressure of 2.5 GPa) and became equal to the shear strength of intact rock. It had been reported that these rocks exhibit brittle fracture behavior up to confining pressure of 3 GPa, which is beyond the value where the friction becomes equal to the shear strength of intact rock. This does not support the hypothesis that the friction is the boundary of the brittle-ductile transition. The obtained friction of each rock was found to form a boundary between two types of brittle fracture. Therefore, it is confirmed for the studied rocks that the low-pressure brittle-fracture occurs while the shear strength is higher than the friction and that the high-pressure brittle-fracture occurs when the friction attains to the shear strength.

(F-6)

(10) On the Strength Characteristics of the Saturated Heavily Weathered Decomposed Granite

Akai, K., Kamon, M., Ohya, M. and Kitamoto, Y.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 55–60, 1984,

The undrained shearing strength of undisturbed samples of a heavily weathered decomposed granite was investigated. It is recognized that the weak planes like as joints and sheeting, which were left in weathered decomposed granites, are one of the main reasons among the great varieties in strength properties of the weathered granite. The characteristics of these weak planes with different angles in the specimens was studied in relation to the bulk strength and the shearing patterns. Although a freezing method is often used to prepare the testing samples, the effect of freezing is not clear to keep still the samples under the undisturbed condition.

Firstly, it is shown that the freezing effect makes the initial elastic coefficient of the samples decrease in and the peak strength unchanged. Secondarily, it is decided that weak planes between 45 to 80, inclined from the horizontal plane, affect strongly to the shearing strength of the samples as well as the failure pattern. The samples inclined at 60 showed the biggest decrease in the strength. Finally, the microscopic patterns in relation to the weak planes and shearing planes were observed by a scanning electron microscope.

(F-6)

(11) Applicability of Probability Function to Strain-Softening Process of Soft Rocks

Yoshinaka, R., Shimizu, T., Abe, K. and Morita, E.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 61–66, 1984,

Most of the rock materials change their stress-strain curves from the brittle ones to the ductile ones affected by effective confining pressure, temperature, duration of loading and so on, especially soft rock shows sensitive behavior to those conditions.

This paper describes the method to formulate the stress-strain relationship in the softening process of soft rock by applying the probability function. From the point of view that the amount of the total or plastic strain after peak stress is the indication of the failule potential up to complete failure of residual state, we regard these value as random variables.

The applicability of this formulation to soft rocks is investigated refering to the results of the triaxial compression test of many kinds of soft rocks which have been performed in our laboratory for several years. Then it is founded that Weibull distribution is the most suitable probability function to express those experimental results. Moreover, it is confirmed that this formulation can be also applied to hard rock (except Wawerski's Class 2).

In addition, enlarging this method to the plastic strain, it is proved that the same formulation can be also adopted to the relationship between axial strain and plastic axial strain and between plastic axial strain and plastic volmetric strain.

From the consideration described above, we may conclude that the various stress-strain relationships in strain-softening process of soft rock can be expressed easily and practically by use of only one probability function; Weibull distribution.

(F-6)

(12) On the Compression Properties of Mudstones

Komiya, Y. and Shinjo, T.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 67–72, 1984,

In order to investigate the compression properties of mudstones and the effect of weathering on them, oedometer tests were carried out under maximum consolidation pressure of 640 kgf/cm². This series tests was performed on the mudstones of Neogene Tertiary and their weathered and remolded samples. The results of these tests show that the compression behavior of mudstones is similar to that of natural deposited clays but the former consolidation yielding stress is extremely greater than the latter. The compressibility of mudstone has been restrained by cementation bonds and thixotropic hardning. Based on the experimental data, a model describing the compression curve of mudstone is shown and this model is useful for estimating the change in compressibility caused by weathering.

(F-6)

(13) The Creep Properties and Constitutive Equations of Rock

Akagi, Y. and Kawamoto, T.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 73–78, 1984,

The constitutive laws of rock are usually considered from the results of a constant strain rate test. However it may be valid to constitute the material law based on creep test results when we need to extract the time-dependent component in the laws. Because the variation of properties appears better sensitively on the creep phenomenon than the stress-strain behavior. A rheological model has generally not been used to constitute the stress-strain-time law of rock because its application has restricted within linear viscoelastic field. However it will be possible to describe phenomenologically the nonlinear behavior of rock by linear mechanical models if different models are assigned to describe before and after failure. This report suggests that a rheological model may be able to apply to the general material laws of rock, and presents the practical method to determine the model constants. The modelling is done under the consideration of creep test results for rock specimens. The creep tests were performed under seven uniaxial compressive stresses that correspond to 10~72% of the unconfined compressive strength. The experimental results are arranged in the standpoint of nonlinear creep field, that is , the stress dependency of creep strain , creep strain rate and retardation spectra etc. will be discussed. Finally it is made clear that the models represent the practical behavior of rock,e.g. strain hardening and softening and their strain rate effects etc. by numerical simulations.

(F-8)

(14) A Study on the Dilatancy of Rock

Sato, M., Ito, H. and Kamemura, K.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 79–84, 1984,

Dilatancy prior to rock failure is interpreted as the consequence of cráck propagation and opening, being based upon a great deal of experimental results which are obtained from the observation of acoustic emittion or velocity attenuation of elastic wave during compressive and creep test of rocks.

In order to understand the relationship between the crack propagation and dilatancy, a numerical analysis has been carried out by means of Finite Element Method, in the model of which free propagation of crack is admissible. Following characteristics concerning the crack propagation are obtained from the numerical results.

(1) As compressive stress increases, open cracks grow.

(2) Inelastic volume change occurs owing to the crack openings.

(3) Direction of crack growth is generally parallel to the direction of maximum compressive stress.

An idealized model, explaining the mechanism of the crack growth is also discussed. Inelastic volume change caused by the crack opening is estimated by the technique of fracture mechanics, and it is found that, when a crack grows in the direction if maximum compressive stress, an amount of volume change is in proportion to the square of differential stress ($\sigma_1 - \sigma_2$) and in inverse proportion to the confining stress (σ_2).

The varidity of proposed model is examined by comparing with the results of Finite Element analysis, and it is shown that the idealized model for crack growth is appropriate.

(F-6)

(15) Ten Year Creep Experiment of Small Rock Test-Pieces

Ito, H. and Sasajima, S.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 85–90, 1984,

Since August 1974, three granite test-pieces (21×2.5×2 cm) and three gabbro test-pieces (16×2×1.5 cm) have been supplied to creep tests by bending. The laboratory has been situated in a vacant adit in Kisenyama Underground Power Station of Kansai Electric Power Inc., Kyoto, where the constant room temperature (18 °C) and humidity (nearly 100 %) have been kept naturally. A deflection of the test-piece has been measured by making use of interference fringes of Na-D monoclomatic light. The deflection curve at the start of test must be given by $y = 1/E \cdot X(x)$, where E is Young's modulus. Since the deflection curve changes with time t, its empirical formula is assumed to be $y = T(t) \cdot X(x)$. A numerical value of T(t) (cm^2/dyn) is determined from the measured values of deflection and a mean square error ε of the measurement is also calculated in an unit of the wavelength λ. The chronological changes of T(t) and ε obtained over about 10 years are shown for each test-piece. From these results, a viscosity of the secondary creep is found out to be an order of 10^{21} poise for both the granite and the gabbro. Especially this experiment reveals that the creep of rocks does not show a steady and monotonous progress, but often turns back and that a quantity and a period of the turn back reach 10 % of T(t) and 2 years in maximum respectively. The turn back may be caused by release of the resudial strain energy retained in heterogeneous rock, as have been mentioned by Price (1964) and Tan and Kang (1980). Lastly the authors strongly suggest that there exists the turn back phenomenon in some rocks of the earth crust.

(F-8)

(16) Strength and Deformation of Rock Masses with Joint Roughness

Hamajima, R., Valerio, G., Yamashita, K. and Kusabuka, M.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 91–96, 1984,

For rock like materials with one joint set and rock mass models with many joints set, bi-axial compressional tests were made in order to clarify the effects of joint roughness on the strength and deformation of rock masses. Further consideration for joint roughness was conducted by direct shear test and the following results were obtained.

(1) For one joint set rock like material, both the joint roughness and confining pressure give more large effect than one for rock mass model with many joints set.

(2) Rigidity of rock mass decrease rapidly with the increase of number of joints. However, the effects of joint roughness on rock mass rigidity are not so large.

(3) The effects of roughness on the peak strength of bi-axial compressional test become largely with the increase of the number of joints.

(4) The shearing strength for joint surface with roughness consists in the parts between the shearing strength for smooth joint and residual strength of intact rock material without any joint.

(F-6)

(17) Irreversible Characteristics of Discontinuous Rock

Nakagawa, K., Nozaki, T. and Kuramochi, T.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 97–102, 1984,

This study aims to investigate the irreversible characteristics of the discontinuous rock mass. The rock mass behavior is seriously influenced by the discontinuity of the rock mass as well as the mechanical properties of the intact rock, and the behavior is different far from that of the intact rock in many cases. Especially the irreversible deformation is the typical characteristics of the rock mass and often observed in the field tests although the intact rock behaves almost elastically. Therefore, it is obvious that the irreversibility of the rock mass is caused by the discontinuity.

In order to investigate the irreversible characteristics of the discontinuous rock mass, biaxial comprission tests were carried out on the models of rocks. Each specimen, the size of which is 10cm x 20cm x 40cm, was a assemblage of about forty blocks of gypsum plaster. The tests were performed on the specimens with verious inclenations of the bedding planes by increasing vertical stress at constant pressure. The results of the tests showed anisotropic strength characteristics as well as anisotropic and irreversible deformation.

The anisotropic and irreversible deformation of the model rock mass was examined on the assumption that the behavior of the discontinuous rock mass can be macroscopically represented as the behavior of a virtual continuum. The behavior owing to the discontinuity was isolated from the test results and the close examination of it lead the characteristics as follows: The increase of the shear stress yielded the irreversible distortion of the rock mass, and corresponding to the distortion the anisotropic dilatancy was brought about. By applying the theory of plasticity it will be possible to express these irreversible characteristics an the stress-strain relationship of a plastic material.

(F-8)

(18) Relationship between Longitudinal Wave Velocity Anisotropy and Pore Structure

Saito, T. and Sato, S.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 109–114, 1984,

Longitudinal wave velocity was measured for nineteen lava samples by ultrasonic pulse method at room temperature and atmospheric pressure. Lava samples contain oriented ellipsoidal pores. The pore length (L) was measured in the same three orthogonal directions as the longitudinal wave velocity, the indices of axial ratio being defined by Lb/La, Lc/Lb and La/Lc. Relationship between longitudinal wave velocity anisotropy and the axial ratio of pores was investigated.

The main results obtained are as follows:

1) For axial ratio of pores ranging from 0.61 to 1.72, velocity differences in dry state are in the region of -0.85 ~ 1.16Km/sec, and those in saturated state are in the region of -0.85 ~ 1.02Km/sec.

2) Longitudinal waves along the major axis of pores propagate faster than

those along the minor axis of pores. Longitudinal wave velocity anisotropy is mainly caused by the oriented pores.

3) Longitudinal wave velocity anisotropy in dry state is larger than that in saturated state. This is caused by the difference of elastic constants between air and water filling the pores. (F-2)

(19) Rockmass Classification for Weathered Granite and Evaluation of Bearing Capacity of Foundation Ground of Long Span Bridge

Ishikawa, K., Miyajima, K., Yamada, K. and Yamagata, M.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 293–298, 1984,

The rockmass classification for weathered granite of the ground of sea bed for the foundation of long span bridge is carried out by Index-test which was mainly by physical logging of borehole. In this paper we propose a new method of classification which indicates quantitatively by calculating porosity of rockmass from these measuring results and by the grade of weathering of granite. In this classification, we consider the effect of over burden pressure and relate it to the deformation property of rockmass, which was obtained by Design-test.

Reffering to the propaty of bearing capacity of weathered granite, we investigated many results of laboratory and in-situ tests. And we classified the ratio of shearing stress by rock classification, when creep deformation of long-term was not larger than yield strain of short term, using deformation index. Therefore we evaluated the effect of confinning pressre of creep property and assumed that the relation-ship of stress-strain was nonlinear. From these result, we made a caluclation chart of bearing capacity of deformation-index and each over burden pressure. And simulation of insitu tests were carried out. Then we presumed the long term allowable bearing capacity of bridge foundation that reflected the effect of depth of embedment. So we mention some of these examplas. (F-1)

(20) Evaluation of Rock Fracture Toughness in the Presence of Pressurized Water at Elevated Temperature by Means of AE Technique

Takanohashi, M., Miyazaki, S. and Takahashi, H.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 391–396, 1984,

Fracture toughness tests were performed on four kinds of rock samples of granite, andesite, tuff and mudstone to evaluate the fracture behavior of subsurface rock materials in geothermal areas. The effects of temperature, confining pressure and water environment on the rock fracture toughness were shown through experiments using pre-notched cylindrical specimen in the presence of pressurized water ranging from 0.1 to 30 MPa at a maximum temperature of 224°C. The rock fracture toughness (K_{iAE}) is defined by the critical stress intensity factor of the crack tip region at the onset of the main crack propagation which corresponds to an abrupt increase of ΣE_{AE} before the maximum differential pressure.

For granite, the value of K_{iAE} at 200°C and 20 MPa decreases by approximately 20% of the value at room temperature and atomospheric pressure. On the contrary, the value of K_{iAE} of andesite is independent of high temperatures and confining pressures provided that the test environment conditions are less than 224°C and 27.4 MPa. Intermediate values of K_{iAE} between granite and andesite are obtained in the same manner as for tuff and mudstone.

In the Takinoue geothermal field, an increase in the K_{iSF} (the subsurface field fracture toughness) of tuff, to neary 10 MPa yields results which are consistent with those obtained in laboratory experiment. (F-8)

(21) Stress Corrosion Cracking Behavior of Granite in Pressurized High Temperature Water Environment

Kojima, T., Shoji, T. and Takahashi, H.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 397–402, 1984,

Stress corrosion cracking tests of Granite in high temperature and high pressure water environment up to 250°C were carried out in an autoclave with refreshing water loop. Thick-walled cylindrical specimen with a sharp slot on an inside wall was used to characterize a cracking behaviour by Fracture Mechanics. During the tests, a pressure difference between inside and outside of specimen was kept constant and variations in pH and in permeability with testing time were recorded and also a time to failure was measured. A new procedure to obtain a stress corrosion cracking law from a relationship between an initial applied stress intensity factor Ki and a time to failure t_f was developed because of a difficulty to measure a crack growth length in an autoclave system. Increasing testing time, increasing permeability and shifting pH to high values depending on testing conditions. Effects of high temperature water on cracking behaviour can be interpreted from a thermally-induced micro-cracking effect and a enhanced dissolution effect. A former effect was apparent above 150°C and a later above 200°C. These facts were reduced from evidences that initial permeability of specimen increase above 150°C and initial increase of permeability with testing time was clear above 200°C. Furthermore relationships between the normalized stress intensity factor, K/K_{Ic} and crack growth rate delineated a difference between the cracking characteristies at RT. and 150°C and those at 200°C and 250°C. Consequently, environmentally enhanced crack growth of Granite in high temperature water can take place at a stress intensity factor far below fracture toughness, K_{Ic}, which should be taken into consideration to keep crack-like reservoir stable for a service life.

(F-8)

(22) AE Activity during Slow Cyclic Temperature Change between 210K and 390K

Ehara, S. & Terada, M.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 403–408, 1984,

AE activity and thermal expansion coefficient of rocks were measured. These rocks were subjected to cyclic temperature change between 210K and 390K at a slow rate. During thermal cycling between 270K and 330K, small number of AE events was observed and the thermal expansion coefficient was independent of the thermal cycling. In the 1st heating cycle above 330K and 1st cooling cycle below 270K, there were an increase in AE activity and a marked change in the thermal expansion coefficient. The thermal expansion coefficient became highly temperature dependent during these stages; it increased during heating and decreased during cooling. In the succeeding cycle within the temperature of the previous cycle, minor AE activity and less temperature dependency of the thermal expansion coefficient were observed. The thermal expansion coefficient was independent of temperature in the axial direction under a uniaxial stress. After the removal of the stress, the coefficient increased with temperature and AE activity again became obvious in the heating cycle. These observations suggest that the thermally induced cracks play a major role in AE activity and cause the change of the thermal expansion coefficient of the rock. These cracks are the result of the thermal cracking and can form even in a slow temperature change due to the mismatch of the thermal expansion among the mineral grains. The cracking causes the increase in AE activity and creates new crack porosity , which causes the increase of the thermal expansion coefficient during heating and the decrease of the coefficient during cooling. In the succeeding cycle, the crack porosity created in the previous cycle reduces the thermal cracking, because it provides the space in which surrounding grains can expand to adjust the mismatch of the thermal expansion among the grains. Uniaxial stress causes the suppression of the thermally induced cracks normal to the loading axis as well as the crack closure.

(F-8)

(23) Characteristics of Rock concerning to Occurrence of Alkali-Aggregate Reaction

Shibuya, T., Fujisaki, K., Yamamoto, H., Imadate, F. and Horiuchi, S.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 409–414, 1984,

It began to be found out that some concrete structures were deteriorated due to alkali-aggregate reaction. As the first step of investigation on alkali-aggregate reaction, we carried out to study the characteristics of rock, especially andesite aggregates containing deleterious matter.

(F-2)

(24) Mechanical Behavior and Failure Criterion of Jointed Soft Rock

Adach, T. and Morita, E.

Proceedings of the Japan Society of Civil Engineers, No. 320, pp. 99–111, 1982,

The effect of discontinuous plane on the mechanical behavior of soft rock mass was investigated in laboratory tests by using mud stone. Namely, a series of triaxial compression tests was performed on specimens each of which had a pre-cut plane with various angle to the maximum principal stress plane. What we found from the test results are as follows.
Under confining pressure lower than the transitional stress of the material, the stress-strain relation is affected by existence of and the angle of pre-cut plane, whereas confining pressure greater than the transitional stress the mechanical behavior does not depend upon existence of discontinous plane. The peak and residual strength criteria for the specimens were found to be similarly defined as those for the intact rock specimen. Namely, when confining pressure is lower than the transitional stress, the peak strength changes with the angle, θ, and takes its minimum value at $\theta = 60^0$. The residual strength, however, is not affected by the angle, θ, and coincides with that of intact rock. And the peak strength of specimen with pre-cut plane lies between the peak and residual strengths of the intact rock.

(F-6)

(25) Proposal of a Yield Function and Description of Plastic Behavior of Soft Rock

Hirai, H. and Satake, M.

Proceedings of the Japan Society of Civil Engineers, No. 320, pp. 159–164, 1982,

The present paper provides a yield criterion to describe the plastic behaviour of soft rocks. The yield function shows a simple form having invariants of stress tensor. The isotropic hardening paprameter is expressed by taking into account the plastic work divided into two parts related with the change in volume and the change in shape.

The proposed yield function takes the cap's type which means the closed form in the stress space. On the contrary, the failure function is of Mohr-Coulomb type opening in the hydrostatic stress axis. The dilatancy character of soft rocks is well simulated by the present yield function.

It was found that the stress-strain relationship derived from the proposed yield function is capable of describing properly the experimental data for the plastic behaviour of soft rocks. (F-6)*

(26) Fracture and Energy Dissipation of Soft Sedimentary Rock in Triaxial Compression

Akai, K., Ohnishi, Y. and Yashima, A.

Proceedings of the Japan Society of Civil Engineers, No. 321, pp. 123–130, 1982,

The stress-strain behavior of soft sedimentary rock, which usually shows a decrease in strength after reaching a peak value, has been recognized for quite some time. The loss of strength contributes significantly to the manner in which the stresses and strains are distributed and leads to a progressive type failure. A microscopic view of failure mechanism in a rock sample has been presented by many researchers, supported with the techniques of acoustic emissions and fractography. The behavior of soft rock must be reviewed in this standpoint.

A new triaxial testing system which is servo-controlled was designed and constructed. The control signals and test data are processed in a microcomputer.

This paper describes the outline of experimental procedures and interprets the strain-softening behavior of soft saturated tuff by a energy theory, accounting for the growth of cracks in a test sample. A part of the work done to the specimen would be stored as strain energy in the specimen, and the other would be dissipated with in the specimen as a dissipated energy. The specimen may be directly related to the nonrecoverable energy. The failure process of the rock sample will be interpreted as a energy transfer in this study.

(F-6)

(27) Effect of Adjacent Blast Operation on Vibration Behavior of Existing Tunnel

Hisatate, M., Sakurai, S. and Ito, T.

Proceedings of the Japan Society of Civil Engineers, No. 332, pp. 67–74, 1983,

When blasting operations are conducted near an existing tunnel, it is nessesary to pay much attention to the tunnel in order not to cause any serious damages.

In the analytical estimation of tunnel movements caused by the blast operation, it is very important to take into account such factors that

[1]:blasting waves radiate three dimensionally,
[2]:blasting accompanies fracure of the ground,
[3]:ground and tunnel movements are strongly affected by the amount and the kind of explosives.

However, these factors have not been considered. in the previous contributions, so it is impossible to apply the analytical results obtained to actual problems.

In this paper, an analytical approach to forecast the dynamic bahavior of existing tunnel linings due to an adjacent blast operation is proposed by taking the above mentioned factors into account. A finite element method(FEM) is employed, in which such executive conditions as weight and detonation velocity of explosives and the distance between an existing tunnel and a blasting point are considered. In the first step, a two dimensional analytical model, which takes fracture of the ground and three dimensional effects of blasting into account, is proposed. Then the appropriateness of this model is shown through comparison of analytical and field measurement results. Finally, lining stresses analyzed by this method are compared with those by the observational method, and some considerations are given on dynemic characteristics of tunnel linings.

(F-7, G-6)

(28) Mechanical Properties of Diatomaceous Soft Rock

Maekawa, H. and Miyakita, K.

Proceedings of the Japan Society of Civil Engineers, No. 334, pp. 135–143, 1983,

This paper describes the mechanical properties of the diatomaceous soft rock distributed widely in tertiary deposit of Noto Peninsula in Ishikawa Prefecture.

The soft rock is very porous and has large cementation bond, and furthermore is regarded as an ideal material for experimental sample because of its uniform, undisturbed, unweathered and saturated condition. Its main ingredients are remains of diatom, clays and volcanic ashes. In spite of its large void ratio (2.6) the results of unconfined compression test proved that q_u value was 19～22kgf/cm^2 (1.86～2.16MPa) and this soft rock seemed to be a typical, brittle material. But there was marked lowering in its strength by remolding, and it became a cohesive clay. For this reason it has been widely known as the material with many mechanical problems for foundation work.

In this paper, therefore, the mechanical behavior of the soft rock in various experimental conditions under triaxial stress (UUtest, CUtest, CDtest) has been studied, and consequently seemed to be very similar to well-known behavior of over-consolidated sensitive clay. It was very remarkable that the results of CDtest under over-consolidated condition showed clearly the unique yielding behavior for which there has been very few reports. The yield locus for boundary surface which had the component of plastic deformation coincided with the theoretical curve of Cam-Clay model (Roscoe et al). Moreover the unique behavior at failure of the cementationed soft rock was investigated.

(F-6)

(29) Proposal of a Time-Dependent Yield Function and Characteristics of Yielding of Soft Rocks

Hirai, H., Satake, M. and Yanagisawa, E.

Proceedings of the Japan Society of Civil Engineers, No. 334, pp. 155–162, 1983,

The present paper deals with a time-dependent yield criterion of soft rocks. The yield function is represnted by the stored energy and dissipative energy.

The proposed yield function is capable of describing properly the time-dependent behaviour such that the yield stress increases with the increase of loading rate and yielding occurs under constant stresses.

For two limiting cases that the loading condition is very fast and very slow, the stress-strain relationship derived from the proposed yield function is capable of describing the experimental results containing the effect of loading rate.

By making some assumptions between the behaviour in the very slow loading and that in creep, it was found that the yield function proposed in the present paper is reduced to those given by Reiner et al. and Olszak.

(F-6)*

(30) An Elastic-Plastic Constitutive Model of Soils and Rocks and Its Application to the Finite Element Analysis

Hirai, H., Yanagisawa, E. and Satake, M.

Proceedings of the Japan Society of Civil Engineers, No. 339, pp. 207–217, 1983,

A new simple form of yield function of soils and rocks was proposed by modifying the old yield function applied to soft rocks. Since the new yield function as well as the old fucntion is considered to be useful to rocks, attention was focussed on the effectiveness of the new yield fucntion to describe the plastic behaviour of soils in the present paper.

The accuracy of the constitutive equation was evaluated by comparing between predicted and measured plastic strains for triaxial tests of soil.

On the basis of the proposed constitutive model, the problem of the foundation subjected to uniform loads was analyzed by the finite element method. It was found that the analytical procedure follows yield regions adequately with the increase of external loads. It was suggested that the computational procedure propounded in the present paper is very applicable to the finite element method.

(F-6)*

(31) Statistical Weight Analysis on the Parameters for Geomechanics Classification of Tunneling

Nakao, K. and Koyama, S.

Proceedings of the Japan Society of Civil Engineers, No. 346, pp. 107–115, 1984,

A statistical reconsideration on the parameters for geomechanics classification of rock mass has been carried out to apply them in the Japanese geological conditions.

Procedure to produce the parameters from the data base collected in conjunction with tunnel deformation and geomechanical rock conditions is reported.

Analysed results of 152 examples of tunnel excavation in the Japanese geology so far collected are compared with the weighting of classifications by Wickham, Bieniawski and Barton.

The authors concluded that the greatest weight should be placed on the thickness of tunnel overburden presented by the sectional area of tunnelling, whereas the RQD and joint condition constitute the greatest factor in the aforesaid researchers. (F-1)*

(32) Experimental Determination of Rock Thermal Diffusivities with Different Hydraulic Conditions

Sato, K. and Sasaki, Y.

Proceedings of the Japan Society of Civil Engineers, No. 351, pp. 127–135, 1984,

When we deal with the heat transfer problems in rock ground, the evaluation of heat transfer parameters becomes important as well as the determination of hydraulic parameters such as the permeability and storage coefficient. This paper presents how to determine the thermal diffusivity of rocks having different hydraulic conditions in a laboratory, and the values of thermal diffusivities with six kinds of rocks collected from different locations in this country were determined by using two inherent apparatuses. The utility of the apparatuses proposed in this paper was confirmed, and the rock thermal diffusivities were $0.333\times10^{-6}\sim1.19\times10^{-6}\ m^2/s$ for many kinds of rocks. (F-8)

(33) Strength-Deformation Properties Mudstone under Cyclic Loading

Nishi, K.

Proceedings of the Japan Society of Civil Engineers, No. 352, pp. 41–50, 1984,

The main object of this study is to clarify the strength and deformation characteristics of mudstone deposited during the Tertiary Period, which is widely distributed in Japan, for the wide range of effective confining pressure σ'_m (=294 kPa~5 880 kPa) during cyclic loading. It is found that degradation of shear strength according to increase of the number of cycles is relatively small in comparison with that of soft soils. Shear strength mobilized at irregular cyclic loading tests using actual earthquake acceleration records is about 110 %~120 % of that obtained by monotonous loading tests, and the relation between shear modulus G and σ'_m at small strain level is expressed by two straight lines with breaking points, which is given as σ'_m equivalent to consolidation yield stress, in the log scale paper. (F-7)

(34) Dynamic Strength-Deformation Properties of Mudstone with Weak Plane

Nishi, K.

Proceedings of the Japan Society of Civil Engineers, No. 352, pp. 51–60, 1984,

To clarify mechanical properties in particular strain rate dependency and cyclic effect on strength and deformation of mudstone with weak plane, triaxial and cyclic triaxial compression tests are performed on specimens which has discontinuous plane with variable angle θ to the maximum principal stress plane. We mainly describe dependency of strength and deformation on the angle, and deformation characteristics during cyclic loading, and strain rate dependency of strength and Yong's modulus. Particularly, it is found that maximum deviator stress $(\sigma_1-\sigma_3)_f$ at $\theta=60^\circ$ nearly equals the residual strength, and rate dependency of strength clearly can be seen for the wide of strain rates, and $(\sigma_1-\sigma_3)_f$ at $\theta=60^\circ$ can be given by failure criterion for residual strength of intact specimen based on effective stress. (F-7)

(35) Strength Properties and Failure Criterion of Sandstone
Ochiai, H., Hayashi, S. and Tanahashi, Y.
Proceedings of the Japan Society of Civil Engineers, No. 352, pp. 207–210, 1984,

Strength properties of sandstone prepared in cylindrical specimens with different moisture contents were studied using triaxial compression test under confining pressure in the range of 0 to 80 MPa. It is shown that the relations between strength and confining pressure are generally non-linear, and the non-linearity depends on the moisture content of specimen. In order to express these strength properties of sandstone, Lade's failure criterion for soil with curved failure surfaces was extended for including the tensile strength in the criterion and was applied to the test results. As the results, it may be concluded that this failure criterion is available for rock as well as for soil when the value of material parameter related to tensile strength is determined from the uniaxial tensile or compressive strength. (F-6)

(36) An Application of Damage Tensor for Estimating Mechanical Properties of Rock Mass
Kyoya, T., Ichikawa, Y. and Kawamoto, T.
Proceedings of the Japan Society of Civil Engineers, No. 358, pp. 27–36, 1985,

Distributed discontinuities essentially affect to the mechanical behaviour of rock mass. Such discontinuities can be modelled by introducing the damage tensor of Murakami et al. which was originally proposed for creep failure of metal-like materials. In this paper, the concept is extended to the rate-insensitive rock mass behaviour involving joint sets. An in-situ observation method of the damage tensor is proposed. (F-0)

(37) Fundamental Study on Identification of Elastic Constants and Geometry Characteristics of Inhomogeneous Rock Masses
Ohnishi, Y. and Higashide, A.
Proceedings of the Japan Society of Civil Engineers, No. 358, pp. 93–102, 1985,

Recently attension is being directed toward developing a numerical procedure whose objective is to determine a set of parameters from a set of observed displacements at the field. The procedure, so called "Identification or Inverse" problem, is general and can be applied to any geotechnical problems, in which the system parameters are to be identified. In this paper, the method to identify the elastic constants and geometry characteristics of inhomogeneous rock masses is presented. Elastic parameters are calculated by the optimization process in mathematical programing. Geometry characteristics are determined by Akaike's information criterion (AIC) which estimates the maximum likelihood of the system. Several examples of tunnel problems with loosend area are examined and evaluated by the proposed method. (F-0)

(38) The State of the Arts on Borehole Loading Test

Committee on Rock Mechanics J.S.C.E., Theory and Testing Method Subcommittee

Proceedings of the Japan Society of Civil Engineers, No. 364, pp. 15–22, 1985,

Characteristics of deformation of the rock mass have been measured hitherto mainly through the method of plate loading test. The method has brought fruitfull results, and the technique of measurement, interpretation of data and applying to design rock structures have been nearly established.

We have another method called borehole loading test. In this method, loads are applied to the surface of a bored hole and deformation of the surface is measured. The method has several advantages; obtaining the nature of deformation within the rock mass, simplicity and convenience in operating with less cost. However, it is not so long since the method has been used in the fields. Evaluation of the method has not been confirmed yet in Japan.

Under these circumstances the subcommittee began to collect data on the method, examine the theoretical background and to establish the guide lines of the method.

This report summarizes the recent results of the committee discussions. The contents of this report: Chapter 1. The purposes and applicability of the method, Chapter 2. The testing apparatus, Chapter 3. Preparation for the testing, Chapter 4. Testing procedures, Chapter 5. Interpretation and records of the testing. (F-6)

(39) Effect of Clayey Seam on Mechanical Behavior of Rock Mass

Adachi, T., Yashima, A. and Matsukage, S.

Proceedings of the Japan Society of Civil Engineers, No. 364, pp. 61–66, 1985,

The mechanical behavior of saturated model rock mass with a clayey seam was investigated by conducting a series of undrained triaxial compression tests. In the tests, a rock mass was modeled by a specimen made by sandwiching an alluvial clay seam between two pieces of Ohya-stone (tuff). The effects of the thickness of clayey seam, the inclination of seam plane to the maximum principal stress direction, the shear strain.rate, the confining pressure and the over-consolidation ratio on the mechanical behavior of rock mass were studied based on the effective strees concept. From the experimental results, even if the thickness of clayey seam was so thin, the shear strength of rock mass is found to be governed by that of the clayey seam. (F-6)

(40) The Kaiser Effect of Granite Caused by Various Loading Methods

Murayama, S., Michihiro, K., Saito, J. and Yoshioka, H.

Proceedings of the Japan Society of Civil Engineers, No. 364, pp. 107–112, 1985,

In order to know the Kaiser effect of AE (Acoustic Emission) in triaxial directions of a rock mass, the Kaiser effect of AE in the granite specimens were investigated by applying the compressive pre-stresses of various intensities repeatedly on the respective directions to the specimens.

From the testing results, it was found that the pre-compressed principal stresses were precisely estimated by the Kaiser effect, provided the specimens had been repeatedly pre-compressed until the increment of the residual strain ceased. (F-6)

(41) Measurement of Rock Properties by Borehole Jack Test

Irobe, M. and Kawamura, H.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 1–5, 1982,

It is a defect of the borehole jack test that in the rock near the test point a tension zone appears by the unidirectional jack pressure to the borehole wall. As a result it is possible that the tension crack develops. Although several procedures of the analysis of the test data have been reported by some investigators, the influence of the tension is neglected in their works.

The authors present a method to determine the rock properties in which they take into account the tension crack developement. They give an important conclusion tnat the elastic modulus obtained by their way is much greater than the values determined without consideration of the crack occurence. (F-6, G-2, G-3)

(42) On the Measurement of Strength Characteristics of Rock by Borehole Load Test

Takeuchi, T. and Suzuki, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 11–15, 1982,

This paper discribes a method for estimating the distribution of rock strength characteristics C and Ø by using the yielding point Py of stress strain curves prepared from data obtained by borehole load testing. The rock formation investigated was a uniform, consolidated Neogine layer that showed no cracks. Figure 2 shows the relationship between deformation coefficient Eb as determind by the borehole load test, and Py. This is a logarithmic scale graph which is described by the following linear equation:

$$Py = 0.431\ Eb^{0.607}$$

and relationship between radial strain of borehole wall and deformation modulus Eb at yielding point Py is shown in Figure 3. From these Figures it seems that Py is affected by strength characteristics of rock.

We assumed the two rock model to conduct C and Ø of rock, one is wedge model between radial crack which caused by applied pressure.

On the wedge model the relationship between that isconfining pressure for Py point may be expressed

$$\sigma_3 = \sigma_v \frac{\nu}{1-\nu} = (\gamma - 1)\frac{\nu}{1-\nu} h$$

where ν is poisson s ratio; γ is unit weight, h is overburden hight.

Using the σ_3 and Py points from the depth-Py relationships were used to describe Mohr's circles. Then C and Ø is conducted by following formula basis on the Mohr's circles.

$$\phi = \sin^{-1}\left(\frac{a-A}{a+A}\right) \qquad C = \frac{Ab}{a-A}\tan\phi \qquad A = (\gamma - 1)\frac{\nu}{1-\nu}$$

Next, elasto-plastic model was assumed as 2 demensional and a concentric circle. The authors combined thick cylindrical theory with the plastic region concept to investgated the relatioships between yield stress and overburden pressure and C , Ø .

At the condition of the plastic state in borehole wall following formula is obtained.

$$P = C\cos\phi + (1 + \sin\phi)\,P_0$$

Where P is applied pressure, P is overburden pressure. Then,displacement of the borehole wall in plastic state is shown as follows.

$$U_{e+p} = \frac{1}{E}\left\{(1-\nu)P_o + (1+\nu)Y\right\} R_o \cdot \exp\left(\frac{P-Y-P_o}{Y}\right)$$

From these results,Figure 8 and 9 were conducted.We may use the above formula for measurement results at two different depth,where confining pressure are P_{01},P_{02} and yield stress, P_{y1} , P_{y2}. We obtained formula:

$$\phi = \sin^{-1}\frac{P_{y2}-P_{y1}}{P_{02}-P_{01}} \qquad C = \frac{P_{y1}-(1-\sin\phi)P_{01}}{\cos\phi}$$

Some actual results calculated by above two method were compared in Table 1.

(F-6, G-3)

(43) Mechanical Behavior and Failure Criterion of Jointed Soft Rock

Adachi, T. and Morita, E.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 31–35, 1982,

Even for soft rocks, material actually considered in civil engineering projects is the rock mass with discontinous planes, such as fissures and joints. It is less possible that an intact rock itself is of interest. After the rock specimen fails under confining pressure lower than the transitional stress of the rock, it reaches the residual strength state with further shear deformation. A single shear plane occurs, and the specimen is sliding along this plane. In other words, the residual strength state may be considered to reflect the case where the mechanical behavior of the material is entirely dominated by discontinuous plane. Furthermore, the failure plane which occurs in the specimen is in the easiest direction for failure to occur to the direction of maximum principal stress. Therefore, the strength in this stage may coincide with the maximum strength of the rock mass with discontinuous planes. Namely, the lower bound of the rock mass strength should coincide with the residual strength obtained by the triaxial test. This is schematically illustrated in Fig.1. It can be also seen that the upper bound of the rock mass strength corresponds to the peak strength of intact rock, whereas the lower limit is bounded by the residual strength, and the rock mass strength in the field lies at least within these limits.

In the previous study, this point of view for the rock mass strength was confirmed by conducting the tests on specimens each of which had a pre-cut plane. However, we did not obtain the definite failure criterion that was able to explain where the rock mass strength lay in the range given in Fig.1 due to the angle between the direction of discontinuous plane and the maximum principal stress plane.

In this study, by carring out the similar triaxial tests with a mud stone, a failure criterion was derived for soft rock with discontinuous planes based upon the angle between directions of discontinuous plane and of principal stress plane as a parameter.

As shown in Fig.2, the failure configurations were divided into two categories, namely, in the first one failure took place by sliding along the pre-cut plane, while in the second a new sheared off plane other than pre-cut plane developed by failure. In order to make clear the failure mechanism and to derive the failure criterion for the material with discontinuous plane, first of all for the case of sliding failure along the pre-cut plane the effective normal stress σ' and shear stress τ acting on the plane are obtained at both the peak and residual strength states, respectively. Similarly, for the case of new sheared off plane developed by failure σ' and τ acting on the plane are also calculated at both strength states. Data were plotted on log-log scale paper to obtain a failure criterion for both the peak and residual strengths in Fig.5. It is seen in the figure that each relation for the peak and residual strengths is expressed by a straight line Based upon the aforementioned results, new failure criterion represented by the relationship of σ' and τ is given by Eqs.(1)-(3). It can be said that in the case when the strength criterion for soft rock expressed by the relationship between σ' and τ, it is good enough to give two relations for each of the peak and residual strength states irrespective of intact rock or rock mass.

By using thus obtained failure criterion, the failure mechanism of specimen with pre-cut plane is discussed by using Fig.6. As the results, it is found that sliding failure along pre-cut plane would occur only when the angle of the plane θ lies between θ_1 and θ_2. However, the range of angle decreases with the increase of confining pressure level since the peak strength line is not parallel to the residual strength line when the confining pressure is less than the transitional stress of the material. Fig.7 makes the comparison of thus obtained bounded angles with the experimental results. And it can be said that the failure mechanism discussed in Fig.6 well explain the experimental evidences.

When the failure criterion is expressed by the relationship between stress deviator $q = (\sigma_1-\sigma_3)/2$ and mean effective normal stress $\sigma_n' = (\sigma_1'+\sigma_3')/2$, it can be seen that the upper bound of the rock mass strength corresponds to the peak strength of intact rock, while the lower limit is bounded by the residual strength as shown in Fig.10.

(F-6, G-3, G-4)

(44) Mechanical Properties Relating to Texture or Structure in Dolomite

Matsumoto, Y., Iemura, T. and Tanaka, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 36–40, 1982,

The authors have statistically analyzed the correlations between the minor constituents and the strengths or Young's modulus in dolomite. From these results, they can have estimated the positive correlations between the content of SiO_2(%) and the compressive strength, the tensile strength or Young's modulus, and the content of Fe_2O_3(%) and the compressive strength in dolomite, respectively. Moreover, they have also estimated the negative correlations between the content of Fe_2O_3(%) and the tensile strength or Young's modulus in dolomite, respectively. Then, as a method which explains the above mentioned correlations experimentally and theoretically, they have observed the minor constituents and the microscopic cracks etc. in the thin specimens of dolomite by the use of a polarizing microscope and a scanning electron microscope. On the basis of the results of the observation, they have considered the influence for the strengths and Young's modulus. Consequently, the results to be mentioned are as follows :

In many cases, most of the quartz and clay mineral granules which are the main minor constituents in dolomite, exist stably in the transgranules and intergranules, without the company of the microscopic cracks. It is observed, in many cases, when these cracks propagate in the samples, under the microscopes, that the microscopic cracks in the samples broken by triaxial stiffness compression tests, avoid, or stop at the quartz granules and the microscopic laminae where the clay minerals exist.

Accordingly, it is considered that the positive correlations between the compressive strength and the content of SiO_2(%) or the content of Fe_2O_3(%), and Young's modulus and the content of SiO_2(%), are probably ascribed to actions similar to the dispersion strengthening or the precipitation strengthening in the case of the quartz granules, and to the intergranule strengthening in the case of the clay mineral granules, respectively, as shown in the strengthening mechanism of structural materials. Subsequently, it may be considered that the negative correlations between the tensile strength or Young's modulus and the content of Fe_2O_3(%), are caused by a characteristic action in dolomite, where the clay mineral granules promote tensile ruptures. In other brief words, it may be considered that there are relations between the texture, or the structure, and the mechanical properties in dolomite.

(F-3, F-6)

(45) Time-Dependent Stress-Strain Relationship of Soft Rocks

Hirai, H., Satake, M. and Yanagisawa, E.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 41–45, 1982,

So far some criteria related to yielding of viscoelastic materials whose plastic behavior is independent of hydrostatic pressure have been proposed. Since the plastic behabior of viscoelastic materials such as soft rocks depends on hydrostatic pressure, the foregoing yield criteria are considered not to be sufficient to predict yielding. A yield criterion is proposed in order to elucidate phenomena associated yielding of soft rocks. By use of this yield criterion, the time-dependent behavior of soft rocks is investigated. The appropriateness of the yield criterion is examined through experimental data.

Followings are the results of this study.

(1) For soft rocks, a yield criterion which consists of the stored energy and the dissipative one is proposed.

(2) By use of the abcve criterion, the influence of loading rate on yield stress is investigated. It is shown that as the loading rate increases, the yield stress increases.

(3) For the limiting cases that the loading condition is very slow or very fast , the stress-strain relationships of soft rocks are represented.

(4) It is shown that yielding is caused by creep under the condition of constant stresses.

(5) The appropriateness of the proposed criterion is studied through some characteristics of mechanical behavior of soft rocks.

(F-6, G-2, G-3)

(46) Elasto Plastic Analysis considering Strain-Softening, Dilatancy and the Existence of Weak Plane

Sato, M., Harada, H., Hirano, I. and Kamemura, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 46–50, 1982,

In onder to examine the stability of underground openings in rock, non linear behavior of rock should be considered. Especially strain-softening and dilatancy, which can be seen after yielding, play an important role in the rock behavior around underground openings. The existence of weak plane, where the strength are less than that of sound part, is also important in the examination of rock stability.

In this paper, authers tried to express these non-linearity as exactly as possible using finite element method with in a framework continuum mechanics. Following rock behavicr have been considered:

(1) flow of shear deformation after yielding

(2) dilation of volume along with shear flow

(3) strain-softening

(4) existence of weak plane

Using a new numerical scheme for good convergency of non linear iteration, simple circular tunnel model have been analyzed. Results show that the proposed method is very effective for the analysis of rock with several yield conditions and needs less computation time.

(F-6, G-2, G-3)

(47) Evaluation of Deformation Behavior of Rock Mass considering Mechanical Properties of Joint and Intact Rock

Sekine, I., Yoshinaka, R. and Yamabe, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 61–65, 1982,

Structural discontinuities such as joints, bedding planes and fractures are widespreaded in rock mass. It is well known that the deformability of jointed rock mass is greatly influenced by the properties of intact rocks and discontinuities which form rock mass. In this paper a method is presented for evaluation of jointed rock mass considering nonlinear joint properties. And it is compared with experimental results obtained from the loading test used jointed rock mass model.

The outline of this study is as follows:

(1) Direct shear test and uniaxial compression test are performed for the investigation of mechanical properties about artificial joints. To allow the displacement measurements to be made directly on joints, the contact gage method are introduced.

(2) Nonlinear joint properties are approximated by the hyperbolae function for representing shear stress-displacement relation.

(3) Joint normal stiffness increases exponentially in proportion to the joint closing, and this relation is expressed by the exponential function.

(4) A series of Bi-axial loading test using jointed rock models are performed with tuff.

(5) Equivalent deformation moduli (E, G, ν) of jointed rock mass are evaluated by equating the summation of deformations in both rock and discontinuities, and the load-deformation behaviour obtained from the experiments and theoretical calculations are compared. It is clarified that the method used to evaluate the deformation behaviour of rock masses can approximately explain the experimental results.

(F-6, G-2, G-3)

(48) Pulling-Out Resistance of Electric Transmission Tower Footing Partially Penetrating into the Surrounding Ground at Its Bottom Slab

Kitahara, Y. and Ito, H.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 66–70, 1982,

With Relation to the Inverted-T-type footing generally used to electric transmission tower in Japan, Chubu Electric Power Co. has developed the footing, the bottom slab of which penetrates into the surrounding ground so as to expect the penetrating parts of dentiform to resist effectively to pulling out load.

In order to make clear the effect of this penetrating parts on pulling-out resistance and to estimate the capacity force, experimental analysis by the methods in laboratory or in field and by the computational analysis by F.E.M., in which non-liearity of mechanical properties of soils were taken into consideration, were carried out.

Results obtained are as follows.

1. The pulling-out resistance of footings having the penetrating parts of dentiform at its bottom slab exceeds that of those without penetrating parts in 30-100%. However, the number of penetrating parts has practically little effect on the resistance.
2. By the proposed stress-strain function showed as follows, could be represent approximately, the non-linear deformabilities of sandy, silty, clayey materials in the ground.

$$(\sigma_1 - \sigma_3) = (a\sigma_3 + b)\{1 - e^{-|\varepsilon_1|(c\sigma_3 + d)}\}$$

in which σ_1, σ_3 ; maximum and minimum compressive principal stresses
ε_1 ; maximum axial strain of compressive direction
a, b, c, d; constants of material determined by mechanical test

3. Three dimentional F.E.M. of the successive incremental load procedure, in which is considered, the non-linear mechanical properties proposed above, is applied for estimating pulling-out resistance of this type of footing. The computional results showed a good agreement with the experimental ones in laboratory or in field.
4. As a design criteria, practical solution is proposed for estimating pulling-out resistance of footing having a circular shape. In the ease of this type of foot-

ing having penetrating parts of dentiform, axi-symmetric F.E.M. is applied for making the clear the equivalent value of radius r which can be replaced into the practical solution mentioned above. The equivalent value is found to be $1.23 \times r_0$. Where r_0 is a radius which gives the same areas of the footing including its penetrating parts.

(F-6, G-3, G-4)

(49) Experments and Analyses on Effects of Rock Bolts as Reinforcement in a Tunnel

Yoshikawa, K., Asakura, T. and Kawakami, Y.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 71–75, 1982,

Generally, it is said that tunnels are stiff structures against earthquakes. But according to the investigations about past earthquake disasters of railway tunnels, the lining near the entrance of the tunnel in unstable ground were damaged by strong earthquakes. Especially tunnels without invert concrete were damaged considerably. So the experiments were performed to confirm the effects of rock bolts as reinforcement in such tunnels. 1/10 size models of standard section for Shinkansen were loaded vertically or horizontally. The results of the experiments were analyzed by NATMFEM program.

The summaries are shown as follows.

1) By the rock bolts in the floor part ground surrounding tunnel is reinforced and made difficult to be damaged.

2) The displacement of the model which is reinforced by rock bolts is restrained to the same extent as that of the model which has invert concrete in the range less than $110 tf/m^2$.

3) The joints of sidewall and arch are not structural weak points if the excution of jointing is perfect.

(F-6, G-3, G-4)

(50) Fundamental Study on Effects and Design of Rock Bolting

Saito, T. and Amano, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 76–80, 1982,

Lately in Japan, fully-bonded rock bolts are getting popular as one of the main members of tunnel supports. Their adoption may be due to the received effects of rock bolting. However, the mechanism and the design theory of rock bolting are not clarified adequately.

In this paper, at first, the behavior of rock bolt with rock movement around it, is considered based on the fundamental equilibrium of rock bolt and the interaction between rock and bolt. As the results, it is pointed out that the displacement and axial stress in the rock bolt induced by the rock movement, can be obtained analytically by solving the simple differential equation. The distributions of axial stress in the rock bolt induced by various type of rock movements are examined by this equation. The coefficient which represents the effects of interaction between rock and bolt, can be determined by the pull test of rock bolts.

Subsequently, it is considered that the effects of rock bolting is appreciated with the elastic strain energy in rock bolts induced by rock movements. By this idea, the most suitable length of rock bolts can be determined. Further, knowing the variation of the strain energy in rock bolts corresponding to the displacement of the tunnel wall, rock bolting can be designed as well as the concrete linings and steel arch supports, through the strain energy in the supports.

(F-6, G-3, G-4)

(51) Peripheral Behavior of Tunnel in Kamuikotan Metamorphic Zone

Takasaki, H., Kurata and Kusumoto, F.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 101–105, 1982,

A rock condition of Inasato Tunnel, where is in the central part of Hokkaido and is under construction, consists of shist and surpentine.

This area has always displayed an expansive tendency in case of tunnel work, because it's charastalicity is very poor and easy to pick a plastic flow up.

For that reason, the big test gallery was excavated by NATM for two years.

This report describes a part of investigated results, that is to say, relationship among deformation, ground pressure and distance from face of tunnel, and effect of supports.

The important outcomes are as in the following:

(1) Tunnel deformation should be kept as small as possible. This depends on the reason why mitigation of ground pressure keeping step with tunnel deformation is very little.

(2) A great part of deformation occurs within 2 X D (width of tunnel) before and behind a face. Besides amount of deformation before a face gets 30-40% of that number. Accordingly, it is need to make a deformation before a face decrese for accound of keeping a small total-one.

(3) In this rock condition, a 3-dimensional thinking and/or observation, deformation-ground pressure-distance from face, is necessary for understanding a peripheral behavior of tunnel.

(4) In a short time duration just after excavation, Steel rib not shotcrete system mainly supports a force. To use a too big one brings a possibility of failure, however.

(F-5, G-3, G-4)

(52) Influences of Fault System on Groundwater Movement in Rock Mass

Suzuki, T. and Kojima, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 161–165, 1982,

In most crystalline rock mass, groundwater flows mainly through faults or major fractures. The purposes of this paper are to pick up the factors which govern the flow in rock mass and show the influences of these factors by computer simulations. The following factors can be considered to determine the flow through faults.

1) Geological properties of faults.
2) Depth or overburden pressure.
3) Hydraulic characteristics of fault intersections.

As the first step, we classified the fault into three types as follows.

a) Concentration of clean joints.
b) Fault filled with brecciated materials.
c) Fault filled with clay.

From our laboratory permeability test, it is clear that the permeability of each type of fault mentioned above differently decreases with normal stress or overburden pressure. The importance of taking account of geological properties of faults and overburden pressure is shown by computer simulations considering them.

In actual rock mass, some fault intersections exist. It will be shown that the third factor plays an important role on groundwater movement, i.e., flow rates through faults change considerably by the hydraulic conductivity of fault intersections and sometimes flow directions change. As the result of this fact, the possibility of grounwater cotrole by the improvement of hydraulic conductivity of fault intersections can be considered. This possibility also is shown by computer simulations dealing with the flow around oil storage cavern when fault intersections are grouted. (F-4, G-5)

(53) Consideration on Seepage Flow through Multi-Impermeable Layered Slope

Komada, H., Kitahara, Y. and Akashi, R.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 166–170, 1982,

For the purpose of verifying that the developed analysis method of the seepage flow in saturated-porous media could be applied to the seepage flow through multi-impermeable layered slope, the analytical values of the steady seepage flow through a slope were compared with the observed values. It was estimated from the observed pore pressure distribution that there were a few water tables in the slope. On the other hand, the same things were estimated from the results of the numerical analysis. Considering that the analysed slope has complex layers, application of the above method to the analysis of seepage flow through the slope with a few water tables or unsaturated zone is considered to be possible.

It was considered as hydraulic fracturing that the seepage velocities became more than the critical velocity and the soil particles within the slope were swept away. The analysis on this phenomenon have been possible by developing the above analysis method of the seepage flow in saturated-unsaturated porous media. Applying the analysis method to the forecast of the fracture of slopes under heavy rain, the fracture of surrounding slopes of the reservoir under rapid draw down of the water table and etc. is considered to be possible. (F-4, G-5)

(54) Study on Groundwater Flow around Unlined Rock Caverns by Means of Green's Identity Formula

Momota, H. and Kusumoto, F.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 171–175, 1982,

In underground unlined rock caverns, an oil material can be stored by the aid of natural or artificial groundwater pressure around the caverns. The groundwater in the bedrock plays a role of prevention of both gas leakage from caverns and mixture of oil between two caverns. In analysis, the former can be checked by vertical hydraulic gradient (Io) and the latter can be checked by horizontal hydraulic gradient (I_H) around caverns. In order to solve these phenomenan in seepage problem, a method of numerical analysis using boundary integral (Green's Identity Formula) have been proposed instead of FEM, because FEM is somewhat complicated in mathematical and computational technique.

In this paper, the effects of artificial groundwater on the oil-strage caverns with an array of boreholes for water supply were estimated by two dimensional steady seepage analysis using Green's Identity Formula.

As the result of analysis, conclusions are as follows.

(1) The vertical hydraulic gradient (Io) decreases with the increase in number of caverns (N), but it nealy constant in case of $N \geqq 5$.

(2) Among changes of the distance between two caverns (S), the distance from cavern to horizontal boreholes (L) and the difference of potential head between cavern and boreholes (Δh), changes of L and Δh are more effective to Io than that of S.

(3) Even in case of the flow between two caverns without boreholes, where one cavern is empty and another is full, prevention of mixture of oil between two caverns is possible if nessary condition for S, L and Δh are ensured.

(4) The calculation for sixteen caverns with only horizontal boreholds show that the discharge and hydraulic gradient by means of Green's Identity Formula agree well to those by FEM. (F-4, G-5)

(55) Static Demolition of Rock-Like Materials

Nakagawa, K., Kudo, Y., Hashimoto, K., Yamamoto, T. and Tanaka, H.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 176–180, 1982,

Static demolisher, which expands gradually by hydration of CaO and some kind of silicates, seems to be useful in rock excavation or demolition of old buildings in urban area.

In this study, the condition between the hole diameter and the hole spacing which give the contour formation in a mass of rock-like materials was discussed. Then a simple formula

$$knD\sigma_i = (l - nD)\sigma_t$$

which gives the contour formation condition was proposed and its applicability was confirmed experimentally. Here, l and D are the contour length and hole diameter respectively. σ_i is the swelling pressure of the demolisher and σ_t is the tensile strength of the material. n is the number of holes and k is a material constant.

A series of experiments were conducted by using concrete specimen and demolisher " Brister 150 " by Onoda Cement Co. Ltd.. With the constant k=1, the crack formation through the specimen was predicted using the formula. (F-6)

(56) Rock Properties and Their Effect on Thermally Induced Stresses Under Low Temperature

Kinoshita, N., Ishizuka, Y. and Hibi, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 181–185, 1982,

In this paper, laboratory experiments and thermal stress analysis by the finite element method were performed to investigate the behavior of rocks under thermal stresses.

The materials used in the investigation were intact rocks (granite) and randomly jointed rocks which were made by heating the intact rocks. The rock specimen used was a cube of 30 cm with a 3.8 cm borehole in the center. The temperature of the borehole wall was lowered by liquified nitrogen at the rate of -20°C/hr and the outer surface of the specimen except two surfaces having the hole was kept at 10°C. Temperatures, strains and acoustic emission (AE) events were measured during the experiments.

Since mechanical and thermal properties of rocks depend on the temperature according to previous rock experiments, the thermal stress analysis was executed considering the temperature dependence.

The main results obtained are summarized as follows:

(1) Even rocks with a small porosity such as granite indicated a freezing expansion phenomenon in a wet state. The freezing of rocks excelled in the direction of a heat flow and had influence on the thermal stress distribution of the surrounding rocks.

(2) Beyond the minimum temperature of LPG storage, cracks observed by the naked eye and AE generated have not produced in the specimen of randomly jointed rocks as well as intact rocks. The tensile fractures by the thermal stress analysis were not produced, either.

(3) On the other hand, at a LNG storage operating temperature, cracks have been observed in only one case of rock specimens. However, the number of AE generated increased and tensile fracture zones by the thermal stress analysis were rather progressive in every specimen at the operating temperature. As a result, we could conclude that it is difficult to maintain a rock stability under thermal stresses at this temperature.

(4) For the specimens in a wet state, there were no distinctions between intact rocks and randomly jointed rocks among the initiated temperature of AE generated, the initiated temperature of the tensile fracture and the propagation of tensile fractures by the thermal stress analysis.

(F-6, F-8)

(57) Influence of Distribution and Properties of Geological Discontinuities to the Permeability of Granitic Rockmass

Kojima, K., Kondo, H. and Suzuki, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 11–15, 1983,

The fracture characteristics of granitic rock mass in Japan are described here for the relation of permeability.

Some typical figures are shown in this paper which give the relationship between hydraulic conductivity and some properties of geological discontinuities such as joints and faults. Especially, main flowpath of undergroundwater is in the remarkable fractured zones in rockmass, so it was found that the discontinuities are highly related to the permeability, which are expressed by the cumurative width of fractured zone in each 10 m of cores. And this index for permeability shows negative exponential distribution.

Then the basic conception is discussedfor the prediction of fracture distribution in actual rockmass and for making appropriate models to numerical calculation. (F-2, F-4)

(58) In-Situ Measurement of Shear Strength of Rock by Borehole Load Test
Takeuchi, T., Tanaka, T. and Ohhashi, T.
Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 21–25, 1983,

This paper discribes a method for estimating the shear strength,i.e.cohesion,C, and angle of friction,ϕ,by borehole load test for the uniform rocks which have no cracks or joints. Under the assumption that the rock mass behaves on the mohr-coulomb criterion,displacement of the borehole wall after the yielding,U_{RY},can be expressed by the following formura.(after Takeuchi et al.,1982).

$$U_{RY} = \frac{1+\nu}{E}[(1-2\nu)Po-Y]Ro\ \exp(\frac{P-Y-Po}{2Y}) \quad \text{-------------------------(1)}$$

$$Py=C\cos\phi + (1+\sin\phi)Po=Y-Po$$

Where, E: deformation modulus ν: poisson's ratio Ro: radius of the hole
C: cohesion of the rock mass ϕ: friction angle of the rock mass
Po: confining pressuer $Y=C\cos\phi + Po\sin\phi$

When the stress-deformation curve is expressed by equation (1) with the shear strength obtained from the triaxial compression tests on the specimens sampled from measurering point of borehole load test,this curve is consistent with the stress -deformation curve in-situ measured by borehole load test as shown in Fig.1.

This implies that the shape of the in-situ stress deformation curve can be determined by means of eqa.(1)under the assumption thatthe shear strength from triaxial test is identical with the one in-situ. Also,curves can be expressed by eqa.(1)with assumed yieled stress Py. So,the stress-deformation curve in-situ can be compared with curves drawn for several yielding stress Py. It is posible to find the curve consistent with the curve in-situ and the yielding stress can be determined. The yielding stress Py determined as above is more exact than the Py by visual observation of the in-situ curve.

Two or more values of the yielding stress that are measured at different depths at the same geological layer are needed to estimate the shear strength. If the distribution of the yielding stress Py in the direction of depth are known and the relationship between Py and depth is linear,shear strength can be determined as shown in Fig.3.

As an exception,the shear strength can not be determined at a site where the shear strength is different from surroundings. However,it is possible to assume that cohesion can be determined without serious error with the condition that the friction angle is smaller than a certain value. The example of the relationship between cohesion and friction angle is shown in Fig.4. (F-6)

(59) Impact Breaking Strength of Sandstone

Sakai, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 26–30, 1983,

The mechanism of breaking due to the impact on materials such as rocks has not yet been clarified. This research aims at theoretically and phenomenally interpreting the behavior of rocks under impact load, and determining the impact breaking strength of rocks by discussing the breaking of rocks in view of energy balance. For the test, the columnar test pieces of sandstone were used in all cases, and the axial impact load corresponding to mono-axial compression test and the impact load in diametral direction corresponding to pressure rupture test were applied to them, thus the impact breaking test was carried out.

In the impact pressure rupture test, the breaking due to pressure rupture arose in the central part along the diameter of columns, and outside that part,the breaking due to pressure crushing occurred,in this way, a part of the test pieces broke down. The extent of this region of pressure crushing depended on not only the intensity of impact load but also the breaking strength of rocks.

For the breaking criterion, considering that the sandstone used for the test was nearly isotropic and homogeneous, the breaking criterion of Drucker-Prager with two parameters, which has been widely used for rocks, was adopted. (F-6)

(60) Post-failure Behavior in Triaxial Compression Test Controlled by Radial Deformation

Saito, T., Hasuka, Y. and Nishii, O.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 36–40, 1983,

Post-failure behavior of rocks is considered to be deeply concerned with the mechanism of rock pressure phenomena, such as rockbursts. However, it is difficult to obtain the complete stress-strain relations of hard rocks, and further, Wawersik et al. (1970) introduced a concept that there exists another kind of rocks which have the load - displacement curves with a positive gradient in the post-failure region and called this type a class II . In case of class II type rocks, any stiff testing machine cannot control the progress of the fracture. Therefore, to cotrol these rapid progress of the fracture, Sano et al. (1975) proposed the servo-controlled compression test using the diametral deformation as a feed-back signal. The authors applied this control method to triaxial compression tests and examined the post-failure behavior on some rocks.

In case of Izumi sandstone, it is found that the behavior of class II type is shown under the confined pressure, 0 - 50 MPa, and this tendency is more intensive under the confined pressure 20 - 50 MPa than 0 - 10 MPa, and under these confined pressure, the single apparent shear plane is observed in the specimen. Inada granite does not show the behavior of class II type, but even under the high confined pressure, 100 MPa, does not show the ductile behavior. In comparison between two types of Horonai sandstone, one of which belongs to the seam where the rockbursts are apt to occur and other does not, the former shows the behavior of class II type.

On the analysis for class II behavior, the structural model of specimens containing the single shear plane are considered and the behavior of shear plane is supposed based on the results of the direct shear tests. Simulating the triaxial test with this model, the condition for the appearance of class II behavior is obtained. But the formation of the single shear plane is concerned with the characteristics of the rock materials. (F-5)

(61) Rock Shear Test under Constant Deformation Rate and Dilatancy of Rocks during Shear

Esaki, T., Aoki, K., Ndamukong, S.A. and Nishida, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 41–45, 1983,

With the aim of carrying out the following tests:-

(1) Rock shear test under high normal stress,

(2) Rock shear test with controlled vertical deformation and

(3) Shear test of rocks containing discontinuous planes,

we designed a new shear testing machine which was used in the present investigation.

Two rock types, Ainoura sandstone and Akiyoshi marble, were used in our tests involving the first two objectives mentioned above. The data from our tests give very plausible shear stress versus shear displacement curves (Fig.3) which are comparable with those of triaxial stiff tests. Particular attention is drawn to the interesting fact that rock dilatancy characteristics can be observed during shear.

With regard to the controlled deformation tests, our machine handled the situation very successfully, hence characteristic curves of sundry normal stresses were obtained as shown in Fig. 4.

From Fig. 6, it is observed that the data on the failure criterion are very reproducible but have slightly higher peak and slightly lower residual values than those of triaxial tests. (F-6)

(62) Mechanical Behavior of Sedimentary Rock (Tuff) under Cyclic Loading

Ohnishi, Y., Kawanishi, M., Soya, M. and Shichijo, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 61–65, 1983,

Foundations of dams, roads and bridges, underground space like tunnels and chambers are subjected to cyclic loading caused by earthquakes, traffics, blasting, etc.. The effects of cyclic loading on several different civil engineering materials such as steel, concrete and soil have been investigated. A typical phenomenon is so called cyclic fatigue in which a material fails at a stress level lower than its static strength. However, little work in this subject has been done in the area of rock mechanics. The influence of combined stresses and pore water pressure have not been investigated.

It is known that the fatigue curve in cyclic loading is similar to the static creep. The reason why is not well documented theoretically or experimentally. Scholz and Koczynski tried to explain these rock behaviors under cyclic loads with hard crystalline rocks. Their conclusion was that three types of cracking result in dilatancy* stress-induced cracking; stress-corrosion cracking and fatigue cracking. Rock fracture is sensitive ti which type is prevalent.

The purpose of this research is to examine a number of features that are not well observed in more conventional test. Soft saturated porous sedimentary rocks (tuff) were selected for undrained triaxial test. Deformation, strength and behavior of pore water pressure under quasi-static and cyclic loading have been investigated. In addition, creep tests were conducted to know the "long-term" strength. The results of these tests are interpreted in view of the complete stress-strain curve. (F-6)

(63) Weathering of the Granite in Kaduna Distinct, Nigeria and Its Geotechnical Properties

Kaneko, S., Sueoka, T. and Yasu, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 91–95, 1983,

The ground in Kaduna district, Nigeria has been investigated from the view point of weathering of the granite and compared with Masado which is the decomposed granite soil in Japan.

The following conclusions have been obtained.

(1) The ground in Kaduna district, Nigeria can be classified to seven kinds soil layers from geotechnical engineering view point.

(2) With decrease of the depth in the ground, fines content increases as shown in (Fig.-3). Compared with Masado in Japan, the particle size distribution of D-layer samples in the district is similar to the one of Masado.

(3) The soil porosity of the ground varies with depth. The largest porosity value exists in C-layer and the value decreases with the decrease of the depth as shown in (Fig.-4), however the same trend cannot been seen in Masado in Japan.

(4) The particle size distribution of the soils in the district varies with depth, and the third layer (C-layer) particle size distribution is not suitable for the compactibility as shown in (Fig.-5).

(5) The relationship between ignition-loss or $H_2O(+) + H_2O(-)$ value and the soil porosity in the district has different trend from the one of Masado as shown in (Fig.-8).

(6) Mechanical properties of the ground has a little different trend from Masado in Japan as shown in (Fig.-9), especially in upper soil layers (B, C-layers) in the district. The cohesion component Cu in the triaxial test (UU-test) depends on its soil porosity as shown in (Fig.-11) in case of the degree of saturation Sr = 70 ∿ 90% and the confining pressure σ_3 = 0.5 ∿ 1.5 kgf/cm^2. (F-2)

(64) How to Simplify the Geometry of Discontinuous Rock Masses by Crack Tensor

Oda, M. and Suzuki, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 96–100, 1983,

Discontinuities like faults and joints (called cracks) are of widerspread occurence in rock masses in situ, with cery complicated geological setting. The complexity especially in their geometry is no doubt a major obstruction in the development of theory useful to predict the mechanical behavior of rock masses. In order to overcome the obstruction, a tensor (called crack tensor) is introduced to abstract the geometry formed by cracks without losing generality. As an example, a trial based on acceptable simplifications is successfully done to formulate an overall elastic compliance due to cracks in terms of the proposed tensor. With the help of the geometrical probability, the tensor is expressed by quantities measureable in the field by which it becomes possible to use it in the practical rocks mechanics.

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(65) Crack Tensor for Discontinuous Materials and Its Effect on Their Mechanical Properties

Suzuki, K., Suzuki, K. and Oda, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 101–105, 1983,

A second rank tensor F_{ij} called crack tensor has been introduced to show crack geometry for discontinuous geological materials. Uniaxial compression tests on gypsum plaster samples with random cracks are reported to examine the applicability of crack tensor in practice, with the following conclusions.

1) The first invariant of crack tensor F_{ij} is important as an index measure for evaluating the crack intensity which is related to the number and dimension of cracks.

2) The measure Γ which is deduced form the second invariant of the deviatric part shows a distance from an isotropic crack system. It is important as an index for measuring the degree of anisotropy due to the prefered alignment of discontinuity, and is powerful to evaluate the mechanical anisotropy of cracked materials.

3) The principal axes of the crack tensor are identical to the principal axes of crack anisotropy. There is no doubt that the principal axes as well as the measure is very important in the analysis of anisotropy of anisotropic discontinuous materials. (F-0)

(66) Fracturing of Granite Specimens with Demolition Agent

Kudo, Y., Hashimoto, K. and Nakagawa, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 106–110, 1983,

Demolition agent can gradually fracture rock and concrete by static pressure where blasting is restricted or prohibited and seems to be useful in rock excavation or demolition of old building in urban area.

In the previous study, we proposed the following contour formation for fracturing the rock-like materials with demolition agent;

$$knD\sigma_i=(l-nD)\sigma_t$$

where l and D are the contour length and hole diameter, respectively. σ_i is the expansive pressure by demolition agent and σ_t is the tensile strength of the material. n is the number of holes and k is a material constant. Experimental results using concrete specimen agreed well with proposed equation with k=1.0.

In this report, a series of experiments are conducted by using granite specimens. Equation of the contour formation condition is modified as follows;

$$(S-D)/D=k(\sigma_i/\sigma_t)$$

in which S is the spacing between boreholes and compared with experimental data. The same trend as the concrete specimen is observrd and with the constant k=1.0, the crack formation through the specimen was predicted using the modified formula. (F-2)

(67) A Consideration for Strain Softening Characteristic of Rock Material

Hamajima, R. and Kusabuka, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 126–130, 1983,

Rock material has strain softening and dilatancy characteristics, and it is necessary to consider such mechanical characteristics of rock material in the analysis of rock media.

Now these strain softening behaviors of rock material do not always depend on its material characteristics. Rather they are often shown apparently by the structural characteristics of rock. In this study, a splitting tensile test, uniaxial and biaxial compression tests and a direct shear test were made with attention paid to the behaviors after the peak load, a study was made on various strain softening characteristics and a numerical analysis was made on these characteristics.

In this study, a numerical analysis was first made on the results of the splitting tensile test and uniaxial compression test, which has revealed that some strain softening behaviors can structurally be shown without considering the strain softening behaviors of rock material.

In this case, cracks existing in rock material have a large effect on its strain softening behaviors, and through propagation of these cracks, rock elements structurally show strain softening behaviors.

Next a constitutive equation of material was derived considering the strain softening behaviors obtained from the direct shearing test, and an analysis was made on a direct shearing test model considering the strain softening behaviors as the material characteristics. As a result, it was made chear that the strain softening behaviors were strongly governed by the structural characteristics of rock material as well as the material characteristics.

In view of the above, in the numerical analysis on strength and deformation characteristics of rocks, it is necessary to use an analysis method which can fully consider the development of cracks of slip.

Particularly in a study on the rock strength, there are 2 cases; one where cracks or slip occurs at once and causes a rapid reduction of strength and the other where cracks or slip gradually develops leading to comparatively stable destruction. For characteristics are fully considered.

(F-6)

(68) Trap Door Experiments to Study the Difference between Sandy Ground and Clayey Ground in Tunnelling

Kitagawa, S., Kawakami, Y. and Onoda, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 230–234, 1983,

We have recognized the difference between sandy ground and clayey ground in regard to behavior of ground around tunnel through our experience. In order to study this problem we made trap door experiments. In these experiments we measured sinking of the trap door and pressure on the bottom of the experimental box. And we used standard quartz sand, fine quartz sand, rock powder, and bentonite for ground model.

As a result, we can separate them to two groups by the behavior of ground, one of which is composed of standard quartz sand and fine quartz sand, the other is composed of rock powder and bentonite. We temporally name the former sandy group and the later clayey group.

Sandy group is suitable for modified Terzaghis theory on earth pressure, which is considered about shear strain. So, earth pressure decreases rapidly with slightly sinking of the trap door, and if overburden is more than about width of the trap door, earth pressure is almost as same. On the other hand, clayey group is not suitable for that theory. Earth pressure depends on sinking of the trap door and the overburden. In sandy group the behavior of ground is as same as what Terzaghi thought, so the ground beside the trap door surely supports it on the trap door. On the other hand, in clayey group the ground beside the trap door is consolidated and deformed, so it can not surely support the ground on the trap door.

(F-6)

(69) Yield or Failure Criterion for Discontinuous Materials

Suzuki, K. and Oda, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 1–5, 1984,

The applicability of crack tensor as an index measure for crack geometry of discontinuous geological materials has been proved by the results of uniaxial compression tests on gypsum plaster samples with random cracks. In order to extend its applicability,biaxial compression tests on gypsum plaster samples and uniaxial compression tests on samples made of some different kinds of matrices and on gypsum plaster samples with partly closed cracks are reported with the following conclusions.

1) Similarity condition for crack geometry in terms of crack tensor gives mechanical similarity for discontinuous materials normalized by the strength of each matrices.

2) In order to express mechanical behavior of discontinuous materials more pricisely, for example,crack tensor should be a function of coefficient of friction on crack surface.

3) Proposed failure criterion which takes account of above conclusions offers an explanation for the behavior of isotropic discontinuous materials in a limited range of stress conditions.

(F-6)

(70) Elastic Compliance for Rocklike Materials with Random Cracks

Oda, M., Suzuki, K. and Maeshibu, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 6–10, 1984,

Elastic compliance for cracked materials like rocks and rock masses is theoretically formulated in terms of the generalized fabric tensor which has been introduced as an index measure to express explicitly the crack geometry. By means of uniaxial compression tests and of supersonic wave velocity tests on gypsum plaster samples with random cracks, the formulation is proved to be a good approximation for describing the elastic response of cracked materials. The conclusions are summarized as follows:

1) The principal axes of the fabric tensor of second-rank exactly coincide with the symmetry axes of the elastic compliance tensor of fourth-rank.

2) The so-called self-consistent method is very useful to estimate the overall elastic moduli by taking into account the effect of elastic interaction between cracks.

3) Since the supersonic wave velocity is closely related to the character of the fabric tensor, it can be expected that the field measurement of wave velocity is useful to estimate fabric tensor of in situ rock masses.

(F-6)

(71) Experimental Study on the Transient Behavior of Groundwater Flow above Heat Source in Idealized Model of Fractured Rock

Watanabe, K. and Furukawa, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 41–45, 1984,

Transient and unstable behavior of thermally induced groundwater flow immediately above a heat source in idealized model of fractured rock was experimentally studied. Experiments were performed in soil box (dim. ; 105cm × 60cm × 15cm) surrounded with insulating plates. The soil box was divided into three parts by two interfaces which were inclined θ degrees to horizontal plane. The central part simulating fractured zone was filled by larger glass spheres of diameter 2.5-3.5mm or 0.5-0.8mm, and the remaining parts were filled by finer glass spheres of diameter 0.1mm to represent intact rock mass. Water could freely flow through the interfaces. Heat was electrically supplied from bottom of the soil box by the use of rubber heater seat. Change of temperature distribution was measured by means of 10 thermisters buried in the model and thermosensitive liquid crystal film (T.L.C.F.) set in front of the model. T.L.C.F. is very convenient to see the two dimensional form of temperature distribution.

Obtained results were as follows :

(1) It was found very clearly by the use of T.L.C.F. that temperature in high permeable fractured zone was considerably lower than it in intact rock at lower part of the model.

(2) Unstable flow such as plume was generally observed in high permeable fractured zone.

(3) Quantitative study on the unstable flow above heat source should be needed to evaluate heat transfer rate in fractured zone. (F-0, G-5, G-7)

(72) Fracture Toughness Test of Rocks under Low Temperature

Ishizuka, Y., Hibi, K. and Kinoshita, N.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 61–65, 1984,

This paper describes the fracture toughness (K_{IC}) of rocks as a function of a temperature and the relationship between the fracture crack and acoustic emission (AE) events.

Inada granites and Watarase granites have been used for the fracture toughness test, the three points bending test in accordance with ASTM standards. Inada granites have beeen tested in a dried state and in a saturated state in the temperature range from room temperature to -80°C. As for Watarase granites, specimens collected in the different three directions have been tested in the room temperature to examine the anisotropy of K_{IC}. During testing, applied load, crack opening displacement and AE have been measured.

The findings are summarized below:

(1) As the temperature is lowered the fracture toughness of rocks increases. Especially, marked temperature dependence of the fracture toughness is caused for saturated specimens. This result appears to be explained in terms of change from water to ice in rocks.

(2) With regard to the relationship between fracture crack and AE, the initation of stable fracture crack coincides the initation of AE ringdown-count and the initation of unstable fracture crack propagation corresponds with the point which m-value decreases from the peak point suddenly. (F-0, F-6, F-8)

(73) A Method of In-Situ Thermal Diffusivity Measurement (I)

Hane, T., Kinoshita, N., Ishii, T. and Fujii, I.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 66–70, 1984,

In designing an underground structure, it is important to consider the heat transmission in the rock adequately.

Analytical methods such as F. E. M and F. D. M give excellent solutions for heat conduction problems with satisfactory accuracy, but the results are naturally much influenced by the thermal properties used for the calculations.

In general, as would be expected, the value of the material properties is not stable and changes with variations of water content, anisotropic state and material phase.

Hence, thermal properties by small specimen, which is frequently applied, does not always give the value coincident with that measured under in-situ condition.

Under such circumstances, the authors offer a new and simpler method of thermal diffusivity measurement, which are applicable to in-situ condition.

In this paper, authors discuss the accuracy by the experiments on a laboratory scale using polycarbonate specimen, and by the quantifications of the measurement error factors.

According to these experiments conducted, it is concluded that the measurement of thermal diffusivity by mean of the offered method is possible with adequate accuracy within -4.8$\sim$+3.4% errors. (F-0, F-2, G-7)

(74) A Method of In-Situ Thermal Diffusivity Measurement (II)

Hane, T., Kinoshita, N., Ishii, T. and Fujii, I.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 71–75, 1984,

In general, small specimen in frequently used for the termal properties measurement, but thermal diffusivity for actual structures vary too much with water content of a material, the related temperature and applied thermal boundary conditions.

Therefore, the measured thermal diffusivity using small specimen is not always reliable.

Under such circumstances, a new and simpler measurement method of in-sity thermal diffusivity has been studied by the authors.

In this paper, through the application of this method to the acutal cavern located at Ohya region in Tochigi prefecture, the accuracy of this method is discussed.

Then, the other experiments were performed using the specimen sampled the same cavern to compare the results with those already obtained for actual cavern.

The testing conditions on speciments are as follows;

Condition A-(I) First the specimen A was entirely wrapped with polyethelene film and kept for several days under the conditions of the room.

Then, it was in a constant temeprature and humidity (5°C, 95%RH) for two days.

Condition A-(II) The specimen A-(II) is the same specimen A, used for the previous experiment, it was kept in constant temperature and humidity (5°C, 95%RH) for two weeks.

Condition A-(III) The specimen A-(III), used for the experiments, it was left in the water for two hours.

It was wrapped with polyethylene film, it was kept in constant temperature and humidity (5°C, 95%RH) for two days.

Condition B-(I) The another specimen B was also sampled from the same cavern.

It was wrapped with polyethylene film, left in the room for a week, and kept in constant temperature and humidity (5°C, 50%RH) for two weeks.

Condition B-(II) The specimen B-(II), used for the experiments, was left in the water for two hours.

Then, after wrapping with polyethylene film, it was kept in constant temperature and humidity (5°C, 50%RH) for two weeks.

In these experiments, it is concluded that the measurement of in-situ diffusivity is possible with adequate accuracy.

On the other hands, it is recognized that usual method for thermal diffusivity measurement would never give representative values for actual structures.

(F-0, F-2, G-7)

(75) Influence of Stress State and Temperature in the Permeability of Rock Core Samples Containing Various Joint Infills

Kojima, K. and Koike, Y.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 81–85, 1984,

Recently as the growing needs for the development of underground opening, the problems of prediction and control of underground water movement have attracted major interests. Especially in the geologic isolation of radioactive waste, the problem of underground water flow has great influence in radioactive nuclide migration from the repository.

By the way in a rock mass, flow paths are consists of geological discontinuities such as faults and joints, and the distribution and properties of those are generally complicated. From that standpoint, the authors have examined the permeability of jointed rock under the condition of 0 to 19.8 MPa in confining pressure, 20 to 100 °C in temperature. And tested samples contain natural joint with various infills, or artificially induced crack.

As the results, the following things are clarified.

1) In sequence of cyclic loading to the joint-containing rock samples, changes of hydraulic conductivity due to confining pressre are indicated as two types of curve. One is curve representing the most loosened condition of the sample and the other is curve which converges at the stress level about 20 MPa. These phenomenon are maybe correspondentced to the weathered or geologically unloading condition in actual rock mass.

2) Hydraulic conductivities of various rocks greatly differ due to the properties of joint surface and filling materials, but the trend curves to confining pressure mentioned in 1) are almost resemble in regardless of of these properties.

3) Increasing the temperature of rock sample from 20 to 80 °C, permeability of clean joint decreases to about one third of the value at 20 °C but altered clay-containing joint dosen't decrease so extremely.

(F-0, F-4, G-7)

(76) Experimental Studies on Elasto-Plastic Behavior of Soft Silt Stones
Yoshinaka, R., Yamabe, T., Shimizu, T., Abe, K. and Morita, E.
Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 86–90, 1984,

Consolidated drained triaxial compression tests were performed on two kinds of soft silt stone. The test results are compared with that of the other many soft rocks. And elasto-plastic behaviour of these silt stones are examined with based on non-associated flow rule. And the applicable yield function and plastic potential function are proposed in this paper.

Plastic potential is determined by the plastic incremental vector on the corresponding stress space. The plastic potential has a shape of ellipse in (p,q) plane. Stress dependency of the elliptic potential parameter (a,b) is investigeted for consolidated drained stress psth.

Yield function is a type of modified Cam clay model, but the yield point by volumetric stress does not agree with the yield point on p-axis obtained from shearing process.

(F-6)

(77) Background of Geotechnical Calssification of Soft and Weak Rocks
Hayashi, M.
Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 91–95, 1984,

It has been growing the geotechnical needs to be classified the mechhanical properties of soft and weak rocks, in order to synthetize the geological survey, rock and soil tests, numerical analysis, design and monitoring of rock structures, as well as data banking.

This paper presents a classification based on the uniaxial compressive strength and shear wave velocity as well as water absorption ratio and so on. Usual index was longitudinal wave velocity for hard rock. This paper emphasizes the feasibility of shear wave velocity and water absorption ratio for weak rocks. This classification is consistent from hard rock to soil material.

Soft rocks are classified to four classes from D_H, D_M, D_L, and E. More detailed, these classes are divided into two features : one is normal soft and other is abnormal soft or weak which are devided based on the water absorption ratio. The boundary between normal and abnormal in each class is set at the 5 percents water absorption ratio.

This classification should be verified the feasibbility of engineering judgement of tunnel construction, earthquake resistant design of nuclear power stations' foundation and slope stability and dam foundation.

The author appreciates for their presentations of test data of rock properties of soft rocks from Mr. K. KASUYA, Mr. T. IMAI and Mr. T. YOKOTA, and also for the valuable suggestion from Mr. M. OGATA and our colleges in CRIEPI.

(F-1)

(78) Mechanical Behaviors of Soft Rocks under Cyclic Loading in Triaxial Compression

Kobayashi, R., Matsuki, K. and Kudo, H.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 111–115, 1984,

In recent years, foundations of such as power stations or bridges have been constructed on so called soft rock mass. In these cases, soft rock mass is subjected to pretty severe cyclic loading in comparison with its strength under both confining pressure and pore pressure. For the safe design of soft rock foundation, it is prerequisite to clarify the cyclic fatigue characteristics of soft rock under triaxial compression.

In this work, cyclic fatigue test using 1Hz sinusoidal wave was conducted under confining pressure for two kinds of rocks; Hirono sandy mudstone and Kimachi sandstone. Their uniaxial compressive strengths are 59 and 540 kg/cm^2, respectively. In addition to the cyclic fatigue test, repeated loading-unloading test was also conducted using ramp wave of increasing maximum strain in order to know the fundamental relationship between differential stress and visco-plastic strain (permanent strain).

This paper mainly describes the cyclic fatigue process discussed from the view point of visco-plastic axial strain. Except the condition where the maximum differential stress is below the fatigue limit, the visco-plastic strain rate per number of cycles $\dot{\varepsilon}_a^{vp}$ initially decreases with the visco-plastic strain ε_a^{vp} until $\dot{\varepsilon}_a^{vp}$ reaches its minimum. After that, $\dot{\varepsilon}_a^{vp}$ begins to increase and finally the specimen collapses. On the other hand, in the relationship between differential stress σ_d and visco-plastic strain ε_a^{vp} , σ_d-ε_a^{vp} curve, which is obtained in the repeated loading-unloading test, differential stress σ_d increases with visco-plastic strain until σ_d becomes maximum, and, then, σ_d decreases and finally reaches the residual strength. Furthermore, the relationship between the maximum differential stress σ_m and the visco-plastic strain ε_a^{vp} at the failure point in the cyclic fatigue test well coincides with the σ_d-ε_a^{vp} curve as shown in Figs.6 to 9.

Considering the facts mentioned above, the fundamental concept of cyclic fatigue process is presented as schematically shown in Fig.10. In this concept, it is assumed that the visco-plastic axial strain rate per number of cycles $\dot{\varepsilon}_a^{vp}$ strongly depends on the difference between the differential stress σ_d in the σ_d-ε_a^{vp} curve and the maximum differential stress σ_m in the cyclic fatigue test (σ_d-σ_m) at the corresponding visco-plastic strain ε_a^{vp}.

As shown in Figs.11 to 14, the relationship between the visco-plastic strain rate $\dot{\varepsilon}_a^{vp}$ and the stress difference (σ_d-σ_m) in the process of cyclic fatigue lies within a region except the cases where σ_m is below the fatigue limit. This relationship is almost independent of the magnitude of the maximum differential stress σ_m in the cyclic fatigue test. Thus the concept presented in this paper well explains the fundamental behaviors of the visco-plastic axial strain ε_a^{vp} in the cyclic fatigue process of rocks.

(F-0, F-5, F-7)

(79) Mechanical Behavior of Soft Sedimentary Rock under Repeated Loading

Adachi, T., Ohnishi, Y., Soya, M. and Hichijyo, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 116–120, 1984,

Foundations of dams, roads and bridges, underground space like tunnels and chambers are subjected to cyclic loading caused by earthquakes, traffics, balsting, etc.. The effects of cyclic or repeated loading on several different civil engineering materials such as steel, concrete and soil have been investigated. A typical phenomenon is so called cyclic fatigue in which a material fails at a stress level lower than its static strength. However, little work in this subject has been done in the area of rock mechanics. The influence of combined stresses and pore water pressure have not been investigated.

It is known that the fatigue curve in cyclic loading is similar to the static creep. The reason why is not well documented theoretically nor experimentally. Scholtz and Koczynski tried to explain these rock behaviors under cyclic loads with hard crystalline rocks. Their conclusions was that three types of cracking results in dilatancy stress-induced cracking; stress-corrosion cracking and fatigue cracking. Rock failure or fracture is sesitive to which type is prevalent.

The purpose of this research is to examine a number of features that are not well observed in more conventional test. Soft saturated porous sedimentary rock(tuff) were selected for consolidated undrained triaxial test. Deformation, strength and behavior of pore pressure under quasi-static and repeated loading have been investigated. In addition, creep tests were conducted to know the "long-term" strength. The results of these tests are interpreted in view of the complte stress-strain curve.

In order to check the existence of complete stress-strain curve, triaxialtests with variable stress rate and strain rate are performed. It was found that the bahavior pointed out by Scholtz on crystalline rock is quite different from our tuff. The reason why is now under investigation by using weathered ganites.

(F-5, F-7)

(80) A Study on the Preparation of Models of Jointy Rocks

Kikuchi, K., Mimuro, T., Ohmura, F. and Hara, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 126–130, 1984,

For founding a civil engineering structure on jointy rocks, it is absolutely required to know the distribution conditions of joints in the foundation rocks, for clarifying the mechanical properties and permeability characteristics of the foundation rocks. It is also important for effectively executing such foundation treatment as grouting made for improving the foundation rocks.

Joints in rocks are generally said to be regularly distributed, but the regularity is not perfect. Therefore, a rock joint model used for examining the mechanical properties and permeability characteristics of rocks is an approximate model obtained by simplifying and regularizing actual conditions of the rocks. The authors have been variously studying for preparing the approximate model. This report describes the methods of investigating the opening widths of joints as one of the elements deciding the distribution conditions of joints, and the methods of evaluating and analyzing the opening widths required for preparing models, based on the results of studies made at an underground fuel storage site on I island and at T pumping-up power plant site.

The conditions of joint opening widths were examined and evaluated in reference to the results of the investigations made on the ground surface and the description of bore-holes. In this case it is characterized that the method of investigation mentioned below.

On the ground surface survey, the opening width was measured by a thickness gauge, and it was used a bore-hole television set for the description of bore-hole wall.

The examinations of joint opening widths clarified the following :

i) The joint opening width has correlativity with the joint length (continuity), and in general, the longer the wider. In this case, the rate of the width to the length depends on the orientation of the joint concerned.

ii) The joint opening width increases according to approach to the ground surface from the underground.

The above conditions can be well understood in view of the topographic evolution cycle caused by geomorphic agents and the generation mechanism of sheeting joints.

In the preparation of models of this time, the methods of examining and evaluating opening widths newly contrived this time have been applied, in addition to the methods of examining and evaluating such joint distribution elements as (1) orientation of joints, (2) lengths of joints and (3) distribution densities of joints. This method is surmised to make the rock joint models more realistic.

(F-3)

(81) Dynamic Photoelastic Studies of Wave Propagation in Slit and Fault Model

Sato, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 131–135, 1984,

Dynamic photoelasticity was used to study some foundamental aspects of wave propagation in a two-dimensional model with a deep and very narrow trench or a slit and a model with a fault filling the slit by lower characteristic impedance material, and to obtain information on the dynamic event associated with the various wave generated by plane wave incidence to those inhomogeneous region.

Photoelastic models were fabricated from Epoxy Resin plate which was 4.4 × 200 × 400 mm in size. A slit was cut to a depth 100 mm and a width 1.5 mm, and inclined to the free boundary of the plate so that plane distortional waves struck the slit axis with incident angle of 53.6° to 90°.

Softened Epoxy Resin was filled in the slit to obtain a fault model with a characteristic impedance mismatch of 1 to 0.4.

Travelling load method, which was performed by longitudinal compressive impact on one end of brass rod bonded to a longer edge of model plate by means of a lead bullet driven by air gun, was used to generate plane longitudinal and distortional waves simultaneously in the model plate, and the predominate pulse length of these waves were 10 cm and 5 cm respectively.

A high-speed drum type framing camera operating at 80,000 frames per second, was used to record the colored dynamic isochromatic fringe patterns associated with the propagating stress waves.

The dynamic isochromatic fringe patterns presenting cylindrical wave, headwave, Rayleigh wave, and reflected waves generated from the free boundaries and an end of slit associated with several angle of incidence of both type of pulses were discussed in detail. It was noted that the headwave and Rayleigh wave propagating from an end of slit had predominate effects on both free boundaries of the slit.

To evaluate the effects of the characteristic impedance mismatch and the difference of incident angle of pulses, the transmission and reflection coefficients of the boundaries of fault, presented by dynamic isochromatic fringe orders, were compared with reference model. But the differences of those effect were a little comparing with those of slit model in any incident angle in an range of the characteristic impedance mismatch.

It is clearly shown that the dynamic photoelastic method provides visual information over the entire region of interest and is very usefull in interpretation and analysis of the complex behavior associated with stress wave reflection and transmission encountered in the seismic problems above mentioned.

(F-0, F-7)

(82) Dynamic Deformation and Failure Characteristic of Rock Foundation by Cyclic Shear Loading Test

Fujiwara, Y., Hibino, S., Kanagawa, T., Komada, H., Ishida, T., Nakagawa, K. and Shin, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 136–140, 1984,

Nuclear power station are built on rock foundations. Dynamic properties of foundations have been obtained by dynamic triaxial tests using boring cores in case of weak rock foundations. In case of hard rock foundations,however,it is very difficult to obtain dynamic properties of foundations by core samples due to cracks and joints. The authors,therefore,have newly developed the in situ dynamic shear loading apparatus. Using this device various dynamic characteristics such as shear modulus,ultimate strength,damping ratio are obtained.

Some results obtained are as follows ;

The kinds of rock foundations are tuff-breccia and pumice-tuff .

(1) Dynamic shear moduli G_d increase in proportion to increase of normal stress magnitude σ_n.

(2) Dynamic shear moduli G_d discrease in propotion to increase of shear strain magnitude γ within the range of $3x10^{-5}$ to $2x10^{-2}$.

(3) Damping ratio h increase as shear strain γ increase.

(4) Near the yielding of specimen,shear strain γ increase immensely.

(5) In case of the tuff-breccia,dynamic shear yield γ_B were $(3.4\sim4.1)x10^{-3}$.

(6) In case of the pumice-tuff,the dynamic shear strengths were 14,18 and 22 kgf/cm^2. Comparing the static shear strengths ,the dynamic shear strengths were lower by about 23 %.

(F-6, F-7)

(83) Compressional Strength of Cracked and Jointed Rock Mass

Hamajima, R., Kusabuka, M. and Yamashita, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 145–149, 1984,

Usually rock mass contains many cracks and joints, and is at a three-dimensional stress state. When the constitutive equation necessary for their analysis is determined based on experiments, the strength deformation characteristics differ according to size and shape of the specimen, and the loading method, i.e., rigid plate loading or uniform pressure loading. Particularly when the behaviors after the peak load are put in question, these factors have a large effect. Thus the constitutive equation determined based on experiments generally contains the material characteristics as well as the structural characteristics, and so it can not be said that this constitutive equation represents true material characteristics. Especially in case of rock mass, the constitutive equation is more complicated due to discontinuity such as cracks and joints the rock mass contains. But it is very difficult to obtain the constitutive equation which contains all such discontinuities. Especially in rock mass, the analysis which considers such discontinuities is necessary because sliding between joints and the progress of cracks have a large effect on the material and deformation characteristics. The authors have made clear the following by using a discontinuous analysis method.

(1) Stress distribution on jointed anisotropic rock mass: There is a joint inclina-

tion where the stress distribution changes suddenly by sliding between joints.
(2) Strength and deformation characteristics of cracked rock mass having several basic crack patterns: Stable and unstable fractures occur according to the progress of cracks.
(3) Simulation to the direct shearing test on rock: In the analysis on a low confined stress state, cracks occur and show strain softening characteristics. Therefore the strain softening characteristics seen in rock mass are also attributed to the structural characteristics.

The constitutive equation used in the above analysis is based on the Coulomb's failure criterion, and the discontinuity of rock mass can be expressed comparatively well by such a simple constitutive equation. In this study, the following experiments were further made in order to make clear the fundamental characteristics of discontinuous rock mass.

(1) Strength and deformation characteristics by various stress paths of cracked rock mass having basic crack patterns.
(2) Changes of number and angle of joints, and further the strength and deformation characteristics of the rock mass having random joints.
(3) Changes of the strength and deformation characteristics of discontinuous rock mass by rigid plate or uniform pressure loading. (F-3, F-6)

(84) Consideration on the Relationship of Strain Distribution to Uniaxial Compressive Strength

Tano, H., Kitagawa, M., Watanabe, H. and Satake, M.
Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 150–154, 1984,

This paper proposes a statistical parallel model of size effect under uniaxial compression test in consideration of the bending moment caused by eccentric load, which is an experimental errors and it can not be avoided.

This unsymmetrical distributed load gives the strain gradient to the specimen. On the other hand, the experimental results of strains measured by means of strain gauges show a decrease of strain gradient in inverse proportion to the diameter of specimen.

Taking above facts into account two typical statistical models, the phenomena of size effect of uniaxial compressive strength can be explained by the parallel model.

From the consideration used by the parallel one, it is concluded as follows;

(1) The strain(stress) gradient decreases the probability of cleavage fracture of specimen, so that the apparent strength increasing of small size one is observed. This phenomena under uniaxial compression testing is called by "size effect".
(2) In the case of rock-like materials with the small variance of strength, the phenomena of size effect(i.e. apparent strength increasing) disappears in the large scale specimen due to the uniformed strain distribution. (F-0)

(85) Evaluation of Shear Strength of Rock by Borehole Test

Tanaka, T., Ohhashi, T. and Takeuchi, T.
Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 175–179, 1984,

We have been considered methods for estimating shear strength of rocks by borehole tests and proposed two methods as follows:

1) A method for estimating shear strength, i.e. cohesion C, and angle of friction, ϕ, by the borehole load test under an assumption that the rock mass behaves on the Mohr-Coulomb criterion.
   This method is suitable for uniform rocks which have no cracks or joints.
2) A method that the shear strength is determined directly by Rock Borehole Shear Tester (RBST). A schematic diagram of RBST is shown in Fig. 1.
   As shown in Fig. 1, the loading equipment which has two shear plates located in the opposite side each other is inserted into a borehole, a shear plates are contacted closely to the borehole wall and a normal stress is applied, then, a shear stress is applied by pulling up the loading equipment using the center hole jack set up at the borehole mouth.

This paper discribes some examples in which both methods, mentioned above, were applied to the same rock masses. In the case of uniform rock mass, the shear strengths obtained from two methods showed similar values.

When the rock mass was not homogeneous, however, shear strengths were different, due to various factors such as size of loading area, mechanism of failure.

(F-6)

(86) Tensile Strength Anisotropy of Granite

Kudo, Y., Hashimoto, K. and Nakagawa, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 295–299, 1984,

Granite contains numerous preexisting cracks which are preferentially oriented along three mutually perpendicular planes. These planes are called as rift, grain and hardway plane in order of ease of splitting. The cracks significantly affect the mechanical property of granite. In this study we wish to report tensile strength anisotropy of granite and the correlation among the compressive wave velocity anisotropy and the tensile strength.

Kurokami granite was chosen for this test. Oriented drill cores were cut in three mutually perpendicular directions from large block of granite and the cores were cut into disks. Compressive wave velocity and tensile strength were measured for diametric direction at 15° intervals, from 0° to 180°. Anisotropy of compressive wave velocity is greater in the grain and hardway planes than in the rift plane.

Tensile strength anisotropy $(\sigma_{tmax}-\sigma_{tmin})/\sigma_{tmax}$ ranged from 12% to 33% in each planes. Therefore if we wish to examine the tensile strength of same block from the cores drilled arbitrary directions, we must consider same degree of change. There was a strong correlation among the anisotropy of compressive wave velocity and the tensile strength anisotropy.

(F-0, F-6)

(87) An Approach to the Evaluation of Fracture System in Rock Mass by Probability Model

Nishimura, T. and Kojima, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 1–5, 1985,

It is very difficult to investigate fracture system and illustrate its geological section deterministically from the restricted data obtained from field survey.

Probability works are another way toget appropreate fracture model adding to the field data.

Traces of fractures on any section are illustrated here based on the survey of probability distribution of length and density of the dominant fractures, computer calculation and graphics.

In this paper, geologic sections of fracture system obtained this are also compared with some field evidences. (F-3)

(88) A Study on the Modeling Method of Jointy Rocks

– On the Joint Networks and Roughness –

Mimuro, T., Kobayashi, T., Kikuchi, K., Inou, M. and Shiogama, Y.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 6–10, 1985,

For finding the mechanical properties and permeability of jointy rocks, it is absolutely necessary to know the distributional condition of joints of foundation rocks and to establish the method of investigation, of analysis and of estimation of the properties of joint planes.

It is considered that the elements deciding the distributional condition of joints are enumerated as follows, 1) orientation, 2) length, 3) distributinal density, 4) opening width, 5) networks, 6) roughness, and 7) filling. Previously authors proposed the opinions about the above mentioned elements from 1) to 4), and discussed on the modeling method of the rock joint observed in the fields actually.

In this paper, we discussed especially on the fundamental problem of the above mentioned elements of 5) and 6).

The results obtained are summarized as follows.

1) On the joint networks, it can be cleared up the patterns of joint connection. Consequently we proposed the improvement of the modeling method considered joint networks.

2) We made a comparative study on the joint roughness using various

methods. Consequently it is obtaind the possibility that the joint roughness can be estimated using simplier indexes, such as " the difference of height ", " standard deviation ", and the combination of these.

Futher study on the relation between joint roughness and shear strength and on " filling " shoud be carried out. Consequently we aim to make the rock joint model more realistic.

(F-3)

(89) A Study on the Evaluation of Rock Discontinuities

Sato, M., Kamemura, K. and Kubo, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 11–15, 1985,

Rock mass contains innumerable cracks which range in size from faults to microscopic cracks, and the mechanical stability of underground structures and geohydrologic property of rock mass depend upon the geometry and distribution of these cracks.

In this paper, cracks, which are smaller than the structure and distribute with high density, are examined. A method for evaluating the effect of these cracks on the mechanical and hydrological property of rock mass is presented.

A crack is regarded as a disk with r in diameter and t in thickness. Supposing that the physical property of the crack can be expressed by second rank tensor, some proprety of rock mass averaged over the total volume can be represented by tensor eij ;

$$e_{ij} = \frac{\pi\rho}{4} \int_t \int_r \int_\Omega \{\alpha(\delta_{ij} - n_i n_j) + \beta n_i n_j\} D(n,r,t)\, d\Omega dr dt \quad (1)$$

where ρ denotes volume density of crack, D is the density function, and α and β represent the physical properties of lateral and normal direction to a crack respectively. The anisotropy of rock mass can be characterized by equation (1).

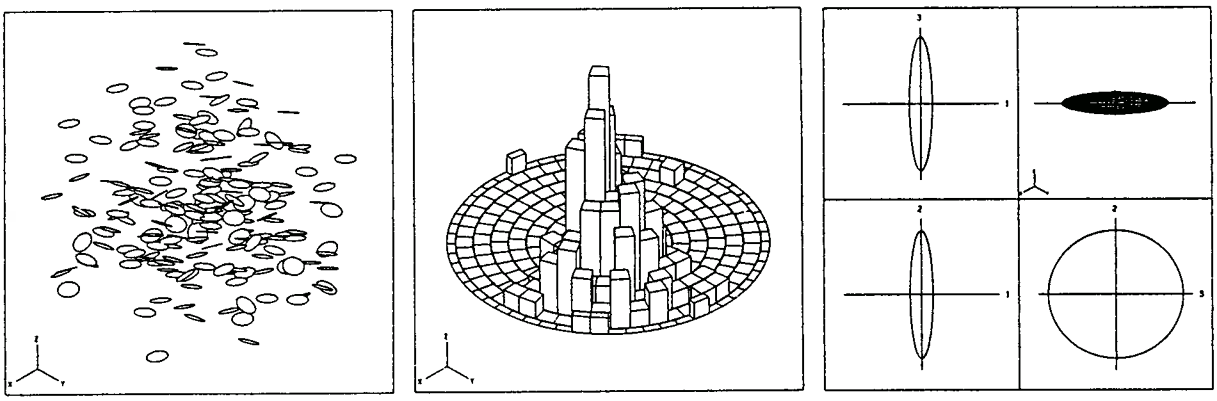
This kind of averaging, however, has some disadvantageous, for instance,

i) it is difficult to take shear behaviour into consideration

ii) cracks are generally treated as idealised planes, such as disks or ellipsoids.

Therefore, values of the tensor eij should be modified by in-situ testing.

Examples of analysis are shown in Fig. 1.



a) Distribution of cracks b) Density function c) Tensor eij

Fig. 1 Examples of analysis

(F-3)

(90) Finite Element Analysis of Discontinuous Rock Masses by Crack Tensor Theory

Yamabe, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 16–20, 1985,

Finite element analyses on cracked materials like rocks and rock masses are performed by using the elastic compliance in terms of "Crack Tensor" proposed by Oda (1983), which has been proved to be useful for approximating the elastic behaviour of cracked materials. In this paper, the compliance is slightly modified by a new parameter "t" in order to take into account the effect of substantial contact condition between crack surfaces on the elasticity.

The conclusions are summerized as follows:

1) Overall elastic moduli of cracked materials calculated by FEM show a substantial accordance with the experimental results of uniaxial compression tests.

2) Subgrade reaction for rock masses can be expected to be considerably influenced by the parameter "t" as well as the crack tensor.

3) A method to estimate the parameter "t" is proposed by using the stress-deformation curves of plate bearing tests in situ together with the crack tensor and the elastic constants of intact rock.

(F-3)

(91) Generalized Crack Tensor and Its Application to Rock Mechanics

Oda, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 21–25, 1985,

Elastic compliance and permeability tensors for jointed rock masses are formulated in terms of the generalized crack tensor $\underset{\sim}{F}^{(m)}$ with the following definition;

$$\underset{\sim}{F}^{(m)} = \frac{\pi\rho}{4}\int_0^\infty\int_\Omega r^m \underset{\sim}{n}\,\underset{\sim}{n}\cdots\underset{\sim}{n}\; E(\underset{\sim}{n},r)\,d\Omega dr$$

where ρ = volume density of cracks,

r = size of a crack (diameter),

$\underset{\sim}{n}$ = unit vector normal to a crack,

$E(\underset{\sim}{n},r)$= probability density of cracks,

Ω = solid angle, and

m = positive integer.

Each crack is treated as a parallel opening connected by two springs whose normal and shear stiffness are determined by taking into account the experimental results by Barton et al. (1972) and Bandis et al. (1983). By means of summing up displacement jumps associated with cracks along a given scanline, the elastic compliance $C_{ijk\ell}$ due to the presence of cracks is formulated as

$$C_{ijk\ell} = \{(\frac{1}{k(\underset{\sim}{\sigma},\underset{\sim}{N})} - \frac{1}{g(\underset{\sim}{\sigma},\underset{\sim}{N})})\,F^{(3)}_{ijk\ell} + \frac{1}{4g(\underset{\sim}{\sigma},\underset{\sim}{N})}(\delta_{ik}F^{(3)}_{j\ell} + \delta_{jk}F^{(3)}_{i\ell} + \delta_{j\ell}F^{(3)}_{ik} + \delta_{i\ell}F^{(3)}_{jk})\}$$

where $F^{(3)}_{ij}$, $F^{(3)}_{ijk\ell}$ = second and fourth rank crack tensors with m=3,

$k(\underset{\sim}{\sigma},\underset{\sim}{N})$ = normal stiffness depending on $\underset{\sim}{\sigma}$ and $\underset{\sim}{N}$, and

$g(\underset{\sim}{\sigma},\underset{\sim}{N})$ = shear stiffness depending on $\underset{\sim}{\sigma}$ and $\underset{\sim}{N}$.

Each crack is also treated as a parallel opening with a aperture t which depends on normal stress acting on it. Adopting the cubic law for laminar flow of fluids through open cracks consisting parallel planar plates, an equivalent permeability tensor k_{ij} is formulated as follows:

$$k_{ij} = \lambda(P_{kk}\delta_{ij} - P_{ij})$$

$$P_{ij}=\left\{\frac{1}{c^3}F^{(5)}_{ij} - \frac{3/c^2}{k(\underset{\sim}{\sigma},\underset{\sim}{N})}\bar{\sigma}'_{k\ell}F^{(5)}_{ijk\ell}+\frac{3/c}{k^2(\underset{\sim}{\sigma},\underset{\sim}{N})}\bar{\sigma}'_{k\ell}\bar{\sigma}'_{mn}F^{(5)}_{ijk\ell mn} - \frac{1}{k^3(\underset{\sim}{\sigma},\underset{\sim}{N})}\bar{\sigma}'_{k\ell}\bar{\sigma}'_{mn}\bar{\sigma}'_{op}F^{(5)}_{ijk\ell mnop}\right\}$$

where λ = 1/12 when the rock mass is fully disintegrated by many cracks,

c = dimensionless constant,

δ_{ij} = Kronecker's delta,

$F^{(5)}_{ij}$, $F^{(5)}_{ijk\ell}$ = second and fourth rank crack tensors with m=5, and

$\bar{\sigma}'_{ij}$ = stress tensor.

(F-3)

(92) Failure Criterion for Anisotropic-Discontinuous Materials by Means of Crack Tensor

Maeshibu, T., Oda, M. and Suno, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 26–30, 1985,

It is well known that the crack geometry of in-situ rock masses has much effect on its mechanical properties. The so-called crack tensor has been introduced by Oda (1983) as an index measure for analytically identifying the crack geometry (density, size and orientation). By means of uniaxial and biaxial compression tests on gypsum plaster samples with random cracks, failure criteion of discontinuous materials is discussed in terms of crack tensor. The conclusions are summarized as follows:

1) Linear Mohr's criterion seems reasonable for the failure criterion of discontinuous materials if the applied stress is within a limited range. The friction angle is constant irrespective of crack geometry, while the cohesion is linearly related to the logarithm of uniaxial compressive strength.

2) The characters of uniaxial compressive strength for anisotropically cracked materials are experimentally investigated, with special concern with the effect of crack tensor (crack geometry), mechanical property of matrix and nature of cracks on them.

(F-6)

(93) Strength-Deformation Characteristics of Rock Joints

Hamajima, R., Kusabuka, M., Yamashita, K. and Gutierrez, V.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 31–35, 1985,

The mechanical characteristics of a rock mass is influenced by the discontinuities of the joints and faults normally contained in it. Especially the roughness characteristics of the discontinuous part determine the strength-deformation characteristics.

Although many researchers had been studying these mechanical characteristics of joint roughness, Barton indicated the influence of the JRC (Joint Roughness Coefficient) upon the shearing strength,shearing stiffness and normal stiffness in the case it is related to the size effect. However, the Barton's constitutive equation is applicable for small values of the confining pressure. Ladanyi & Archambault considered a constitution of the asperities of roughness in the condition of sheared off and producing progressive failure. Nevertheless, this constitution can be applied only for regular asperities shape.

In this work the prevailing frecuency of an irregular asperity roughness was transformed into a piece of a triangular asperity roughness. In both models was performed direct shear tests in order to obtain the plot of the τ - σ curves of the peak and residual shear strength, as well as the mechanical characteristics of direct shearing strength, shearing stiffness, dilatancy,etc. Clearly it is apreciated good agreement in the results.

In the case of resulting many prevailing periods it is thought possible to use a revision of it, and so the equation of Ladanyi & Archambault could be applied for joint surfaces having irregular asperity roughness.

(F-6)

(94) Analysis of Discontinuous Rock Mass

Hamajima, R., Kusabuka, M., Yamashita, K. and Gutierrez, V.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 36–40, 1985,

Regarding the mechanical characteristics of a rock mass, especially in the case of studying its bearing capacity, a thoroughly study of the strength after the peak load is important. The case of quick dropping of the bearing capacity after peak load need sufficient study in consideration of the structures safety.

Analysing these strain softening characteristics of discontinuous rock masses having many joints, we must consider the strain softening produced owing to the fracture of intact material and that produced owing to slip on the joint surface.

In the case of rock masses having few joints the fracture of intact material has a large effect on its strength; moreover, a remarkably strain softening occur. With increasing of the number of joints, however, the mechanical characteristics of rock masses are governed by the slip of joints, showing no fracture of the intact material, and mechanical characteristics of loose sand are observed.

Although in the case of smooth joint surfaces the shearing strength-deformation characteristics has a perfect elasto-plastic behavior, in joint surfaces having roughness, it is produced strain softening after the peak. Considering this strain softening and using the constitutive equation of Ladanyi & Archambault, its numerical analysis can be performed. In this case, in accordance with the deformation of the shear plane, the numerical method should consider the condition of perfect-elasto-plasticity.

This work deal with the analysis of plane stress, however, it is thought this method could be modified to use in thecase of plane strain.

(F-6)

(95) Tensile Strength Anisotropy of Granite

Kudo, Y., Hashimoto, K. and Nakagawa, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 41–45, 1985,

Granite contains numerous small defects which are preferentially oriented along three mutually perpendicular planes. These three planes are called,in a quarryman's terminology, rift plane,grain plane and hardway plane in order of ease of splitting.

In this study,we are reporting the tensile strength anisotropy of Oshima granite and Kurahashi-jima granite and comparing the tensile strength anisotropy to the results from thin section analysis and P wave anisotropy.

Drill cores were cut in three mutually perpendicular directions from a large block of granite and the cores were cut into disks. P wave velocity was measured in diametric directions at 15 intervals.The diametric compression test was performed in the same directions. From the same blocks, three thin sections were cut parallel to the rift plane, grain plane and hardway plane to check the preferred orientations of pre-existing microcracks and healed microcracks(planes of fluid inclusions).

From the thin section analysis, we found that the cracks of both Ohshima and Kurahashi-jima granite mainly consist of open microcracks, in quartz, parallel to the rift plane and grain plane and healed microcracks, in feldspar, parallel to hardway plane. Healed microcracks were also found in other directions.

There was a strong correlation between the strength anisotropy, the preferred orientations of open microcracks in quartz and P wave anisotropy and there was also a correlation between the tensile strength anisotropy and the healed microcracks.

(F-6)

(96) Rigid Plastic Finite Element Method with Friction Angle

Tamura, T., Kobayashi, S. and Sumi, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 46–50, 1985,

We investigate a numerical approach to analyze the limit state of continuum such as rock foundation by means of the rigid plastic finite element method. Most of studies of this method in the literature have not taken into consideration the effect of the internal friction angle since there may be a rather complicated problem concerning the concept of the admissible strain rate for the yield function which depends on the mean stress, i.e., for the yield condition with the internal friction angle. In other words, it seems to be difficult to form a strain rate which satisfies the associated flow rule for some stress state being on the yield surface. But if we apply the rigid plastic finite element method to the rock-like material, it is always necessary to consider the effect of the internal friction angle and therefore we have to investigate how to treat this difficulty.

In this paper, we firstly write in concrete form the constraint condition on the strain rate in order that it can become kinematically admissible for Drucker-Prager yield condition. Secondly, we formulate the rigid plastic finite element method with the internal friction angle by using the variational principle with several Lagrange multipliers and make clear the indeterminate stress associated with constraint conditions on strain rate. After showing some results of numerical calculation, we refer to the formulation in case of the non-associated flow rule, which is necessary to reduce the volumetric expansion due to the dilatancy.

(F-6)

(97) Prediction of the Failure Strength Based on the Crack Behaviour in the Rock

Takahashi, M., Koide, H., Kinoshita, S., Ishijima, Y. and Nakamura, A.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 51–55, 1985,

Recently, considerable progress has been made in the branch of physical characteristic measurement in the rock mechanics with high measurement techniques. Now, we have obtained many informations related to changes of the microscopic structure. For example, AE concentration to the final fault plane, dilatancy anisotropy, velocity anisotropy, velocity recovery and so on.

We have obtained many informations related to the failure strength and deformation and elastic wave velocity on the rocks in our laboratory experiment under true triaxial compressional stress where three principal stresses are different from each other.

Thus, we have predicted the failure strength of rock using the extended method of the effective shear strain energy criterion. We assume that homogeneous rock specimen can be regarded as an elastic material containing a large number of uniformly distributed and randomly oriented closed, plane cracks. When three principal stresses applied to the rock specimen, the surfaces of any closed crack can be subject only to normal compressive stress and shear stress, σ_n and τ, respectively. The effective shear strain energy per unit volume of rock specimen stored around the closed cracks is

$$W_c=\bar{k}\tau_{eff}^2$$

Here $\bar{k}$ is constant and τ_{eff} is regarded as the effective shear stress, $\tau_{eff}=|\tau|-\mu\sigma_n$, μ is the coefficent of sliding friction between the opposite surfaces of the closed cracks.We must sum up Wc for each crack through a unit volume of rock subject stress. The extended effective shear strain energy criterion is as follows.

$$W_{eff}=W_c(\sigma_2,\sigma_3)$$

$$W_c(\sigma_2,\sigma_3)=W_{eff}(\sigma_2=\sigma_3)=W_{eff}(Co)\{1+c\frac{\sigma_3}{\sigma_2}\} \qquad (\sigma_2=\sigma_3<\sigma_3')$$

$$=dW_{eff}(Co) \qquad (\sigma_2=\sigma_3\geqq\sigma_3')$$

$$W_c(\sigma_2,\sigma_3)=eW_{eff}(\sigma_2=\sigma_3) \qquad (\sigma_2>\sigma_3)$$

Here, Co is the uniaxial compressive strength, c, d, and e are constants for individual rock. It is noticed that the predicted and obtained values are in good agreement.

(F-6)

(98) Strain Rate Controlled Tests of Rock and Failure Criteria under Generalized Triaxial Stresses

Nishida, T., Esaki, T., Aoki, K., Kimura, T. and Adachi, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 56–60, 1985,

In order to obtain the failure criteria and stress-strain behavior such as strain-hardening phenomena of rock, octahedral shear strain γoct was increased at constant rate under the constant mean principal strain εm. Specimens used were 4cm cubes of Akiyoshi marble, uniaxial strength=71.4MPa and were tested under the conditions for $\mu'=-1$, $-1/3$, $1/3$ and 1, where $\mu'=(2\varepsilon_2-\varepsilon_1-\varepsilon_3)/(\varepsilon_1-\varepsilon_3)$ and ε_1, ε_2 and ε_3 are maximum, intermediate and minimum principal strain respectively. In addition to these tests, constant mean stress tests (σm=const.) were performed.

A comparison was made between strain and stress controlled tests. The test results are as follows;

(1) On the hydrostatic stress axis, Akiyoshi marble has the End Cap at a mean principal stress of σm=380MPa.

(2) The shapes of the failure curves which are cut by the plane perpendicular to hydrostatic axis change with the value of σm. At lower σm, they are non circular but triangular as in previous papers. But, when σm=300MPa, the shape becomes to partially concave.

(3) The stress loci obtained by the constant mean principal strain tests deviate from the hydrostatic stress axis and go toward the failure curve with increasing octahedroral shear strain γoct. Finally, the loci converge asymptotically to the failure curve.

(4) A comparison of the loci under εm=const. tests and σm=const. ones which are perpendicular to the hydrostatic axis reveals that the loci of the former are divided into two regions at σm=220MPa, which cause a volume contraction and expansion as indicated in Fig.5.

(F-6)

(99) Uniaxial Compression Test of Artificial Mudstone

Sakurai, T. and Takahashi, A.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 61–65, 1985,

It is important to determine the strength of fractured rockmass which is impossible to get or make the testing specimen. As a way to discuss it, artifitial mudstone is made from dried and crashed natural mudstone, which is put into the cylinder with inner diameter of 35 mm and pressed to reconsolidate. Pressing load, loading time and water content are selected as the parameters to make it with the ranges of 1-20 t, 1-60 minutes and 10-45 %, respectively.

As the testing results, the density and uniaxial compressive strength of artificial mudstone are mainly controlled with water content. The failure mode in uniaxial compression test is also determined by water content. And it is shown that both peak and residual strengthes of artifitial mudstone become lower as water content increases. (F-6)

(100) Time Dependent Behaviour of Rock Especially Focused on Tertiary Creep

Okubo, S. and Nishimatu, Y.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 66–70, 1985,

This paper presents selected laboratory creep data from experiments conducted on samples of Sanjome andesite and Kawazu tuff.The experiments were designed mainly to determine strain-time behaviour patterns in tertiary creep of these samples under uniaxial compression.

The creep behaviour of the samples can be devided into three stages. During the first stage starting immediately after loading,creep rate is continuously decreasing with time and logarithmic law fits for most part of this period. In the successive stage,creep rate remains in very limited region. Then creep rate is increasing monotonously toward the failure.These stages may be called as the primary,secondary and tertiary creep,respectively. Though creep behaviour of rock has been a subject of interest,only little cosideration has been given to tertiary creep.

Special attention has been given in this study to measure the strain-time characteristics of samples in tertiary creep. Tertiary creep is signified by a continuous increase of strain rate. In this study,very interesting feature of this strain rate increase was found;
"The strain rate at a certain time in tertiary creep is inversely proportional to the time to go to final failure."
This relatively simple experimental law can be used to estimate a failure time of gateway,tunnel and underground structures. And,hopefully it can be applied to preliminary estimation of earthquake.

The constitutive equations of sample rocks has been proposed based on the experimental results of creep. The model consists of two units in series;i.e. a linear spring and a nonlinear dashpot. The characteristics of dashpot can be directly obtained by the strain-time behaviour in creep because strain of linear spring remains constant in creep. The obtained constitutive equations were used to reproduce stress-strain curves in uniaxial compression test. The simulation was carried out numerically by a computer. The calculated results were compared with the experimentally obtained stress-strain curves,and it is found that the calculated ones coincide with the experimental. It should be emphasized that the proposed constitutive equation can be applied to not only pre-failure region but also post-failure region .

(F-6)

(101) Influence of Discontinuous Plane in Rock Masses to Plate Load Test

Terada, K., Sugihara, Y. and Uno, H.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 76–80, 1985,

By using the modulus of elasticity obtained from laboratory tests on mud-stone and the mechanical properties of jointed rock masses obtained from re-loaded triaxial compression test for rock specimens with a fractured plane, a two-dimensional finite element model for jointed rock masses was proposed. In order to verify the appropriateness of the proposed model, a numerical analysis of a plate load test was carried out. Since the results of the numerical analysis exhibited a similar tendency to the in-situ plate load test results, the proposed numerical model was proven to be appropriate.

Moreover, to investigate the influence of joint parameters on deformability of jointed rock masses, a parametric study was done based on the above proposed model, considering the following properties of joints as parameters:

1) joint spacing;
2) angle of joints;
3) influence of cross joints;
4) mechanical characteristics of joints;
5) discontinuity of joints;

Following are the results obtained from this study.
The most dominant property which influences the deformability of a jointed rock mass is the mechanical characteristics of the joints.
The second dominant property is the spacing of joints, which is equivalent to the joint density.
Neither the discontinuity of joints, nor cross joints, have any remarkable effect on the deformability of jointed rock masses.

In this study, analysis considered the shearing strength of joints as a main mechanical characteristics of joint was made, but it seems to be necessary to make an analysis which will consider also the stiffness of joints in the future.

(F-6)

(102) Interpretation of Borehole Jack Test with Joint Stiffness

Tanimoto, C., Hata, S. and Nishio, A.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 81–85, 1985,

To speak of jointed rock, which we confront with widely through rock works in Japan, mechanical properties and behaviors of jointed rock are affected strongly by a state of joint or discontinuity. We can say that behavior of joint is extremely predominant over that of intact rock. However, there is very few analysis with consideration of joint behavior, and it has been widely developed to assume a certain uniform solid in which any joint concept is not considered by uniforming everything to one. So long as one takes this concept, any realistic rock behavior cannot be taken account into analysis.

Our approach is to clarify joint properties through the borehole jack test, which is much simpler and more economical than a conventional test such as plate loading and/or rock shear test, and to represent mechanical properties of joint (or discontinuity) both qualitatively and quantitatively with a concept of joint stiffness proposed by Goodman [1976] .

As the fundamental study, several simplified models are discussed with forrowing parameters: joint spaceing, orientations of discontinuities, normal joint stiffness and shear joint stiffness, and elastic properties of solid rock. Next, enlarging this concept, discontinuities posing in arbitrary three dimensional state are discussed through our numerical model. Experimental model produced by plaster blocks as well as numerical analysis were tested in the bi-axial loading vessel.

Based on the results obtained by the numerical and experimental studies, relationships between deformability of jointed rock, orientation of discontinuitiy, loading direction, and joint spacing are described in this paper. Also, we carried out several field mesurements with a borehole jack and a borehole TV camera with 65mm dia. into the base rock consisting of chert and schalstein.

From the result mentioned above, we propose a useful method how to evaluate realistic joint stiffness and mechanical properties of jointed rock more quantitatively.

(F-6)

(103) The Borehole Loading Test and Analysis of Tunnel Excavation in Squeezing Rock Conditions

Yuasa, Y., Amamoto, H. Nakamura, T. and Iwasaki, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 86–90, 1985,

In the excavation of the tunnel in biotite schist in Nagasaki prefecture, the large deformation at the tunnel wall was observed as overburden increased. For the purpose of exploring the cause, the rock properties were measured by new borehole loading instrument with 8 pistons. The borehole loading tests were carried out in two directions, vertical and horizontal directions, and each length was 10 meter.

The analysis of the ground behavior was conducted with the FEM program which can manage the viscoelastic and viscoplastic behavior of the ground, using the rock properties from the borehole tests.

The results of analysis shows that the less strength of rock mass than the overburden stress caused the plastic behavior of squeezing at the tunnel wall. The FEM program could analyzed the time-dependent deformation of tunnel with the steps of the excavation and the concrete lining support system.

(F-6)

(104) Fracturing of Rock-Like Materials by Liquid Pressure

Hashimoto, K. and Kudo, Y., Nakagawa, K. and Hagimori, K.

Proceedings of the Symposim on Rock Mechanics, JSCE, 17th, pp. 91–95, 1985,

Recently, there has been a marked tendency to excavate hard rocks close to urban areas or established structures. Thus, the former excavation method of using explosives is limited because of various reasons. Therefore, non-explosive methods are widely used and are in great demand. The excavation of rocks using the pressure of a demolition agent or a liquid are important mainly because they are easy to handle. Thus, the behavior and machanism of fractures are important for us.

In this study, a fracture experiment, using cement mortar specimens, was performed with the objective of getting basic data of using liquid pressure and the experimental results were analyed with the finite element method.

In this experiment, cylindrical specimens with one borehole and rectangular specimens with the holes parallelpiped were used and the fracturing conditions and mechanisms were discussed.

The numerical results showed a good simulation of the fractures in the cement mortar specimens. (F-6)

(105) Electric Model for the Permeability of Fracture System around Underground Cavern

Kojima, K. and Yokoi, K., Nishimura, T. and Edogawa, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 151–155, 1985,

The preliminary results of electric model experiment are described to make permeabilitymodel of fractured rock mass for the prediction of behavior of hydraulic flow through fracture system around rock cavern.

The fracture system is printed out by XY recorder with electrically conductive ink based on the data obtained from field survey.

The relations between heterogeniety and anisotropy of permeability, and density ,continuity and direction of dominant fractures are discuss-ed here from the results of this experiment. (F-4)

(106) An Analysis of Water Flow through Discontinuities in Rock Masses Taking Account of Existence of Turbulent Flow Region

Miyata, M., Takahasi, N., Nashimoto, Y. and Yajima, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 156–160, 1985,

The simulation of water flow through rock masses is generally analysed with Darcy's Law by replacing the rock masses, in which discontinuities are developed, with the equivalent continuum like sandy or clayey ground, whereas the behavior of this flow may actually be governed by discontinuities such as joints, faults.

This solution, however, may contain several problems i.e. in the case that;

① paticular discontinuities are dominant,

② and the turbulent flow region is expected.

For resolving these problems, the influence, which is caused by the existence of turfulent flow region to the whole flow, is examined by a theoretical solution.

And a method of analysis of water flow through discontinuities in rock masses taking account of the existence of turbulent flow region is also mentioned together with the analysis examples. (F-4)

(107) Turbulent Flow Formed under an Injection Well in Unsaturated Fractured Rock and Its Influence on the Measurement of Permeability

Watanabe, K. and Ashikawa, R.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 161–165, 1985,

Some artificial reservoirs are now planned to construct on the high permeable fractured rock mass such as erupted or intrusive volcanic rock of Quaternary period. Accurate measurement of permeability of fractured rock is indispensable in such areas because some protection works to lower the amount of leakage from these reservoirs must be taken into account in the course of these plannings.

Most of permeability tests such as injection tests should be performed in situ under the unsaturated condition as the location of groundwater table is in usual deep in high permeable rock mass. From the reason, flow behavior of water injected in each unsaturated fracture must be basically studied for the accurate measurement of permeability. Moreover, as pointed by many previous authors, water injected may flow under the turbulent condition in some high permeable fractures. Consequently, the influence of turbulence on flow resistance should be well evaluated to properly estimate the permeability.

In the paper, at first, the flow patterns of fluids of some different viscosities injected under the low pressure conditions into a opened fracture are experimentally studied by the use of two fracture models. In these models, the fracture is simulated by the interstice between two vertical flat plates. Some small thin plates are also inserted in the model to partly decrease the permeability. From these experiments, it was found that the injected fluids essentially flow downward by the gravity acceleration and that the flow can be approximated by the one dimensional flow under the condition of unit hydraulic gradient. In addition to these points, comblike pattern of flow was generally observed below the low permeable parts.

And after, resistance values of some fluids flowing not only in these models but also in two actual fractured rock were tried to measure with following conclusions.

(1) High viscous fluid should be used to accurately measure the permeability of unsaturated high permeable fractured rock mass.

(2) The relation between resistance coefficient f and Reynolds number Re of flow in fractured rock mass can be obtained by the successive injection tests with some fluids of different viscosities under the constant condition of pressure.

(3) The gap width of fracture dominating the permeability near the injection well can be estimated from the relation between f and Re. (F-4)

(108) A Basic Study on Two-Phases Flow of Air and Water around Cavern

Momota, H. and Sato, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 166–170, 1985,

When we deal with the behavior of compressed air around rock cavern, it is needed to study the two-phases flow in porous media. Recently, the FEM technique for analyzing air flow has been proposed by taking account of compressibility and interaction between air and liquid. Because the character of the phenomenon has some difficulties, basic experimental and theoretical studies have been required. In this paper, the authors try basic research of two-phases flow in porous media around cavern. Then, the characteristics of two-phases flow are discussed by experimental results obtained from a laboratory by using simple models.

Main results obtained from this study are as follows;

1. Air penetration occurs at the top of cavern and finger-shaped peneration appears over critical air pressure.
2. Air phase takes the form of wedge shape with angle 20~35° in steady state.
3. Air penetration occurs easily with increase of permeability.

(F-4)

(109) Study on Leakaged Air from Compressed Air Storage Cavern in Rock Mass

Komada, H., Nakagawa, K., Miyashita, K. and Murata, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 171–175, 1985,

Feasibility study on Compressed Air Energy Storage(CAES) are carrying in the world as one of the new electric power storage systems, in which compressed air is generated during slack hours by means of a motor compressor and is used as energy for peak hours, fundamentally requires large scale compressed air storage in underground caverns.

In order to store the compressed air into an unlined cavern in the rock mass, it is necessary to solve the problems concerning air leakage. So this paper describes the followings.

(a) Investigation on phenominon of air leakage from underground cavern by experimental model.

(b) Verification of code of two-phase flow analysis on immiscible fluids in porous media by simulating the result of the experimental model.

(c) Forecast of leakaged air from the cavern by two-phase flow analysis code.

And the following results were obtained.

(1) Leakaged air from underground cavern by experimental model.

It was obtained from the experimental models, which are made by the porous material, that minimam vertical hydraulic gradient around the cavern for preventing air from leaking should be maintained to be −4 to 0.

(2) Verification of two-phase flow analysis code.

The code of two-phase flow analysis in two dimensions have been developed. This code was verified by simulating the leakaged water into the cavern and the leakaged air from the cavern obtained from the experimental models.

(3) Forecast of leakaged air from the cavern.

It was expected by numerical analysis using the above code that the leakaged air was ignored, on condition that the compressed air with 35 atm was stored in underground caverns at 334m depth under water table. (F-4)

(110) Linear Thermal Expansion Properties of Rocks at High Temperature

Okuno, T. and Kinoshita, N.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 176–180, 1985,

Linear thermal expansion properties of rocks at high temperatures differ with each rock type, and are characterized by some different reasons.

In order to clarify a reason which has a remarkable effect on the thermal expansion properties of rocks subjected to slow and uniform temperature changes, the linear thermal expansion of three rock types has mesured during both heating up to 500°c and cooling down to room temperature. Three rock types are Inada Granite, Komatsu Andesite, and Akiyoshi Marble. The mesured values and calculated values from mineral composition are compared. In addition, size effects on the thermal expansion of Inada Granite and Komatsu Andesite have investigated.

The following results have been obtained.

(1) Inada Granite; During heating up to 500°c, aspecimen 4.8mm in diameter indicates smaller linear thermal expansion than that of a specimen which has more than 10mm in diameter.

(2) Komatsu Andesite; Residual strain at room temperature after cooling is very little.

(3) The linear thermal expansion during cooling is similar to calculated value from each mineral composition for all rock types.

Therefore, the following conclusions are proposed.

(1) a specimen which has more than 10mm in diameter should be used in order to mesure linear thermal expansion for Inada Granite which has large average grain size and differential thermal expansion between grains.

(2) Komatsu Andesite has smaller residual strainsthan Inada Granite and Akiyoshi Marble during cooling. (Komatsu Andesite has very little differential thermal expansion between grains and anisotropic thermal expansion in a grain. On the other hand, Inada Granite and Akiyoshi Marble have differential thermal expansion between grains or anisotropic thermal expansion in a grain.)

(3) Linear thermal expansions of forming minerals have a dominant effect on the lenear thermal expansion of rocks under the temperature which has been applied.

(F-8)

(111) Study on Three-Dimensional Effect of Groundwater Flow and Heat Transport around Underground Caverns

Ito, Y., Sato, K. and Shimizu, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 181–185, 1985,

Until now, various types of underground caverns for the purpose of the electric power station, energy storage and underground disposal of nuclear pollutants have been constructed in rock ground. When we deal with the dynamic problems of caverns, it is one of the key subjects to find three-dimensional characters of the groundwater flow and heat transport around the cavern in rock masses.

From such points of view, this paper presents some numerical and experimental studies with groundwater motion and heat transport around the cavern. In order to examine these problems in rock aquifer, two- and three-dimensional numerical approaches on groundwater behavior and heat transport around the cavern are done by means of the finite element method and the modified Fluid in Cell method under different hydraulic conditions. The results obtained from many numerical computations are compared with experimental results by sand models having three kinds of cavern models. Then, three-dimensional effects of those around the cavern are confirmed by this study.

The main conclusions by this study can be summarized as follows:
The correlation was found between Q_{II}^*/Q_{III}^* and L/ℓ for the groundwater flow around the cavern. In particular, the three-dimensional effects of flow appears clearly in unconfined aquifer. It is confirmed that there is no three-dimensional effect of heat conduction and heat convection effect can not be ignored for a large seepage velocity.

(F-8)

(112) Experimental Study on the Generation of Plumes from a Heated Boundary in a High Permeable Fracture

Watanabe, K., Ohno, H. and Asaeda, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 186–190, 1985,

Although the thermal convection in a fractured rock mass is a subject of concern of a good deal of research, the flow mechanism of the convection is not still being clarified. The difficulty in this study is mainly arisen not only from the geometric and geologic complexity of the fracture system in the rock mass but also from the chaotic nature of flow that is maintained by the plumes irregulary generated from the lower heat source in the rock mass.

The investigation reported here was intended to experimentally clarify some characteristics of the plumes such as the time required for outbreak of the plumes (Tv), the average spacing among the plumes (Lv) and the thickness of a conduction layer (Hv) that is formed immediately above the heat source before Tv. The experimental apparatus used here was mainly composed of two vertical acryl plates of 200cm wide, 30cm high and 1.5cm thick. The interstice of 1.0cm wide between these plates simulated a fracture developed vertically. Two kinds of glass beads (average diameter ; 2.5mm, 1.2mm) were prepared as the filling materials in the fracture model. Heat was electrically supplied from the bottom of the model through a thin stainless steel plate by a rubber heater plate. For insulation, plates of polystyren foam of 3.0cm thick were mounded both sides and top of the model. In this paper, the geometry of the plumes, transient change of the temperature distribution in the model and the generation time Tv of the plumes were mainly discussed on the basis of the results of ten experimental cases and some theoretical considerations.

As the result, it was found that the Tv value was well approximated by the following equation.

$$Tv \propto (\alpha k F_H / \rho c \kappa)^{-1} \qquad \text{----------} \quad (1)$$

where, α is the coefficient of thermal expansion, k is the permeability, F_H is the heat flux supplied, ρ is the specific density, c is the specific heat and κ is the thermal conductivity coefficient.

(F-8)

(113) Finite Element Analysis of Fluid Flow and Transport of Radioactive Nuclides in Discontinuous Rock

Ohnishi, Y., Shiota, T., Nishigaki, M. and Kobayashi, A.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 191–195, 1985,

Performance assessment of some potential high-level waste repository sites will require analysis of radionuclide transport in discontinuous rock. Radionuclide transport then is the combinated effect of advection and hydrodynamic dispersion with radioactive decay and adsorption on the geologic media. Especially it has been recongnized that fracture plays a very important role in conducting transport of radionuclide through rocks, and so much effort has been direct -ed toward studying fractures and fracture systems on a quantitative basis.

This paper presents the formulations of a two-dimensional finite element model designed to simulate the ground-water flow and radionuclide transport in fractured system with substansially permeable rock matrix and the results of several one- and two-dimensional simulations. The model regards the fractured system as one continuum with a number of discrete discontinuities corre -sponding to individual lines of fractures. At first the ground-water flow is simulated and then, inputting the calculated water velocity as the data, the transport is simulated.

The code takes into account:

(a) advective-dispersion transport,

(b) chain reactions of radionuclide components,

(c) adsorption on the geologic media

and uses an upstream-weighted resudial technique to overcome oscillations of the numerical solutions when the convective termes are dominant. (F-4)

(114) Experimental Study on Dispersion of Radioactive Isotopes Solutes Water in Rocks

Sato, K. and Sasaki, Y.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 196–200, 1985,

When we deal with the dispersion problem of disolved pollutant in rocks, the determination of despersion coefficient becomes important as well as the evaluation of hydraulic parameters such as the permeability and storage coefficient.

This paper presents how to measure the dispersion of radioactive isotopes solutes: ^{60}Co, ^{85}Sr, ^{137}Cs, in addition to clarify the dispersion mechanism of radio-active solute in rock seepage flow.

An inherent apparatus is newly proposed to study the dispersion and adosorption phenomena in rock seepage flow, and the utility of the apparatus proposed in this paper is confirmed. Some different properties of radio-active solute dispersion are revealed as compared with those of salt water dispersion in rocks. (F-4)

(115) Microtremor Characteristics of a Rockfill Dam Located in a Waste-Filled Valley

Ohmachi, T., Nakao, M., Toshinawa, T. and Tanaka, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 211–215, 1985,

Ohshirakawa Dam is a center core rockfill dam with the maximum height of 95 m and crest length of 388 m. Quartz porphyry is exposed over the entire right-bank side of the dam site, but on its left-bank side is located a waste-filled valley composed of fan sediments, andesite agglomerate and ancient river bed gravels. Figure 1 shows outline of the dam site and a profile along the dam axis, from which it can be seen that canyon shape at the dam site is asymmetric and the dam axis is bent at the middle part by 35 degree.

Microtremor measurements were done on a suny summer day, using instruments whose overall characteristics are flat in a frequency range over 1.5 Hz. Motion of both abutments, the dam crest and the foundation was measured in terms of velocity. Observatin points are indicated in Fig. 1 by L.A., R.A., C1, C2, C3 and G1 which is located in a upper inspection gallery.

In Fig. 2 are shown particle orbits in a horizontal plane at both the abutments, from which direction and amplitude of the ground motion could be found. Fourier spectral ratios (LA/RA) shown in Fig. 3 reveal a peak frequency around 1.0 - 1.2 Hz. This will give Vs=480 - 580 m/s as shear wave velocity averaged over the whole deposits.

In Fig. 4 are shown Fourier spectra at the points C1 and C3. A peak can be seen at 2.4 Hz in all the apectra. The frequency component corresponds to the motion shown by particle orbits in Fig. 5. Note that the principal axis of the motion is slightly inclined against the dam axis. Particle orbits in Fig. 7 show the motion of 2.0 Hz component at the points C2 and G2, indicating coupled motion of the dam and foundation. These frequency components could be attributed to vibration modes illustrated in Fig. 8.

(F-7)

(116) Analysis of the Execution Data on the Difficult Ground Condition in Tunnelling

Yoshikawa, K., Sakurai, T. and Asakura, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 216–220, 1985,

There are two typical phenomena that bring the most difficult conditions in tunnelling. They are squeezing of ground mass around opening and running of ground with water inflow. Generally, the former occures in the ground consisting of argillaceous soils, which we call " C ground ". The latter occures in the ground consisting of sandy soils, namely " ϕ ground ".

This report analyses the ground conditions statistically, and mainly discusses the correlations between convergence value and competence factor in C ground, and covering height in ϕ ground refering the data of execution records. The data were classified by 50% fine grain contents into C ground and ϕ ground.

The results of analysis are as follows.

As the classification index of C ground, mechanical properties represented by competence factor and physico-chemical properties represented by montmorillonite contents and plasticity index are important.

In the case of ϕ ground, the covering height over about 40 m makes the tunnel face unstable and causes to be obliged to take extraordinary countermeasures.

(F-1)

(117) On Evaluation Method of Swelling Phenomenon in Neogene Mudstone Area in Case of Tunnelling

Fukushima, A., Ikoma, M., Kitagawa, T., Takasaki, H. and Mizutani, F.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 221–225, 1985,

This paper refers the evaluation method of swelling phenomenon in Neogene mud-stone area in case of tunnelling.

First of all , we apply the conventional methods , which were proposed before , to the typical 5 tunnels data and evaluate the results , prediction accuracy of swelling phenomenon.

Then , for finding out the better way to predict swelling phenomenon, we analyze factors which are related to it useing the Quantification Theory II by Hayashi.

With the result of analysis , the competence factor (uni-axial strength/ unit weight X overburden) , the unit weight and the plasticity index are picked up as the principle factors.

And we set up the discriminant criteria based upon the discriminant score of 3 factors. So we get the 91% prediction accuracy of swelling phenomenon. (F-1)

(118) Mechanical Properties of Diatomaceous Soft Rock (Diatomaceous Earth) in Noto Peninsula

Miyakita, K. and Maekawa, H.

Tsuchi-to Kiso, JSSMFE, Vol. 31, No. 1, pp. 83–88, 1983,

There are many mechanical problems about the diatomaceous soft rock distributed widely in Noto Peninsula in Ishikawa Prefecture. In this paper its fundamental, mechanical behaviour has been made clear. The important results are following. The results by both consolidation test and triaxial one seem to be very similar to well known behaviour of over-consolidated sensitive clay, and the triaxial test under various drained conditions has shown the extremely unique tendency based on its particular, physical properties (e.g. porousness and cementation bonds). (F-5)

(119) On the Salt Illuviation and Destruction of Footing (Tsukaishi)

Takaya, S.

Tsuchi to-Kiso, JSSMFE, Vol. 31, No. 1, pp. 101–104, 1983,

The footing (called tsukaishi) of Japanese common houses have been made of natural stone. But it was substituted concrete for stone in recent years. The. destroyed footing was found out under the floor in many houses at the suburbs of Miyazaki city, Miyazaki pref.

The results of investigation, surface soils showed alkalinity and large amount of magnesium, sodium, calcium and sulfate accumulated. Therefore the cause of destroyed footing was estimated the salt accumulation. (F-8)

(120) Application of Multistage Triaxial Test on Jointed Specimen

Nishigaki, Y. and Kido, W.

Tsuch-to-Kiso, JSSMFE, Vol. 31, No. 7, pp. 17–22, 1983,

"A maltistage triaxial test" is proposed by K. Kovári. This paper presents results of the test on many kinds of jointed specimens which can not be generally supplied for a series of identical condition. Their results are classified into three patterns on stress path diagram. Residual strength parameter indicates small friction angle for smooth joint and large one for rough joint. This means that the joint strength is controlled by the joint roughness. Pore pressure and strain at failure are also controlled by the joint roughness. (F-6)

(121) Statistical Estimation of Rock Strength

Matsuo, M., Kawamura, K. and Itabashi, K.

Tsuchi-to-Kiso, JSSMFE, Vol. 31, No. 8, pp. 11–16, 1983, For design reliability with rock structures, it is imperative to statistically ascertain strength parameters such as compressive strength, tensile strength, angle of internal friction, and cohesion. To solve practical problems, it is useful if estimations can be made by simple and low-cost rock exploration and tests. The present study investigates the design applicability of angle of internal friction and cohesion as obtained by simulation and approximated methods. (F-1)

(122) Consolidation Characteristics for Tertiary Mudstone

Shinjo, T. and Komiya, Y.

Tsuchi-to-Kiso, JSSMFE, Vol. 32, No. 2, pp. 11–16, 1984,

This paper discusses the one dimentional consolidation characteristics of mudstones and their remolded samples under high pressures (p_{max}=640 kgf/cm^2). Some properties of the samples, testing methods, and experimental errors are first described. Then the consolidation behaviors and consolidation parameters of the mudstones are presented and they are compared with those of the remolded samples. Through these experiments, it is concluded that the consolidation behaviors of mudstone are similar to those of sedimentary clay. (F-5)

(123) Some Measurements of Heat Conduction Parameter with Rocks

Sato, K. and Sasaki, Y.

Tsuchi-to-Kiso, JSSMFE, Vol. 32, No. 3, pp. 47–52, 1984,

The heat conduction parameters such as heat capacity, thermal conductivity and thermal diffusivity are necessary for solving the heat conduction equation. This paper is to represent a new model of one-dimensional heat conduction apparatus and a method to measure the thermal diffusivity of rocks by using it in laboratory. The thermal diffusivity values for three tuffs from different localities and an andesite range from 1.32×10^{-3} to 3.35×10^{-3} m^2/h. The result suggests that the new apparatus and the method are quite useful for measuring the heat conduction parameters of rocks. (F-8)

(124) Durability of Material Rocks for Rockfill Dams

Nakamura, Y.

Tsuchi-to-Kiso, JSSMFE, Vol. 32, No. 7, pp. 21–28, 1984,

This paper describes the current state of the arts of evaluation procedures of durability of rock materials used for rockfill dams. For rational evaluation of the durability of rock materials under natural environments, outdoor exposure test is desired in addition to various accelerated deterioration tests such as freezing and thawing tests, wetting and drying tests and sodium sulfate soundness tests. It is possible to prevent effectively low quality rock materials used for inner rock zone of rockfill dams from deterioration by use of durable material rocks for outer rock zone or riprap. (F-0)

(125) Compaction Characteristics and Stabilization of Shimajiri Mudstone

Sunagawa, T. and Uehara, H.

Tsuchi-to-Kiso, JSSMFE, Vol. 32, No. 8, pp. 11–16, 1984,

The Shimajiri mudstone is from a Pliocene to Miocene stratum which is widely distributed in the southern and central areas of Okinawa Island. This paper is to report the compaction characters and the stabilization effects by using the following three samples; i.e., (1) Shimajiri mudstone passing through square opening of 38.1 mm, (2) the mudstone-cement mixture, and (3) the mudstone-slaked lime mixture. The optimum moisture content and the maximum dry density vary, depending mainly on the initial moisture content, the compaction and the additive content. (F-2)

(126) Anisotropic Elastic Deformation and Strength Properties of Mudstone

Shinjou, T. and Komiya, Y.

Tsuchi-to-Kiso, JSSMFE, Vol. 32, No. 11, pp. 49–54, 1984,

Deformation behaviour of Shimajiri mudstone in Okinawa. under drained and undrained conditions is theoretically examined at first by the cross-anisotropic elastic theory and then the five independent drained elastic parameters have been obtained from the test results. Comparison of the test results with those analysed on the undrained behaviour suggests that the drained elastic parameters obtained can be used for prediction of the undrained anisotropic elastic parameters and pore pressure coefficient A or the gradient of effective stress path. (F-6)

(127) Tests and Determination of Design Parameters for Coarse Granular Materials

Matsumoto, N.

Tsuchi-to-Kiso, JSSMFE, Vol. 33, No. 6, pp. 7–12, 1985,

Coarse grained granular materials such as rockfill materials, gravels and other coarse grained deposits have been used as construction materials and foundations in various fields. The paper describes testing procedures and determination of design parameters of coarse grained granular materials. The effects of maximum grain size on the strength and density tests in laboratory, field permeability tests for sand and gravel deposits, dynamic deformation property tests and time dependent decay of properties of poorly qualified rock materials are discussed. (F-0)

(128) Material Constants and Stress-Strain Characteristics of Coarce-Grained Materials

Miura, N., Murata, H., Yasufuku, N. and Akashi, R.

Tsuchi-to-Kiso, JSSMFE, Vol. 33, No. 6, pp. 13–18, 1985,

The dependency of mechanical properties of coarse-grained materials on the particle-size and the magnitude of confining pressure is described. Large-scale triaxial compression tests are carried out on a weathered granite, a greenshist and a basalt. Major conclusions obtained are that (1) the compressibility of the materials considerably increases at a high pressure range and the $e \sim \log p$ curve becomes bi-linear, (2) the strength parameter ϕ and the initial tangent of stress-strain curve strongly depend on the confining pressure by virtue of particle-crushing, (3) the stress-strain curve predicted by a proposed equation works well as a first approximation of the experimental curve. (F-6)

(129) Density Control and Shear Test for Rock Materials

Akashi, R.

Tsuchi-to-Kiso, JSSMFE, Vol. 33, No. 6, pp. 19–24, 1985,

Based on a series of compaction and triaxial compression tests on rock materials having various particle size distributions, it was found that the concept of the effective void ratio which eliminates the void in rock particles results in the simpler understandings of degree of compaction and shear strength of rock materials. Using the concept of the effective void ratio, proposed are a new density control method for rock materials and a shear test method for examining the strength obtained through the compaction activities in fill dam constructions. (F-6)

(130) Grain-Size Distribution of Rockfill Materials Subjected to Laboratory Tests

Ishii, T.

Tsuchi-to-Kiso, JSSMFE, Vol. 33, No. 6, pp. 25–30, 1985,

Frequently, rockfill materials include large particles which are of one metre diameter. Since the testing apparatus for getting mechanical properties of rockfill materials are smaller than such particle size, modified gradation is introduced in specimens.

In this report, a method of modifying the gradation is discussed. Firstly, analysis of gradation of real rockfill materials is done. Secondly, relationship between grain size distribution and texture is examined imaginarily. Finally, using these informations, a method of modifying the grain size distribution of rockfill materials to be tested in the laboratory is proposed. (F-6)

(131) Drained Triaxial Compression Test on Riversand and Gravel

Moroto, N.

Tsuchi-to-Kiso, JSSMFE, Vol. 33, No. 6, pp. 31–36, 1985,

Triaxial compression tests were carried out on river sand and gravel specimens (10cm in diameter and 25cm in height) under drained condition. The diameters of grains were arranged from 0.25 to 9.52 mm with the uniformity coefficient $U_c=1.30\sim6.17$. Shape of grains is evaluated in terms of roundness. The main purpose of this investigation is to determine the effect of grading on the internal friction angle ϕ_0 for the same grain shape and initial relative density of specimens. The confining pressures were chosen as normal levels from 0.5 kgf/cm^2 to 2.0 kgf/cm^2 to avoid the effect of particle breakdown on ϕ_0. (F-6)

(132) The Survey of Results about Rockfill Materials Tests and Its Design Parameters

Matsui, I.

Tsuchi-to-Kiso, JSSMFE, Vol. 33, No. 6, pp. 37–42, 1985,

Contents of this report are devided to 3 parts, A. Investigation of literatures on tests of granular mass, B. Collection of the test data and analysis, C. Concept on the design strength of granular mass

Part A describes the literature study on the factors influencing the strength of granular mass. Part B describes the summary of test data of 72 filldams in Japan, including kind and class of rocks, phisical properties, compactive properties and strength characteristics of granular mass. The relationships between the properties, such as $\rho_d(e_b)\sim c,\ \phi$, are also included.

Part C describes the overall summary of test data, design strength and actual performance in banking of fill materials. In conclusion, problems to be studied in the future are pointed out. (F-6)

(133) Fabric Tensor for Discontinuous Geological Materials

Oda, M.

Journal of the Japanese Society of Soil Mechanics and Foundation Engineering, Vol. 22, No. 4, pp. 96–108, 1982,

Geometrical property (fabric) of discontinuity in geological materials is discussed in terms of (1) position and density, (2) shape and dimension and (3) orientation of related discontinuities such as joint, fault and discrete particle. By taking into account these geometrical elements, a unique measure called fabric tensor F_{ij} is definitely introduced to embody the fabric concept without loss of generality.

The first invariant of F_{ij} is important as an index measure to evaluate the crack intensity which is related to the number and dimension of cracks. Porosity of granite is shown to be an index measure equivalent to the first invariant of F_{ij}. According to uniaxial compressive tests on gypsum plaster samples with two-dimensionally oriented cracks and granite samples, the logarithm of the first invariant of F_{ij} is linearly related to their uniaxial compressive strength.

A measure Γ which is related to the second invariant of the deviatoric part of F_{ij} shows a distance from an isotropic fabric. So, it is expected to be an index to measure the degree of anisotropy due to preferred alignment of discontinuity.

The principal axes of F_{ij} are identical to the principal axes of fabric anisotropy. There is no doubt that Γ and the principal axes are important in the analysis of anisotropic-discontinuous geological materials. (F-6)*

(134) Fundamental Study on Flow Resistance in Rock Fissures

Sato, K, Watanabe, K. and Kotajima, N.

Journal of the Japanese Society of Soil Mechanics and Foundation Engineering, Vol. 24, No. 1, pp. 1–8, 1984,

With respect to hydraulic analysis of the groundwater movement in fractured rocks, the determination of permeability and the establishment of resistance law is one of the most important tasks. In particular, it is needed to clarify the flow characters of an elementary fissure in a number of interconnected fractures on the basis of dynamic analysis of viscous fluid. This paper presents the flow analysis and resistance law for the elementary fissure having irregular and rough wall in the interstitial channel. Typical flows of viscous fluid through single fissure models were analyzed by the finite difference method of Navier-Stokes and vorticity equations. In addition, an experimental spectrum analysis of fracture samples obtained from granite rocks was carried out in the laboratory. Then, a permeability formula was proposed for the single fracture. (F-4)*

(135) Elastic Compliance for Rock-Like Materials with Random Cracks

Oda, M., Suzuki, K. and Maeshibu, T.

Journal of the Japanese Society of Soil Mechanics and Foundation Engineering, Vol. 24, No. 3, pp. 27–40, 1984,

Elastic compliances for cracked materials like rocks and rock masses are theoretically formulated in terms of the generalized fabric tensor which has been introduced as an index measure to express explicity crack geometry. By means of uniaxial compression tests and supersonic wave velocity tests on gypsum plaster samples with random cracks, the formulation is proved to give a good approximation for describing the elastic response of cracked materials. The conclusions are summarized as follows: The principal axes of the fabric tensor of second-rank exactly coincide with the symmetry axes of the elastic compliance tensor of fourth-rank. The so-called self-consistent method is very useful to estimate the overall elastic moduli by taking into account the effect of elastic interaction among cracks. Since the supersonic wave velocity is closely related to the character of the fabric tensor, it can be expected that the field measurement of wave velocity is useful to estimate fabric tensor of in situ rock masses. (F-8)*

(136) Measurement of Crack Distribution in a Rock Mass from Observation of Its Surfaces

Kanatani, K.

Journal of the Japanese Society of Soil Mechanics and Foundation Engineering, Vol. 25, No. 1, pp. 77–83, 1985,

The anisotropy of the crack distribution in a rock mass is characterized by what is termed the "fabric tensor," and its geometrical interpretation is given. A practical procedure is presented to determine the internal crack distribution by observing cross-sections of cracks that appear on plane surfaces of the material by means of the stereological principle. Only three types of surfaces are necessary for observation. (F-3)*

(137) Studies on Fracture Toughness of Various Rocks

Otsuka, N. and Kobayashi, R.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 98, No. 1127, pp. 1–6, 1982,

In order to determine the fracture toughness of various rocks, the splitting tests under the stiff-load are undertaken on eight kinds of rocks, namely OGINO tuff, KIMACHI sandstone, IZUMI sandstone, EMOCHI andesite, INADA granite, fine grained AKIYOSHI marble, medium grained AKIYOSHI marble and TOHOKU marble.

The rock specimens (200mmx150mmx20mm) in which have a slot are prepared in this test. The crack initiation and the process of crack propagation are studied by the measurement of splitting load, crack opening displacement and crack length. The values of fracture toughness K_{IC} of various rock specimens are determined with the compliance method, and the relationships between fracture toughness and mechanical properties are investigated.

The main results obtained in this studies are as follows;

(1) As a result in this test, it is seen that the fracture behaviours of rock specimens are divided into two groups. That is, the fracture crack of rock specimens of one group initiates after the maximum load point in the splitting load-crack opening displacement curve and propagates in a straight line, as OGINO tuff, KIMACHI sandstone, IZUMI sandstone, EMOCHI andesite and INADA granite. The fracture crack of rock specimens of other group initiates at the boundary of grains in rock before the maximum load point and the fracture crack in rock specimens propagates slowly along the boundary, as medium grained AKIYOSHI marble and TOHOKU marble.

(2) From the relationship between fracture toughness and mechanical properties of various rocks, it becomes clear that fracture toughness of rocks increases in proportion to compressive strength, tensile strength and shear strength, and that fracture toughness decreases with the porosity of rocks increases. (F-8)

(138) Effect of Pore Pressure on Mechanical Behavior of Rocks under Confining Pressure

Goto, T., Sato, T., Fukai, S. and Irie, M.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 98, No. 1131, pp. 393–398, 1982,

The effect of pore pressure on the mechanical behaviour of rocks has been investigated in order to confirm the validity of the effective confining pressure law among rocks with various properties and textures. The triaxial compression tests of Noboribetsu tuff, Horonai sandstone and Akiyoshi marble were carried out with servo-controlled facilities for confining pressure and pore pressure combined with a conventional hydraulic testing machine. The stress strain curves of the three kinds of rocks were determined over the full range of deformation involving both pre- and post failure regions under the condition of confining pressure and pore pressure extending up to 700kg/cm^2.

The experiment showed that the effective confining pressure law was valid for Noboribetsu tuff and Horonai sandstone but the fracture criterion of Akiyoshi marble was scarecely explained by this hypothesis at the strain rate of 6x10^{-5}/sec. Since the tuff and the sandstone were more porous and permeable than the marble, this hyposesis seems to be more realistic to rocks whose pores are fully interconnected. Concerning the marble the effective confining pressure law may be gradually valid with the decrease of strain rate. (F-8)

(139) The Charpy Impact Test of Rock

Okubo, S., Okiyama, T. and Nishimatsu, Y.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 98, No. 1132, pp. 483–488, 1982,

The Charpy impact test which is recognised as a fast, inexpensive and versatile method of obtaining meaningful data on dynamic fracture of materials was carried out to propose the simple ways of obtaining the fracture energy, W, and the crack propagation velocity.

The total absorbed energy, ΔE, in Charpy test contains, in addition to W, a considerable amount of loss energy, L, mainly spent to accelerate the broken specimen and caused by friction between the specimen and its support. The test with a broken specimen slightly connected by cellophane tape, which may be called "Blank Test", was performed to estimate L because the absorbed energy in the blank test, ΔE_{blank}, may be the summation of the kinetic energy of broken specimen and the frictional loss. Experimentally, it was verified that L can be equated with ΔE_{blank} at the same counter angle of pendulum. Therefore, W can be calculated by $(\Delta E - \Delta E_{blank})$.

In the second part of the paper, a new approach to crack velocity measurement was discussed. The very fine lines of conducting silver paint were applied to the side of the specimen, spaced at 3 mm intervals. In the test, the subsequent failure of paint lines associated with crack propagation through the specimen was monitored as a series of small step voltage change in the recording circuit. The results showed that the crack velocity first accelarated and attained to the maximum near the centerline of the specimen, followed by the rapid decrease toward the end of the crack path. The maximum velocity measured in this experiment was about 60% of the theoretical terminal velocity (=0.38 E/ρ).

(F-7)

(140) Relationships among Grain Size, Shape of Pore, and Variation of Longitudinal Ware Velocity with Saturation in Granite

Saito, T., Sato, S. and Abe, M.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 98, No. 1137, pp. 1111–1116, 1982,

Variation of longitudinal wave velocity with respect to water saturation was measured for twenty seven kinds of granites by ultrasonic pulse method at room temperature and atomospheric pressure, and the relationships among grain size, shape of pore and longitudinal wave velocity were investigated. Kuster's expressions for bulk and shear moduli were applied to estimate the shape of pore in granite.

The main results obtained are as follows:

1) The effect of water saturation on the longitudinal wave velocity is comparatively larger for granites than other types of rocks such as volcanic and sedimentary rocks. The velocity difference between saturated and dry states increases with increasing effective porosity, and does not depend on grain size.
2) The indices of granites, which mean the velocity change corresponding 1% effective porosity, indicate 0.87–3.48. The values of aspect ratio estimated based on the Kuster's expressions are $3.6-16.5 \times 10^{-3}$. It is therefore assumed that the large indices are caused by the fact that the shape of pore in granite is in the form of cracks.
3) The values of aspect ratio of pores in granites are larger than those of crystalline limestones, and have no correlation with grain size. These facts suggest that the velocity difference in granite mainly depends on the effective porosity.

(F-8)

(141) Effect of Confining Pressure on Fracture Proppant

Tanaka, S.

Journal of the Mining and Metallurgical Insitute of Japan, Vol. 98, No. 1138, pp. 1219–1224, 1982,

Fracture conductivity measurements in the laboratory are made under confining pressures up to 30MPa at ambient temperature, using water as flowing fluid. Three kinds of proppant, i.e. glass beads, Goshiki silica sand (Japan) and Ottawa silica sand (Canada), and two kinds of rock, i.e. Berea sandstone (U.S.A.) and Inada granite (Japan) are put to the test. Simulated packed fractures are prepared by placing a proppant between core halves. Decreases in fracture thickness and porosity with pressure are calculated by an amount of water squeezed out from the fracture with an increase in confining pressure. Change of specific surface of the proppant with an increase in confining pressure is calculated by fracture conductivity, fracture thickness and porosity. The confining pressure at which proppant crushing or proppant embedment into walls of fracture occurs is estimated from the change of the specific surface.

(F-8)

(142) A Base Friction Apparatus and Mechanical Properties of a Model Material — Fundamental Study on Mechanical Properties of Rock Structures with Discontinuity (1 st Report) —

Kawamoto, T., Obara, Y. and Ichikawa, Y.

Journal of the Mining and Metallurgical Insitute of Japan, Vol. 99, No. 1139, pp. 1–6, 1983,

A new type of a base friction apparatus has been introduced, so that mechanical properties of a model material and the similitude law for the practical rock structures have been studied, and several experimental results are here.

This machine is used for the study of the effects of gravity using frictional force at the bottom of two-dimensional models, and it is unique that the model is applied pressure on the surface so that the frictional force can be large.

The similitude law is considered by introducing the concepts of stress scale and geometric scale. The strength of model material considerably depends on its density and geometric scale is determined by the density. For the behavior of practical rock structures, however, the law is not usually satisfied, the behaviors of these structures can be expressed qualitatively if the model material is properly selected.

(F-8)

(143) The Effect of Temperature on the Friction between Rocks and Hard Alloy for Rock Cutting – Tribology of Rock Cutting Tool –

Nishimatsu, Y. and Akiyama, M.

Journal of the Mining and Metallurgical Insitute of Japan, Vol. 99, No. 1139, pp. 19–24, 1983,

A co-axial rotation type wear and friction test rig is used for the wear test of hard alloy for rock cutting. The friction force and surface temperature of hard alloy specimen are measured under the constant contact pressure and rotation speed. The temperature of contact plane between hard alloy and rock sample is estimated from the temperature gradient on the side wall of hard alloy specimen by means of the theoretical equation of heat transmission.

It is concluded that (1) the temperature of contact plane is proportional to the power consumption as indicated theoretically, (2) the coefficient of friction between the hard alloy and rock sample is not dependent of the contact pressure, but decreases with increase of temperature of contact plane.

(F-8)

(144) An Experimental Study on the Thermal Fatigue of Rocks

Kobayashi, R., Sakai, N. and Matsuki, K.

Journal of the Mining and Metallurgical Insitute of Japan, Vol. 99, No. 1140, pp. 81–86, 1983,

It is well known that rocks are more or less deteriorated by sudden cooling after being heated. Furthermore, by repeating the cycle of heating-cooling, rocks might be expected to be weakened more severely.

In this paper, measuring the changes of the physical and mechanical properties of rocks including apparent specific gravity, P-wave velocity, Young's modulus and uniaxial compressive strength, the thermal fatigue process of rocks is characterized for four kinds of rocks, namely, OGINO tuff, EMOCHI welded tuff, AKIYOSHI marble and INADA granite. The cylindrical specimens are suddenly submerged into water after being heated and the cycle is automatically repeated in the testing machine. The maximum temperature and the maximum cycles in the experiment are 600°C and 5^4, respectively.

The main results obtained are as follows:

(1) The main failure mechanism is different between the crystalline rock and the sedimentary rock. The failure of the former takes place by the thermal interaction between minerals and that of the latter by the transient thermal stresses. As the result, crystalline rocks collapse to be particles or powders and sedimentary rocks are fractured initiating regular thermal cracks (Fig. 6).

(2) The strengths of the rocks except welded tuff decrease remarkably within 5 cycles if the temperature is sufficiently high and the cooling time is larger enough (Fig. 3).

(3) The strengths of the rocks except marble decrease as the cooling time increases. However, the additional effect is very small if the cooling time is larger than that needed for the specimens to be perfectly cooled (Fig. 4).

(4) The cycles at which the specimens collapse exponentially increase as the temperature decreases (Fig. 5).

(F-8)

(145) The Effect of Strain Rate on the Triaxial Strergth of Sanjome Andesite – The Time-Dependent Mechanical Behavior of Rock (1 st Report) –

Yamaguchi, T., Okubo, S., Nishimatsu, Y. and Koizumi, S.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1140, pp. 87–92, 1983,

The effect of strain rate on the uniaxial and traxial compressive strength for Sanjome andesite is examined varying the strain rate from 0.85 to 850 μ/sec. by a step of 10 fold change under the confining pressure up to 400 kg/cm^2.

The preliminary uniaxial compression test shows that:

(1) the uniaxial compressive strength decreases with only small increase of moisture content in the test piece.

Therefore, a special care has been taken in preparing specimen for the following test programme. The test results are as follows:

(2) the increment of differential stress at the strength failure point is revealed to be about 75 kg/cm^2 when the strain rate increased by a factor of 10;

(3) the square of the maximum principal stress at the strength failure point increases linearly with the confining pressure;

(4) the inelastic strain at the strength failure point increases linearly with the confining pressure. Though under a constant confining pressure, inelastic strain is almost constant regardless of strain rate.

(F-6)

(146) Temperature Distribution around Underground Openings Excavated in Rock Mass Due to Storage of Liquefied Natural Gas

Inada, Y. and Shigenobu, J.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1141, pp. 179–185, 1983,

In case of underground storage of L.N.G. whose temperature is $-162°C$, we must consider a mechanical and thermal stresses.

A temperature distribution around openings is necessary for getting a thermal stress distribution.

In this study, theoretical analysis for temperature distribution around underground openings in various thermal conditions. The finite divided elements method is adopted for the analysis. (F-8)

(147) Shape of a Crack-Like Reservoir in a Hot Dry Rock for Extraction of Geothermal Energy

Abe, H., Sekine, H., Shibuya, Y.

Jouranl of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1144, pp. 433–436, 1983,

The extraction of geothermal energy from hot dry rocks in the earth's crust has received wide attention. An abundand amount of geothermal energy could be recovered from hot dry rocks by circulating fluid through crack-like reservoirs which are created by a hydraulic fracturing technique. During the extraction of geothermal energy, the surfaces of the crack-like reservoirs are cooled by the fluid and the thermal contraction of the rock occurs. When the stress intensity factors at the border of the crack-like reservoir attain the fracture toughness of rock, the reservoir begins to propagate at the border. Therefore, in the design of crack-like geothermal reservoirs, the fracture mechanics study of a water-filled crack including thermoelastic effect is needed to control the mechanical behavior of the reservoirs.

This paper is concerned with the shape of a vertical two-dimensional crack-like reservoir in the earth's crust on the basis of the theory of quasi-static thermoelasticity. The surrounding rock is assumed to be a continuum which is homogeneous and isotropic with respect to thermal and elastic constants. By using the singular point method, a set of singular integral equations for density functions derived. The singular integral equations are solved by means of the collocation method and the inversion formula. Numerical calculations are carried out to find the shape of the crack-like reservoir, and the opening displacement of the reservoir against time is shown. The variation of the volume of the reservoir is also plotted against time. An approximate formula is also proposed to estimate the volume of the reservoir. (F-8)

(148) Studies on Stress and Deformation in the Specimen Being Shown by the Rotary-Die-Type Simple Shear Testing Apparatus

Mizuta, Y., Kunimatsu, S. and Ogino, S.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1144, pp. 437–442, 1983,

The strength of material is usually determined from the fracturing load through brief calculation formula assuming simple stress distribution in the specimen. However, complicated stress distribution may be caused in the specimen under some kind of shear test.

The authors have performed single-plane shear test using the rotary-die-type simple shear testing apparatus, which was suggested from I.B.G. standard plan and improved by Kobayashi. They have analyzed the boundary conditions between the specimen and the shearing tool and confirmed it by the measurement. Then they have analyzed elasto-plastic behaviour of the specimen considering the above conditions.

It is suggested from the results obtained that inclination between the vertical plane and the shear-plane prescribed must not be far from 27°50′ for significant shear test. (F-6)

(149) Studies on the Shock Wave Velocity Generated by Detonation of Explosive in an Experimental Cylindrical Gallery

Shibuya, T. and Isobe, T.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1144, pp. 443–448, 1983,

Shock waves generated by the explosion of gases or explosives contain a great deal of energy. It will decrease in its quantity as traveling further from the explosion sourse. In the present investigation studies have been carried out on the phenomena of the decreasing process of shock wave as its object. Experiments were done in a small test gallery, whose diameter, length and wall thickness are 450 mm, 10 m and 6 mm, respectively. Setting No.3 Kiri-dynamite on the corner cutting mortor, test blastings were practised several times. The shape of angled mortor is 120 mm in diameter and 1 m in length having 5 x 5 cm right angle notch in its direction of axis. Blastings were always executed towards the exit of gallery.

The velocity of shock wave is obtained by measuring the arrival time of shock wave to each measuring point. The pressure of shock wave was calculated from the velocity.

As a result of the present study, it is concluded that pressure (P), velocity of shock wave (V) and its traveling time (t) are the functions of distance (R).

Namely, the incident pressure P (atm) has a relation of

$P = k_1/R^{2/3}$,

the velocity V (m/msec)

$V = k_2/R^{1/3}$,

and traveling time t (msec)

$t = k_3 \cdot R^{4/3}$,

where coefficient k_1, k_2 and k_3 are bound as $k_1 \propto k_2^2 \propto k_3^{-2}$, R is the distance between measuring & blasting point.

(F-7)

(150) Visco-Elastic Behaviour of Sanjome Andesite under Pulsating Load

Okubo, S., B. Liu, W., Yamaguchi, T. and Nishimatsu, Y.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1148, pp. 893–898, 1983,

Laboratory experiments have been performed on samples of Sanjome andesite in which the differencial stress was repeatedly cycled up to mainly 70% of the intact sample strength.

The stress-strain hysteresis loops under a sinusoidal compressive stress have shown crescent-type and suggests a non-linear visco-elastic behaviour. A Voigt model in which a linear spring is replaced by the non-linear spring as obtained by the experimental results are proposed to explain the non-linear visco-elastic behaviour of the sample rock.

A careful examination indicates that so far as the periodical time of the pulsating load may keep constant, the model with a constant viscosity can be applied to the experimental results conducted under various stress amplitudes and confining pressures.

(F-7)

(151) Studies on the Influence of NaCl Concentration in Its Aqueous Solution to Mechanical Characteristics for Soft Rock and Its Mechanism

Ishihara, Y. and Hagiwara, Y.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1149, pp. 959–963, 1983,

The mechanical characteristics for soft rocks are influenced by water. And the behaviors of clay minerals in soft rocks are one of primary factors on the influence of water. Well, it is known that the force acting between clay grains are changed by the kinds and concentration of pore fluid.

In this studies, by way of soft rocks, Ohya Tuff and Shirakawa Tuff are chosen, and the influence of NaCl concentration in its acqueous solution to mechanical characteristics and its mechanism are investigated.

The main results obtained in this studies are as follows;

(1) When NaCl concentration in its acqueous solution becomes dilute, longitudinal wave velocity and uniaxial compressive strength for Ohya Tuff and Shirakawa Tuff indicated the tendency of a decline.

(2) We considered that the tendency of the change of mechanical characteristics for soft rocks are the results of the change of the degree of union in soft rocks. That is to say, when the NaCl concentration in its acqueous solution in soft rocks changes, the force based on the repulsive force and attractive force between clay grains changes, and its force causes the change of the degree of union in soft rocks, and that's change of the degree of union in soft rocks influence the mechanical characteristics for the soft rocks.

(F-2)

(152) Mechanical Properties of the Rock Specimens with an Artificial Cracked Plane — Fundamental Studies of Mechanical Properties on Jointed Rock-Mass (1 st Report) —

Yamashita, S., Amano, K. and Kawabe, K.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1150, pp. 1021–1028, 1983,

For the purpose of clarifying the mechanism of failure of jointed rock-mass, two series of uniaxial and triaxial compression tests were carried out on the specimens with an artificial cracked plane, which made various angles with the horizontal plane.

Two types of jointing conditions were used for cracked planes of the specimens; a) jointed with only surface friction, and b) adhered with polyester resin. The tests with these conditions were called "Friction test" and "Adhered test" respectively.

The following results are obtained;

1) The compressive strength of cracked specimen varied with the angle of cracked plane.
2) In both of the tests, there is a critical angle of cracked plane, which divides the failure state of the specimen into two states; breaking throughout the specimen or sliding on the cracked plane.
3) The compressive strength of the specimen, which has lower angle of cracked plane than the critical angle, is nearly equal to that of non-cracked specimen at the friction test, and is nearly equal to, or fairly lower than that of non-cracked specimen at the adhered test.
4) In both tests, Mohr envelope for the criterion of sliding, which is obtained by the stresses at sliding on the cracked plane with various angles, agrees with the envelope from simple plane of the weakness theory introduced by Jaeger.
5) But the Mohr envelope for the criterion of breaking at the adhered test does not agree with the envelope from Jaeger's theory.

These results will be checked again by further investigations.

(F-6)

(153) The Creep Behavior of Sanjome Andesite under Confining Pressure — The Time-Dependant Mechanical Behavior of Rock (2 nd Report) —

Yamaguchi, T., Okubo, S., Nishimatsu, Y. and Koizumi, S.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1150, pp. 1029–1034, 1983,

The compressive creep of Sanjome andesite was examined under the confining pressure from 0 to 400 kg/cm^2.
The results are as follows:

(1) The creep behavior of the specimen can be divided into two stages. During the first period starting immediately after loading, creep rate is continuously decreasing with time and the logarithmic creep law fits for most part of this period. In the successive stage, creep rate is increasing monotonously toward the failure.

(2) The characteristic time, t_c, at which creep rate takes its minimum is found to be related to the lifetime of the specimen, t_f, by the following equation,
$t_f \cong 2\ t_c$.
In other word, the period of the first stage is nearly equal to that of the second.

(3) Comparing at the same elapsed time, creep rate increases with creep stress level under a given confining pressure, and increases with confining pressure under a given stress level.

(F-7)

(154) Determination of Fracture Toughness of Granitic Rock by Means of AE Technique

Takahashi, H., Hashida, T., Tamagawa, K., Yuda, S. and Suzuki, M.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 100, No. 1151, pp. 17–21, 1984,

This paper describes the results of an experimental research in which the fracture toughness of a granitic rock is determined by means of AE technique. ASTM standard specimens of the notched bend type having width from 30 to 508mm were tested.

The deformation and fracture behavior showed a significant nonlinearity and a stable crack growth were observed in all the tests. AE signals were detected at low load level, which indicates the occurrence of microcracking near the initial notch tip. Furthermore an analysis of the waveform and frequency spectrum of AE signals leads to a conclusion that there exists a close relationship between micro-fracture process at the crank tip and AE signals.

J-integral procedure were reasonably used because of the nonlinear deformation behavior. The relationship between the accumulated AE energy and J-integral provides a clear indication of the onset of a stable crack extension, denoted by J_{IAE}. The values of J_{IAE} determined on the different specimens are independent of specimen size. This evidence suggests the feasibility of using a J-integral fracture criterion for this materials. A combination of non-linear fracture mechanics and AE technique provides a suitable procedure for determining the fracture toughness of rocks.

(F-0)

(155) Representation of Pore Structure of Rocks and Evaluation of Pore Diameter Distribution by Two- and Three-Dimension Network

Chida, T., Sakai, N., Tadaki, T. and Shimoiizaka, J.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 100, No. 1152, pp. 61–66, 1984,

Pore structure was analyzed by using two- and three-dimensional network model. In these models, the pore structures are assumed to be network systems of cylindrical segments of different diameters and different lengths.

The models were applied to analysis of experimental mercury porosimeter results of pore size distribution of rocks and coal.

The following results are obtained.

1) The theoretical results agree well with the experimental results.
2) The hysterisis curves of penetration and drainage can be explained by the model.
3) The network size and the linkage probability of the segments of comparatively large diameters have large effect on calculation results of penetration and drainage.
4) The pore volume fractions given directly from experimental results by using the "bundle of capillary tube" model are not correct, and the fraction of segments of comparatively large diameter is larger than that calculated from experimental results

(F-3)

(156) On the Flaking-Destructive Phenomena of Porous Material Induced by Involved High Pressure Gas –Study on Coal and Gas Outbursts (1 st Report) –

Ujihira, M., Isobe, T. and Higuchi, K.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 100, No. 1153, pp. 225–232, 1984,

Experimental studies on destruction of cement mortar induced by internal high pressure gas were carried out. In this 1st Report, flaking type destruction of mortar are shown photographically, and its charactericities are discussed. The results obtained from them are as follows:

1) Under an experimental condition, that is $\bar{S}_t = 1.0$ (kg/cm^2) and $\bar{P}_r = 28.5$(%), when one end surface of confined mortar in which high pressure gas (5 – 6kg/cm^2) has been existed is suddenly exposed to the atmospheric space, the mortar is usually flaked into pieces from surface to bottom. And the demolished cavity that was formed in the vessel was very similar to those of conical outbursts.
2) It is confirmed that the most necessary condition for the occurrence of mortar outbreaking is the creation of steep gas pressure gradient within the narrow neibourhood from the surface of material.
3) A lot of cracks that are nearly pararell to the surface are possible to be created by tensile stress that will be distributed corresponding to the gas pressure distribution.
4) If the internal gas pressure is set up higher, the depth and the volume of the demolished cavity becomes deeper and larger.

(F-8)

(157) Acoustic Emission Activities and Fracture Processes of Brittle Rocks in Uniaxial Compression Tests —Studies on a Mechanism of Brittle Fracture of Rock in Compression (1 st Report) —

Yamashita, S., Amano, K., Otsuka, K. and Kawabe, K.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 100, No. 1155, pp. 385–390, 1984,

For clarifying a fracture process of rock, two series of uniaxial compression tests loaded by a stiff testing machine and by conventional testing machine were carried out for cylindrical samples of several rocks with two types of slenderness-ratios.

In these tests, both the axial, lateral and volumetric strain behaviors vs. stress and the AE (acoustic emission) activity behaviors vs. stress were observed at the same time. Furthermore, the characteristic points were determined from the stress-strain curves by the hypothesis of Bieniawski and from the stress-AE counts curve by finding the rate of change in the AE counts. Finally, comparisons were made between two types of characteristic points obtained by the above methods.

The results obtained are summarized as follows:

1) There are the so-called "size-effect" in the strength of failure of the specimens of the same rocks with various height, but there is little difference between the strengths of the same samples obtained by the above two testing methods.
2) The level of the stress-ratio of the characteristic point A for the crack closure on the volumetric strain-stress curve agrees with that of the ceasing point A' of the initial AE activity on the stress-AE counts curve. Besides, the level B for the fracture initiation agrees with that of the reactivating point B' of AE counts.
3) The characteristic point C associated with the beginning point departing from linearity of the axial strain-stress curve agrees with the point C' where the rate of AE counts is going to increase.
4) The characteristic point D, defined as the beginning point when the slope of the volumetric strain-stress curve becomes infinite, is different from the point C or C'.
5) The average level of stress-ratio of the characteristic points for all over the tests is about 44% of the strength of failure for the point B and its coefficient of variation (c.v.) is about 10%, about 64% for the point C and its c.v. is only 4.4%, and about 77% for the point D but its c.v. is 18%.

The above results do not coincide in part with the hypothesis and the experimental results of Bieniawski. It will be realized that the observation of the point C on the stress-axial strain curve gives the more accurate and reliable measure for predicting the fracture state of brittle rock than the observation of the point D on the volumetric strain-stress curve. (F-5)

(158) Shear Tests Under Constant Deformation Rate and Shear Properties of Rooks by Use of a Newly Designed Direct Shear Testing Machine —Study on the Direct Shear Test of Rocks (1 st Report) —

Esaki, T., Ndamukong, S. A., Aoki, K. and Nishida, T.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 100, No. 1155, pp. 391–396, 1984,

With the aim of carrying out direct shear tests under high normal stress on intact rocks and rocks containing discontinuity planes, we designed a new direct shear testing machine which was used in the present investigation.

Two types of rock, Ainoura sandstone and Akiyoshi marble, were used in our tests. Obtained data give very plausible shear stress versus shear displacement curves which are comparable with those of triaxial tests.

A strength drop is noticed in the saturated state as is the case with triaxial tests. It is also observed that data on the failure criterion are very reproducible but have slightly higher peak and slightly lower residual values than those from triaxial tests.

Particular attention is drawn to the interesting fact that rock dilatancy characteristics can be observed during shear.

(F-6)

(159) On the Process of Destruction of Porous Material in which High Pressure Gas is Involved — Study on the Coal and Gas Outbursts (2 nd Report) —

Ujihira, M., Isobe, T. and Higuchi, K.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 100, No. 1155, pp. 397–403, 1984,

Experimental studies on destruction of porous cement mortar in which high pressure gas is involved were carried out. The destructions were caused by sudden exposure of a test piece face towards atmospheric spaces. And the propagating phenomena of flaking destruction were recorded using strain gauges and gas pressure transducers set in the mortar. At the same time the phenomena were also snapped continuously by high speed camera through the transparent window attached on the apparatus. The results obtained are as follows:

(1) It was found that the microcracks generated just under the surface of test piece had been propagated towards bottom direction. Under the condition, that is internal gas pressure $P_G \geqq 3$ kg/cm^2, the propagating speed might be 12 ~ 36 m/s. And the higher the gas pressure becomes, the more quickly the phenomenon terminates.
(2) Macrocracks are also propagated from surface to bottom in like manner as microcracks. The results obtained above, flaking destruction of test piece could be considered as the chain reacting phenomena.
(3) Basically, the destructive process caused by gas pressure contained in the pores of material could be explained as follows.
  1) Gas pressure nearby the surface of porous material drops by the sudden exposure of the surface of it to the atmospheric spaces.
  2) Steep gas pressure gradient is resulted just under the surface of test piece.
  3) Then tensile stress distribution will be changed corresponding to the gas pressure distribution.
  4) And at last, flaking destruction will occur in succession from the surface towards internal part of porous material.

(F-8)

(160) Energy Approach on the Process of Fracture of Brittle Materials

Kimura, T., Esaki, T. and Nishida, T.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 100, No. 1156, pp. 475–480, 1984,

The total energy applied from an external system of a given specimen, in the process of fracture, is transformed into elastic strain energy and irreversible energy. The elastic strain energy is related to the violence at the fracture of brittle materials which characterizes rock or coal bursts.

In this paper, compression tests under a generalized triaxial stress system were made to obtain a three dimensional distribution of elastic strain energy in the failure surface. Results from the tests reveal that:-

(1) Elastic properties of the substance in a given specimen are shown by the gradient of the reloading curve rather than that of the envelope curve obtained from cyclic loading.

(2) The strength of mortar is neither influenced by the loading path nor cyclic loading. The failure criterion of mortar is represented as the failure surface which is somewhat convex outward beyond that obtained by Mohr-Coulomb.

(3) Elastic strain energy attains a maximum value at failure during the uniaxial compression test.

(4) Irreversible energy depends on the loading path, but elastic strain energy does not. The latter is dependent on the stress state in the failure surface. The locus of elastic strain energy in the failure surface is represented by an ellipse in the Rendulic plane whose major and minor semi-axes are related to Young's modulus and Poisson's ratio of the specimen.

(F-5)

(161) Compact Shear Test of Rocks – A Study of the Process of Shear Fracture of Rocks (1 st Report) –

Kobayashi, R., Matsuki, K. and Sone, Y.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 100, No. 1156, pp. 481–486, 1984,

As the rock mass is usually in the compressive state of the stress, the shear mode fracture toughness is considered to play more important role on analyzing the fracture behaviour of underground rock structure. However, this type of the fracture toughness testing is so difficult that most investigations to date have concentrated on the mode I fracture toughness.

In this paper, in order to evaluate the mode II fracture toughness of rocks, so-called compact shear test is undertaken for two kinds of rocks; Kimachi sandstone and Tohoku marble. Mode II stress intensity factory in the compact shear test is calculated with finite element technique using displacement method and correction factors for wide range of both crack length and stress ratio p/q are determined.

To detect fracture initiation from the tips of pre-cracks, two methods are used in this test; one is to measure the strains near the tips of pre-cracks with strain-gauges and the other to count acoustic emissions in a specimen.

As the first phase of this study, the size and shape effect on the mode II fracture toughness of Kimachi sandstone are investigated and the appropriate dimensions of the specimen where the fracture toughness is almost independent of the geometry of the specimen are determined as 110mm wide, 60mm high and 30m thick with crack length of 20mm.

The minimum value of the mode II fracture toughness is obtained from the load where the strains near the tips of pre-cracks are increased rapidly corresponding to the fracture initiation.

The ratio of this value of the mode II fracture toughness $K_{IIc\text{-}\epsilon 1}$ to the mode I fracture toughness K_{IC} is proved to be about 1.10 for Kimachi sandstone and about 1.19 for Tohoku marble.

(F-6)

(162) A Non-Linear Rheological Model for Sanjome Andesite –The Time-Dependent Mechanical Behaviour of Rock (3 rd Report) –

Yamaguchi, T., Okubo, S. and Nishimatsu, Y.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 100, No. 1158, pp. 631–635, 1984,

The non-linear rheological model is proposed in order to explain the time-dependent behavior of Sanjome andesite. The model consists of two units in series; i.e. a linear spring and a non-linear Voigt model. Considering various test results on the time-dependent behavior of sample rock, the constitutive equation for non-linear Voigt model is assumed as

$$\varepsilon_{\nu} = \eta \exp(\delta \sigma) \cdot \exp\{-\delta k \varepsilon_{\nu} (1 - \varepsilon_{\nu}/C)\}$$

where σ is the stress applied to the model, ε_{ν} is the viscous strain and η, δ, k, c are the material constants.

This model is especially deviced to describe the following phenomena.

(1) In the constant strain-rate loading, the gradual increase of compliance toward the strength failure point and the strain-rate dependency of the strength; the stress at the strength failure point increases by about 75 kg/cm^2 as the strain rate is increased by a factor of 10.

(2) In the creep, a linear increase of the creep with logarithm of the elapsed time, and the subsequent accelated creep; creep strain-log time curves are of congruence in regardless of a creep stress.

(F-8)

(163) Studies on the Influence of Salt Concentration in Solution Being Contained in Soft Rocks on Mechanical Characteristics for Them and Its Mechanism

Ishihara, Y. and Hagiwara, Y.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 100, No. 1158, pp. 637–642, 1984,

The influence and mechanism of salt concentration in solution being contained in soft rocks on mechanical characteristics for them are investigated.

The results are as follows.

(1) When $CaCl_2$ concentration in solution being contained in soft rocks becomes dilute, the uniaxial compressive strength and the longitudinal wave velocity of them indicates the tendency of decline.
The relation between NaCl and $CaCl_2$ concentration in solution being contained, C (mol/l), and the uniaxial compressive strength, σ_C (kg/cm^2), are as follows.
About NaCl solution $\sigma_C = -1.34(-\mathrm{Log}\ C) + 51.0$
About $CaCl_2$ solution $\sigma_C = -0.92(-\mathrm{Log}\ C) + 48.5$
where $10^{-4} \leqq C \leqq 10^{0}$
And the relation between NaCl and $CaCl_2$ concentration in solution being contained, C, and the longitudinal wave velocity, V_p (km/sec), are as follows.
About NaCl solution $V_p = -0.066(-\mathrm{Log}\ C) + 2.63$
About $CaCl_2$ solution $V_p = -0.034(-\mathrm{Log}\ C) + 2.65$
where $10^{-4} \leqq C \leqq 10^{0}$

(2) When NaCl and $CaCl_2$ concentration in solution being contained in soft rocks becomes dilute, the vertical strain caused by expanding of soft rocks becomes higher. The relation between NaCl and $CaCl_2$ concentration in solution being contained, C, and the vertical strain caused by expanding of soft rocks, ε_V, are as follows.
About NaCl solution $\varepsilon_V = 2.40 \times 10^{-4}\ (-\mathrm{Log}\ C) + 2.67 \times 10^{-3}$
About $CaCl_2$ soution $\varepsilon_V = 1.26 \times 10^{-4}\ (-\mathrm{Log}\ C) + 2.94 \times 10^{-3}$
where $10^{-4} \leqq C \leqq 10^{0}$

(3) In order to destroy the structure of clay minerals in soft rocks, samples had been heated. When NaCl and $CaCl_2$ concentration in solution being contained in samples being heated becomes dilute, the longitudinal wave velocity of samples being heated does not indicate any change.

(4) The relation between the uniaxial compressive strength, σ_C, and the vertical strain caused by expanding, ε_V, of soft rocks has been investigated. And, the relation between the longitudinal wave velocity, V_p, and the vertical strain, ε_V, has been investigated, too.
As the results, next relation are obtained.
$\sigma_C = -k_1\,\varepsilon_V + \sigma_0,\quad V_p = -k_2\,\varepsilon_V + V_0$ (F-8)

(164) The Uniaxial Compressive Test of Rocks Controlled by a Negative Feed Back of Stress Rate

Okubo, S. and Nishimatsu, Y.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 100, No. 1161, pp. 1052–1056, 1984,

Uniaxial compressive tests for eight rocks including one marble, one granite, two andesites and four tuffs were carried out by a servo-controlled testing machine under a condition of a constant rate of (ϵ-σ/E'). Complete stress-strain curves of all rocks were obtained and it was found that the post-failure behaviour of rocks except a marble can be classified to Class II. In all tests, rock failure was fully controlled with the newly proposed negative feed back of stress rate. It shows a great potential of the proposed testing method to investigate the post-failure behaviour of brittle materials as rocks with a minimum modification to a conventional servo-controlled testing machine.

Finally, a brief discussion concerning the fundamental mechanism of Class II post-failure behaviour is given on the basis of the test results.

(F-5)

(165) Properties of Rocks Sheared with Restricted Normal Displacement and Those of Anisotropic Rocks Sheared at Constant Normal Stress – Study on the Direct Shear Test of Rocks (2 nd Report) –

Nishida, T.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 101, No. 1163, pp. 1–7, 1985,

Shear tests were conducted on sandstone and marble samples described in the 1st. Report and on shale samples. Sandstone and marble were sheared while restricting normal displacement, and shale specimens sheared at constant normal stress perpendicular and parallel to stratification.

Normal stiffness values were higher for marble than sandstone. Shear stiffness increased with initial normal stress and indicated no glaring disparity between specimens sheared at constant normal stress and those sheared otherwise. Peak and residual strengths at corresponding normal stresses for both test procedures were virtually equal and the results compare favourably with those obtained by use of the triaxial compressive testing machine.

During shearing with restricted normal displacement, eventual maximum normal stresses were multiples of respective initial normal stresses. Gradients of positive slopes of curves for sandstone decreased as initial normal stress increased. Marble manifested a reverse trend. At failure, a conspicuous drop in normal stress was noticed for sandstone but marble exhibited no such phenomenon. These discrepancies are attributable to differences in their elastic module.

More powder was produced per unit shear displacement then during tests conducted at constant normal stress. Greding analyses of the powder indicate non-dependence of grain size on normal stress.

With shale, no significant difference was observed in seismic wave velocities measured perpendicular and parallel to stratification. Slightly lower peak but higher residual angles of internal friction and higher dilatancies were obtained for specimens sheared perpendicular to stratification.

Field and labolatory test results agree reasonably. Peak strengths of field tests fall between residual and peak strengths of laboratory tests.

(F-6)

(166) Compact Shear Test of Rocks under Confining Pressure — A Study on the Process of Shear Fracture of Rocks (2 nd Report) —

Kobayashi, R., Matsuki, K. and Sone, Y.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 101, No. 1164, pp. 49–54, 1985,

In the previous paper, the authors proposed the method, so-called compact shear test, for determining Mode II fracture toughness of rocks.

In this study, the compact shear tests are conducted under confining pressure in order to evaluate the effect of confining pressure on the Mode II fracture toughness for six kinds of rocks, i.e., Kimachi sandstone, Ogino tuff, Emochi welded tuff, Inada granite, Akiyoshi marble and Tohoku marble. The specimen is 110mm wide, 60mm high and 30mm thick with two 20mm pre-cracks as shown in Fig. 1.

K_{IIC} of the various rocks are found to increase with confining pressure. For example, the ratios of K_{IIC} under the confining pressure of 240 kg/cm^2 to that under atmosphere are 3.4 for Kimachi sandstone, 4.1 for Ogino tuff, 2.3 for both Emochi welded tuff and Inada granite, 2.8 for Akiyoshi marble, and 2.5 for Tohoku marble. For each confining pressure, a consistent relationship is found between secant Young's moduli and K_{IIC} of the rocks employed as shown in Fig. 8.

Although the ratio of Mode II fracture toughness obtained in this study to Mode I fracture toughness evaluated with the splitting testing method is about 1.1 at atmospheric pressure, this ratio(K_{IIC}/K_{IC}) increases more or less with confining pressure for four examined rocks as shown in Fig. 9. This shows that Mode II fracture toughness is more affected by the confining pressure than Mode I fracture toughness.

(F-6)

(167) On the Sensitivity of a Stressmeter Named Hydraulic Capsule

Ishijima, Y., Fukuda, K., Sato, K. and Kinoshita, S.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 101, No. 1165, pp. 139–144, 1985,

A low modulus instrument named hydraulic capsule for monitoring stress changes in rock is described with particular reference to its sensitivity. Method to estimate the stress change in rock from the recorded pressure change has been proposed based on the two dimensional elastic model: Knowing the rock stiffness and the length of the tubing, the pressure change can be easily converted to the change of rock stress using Eq. 3 with an aid of two graphs as shown in Figs. 9 and 10.

Its correctness has been verified in the laboratory study for several types of materials.

(F-0)

(168) On the Stress Loci by Strain Controlled Test of Rock under Generalized Triaxial Stresses

Kimura, T., Aoki, K, Esaki, T. and Nishida, T.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 101, No. 1170, pp. 453–458, 1985,

Stress rate and strain rate controlled tests of sandstone were carried out under generalized triaxial stresses. In order to obtain stress loci in the principal stress space, in the latter tests, octahedral shear strain was increased under both conditions of the increment of horizontal principal strain $d\epsilon_h = 0$ (uniaxial strain) and the increment of mean principal strain $d\epsilon_m = 0$.

The results from the tests reveal that:—

(1) The failure curve of sandstone is somewhat more convex outward than that of Mohr-Coulomb. The lubricant inserted between the specimen and the platen reduces the failure strength in triaxial compression tests, but does not in triaxial extension tests.

(2) Under the condition of $d\epsilon_h = 0$, the stress states change toward the failure curve, with a decrease in the gradient of stress loci which depends only on the Poisson's ratio of the specimen.

(3) Under the condition of $d\epsilon_m = 0$, the strain at the peak in differential stress-strain curves which clearly appears as ϵ_2 runs from ϵ_3 to ϵ_1, does not agree with that at the extreme value in stress-strain curves. The stress states deviate from the line perpendicular to the hydrostatic axis and sharply change just before reaching the failure curve. They all tend to be directed toward a certain point thereafter. For the condition of plane strain ($d\epsilon_2 = 0$), σ_2 is not constant but decreases with $\sigma_2 = (\sigma_1 + \sigma_3)/2$. The difference in the relative value of ϵ_2 to ϵ_3 makes the distinct stress loci, which are expressed in terms of the normal and shear stresses on the fracture plane.

(F-6)

(169) Simulation for Fracture Initiation and Propagation of Rock under Uniaxial Compression — Studies on a Mechanism of Brittle Fracture of Rock in Compression (2 nd Report) —

Yamashita, S., Amano, K., Otsuka, K. and Nakagawa, K.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 101, No. 1171, pp. 503–509, 1985,

In order to clarify the fracture process of rock, the stress-strain behaviors associated with the fracture-initiation and -propagation from an initial crack were simulated in this study by the Finite Element Method.

The results of this simulation indicated:

1) At the stress level of the characteristic point B, that was the point of the onset of dilatancy in the stress-volumetric strain curve, the fracture was initiated and propagated in the direction of the loading axis due to the tensile stress around the initial crack.

2) Beyond the stress level of the characteristic point C, that was the point of the onset of non-linear strain behavior in the stress-axial strain curve, the fracture was propagated as an extending crack due to the shear stress in the direction across to the loading axis.

It was found that the stress-strain behaviors obtained from uniaxial compression tests in the 1st report coincided with those from the above simulations.

(F-6)

(170) Discussion on a Fracture of Rock by Uniaxial Cyclic-Loading Test — Studies on a Mechanism of Brittle of Rock in Compression (3 rd Report) —

Yamashita, S., Amano, K. Otsuka, K. and Tsutsui, Y.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 101, No. 1174, pp. 753–759, 1985,

In this study, cyclic-loading tests under uniaxial compression were carried out on rock specimens to verify the mechanism that was proposed by the simulations of the 2nd report. In these tests, both stress-strain and stress-acoustic emission (AE) activity relations were monitored on loading, unloading and reloading paths to characterise such points on the stress-strain curve as fracture initiation (point B, by Bieniawski) and onset of unstable fracture propagation (point C).

The results obtained were as follows:

1) In the unloading and reloading processes between the stress levels of the characteristic points B and C, a quasi-elastic deformation is observed in the stress-strain curve and the "Kaiser Effect" can be detected in the stress-AE count activity curve.
2) When the stress level in either unloading or reloading process is increased beyond the level of the point C in the stress-strain curve, a plastic deformation appears, the Kaiser Effect vanishes re-activating AE count, and a delayed fracture appears if the stress is maintained at that level.

From these results it is concluded that the characteristic point B and C correspond to the initiation of tensile fracture propagation and the onset of shear fracture propagation respectively.

(F-6)

(171) Experimental Study on Hydraulic Fracturing of Permeable Soft Rock

Akai, K., Ohnishi, Y. and Yashima, A.

Journal of the Society of Materials Science, Japan, Vol. 31, No. 342, pp. 295–300, 1982,

Recently, hydraulic fracturing technique is being used worldwidely to determine the in-situ stress in the earth's crust. Most of the works deal with hard impermeable rock masses and therefore the theories are developed to suit for such kind of rock. However, there are so many cases where the rock masses are saturated and permeable. They are usually soft and weak. The in-situ stress determination in such soft rock mass has eagerly been searched for, but an effective method has not been invented yet.

In this paper, the result of the feasibility study for the hydraulic fracturing technique on the soft rock (mudstone) was reported. The mechanical properties and the behavior of soft rock during injection of pressurized water were investigated. Vertical and horizontal fractures were created in a modified triaxial cell under various stress conditions. The flow rate and the pressure-increase rate in a drilled hole were found to be very influential to the fracture orientation. Also, the application of this hydraulic fracturing technique to the field problems was briefly discussed.

(F-4, F-6)

(172) Radiation Pattern of Acoustic Emission

Ohtsu, M.

Journal of the Society of Materials Science, Japan, Vol. 32, No. 356, pp. 117–123, 1983,

Acoustic Emission (abbreviated as AE) is the transient elastic wave emission due to microfracturing in a solid. In the previous paper, theoretical representation of AE wave motions in concrete was reported by applying the theory of dislocation and elastodynamics. Once sources are mathematically described by the dislocation model, AE waveforms generated by various types of source mechanisms are characterized with emphasis on features of the radiation pattern, which is the spatial distribution of amplitude and polarization of first motions.

In this paper, fundamental studies in regard to radiation patterns of AE wave motions are reported. Such patterns are verified in the experiments. In the source location experiments, the types of sources can be classified into two groups from AE characteristics based on the radiation pattern. They are associated with tensile cracks and others.

From the relation between the radiation pattern and the dislocation model, in addition, the orientations of dislocation models may be determined. The improved source location technique useful for such an attempt is developed and applied in the experiments. The results show that the determination of source kinematics by the aid of the radiation pattern is promising in concrete.

(F-6)

(173) Thermal Expansion of Rocks from 80 to 300 K

Ehara, S., Yanagidani, T., Hirao, K. and Terada, M.

Journal of the Society of Materials Science, Japan, Vol. 32, No. 363, pp. 111–117, 1983, Thermal expansion of several rocks down to 80K was measured with a dilatometer under dry and wet conditions at atmospheric pressure. According to the results of thermal expansion measurements, the rocks could be classified into two groups: granitic and non-granitic. For the non-granitic rocks in this study, *i.e.*, tuff, sandstone, andesite, and basalt, the thermal expension coefficient increased in proportion to porosity but in inverse proportion to density, Young's modulus, and the strength. On the other hand, for granitic rocks (two granites and quartz-diorite), the thermal expansion coefficient increased in proportion to density and Young's modulus, but decreased with an increase in porosity. These differences are attributable to the pore and crack shape within the rocks. Low aspect ratio cracks are the main cause of granitic rock porosity, and they cancel the thermal expansion of the whole rock because they can provide space for the expansions of the surrounding grains. On the contrary, high aspect ratio pores, mainly within non-granitic rocks, only negligibly affect the thermal expansion of the whole rock.

When the rock was saturated with water, the thermal expansion coefficient became higher than that under a dry condition. As the thermal expansion coefficient of ice is several times higher than those of rocks, the ice in pores and cracks contributes to the increase in the thermal expansion coefficient. And in the case of granitic rocks, this is partly because the ice existing in the crack increases its net aspect ratio and reduces the space available for the expansion of the mineral grains. The large and complicated hysteresis patterns of wet rocks seen upon thermal cycling are due to temperature differences between the freezing and melting of water in the rock pores and cracks. (F-8)

(174) Source Location of AE Events during Creep in Ohshima Granite

Yanagidani, T., Ehara, S., Terada, M., Nishizawa, O. and Kusunose, K.

Journal of the Society of Materials Science, Japan, Vol. 33, No. 366, pp. 34–39, 1984,

The source location of acoustic emission (AE) events was performed during the creep of Ohshima granite under uniaxial compression. During the stage of loading up to the creep stress, AE events were randomly distributed throughout the sample. As soon as the transient creep was initiated, abrupt migration and clustering of AE events into several near-surface zones were clearly observed. These migration and clustering strongly suggest the rapid anisotropic development of dilatancy at the very beginning of transient creep. These clusters, though the shape of each one was "volumetric", formed a shear band at an angle 30～35° to its loading axis. The spatial distribution pattern of AE events established in this stage was retained until the main fracture. By the end of transient creep. AE events began to concentrate into one of these clusters; on the other hand, the activities of other clusters were reduced gradually. This change was spread broadly and continuously in time until the main fracture. There was no fundamental difference in the spatial distribution pattern of AE events between the stationary and the tertiary creep. In the latter half of the creep, the occurrence of AE events was limited within only one cluster which remained active, and the acceleration of AE activity was seen before the main fracture in this cluster. And its shape was spheroidal whose long-axis was parallel to the loading axis. (F-7)

(175) Surface Strain Mapping during Creep in Ohshima Granite

Yanagidani, T., Ehara, S., Terada, M., Nishizawa, O. and Kusunose, K.

Journal of the Society of Materials Science, Japan, Vol. 33, No. 366, pp. 41–47, 1984,

Surface strain mapping of Ohshima granite during the creep experiment shows that a uniformity of loading up to the creep setting stress was attained, and that a large change in strain field occurred during the early stage of transient creep. The change of the strain field represented the anisotropic development of dilatancy immediately after the creep initiation. The pattern of strain distribution established in this stage was rarely changed in the subsequent course of the creep. The accelerating increase noted in one of the circumferential strain gages during the tertiary creep documents a strong localized deformation before the main fracture. The clustering region of AE events during the tertiary creep, which was determined by the simultaneous measurement presented in the other paper, was close to the region where the strong localized deformation was observed in this surface strain mapping. The projection of AE hypocenters to the specimen surface revealed that the hypocenters of AE events during the creep were mostly located between the strain gages. This biasing was explained on the basis of the role of water vapor in stress corrosion cracking. The adhesion of strain gage prevents the transport of water vapor from the surface of specimen to the crack tip. (F-6)

(176) Fracture Toughness of Rocks under Bending

Matsuki, K. and Kobayashi, R.

Journal of the Society of Materials Science, Japan, Vol. 33, No. 369, pp. 18–24, 1984,

Although natural cracks such as fatigue cracks are favourable as a pre-crack for fracture toughness testing of rocks, it is very difficult to measure the exact length of natural cracks because of the opaque nature of rock and the unevenness of the crack-front.

In this paper, by measuring the compliance of the crack opening displacement under bending, the effective length of fatigue cracks was estimated for two kinds of rocks; Ogino tuff and Tohoku marble, and the result was compared to the actual crack length on the side of the specimen. Furthermore, in order to know the fracture toughness of the rock containing natural cracks by using an artificial notch, the fracture toughness of rock specimens with a chevron-notch was measured and compared with those with another types of pre-cracks including fatigue crack and straight-through notch.

The main results obtained are as follows:

(1) The relationship between the observed length and the effective length of the fatigue crack depended on the texture of the rock. The effective crack length of the marble was mostly smaller than the observed one while the effective crack length of the tuff is larger than the observed one. The stable values of the fracture toughness were obtained from the effective crack length.

(2) The fracture toughness obtained from the chevron-notch was nearly equal to that from the fatigue crack using the effective crack length.

(3) The fracture toughness obtained from the natural cracks of chevron-notch and fatigue crack was considerably larger than that from the artificial straight-through notch because of the unevenness of the crack-front. (F-8)

G. [Analysis of Rock-Engineering Problems]

(1) Fundamental Study on Mechanical Behavior of Rock Mass with Clayey Seam

Adachi, T., Yashima, A. and Matsukage, S.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 103–108, 1984,

The mechanical behavior of a rock mass with clayey seams was investigated by conducting a series of triaxial compression tests (CU-test). In the tests, a rock mass was modeled by a specimen made by sandwiching an alluvial clay seam (sampled from Osaka bay) between two pieces of Ohya-stone. And the thickness of the clayey seam, the inclination of the principal stress to the seam plane, the shear rate, the confining pressure and the over-consolidation ratio were selected as the testing parameters. The behavior of the modeled rock mass was discussed on the basis of the effective stress. From the experimental results, even if the thickness of the clayey seam is so thin, the shear strength of a rock mass is found to be governed by that of the clayey seam, and understanding the behavior of the pore water, especially the income and outgo of the pore water between the clayey seam and the surrounding rock is concluded to be very important. (G-2)

(2) Measurement of Crack Distribution in a Rock Mass from Observation of Its Surfaces

Kanatani, K.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 115–120, 1984,

The anisotropy of the crack distribution in a rock mass is characterized by what is termed the "fabric tensor", and its geometrical interpretation is given. The description in terms of the fabric tensor amounts to approximating the distribution by spherical harmonics of up to the second rank. Then, a practical procedure is presented to determine the internal crack distribution by observing cross-sections of cracks that appear on plane surfaces of the material by means of the stereological principle, i.e., by counting the number of intersections between probe lines and the cross-sections of the cracks. This method requires only three types of surfaces for observation. (G-0)

(3) Permeability of Jointed Rock Masses by Means of Crack Tensor

Oda, M., Maeshibu, T., Hatsuyama, Y. and Suno, S.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 121–126, 1984,

A jointed rock mass is treated as homogeneous, anisotropic porous material in order to formulate an anisotropic permeability tensor in terms of the symmetric, second-rank crack tensor which depends only on the geometrical properties of the related cracks such as aperture, size and orientation. The conclusions are summarized as follows: (1) The trace of the anisotropic permeability tensor is linearly related to the trace of the crack tensor, (2) the eigenvectors of the both symmetric tensors are coaxial, and (3) the deviatoric part of the fabric tensor is indicative of the anisotropy of the permeability. These results are well supported by the numerical analyses (FEM) on the permeability of two-dimensional cracked bodies by Long, Remer, Wilson and Witherspoon (1982). Stereological approach based on geometrical statistics provides a powerful tool for the purpose of representing the fabric tensor in terms of in situ measureable quantities; i.e., (1) crack orientation, (2) trace lengths, and (3) number of cracks per unit scanning length.

(G-5)

(4) A Study on the Modeling and Quantitative Estimation of Joint Distribution in Rocks

Mimuro, T., Kobayashi, T., Kikuchi, K., Nagai, H., Inou, M., Katoh, K. and Ueno, I.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 127–132, 1984,

For founding a civil engineering structure on jointy rocks, it is absolutely required to know the distribution conditions of joints in the foundation rocks, for clarifying the mechanical properties and permeability characteristics of the foundation rocks. It is also important for effectively executing such foundation treatment as grouting made for improving the foundation rocks.

Joints in rocks are generally said to be regularly distuributed, but the regularity varies on locations and conditions. Therefore, a rock joint model should be one that approximate the mechanical properties and the permiability characteristics. The authors have been presenting the methodology of quantitative estimations and Analysis for the distribution deciding elements of joints such as, 1) orientation, 2) length, 3) distribution density, 4) opening width, 5) networks, and 6) roughness, 7) filling, of joints.

In the present paper, the traditional method, which treats the orientation, length and spacing data, has been re-evaluated and a new modeling method for the rock joint model is mentioned.

The basis of this new method can be summerized as follows.

1) Joints orientations are analyzed and reduced to dominating orientation using the "Analyzing method based on polar coodinates by the use of electric computer" developed by the authors, and estimated with "separability ratio", "disturibution ratio", and"concentration ratio" of joint group.
2) Joint lengths and spacing should follow the frequency distribution obtained by the ground surface survey on joints.
3) Joints excluded from a group should be expressed.

Further study on "networks", "roughness", "filling" will be carried on and the model will be checked with data of the ground survey on joints.

(G-0)

(5) Long Term Strength Properties of Poor Rockfill Materials

Matsumoto, N. and Watanabe, K.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 133–138, 1984,

It is sometimes difficult to find good rockfill materials in construction of fill dams, although an intensive search should be made to obtain the best possible rock within reasonable distance from the dam. In case of poor quality rocks, their long term strength properties are of importance.

The authors conducted long term dry-and-wet cycle laboratory tests for rock particles and compacted cylindrical specimens for the same rock. Rocks are altered and weathered dolerite which is borrowed from the quarry site for Sagae Dam.

The rock particles which were subjected to 40°C oven dry and submerged wet cycles did not show almost any change in their shape and weight loss up to 5 cycles. From 10 cycles, rock particles gradually began to develop hair-line cracks, and at 30 cycles, most of rock particles broke into pieces and decreased their point loading strength. In this dry-and-wet cycle tests, the degree of saturation of rock particles changed from about 100 % to 50 %.

Compacted cylindrical specimens of 30-cm diameter and 60-cm height were subjected to submerged and drained cycles and long term loading of confining pressure. The degree of saturation of cylindrical specimens varied from about 100 % to 40 %, while the degree of saturation of rock paticle itself remained always more than 100 %. Test results show that long term strengths of compacted cylindrical specimens subjected to dry-and-wet cycles were much the same as before the long term loading. The deformability of cylindrical specimens subjected to long term loading in triaxial tests is small compared to that of the specimens which were not subjected to long term loading. (G-3)

(6) The Actual Condition and Some Considerations about the Scattering of the Mechanical Properties of a Rock Masses

Ito, H., Kitahara, Y. and Nozaki, T.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 139–144, 1984,

For the evaluation of the stabilities of the foundation ground of a structure and a large slope, it is a very importance on their designs that investigate the scattering of the values of the mechanical properties which influences toward the stability of a ground. The purpose of this paper can clarify the actual condition about the scattering of the value of the mechanical properties of a rock foundation. The collection and the analysis about the results of the past examinations were performed. The charactaristic of the scattering in every kinds and classification of the rock masses about the uniaxial compressive strength which is most in quantity of the collected datum are investigated and also the fitting of a function for the distribution shape of its scattering is examined. Moreover, the distribution charactaristics of the scattering about the confined compressive strength and its modulus of deformation are also examined in the same way as the case of the uniaxial compressive strength. On the other hand, it is conducted the examination about the influence of the number of a speciman which affects on the distribution charactaristic of the scattering of value of mechanical properties by the means of the random sampling method and the other method. (G-0)

(7) Effect of Geological Factors on Mechanical Properties of Rocks

Hoshino, K.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 145–150, 1984,

Among the geological factors such as density, porosity, saturation degree of interstitial water,chemical constitution, mineral composition, and grain-diameter that effect mechanical properties of rocks, porosity is the most important one.

Solidification of the clastic sedimentary rocks become greater as the pores in rock are getting smaller during progressive stages of compaction. Strength, elastic modulus, viscosity, velocity of elastic wave are much influenced by porosity as shown in Tab. 1. Strength decreases exponentially as porosity increases according to formula 2 - (1).

The igneous rocks are also affected by porosity in the same relation, although most igneous rocks are crystalline and few in porosity, while some volcanic rocks have larger porosity caused by microfractures or the gas emission during eruption.

The intact crystalline rocks and the sedimentary rocks at final stage of compaction have nearly same porosity and strength, whereas under-consolidated sediments and the altered volcanic rocks are of same range in strength (Tab. 4). The mechanical properties of the clastic rocks are essentially little related to the geological name.

In the igneous rocks, mineral composition is next important factor. At atmospheric pressure, strength decreases as the rocks change from acidic to basic in mineral composition, while at higher confining pressure, strength increases as mineral composition changes from acidic to basic. The elastic wave velocity decreases at both confining pressures as it changes acidic to basic. The strength of the igneous rocks decreases as grain-diameter increases. Those factors such as mineral composition and grain-diameter are in linear relation to strength. (G-1)

(8) In-Situ Deformability Plate Test of Rock Masses Controlled by Electronic Processing Devices

Kuroda, S. and Fujita, K.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 151–156, 1984,

In this paper, we propose the automatic loading and measurment processing system for a plate test controlled by the microcomputer instead of the conventional manunal control and log. This processing system is mainly composed of microcomputer,hydraulic control valves, hydraulic pump,sencers and transducers.Based on the model tests and protoype tests at the survey tunnels,the acuracy of control and reliability of this system in any cases are discussed. (G-3)

(9) Dynamic Characteristic of Rock Foundation under Cyclic Shear Loading

Fujiwara, Y., Hibino, S., Komada, H., Kanagawa, T., Nakagawa, K., Ishida, T. and Shin, K.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 157–162, 1984,

Recenty ,important structures such as nuclear power stations have been built on hard rock foundation or soft rock foundation . In the past , dynamic properties of foundations were obtained by dynamic triaxial test with core samples in case of soft rock foundations . But , in case of hard rock foundation , it contains many cracks or joints ,therefore it is very difficult to obtain dynamic properties by core tests . Therefore , the authors have newly developed the in situ dynamic shear loading apparatus .

We repot dynamic deformation and failure characteristic of a few foundations obtained by the apparatus . (G-6)

(10) Displacement Measurement near the Tunnel Face

Asakura, T., Kawakami, Y., Baba, T. and Onoda, S.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 181-186, 1984,

In earth or soft rock tunnels,the evaluation of tunnel face stability and the estimation of final convergence values are important factors in taking quick decisions whether a change of support pattern is necessary. For that purpose,the characteristics of the rock behavior surrounding tunnel should be understood immediately after excavation.

The instrument has been designed to measure the rate of early displacement immediately after excavation. It consists of three parts: a measuring part(a displacement gauge installed at the top of an aluminum pipe),an amplifier and a recorder. By this instrument, the rate of displacement was measured before initial reading of the convergence measurement.

The measurement results are summarized as follows:

(1) In soft rock tunnels,the measured value of the rate of early displacement v_0

corresponds to the final convergence value δ_{max}.

(2) The tunnel face stability is predicted by the rate of early displacement v.

Also the frequent convergence measurement is recommended which measures convergence values just before and after excavation of each face of the tunnel. By this method,the displacement caused by the excavation process can be separated from the time dependent displacement.By the above method,tunnel closures has been measured in several tunnels.

The results are summalized below:

(1) From 30% to 70% of displacement due to the time dependent displacement.

(2) In earth tunnels,the rate of time dependent displacement slows down rapidly.

Since both method (the measurement of the rate of early displacement and the frequent convergence measurement)can be carried out easily,they will be economical and convenient way of controlling tunnel construction. (G-4)

(11) Numerical Method of Viscoelastic Analysis Using Combined Finite and Boundary Element Methods in Geotechnical Engineering

Shinokawa, T., Kaneko, N., Yoshida, N. and Kawahara, M.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 205–210, 1984,

In order to carry out a numerical analysis in geotechnical engineering, a new numerical method of viscoelastic analysis by the boundary element method (BEM) is proposed. This method adopts the time marching method and can be formulated as given below:

First, the boundary integral equation can be derived in the original domain using the "Elastic-viscoelastic correspondence principle". Since this equation consists only of the boundary integral term, it does not require the provision of the cells in the analytical domain. Second, the fundamental solution can be obtained based on the "Elastic-viscoelastic correspondence principle" using the Kelvin solution of the two-dimensional linear elastic solution. By substituting the fundamental solution in the boundary integral equation, the equation is modified, and backward difference is operated in a form of time function. Finally, the boundary integral equation in an incremental form can be derived. The hereditary integral can be evaluated using only the previous values before the current time since BEM can be formulated in an incremental form with time.

The proposed method is combined with the finite element method (FEM). A computer program of the combined method can easily be made by adding the boundary element to the conventional FEM program.

The validity of the combined method is verified since several numerical results are well in agreement with the exact solutions. It can be concluded that the combined method can be applied in the analysis of the geotechnical engineering such as underground nuclear power plants and tunnels. (G-2)

(12) Application of Three Dimensional Elasto-Plastic Coupling Analysis (BEM+FEM) to Tunnel Problems

Hisatake, M. and Ito, T.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 211–214, 1984,

A finite element method (FEM), which can easily take construction sequences of a tunnel and non-lineality of the ground into account, is a very powerful method to solve problems which have finite regions. In three dimensional problems with bulky regions, however, FEM is likely to cause the increase of amount of computer storage and time, and this may severely limit the applicability of this method to tunnel problems.

On the other hand, a boundary element method (BEM), which can take boundary conditions at infinity in problems with infinite regions into account, can reduce dimensions of system matrixes in comparing with those of FEM. Therefore, BEM is a very efficient numerical tool for solving problems involving bulky three dimensional regions. But in this method, treatment of rock bolts and construction sequences of a tunnel become very complicated, because in these cases analytical regions have to be discretized into finite regions like the finite element analysis.

In this paper, in order to develop both advantages of FEM and BEM, procedures of three dimensional elasto-plastic coupling analysis are presented. By applying the proposed method to tunnel problems, some considerations on rock bolts, shotcrete and plastic regions are given.

(G-2)

(13) Three Dimensional Back Analysis by Optimization Method and Application to Practical Tunnel

Hisatake, M., Ito, T., Kato, S. and Manabe, K.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 215–220, 1984,

In order to estimate initial stresses and mechanical constants of the time dependent ground, a three dimensional back analysis method based on optimization technique is proposed, in which a finite element method and a simplex method are employed. The proposed method is applied to a practical tunnel problem and results obtained by this method are shown to have good agreements with field measurements.

(G-4)

(14) Computer Modelling of Roadway Failure from the Stochastic View Point

Okubo, S. and Nishimatsu, Y.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 221–226, 1984,

A fairly simple 2-dimensional model based on stochastic theory has been applied to simulate time-dependent failure of an undergroung roadway in mine.In the calculation,FEM technique is used,and the obtained results are compared with the results measured at Fukazawa mine in Akita prefecture.The roadway considered in this study is U-shaped and supported by rockbolts installed in 1m by 1m pattern.The calculated results of convergence, extension and bolt-load indicate a fairly good coincidence,at least in qualitative means, with measured ones.Some discrepancy may be attributed to the existance of joint planes which are not considered in the calculation model.

By the virtue of the model versatility,the simulation has been carried out for various conditions.Through the calculation,it is found that rockbolt support can retard the failure in great extent,say 10 times.Also,it is shown that rockbolts should be installed while the failure region remains within a critical depth from the wall.

It can be said that the model showed a great potential for application purpose. Simplicity of this model requires a minimum modification of a standard FEM program and also minimum laboratory work to obtain necessary parameters.Application of this model to tunnel, dam,slope,underground storage and plant is hopefully possible and remains for future research.

(G-2)

(15) Fundamental Study for Reinforcing Effects of Rockbolt in Discontinuity

Kitagawa, T., Yoshinaka, R., Norose, S. and Sakaguchi, S.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 233–238, 1984,

Recently, rockbolts as support measures are very popular in use in construction of underground excavations, such as tunnels, power stations, storage houses and so on. But it is pretty difficult to evaluate their effects and to introduce them quantatively into the design. The difficulties are originated in the complexities of the strength- and/or deformation-characteristics of the rockbolted rock mass.

So we investigated the existing underground quarry openings excavated in the tertiary welded tuff (so-called Ohya-Ishi) which is homogeneous , but few-jointed soft rock mass. The openings are the type of room and pillar/wall, and located at the depth of 80-

130 m. The sizes of pillars are about 50 m in height and 10-15 m in width, and the rooms have the same dimensions. There, we recognized that the openings are effectively reinforced by rockbolts.

Then, we performed a elementary laboratory experiments, modeling the discontinuity reinforced by rockbolt, to investigate the characteristic strength and deformation behaviour. The experimental models are made of mortar and the sizes are 60 x 60 x 20 cm. They have the discontinuities of which roughness are provided by the Barton's JRC and rockbolts are installed intersecting the discontinuity at the angle of 45° and 90°.

This paper presents a meaningfull experimental results, consisting of the hyperbolic approximation in the deformation-characteristics and the failure criteria about the strength-characteristics of the rockbolted discontinuity. (G-4)

(16) Study of Mine Roadway Deformation and Failure by Two Dimensional Scale Model

Matsui, K. and Ihara, M.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 239–244, 1984,

This paper deals with the deformation and failure of the mine roadway excavated in multi-layered strata. Scale model study is made to clarify the deformational behaviors of the roadway under various strata conditions.

Results are presented of an arched roadway driven in coal and weak coal measure rocks. The deformation of the roadway is compared with the general progress of the failure of the surrounding rocks. FEM analysis is also carried out to examine the development of the failure in the vicinity of the roadway. (G-2)

(17) Distinct Element Analysis and Model Test of Ground Movement Due to Shallow Tunneling

Kiyama, H., Fujimura, H. and Futagi, T.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 245–250, 1984,

In order to study the ground movement due to the shallow tunneling, an analytical model of a granular ground in a lowering panel bin was assumed. The granular ground is made of glass-bars of 1 cm in diam. which are piled up in some regular arrays in the bin. The bin is 40 cm in width and 40 cm in height. The lowering panel of 8 cm in width is attached to the center of the bottom of the bin.

The lowering panel model was analysed by the distinct element method (DEM) as well as by the experiments under the same conditions. From the results it becomes clear that the deformation behaviors of the ground are very similarly analysed both in the time scale and in the geometry by the two methods. This fact may also verify the reality of the DEM simulation.

Putting together the results obtained by the DEM analysis and the experiments, the behaviors of particles and the patterns of the ground movements were discussed. As for the characteristic particle behaviors, the initial failure zone, roof-arch, ground-arch and sliding plane were demonstrated in the model. It was found that they are governed by the angle of particle contacts in the particle array.

Thus the different particle arrays result in the different ground movements, which can be classified in the typical patterns, such as V-funnel type, W-funnel type, chimney type and funnel-chimney coexistence type. (G-0)

(18) Model Experiments on the Difference between Sandy Ground and Clayey Ground about Stress Distribution around Tunnel

Kitagawa, S., Kawakami, Y. and Baba, T.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 251–256, 1984,

It generally has been recongnized that the deformation of tunnel in clayey ground is much larger than that in sandy ground. Small scale model experiments were carried out to study the cause of this difference. Ground models were made of soft mortal and plaster. As a result of the experiments,it was recongnized that the mechanism of stress distribution in the ground causes the difference of tunnel deformation between sandy ground and clayey ground. Increase of tangential stress caused by tunnelling is uniform in sandy ground,on the other hand,it in clayey ground is concentrated near the tunnel wall. So the ground around tunnel is hard to be broken in sandy ground,but it is easy to be broken in clayey ground. These phenomena in clayey ground are roughly accounted by theory of elasticity and plasticity,but those in sandy ground cannot be accounted by this theory. (G-1)

(19) Study on Behaviour of Rock Mass Around the Underground Cavity after Excavaton Work with Special Reference to Joint Distribution Characteristics

Kyoya, T., Kawamoto, T., Ohashi, T., Kusabuka, M. and Kashiide, M.

Proceeditns of the Japan Symposium on Rock Mechanics, 6th, pp. 269–274, 1984,

Rock mass differs from soil in many aspects of their mechanical behaviours. The most significant one is that the presence of discontinuities in rock mass play a dominant role in the deformation and collapse behaviours. The numerical Analysis of such rock structures as tunnels, underground cavities, rock slopes, etc., requires special consideration to account for anisotropic behaviours of rock mass, which is caused by distributed discontinuities involved.

KYOYA et al (1983) proposed 'Elasto Plastic Damage Model' for rock mass and rock-like material with distributed discontinuities. This numerical model is constructed based on the concept of 'Damage Mechanics' : In this model distributed discontinuities are represented by 'Damage Tensor' , of order two. Its mechanical meaning is to transform rock mass involving distributed discontinuities into equivalent continum media. The advantages of using this model is that it can handle such small scale of discontinuities as joint sets and microcraks in rock specimens, as it depends on the problem.

This article describes the attempt to apply 'Elastic Damage Model' to a certain Underground cavity. First 'Damage Tensor' is determined from the results of joint survey. Then some numerical analyses are carried out by FEM incorporating 'Elastic Damage Model'.

The results encourages us to apply this model to various kinds of problems in practice.

(G-0)

(20) Simplified Procedure for Dynamic Analysis of Three Dimensional Earthdam – Foundation Systems –

Ohmachi, T. and Soga, S.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 305–310, 1984,

A simplified procedure for dynamnic analysis of a realistic earthdam with foundation interaction is presented for practical application. It regards a three-dimensional dam-foundation system as a series of prismatic finite elements of two degrees of freedom interconnected each other along the dam axis. After formulating the procedure, analytical examples are presented, showing comparisons with observations. (G-6)

(21) Interactions in Rock Mechanics

Hudson, J. A.

Proceedings of the Symposium on Rock Mechanics, 6th, p. 335, 1984, As the subject of rock mechanics matures and its horizons are expanded, the complexity of the necessary analysis increases. This applies not only to the actual numerical techniques but also to the number of parameters involved and the interactions between them. In particular, many civil and mining engineering problems concern the rock structure, water flow in the rock mass and the in situ stress field. These subjects cannot be studied in isolation; the interactions between them must be considered. For example, water flow is affected by both rock structure and in situ stress.

The idea of interactions in rock mechanics subjects is developed conceptually using a matrix approach - from the simplest example of interactions in basic geometry to the complex interactions involved in problems concerning discontinuities, water and stress. The approach is useful for considering many aspects of rock mechanics, including the complete analysis of plane, wedge and toppling failure in slope stability.

The paper concludes with a discussion on the extension of the ideas to extremely interactive rock mechanics problems such as geothermal energy and radioactive waste disposal where rock, heat, water and stress all interact within the rock mechanics system. (G-0)*

(22) Applications of the Boundary Integral Equation Method to Rock Mechanics

Kobayashi, S.

Proceedings of the Symposium on Rock Mechanics, 6th, pp. 337–342, 1984,

The boundary integral equation method (BIEM) is known to be advantageously applied mainly to linear boundary-initial value problems for irregular or for the infinite domain. The present paper describes how BIEM is formulated and applied to rock mechanics. First, the formulation of the BIE for field problems is discussed from rather general point of view. formulation of BIEM for non-linear problems is also briefly discussed. Then a combination of the BIEM and the finite element method (FEM) is presented. Finally, some typical examples in rock mechanics are solved by the use of these methods in order to demonstrate the applicability and versatility of these methods. Examples include 1)three-dimensional elastic stress analyses around a face of a circular tunnel excavated in an anisotropic rock as well as homogeneous one, 2)moving boundary problems such as the branch crack propagation and determination of the phreatic boundary in seepage, 3)elastoplasticity analyses such as two-dimensional hole, and 4)elastodynamic problems as transient stresses around a circular and horse-shoe-shaped lined tunnel due to transient waves and non-homogeneous ground movements. An example of eigenfrequency problem is also shown. (G-2)

(23) Quasi-Three-Dimensional Analysis of Groundwater Flow in Discontinuous Rock Mass

Ohnishi, Y. and Nishino, K.

Proceedings of the Symposium on Rock Mechanics, 6th, pp. 343–348, 1984,

The engineer is faced in many fields of science with problems connected with the flow of fluids through discontinuous or fractured media. In civil engineering, for example, water often flows through rock masses (dam foundations, surface or underground rock structures, natural or artificial slopes). The analysis of subsurface fluid flow is sometimes complicated by the fact that rock masses, especially at shallow depth may contain various systems of discontinuities. Althrough it has been recognized that discontinuities play a very important role in conducting fluids through rocks, attempts to study discontinuity systems on a quantative basis have began recently. The purpose of this study is to develope a numerical technique to analyse the behavior of groundwater in discontinuous rock masses. Quasi-three-dimensional finite element analysis has been done to take into account the 3-dimensional flow characteristics in the conventional 2-dimensional plane problem. The numerical model uses line elements to represent joint or fracture segments. The joint is assumed as a main conduit for fluid flow in the rock mass. In two examples, the quasi-3-dimensional approarch shows the great possibility of application to the analysis of subsurface flow in discontinuous rock masses. (G-5)

(24) The Solution of Nuclide Migration Problems by the Finite Element Method

Utsugida, K., Tanaka, S. and Ishii, T.

Proceedings of the Symposium on Rock Mechanics, 6th, pp. 349–354, 1984,

For the disposal of nuclear wastes in the ground, it is an important problem to assess the influence in the environment. The nuclides included in nuclear wastes will migrate in the ground with fluid flow some day, though these are in solid form and packed in a canister. It is inferred from the fact that the nuclides have a long life compared with canisters. The half-life of some nuclides, especially for high-level nuclear wastes, reach to be on the order of 10^4 years.

On the other hand, the nuclide decays and changes to the other repeatedly, that is, the decay chain. Each nuclide has different properties such as the distribution coefficient, the diffusion coefficient and the decay constant. Furthermore, it is different in hazard index such as the maximum permissible concentration. Accordingly, it is important to know the migration of each nuclide with fluid flow in the ground.

This paper presents the derivation of the nuclide transport equation, the coupled formulation of the nuclide decay equation in solid form and the nuclide transport equation in the ground by the finite element method, and the results of the basic numerical analysis.

The nuclide transport equation is derived assuming that the geological medium is a composite material which consists of fluid and solid phases, the nuclide transport is generally caused in fluids, the nuclide concentration in the fluids and solids is always in equilibrium and the ratio is expressed by the distribution coefficient.

Meanwhile, the Galerkin method is employed to derive the functional equation for nuclide transport. The one-dimensional element is then used in modeling nuclide transport in a fracture media, and it is linear or quadratic isoparametric element.

Some results of the numerical analysis compared with the analytical results are shown to be in good agreement. (G-5)

(25) In-Situ Stress Measurement by the Hydraulic Fracturing Method – Stresses Measured in the Boreholes 100m to 800m Deep –

Tsukahara, H. and Ikeda, R.

Proceedings of the Symposium on Rock Mechanics, 6th, pp. 367–372, 1984,

Hydraulic fracturing stress measurements have been made in boreholes of various depths; two of 100m, one of 250m, nine of 450m, one of 600m, and another of 800m, in the Kanto-Tokai area for the last seven years. About 80 sets of in-situ stresses have been obtained successfully from these 14 boreholes. The maximum and the minimum horizontal compressive stresses increase linearly with depth in each borehole. The difference between the maximum and the minimum principal stresses also increases with depth. The increase of the stress difference with depth is interpreted in terms of large stress relaxation in shallower parts in the boreholes where low confining pressure and many pre-existing microcracks are dominant. A plot of octahedral shear stresses of the in-situ stresses against the mean effective stresses suggests that stress relaxation because of anelastic deformation of the rocks has great effects on the crustal stress in the shallows. The maximum shear stress at the depth of 400m ranges from 1MPa to 8MPa depending on the site. However, it is not always the case that the regions of small shear stresses are inactive in microseismisity and crustal movement. The maximum compressive stress direction is obtained from detection of the fracture azimuth after the hydraulic fracturing. Stress direction measured at each borehole agrees well with that estimated from geologic and seismic methods near the measurement site. (G-1)

(26) Stress State of the Upper Crust in Western Japan Inferred from the Results of In-Situ Stress Measurements

Tanaka, Y. and Ikeda, R.

Proceedings of the Symposium on Rock Mechanics, 6th, pp. 373–378, 1984,

The project of crustal stress measurements formed by Kyoto University and the Research Group for Crustal Stress in Western Japan, started in-situ stress measurements for the purpose of the basic research on earthquake prediction in 1978 and have determined the three dimensional stress states at 13 points using the stress relief method at the borehole bottom mainly. The stress measurements for the earthquake prediction aim at clarifying the stress states in deep underground and estimating the degree of strain energy accumulated. At the first step, the stress states at many points need to be compared each other, eliminating the influence of topography and the artificial disturbance, and taking the difference of the depth at measuring points into account. The stress-depth relations are investigated based on the selected data, which were measured in the limited area, inner zone of Japanese island on the north side of Median Tectonic Line, and within the relatively stable period of time on earthquake activities. The probable relations between the maximum and minimum stress in the horizontal plane, σ_{h1} , σ_{h2} (MPa) respectively, which are expected to be under less influence of topography, and the depth H(m) are obtained as follows: $\sigma_{h1} = 2.5 + 0.029H$, $\sigma_{h2} = 1.0 + 0.020H$. These stress values at each measuring points in the same depth, 300m, making the correction according to these relations, are compared and found to be very similar except at few points. This result suggests that highly stressed districts and the disturbance by topography are possible be pointed out by this treatment. The directions of these stresses are also found to agree with those of focal mechanism solution of shallow earthquakes and principal strain obtained by geodetic surveys. The planes of maximum shear stresses derived from measured three dimensional stress states are projected to streographic net of lower hemisphere, considering the mode of failure caused by them. It is found that the measuring data are probable to include the topographical and artificial disturbances in the case of Normal Fault type, and that the derived fracture planes at each point are correspond to the strike of the neighbouring active faults in the central part of Kinki district.

(G-1)

(27) On the Measurement of Rock Stresses by Two Different Methods

Koizumi, S., Nishimatsu, Y., Koide, H. and Miyake, K.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 379–384, 1984,

In this paper, the authors report the result of rock stress measurements by the borehole deformation and hydrofracturing methods in the same boreholes, and discuss on the accuracy and error sources of the rock stress measurement.

The rock stresses in three dimensions are measured in the three boreholes drilled in three orthogonal directions, respectively, in a undeground gold mine, in Izu Penninsula.

In the measerement by borehole deformation method, the extension of borehole diameters caused by overcoring is measured with a borehole deformation gauge. The observed data are adjusted by the least square method, and the standard deviation is estimated.

The measurement by hydrofracturing method is conducted in the same boreholes after the measurement by borehole deformation method, and the crack reopening pressure and shut-in pressure are used to estimate the magnitude of rock stresses. The ring shaped core is recovered by overcoring after hydrofracturing and obeserved visually to clarify the hydraurically induced crack. The states of rock stress in three dimensions estimated by the two different methods are compared with each other, and evaluated from the viewpoints of plate-tectonics as well as measurement engineering.

It is indicated that the results of both measuring methods agree with each other in a reasonable range of deviation, and give an additional reasonable data to the present knowledge on the state of rock stress in Tokai district, Japan.

(G-1)

(28) Field Measurement of Stress and Property in Rock Ground at Salt Mine

Kikuchi, S. and Nakamura, T.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 385–390, 1984,

The salt mine of Domtar Chemicals Group, Sifto Salt Division, is located in the town of Goderich, Ontario, Canada. Its base is about 600m below the bottom of Lake Huron. The Goderich mine has abandoned the conventional mining method of room-and-pillar and adopted the time control technique of a Stress Control Method (SCM) mining pattern.

The time control technique of SCM called 3 or 4 room entry systems, is designed on the basis of the rock mechanics studied over the five years and of the analysis of the ground behavior utilized FEM which is considering viscoelastic and viscoplastic behavior of the ground (REM).

We report here about the abstract of SCM in the salt mine and results of borehole loading test in the field.

The results of test were compared with the prediction of the analysis using REM as to the behavior of the ground and the stress distribution surrounding the rooms. In-situ material properties utilized in REM for analysis of the stability of the room were determined by the tests. The measurement equipments in the field were a stressmeter S-100 and a propertymeter P-100 with eight pistons of 19mm diameter.

In the stress measurements, a secondary stress envelope surrounding the entire span of the 4 room entry and the stress distribution were agreed with the analysis by REM.

The computer run used mine models for REM with in-situ properties from the results of P-100 were conducted and compared with field data of measured room closure.

These results have generally good agreement, but involve a few problems in making analysis with respect to a long-term stability of the rooms and, as result, a little modification was required on mine models for REM.

We will establish the optimum design method for the underground cavities in Japan (involving tunnels), utilizing REM computer program with data from in-situ measurement systems.

(G-1)

(29) Proposal of a Calculation Method for the Strength Bearing Load on Tunnel Steel Arch Supports

Sakamoto, S., Oka, Y. and Matsumoto, Y.

Proceedings of the Japan Society of Civil Engineers, No. 317, pp. 1–13, 1982,

This paper proposes a calculating method for the strength bearing load on steel arch supports used for rock tunneling. This method gives the relations between their strength, the arch shape and size, as well as their strength and the cross-sectional size of a shape steel.

The generation of a passive load at the block point is mainly due to the fact that the deformation caused in the support by the active load is restricted on the rock ground side. By considering this fact, the basic equation for the determination of a passive load can be derived.

The authors assumed the mechanical conditions of the support ends and the joints of the tunnel steel arch supports, after considering the experimental results obtained by full scale tests in the laboratories of the Japanese National Railways and the Public Works Research Institute of the Ministry of Construction. Consequently, a method that can be used in practice for the purpose of calculating the strength, the deflection etc. of the support was obtained.

The authors have investigated the different influences regarding the strength of bearing load due to the arch shape and size, the cross-sectional size of a shape steel, the distribution of the active active loads and the many different mechanical conditions on the support according to the above mentioned method. The results to be emphasized are as follows:

In the case where the active loads distribute asymmetrically, the stress is considerably unfavorable. However, the passive loads are generated so that the total loads should become more like a symmetrical distribution. Thus, a more serious condition in stress, is prevented, though a perfect symmetrical distribution of the total load can never be obtained.

There are two ways of increasing the strength of bearing load on the supports. One way is to increase the cross-sectional size of the shape steel. The other way is to decrease the distance between the supports. Comparing the former with the latter on the effectiveness for the strength of bearing load, it can be said that the former is more effective than the latter when the active loads are distributed concentratively. However, it cannot be said that the former is more effective than the latter when the active loads are distributed symmetrically or asymmetrically. (G-4, H-5)

(30) An Evaluation Technique of Displacement Measurments in Tunnels

Sakurai, S.

Proceedings of the Japan Society of Civil Engineers, No. 317, pp. 89–100, 1982,

The author proposes a method for evaluating the stability of tunnels during construction. According to the proposed method, an evaluation of the stability of the opening can be carried out directly from the measured displacements without analyzing the stress distribution. The method is based on the concept of strain rather than stress at failure, so that it does not require any stress analysis.

Let us consider that the displacements are measured at several points in the surrounding media, a continuous displacement function can be assumed so as to interpolate the measurements among measurement points. The strain distribution can then be derived by taking derivatives of the displacement function considering the relevant kinematic relationships in continuum mechanics. Comparison of the derived strain with the allowable value of strain at failure makes it possible to assess the stability of the opening. If the derived strain tends to be greater than the allowable strain, an artificial support such as steel ribs as well as rock bolts and sprayed concrete must be added to achieve the stability of the opening. (G-4, H-5)

(31) Three Dimensional Model Tests on Tunnel Statics

Konda, T., Inokuma, A. and Ishimura, T.

Proceedings of the Japan Society of Civil Engineers, No. 322, pp. 89–100, 1982,

The redistribution of stress due to tunnel excavation is a three dimensional process. The stress around face changes with the advance of face. The authors investigated the earth pressure distribution around the face of tunnel by the scaled model test using sand. The tunnel excavation process was simulated in the test. The apparatus consists of a sand box, a lining model and small load cells. The lining model was pushed into the ground with the advance of face and the earth pressure on lining was measured by the load cells placed under the lining. Simultaneously, the change of the earth pressure around the face was measured by the load cells through the pressure plates prepared on the bottom of the apparatus in advance of the excavation.

The test results show that the situation of earth pressure distribution can be divided into four domains. The domain 1 remains in initial stress condition. The earth pressure in the domain 2 increases due to the influence of excavation but behaves elastically. The increased earth pressure decreases by the effect of the approaching face in the domain 3. The decreased earth pressure again increases by the constraint of the lining with the advance of face in domain 4.

The test results were compared with the theoretical calculation and relatively good agreement was obtained. And also, the influence of such parameters as the angle of friction, cohesion and the depth of tunnel on the earth pressure were discussed. (G-4)

(32) Coupled Stress Flow Analysis of Discontinuous Media by Finite Elements

Ohnishi, Y. and Ohtsu, H.

Proceedings of the Japan Society of Civil Engineers, No. 322, pp. 111–120, 1982,

The purpose of the present study is to develop a method for simultaneous solution of stress and flow in a deformable fractured porous medium where is saturated or unsaturated. A computer program has been developed by modifying existing consolidation programs to consider interactions between fractures (discontinuities) and porous medium when both flow and stress fields are coupled. The program can handle problems in rock masses where fractures extend from one boundary to another, intersect each other, or are isolated in the porous medium. It also capable of handling saturated and unsaturated flow problems in which the position of free surfaces can be determined. The region under investigation may be two dimensional or axially symmetric. Solutions can be obtained for either a steady-state flow field under static equilibrium or a non-steady flow field in conjunction with quasi-static equilibrium conditions. (G-2, G-5)

(33) Evaluation of Elastic and Damping Characteristics of Bed Rock by the Vibration Test of the Foundation

Ueshima, T., Hirata, K., Shiomi, S. and Watanabe, K.

Proceedings of the Japan Society of Civil Engineers, No. 329, pp. 13–26, 1983,

It is considered that field vibration test of the foundation has an important meaning in the following respects. One is to investigate the dynamic interaction characteristics of the actual ground-foundation system, another is to examine the applicability of the half-space theory or finite element analysis in the interaction problem. From this point of view, field vibration test of the foundation was carried out and the result was examined by half-space theory and finite element analysis.

A distinctive feature of the experiment is as follows. (1)The foundation used for the experiment was built on the bedrock of which the shear wave velocity is about 700m/s in surface layer. (2) Large-sized foundation(14m x 14m in plane, 7.3m in height, 3406t in weight) was made for vibration test which corresponds to the foundation of a large structure. (3) Small-sized foundation (4m x 4m in plane, 4.3m in height, 166t in weight) was also made nearby the large-sized foundation to examine the size effect. (4) For both foundations, vibrating force was varied and the influence of vibrating force on response was examined. Especially for large-sized foundation, rotating mass vibrator which generates maximum vibrating force of 150t was used.
(5) Besides the motion of the foundation, contact pressure distribution,

compressive strain and velocity of the bedrock under the foundation were measured.

As the result of numerical simulation, applicability of half-space theory on the bedrock was proved to some extent, but in this case, it was known important how to determine the "equivalent Vs". In the numerical simulation by F.E.M. (the name of the code is "BES-1"), the behaviors of both large-sized and small-sized foundations could be simulated with the same ground model after several times of trial. And applicability and validity of finite element analysis in the interaction problem were shown. (G-6)

(34) An Analysis of Tunnel Excavation by Limit Analysis Considering Strain Softening

Ishibashi, K. and Matsumoto, Y.

Proceedings of the Japan Society of Civil Engineers, No. 331, pp. 103–111, 1983,

It is widely known that the rock mass constructs an unstable linkages of rigid blocks or causes the separations of them in the ultimate fracture form. On the other hand, the rock materials show the strain softening characters under the low restraining stress conditions. In general, the earth depth constructing the underground structures is small. Therefore, it may safely be said that the rock mass lies under the conditions of low restraining stress.

The authors suggest the limit analysis method utilizing the RBSM (rigid body spring model) for the analysis of the rock mass behaviors. This analytical method enable to formulate the strain softening characters of isotropic homogeneous rock mass.

The rigid body elements are connected by springs on the boundary edges of elements. In the case of the plane element, three kinds of springs to restrain the normal, the tangential and the rotational relative displacement of the adjoining elements are considered. In the elastic region, the strain softening region and the flow region, the stress strain relation is approximated by the straight line, respectively. The characteristics of springs in the elastic region conform the Hook's law. In conformity with the plastic flow rule, the characteristics of springs in the plastic region are given. The Mohr-Coulomb's criterion is employed as the yield condition of the rock mass. We assumed that the rock mass is the material which cannot resist for the tensile stress above the selfstrength.

The model experiment was carried out and it is clarified that the results by this method agree well with the experimental results. Furthermore, the usefullness of this analytical method is revealed by some applications for tunnel excavation problems. (G-2, G-4)

(35) Application of Cundall's Discrete Block Method to Gravity Flow Analysis of Rock-Like Granular Materials

Kiyama, H. and Fujimura, H.

Proceedings of the Japan Society of Civil Engineers, No. 333, pp. 137–146, 1983,

A gravity flow of rock-like granular material may produce a large flow loading on a containing structure such as a bin, silo or bunker. The authors make some modifications on the distinct element method (DEM) proposed by Cundall and apply it to the flow analysis.

In order to treat a large number of particles in the flow analysis the element shape is simplified in a circle and all the expressions of DEM are rewriten for the circle element. The stiffness of contact-spring is rationally determined from the analytical solution of elastic contact of two cylinders.

A number of computer runs for different particle arrangements in a flat- bottom bin are carried out. It is observed that the particle arrangement governs the static pressure which varies from active to passive conditions at the initial filling as well as the flow pattern which alters from funnel to piping at the withdrawal flow, that the flow pattern affects the form and strength of arch and the probability of arching, and that the large flow loading (over pressure) occurs mostly at the formation and collapse of arching.

These characteristics of flow can explain well our experimental results in the past and it is recognized that the DEM is a promising tool for the flow analysis. (G-2)

(36) A Study of Seepage through Abutment of Dams

Kimura, K. and Ohne, Y.

Proceedings of the Japan Society of Civil Engineers, No. 336, pp. 95–103, 1983,

In recent years fill dams have been actively constructed even on pervious foundation or weathered bedrock. This consequently has provided dam engineers with some problems on the design and construction of fill dams, for example, instability of embankment and abutment foundation caused by roundabout seepage flow. It has been reported in some homogeneous dams that roundabout seepage flow led to abnormal rise of the phreatic surface in the downstream part of the dam, resulting in local slide due to the increase in pore water pressure. However, few attentions have been paid up to the present on the characteristics of roundabout seepage and its effect on the stability of fill dams.

In the present study, three dimensional roundabout seepage flow through abutment foundation which underlies beneath a center core dam with a cutoff wall is investigated by model tests and numerical computations by the finite element method. Some practically useful formulas are proposed through these investigations to obtain the quantity of seepage, the shape of surface of seepage and the shape of phreatic surface along cutoff wall. Also discussing is the applicability of two dimensional theoretical solutions for interpreting three dimensional characteristics of such flow. (G-5)

(37) Back Analysis of Displacement Measurement in Tunneling

Sakurai, S. and Takeuchi, K.

Proceedings of the Japan Society of Civil Engineers, No. 337, pp. 137–145, 1983,

The present paper deals with a method of back analysis to be utilized for the interpretation of field measurements in monitoring the stability of tunnels. The method belongs to an inverse approach based on the finite element formulation, assuming the ground media in which tunnels are excavated to be linear, isotropic and elastic. Assuming Poisson's ratio and the vertical initial stress, the method derives the complete initial state of stress and Young's modulus from a set of relative displacements measured between adjacent measuring points. In order to verify the mathematical sensitivity of the proposed method of back analysis, computer simulations are presented. (G-1, G-2)

(38) Fundamental Study on Unsteady Flow around Underground Cavern in Unconfined Groundwater

Sato, K. and Iizawa, M.

Proceedings of the Japan Society of Civil Engineers, No. 337, pp. 213–221, 1983,

The authors examine some fundamental characteristics and movement of groundwater around the cavern in unconfined rock aquifer by virtue of the numerical computation, and compare their results with those of experiments by Hele-Shaw model. By solving the finite difference equations derived from a set of governing equation and boundary conditions, the degression mechanism of seepage hydrograph into the cavern and the withdrawal process of free surface with time after the excavation of cavern are clarified. The over-relaxation method for solving the required finite difference equations is adopted.

It is proved that the degression curve of seepage flow rate with time can be expressed approximately by an exponential decreasing function of time and three degression stages including abruptly decreasing stage and constant stage at time elapsed enough are found in both experiment and numerical computation. Draw-down free surface and flow rate are much affected by anisotropy of rock aquifer. (G-5)*

(39) Analysis of Dynamic Strain around Rock Cavern and Earthquake Resistant Design

Hamada, M., Izumi, H., Iwano, M. and Shiba, Y.

Proceedings of the Japan Society of Civil Engineers, No. 341, pp. 197–205, 1984,

The authors analyzed the dynamic deformation of a circular cavern in semi-finite body by using elastic wave theory. It was established that the ratio of the dynamic strains in the lining to those in the rock caused by input waves was mostly constant, unaffected by the frequency or the wave length of the input waves. This result shows a good agreement with the result clarified by the earthquake observation conducted in a railway tunnel.

Furthermore, the authors proposed a mathematical model for the evaluation of the dynamic strain of rock caverns, based on the numerical results and the earthquake observation, and developed a rational procedure for the earthquake resistant design for the rock caverns of the underground nuclear power plant and the nuclear waste disposal field. (G-6, H-5)

(40) Experimental Study on Groundwater Motion around Underground Caverns

Ito, Y., Sato, K. and Shimizu, T.

Proceedings of the Japan Society of Civil Engineers, No. 342, pp. 97–106, 1984,

Numerous rock cavern are in use for the purpose of underground electric power stations, the fuel stock piling and the repository of radioactive nuclides. This paper studies the groundwater motion around the rock caverns. To make clear basic characteristics of flow in rock aquifer, many experiments concerning the degression of phreatic surface and discharge into cavern are carried out by Hele-Shaw model for various boundary conditions. For the sake of practical use the extention of experimental knowledge for field application is done by the aid of theoretical analyses in uniform rock masses. The theoretical results are, moreover, compared with those of experimental measurements. The validity in the present study is confirmed. (G-5)

(41) A Study of Stability around Underground Openings Excavated in Rock Mass Due to Storage of LNG

Inada, Y., Kitamura, S. and Okada, A.

Proceedings of the Japan Society of Civil Engineers, No. 343, pp. 35–44, 1984,

The demand for LNG,which has an important role as substitute energy for petroleum,has rapidly increased recently in Europe,America and Japan.

This is especially true in Japan,where by 1990 the import of LNG is expected to increase by a factor of 2.4 over what it was in 1983.

Reasons for this increase include the desire to stabilize energy prices and not to to increase the quantity of imported petroleum. The increase in LNG will focus attention on the problem of storage. To date,semi-underground tanks have generally been used for storage at -162°C. But,because the method requires a large area of reclaimed land for disaster prevention and because it is necessary to comply with recent sea pollution control regulations,this storage method is not the best for Japan,which has little available land. Thus,it is necessary to consider an alternative storage system.

When underground openings are excavated in a rock mass for storage of LNG, as it temperature is -162°C,steep temperature gradients and thermal stress occur around the openings. That is,the plastic zone and cracks around openings will expand with time.

This paper presents the results of consideration of theoretical analysis for the stability of underground openings excavated in rock mass for storage of LNG. (G-4)

(42) Computational Approach to Stability Analysis of Excavation in Rock Mass by Keyblock Method

Kawamoto, T. and Fujikawa, T.

Proceedings of the Japan Society of Civil Engineers, No. 346, pp. 47–55, 1984,

One of the significant problems occured in the excavation of hard rock mass is structural failure caused by falling or sliding of blocks defined by intersecting structural discontinuities. It is believed that it will be the effective method against structural failure to forecast the existence of keyblocks prior to the excavation, to search and then to support such keyblocks right after the excavation. This paper is to explain how to forecast the shape of keyblock and to calculate required supporting force by utilizing stereographic projection method of computerizing when the data of discontinuities in rock mass are obtained. (G-4)

(43) Design Study on a Geological Repository with Respect to Heat Generated from High Level Radioactive Waste Forms

Ishii, T., Utsugida, Y., Imazu, M. and Araya, S.

Proceedings of the Japan Society of Civil Engineers, No. 355, pp. 124–133, 1985,

The Geological Disposal is a method of isolating high level radioactive wastes in deep geological formations. Disposal tunnels at depth of 1 000 m were studied with respect to mechanical stability and seismic stability, and the layout of the repository was conceptually designed for efficient operations. After 30 yrs. cooling storage waste forms can be burried at intervals of 8 m, and after 100 yrs. they can be burried at intervals of 2 m. This paper has been presented in order to offer some considerations concerning heet generated from waste forms and to design a appropriate geological repository. (G-7)

(44) Seismic Resistance Evaluation Method for Foundation Ground of Nuclear Power Plant and for Civil Engineering Structures

A Seismic Design Working Group, Ground Integrity Subcommittee, Cimmittee of Civil Engineering Nuclear Power Faclities

Proceedings of the Japan Society of Civil Engineers, No. 356, pp. 11–24, 1985,

Standardization of seismic assessment has been studied on the structures of foundation ground, excavated slope behind the plant and out door fascilities of the nuclear power plant.

The national design criteria of whole structure of nuclear power plant has been authorized by the seismic standard of Japanese Government in which evaluation of seismic design force has been authorized.

Based on the seismic design force, this report presents the standardized method of seismic analyses of foundation, slope and burried conduit of nuclear power plant and evaluation of safety in several cases of Japanese seismic condition.

Design method is guided by the preliminary pseudo static analysis, subsequent static numerical analysis and consequent dynamic analysis. Degrees of safety is stepwise by required for these three analyses.

Seismic assessment is concerning with the seismic residual deformation and requires adequate degree of safety depending on the methods of analyses. (G-6)

(45) Evaluation of Stability of Underground Openings by Using Micro-Computers

Sakurai, S. and Shinji, M.

Proceedings of the Japan Society of Civil Engineers, No. 358, pp. 37–46, 1985,

This paper deals with a method of monitoring the stability of underground openings during the construction. The method is based on the interpretation of displacements measured in the field. The strain evaluated from measured displacements is compared with the critical strain of materials. If the occurring strain is still smaller than the critical strain, the stability of openings is guaranteed. Normalized initial stress is used for determining the strain distributions around the openings. Back analysis plays an important role for obtaining the normalized initial stress from measured displacements. In order to make a quick interpretation of field measurements, microcomputers are generally placed at construction site so that the back analysis can be performed right after taking measurements.

In this paper, the mathematical formulation of the back analysis for the use of microcomputers is shown together with some results of case studies. (G-4)

(46) Three Dimensional Elasto-Plastic Coupling Analysis of Tunnels by FE and BE Methods

Hisatake, M. and Ito, T.

Proceedings of the Japan Society of Civil Engineers, No. 358, pp. 77–84, 1985,

A method of coupling a boundary element method (BEM) with a finite element method (FEM) is developed to analyze three dimensional elasto-plastic problems of tunnels in infinite ground.

In the proposed method, FEM handles construction sequences and elasto-plastic behavior of the ground surrounding a tunnel, and BEM which is applied to the infinite elastic region takes into account boundary conditions at infinity.

By performing some coupling analyses, the following conclusions are obtained. (1) The coupling method is shown to be a reasonable one in the problems with infinite region. (2) Economical coupling analysis of tunnels can be performed by considering geometrical symmetry proposed here. (3) In an elasto-plastic coupling analysis, it is not necessary to make stiffness matrix of BEM region repeatedly. (4) Applicability of the coupling method to tunnel problems is confirmed. (G-4)

(47) Behavior of Semi-Underground Power Station by Near Field Strong Earthquake Observation

Komada, H., Hibino, S. and Egawa, K.

Proceedings of the Japan Society of Civil Engineers, No. 358, pp. 85–92, 1985,

The earthquake observation has been carried out at Ochiai semi-underground hydroelectric power station installed in a cylindrical pit of 15 m in diameter, 22 m in depth in rock mass in purpose of evaluating the earthquake resistance of semi-underground nuclear power plants. The behavior of the cylindrical pit has been analysed mainly by the observed seismic waves of the near field strong earthquakes, which happend in August, 1983. And some of the obtained results are as follows.

(1) Rations of subsurface maximum accelerations to surface maximum accelerations were almost in range from 1/2 to 1 in radial direction and 7/10~1 in vertical direction.

(2) The power spectrum in high frequency domain of more than 8 Hz in radial direction and more than 11 Hz in vertical direction decrease according to the depth from the ground surface. (G-6)

(48) Application of Distinct Element Method to Toppling Failure of Slopes

Ishida, T., Hibino, S., Kitahara, Y. and Asai, Y.

Proceedings of the Japan Society of Civil Engineers, No. 358, pp. 147–156, 1985,

Recently, the stability of slopes during earthquakes has become to be an important engineering problem, especially in case of the earthquake-proof design of nuclear power plants. But, for fissured rock slopes, some problems are remained unresolved, because they can not be treated as continua. The authors have been investigating toppling failure of slopes, from a point of view which regards a fissured rock mass as an assemblage of rigid blocks. DEM (Distinct Element Method) proposed by Cundall (1974) seems to be very helpful to such a investigation. So, in this paper, the applicability of DEM to toppling failure of slopes is examined through the comparison between DEM results and theoretical or experimental results using 3 simple models. (G-4)

(49) The Present Condition and Problems of a Land-Sliding Prevention

Watari, M.

Proceedings of the Japan Society of Civil Engineers, No. 361, pp. 21–27, 1985,

Recently rockslide which is one of types in landslide classification has been increasing significantly and most of them have been caused by many constructions, such as large-scale earth works, excavation of tunnels and impounded water by dams in Japan.

These facts indicates that a new explanation had to be added to current theory of landslide mechanism.

Deformation of slope caused by artificial loading and unloading increases strain in the mass and at the extreme condition, the strain accumulated in a certain stratum (probable slide surface) causes landslide.

Cause of this kind of landslide is recently being clarified to be triggered by gravitational creep of mountain slope, erosion in long term and artificial unloading short term.

Cyclic occurence of this movement deteriorates the mass from rock to finally detritus. This decreases the stability of slope and forms deformation at the same time, so-called topography of landslide.

As the movement of slide mass is activated, the permeability in the mass increases. The stability of slide mass decreases by rise up of ground water level and easy infiltration of rainfall.

It is quite important to interpret the topography of potential landslide area and to analyse their mechanism. (G-0)

(50) Prediction of Nonstationary Earthquake Motions on Rock Surface

Sugito, M. and Kameda, H.

Proceedings of the Japan Society of Civil Engineers, No. 362, pp. 149–159, 1985,

Nonstationary earthquake motion prediction models are proposed on the basis of rock surface-ground motion dataset. Ground motions on rock surface with the shear velocity of 600 ~700 m/sec are dealt with. The ninety-one components of acceleration time histories on rock surface level are arranged, which consist of (i) rock surface-ground motions estimated from the accelerograms recorded on alluvial and diluvial sites, (ii) rock surface-ground motions modified from bed rock ground motions, and (iii) ground motions recorded on rock surface. On the basis of this dataset, two earthquake motion prediction models are developed, one (EMP-IB Model), a prediction model for given magnitude and epicentral distance, and the other (EMP-IIB Model), an advanced model which deals with the effect of successive faulting and relative site locations on ground motion characteristics. (G-6)*

(51) A Study on Heat Conduction around Caverns

Sato, K. and Ito, Y.

Proceedings of the Japan Society of Civil Engineers, No. 363, pp. 97–106, 1985,

The caverns are of use for such various purposes as the electric power station, fuel stock piling and repository of exhausting materials. The present study deals with the heat conduction around the oil cavern and the canister for reposing the radioactive nuclides. The measurement of temperature is done by thermometer as well as the photographic observation due to Thermosensitive liquid-crystal-film in a laboratory. The experimental results are compared with several numerical calculations obtained from the modified Fluid in Cell method on the basis of a set of energy and groundwater equations. (G-7)

(52) Fundamental Study for Estimation of Initial Geo-Stress Using the Acoustic Emission

Ishibashi, K., Konagai, K., Mitarashi, Y. and Matsumoto, Y.

Proceedings of the Japan Society of Civil Engineers, No. 364, pp. 23–30, 1985,

In this paper, the authors deal with the correlation between the releasing stress level on the preceded stress-strain diagram and acoustic emission (AE) under the repetitional loading. Models of soft and hard rock were made with cement mortar and the specimens were loaded by a stiff testing machine. The AE count rate, the mean square of amplitude and the frequency of AE wave were employed as the AE parameter.

It was clarified that the point of inflection in the increasing section of the AE count rate curve corresponds with the maximum hysteresis strain at the pre-loading, and the region included the releasing point on the stress-strain curve can ascertain with the position of the peak on the AE count rate curve. Based on the above test results, a new estimating method of initial geo-stress was suggested. (G-1)

(53) Studies on the Parameters of Supports and Grounds for theTunnel Design Program
Tsuchiya, T.
Proceedings of the Japan Society of Civil Engineers, No. 364, pp. 31–40, 1985,

We studied about the input parameters of supports and grounds for the tunnel design program reported in previous proceedings, 346／Ⅲ-1. Creep tests of shotcrete in early stage of less than 1 week were done to decide equivalent modulus of elasticity. Tensile tests about ordinary bar and twisted bar clarified their characteristics, from which we find it appropriate to use the former for general tunnels and the latter for large deformation tunnel. Parameter studies of ground have been made comparing the measured and the calculated values of 12 tunnels, and therefrom it appears that initial lateral coefficient K_0 is strongly correlated to overburden H. Modification factor to modulus of elasticity was thus obtained for each class of ground. (G-4)

(54) Three-Dimensional Groundwater Analysis of Tunnel and Cavern in Fractured Rock Ground with Weathered Layer
Momota, H. and Sato, K.
Proceedings of the Japan Society of Civil Engineers, No. 364, pp. 41–50, 1985,

Until now, the quasi-three dimensional groundwater flow analysis has been used for many kinds of groundwater simulations in this country. However, to apply its computation method to the groundwater flow analysis for the tunnel and cavern in fractured rock masses is not available, because the discharges of both tunnel and cavern are unknown beforehand. In this paper, the authors proposed a new FEM technique for analyzing the flow around tunnel and cavern in fractured rock ground. The groundwater model is composed of some fractures and weathered layer on the rock ground, and the model can be applied to analyze the flow in both saturated and unsaturated aquifers under the assumption that the flow in weathered layer is subjected to the Dupuit's approximation. (G-5)

(55) Evaluation of Stalility of Excavated Jointed Rock Mass by Block Theory
Ohnishi, Y., Nagano, K. and Fujikawa, T.
Proceedings of the Japan Society of Civil Engineers, No. 364, pp. 209–218, 1985,

A number of analytical tools are available for engineering calculations involving excavations. These include numerical methods, physical model techniques and limit equilibrium analysis. Block theory is new and it uses the stereographic projection. It can be applied to analyze the three dimensional system of joints and other rock discontinuities to find the critical blocks of the rock mass when excavated along defined surfaces. This paper describes the way to find key blocks in the systems of joint networks and to support them by bolting or other suppoting methods. For a severly

jointed rock mass, an idea of a key block existing space which contains all key blocks in the excavated rock surface is proposed and it is used for determining the optimum support forces which stabilize such jointed rock mass.

(G-4)

(56) Model Study on Borehole Loading Test Applied to Jointed Rock

Tanimoto, C., Hata, S. and Kariya, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 6–10, 1982,

Borehole loading test is one of the simplified field measurements applied to boreholes with conventional size of 50 - 70 mm in diameter, and recently it has been widely developed for the reasons of its easy operation and low costs in feasibility study and preliminary investigation concerning underground foundation, widely spread fault and fractured zones and long tunnels with wide variation of geological and geometrical difficulties.

On the other hand, inspite of such wide applications the foundamental mechanism of loading in jointed rock is not yet clearly discussed. So this study was initiated for the purpose of analyzing the influence of joint spacing to defomation moduli obtained through borehole loading test.

These several years the authors have been carring out field tests and model tests in the laboratory by applying two different typed loading apparatus, that is the pressure-meter G - type for mobilizing uniform inner pressure in a borehole and KKT - 65 of jack loading for mobilizing uniform wall displacement locally.

In this paper the contents of model study and some relationships among joint spacing, applied load and resultant deformation moduli in comparison of the result obtained through field measurement in the tunnel project are mentioned.

Tests were carried out in the two types of geology, tuff and rhyolite, whose deformation moduli obtained by tri-axial tests in laboratory are $6 - 7 \times 10^3 MN/m^2$ and $30 \times 10^3 MN/m^2$ respectively. According to the result, the deformation modulus obtained by KKT shows approximately two times of the value by the pressure-meter. And it is considered both of that values were influenced somehow by the relaxation of rock. Through KKT gave reasonable result comparing with the variation of geology, the result by pressure-meter were considered strongly influenced by the degree of unevenness of borehole surface and not to agree with engineer's observation. Further discussion is required.

The result of deformability by KKT could be related very well with the joint frequency, which is defined by number of joints per meter. It is concluded that the deformation modulus for $n = 20$ is half of the one for $n = 0$ concerning rhyolite distributed Arima Area located 15 km north of Osaka, and this relation can be applied to evaluating the magnitude of convergence monitored in the nearby tunnel construction.

The dimension of the model ground provided for the laboratory tests is 40 cm x 40 cm square in horizontal plane, 37 cm in depth and the block in this dimension is set up in the cylindrical container made by steel with 25 mm thick. The four vertical surface of the test block are covered tightly by the flat jacks with the same area. The space between the outer surface of flat jacks and the container is filled with high strengthened mortar. Jointed rock mass to be tested is simulated by the assembly of plaster block,and the physical properties of block are : $3,620 MN/m^2$ for deformation modulus, 0.33 for Poisson's ratio, $10.9 MN/m^2$ for uni-axial compression strength. Three types of test block are prepared and I, II, and III type are corresponding to the cases of $n = 0$, 15, and 25 respectively.

From these laboratory tests, it is found that the models including joints behave as plastic bodies under low confining pressure, such as below $0.5 MN/m^2$, and under high confining pressure, such as $3 MN/m^2$, they behave as elastic bodies and have higher deformation moduli. The ratio of the former versus the later is approximately 2.0. Further it is clearly confirmed that the deformation modulus decreases when joint frequency increases as shown in Fig.8.

(G-3, G-4)

(57) Anisotropy of Deformation Property by Loading Directio of In Site Tests – In the Case of Weathered Granite –

Ishikawa, K. and Miyajima, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 16–20, 1982,

In this paper we describe the anisotropy of deformation property of different loading direction by in-situ test, in the case of weathered granite.

We carried out the plate loading tests in vertical direction and horizontal direction in the test pits and calculated the deformation modulus and tangential elastic modulus and then investigated the results of two different loading direction.

The summaries of results are followed.

1) In the case of heavy weathered rocks which have few cracks, the values of deformation modulus and the elastic modulus of different direction were different.

2) The anisotropy of deformation property was occured by the reason except the direction of cracks of rock masses. It seems that the direction of crack of rock masses doesn't affect the anisotropy of deformation property of loading direction.

3) One of the reasons is the effect of open stress or looseness by the drilling of test adits.
The degree of looseness of the side wall of test adit is larger than that of the bottom wall. Then, the ratio of both deformation modulus, Dh/Dv is smaller than 1.0.

4) Other reason is the effect of over burden pressure (initial confining pressure). In general, the confining pressure under the load plate, in the elastic state, of side wall is larger than that of bottom wall. And then, the ratio of both elastic modulus Eh/Ev is from 30% to 50% larger than 1.0.

5) Dh/Dv, the ratio of deformation modulus represents the degree of looseness effect of loading direction. Eh/Ev, the ratio of elastic modulus represents the degree of effect of over burden pressure.

6) Eh/Ev/Dh/Dv (= Eh/Dh/Ev/Dv) the ratio of deformation modulus and elastic modulus of each loading direction represent the degree of anisotropy of loading direction. In the case of weathered rocks it is between 2.5 and 1.0. The more the weathering goes, the larger it becomes.

7) In the case of weathered rocks, we must pay the attention to the anisotropy, which is the looseness and the over burden pressure, besides the direction property of crack of rock masses.

(G-2, G-3)

(58) Values of Ground Looseness in Loading Test on Soft Rocks

Jin, H., Morita, Y. and Haruta, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 21–25, 1982,

In insitu plate loading test the looseness in the surface zone below the loading plate is caused by drilling or facing etc. It influences largely the result of test with the rock materials in the surface zone.

Two cyclic bore hole loading test with 30cm diameter was carried out twelve times on the alternation of mudstone and sandstone called Kobe layer. As shown in Fig. 3 obtained load-settlement curve was concave in the 1st cycle, but it was straight or convex in the 2nd cycle. So the writers considered that the looseness was closed gradually in the 1st cycle and it was almost taken off in the 2nd cycle.

It was obtained that the result of load-settlement analysis by FEM coincided well with the measured value in the 1st cycle by reducing the modulus of deformation E in the surface zone 20~50% to that of fresh zone.

In fact the looseness of the rock ground happens in the excavation at the site construction work, but it little influences considering the ratio of similarity with the structure. If the result of such loading test applies in the deformation analysis of the actual structure, the settlement should be overestimated.

The modulus of deformation E in loosened zone should be measured in the actual test, but E_0 in fresh zone couldn't be measured before and it's too necessary for the analysis of deformation.

The device of SBP (Self-Boring Pressuremeter) and BLT (Bore-hole Loading Test) developed recently should be suitable to measure the modulus of defor mation E_0 in fresh zone.

(G-2, G-3, G-4)

(59) Behavior of Saturated Soft Rock Under Cyclic Loading in Triaxial Compression

Akai, K., Ohnishi, Y. and Yoshida, J.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 26–30, 1982,

Foundations of dam, road and bridge are subjected to cyclic loading caused by earthquakes, traffic, blasting, etc. The effects of cyclic loading on several different civil engineering materials such as steel, concrete and soil have been investigated by intensive researches. A typical phenomenon is so called cyclic fatigue in which a material fails at a stress level lower than its static strength. However, little work in this subject have been done in the area of rock mechanics. Some of the results are in uniaxial and in dry condition. The influences of combined stresses and pore water have been unknown.

According to Scholtz, cyclic fatigue may be caused by progressive dilatant creep plus additional damage produced bt the cycling itself. The former leads to a pronounced loading rate effect on fatigue, the latter to a complex effect of cyclic amplitude on fatigue.

The purpose of this paper is to examine a number of features of rock deformation and fracture that are not well observed in more conventional tests. Soft saturated porous rocks were selected for undrained triaxial tests in the research. Deformation, strength and behavior of pore water pressure under cyclic loading have been investigated. In addition, creep tests were conducted in order to know the relationship between creep, cyclic loading and more conventional constant strain rate or loading rate experiments.

(G-2, G-3)

(60) Distinct Element Method and Its Application to Rock Mechanics Problems

Ohnishi, Y., Tanimoto, C., Yoshioka, A. and Kariya, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 51–55, 1982,

Discontinuous rock masses can be analysed in either of two ways. The weakening and softening influence of the network of discontinuities can be accounted for implicity in calculations by modifying the strength and deformability properties assumed for a rock mass. Or, the actual properties of individual discontinuities can be introduced explicitly in the analysis.

Numerical methods have recently been used often for the remarkable progress of computer technology. Finite element method is most popular in this field. However, it basically depends on infinitesimal strain continuum theory and its extention to large displacement discontinuous media is not so easy.

Recently two discrete element methods which can take into account the large deformation during or after the failure of rock masses and structures were proposed by Cundall (1971) and Kawai (1978). In this study both methods have been evaluated. However, our main interest was to apply the Cundall method (Distinct Element Method: DEM) to rock mechanics problems.

DEM can model the behavior of assemblages of rock blocks and display this behavior on CRT screen. In this method, the computer calculates the displacements, rotations and interactions of the blocks as a function of time and generates failure surfaces in those area where instabilities exist. A failure plane developes naturally during the cource of the analysis. DEM differs from FEM in that as an instability develops the rock blocks are free to undergo large displacements and rotations. The blocks are allowed to separate if displacements and rotations so dictate.

In this paper, a brief review of DEM is presented and example problems such as stabilities of slopes and tunnels at the area of discontinuous rocks are solved to demonstrate the usefulness of this method. Original DEM program was modified to account for the influences of seepage flow and underground water pressure distribution.

(G-2, G-3, G-4)

(61) Analysis of the Fenner-Pacher Curve

Fukushima, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 56–60, 1982,

The reciprocal relationship between the required lining resistance and radial deformation of the cavity has been studied by R. Fenner and F. Pacher. The graph which demonstrates this relationship is called the ground reaction curve or Fenner-Pacher curve and this relationship is one of the most important factors of the New Austrian Tunnelling Method (N.A.T.M.).

However, this relationship has not been comprehensively studied quantitatively, so the author tried to do so, but could not discover the ascending portion of the curve with the elasto-plastic analysis of tunnel in the gravitational field. He, therefore tried to introduce the idea of loosening of the surrounding ground before the installation of supports.

After installation of supports, the re-compaction of the surrounding ground seems to occur, which produce a positive or inverted ground arch corresponding to the difference in the deformation of the tunnel lining and adjacent ground.

These phenomena appeared to be similar to that which occurs around a pipe culvert embedded in an embankment, so the author was helped by the Marston-Spangler's theory.

The Fenner-Pacher Curve was accordingly modified to a family of curves each is corresponding to the rate of the loosening. The author proposed that these new ideas can explain the several phenomena which hitherto have remained unexplained.

(G-2, G-3, G-4)

(62) Study of Strain around Tunnels Based on Experiments Using a Model

Gomi, M. and Higo, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 81–85, 1982,

This paper is intended to describe the results of experiments to measure the strain around tunnels using a model.

As regards the size of the model, a mortar plate of 2 × 2 m with a thickness of 20 cm was used. The compressive strength was approximately 80 kg/cm^2. The strain on the surface was measured by affixing a wire strain gauge to it.

Loading was carried out with two-directional loading equipment. According to the results of the experiments, the strain around tunnels showed the following characteristics for an R-radius.

1) When there are no supports, the strain ε_r in the direction of the radius is extremely small between 1 and 1.5R, drastically changing between 1.5 and 2R.

2) When there are supports, the strain ε_r in the direction of the radius shows a gradual increase between 1 and 1.5R. (G-4)

(63) Interpretation of Characteristic Line for Tunnel Stability

Tanimoto, C., Hata, S. and Kariya, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 86–90, 1982,

In the discussion on rational design of support system it is required to establish some characteristic lines which show the relationship between support load and deformation of the ground. The so called Fenner-Pacher Curve, showing a minimum point of support load, is one of the representative curves in NATM. Though many papers related to NATM have been published, it is pointed out that there are very few examples which were led from practical and concrete data concerning minimum support load. Also, the actual bearing ring to be mobilized around a tunnel which NATM aims necessarily is not well explained.

In this paper the authors introduced some representative characteristic lines proposed in the past, summarized deformation and its velocity observed tunnels in Europe, U.S. and Japan, classified support load to be expected in the construction procedure based on the empirical data concerning deformation velocity and analyzed the feasibility of support recommendation for tunnels in Japan which are subjected to difficult geological conditions.

For the practical use, the authors described the equations for analyzing strain-softening behavior around a circular opening, which were derived from strain energy theorem and Mohr-Coulomb's yield criteria for the initiation of strain softening and plastic flow in residual state. The parameters to be provided are 10 pieces as following:
radius of a circular opening (a); Young's modulus (E); Poisson's ratio (ν); unconfined compressive strength (q_u); angle of internal friction (ϕ); negative slope of deformation coefficient for softening zone (ω); hydrostatic initial stress (p_o); inner pressure acting on the wall of an opening corresponding support load (p_i), unconfined compressive strength at residual state (q'_u); and angle of internal friction at residual state (ϕ').
as a result, followings are obtained:
radius of elastic-softening boundary (R_1); radius of softening-flow boundary (R_2); ratio of R_1 to R_2 (S_1); ratio of R_2 to a (S_2); strains on the wall in tangential and radial directions (ε_t^* , ε_r^*); stresses on the wall in tangential and radial direction (σ_t^* , σ_r^*); and displacement of the wall in the radial direction (U_w).

By giving concrete figures we can establish the concrete characteristic line in case of tertiary mudstone showing expansive behavior, and it is possible to estimate minimum points of support on the characteristic line when the inner ring showing plastic flow may be considered to behave as fluid.

The following are concluded:
1) Concerning strain softening rock it is realized that there exist two points on a characteristic line showing minimum support load when allowable limit of strain induced to rock near the tunnel perimeter is determined and rock is subjected to plastic flow.
2) The relation between deformation velocity and support load can be classified as following: below 0.1 mm/day for slight; 0.1 - 1 mm/day for medium; 1 - 3 mm/day for heavy; 3 - 5 mm/day for very heavy; 5 - 10 mm/day for extremely heavy; and over 10 mm/day for exceptionally heavy. According to this, most of tunnels driven through 'Green Tuff region' in Japan show remarkably high deformation velocity, and specific support recommendation for them should be established. (G-4)

(64) A Mathematical Model of the Rock Pressure around Tunnel from the Rheological Point of View

Nishimatsu, Y. and Okubo, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 91–95, 1982,

The convergence of tunnel cross-section near the drifting face is dependent on both of the distance from the face and the time elapsed after excavation.

In order to evaluate the effect of stiffness of support as well as the time elapsed before support construction on the convergence of tunnel cross-section and the rock pressure on support, a two-dimensional theoretical model is proposed.

In this theoretical model, the effect of face wall on the convergence is evaluated as the convergence induced before support construction. Zenner model is assumed to express the rheological properties of the fractured zone around tunnel.

The result of numerical calculation of this theoretical model gives a time-dependent convergence curve similar to those observed in the field.

It is indicated that the effect of the time elapsed before support construction is more remarkable than the effect of support stiffness, on the convergence, and the radius of fractured zone increases gradually toward a final equilibrium state.

Furthermore, the authors show an example of Fenner-Pacher diagram obtained by means of this theoretical model, and discuss on the effect of rheological properties of fractured zone on this diagram.

(G-2, G-4)

(65) Large and Peculiar Shape Earth Tunnel Construction in Shallow Depth by the Vertical Anchor Method and NATM

Kimura, S., Nagai, T., Ueno, M. and Kondoh, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th pp. 96–100, 1982,

1. Vertical Anchor Method (VAM) and NATM

These methods were adopted to the special works where two different section of large scale river tunnel in Tama New Town met each other at an angle of 30 degrees.

Conditions of this construction are following:

1) Cross section of tunnel excavation; $84m^2 + 48m^2$, max. $160m^2$
2) Geology; 5m thick from the surface of the ground, and to the crown is alluvial deposit. The upper surface of tunnel excavation is loose sand formation, and the lower is firm.
3) Filling plan over about 10m thick is determined for New Town Development.

According to many difficult conditions, VAM was to be employed to prevent deformation and subsidence. Before the NATM excavation, numerous holes are bored reticulately until S.L. in vertical from ground surface, and poor mortar is poured into each hole, and then, single steel bar is inserted.

It has proved to be very effective for stability of tunnel face and decrease of deformation by regarding the actual results of mesurements.

Especially the result about axial force of anchor bolts is interesting by reason that gauges of pre-set bolts indicates before excavation. The result of turning over from compression before arrival of surface to tension side immediately after passing in every date of axial force, it is possible to consider transition of three dimensional stress around a cavity.

2. NATM in Shaft

NATM in Shaft is adopted for the first time in Japan for earth tunnel adjacent to shaft, 16m in depth, 11m in diameter. This method has many advantages of stability, economy, safety, goodness of working, and shortening of period.

(G-4, H-5, K-11)

(66) Newly Developed Friction Table Device Applied to Tunnel Stability

Tanimoto, C., Ohnishi, Y., Yamamoto, T. and Yoshioka, A.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 106–110, 1982,

The friction table devices, which can mobilize gravitational field, have been conveniently employed for the analysis of geotechnical problems,but through the application of conventional device, whose prototype was proposed by R.E.Goodman. We found that introducing lateral pressure to gravitational field gave very stable results,which are much more realistic in the analysis of underground opening in jointed rock. The magnitudes of gravitational and lateral load to be applied can be known by monitoring load acting to cantilevers, attached strain gauges on and by adjusting counter weights acting to both ends of movable flames. The dimensions and mechanism are described.

The following cases were discussed :

(1) Rectangular and circular openings : in the ground whose direction of predominant joint orientation is horizontal, with various span lengths.
(2) Rectangular and circular openings whose direction of joint orientation is at the inclination of 30°, 45°, 60° from the horizontal direction.

Two sizes of sugar cube were employed as model units whose dimensions are 18 x 18 x 19 and 14 x 14 x 15 in mm respectively and composing these units correspond to the states for joint frequencies of 55.6 and 71.4 per meter. Two formations are available in the forms of grid and zig-zag.

Through the model study by the improved device, which can give stable and visual solution, we conclude as follows :

(1) The relation between tunnel span length and the settlement of tunnel crown is proportional in case of a rectangular tunnel and parabolic in case of a circular opening to the tunnel span. And it was confirmed clearly that a circular tunnel is more stable than a rectangular one because of arching effect. Under the condition of fixing constant diameter there exists a certain specific joint spacing where an opening forms uniform arch action, judging from the concave curve showing the relation between settlement of crown and joint numbers. Consequently, the ratio of joint spacing to tunnel span length should be one of the important parameters determining deformability and stability of rock mass.

(2) The loosened zone near the tunnel crown is apt to shown rectangular shape for the case of grid formation and triangular for the case of zig-zag one. A height of loosening is nearly equal to the tunnel span when a ratio of lateral pressure to gravity field is less than 1.5. In general the loosened zone in the case of zig-zag formation is smaller than in the case of grid formation, approximately one third. The difference between various formations comes from the magnitude of dilation along joints. The former should be subjected to highest dilation and the latter should be lowest.

(3) Correlationship between crown settlement and lateral pressure is clearly recognized through our model study, and the lateral load should be considered one of the important parameters in analyzing tunnel stability in jointed rock.

(4) A key stone playes an important role in mobilizing confinement effect and in the model test the existence of some key stones at the crown and at spring line was confirmed. Thus, this model test should be also carried out for the purpose of finding the location of key blocks along the surface of an opening and of discussing appropriate size of blocks linked together with rockbolts in support recommendation.

(G-2, G-4)

(67) Field Measurement and Consideration on Deformability of Soft Sedimentary, Thin Overburden Soil in Tunnel Excavation

Terado, Y. and Kimura, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 111–115, 1982,

In designing and excavating for tunnel , it is the most important to understand deformability of mediums around tunnel. When excavating soft sedimentary , thin overburden soilground , we must know well about it to key operations safe and efficient.

We intended to grasp common characteristics when excavating a tunnel . This tunnel is excavated in soft sedimentary , thin overburden , cohesionless soil. Dimensions of supporting systems are minimized considerably.

Several kinds of field measurements were done with borehole—inclinometer and extensometer. In conclusion we can recognize as follows

1、An upheaval of ground surface in front of tunnel face occurs with the advance of excavation.
   It becomes 2~9 % of total settlement.
2、Supporting systems with shotcrete , steel—ribs , and rockbolts have an effect to limit a zone badly influenced by excavation. It may be in about 0.3 D above the crown and in about 0.3 D ahead of top heading , where D is equal to 10.7 m , which means a diameter of a cross section.
3、When making full use of an longitudinal arch effect of supporting systims , ground settlement is under the control of advancing top heading.
   A transverse range in 1~1.5 D from center is affected by excavation.
4、Thin as overburden is , if it is 10 m in thickness , a medium ahead and behind of top heading , above crown behaves as one body. But this quality is weak considerably in cohesionless soil.
5、Sudden relative displacement of a zone close above crown and ground surface occurs when top heading reaches .
   Afterwards it recovers in small quantities with the advance of excavation.
6、It is recognized that about 30% of total displacement at the crown occurs by the time top heading reaches and displacement is measured.

(G-2, G-3, G-4)

(68) Study on Rock Stress States in Japan Based on Measurements
Saito, T., Ishida, T., Tamai, A. and Tanaka, Y.
Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 116–120, 1982,

The authors have been carrying out in-situ rock stress measurements in the Japanese Islands at various opportunity. In this paper, a general view of the results at 18 points are shown, and the factors affecting these results are discussed.

The method of in-situ stress measurement is one of the stress relief method by using improved 'doorstopper' with 8 element gages which are developed by the authors and others. One of the advantage of this method is that three dimensional stress state can be determined with sigle bore hole.

Rock stress states are discussed with vertical stress component σ_V , maximum and minimum horizontal stress components, σ_{H1} , σ_{H2} respectively. At first, the variation of these stress components according to the depth are investigated. It is indicated that σ_V approximately corresponds to the overburden pressure and average value of horizontal stress σ_{Hav} in Japan tends to belong to the lower value group in comparison to that tendency of the world, in spite of the tectonically active region. The main factor which is concerned with the cause of σ_{H1} , is assumed to be different from that of σ_{H2} , because of the larger deviation and the different rate of increase with depth for σ_{H1} .

It is supposed that the initial rock stress have local characteristics in addition to that of depth. Trajectories of the maximum horizontal tectonic stress inferred from present-day crustal movements obtained by geodetic surveys are approximately agree with that of σ_{H1} . Therefore, σ_{H1} supposed to be related deeply with the tectonic stress.

Rock stress state in Japan can be roughly estimated according to the general tendency obtained. However, with respect to σ_{H1} , local characteristics should be taken into account. (G-2, G-4)

(69) Measurement of the Bedrock Behavior by the Large Cavern Opening at the Tanbara Underground Powerstation

Miyake, K., Horiguchi, J. and Nishiwaki, Y.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 121–125, 1982,

The depth of the Tanbara Underground Powerstation, which is sited mainly in hard conglomerate with few joints, is approximately 270m below surface.

It consists of two cavities, a machine hall cavity (49.4m high, 26.6m wide and 116.3m long) and an adjoining transformer hall cavity (16.5m high, 17.5m wide and 118.0m long). They are located in parallel and the distance between their side walls is 36m.

During excavating the caverns, we measured the bedrock deformation to confirm the stability of the caverns and the appropriateness of the supports and linings. To check the deformation of the surrounding rock, we measured the changes in properties, stress and displacement of the bedrock.

According to the results of these measurements, the following conclusions were obtained.

1) The bedrock behavior around the caverns during the opening is considered to have been caused mainly by the faults which existed in the vicinity of the caverns.
2) The bedrock deformation was small because the faults were few and small in size.
3) In regard to the bedrock displacement, we measured the absolute displacement as well as the relative one. The results of the measurements indicate that the bedrock displacement contains the bulge of the side walls and the displacement by the effects of mutual interference of the adjacent caverns. (G-2, G-3, G-4)

(70) Behaviour of Rock Masses around an Egg Shaped Cavern with Rock Bolts and Shotcrete

Hibino, S., Kanagawa, Y. and Inamoto, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 126–130, 1982,

Stability of a cavern depends mainly on such factors as magnitude of geo-stresses, strength of rock masses, size or shape of a cavern etc. As to the shape of a cavern, the authors have made it clear that an egg shaped cavern exceeds an ordinary mushroom shaped one in its stability by the numerical analysis method.

The Hokuriku electric power company has constructed a large egg shaped cavern for a power station for the first time in Japan. The authors, therefore, carried out forecasting of the behaviour of rock masses around the cavern during excavation by the numerical analysis method developed by one of the authors. Through the excavation, many kinds of measuring were performed including rock deformation, stresses in shotcrete, convergence of the cavern, forces in rock bolts etc. The followings are some results obtained.

(1) Set timing of rock bolts

Set timing of rock bolts has been prooved to be very important. Rock bolts of 3 m length were set in the early time just after the excavation of the arch gallery, and forces of which were 1300 - 3400 kgf/cm^2. Forces of 5 m rock bolts set after the following excavation of the arch part were, however, comparatively low values of 0 - 600 kgf/cm^2. This fact shows the set timing of rock bolts in the arch part should be as soon as possible.

(2) Length of rock bolts

From stress distributions in rock bolts, the 5 m length of rock bolts was found to be a suitable in the design for the cavern. The position of maximum stresses in rock bolts located in the middle part of rock bolts in case of 5 m length rock bolts. On the contrary, in case of 3 m length rock bolts, the position was at the bottom part of rock bolts. The former case of the distribution is desirable.

(3) Time history of settlement in the arch part rock foundation

Subsidence of the arch part of the cavern was very remarkable in the stage of the arch part excavation, and the value of additional settlement in the following stage of main part excavation were small. Delaying of setting time leads rock bolts to be not so effective.

(4) Distribution of settlement in arch art rock foundation

Settlements in the region between rock surface and 3 m inside rock mass were remarkable, and in the more inner part of rock mass the settlements scarcely occurred. From this fact, it would be concluded that the length of rock bolt should be longer than 3 m.

(5) Comparison between the analysis and the measuring

Rather good agreements were found in the distribution and the time history of the arch part settlements, which shows the analysis method being usefull.

(G-4, H-5, K-11)

(71) Effects of Discontinuities on the Smooth Blasting Contour Formation

Nakagawa, K., Sakamoto, T., Hashimoto, K. and Fukutani, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 131–135, 1982,

Since rock mass contains the geological discontinuities, it is required to clarify the effects of the discontinuities on the evenness of the smooth blasting contour. In order to simulate the propagation of blast cracks and the formation of smooth blasting contour in the rocks containing discontinuities, blasting tests were conducted by using concrete specimen which contains discontinuity plane.

Throughout the blasting tests, the following conclusions are summarized.

1. The blasted contour which connects the adjacent blast holes usually consists of blast cracks and pre-existing discontinuity plane.
2. When the blast hole is adjacent to the discontinuity plane, the cracks propagate radially from the blast hole and form a crater against the plane. When the blast

hole is distant from the plane, only one crack may propagate perpendicularly to it.
3. When the discontinuity plane is thin and the angle between the discontinuity plane and SB plane is nearly rectangle, the cracks joining the blast holes may be straight in spite of the presence of the discontinuity plane.
4. When the discontinuity plane is thick or the blast hole is adjacent to the plane, the blasted contour contains the pre-existing discontinuity plane.
5. The unevenness of the contour is governed not only by the thickness of the discontinuity plane and the spacing between the holes but also by the angle between the discontinuity plane and SB plane. (G-4, K-4)

(72) In-Situ Experiment on Characteristic of Shotcrete for Pressure Tunnel

Hakoshima, S., Kubota, K. and Kashiwayanagi, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 141–145, 1982,

Shotcrete which is the main supporting member of NATM is advantageous in terms of sharing the inner pressure with surrounding bedrock because of the good attaching. Thus, if pressure tunnels can be lined by only the shotcrete, construction of the tunnels will be advantageously achieved in both economic-wise and strength-wise. Along the said line, in-situ experiment has been performed and the behavior of the tunnel lined by shortcrete was analysed under conditions of inner and/or outer pressure.

The analysis resulted in indicating that shotcrete is effective as a lining for pressure tunnel. (G-4, K-11)

(73) Earth Pressure Determination of Shotcrete Tunnel Lining

Shinji, M. and Sakurai, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 151–155, 1982,

Earth pressures acting on a tunnel lining can be back-analyzed from the measured deformations of lining. This technique has already been well established as "Integrated Measuring Technique" for steel suport structures. An applicicability of the technique to shotcrete lining, however is still questionable, because of irregularity of the lining surfaces and complexity of the mechanical properties of shotcrete.

The objective of the present work is to verify an applicability of Integrated Measuring Technique to irregular shaped shotcrete tunnel linings.

It is concluded from computer simulations that the difficulties caused by the surface irregularity of shotcrete can be overcome by a smoothing method of the measuring data.

It is also shown that the realtime stress determination test proposed here has a good potential for determining stresses directly from strains without using any conventional stress-strain relationships stresses acting.

(G-4, K-11)

(74) On the Rock Pressure Measurements of the Shotcrete by Curvometer and Deformeter at NATM Tunnel

Kitagawa, S., Ohnuki, T., Kondoh, T. and Tsuchiya, H.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 156–160, 1982,

In order to construct tunnels economically and in stable condition, it is necessary to make stress and displacement of temporary supports keep under the allowable level of stabilities. For the construction of tunnels by NATM, the stress distributions besides deformation behaviors of the shotcretes with respect to the verification of stabilities of the primary supports will be of great importance.

Kovari proposed "Integrated Measuring Technique" as an efficient method for the stress determination of steel supports and concrete linings, and also developed "Curvometer and Deformeter" as convinient instruments for the stress evaluation. Based on Kovari's method, Sakurai proposed recently a technique for evaluating rock pressure working on the shotcrete in high precision.

This article describes an actual results of stress measurements of shotcrete carryed out at A- tunnel using Curvometer and Deformeter, and that the features of stress distribution obtained from the real data have a good correspondence with the characteristics of rock conditions and of the strain distribution of the surrounding rocks after excavation. The measurements were carryed out in the upper half section excavated through the weak mudstone of Tertiary age, which has the depth of 360m from the surface and the uniaxual compressive strength of around 40 kgf/cm². The tangential stress, the bending moment and the radial rock pressure of shotcrete arch grew remarkably bigger, up to 430 kgf/cm², 2.4 kgf/cm² and 22 kgf/cm² respectively, at the left side of tunnel than at the right side with the progress of the tunnel face. The strain distribution, maximum principal strain above all, also arose to maximum values up to 1 to 6 % in the surrounding rocks at the left side of the tunnel. Considering the strongly sheared faults at the left side of the tunnel, it is clear that the features of stress distribution of shotcrete depend significantly on the strain distribution around the tunnel.

According to the results, the proposed method by Kovari and Sakurai to determine rock pressure will have a good validity for the real shotcrete lining too. (G-4, K-11)

(75) A Method to Classify the Rock Conditions by Means of Drilling Cores — Rock Grade Classification for Engineering Purpose of Dam Foundations —

Kikuchi, K., Fujieda, Y., Kobayashi, T., Takeshita, Y., Shimizu, K. and Ono, M.
Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 6–10, 1983,

This paper prensents a new system of rock grade classification to be used for dam foundation engineerings. Paying attention to the conditions of rock cores obtained by drilling, two indices defined as below were used to study their relations to the rock grade classification.

$$RQD_{(N)} = \frac{L_N}{L} \qquad RCI = \frac{l_n}{n}$$

where $RQD_{(N)}$ = modified rock quality designation

L_N = total length of cores longer than N cm in L cm

N = optional length (cm)

L = unit length of core drilling; generally 100 cm

RCI = rock classification index

L_n = total length of cores from the longest core to the n th length core in L cm

n = optional number but 3 or less

The result of the study indicate that there are good correlationships between these indices and rock grade classification developed by visual inspection of rocks.

The relationship between RCI and elastic properties of rock mass obtained by borehole deformability test was also studied and a good correlation was obtained in this case too.

In the last analysis, the rock grade classification by means of drilling cores was summarized in the form of table for hard massive rocks. (G-0)

(76) Experimental Studies on Plastic Deformation Behavior of Soft Rocks

Yoshinaka, R. and Yamabe, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 46–50, 1983,

Triaxial compression tests under consolidated-drained condition were performed using many soft rocks in Japan. Plastic deformation properties of these soft rocks are examined, and compared with that of clays and hard rocks.

Main results obtained from the experiments are as follows:

1 Mechanical properties of soft rocks are greatly influenced by bonding strength.

2 Deformation behaviour of these soft rocks under high spherical stress, are quite different from that of normally consolidated clays.

3 Under monotonic loading condition, the shape of plastic potential can be considered to be ellipse.

4 Shearing process after loading history of spherical stress, are also influenced by bonding strength. (G-2)

(77) Creep Movement of a Crystalline Schist Slope and Its Cause

Sassa, K., Takei, A. and Marui, H.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 51–55, 1983,

There are many crystalline schist landslides in Japan. Their slopes are well disturbed by tectonic and landslide movement, their rocks are near the residual state, accordingly they move a little at heavy rains every year. Such a small annual movement is generally called as 'creep'. Observing its movement in detail by extensometers, its creep is divided in two categories, one is the usual landslide movement in a form of block surrounded by a comparatively clear shearing surface, another is a compressive creep over the whole slope quite different from the block movement. The authors reported the movement and the mechanism of the former block type movement in the referred papers. Then, this paper discusses the existence of the compressive creep and its probable cause.

The test field is a crystalline schist slope of 25-30 degrees in inclination, 1.2 km in length which is located in Shikoku island. About thirty extensometers are set completely continually from the top of the slope to its toe. The observation of extensometers in these nine years has detected usual block movements of Fig.4 and an unexpected compressive creep of Fig.5. The compressive movement over the whole slope (a long range) is out of the usual idea of landslide.
To examine the cause of its compressive creep, we performed the back analysis of the slope in use of Janbu method and investigated the co-relation between the annual movement and the annual precipitation & the yearly peak ground water level. These examinations have disclosed that a component of creep remains even in the year of almost half value of the average yearly precipitation, and also remains even in the year of the peak ground water level of 15 m below the highest, 10 m below the average of the yearly peal ground water level during 1974 - 1981, though the decrease of 7 m in the peak ground water level increases the safety factor by 20 % according to the back analysis of this slope. These facts suggest the existence of a creep component which can not be explained by the ordinary mechanism that pore pressure decreases the

shear resistance and sliding takes place along a surface.

The former researches of references have found that "underground erosion" is very active due to the high permeability and the steepness of slope, and active vertical subsidences take place. Observation of transported sediments in a drainage well which is sheared and a ground water path passes through it, recorded 1.3 kg in 1980, 1.1 kg in 1981 and 23.3 kg in 1982. Hence, we now suppose that the fall-off of fine particles by infiltration and their transportation along the ground water path increases the void in the ground layer, deformation proceeds filling the increasing void, and it appears in forms of subsidence and compressive creep discussed in this paper. It is illustrated in Fig.10, and its image is similar to the snow deposit on a slope which gradually subsides and creeps downward with its melting of snow crystals. So, it would be said that the deterioration (weathering, fall-off of fine particles and underground erosion) of the slope is not of a geological time scale, but it is working at present as the cause of creep which is sensed by the geophysical extensometer measurement of the ground surface. (G-4)

(78) Nonlinear Creep Properties of Rock

Akagi, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 56–60, 1983,

A series of uniaxial compressive creep tests under seven stress levels have been performed on cylindrical specimens of Kobe layer sandy tuffs in a room of constant temperature and moisture(19C 20C,80 85%). The magnitude of creep stresses are as follows;$0.1\sigma_s$,$0.2\sigma_s$,$0.32\sigma_s$,$0.46\sigma_s$,$0.56\sigma_s$,$0.61\sigma_s$ $0.72\sigma_s$,where σ_s is unconfined compressive strength and 72Mpa. Axial and hoop strains were measured by polyester strain gauges using an auto-digital-strainmeter and auto-timer.

The test results obtained as seven creep curves in Figure 1 were rearranged in other kind of figures which are the creep strain rate-time relations in Figure 2, the retardation spectra in Figure 3, the time dependency of nonlinear strain in Figure 4, the stress- strain curves at any times after loading in Figure 5, the time variation of Poisson's ratio in Figure 6, the stress dependency of recoverable strain and residual strain in Figure 7.

Throughout these results, the following conclusions are summarized.

1) The retardation spectra take three types of figure depending on the creep stress level,
   (1) an increasing type with time for high stress levels over $0.72\sigma_s$,
   (2) a flat type for middle stress levels of $0.56 \sim 0.61\sigma_s$,
   (3) a decreasing type for low stress levels below $0.46\sigma_s$.

It is suggested that an increasing type of spectrum appears for stationary creep, a flat type of spectrum correstponds to logarithmic creep which its process continues till infinite time, a decreasing type of spectrum means linear transient creep.

2) The creep stress and creep strain are linear relations up to a stress level of $0.46\sigma_s$ at any lapse of time.

3) These stress-strain relations for high stress levels over $0.56\sigma_s$ are nonlinear, and the degree of nonlinearity becomes remarkable with the lapse of time.

4) Althogh Poisson's ratio is independent of time up to $0.5\sigma_s$, it is remarkably increase with time under high stress levels over $0.61\sigma_s$.

In the results, the creep behavior of sandy tuff is classified to three regions depending on the creep stress levels,
   (1) a linear creep region under low stress below $0.46\sigma_s$,
   (2) a nonlinear creep region for the stress but which stable for the lapse of time,
   (3) a nonlinear creep region which the nonlinearity is variable with the lapse of time in spite of the stress is constant. (G-2)

(79) A Procedure for Three Dimensional Stress Determination by Hydraulic Fracturing

Mizuta, Y., Ogino, S. and Sano, O.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 116–120, 1983,

For the determination of in-situ stresses, hydraulic fracturing has an advantage over other stress measuring methods, in that it can be used at considerably greater depths from a point of access.

Dispite the increasing use of hydraulic fracturing, however, there are uncertainties associated with the interpretation of the resulting data. In particular, confidence in the calculated maximum principal stress is less than in the minimum principal stress, although the former is often of great moment. Furthermore, where the borehole axis is not parallel to principal stress direction, the interpretation of hydraulic fracturing data with respect to stress magnitudes and directions is unclear.

laboratory hydraulic fracturing of intact rock in biaxial compression was effected in order to investigate fracture extention under conditions in which the principal stresses were inclined to the axis of the pressurized borehole.

In-situ hydraulic fracturing of jointed rock was also carried out in order to investigate joint effect on fracture initiation direction and pressure-time relation.

Two typical fracture patterns were produced, which were able to occur at any borehole onclination.

One type of fracture, called here a "longitudinal" fracture initiated along the borehole axis bypassing the sealing elements, the fracture changing direction to become perpendicular to the minimum principal stress after bypassing the sealing elements. Re-opening such a fracture using low fluid injection rates leads to a stable flow established whereby fluid flows into the borehole beyond the sealing elements. For a given flow rate, the fluid pressure is proportional to the normal stress component perpendicular to the fracture, the pressure being scarcely affected by the remaining stress components. Numerical analysis, applying the concept of an hydraulic aperture, was employed to explain these facts.

The other type of fracture, called here a "transverse" fracture initiated across the sealed-off section. This fracture is perpendicular to the minimum principal stress and continued to extend in this plane, if it is produced in intact rock, suggesting that difference among principal stresses are relatively large.

Short sealed-off section, short sealing elements and rapid fluid injection may assist in producing a fracture of the first type.

The study suggests that the complete stress state in intact rock can be evaluated from tests on two fractures(longitudinal and transverase fractures) in a single borehole and the authors proposed a overall procedure for three dimensional stress determination, interpretating hydraulic fracturing data from the boreholes with different inclination. Hydraulic fracturing data from "transverse" fracture produced in jointed rock can be also utilized in the procedure.

In order to examine the accuracy of the method, example hydraulic fracturing data were considered and it is found that three dimensional stress state can be given with some accuracy.

Finally, outline of the hydraulic fracturing apparatus for the rock stress determination for the purpose of design of underground space, which the authors are now using, was shown.

(G-1)

(80) Crack Propagation Characteristics of Cracked Rock Media

Hamajima, R and Kusabuka, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 121–125, 1983,

Rock media usually have cracks and joints, and show the mechanical characteristics as an anisotropic body. Many numerical and experimental studies have been made on them. However the method of numerical analysis which can fully express the mechanical characteristics of anisotropic rock media having such discontinuities has not yet been developed. Recently the necessity of large excurvations has increased and the establishment of such an analysis method is urgent to clarify the mechanical behaviour of jointed and cracked rock media with strong anisotropy.

In this paper a experimental and numerical study was made on the models having several basic crack patterns in order to clarify the mechanical characteristics of based on the "rigid body spring models" proposed by Kawai. In these models it is assumed that the elements themselves are rigid and they are connected by two types of springs distributed over their interface boundaries. Using the Mohr-Coulomb's failure criterion and considering the effect of contact as well as separation on the two points of interface boundaries of each elements, the elasto-plastic analysis was carried out by basing on the initial stress method. It has been presented that calculated results for the stress distribution of jointed rock media were in fairly good agreement with the results of the photoelastic experiment and that it was considerably different from that of the compressed homogeneous continuous media.

In this study splitting tensile test and uniaxial compression test were carried out on gypsum models of cracked rock media, and this numerical analysis was examined with regard to the rock strength that changes due to the direction and distribution characteristics of cracks. In the splitting tensile test, cracks instantaneously propagate, while in the uniaxial compression test, they gradually propagate as the load increases. Further in a splitting tensile test on rock media having no cracks which was made to determine its tensile strength, the strength varied remarkably with the change of loading plate width. When the loading plate width is small, cracks occur at the loading point and when the width is large, cracks occur at the center of disc and propagate instantaneously all over the surface. It was made clear that this analysis method can comparatively well express the above-mentioned unstable crack propagation characteristics and gradual crack propagation characteristics of cracked rock media. (G-2)

(81) Inverse Problems in Rock Mechanics

Ohnishi, Y. and Higashide, A.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 131–135, 1983,

Mathematical models of groundwater flow or rock mass behavior have in the past decade evolved into powerful tools for studying the geotechnical problems. The well-known major impediment to wider use of such models is that the required distributions of system parameters are difficult to obtain. Usually the best available information is an approximate description of geometry of rock structures or aquifer and some arbitrarily distributed field measurement (observations) collected during fieled tests.

Local parameter values can be calculated by traditional methods only under the assumption of homogeneity. For an inhomogeneous medium, the distributed parameters are mostly obtained by a trial and error process, called "model calibration", in which an estimated set of parameters is succesively adjusted untill the model satisfactorily reproduces the observed field data.

Attention is being directed toward solving the inverse problem in the analysis of rock mechanics. The objective in the solving the inverse problem is to determine a set of parameters from a set of observed displacements. In the example of a tunnel convergence, the elastic modulus and poisson's ratio are set to the unknown parameters. Simplex method was introduced to optimize the solution.

Numerical method used in the research to solve the problem of tunnel convergence is Boundary Element Method. Several examples are shown to evaluate the identified parameters by inverse solutions. (G-0)

(82) Distinct Element Methods with Deformable Blocks

Ohnishi, Y., Abe, Y. and Nagano, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 136–140, 1983,

Numerical methods have recently been used often for the remarkable progress of computer technology. Finite Element Method is most popular in this field. However, it basically depends on infinitesimal strain continuum theory and its extension to large displacement discontinuous media is not so easy.

To portray adequately the response of jointed rock mass requires the correct modeling of the discontinuities, that is, the joints must have both normal and shear stiffness, the blocks defined by the joints must be free to undergo large displacements and rotations. A computer model which satisfies all of these criteria was presented by CUNDALL.

DEM can model the behavior of assemblages of rock blocks and display this behavior on CRT screen. In this method, the computer calculates the displacements, rotations and interactions of the blocks as a function of time and generates filure surfces in those area where instabilities exist.

In this paper, a brief review of DEM is presented an extension of DEM to take into account the deformability of blocks are explained. Simple deformation modes: volumetric and shear deformation: are superpositioned to calculte the deformation of rock blocks. A very simple is shown to demonstrate the function of DEM.

(G-6)

(83) Numerical Analysis of Shaft Excavated in Rock Slope

Obara, Y., Kyoya, T., Ichikawa, Y. and Kawamoto, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 141–145, 1983,

A shaft excavated in a rock slope is numerically simulated by finite elements. Treated models are three and two dimensional (two dimentional one is plane strain), and several mesh patterns are compared. The analyses are linear elastic, and local safety coefficients are checked assuming the Drucker-Prager's criterion for the three dimentional cases, and the Mohr-Coulomb's one for two dimensional cases. Major results obtained are as follows:

1. It is essential to estimate adequately the field of initial stress. For slopes, however, the guess is quite troublesome. If there exist no field data of initial stresses, it may be popular to employ results by finite elements calculated under body force effects. On that case, a nonlinear analysis is preferable, then dominated stresses parallel to the slope are obtained. If a elastic analysis will be inevitable, a large figure of Poisson's ratio should be used, that may account for some chronical tectonic effects.

2. Two dimensional analyses give us overestimated displacements, which result in an unexpected over-design.

(G-4)

(84) A Stress-Analysis about a Circular-Hole by the Finit Element Method and a Comparison of its Results with a Model-Test in Laboratory

Murakami, Y., Nakazawa, T. and Sezaki, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 146–149, 1983,

When a circular hole has been excavated in a homogeneous and isotropic rock mass under a unidirectional (vertical) field of compression, the stresses around the circular-hole have been analyzed by the finite element method. In this analysis, we have adopted the law of Coulomb-Mohr for a local yield criterion of element. We compared this result with the corresponding model-test that was carried out in laboratory, and in this paper, we will reveal the fact that the measurement of Valimue-Cell-Stresses which are based on volumetric strains is very usefull for the judgement of ground stability.

(G-1)

(85) A Study on Elasto-Plastic Analysis of Tunnel Consider in Face Advance

Sato, M. and Kamemura, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 150–154, 1983,

On a numerical analysis of tunnel stability, plane-strain condition in usually employed because of its practicality or less computational efforts. However, three-dimensional effects near the tunnel face can not disregard for the interpretation of support and excavation method.

In this paper, a technique to reflect three-dimensional effect of tunnel face on plane-strain analysis, is proposed. Elasto-plastic analysis under plane-strain condition using proposed method have been carride out. Results are comoared with results of axisymmetric analysis and they showed good agreement.

(G-4)

(86) Application of Distinct Element Method to Toppling Failure of Slopes

Ishida, T., Hibino, S., Kitahara, Y. and Asai, Y.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 160–164, 1983,

Recent years, the stability of slopes against earthquakes becomes to be an important engineering problem to be solved, especially in case of the earthquake-proof design of nuclear power plants. But, for fissured rock slopes, some unresolved problems are remained, because they can not be treated as continua. The authors have been investigating toppling failure of slopes, from a point of view which regards a fissured rock mass as an assembly of rigid blocks. DEM (Distinct Element Method) proposed by Cundall (1974) seems to be very helpful to such a investigation. So, in this paper, the potential applicability of DEM to toppling failure of slopes is examined through an example.

Fig. 5 shows the slope model of toppling failure, which is mentioned in this paper. It is assumed that a horizontal cable bolt is anchored in the base rock through the toe block.

The horizontal cable force which is required to make the slope stable has been calculated by means of the following 3 method;

(1) A fixed block is set as a vertex has a contact with the toe block at a point of 0.3 m high from the base. And, using DEM, the horizontal rebound force at this contact is seeked out and it is regarded as the cable force which is required.

(2) Instead of a fixed block, a constant horizontal force is loaded at the same point, during DEM caluculation. Through some trys and some errors, the minimum constant force which is required to make the slope stable is found, and it is regarded as the cable force.

(3) Using the limit equilibrium method proposed by Goodman and Bray (1976), the cable force is determined.

The results of these 3 methods is showed at Fig. 7. The tendency of (1) > (3) is the same result reported by Voegele (1978). The comparison between (2) to (1), or (2) to (3) is original in this paper. Especially, the result of (1) > (2) is interesting, because it means that the reinforcement before the fissured rock slope begins the toppling failure, which correspond to (2), requires the smaller cable force, or is cheaper than the reinforcement just after the slope has begun to move, which correspond to (1).

From the above results, it is clear that DEM can apply not only to examine the failure modes of fissured rock slopes, but also to estimate the amounts of reinforcements which is required. The application of these methods to the field problems seems to be the next step of our investigation.

(G-4)

(87) Some Consideration on the Seismic Stability of Large Slopes Surrounding the Nuclear Power Plant

Ito, H., Hibino, S. and Watanabe, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 165–169, 1983,

As a series of the research on the seismic stabilities of a large scale slope surrounding the nuclear power plant,large model tests in the laboratory and those numerical simulations, and analysis of stability evalution method are conducted and following discussions are done.

1) Comparison between the mechanical behaviours obtained by the static failure test(that is, inclination test) and dynamic failure test using the large shaking table.
2) Relation between an equivalent seismic coefficient obtained by static test and acceleration by dynamic test.
3) Correlation between static stability evalution method(conventional circular arc slip method, static non-linear F.E. analysis) and dynamic one(2-dimensional dynamic F.E. analysis).

Several results on above mentioned investigation are summarized as follow.

1) Paterns of dynamic failure and static failure of slope are considerably different. That is, it is evident that sliding surfaces of failure in static tests are considerably deep whereas the failured parts are limited only to subsurface at the top in all dynamic test.
2) The results of numerical simulation by static and dynamic analysis concerning the mechanical properties of material and the failure mode are qualitatively corresponded with the behaviour of model test.
3) From the results of static and dynamic stability analysis, it is concluded that the conventional circular arc slip method gives the severest evaluation for slope stability.
4) It is proposed that the seismic coefficient for static slope stability analysis should be used the value of the equivalent instant acceleration.

(G-4)

(88) Slope Stability Analysis by Using of the New Descrete Model (Kawai Model) (In Case of the Shallow Tunnel Excavation under the Slope Ground)

Yada, K., Takeuchi, N. and Kawai, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 170–174, 1983,

In case of the shallow tunnel excavation under the slope ground, the slope stability and the effect of the deviation force of the earth pressure acting to the tunnel are important factors for the design of it. This slope stability is dominated by the interaction between failure of tunnel and its own failure. Limit analysis is required for the calculation of the slipline with considering the loozing zone by excavating tunnel. The new descrete model proposed by Prof. Kawai (Institute of industrial Science, Tokyo University) is suitable for such a limit analysis. We try to analyze the stability by using of this new descrete model. Two stability analyses of shallow tunnel excavation are given in this paper. We have the results as follows,

(1) We can estimate the stability at arbitary point by Load-Displacement curve.
(2) This new descrete model can describe the slipline matched to the actual failure surface.
(3) It is easier to describe the condition of the faults and cracks.

(G-4)

(89) Distinct Element Method Simulation of Experiments on Collapse of Piled Mortar Blocks

Ishida, T., Hibino, S., Kitahara, Y., Ito, H. and Asai, Y.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 16–20, 1984,

Recently, the stability of slopes against earthquakes has become to be an important engineering problem, especially in case of the earthquake-proof design of nuclear power plants. But, for fissured rock slopes, some problems are remained unresolved, because they can not be treated as continua. The authors have been investigating toppling failure of slopes, from a point of view which regards a fissured rock mass as an assembly of rigid blocks. DEM (Distinct Element Method) proposed by Cundall (1974) seems to be very helpful to such a investigation. Last year (at the 15th this symposium), the authors examined about the potential applicability of DEM to toppling failure of slopes, through a numerical model. So, in this paper, with a view to investigate the further applicability of DEM, its simulations of some experiments on collapse of piled mortar blocks are reported.

Two types of the experiments, mentioned below, have been carried out, and its results are compared with DEM simulations.

(1) On a base block, 2 cm × 2 cm (10 cm in length) mortar blocks are piled as a pillar composed of from 1 to 10 blocks, and then the base block are inclined up to the angle at which sliding or toppling occurs. Fig. 4 shows the comparison among these experimental angles (open symbol), DEM results (closed symbol), and the results using a simple limit equilibrium method (solid line) diagramed at Fig. 3. These results are in fairly good coincidence each other as shown in Fig. 4.

(2) The same size 4 mortar blocks are piled on the base block, diagramed at Fig. 6. And then, the base block are inclined up to the angle of collapse. At this experiment, giving 3 frictional angle (ϕ_{AB}=35°:block-block contact, ϕ_{AB}=28°: inserted cellophane tape, ϕ_{AB}=18°:inserted Teflon tape) to AB plane, and always keeping block-block contact (ϕ_{AB}=35°) to the other plane, the rotating feature of block ④ has been observed. The experimental results on rotation of block ④ are the following: Rotation/Nonrotation = 12/8(ϕ_{AB}=35°), 15/5(28°), 2/18(18°), as shown at table 1. On the other hand, Fig. 7 shows DEM simulations in which ϕ_{AB}=35°, 30°, 25°, 20°, 15°, 10° for AB plane, and ϕ=35° for the other plane in all case. From this figure, it is clear that the block ④ rotates at the angle more than 25°, but it doesn't less than 20°. This DEM result coincides with the tendency of the experiments.

Through above 2 comparisons between DEM results and experiments, it seems that DEM gives the reasonable results for such collapse of piled mortar blocks. Considering that these problems may not be treated by the other numerical methods such as FEM and so on, DEM seems to be a very useful method for fissured rock slope analysis.

(G-0, G-4, G-6)

(90) A Study on the Stability Analysis of Rock Blocks Surrounded by Discontinious Planes

Sato, M. and Kamemura, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 21–25, 1984,

A Key Block, an unstable rock block in a discontinuos rock mass, sometimes plays an important role concerning the stability of underground opennings or rock slopes, as R.E. Goodman presented.

This paper explains the selective method of unstable rock block, and the method of a stability analysis.

For the porpose of instantaneous feed back of the results to the site engineer, mathematical algorism is used to select unstable block out of many blocks separated by some discontineous planes, such as faults, cracks, and bedding plane.

New technique related to the slidingsafety of the block is also discussed.

Several test models are examined and it is found that the proposed method gives lower safety rate than the conventional one.

(G-4, G-6)

(91) Slope Stability Analysis by Rigid Plastic Finite Element Method

Kobayashi, S., Tamura, T. and Sumi, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 26–30, 1984,

We investigate a numerical approach to analyze the limit state of the rock slope, assuming the mechanical property of rock is rigid plastic.

It is well known that the collapse analysis of the frame structure can be formulated as the linear programming problem through the upper bound theorem of plasticity. Recently this method was extended to continuum. Since the nonlinear programming problem must be treated in this case, no well-established technique is found out in the literature. And also there is a little theoretical confusion concerning the constraint conditions and the indeterminate pressure.

In this paper, we firstly formulate the problem by using the upper bound theorem and secondly show that the minimization of the upper bound is equivalent to finding out the equilibrium state with the indeterminate pressure. The present numerical procedure is illustrated by the typical problems, i.e., the shallow foundation and the slope stability. Good agreement between the present results and the well known solutions confirms that our approach can be used as a general method for the limit analysis of rock structure.

(G-4, G-6)

(92) New Applications of Distinct Element Method to Rock Mechanics

Ohnishi, Y., Abe, Y., Nagano, K. and Kono, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 31–35, 1984,

Numerical methods have recently been used often for the remarkable progress of computer technology. Finite Element method is most popular in this field. However, it basically depends on infinitesimal strain continuum theory and its extension to large displacement discontiuous media is not so easy.

To portray adequately the response of jointed rock mass requires the correct modelling of the discontinuities, that is the joints must have both normal and shear stiffness, the blocks defined by the joints must be free to undergo large displacements and rotations. A computer model which satisfies all of these criteria was presented by Cundall.

DEM can model the behavior of assemblages of rock blocks and display this behavior on CRT screen. In this method, the computer calculates the displacements, rotations and interactions of the blocks as a function of time and generates failure surfaces in those area where instabilities exist.

In this paper, two new applications of DEM to Rock Mechanics are explained; one for a slope stability problem in dynamic condition, the other for an underground excavation problem with a coupled FINITE ELEMENT-DISTINCT ELEMENT method.

Analysis of slope stability in the dynamic excitation is a direct application of DEM. We emphasize that the conventional satic stability analysis may underestimate the factor of safety in earthquake loading, so the dynamic analysis of discontinuous rock masses should be established by DEM urgently.

A coupled FINITE ELEMENT-DISTINCT ELEMENT method is very promising. It can handle the problems such that the large and infinitesimal deformation regions exist in the same rock mass. For example on the stability analysis of au underground opening, the area far from the opening or concrete lining may be modeled as a contiuum media by FEM. However, the loosened area around the opening should be modeled as discontinuous and it can be done by DEM. Here an example of the coupled FE-DE method is shown briefly.

(G-4, G-6)

(93) Analysis of Discontinuous Rock Mass

Hamajima, R., Yamashita, K. and Kusabuka, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 36–40, 1984,

Rock mass usually have cracks and joints, and show the mechanical characteristics as an anisotropic body. Many numerical and experimental studies have been made on them. However the method of numerical analysis which can fully express the mechanical characteristics of anisotropic rock mass having such discontinuities has not yet been developed. Recently the necessity of large excurvations has increased and the establishment of such an analysis method is urgent to clarify the mecanical behaviour of jointed and cracked rock media with strong anisotropy.

In this paper a numerical study was made on the models having several mesh types including random discretization. In this analysis based on the "rigid body spring models" proposed Kawai, it is assumed that the elements themselves are rigid and they are connected by two types of springs distributed over their interfase boundaries. Using the Mohr-Coulomb's failure criterion and considering the effect of contact as well as separation on the two points of interfase boundaries of each elements, the elasto-plastic analysis was carried out by basing on the initial stress method.

In this paper the following results were obtaind.

(1) Homogeneous and anisotropic mecanical characteristics of materials can be obtained by random or anisotropic discretization.

(2) Plane stress states of steel or gypsum can be calculated by using constitutive equation of Coulomb's type multiplied by amendment coefficient. (G-2)

(94) A Deformation Analysis Considering Water Flow and Heat Transport in Rock Mass

Sato, M. and Kamemura, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 46–50, 1984,

Rock deformation, groundwater flow and heat transfer through a rock mass are not indepndent phenomena.

In this paper, the interaction of these are treated as follows.

i) Rock deformation is affected by a loss of mass due to water flow and by a thermal expansion.

ii) Water flow is affected by rock deformation and thermal gradients.

iii) Heat transfer is influenced by water flow rate and heat due to rock deformation

A convective-disperson and three phase probrem are solved by means of Finite Element Method partly adopting Finite Defference technique, and explicit time integration scheme.

Satisfactory results are obtained from these simulation and it is shown that the method and physical modelling presented here are appropriate. (G-2, G-5, G-7)

(95) Groundwater Flow Analysis around Tunnel and Cavern by Means of FEM in Rock Ground

Momota, H. and Sato, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 51–55, 1984,

Untill now, the quasi—three dimensional groundwater flow analysis has been used for many kinds of groundwater simulations in this country. However, it is difficult to apply its computation method to the groundwater flow analysis on the tunnel and cavern having weathered layer above rock ground, because the discharges both tunnel and cavern are unknown beforehand. In this paper, the authors proposed a new FEM technique for analyzing the flow around tunnel and cavern in rock ground. The groundwater model is composed of some joints and weathered layer, and it is assumed that the flow in weathered layer is subjected to the Dupuit's flow. The model is able to apply for analyzing the flow in both saturated and unsaturated aquifers.

The validity of this analysis was confirmed by two computed results. (G-5)

(96) A Study on the Change of Pore Pressure around the Shaft Excavated in the Soft Rock

Ohtsu, H., Kamemura, K. and Shimo, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 56–60, 1984,

Mechanical and hydraulic behavior of rock mass due to tunnel excavation is very important because of its engineering impact. Recently mechanical behavior of rock mass has been taken up so far with the development of field measurement and numerical analysis. However, a study for hydraulic behavior of rock mass in this process seems insufficient.

In this paper we have examined in-situ test results around the shaft excavated in the soft rock and have compared them with the results of numerical analysis.

The followings are concluded.

1) Groundwater distribution around the shaft is fairly close to the results of three dimensional analysis.

2) The change of pore pressure due to shaft excavation in the soft rock is strongly affected by the stress change due to excavation. Especially that of pore pressure near the face is relatively small in the range of total change because of increase of mean principal stress σm. (G-5)

(97) Rock Hydraulic Analysis Based on Informations of Fractures

Ohnishi, Y. and Nishino, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 76–80, 1984,

The analysis of subsurface fluid flow is sometimes complicated by the fact that rock masses, especially at shallow depth may contain various systems of cracks or fracture surfaces. The rock mass can therefore be regarded as an assemblage of intact rock blocks that are separated by discontinuities. These discontinuities may be faults, joints, fissures, fractures,etc.

Although it has long been recognized that fractures plays a very important role in conducting fluids through rocks, attempts to study fratures and fracture systems on a quantitative basis have began recently.

In hydraulically modeling such a system, we usually model rock mass as a continuous porous media. But one of the important quastions that arises is whether or not the fracture network behaves like porous media. The purpose of this paper is to determine when a fracture system behaves as a porous medium and when it does, what is the appropriate permeability tensor for the medium. A two-dimensional fracture system model is developed. The density, size, orientation and location of fractures in an impermeable matrix are random variables in the model. Simulated flow tests through the models measure directional permeability, K_g. A polar coordinate plot of $1/\sqrt{K_g}$ will be an ellipse if medium behaves like a equivalent homogeneous medium.

Even if the fracture network behaves like porous medium, clear distinct faults or fractures should be recognized as a main conduits for fluid flow. In our approroach, combination of flow in the equivalent porous media for fine fractures and flow in the planar fractures that are discovered and have arbitrary orientations and variable apertures is considered and a numerical code has been developed to determine the hydraulic behavior of such discontinuous systems. (G-5)

(98) The Effect of Intermediate Principal Stress on the Sedimentary Rocks and Their Properties of Residual Strength

Takahashi, M., Koide, H. and Kinoshita, S.

Proceedings of the Symposium on Rock Mecahnics, JSCE, 16th, pp. 96–100, 1984,

The present experimental objective is to evaluate the effects of intermediate principal stress, which affects on the feature of ultimate strength and/or residual strength of the sedimentary rocks. The general stress states in rock samples were realized strictly by using a Mogi-type true triaxial compressional apparatus, in which the three principal stresses are independently controllable. Elastic wave velocities as well as strains were measured during loading. Following results are obtained:

1) The ultimate strength is increasing as the intermediate principal stress increases. This tendency called intermediate principal stress effect is sharply appeared at the low intermediate principal stress and becomes dominant with the increase of minimum principal stress.
2) Ductility is another parameter which affects the intermediate principal stress effect. It is more remarkable in the ductile state than the brittle one.
3) The following generalized Von Mises criterion proposed by Mogi(1971) correlates well the present results.

$$\tau_{oct}/C_o = a + b\{(\sigma_1+\sigma_3)/2C_o\}$$

where, τ_{oct}: octahedral shear stress

Co: uniaxitial compressive strength

a, b: constants

4) The intermediate principal stress affects little on the residual strength.
5) Most of the induced cracks, which are flat and oriented parallel to the intermediate principal stress axis, close after the fault formation. (G-1)

(99) Relationship between Overburden Pressure and Deformation Characteristics of Weathered Granite

Takabatake, Y., Tamura, H., Miyajima, K., Ishikawa, K. and Jyogasaki, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 101–105, 1984,

In-situ deformation characteristics of weathered granite distributed in Hakata-Oshima Bridge foundation were studied by pressuremeter test, plate loading test and velocity logging. Test results of various methods showed that measured deformation modulus of weathered granite of the same material properties increased in the direction of depth.

On the otherhand, deformation modulus by plate loading test on the excavated foundation rock have a tendency to reduce their inherent values before excavation. This tendency may be explained that deformation characteristics of weathered granite depend on confining pressure of the overburden.

Thus, it is necessary to consider the overburden pressure dependency on deformation modulus of weathered rock for comparison of these characteristics before and after excavation. (G-1, G-2)

(100) Variations in Engineering Properties of Class D Rock

Ohtuka, S., Noto, T. and Saito, Y.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 106–110, 1984,

Large variations were found in the strength and deformation characteristics of Class D rock. Although the strength and deformation of Class D (weak) rock is presently treated as uniform, the variations encountered by the authors are large enough that the distribution of strength is of engineering significance.

The variations were noticed in the course of both laboratory tests and in-situ pressuremeter tests. Specimens for the laboratory tests were taken from cores obtained with triple tube samplers. Variations in both types of test results are not a result of scatter in the test data. In fact the two types of tests show very similar results, and are generally in good agreement. (G-2)

(101) Study on the Input Parameters for NATMFEN Analysis

Tsuchiya, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 121–125, 1984,

Many kinds of FEM program have been already published for tunnel analysis. But, in any case, how to determine the input parameters is still remained one of the great problems, because of the complex behavior of the real ground which contains discontinuity and nonhomogeneity.

Using NATMFEM program which is developed for NATM tunnel analysis by Railway Technical Research Institute of J.N.R., the parametric studies on the twelve tunnels were carried out, based on the geological inspection results and the field measurement results. Four of them are earth tunnels, six are soft rock ones and two are hard rock ones. Tunnels under the special conditions such as tunnel in the swelling ground are not involved in these examples.

The conclusions of these studies are as follows.

(1) NATMFEM gives the reasonable predictions about upper half and lower half convergences, crown and surface settlements and rock bolt forces, by using the suitable lateral pressure coefficient Ko and initial deformation modulus Do.

(2) Ko value shows a tendency to change according to the overburden depth and becomes constant in the range deeper than 40 ∿ 50 M.

(3) The input parameters such as Do, C and ϕ, etc. have been established in accordance with the ground classification. (G-4)

(102) A Method of Estimating Mechanical Constants of Jointed Rocks

Chui, Z., Shimizu, N. and Sakurai, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 141–144, 1984,

This paper presents a method of estimating the mechanical constants of elastic modulus, shear strength and angle of internal friction of jointed rock masses. The method is based on the concept of " Critical strain ", which has been suggested by the third author, in addition to a reduction rate of elastic modulus from intact rock to in-situ rock masses.

The outline of the procedure of the method is as follows;

1) Determination of the critical strain of rock specimen by a uniaxial compressive test in the laboratory.
2) Estimation of a reduction rate of elastic modulus from intact rock to in-situ rock mass, considering the behaviour of joint system existing in rock masses.
3) Determination of the uniaxial strength of rock masses by following equation,

$$\sigma_{CR} = E_R \cdot \varepsilon_0 ,$$

where σ_{CR} is the uniaxial strength, E_R is elastic modulus of rock mass and ε_0 is the critical strain of rock mass being assumed to be equal to that of intact rock.

4) Estimation of shear strength c and angle of internal friction ϕ as,

$$c = \frac{\sigma_{CR}\ (1-\sin\phi)}{2\cos\phi}$$

where either c or ϕ must be assumed. The assumption of ϕ is preferable.

(G-3)

(103) Stress Measurements Made in Ductile and Brittle Grounds by Using Computalized Borehole Loading System

Kikuchi, S., Nakamura, T. and Serata, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 155–159, 1984,

Reliable and quick in-situ stress measurement is critically important in design and construction of major civil engineering structures in complex and weak grounds. In such ground conditions, the two conventional methods of stress measurement, namely hydrofracturing and overcoring methods are found to be not only impossible but also often misleading. To overcome this current deadrock, a borehole loading method of stress measurement has been developed as a practical field instrument for application to both ductile and brittle grounds regardless of presence of fractures, permeability of ground and orientation of principal stresses. The stressmeter consists of a plastic cylinder made for hydraulic loading up to 700kg/cm^2, contains four diametric sensors deployed radially at an equal angular interval of 45 degree. The sensors are capable of determining initiation of borehole wall fractures and their orientation. The loading pressure and diametric deformation are recorded automatically for immediate data processing at site.

The principle of the stress measurement method was first evaluated by finite element simulation analysis. Validity of the principle was further examined in laboratory testing by using a small scale laboratory model of the stressmeter probe placed in a borehole drilled through a cube specimen subjected to biaxial preloading. Volcanic rocks was used for the loboratory tests obtaining results closely relating to the computer simulation results.

The field stressmeter with a probe diameter of 99mm was first applied in a sandstone outcrop with little initial stress. The same stressmeter was further applied to brittle rock made of schist and ductile formations surrounding multiple room openings made in a salt mine at the depth of 550m.

Results of the measurement disclosed that it is possible to measure in-situ stress. (G-1)

(104) Method of Estimating Initial Rock Pressure by Acoustic Emission

Murayama, S., Michihiro, K., Saito, J., Fujiwara, T., Yoshioka, H. and Hata, K.
Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 160–164, 1984,

This paper describes the method of estimating the initial rock pressure of the rock mass using the Kaiser effect of acoustic emission in rock specimens. Firstly, the Kaiser effect in variously shaped rock specimens, i.e, cylindrical, prismatic and prismatic with haunch, were examined by applying cylic pre-load of 20-30 MPa and applying a virgin load of about two times greater than pre-load. As a result, the Kaiser effect of cylindrical rock specimen was confirmed as well as prismatic rock specimen.

Thereupon, the size and direction of the principal stress in a certain plane can be obtained by finding the initial rock pressure of three components and expressing these on Mohr's circle. A case study was conducted in which cylindrical granite specimens sampled from a face of IKOMA tunnel where the cover depth over tunnel is 260 m, were tested and the size and direction of principal stress at the cross section of the tunnel were estimated by using the Kaiser effect of accoustic emission. Obtained maximum principal stress σ_1 was 6.5 MPa, with the inclination of 17.9 degree in the counter-clockwise direction from the vertical axis of the tunnel and the minimum principal stress σ_2 was 1.6 MPa. These figures seemed to be reasonable from the view point of actual geographical condition of the tunnel.

Finally, it might be concluded that accoustic emission method mentioned in this paper is to be useful for estimating initial rock pressure. (G-1)

(105) Strain Relief Measurement in Hemi-Spherically Ended Borehole for Determining the Stresses in Rock Masses

Sugawara, K., Okamura, H., Obara, Y. and Kato, H.
Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 165–169, 1984,

This paper presents a new experimental method to determine the complete state of stress, measuring the strains on the hemi-spherical bottom surface of a single borehole with the stress relief technique.

In this method, the accuracy in the stress determined depends on the number of points of strain measurement on the bottom surface and on those disposition. To get the high accuracy, the arrangement of strain gauges on the bottom surface has been examined theoretically, basing on the distribution of elastic strain on the bottom surface obtained by F.E.M. analysis. As an available arrangement of strain gauges a circular one is proposed, in which the points of strain measurement are arranged symmetrically on a circle, of which the zenithal angle is 50 degrees from the center of hemi-spherical bottom. It has been concluded that the complete state of stress is able to be determined with a high accuracy by the circular arrangement above mentioned.

The observation equation to be used in practice to determine the complete state of stress in rock masses has been presented, which is defined the relation between the stress tensor and the strains on the bottom surface, 8 latitudinal and 8 longitudinal, in the case of the circular arrangement. To measure the 16 components of strain a mold-gauge has been made of epoxy resin. The calibration test of this mold-gauge has been done in appropriately oriented borehole in two rock specimens under load, and it is confirmed that the measured values of strain agree with the theoretical results within the exprimental errors.

The error in the stress determined has been estimated by analyzing the results of calibration test and it is clarified that the accuracy in the stress is higher than that expected in the conventional method, determining stress from variations in borehole diameter or the strain on the wall of a borehole. (G-1)

(106) Determination of In Situ Properties andTheir Distribution by Using New Property Meter

Kikuchi, S. and Serata, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 170–174, 1984,

A Borehole propertymeter device (P-100) has been developed, as a computerized field instrument, calibrated through laboratory tests and applied to various field conditions. P-100 has a cylindrical form containing a set of 8 loading pistons which are readily applied to borehole walls simultaneously, to obtain relation of piston loading and its penetration for the individual pistons at the same time. Field application was made at the ground of soft sedimentary strata at Yokohama. Results of the laboratory calibration and field test are presented disclosing the following observations.

(1) P-100 can be applied effectively in a wide range of earth materials from soft mudstone to hard granite.

(2) For hard rocks certain consistent linear relations are found between Young's modulus determined from uniaxial testing of laboratory specimens and elastic piston penetration modulus of borehole. Another similar relationship is found between uniaxial failure strength of laboratory specimens and piston penetration failure strength.

(3) Measurement in the field tests disclose not only material properties at the individual pistons but also their variation along the boreholes depicting the true nature of property distribution in situ. (G-1)

(107) Characteristics of Microtremor Observed at a Dam Foundation with Deposits

Ohmachi, T., Kataoka, S. and Soga, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 180–184, 1984,

It is known that earth and rockfill dams are adaptable to disadvantageous foundations such as uncemented deposits and soft rock. However, from a viewpoint of earthquake resistance of dams, there remain several important subjects still unclarified but required to be urgently solved for future dam construction. Among these are earthquake characteristics at such foundations and dynamic interactions of a dam-foundation system. On this basis, micro- tremor measurements were carried out on and beneath an existing large dam named Kassa Dam.

Kassa Dam is a center core rockfill dam with the maximum height of 90 m and the crest length of 487 m, forming an upper reservoir for a pumped storage power station which is located at about 2 km distant from the dam. Hard dacite (Da) is exposed over the entire right-bank side of the dam site, but on the left-bank side, uncemented deposits mainly of volcanic mud flows (Vm) thickly cover basement rock of the dacite, as shown in Fig. 1.

The measurements were done on summer fine days, using instruments having overall response characteristics shown in Fig. 2. Figs. 3 (a) and (b) give examples of horizontal displacement waveforms of microtremor observed at the left abutment, with Fourier spectra shown in Fig. 4 in which those for observed at the right abutment are also shown. The microtremors at both the abutments show significant differences in the specral shape, and the amplitude level at the left abutment is two or three times larger than that of the left abutment. A frequency component of 6.25 Hz is due to generation at the power station.

Similar measurements were done at different six observation stations simulatneously. The stations were selected at C1, C2 and C3 on the crest and G1, G2 and G3 in the inspection gallery for CG1-series, while C3, C4 and C5 on the crest and G1, G2 and G3 in the gallery for CG2-series which was measured at about three hours later than CG1-series. Fourier spectra of the horizontal displacements in the upstream-downstream direction are shown in Figs. 5 and 6 for which frequency components lower than 1.4 Hz were filtered away. The facts that overall vibration level in CG2 is almost twice as large as that in CG1, and that spectral shape is dissimilar to each other will imply non-stationarity of the microtremors at the foundation. In Fig. 5, three spectra at Sts. G1, G2 and G3 are similar in the shape with inequality in the level as G1>G2>G3, suggesting that the foundation was in a stationary state over a wide range of frequency during the observation. While in Fig.6, it should be noted that several peaks at frequency higher than 2 Hz visible at one station cannot be found at other stations in the gellery. Thus, rock foundation and deposits appear to be in a different vibration state, at least in a frequency range over 2 Hz.

The spectral amplitude are replotted in Figs. 6 and 7 as a ratio againt those at G3. The spectral ratios for C3/G3, G1/G3 and G2/G3 have somewhat similarity in the shape, which will imply that the deposits are likely to behave just like a portion of the embankment dam. A frequency component of 2.3 Hz included in the microtremor of the deposits seems to have induced a vibration mode of the dam corresponding to the frequency. Referring to the results of forced vibration tests and earthquake observations (Ref. 3), the fundmental period of the dam is arround 2 Hz. It is natural that higher modes should be readily induced by such difference in the foundation movement. Further study using numerical and experimental models of the dam-foundation system is required for more detailed quantitative analysis.

(G-6)

(108) Three Dimensional Back Analysis Method for a Tunnel

Hisatake, M., Ito, T. and Ota, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 185–189, 1984,

In this paper, three dimensional back analysis method is newly proposed for a tunnel in order to construct the tunnel safely and reasonably.

Mechanical constants of the ground around the tunnel, stresses which will be released at the excavation of the tunnel face and also stresses in the linings are determined three-dimensionally with only convergence data on the linings.

This approach presented here may be divided into two parts. In the first part, stresses, displacements and earth pressures of the linings are analyzed with convergence data, and in the second part unknowns on the ground are analyzed with the values obtained in the previous part.

By constituting a feedback system based on this method, it is possible not only to assess the tunnel stability but also to determine reasonably such executive conditions as linings thickness, excavation length etc.. (G-1, G-4)

(109) Three Dimensional Coupling of Boundary and Finite Element Methods and Its Application to Tunnel Problems

Hisatake, M., Ito, T. and Ueda, H.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 190–194, 1984,

A boundary element method(BEM) can reduce dimensions of system matrixes in comparing with those of FEM and also can take boundary conditions at infinity into account in a problem with an infinite region. Therefore, BEM is very efficient numerical tool for solving problems involving bulky three dimensional regions.

On the other hand, a finite element method(FEM), which can easily take anisotropy, non-lineality and non-uniformity into consideration, is very powerful method to solve problems which have finite regions. In FEM, however, discretisation of objective regions into finite elements is likely to cause the increase of amount of computer time and storage in some problems with bulky regions, especially in three dimensional problems, and this may severely limit the applicability of this method to some problems.

From the reasons mentioned above, it may be advantageous for some problems to use a coupling method of BEM and FEM.

In this paper, three dimensional elastic and viscoelastic coupling methods, which take geometric symmetry into account, are shown and are applied to a problem of a tunnel with linings and rock bolts. (G-4)

(110) Considerations on the Collapse in the Vicinity of Tunnels — Shallow Overburden —

Kimura, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 195–199, 1984,

A great number of shallow tunnels whose main support members are shotcrete and rockbolts have been excavated in Japan.We,tunnel engineers, still have deep concern for the failure of the tunnel structure and the collapse in the vicinity of tunnels.

It is frequently stressed that the field measurements are of great importance in order to judge that the tunnel is in safety.In this paper the key points in field measurements for safety of shallow tunnels are considered.

Judging from the centrifugal model studies in Cambridge University, Limit Analysis and the results of field measurements,we recognize that there are some fundamental patterns which are representative of the collapse in the vicinity of the shallow tunnel.As far as the bench cutting method is concerned they are as follows,

1. the collapse in the vicinity of the top heading (Fig.12)
2. the collapse in the vicinity of the lower face (Fig.13)
3. the collapse along the sides of the tunnel (Fig.14)

The processes of these collapses above-mentioned are predictable according to the results of the surface settlement and we can obtain the important informations about the collapse in the vicinity of the tunnel from the longitudinal and transversal curves of the surface settlement.

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(G-4)

(111) The Influence of Axial Pressure on the Yielding of Rock Mass around a Cylindrical Tunnel

Kobayashi, Y., Nishimura, M. and Ebisu, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 200–204, 1984,

Today, numerical methods such as the finite element method are mostly used for engineering and construction of a tunnel excavated in rock. Even simple analytical methods, however, may be sometimes helpful enough to obtain the conceptional behavior of the surrounding rock in parametric studies or to validate the predictions of finite element codes.

The purpose of this paper is to clarify the effect of the axial pressure on the surrounding rock of a tunnel with a circular section and to classify the types of stress distribution by yielding behavior of the rock.

For simplicity, the rock mass is assumed to be elastic-perfectly plastic and to obey the linear Mohr-Coulomb yield criterion as well as the associated flow rule of the theory of plasticity; hence dilation is included. It is also assumed that a rock behaves in accordance with the condition of plane strain and that the internal radial pressure decreases as the excavation of a tunnel proceeds.

The internal pressure decreases from the initial value, which is equal to that of the far-field radial pressure, to the final value of zero. As the internal pressure is decreasing, first the inner boundary of the tunnel starts yielding. There are three different modes and two other composite modes in this primary yielding stage depending on the relative magnitudes of the radial, tangential and axial stresses. As it is further decreasing, the inner boundary gets into the secondary yielding stage or starts changing the modes. The surrounding rock mass is, then, divided into three zones through the secondary yielding and the four different solutions are obtained. Thus, all the elasto-plastic analyses with these different yield modes give the complete stress, strain and displacement distributions. The variations in both primary and secondary yield pressures, plastic boundary radii, and tunnel closures are given in terms of changes in far-field rock pressure ratio.

It is studied from the results that the axial pressure is an essential factor in tunnel analyses and that it influences to a large extent the yielding behavior of the surrounding rock mass. (G-4)

(112) Dynamic Behaviours of Tunnel Lining for Upper-Half Due to Blasting of Bench Excavations

Takatani, T., Kitamura, Y. and Sakurai, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 205–209, 1984,

In the conventional tunnelling method of upper-half headings, few works concerning the vibration characteristics of linings for upper-half due to blasting have been done so far. The authors carried out the experiment of measuring the vibration of concrete linings for upper-half as well as the surrounding ground due to the blasting of bench excavations. The following results are obtained from the experiments.

> In the vicinity of blasting point, the particle velocity of the concrete lining is smaller than that of the ground, while both the velocities tend to be identical as a blasting point locates far away from the measuring points.

In order to analyze the problem theoretically, the authors assumed as a simple vibration model of linings a free rectangular plate resting on a semi-infinite elastic medium. The plate is excited by a harmonic vibration source locating underneath the plate. The following results were obtained from numerical analyses (FEM).

> The vertical displacements of the semi-infinite elastic medium become larger than those of the plate in the vicinity of excitation, while they tend to be the same to those of the plate as the vibration source locates far away from the reference points.

It is understood that these computer results can well demonstrate the experimental results. (G-4, G-6)

(113) Two and Three Dimensional Analysis of Rock Applied to Tunnel Excavation Using Ring-Cut Method

Kadota, S. and Ishii, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 210–214, 1984,

The stability of tunnel face is one of the important for tunnel excavation management. To obtain the stability of tunnel face, there are a lot of sub-construction methods, and suitable collections of these construction methods are available for the tunnel excavation management.

In this paper, the effect of sub-construction methods, especially ring-cut method, for the stability of tunnel face is discussed using two and three dimensional finite element analysis.

The results obtained are summarized as follows.

1) Practical two dimensional analysis is not available for the behaviour near tunnel face.

2) From three dimensional analysis, ring-cut method gives powerfull effect for the stability of tunnel face.

(G-4)

(114) Study of the Ground Deformation Resulting from Driving Tunnels

Gomi, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 215–219, 1984,

The relationship between the convergence value at a section of tunnel and its distance from the face are shown for various grounds like hard rock, sandy soil and cohesive ground together with the characteristics of the deformation line in each type of ground.

The following formula is suggested roughly to estimate the deformation in cohesive ground:

$$U = A \log (1 + L)$$

where U = deformation in meters

L = distance from the face in meters

A = primary coefficient

(G-2, G-4)

(115) Large Scale Model Tests on the Effects of Rock Bolts as Tunnel Support in Soft Rock (Part 2)

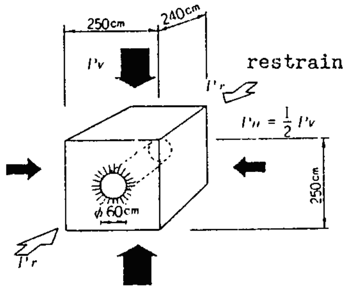
Tsuchiya, T., Yasuda, Y., Tazawa, Y. and Sudo, H.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 220–224, 1984,

For the purpose of studying the effects of rock bolts as tunnel support in soft rock, model tests using a large scale testing device have been carried out.

Artificial rock cubes of 2.5x2.5x2.5 m were made of bentonite mortar, and a bore hole (tunnel) of 60 cm in diameter was provided at the center of the cube. The hole thus achieved was 1/10 scaled of actual tunnel of 6 m in diameter. Around the circumference of the hole, rock bolts support of 20 cm or 40 cm in length and 12 or 24 in sectional installation number were employed.

Schematic view of the model and loading conditions are as shown in Fig. 1.



$K_0 = P_H/P_V = 0.5$

(Part 1 Test : $K_0 = 1.0$)

in which
K_0 : Coefficient of Lateral Pressure
P_H : Horizontal Load
P_V : Vertical Load

Fig. 1 Schematic View of the Model and Loading Conditions

From the experimental studies, the following results were obtained.

1. In the lower loading stage ($P_V \leqq 0.4$ MPa, 4.1 kgf/cm^2), convergence of the tunnel is approximately 0 %. In the range of $P_V > 0.6$ MPa (6.1 kgf/cm^2), failure of the sidewalls takes place by degrees and vertical convergence increases in comparison with horizontal one.
2. The stabilizing effects of rock bolts become operative in the range of $q_u/P_V \leqq 1.7$ (in which q_u : uniaxial compressive strength of the rock , $q_u \doteqdot 10$ kgf/cm^2).
3. Deformation behaviour and failure mode of the tunnel are significantly influenced by the supporting conditions such as length (L) and number (n) of rock bolts.
   In the case in which the total length of the rock bolts (L×n) is maintained constant, it seems to be very useful for improving their stabilizing effects to increase the number (n) of rock bolts.
4. With the increase of the load, the tension of the rock bolts installed at sidewalls increases, however,almost no increase is observed at crown and invert.
   On the basis of these experimental facts, it is conducted that the reduction of L and n of the rock bolts installed at crown and invert can be expected.

It should be recommended to advance continuous improvements and modifications on the evaluation of these results for a better performance in the actual applications.

(G-4)

(116) Three Dimensional Model Test on an Unlined Tunnel under Large Pressure of Overburden

Kanto, K. and Washizawa, E.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 225–229, 1984,

In order to verify the earth pressure phenomena around the vicinity of a tunnel excavated in large mass of overburden of soft ground , three dimensional model tests have been carried out .

This time , we try to separate the deformation around a tunnel into two parts ; one part is dependent on the distance from a tunnel face , and the other part is dependet on the time , and by using respectively equation (1) and (2)

$$u_e = C\,(\,1 - e^{-DL}\,) \qquad \cdots\cdots\cdots\cdots\cdots\cdots \quad (1)$$

where L is the distance from a tunnel face and C and D are constants.

$$u_c = \alpha'(\,1 - e^{-\beta' t}\,) \qquad \cdots\cdots\cdots\cdots\cdots\cdots \quad (2)$$

where t is the time and α' and β' are constants.

These constants what have been calculated are shown in the table 4 of the text.

(G-4)

(117) The Behaviour of the Wall between Double Tunnels
Seki, J. and Inoue, H.
Proceedings of the Symposium on Rock Mecahnics, JSCE, 16th, pp. 230–234, 1984,

This paper shows the behaviour of the wall between double tunnels. The double tunnels have been constructed in mudstone formation by N A T M, and the overburden is about 40 m. The tunnel diameter is about 6 m and the length of the double tunnels'section is 27 m. The width of the wall at S. L. varies from 0.24 m to 2.5 m gradually.

Mudstone is slightly hard (N - value is over 50), but sand layers in mudstone are very weak and bring with water seepage.

The results obtained by measurements are follows,

1) When the width of the wall at S. L. is over 1 m, the deformation of the precedent tunnel is not influenced by the excavation of the succeeding tunnel.
2) Most of load which increases by the succeeding tunnel excavation is supported by the shortcrete lining of the precedent tunnel.
3) If the stress concentration (σ / P) in the wall has been smaller than the ratio of the rock's compressive strength (qu) to the initial load ($P=\gamma \cdot h$), the wall has been safety enough.

(G-1, G-4, H-5)

(118) Field Measurements of the Upheaval Behaviors of the Ground in Front of the Tunnel Face with a Shallow Overburden during Excavation
Kanazawa, H., Kondoh, T. and Tsuchiya, H.
Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 235–239, 1984,

In the case of tunnel excavation in the shallow overburden, some upheaval behaviors of the ground surface are often found ahead of the tunnel face. The displacement behaviors by SLIDINGMICROMETER -ISETH. from the ground surface in vertical direction were obtained during the excavation of Kuromatsu tunnel and the upheaval deformation were observed just ahead of the tunnel face.

In this article, the authors propose a BEAM MODEL to explain the upheaval phenomena. The authors consider the ground formations to be seperated into two parts bounded on the horizontal plane through the tunnel crown. The upper parts are considered as a beam and the lower one as an elastic floor board.

As a result, the theoretical calculation based on the BEAM MODEL proposed by us will consequently show a good accordance to the upheaval phenomena of the ground just ahead of tunnel face during excavation.

(G-1, G-2, H-5)

(119) 3-Dimensional Ground Behavior at Tunnel Intersections
Takino, K., Yamada, N., Kimura, H. and Takeda, N.
Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 240–244, 1984,

On the Enasan Tunnel project phase II 2-lane highway tunnel of 8625m length, longitudinal flow ventilation system with vertical intake and outlet tunnels have been employed.

In order to apply the longitudinal flow ventilation system, it is necessary to install an underground ventilation room, electrical equipment room and dust collection room beside the main tunnel. These rooms are linked to the main tunnel by connecting tunnels, which have the same cross-section as the main tunnel. For connecting tunnel construction work, part of the already built main tunnel's supporting structure must be eliminated in the area where the connecting tunnel and main tunnel intersect, which will yield a cantilevered and extremely unstable state in the excavation of connecting tunnels.

This report outlines the reinforcing work executed prior to the construction in the intersection area, measurement implemented for safety, the results of these, and the method of numerical analysis considering 3-dimensional effects for the evaluation of measurement results.

(G-1, G-4, H-5)

(120) Tunnelling by NATM in Kamuikotan Metamorphic Belt (Adaptation of Back Analysis)

Irie, K., Chikahisa, H., Fukui, T., Yamada, T. and Watanabe, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 245–249, 1984,

INASATO Tunnel was drived in Slate and Serpentinite which belong to KAMUIKOTAN METAMORPHIC ROCK in HOKKAIDO. We show the tunnel behavior and their measurements as follows.

We developed a converse analysis method, considering the effects of supporting system. Tunnel displacements were measured. We applied our converse analysis method to the value of measured displacements and estimated initial stresses and elastic modulus of the ground.

We are able to classify the behavior of ground into certain groups comparing rockbolk strain with ground strain.

As a conclusion, we will study adaptation of our method to field measurements.

We believe that this method is also useful for the analysis of other fields.

(G-1, G-4)

(121) A Consideration on the Displacement Surround Tunnel during the Excavation by NATM

Kobayashi, S., Takada, M., Kondoh, T. and Tsuchiya, H.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 250–254, 1984,

The field measurements were executed to get deformations and stresses induced on the rockbolts surrounding rocks during the excavation of Shin-Usami tunnel of which rocks consists of the altered andesite of tertiary age ,which was excavated by NATM with very short bench of 4m.

The measurements of deformations surrounding rocks were executed by extensometers from the tunnel wall in 8 directions and by inclinometers from the ground surface in vertical direction. Fromthe actual results of displacement, the ratio of displacement obtained by extensometer from the tunnel wall against from the ground surface shows a remarkable difference according to the direction of displacement measurements.

In order to compare the deformation behaviors obtained from the actual results to the theoretical ones, a numerical analysis by FEM are put into practice considering the partition of tunnel face consisting the bench section and the full section. In this article , the authors show that the actual behaviors of surrounding tunnel will be similar to the theoretical one.

As a conclusion , the ratio of displacement appeared at the time that the tunnel face arrived at the measuring section against the total displacement during tunnel excavation obtained by the measuring apparatus from the ground surface will not show the same values according to the measuring directions. (G-4)

(122) Experimental Study on Estimation of Vibration Level

Nakagawa, K., Miura, F., Kunimatsu, S., Chuman, M. and Harada, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 255–259, 1984,

This study aims to find a rational method to reduce the level of vibration in pre-blasting. The vibration level (VL, unit is dB) is used to express the intensity of the blasting vibration here in stead of the peak particle velocity. It is regarded that pre-blasting is made up of a series of single-shot-blastings (SSB) with time delay, namely, delay-blasting (DB) in this study. Experiments were carried out to obtain vibration waves from both SSB and DB.

First, attenuation of VL with distance from the source to the observation stations was estimated and compared with that of the peak acceleration for SSB waves. The attenuation factor of the VL was about one-sixth of that of the peak acceleration. This low attenuation of the VL is attributed to the fact that the duration time increases as the distance increases.

As VL of the DB vibration depends on the time delay of SSB, it will be reduced by controlling the time delay. The dependency of VL on the time delay was examined by the artificial DB waves (ADB waves). ADB waves were made by superposing SSB waves with the same time delays as those of the experimentally obtained DB waves (EDB waves). The validity of the ADB wave was checked by comparing the wave form with that of the EDB wave. These two wave forms resembled closely each other. Finally, VLs were computed from ADB waves by parametrically changing the time delay from 20 to 200 ms. The relationship between VL and the time delay was discussed and it was found that the longer the time delay the lower the VL. (G-6)

(123) The Mechanisims and Effects of Notched Blast Hole Technique and Guide Hole Technique on the Smooth Blasting Contour Formation

Nakagawa, K., Nishida, T., Ono, Y. and Moriya, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 260–264, 1984,

Underground drill and blast excavation is usually accomplished with small diameter holes loaded with high energy explosives. This causes several undesirable effects as overbreak at the perimeter and damage to or loosening of the remaining rock at the perimeter.

Modified drilling techniques, notched blast hole technique and guide hole technique, are sometimes employed in smooth blasting to minimize these effects. Model blast tests were conducted in order to simulate the propagation of cracks from the blast holes with notch or with guide hole. Through the tests, the following conclusions are summarized.

1. When the blast hole is blasted with high explosive, a lot of cracks propagate from the hole. The crack initiated from the notch tip is not extremely long comparing with other cracks.
2. By the blasting with high explosive, the shock wave creates cracks from the guide hole when it passes through the hole. This crack connects with the crack from the blast hole and they form a part of the blast contour along the expected line.
3. When the blast hole is blasted with low explosive, the shock wave level is not sufficient to create cracks from the guide hole. Then the guide hole is of no use in the blast contour formation.
4. When a notched blast hole is blasted with low explosive, only the crack from the notch tip may initiate from the blast hole. The blast contour is formed along the expected line.

(G-0, K-4)

(131) Estimation of the Vibration Level of the Delay-Blasting

Kunimatsu, S., Nakagawa, K. and Miura, F.

Proceedings of the Symposium on Rock Mecahnics, JSCE, 17th, pp. 116–120, 1985,

Recently, there is a tendency that the blasting vibration is regulated by the vibration level from a point of the vibration pollution. The vibration level must be measured by the vibration level meter that satisfies JIS. On the other hand, the time delay in the delay-blasting is considered to have relation to the level. This study aims to clarify the effect of the time delay on the level and to find the relationship between the delay and the reduction of the level.

First, we made researches on the vibration level meter, and approximated its characteristic with a electric circuit that can be calculated numerically. Namely, we developed a computer program which could simulate the response of the level meter.

Second, using the simulation program, we investigated the effect of the time delay on the level with model waves of intermittent sine wave. Parameters of the model waves are frequency, duration time(Td) and time delay(Ti). We also introduce a new parameter Tr defined as Tr=Ti/Td. Intermittent sine wave becomes continuous sine wave at Tr=1. We treat only model waves of Tr>1. Therefore, vibration level has the maximum value at Tr=1. The relationship between the reduction of the level and the time delay was discussed and it was found that the longer the time delay the larger the reduction. The relation is given by the following equation:

$$VLd=(-0.013 \times Td+8.975) \times \log(1/Tr)$$

where, the VLd is the difference of the level at Tr≧1 from that at Tr=1. VLds are 7-8dB at Tr=10.

Next, the same results were obtained from observed blasting accelerograms. The difference between the results from model waves using the above equation and those from observed waves is under 0.7dB. This confirms that the above equation can be used when VLd is estimated.

(G-6)

(132) Behavior of Underground Tunnel and around Rock Mass against Blasting Vibration

Honsho, S., Komada, H., Hibino, S., Fujita, S. and Okifuji, A.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 121–125, 1985,

Blasting vibration measurements and analysis on behavior of underground tunnel have been carried out, for the purpose of simulating the behavior of a cavern in case of earthquake. The tunnel is excavated in tertiary pyroclastic rocks, having the size of about 11 m in diameter, and the blasting charge amount was 50 ~ 800 kg, with the distance of 150 ~ 500 m from tunnel. Main obtained results are as follows.

1) Maximum acceleration and velocity of vibration measured are about 80 gal and 0.7 kine respectively. Supposing the relation,

$$Acc. = K \cdot Q^A \cdot L^B \quad (Q : \text{charge amount} \quad L : \text{distance})$$

coefficient A was obtained to be 0.45 ~ 0.50, B: -1.4 ~ -2.1.

2) Analysing the particle motion around tunnel, the blasting vibrations are seemed to be the sequence of P-wave and SH- or SV-wave.

3) The dominant frequency of vibration are 7 ~ 30 Hz, and the wave length are supposed to be 60 ~ 260 m for P-wave. It means that the behavior of tunnel against blasting vibration may be not so irregular at each side in the tunnel. This was confirmed through the analysis comparing the strain at tunnel li ing and the relative displacement of both side in the tunnel, as the time sequence deformation. (G-6)

(133) Seismic Behavior of a Rock Tunnel — Principal Axes and Three Components of Observed Waves —

Yamaguchi, Y., Tsujita, M., Wakita, K. and Arai, N.

Proceedings of the Symposium on Rock Mecahnics, JSCE, 17th, pp. 126–130, 1985,

In recent years, new type of structures such as underground nuclear power stations, storage caverns for low level radioactive nuclear waste disposal, or oil storage caverns have been planned.

In Japan, for these structures which are to be constructed in the seismic region, reliable seismic design should be achieved based on the observed data.

In order to investigate the behavior of a rock cavern when it is subjected to an earthquake, earthquake observations have been carried out in the Shin Usami Tunnel of JNR's Ito Line, located in Ito City of Shizuoka prefecture.

Seismic Behavior of a rock cavern is dominated by the properties of the three components of an earthquake which propagates through the rock around the cavern. In this report, these properties were investigated through the analyses of the principal axes and the correlation among three components of the observed waves. From the investigation, the following results were obtained.

① The direction of principal axes tends to change remarkably during the time of an earthquake. And observed values tend to scatter remarkably around the maximum principal axis.

② The correlation among three components of the observed waves is very low judging from the crosscorrelation and particle orbits. From these facts, three components of the earthquake in the rock may not be influenced by any specific direction.

③ In the rock around the cavern, phase lag between earthquake waves at any points is small. (G-6)

(134) Rock Slope Protection of Toppling Failure in Terms of Optimum Bolt Angles by Physical Modelings

Deeswasmongkol, N. and Sakurai, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 136–140, 1985,

This paper presents some results of rock slope simulation of toppling failures of varying degree of density of joints and of different joint patterns in relation to optimum bolt angles to be installed on slope for best and effective working function by using 2 two-dimensional block models, 150cmx100cm and 50cmx20cm. Model materials used are mainly aluminum bars.

This physical model is to get the optimum bolt angles in terms of displacements. Hundreds of measurements were carried out manually and then definite and conclusive results were obtained. It is found out that the optimum bolt angles for toppling failure for certain joint inclinations are considerably constant no matter what the degree of discontinuities within the rock mass will be.

It is the authors'hope that empirical conclusions presented in this paper will give light to the engineering practice dealing with slope stability problems.

(G-4)

(135) Stability of a Slope Considered Seismic Displacement

Nomachi, S., Sawada, T., Matsuoka, K. and Kishi, N.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 141–145, 1985,

In the conventional engineering analysis of slopes against earthquake forces, such structures are usually analyzed and designed with the calculation of the factor of safety when an inertia force is considered.

If the factor of safety is less than unity, then the slope is considered to be unsafe. It is true that under static loading, if the factor of safety is below unity, the occurence of sliding is so sudden that there may be much possibility of continuation of the movement. In such cases, the displacements become so large as to render failure. As for earthquake loading, the reduction in stability under earthquake excitations would only exist during the short periods of time for which the inertia force is induceed. Further, during an earthquake the induced inertia forces will also alternate in direction and magnitude numerous time, only those which move away from the slope tend to reduce the stability of the slope.

Thus, during the earthquake, the factor of safety may drop below unity several times which will induce some movements of the failure section of a slope. It is apparent that during an earthquake the factor of safety changes all the time due to different inertia forces acting on the slope. The minimum factor of safety only exists transiently. Thus, the stability of slopes should depend on the cumulative displacement developed during an earthquake. Herein, in addition to calculating the factor of safety of a slope after a given earthquake shock, the effects of earthquakes on the displacements of a slope will be assessed.

This is done as the concept of Newmark.

In this analysis, a soil mass moving downward along a failure surface under inertia force due to earthquake shaking is considered to be analogous to a rigid block with weight and an external force.

The failure mechanism and its corresponding yield acceleration must be determined first so that the logspiral failure surface and external force can be simulated.

Subsequently, the overall displacements of a failure slope under earthquake loads can be assessed. This can be achieved in the following steps:

1. Calculate the yield acceleration at which slippage will just begin to occur.
2. Apply various values of the pseudo-static force to the slope. These values are obtained from a discretized accelerogram of an actual or simulated earthquake.
3. According to the yield acceleration and accelerogram of an earthquake the time history of velocity of the sliding soil mass of a slope can be calculated. The magnitude of displacement can be evaluated by integrating all the positive velocity.

The computation of the yield acceleration by the upper bound techniques of limit analysis has been operated in our previous paper (See reference 6).

Based on this yield acceleration and its associated failure mechanism, the equation of displacements along the potential failure surface is developed in this paper.

(G-4)

(136) Model and Analytical Study on Rock Slope Behavior during Earthquake

Adachi, T., Yano, T. and Tsuji, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 146–150, 1985,

There still remain such unexplained facts as the trigger mechanism of rock slope failure during earthquake. At the Izu-Oshima-Kinkai Earthquake of 1978, rocks buried under surface soil flew out by the earthquake shock and fell down. It was also reported that square stone houses built on mountain ridge only broke down in the case of the South-Italy Earthquake of 1980.

From the evidences, to investigate how surface portion of rock slope behaves when the earthquake shock wave reaches is definitely required. Namely, the conventional study of slope stability during earthquake is not good enough only based on the oscillational point of view.

In this study, first of all, a model assembled by steel balls which consists of foundation and mountain was prepared. The motions of balls located on the model mountainside were investigated when a shock wave propagated from one end of foundation. Secondary, preliminary analyses were carried out to simulate the model test results on the basis of theory of elasticity.

In the model tests, it was observed that the ball on the mid-slope of mountain flew out most heavily and the ball on the top of mountain flew up. The preliminary analyses can at least qualitatively explain the model test results. (G-6)

(137) Study on In-Situ Permeability Tests Conducted on Soft Rock Foundations

Matsumoto, N. and Yamaguchi, Y.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 201–205, 1985,

In designing dams, it is important to obtain the permeability of foundations. In Japan, the permeability of foundations has been usually evaluated with Lugeon test. This test procedure is primarily suitable for hard rocks in which seepage through the joints and cracks prevails.

However, not a few damsites in Japan consist of soft rocks recently. Because soft rocks have few joints and cracks compared to hard rocks and the rock itself is permeable, seepage flow in soft rocks can be assumed to be governed by Darcy's law. Therefore, the permeability of soft rock foundations should be evaluated by the permeability coefficient obtained from the in-situ permeability test.

In this paper, accuracy of several in-situ permeability tests was investigated by large scale laboratory test and numerical analysis. Results obtained from this investigation are summarized as follows :

1) If the permeability test is conducted above the ground water table, considerably accurate permeability coefficient is obtained from following three testing methods :
   a) Designation E-19 established by U.S. Bureau of Reclamation
   b) Designation E-18 packer test established by U.S. Bureau of Reclamation
   c) Sawada's formula
2) If the permeability test is conducted below the ground water table :
   a) Designation E-18 packer test established by U.S. Bureau of Reclamation
   b) Sawada's formula

   Furthermore, the accuracy of the permeability coefficient obtained from above two testing methods is not much influenced by the existence of impermeable layers around the testing area. (G-5)

(138) Analysis of the Fenner-Pacher Curve (Part II)

Fukushima, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 236–240, 1985,

The reciprocal relationship between the required lining resistance and radial deformation of the cavity has been studied by R. Fenner and F. Pacher. The graph which demonstrates this relationship is called the ground reaction curve or Fenner-Pacher curve and this relationship is one of the most important elements of the New Austrian Tunnelling Method (N.A.T.M.).

However, this relationship has not been comprehensively studied, so the author tries to make aparent formula to define this relationship. He uses the circular tunnel in the elastic perfectly-plastic body in the gravitate field and tries to develop analytical solution.

Also he introduces the criteria which distinguish ductile and brittle deformation, the idea of the loosening of the surrounding ground before the installation of the support, re-compaction of them after the installation of the supports and linings, the dilatancy accompanied with plastic deformation according to the associated flow rule, and volume change according to the bulk moduli.

These ideas and observation of the actual tunnel behavior lead him to the conception that the phenomenon which occurs around the tunnel is similar to that which occurs around a pipe culvert embedded in the embankment, so he is helped by the Marston-Spangler's theory and it's modification made by the author himself.

These analysis make clear the fundamental of the Fenner-Pacher curve apparently and possible it to apply to the actual tunnel work.

(G-4)

(139) Limiting Equilibrium for a Discontinuous Rock Mass around a Circular Tunnel

Nishimura, M. and Ebisu, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 241–245, 1985,

A rock mass mostly contains discontinuities, such as faults, joints, cracks, and beddings, which have developed through geological activities, mining operations or construction works. The mechanical behavior of a rock mass, affected by these discontinuities, should be analyzed in another way unlike isotropic soil. There are four different failure modes for a rock mass with discontinuities, depending whether the failure is caused by tensile stress or shear stress, and whether the failure occurs along by the discontinuities or across them. The purpose of this paper is to clarify the mechanical effects on a rock mass, of parallel plane joints in the rock mass around a circular tunnel, the axis of which is aligned parallel to the strike of the joints.

The assumptions for analyses are i) a rock mass is composed of intact rock blocks and joints, ii) the strength of the joints is far below in comparison with that of intact rock blocks, and iii) the behavior of joints obeys the linear Mohr-Coulomb failure criterion. The failure conditions of a rock mass, therefore, are based on the mechanical properties of the joints and the orientation of the stress field.

Since stress analyses are exceptionally complicated due to stress discontinuity which takes place in joints, a theory of limiting equilibrium is employed to simplify them by assuming that joint spaces are infinitesimal and that calculation for rock stresses is based on the condition that a rock mass is elastic, continuous, homogeneous and isotropic.

The factors which govern instable zones satisfying the failure criterion are both vertical and horizontal in situ rock stresses, po, kpo, internal pressure equivalent to the supporting pressure, pi, inclination angle of joints, ψ, and strength constants of joints, cj, ϕj. Variations of instable zones are illustrated for nondimensional parameters, k, pi/po, ψ, cj/po, and ϕj.

The results of this study, for example, help us make decision in selecting locations effective for rock bolt installation. These are also helpful as a practical standard when applied to design and support for underground excavations.

(G-4)

(140) Numerical Method of Viscoelastic Analysis Using Combined Finite and Boundary Element Methods in Geotechnical Engineering

Kaneko, N., Shinokawa, T., Yoshida, N. and Kawahara, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 251–255, 1985,

In geotechnical engineering, at the present, the finite element method (FEM) is the most popular numerical method. Recently, the boundary element method (BEM) is developing as one of the available numerical methods. In FEM and BEM, respectively, there are advantages and disadvantages. FEM is advantageous in analyzing geotechnical behavior when geometry and/or boundary change due to excavation or support system. BEM is advantageous in analyzing the behavior in the infinite domain of the ground. Consequently, it is considered effective to utilize the combined method in which respective advantages of FEM and BEM can be fully implemented.

We have already proposed a new numerical method of viscoelastic analysis using the time marching method by the BEM and have combined it with FEM. In the proposed method, there are two advantages;

1) The boundary integral equation can be formulated only on the boundary. Therefore, it doesn't require the provision of cells in the analytical domain.
2) Since the boundary integral equation can be formulated in an incremental form with time, the hereditary integral can be evaluated using only the values of the previous time step.

In this paper, Several numerical examples are presented to verify the validity and availability of the proposed method. And the combined method is applied to simple tunnel excavation problems in order to confirm the applicability of practical geotechnical problems. It is concluded that the combined method can be applied in the viscoelastic analysis of practical geotechnical structures such as underground openings and tunnels.

(G-4)

(141) A Study of Stability Analysi for Underground Excavation Using Keyblock Theory

Ohnishi, Y., Goodman, R.E. and Fujikawa, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 256–260, 1985,

There are many methods of analysis such as Finite Element Method, Boundary Element Method, which are based on Continuum Mechanics, or Distinct Element Method based on Mechanics of Discontinuity when we estimate the stability of underground caverns.
Block theory is thought as one of the very useful methods of stability analysis has been applied to hard rock mass which has many disco-ntinuities.
It seems for us that Block theory is recogniza-ble because of that easiness to deal with three dimensional problems.
This paper introduces the concept of Block theory and how to calculate the stability of rock face using Block theory of computerizing.

(G-4)

(142) Theories and Practice on Deformation Problem of Foundation

Kawamoto, T.

Tsuchi-to-Kiso, JSSMFE, Vol. 30, No. 11, pp. 3–9, 1982,

Topics on deformation and strength in geotechnical engineering are outlined for both soil and rock mechanics, then constitutive models which are constructed on the facts of experimental results are treated. It should be emphasized that field measurements and back analyses play an important role if the developed theory is applied to engineering practice. Thus several methods and examples of measurements are shown. However there exists still untractable discrepancy between theory and practice on deformation and failure problems in geotechnical engineering. I finally discuss future researches expected.

(G-2)

(143) Deformation Due to Tunneling and Its Analytical Approach – Ex. of Inasato Tunnel in Kamuikotan Metamorphic Zone –

Wakita, A., Takasaki, H., Kusumoto, T. and Akada, M.

Tsuchi-to-Kiso, JSSMFE, Vol. 30, No. 11, pp. 11–16, 1982,

As a result of the Test Gallery which was excavated by NATM in a weak rock zone consisting of schist and supentine, a big deformation that was recognized to be an elasto-plastic was observed.

In this paper, We metioned a characteristic of deformation and ground pressure connected with excavation progress of tunnel face.

Then, by using some analytical models based on the Finite Element Method. we try to indicate how degree we can approach a real phenomena and what being problems are between an analytical model and an actual behavior.

(G-4, H-5)

(144) Some Considerations on the Behaviour of Anisotoropic Rock Masses during the Excavation of Slopes

Kitahara, Y. and Itho, H.

Tsuchi-to-Kiso, JSSMFE, Vol. 30, No. 11, pp. 33–40, 1982,

In this paper, the method for the analytical evalution of the behaviour during the time of excavation of rock masses slope is briefly presented, in which take account of anisotropic deformability, anisotropic shearing strength and the non-linear relation between stress and strain of rock masses.

As the object of actual slope of rock masses composed of fractured zone and the remarked joints, the forecast of behaviour during excavation is carried out by the numerical calculations of anisotropic and isotropic analysis and the comparison between both results obtained are presented here.

Moreover, comparison between the field measurement carried out from the viewpoint of safety execution and the forecast obtained by the numerical calculations are presented. (G-4)

(145) On Resistance Law of Flow through Rock Masses

Sato, K.

Tsuchi-to-Kiso, JSSMFE, Vol. 30, No. 12, pp. 27–32, 1982,

A seepage flow through the rock masses is governed by distribution of inter-connected fissures (a interconnected fissure system) geometric properties of fractured space and physical characters of the rocks, and its hydraulic characters are different from those of a flow in alluvial soil. This paper deals with physical properties of the flow through rock masses, selection of governing hydraulic quantities and modellings of fissure systems and a flow(itself). In addition, the mechanical meaning of the resistance law, and a formulation of permeability are proposed from the fluid mechanical point of view. Accuracy and problems concerning the present permeability measurement (method) are clarified. (G-5)

(146) Decrease of Shear Strength and of Stability of Earth-Structure of Decomposed Granite Soil Due to Submergence

Fukuda, M.

Tsuchi-to-Kiso, JSSMFE, Vol. 31, No. 1, pp. 95–100, 1983,

The paper describes the test results on decrease of the shear strength of the decomposed granite soil due to submergence by using a special apparatus in the first place. Then, based upon the test results, safety factor of the embankment slope and the earth pressure acting on the retaining wall were analized, and their stability was discussed. (G-4)

(147) Slope-Failures Due to Heavy Rainfall in the Shirasu-Region of the Southern Kyushu

Haruyama, M.

Tsuchi-to-Kiso, JSSMFE, Vol. 31, No. 1, pp. 105–110, 1983,

"Shirasu" is the local term for the pyroclastic flow deposits in the Southern Kyushu. Shirasu in natural state is covered directly with younger volcanic ash and pumice fall beds, but the foot and the shoulder of slope are cut off in the case of housing-land development. Consequently, the change of flow courses of overland and subsurface waters causes slope-failures in the event of heavy rainfall. The mechanism of the most frequent slope-failure is the slide of topsoils consisted of younger volcanic ash, followed after the piping in the pumice bed. (G-4)

(148) Geotechnical Properties of Shimajiri Mudstone and a Few Problems for Cut Slope Design

Shinjou, T., Kinjou, Y., Kouchi, S. and Yonekura, T.

Tsuchi-to-Kiso, JSSMFE, Vol. 31, No. 1, pp. 111–116, 1983,

Cut slope failures occur often in mudstone of Neogene Tertiary that belongs to Shimajiri group distributed in the southern part of Okinawa Island, the southwest of Japan. This soft mudstone which frequently contains the weak planes of cracks, faults and thin sand layers in strata is softened easily due to slaking and swelling.

In this paper, a few problems on the current design and practice of cut slopes were discussed briefly from the view point of geotechnical properties, and also the failure types of cut slope was introduced. (G-4)

(149) On the Design of an Underground Dam at Tsuregami Peninsula in Fukui Prefecture

Matsuo, S. and Aoki, K.

Tsuchi-to-Kiso, JSSMFE, Vol. 31, No. 3, pp. 11–16, 1983,

This study deals with the geological survey and the design of an underground dam at Tsunegami peninsula in Fukui prefecture.

Based on the data of topography, geology and rainfall water balance of the region, usable amount of groundwater was estimated and change in groundwater level by storing or pumping was analysed by the finite element method.

Cutoff construction methods for underground dams were examined and an analytical method for determing the optimum locations of pumping was proposed. (G-5)

(150) The Hydrologic Behavior of Underground Reservoir in the Miyako-Jima Island

Aiba, M., Kurokawa, M., Nagata, S., Hosoda, H. and Yoshikawa, M.

Tsuchi-to-Kiso, JSSMFE, Vol. 31, No. 3, pp. 17–24, 1983,

A project of irrigation with a series of underground dams is being planned in the Miyako-jima Island, Okinawa. A test underground dam was constructed, in which various tests have been carried out. This paper describes the hydrological behaviour of the underground dam.

One of the main features of the storage function of underground dams is that surcharge water above the crest of underground dams is relatively large and it can be used for water utilization. Some of new definitions on the storage function of the underground dams are proposed. (G-5)

(151) Recharge, Discharge of Groundwater around Western Foot Area of Mt. Aso

Harada, K. and Tanaka, N.

Tsuchi-to-Kiso, JSSMFE, Vol. 31, No. 3, pp. 39–44, 1983,

Groundwater around the western foot area of Mt. Aso is recharged by rainfall, irrigation water of paddy fields and underflows. The total groundwater recharge is 550 million m^3/year and the pumping up discharge for water resources amounts to 270 million m^3/year in this area.

The above recharged groundwater flows out to the Kengun area and is restored in an underground reservoir of the porous Togawa lava. The overflowning water from this groundwater reservoir springs out at Suizenji and Ezu. The springing discharge amounts to 280 million m^3/year.

Therefore it is concluded that the total amounts of recharge and discharge of the groundwater are balanced in the western foot area of Mt. Aso and the groundwater development decreases the springing discharge. (G-5)

(152) Flow Characteristics of Groundwater around Liquid Storage

Sato, K.

Tsuchi-to-Kiso, JSSMFE, Vol. 31, No. 4, pp. 33–39, 1983,

In recent years, hydraulic problems associated with the use of underground rock caverns for fuel storage have been studied in Japan. This paper examines the flow characteristics of groundwater around these caverns using the results of Hele-Shaws's experiments. Steady-state free surface and seepage rate into the caverns of single and multiple units are discussed together with finite element numerical techniques. (G-5)

(153) Strain Characteristics of Mudstones and Other Soft Rocks Encountered in Expansive Tunnels and Landslide Areas

Fukumoto, Y.

Tsuchi-to-Kiso, JSSMFE, Vol. 31, No. 12, pp. 41–50, 1983,

Landslides and large scale rock deformation in tunnels are mainly observed in regions where the formation is composed of mudstones, tuffs and serpentines. It is commonly believed that rock deformation in tunnels is the result of expansion shear failure of the rock.

In this study, the strain behavior of mudstones was investigated in order to clarify the strain behavior of mudstones leading to failure. The conclusion of the study is that shrinkage plays an important role in the failure of mudstones and other soft rocks. (G-4)

(154) Photoelastic Experiments on Stress Distribution of a Gravity Dam and Its Foundation

Asai, S.

Tsuchi-to-Kiso, JSSMFE, Vol. 32, No. 4, pp. 11–18, 1984,

Stress distributions in a gravity dam and its foundation under the hydrostatic pressure of water in a reservoir were examined by photoelastic experiments with gelstin models. Both reservoir of empty and full conditions were considered.

The results of the photoelastic and numerical analysis showed that the magnitude and the direction of the principal stresses in the upstream side of the dam are highly sensitive to the change in the water level of the reservoir. It was also found that the position where the maximum vertical stress occurs, moves towards upstream side, as the water level raises.

It may be said that the results obtained are reasonable since the stress distributions in the reservoir of empty condition agree with the data in the literature. (G-0)

(155) Improvements of Watertightness of the Shirasu Foundation of the Failing Deposal Dam

Kuroda, T., Hikage, F., Inoue, S., Matsui, S. and Terado, Y.

Tsuchi-to-Kiso, JSSMFE, Vol. 32, No. 4, pp. 27–35, 1984,

It is said that the improvement of the physical and mechanical properties of Shirasu, weakly bonded volcanic ash flow, cannot be easily done by ordinary grouting methods. The Soletanche grouting method with the rotary percussion drilling was used to reduce the permeability of the Shirasu foundation of a tailing disposal dam. It was found that the method ensured that both the coefficient of permeability and the critical pressure were smaller than the design values, which were 1×10^{-4}cm/sec and 2 kgf/cm^2 respectively. (G-5)

(156) Measures for Reduction in Seepage Flow at the Nagara Dam

Inaba, N., Katagiri, K., Endo, Y. and Banno, I.

Tsuchi-to-Kiso, JSSMFE, Vol. 32, No. 4, pp. 37–42, 1984,

As a part of the Bohsoh Canal construction project, the construction of the Nagara dam is in progress. There exists problems of leakage, piping and liquefaction because of the high permeability of foundation on which the dam is going to rest.

In order to prevent piping phenomena and reduce the volume of leakage the core zone was extended towards upstream along the foundation, which was intended to lengthen the seepage pass of leaking water. Since the material used in the construction of the dam was rather permeable, there was the possibility of the occurrence of liquefaction. Therefore the cut-off sheet was installed at the boundary between the dam and the foundation to prevent the water seeping into the dam and the two culverts were provided at the both sides of the dam to lower the point where seepage breaks out on the downstream slope. (G-5)

(157) On the Use of Semi-Pervious and Pervious Materials as Embankment Fill

Nishida, T.

Tsuchi-to-Kiso, JSSMFE, Vol. 32, No. 7, pp. 29-36, 1984,

This paper discusses problems of coarse embankment materials based on the experiences as a consulting engineer for fill dam. Topics discussed here are summarized as follows; (1) Permeability ratio of filter material to impervious material. (2) Grain size distribution of materials for field and laboratory tests. (3) Relationship between values of designed and controlled during construction. (4) Investigation on the weathering of basalt as a riprap material of dam and its countermeasures. This paper gives suggestion for the field test, design and construction control in relation to the above topics. (G-5)

(158) Indoor Test on Dynamic Setilement of Softrock Embankment Due to Train Load
Sunaga, M., Sekiguchi, Y., Yamauchi, N. and Kitagawa, T.
Tsuchi-to-Kiso, JSSMFE, Vol. 32, No. 7, pp. 37–43, 1984,

Indoor repeated load test was conducted in order to investigate the settlement of embankment of soft rock-chips due to train load. The intensity of the repeated load was kept constant during the tests. As a result, the relationship between density of specimens and dynamic settlement was made clear, and it is found that the dynamic settlement decreases as the increase of the density ofspeciment. And through similar gradation test, it is found that the bigger the maximum particle of the rock-chips is, the greater the dynamic settlement is.

(G-6, H-4)

(159) The Stability of Sloping Softrock with Include the Joint
Iwao, Y. and Hashimoto, T.
Tsuchi-to-Kiso, JSSMFE, Vol. 32, No. 11, pp. 45–48, 1984,

The slope failure had occured at the low hill of weathered granite. The joint was included in the soft rock, beside white clay had recognized in the joints. The clay was composed of meta-bentonite, Illite and some other minerals. The shear test and friction test were attempted for the clay and plastic slab. The existence of confined water reduced the friction between the slab and slab as well as between the plastic slab and clay. The confined water and the joint were found to be the major causes of slope failure.

(G-4)

(160) Rigid Body Spring Model Analysis of Large Scale Landslide at Mt. Ontake during the Naganoken-Seibu Earthquake
Mitou, M., Takeuchi, N. and Kawai, T.
Tsuchi-to-Kiso, JSSMFE, Vol. 33, No. 11, pp. 19–24, 1985,

A large scale landslide occurred at Mt. Ontake due to the Naganoken-seibu Earthquake on September 14, 1984.

In this paper, this large scale landslide at Mt. Ontake is examined with elasto-plastic response analysis using Rigid Body Spring Models and the failure mechanism will be discussed based on the calculation results.

(G-4)

(161) A Prediction Method for Landslides by an Earthquake and Its Appraisal Based on the Naganoken-Seibu Earthquake
Momikura, Y., Yasuda, S. and Sakaki, Y.
Tsuchi-to-Kiso, JSSMFE, Vol. 33, No. 11, pp. 41–46, 1985,

A prediction method for earthquake-induced-landslides in volcanic area was discussed, based on the study of the four large scale landslides due to the Naganoken-seibu Earthquake in 1984. The study, conducted by geological investigations and geomorphlogical observations, and also with dynamic soil tests and slope stability analyses, clarified the several factores which affected the unstability of the slopes during the earthquake. Those factors are; 1) there exists the weathered pumice on the surface of rupture, 2) the toe of the slope was eroded by scoring, and 3) others.

(G-4)

(162) Experimental Study on Flow Resistance in Rock Block Media

Sato, K.

Journal of the Japanese Society of Soil Mechanics and Foundation Engineering, Vol. 22, No. 4, pp. 19–29, 1982,

An adequate determination of permeability and flow resistance law is one of the important tasks for the hydraulic analysis of ground water motion in fractured rocks. In this paper, the flow characters and resistance law are experimentally studied by three kinds of rock block media composed of triangular, parallelogrammic and rectangular unit blocks in laboratory. By a newly designed apparatus, the flow rate measurement and flow path observation are carried out with the porosity range of 2.62%~16.21% for each medium. Experimental results are examined by the dimension analysis, and the permeability formula is proposed. (G-5)*

(163) Groundwater Analysis of Underground Cavern by Means of Rock Block Model

Sato, K. and Iizawa, M.

Journal of the Japanese Society of Soil Mechanics and Foundation Engineering, Vol. 22, No. 4, pp. 30–44, 1982,

With respect to the groundwater analysis involving tunnels and caverns in rock, most papers have presented the problems on the basis of the assumption that the porous media were undeformable. Because of the dynamic deformation between fissures and rock masses due to water pressure, the groundwater motion will be affected by the deformable medium in addition to the excavation of underground structures.

This paper aims at an examination of hydraulic behavior and the analysis of groundwater flow by a rock block model which behaves as an elastic body affected by the dynamic change of fissure water pressure. A new equation, which takes the vertical distribution of permeability into consideration is proposed based on both theory and field investigations. By this equation, the groundwater movement around the cavern is analyzed by the rock block model in a confined stratum of fractured rock. Results obtained from the finite difference method are examined by some laboratory experiments, which were carried out by using a rock block model composed of a number of cubic blocks and a cavern. Comparing their numerical and experimental results, it is found that the seepage flow analysis of the underground cavern by means of the rock block model may be valid for not only the analysis of flow around the cavern but also the hydraulic modelling of seepage motion in rock masses. (G-5)*

(164) Gas Flow around a Borehole in a Coal Bed and Its Approximate Expressions – The Case of a Borehole within a Bounded Circular Area –

Omuta, H., Ito, R. and Goto, K.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 98, No. 1127, pp. 21–28, 1982,

This paper deals with the problem of gas drainage by a borehole within a bounded circular area under consideration of absorbed gas. The solution of finite gas flow system needs tedious computer calculations. The purpose of this paper is to present a easy method for calculating both the approximate distribution of gas pressure and the gas flow rate.

The gas pressure distribution and the gas flow rate at dimensionless time T can be approximately expressed by Eq. (7) and (9) respectively by use of the gas pressure gradient function C as defined by Eq. (8). The function C can be obtained by using the various C-curves, for example Fig. 2, which are calculated by computer, but C-value can be calculated with the fundamental C-curve of Fig. 5 at arbitrary α, P_0 and R. by the following procedure.

1) Calculate T_X corresponding to the R by Eq. (11).
2) Read the C/C_X corresponding to the T/T_X from Fig. 5.
3) Multiply the C/C_X by C_X calculated by Eq. (12). This answer is the C at $P_o = 1/50$ and $\alpha = 1$.
4) Then, calculate the $C(P_0 > 1/50)$ by substituting the C into $C(P_0 = 1/50)$ of Eq. (20).
5) Finally, calculate the C at $P_0 > 1/50$ and $\alpha \neq 1$ by substituting the $C(P_0 > 1/50)$ into $C(\alpha = 1)$ of Eq. (16).

The gas drainage period is longer in taking account of absorbed gas than of non-absorbed gas and a larger borehole cannot shorten the period so much. The shortening of boreholes interval is more effective for the purpose.

(G-0)

(165) Influence of Mine Geometry on Seismicity Induced by Mining of Single Coal Seam – Study on the Design of Mine Layout for Working Coal Seam Based on Rock Mecahnics (2 nd Report) –

Isobe, T., Sato, K., Mori, N., Goto, T. and Fukai, S.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 98, No. 1128, pp. 85–92, 1982,

In-situ measurement has been carried out at Sunagawa Coal Mine to study the seismicity in two mining panels; in the first panel the extraction ratio amounted to 77%, on the contrary in the second panel coal pillars were so extensively left that the extraction ratio was 48%. Magnitude distributions of seismic events were followed by the Gutenberg-Richter's formula, $\log N = a - bM$, in which the b-value was the same for two mining panels but the a-value was lower in the panel whose extraction ratio was lower. Spatial rates of seismic energy were 87.4 and 38.4 J/m^2 in the first and second panels respectively.

On the other hand energy release rates associated with mining were determined from the Face Element Method as 1.20 and 0.57 MJ/m^2 in the two mining panels respectively. It was, therefore, concluded that spatial rate of seismic energy was in proportion to energy release rate presumed from an elastic model. Furthermore it was suggested that a slight decrease in extraction ratio might be effective to reduce the hazards of rockburst as well as stowing with wastes and packing with artificial materials.

(G-0)

(166) Grid-Model Method for Three Dimensional Analysis considering Horizontal Displacement of the Ground with a Number of Layers – Study on Ground Movement Caused by Underground Opening (2 nd Report) –

Kimura, T., Esaki, T. and Nishida, T.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 98, No. 1129, pp. 215–220, 1982,

The three dimensional analysis of ground movement due to mining can be simply performed by the grid-model method. However, the application of the method to practical problem is limited to a certain extent because the method is based on some assumptions.

In this paper, two improvements on the method are made in order to remove some of the limits. By one, it is possible to deal with the ground consisting of a number of layers which are different in their Young's modulus, specific weight and thickness. The other is to calculate the horizontal displacement of the ground which has not been considered in the grid-model method until now.

The validity of this improved method is obtained through comparison with finite element method and the precalculating method in some cases.

This grid-model method is superior to finite element method in needful region size and cpu time of computer. Therefore, in the analysis by this method, the ground can be divided into a great number of elements.

(G-2)

(167) Experimental Study on the Floor Lift of Coal Mine Roadway Driven in the Weak Rock (2 nd Report)

Shimada, S. and Hokao, Z.

Journal of the Mining and Methallurgical Institute of Japan, Vol. 98, No. 1129, pp. 221–226, 1982,

Using equivalent materials the authors carried out model experiments of the floor lift occurring when the coal face passed over the roadway driven in the weak rock. In this report the vertical distance between coal seam and the roadway was varied ranging from 10.8 m to 23.4 m, and relations between the convergence and the vertical distance were investigated.

At the bottom of the floor seam stress measurement devices were set up and the stress change acting on the roadway was measured with the advance of the face. This enabled us to obtain the linear relation between the convergence and the additional stress caused by face advance.

As a new controlling method of the floor lift, model study of floor cementation was tried. In this study cementated zone was replaced by harder materials and the convergence was measured with varying the thickness of cementated zone. The thickness of 1.5 m proved to be effective for controlling the floor lift.

(G-0)

(168) A Consideration about Gas Drainage from In Situ Coal Seam by Computer Simulation

Higuchi, K., Isobe, T. and Ohga, K.

Journal of the Mining and Methallurgical Institute of Japan, Vol. 98, No. 1131, pp. 399–404, 1982,

The state around borehole in a coal seam is considered as shown in Fig. 1. This state can be expressed by the simple model as shown in Fig. 2. In this model the gas flow from coal seam to the borehole is considered as consisting of the two-courses; one is direct radial flow toward the borehole, the other is linear flow toward the discoidal fracture.

The total gas flow from the borehole including these two-flows is expressed by the equation (2).

This partial differential equation is solved numerically by using a digital computer.

From the comparison of the calculated results with the observed values following results are obtained.

Permeability of the coal seam in YUBARI district is smaller than that of the KITASORACHI district, but r_1 value (the apparent radius of the discoidal fracture) of the coal seam in YUBARI district is larger than that of the KITASORACHI district.

The larger the r_1 value, the more easily methane in the coal seam can be drained.

(G-0)

(169) Mechanized Longwall Mining System with Liner Road Constructed in Goaf

Sato, T., Goto, T., Sato, K., Yano, T., Fujino, T. and Kashikawa, H.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 98, No. 1132, pp. 489–494, 1982,

The longwall mining at Kushiro Colliery is characterized by highly mechanized face equipments and the majority of output comes from this coal winning method. The rate of face advance has, however, declined with increase of mining depth by a main reason why driving and successive maintenance of gate roads has been confronted with difficulties. To secure a solution of this problem, a new type of gate road system investigated and adopted to retreat mining panels.

In the new system only one of gate roads is driven before winning coal, and another is extended with advance of coal face as if in advance longwall mining system(Fig. 1). At the situation the main gate road is driven in solidcoal by the same way as existing method, but the auxiliary road is constructed in goaf with ring or arch-invert support elements and tubular shield elements so that this gate road can be named as a liner road (Fig. 10).

The structure and size of a liner road was determined so as to satisfy both requirements from ventilation and strucrural analysis. The preliminary design lead us to make use of the standard steel beam for the support element and a thin steel plate for shield element.

Up to the present this system has been adopted to five mining panels so that total coal production amounted to 550,000 tons. In all cases liner roads were perfectly maintained during working of mining panels without any sort of trouble. The new system also revealed the economic feasibility through the result that the expenditure for gate roads in a mining panel could be reduced by about 27% in average comparing with existing longwall system.

(G-0)

(170) The Relation between the Hypocenters of Seismic Events and Mining Condition

Goto, T., Isobe, T., Mori, N., Sato, K. and Kameda, I.

Journal of the Mining and Methallurgical Institute of Japan, Vol. 98, No. 1133, pp. 585–590, 1982,

A seismic method is one of tools to survey the strata state. And especially, this method is effective for monitoring the unstable rock failure caused by stress and strain energy concentration. From this point of view the field investigation has been carried out by using the seismic devices for about nine years at four coal mines in Hokkaido.

In the present paper the hypocenters of seismic events are discussed in relation to the form of mined area as well as the existing faults in the measured domain by using the data obtained at Sunagawa coal mine in 1974 and 76. In the colliery, inclination of the coal seam is about 70° and the hydraulic mining has been employed for more than 2 decades. During the measurment had been excuted about 1500 seismic events whose hypocenters were located in the mining panel were recorded.

These hypocenters have been found to be classified into following 4 types.

(1) hypocenters that were situated near and around the advancing coal face.
(2) hypocenters that were situated at the coal piller that was formed in the working mining panel.
(3) hypocenters that existed at the coal piller remained in the goaf.
(4) hypocenters situated on the faults where the mining activity was continuing.

It is necessary in mine safety to pay attention against type (2) from the point of view of severe coal and rock destruction because this type not only has large magnitude seismic events, but also usually happens near the operation faces.

(G-0)

(171) Rock Mass Inspection by Observation of Propagation Velocity and Attenuation of Sonic Waves

Sasa, K., Nanko, N. and Shibue, T.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 98, No. 1135, pp. 927–931, 1982,

It is very important for mine safety to inspect the rock mass around underground openings. In this study, the rock mass above the hanging wall which had been supported by the pillars was inspected with the progress of the mining of the pillars. The inspection was performed by monitoring the propagation velocity and the attenuation of the amplitude of the sonic wave through the rock mass. A portable equipment to observe a cracking in a rock mass by means of the change in the amplitude of sonic wave was made and used for the detection of crackings. The observation started before the beginning of the mining of the pillars and continued for about two years until the pillars were mined out. The experimental results are briefly shown below.

1) P wave velocity does not change throughout this experimental period.
2) The attenuation of the amplitude of the sonic wave increases in conjunction with the progress of the mining of the pillars, and the increase of the attenuation is going to stop when the pillars have been mined out and the opening area has been filled up with soil.
3) History of the attenuation shows that the rock mass under inspection settles under the condition that the pillars have been mined out.

(G-4)

(172) Experimental Studies on Core Discing

Kobayashi, R. and Sugimoto, F.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1143, pp. 359–364, 1983,

The core discing, which is observed on the boring core collected from rock mass in underground, has attracted interest with respect to the estimate of stress conditions in the rock mass.

In order to investigate the occurrence of the core discing on the soft rock, the laboratory tests are conducted on the blocks of cement-mortar at various compressive strength under the various confining pressures. From the test, the discing phenomenon is observed on the core collected from the block of cement-mortar and the relation between the confining pressure (Pc) required to produce discing and the compressive strength of the block (Sc) is formulated as follows:

$Sc < 0.56 \times Pc + 20$

It is then found that the thickness of disc is thiner and that the recovery percentage of the core is smaller, as the confining pressure increases.

The same boring tests as was stated previously are carried on the blocks of KIMACHI sandstone. Consequently, it is clear that the confining pressure required to produce discing does not conform to above inequality.

Besides, the stresses are analyzed on the simplified model of the boring test with using F.E.M. to investigate the mechanism of producing the core discing. In the stress analysis, it is considered that the failure of core on the blocks of cement-mortar occurs by the shear stress and that the failure of core on the block of KIMACHI sandstone occours by the tensile stress. In this way, it is supposed that the mechanisms of forming core discing are different with the mechanical properties of the rock mass.

(G-1)

(173) Preventives for Outbursts

Kurahashi, T.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1146, pp. 704–707, 1983,

Yotsuyama Mine is one of the three mines in Miike Colliery. Retreating longwall mining system is exclusively employed and the mechanized faces are equipped with sheeld supports and a double ranging drum shearer. The working faces are developed in the Upper, Main and in the selected area of the Lower Split of the Upper Seam. In 1977, the mine experienced an extraordinary phenomenon in a face worked in the Upper Seam West 35th District where the cover of depth was 550 meters, the deepest cover of the colliery at that time. The phenomenon was very similar to outburst. Since then, mine has experienced such severe phenomena very often in the area especially where the seam is immediately covered with hard sandstone and/or the face is very close to the rib of or beneath the residuall pillars. The mine, therefore, has established its own preventives tackling on the problem. This report presents the mine's overall preventives taken to keep the safety and the production.

(G-1)

(174) Measuring Instruments of Microseismic Events with Seismometer

Shiojima, S.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1146, pp. 707–711, 1983,

The observations with the seismometer at Sunagawa Coal Mine started as the study entrusted from Coal Technology Research Institute in 1971. Then processing and analyzing system owned by Coal Technology Research Institute were removed to Horonai Coal Mine in June 1980. So that, at this coal mine, we had recorded on only pen-recorders.

But meanwhile the credibility of systems was lost extremely because it became difficult to record on a pen-oscilograph owing to inferiority of signal transmission lines and increase of noises. In this time the hydraulic mining blocks were shifting to 860L, we had to enrich the measuring instruments of seismic events for the purpose of strengthing safety. The recording on pen-oscilograph became more correct as a result of carring out immediately strengthing and renewing the signal transmission lines and decreasing noises.

We tried the automatic of signal processor after the improvement of signal transmission system. The system owned by Coal Technology Research Institute was so excellent as corresponding to academic study, but in this coal mine, we planed to simplify the obtained data by means of the minimum processing i.e. a seismic source location and magnitude calculation. So that we made for the system to operate easily as one of centralized supervision.

In regard to the processing system, two microcomputers display their abilities which are equivalent to a minicomputer by connecting them in series. The former is in use for sampling the data and the latter for operation and controling peripheral equipments. We order the measuring instruments from electric works, and they are controled in our own program. It is easy for us to operate it in our place of work.

(G-4)

(175) Computerized Sysiem to Analyse AE (Acoustic Emission) and Geopressuse

Higuchi, S.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1146, pp. 711–714, 1983,

In proportion to underground operational depth, observation of underground changes such as geopressure change became quite important to predict and avoid possible bursts.

Minami Oyubari Coal Mine has introduced a sophisticated computer system in 1982 which collects various data such as AE, Geopressure and Displacement, which also presents us useful results of analysis. The system consists of sensor, transmission, calculation and analysis sections. Maximum quantities of sensors are twenty each for AE and Geopressure and sixteen for Displacement. Each are buried mainly in gateroad near production area. Sensors send signals for twenty-four hours continuously through transmission to calculation and analysis sections.

Collected all data are analysed automatically by computer. It is also possible to calculate in various ways under an operator's instruction.

At present, calculation and analysis sections at surface are receiving relatively almost constant signals from underground which show abnormal pressure phenomenon would not occur for a time being.

Accumulation of data must be continued as it is indispensable for an accurate prediction and effective measurements against possible disaster.

(G-4)

(176) The Effectiveness of Sidewall Softening in Mointaining Mine Roadway – Fundamental Study on Roadway Closure (4 th Report)

Ihara, M., Matsui, Y., Ichikawa, Y. and Park, H. M., Makoto, I., Kikuo, M. Yukiyoshi, I. and Hong, M. P.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1149, pp. 965–970, 1983,

Sidewall softening technique is based on the transference of the high stress concentration further away from the roadway sides. This technique is accomplished by softening the parts of sidewalls of mine roadway by drilling holes, explosions or cutting slots into the sidewalls.

The effectiveness of sidewall softening in maintaining mine roadway is studied using finite element analyses and model tests. The results obtained in this study are as follows.

(1) Sidewall softening improves the stress states around mine roadway. But it must be noted that under certain geological or ground pressure conditions softening would produce the tensile stresses in the roof or floor of the roadway.

(2) Floor lift and side closure could be controlled effectively by sidewall softening, especially when the roadway has a weak floor.

(3) Good results of controlling floor lift could be obtained by softening the large parts of sidewalls.

(4) Main failures which occur in the vicinity of the top of softened parts are accompanied by large roof lowering without roof falls. So, in practice, one should take necessary steps to control the roof lowering.

(G-4)

(177) In-Situ Measurement on the Effect of Roadway Support – Measurement at Roadway Supported by Rock Bolts (1 st Report) –

Okubo, S., Amano, K., Koizumi, S. and Nishimatsu, Y.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 100, No. 1151, pp. 11–16, 1984,

Mining industry is now evaluating the rock bolting as a new support method because of its significant advantages: reduced storage and handling requirements, improved ventilation, negligible maintenance and so on. This study has been started to reveal the advantages and disadvantages of the rock bolt support over the conventional arch support and examine its applicability to mines of Kuroko ore deposit on the basis of in-situ measurement carried out at Fukazawa mine in Akita.

In this first report, the measuring system and the results at roadway supported by rock bolts are described. The rock bolts were installed in a square grid at 1m interval, and convergence, radial extension of rock wall and axial force of rock bolt have been measured. Up to this time (200 days after installation), measured values have been continuously increasing, and some are of the considerable amount. For example, convergences are in the order of 50-70mm against the roadway of 3.3m height and 4.5m width. However, rate of increase is descreasing monotonously and no trend of roof fall or wall spalling is observed. Among others, it is most interesting that the results of convergence, extension and axial force follow the semi-log relationship, linear increase of the measured value against log time, except the axial force above its yielding point.

(G-4)

(178) In-Situ Measurement on the Effect of Roadway Support – Effect of Arch Set Support in Comparison with Rock Bolt Support (2 nd Report) –

Okubo, S., Amano, K., Koizumi, S and Nishimatsu, Y.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 100, No. 1153, pp. 219–223, 1984,

Steel arch sets have been widely used in coal and metal mines for roadway support. However, some of them were recently replaced by rock bolts especially in U.S. coal mines and tunnels with large cross-section. Through the current developments of theory and practice, the rock bolt support can be considered as a compatible alternative for the arch support. Included in this second report are the results of in-situ measurements at the arch supported roadway comparing with those at the bolt supported.

Up to this date (200 days after installation), convergence and radial extension of rock wall at the arch supported roadway are considerably larger than those of the bolt supported roughly by the factor of 1.5 to 2. A temporary conclusion may be that the rock bolting is superior to the arch set. Especially in the very early stage, say, within a few days after installation, rock bolting is favored for its immediate effect, while the effect of arch set is delayed until firm contact of arch set or timber lagging with rock wall is established.

Similar to the case of rock bolt support mentioned in the first report, the convergence and radial extension at arch supported roadway follow the semi-log relationship, linear increase with log time. Interestingly enough, the specimen obtained at the test-site follows the logarithmic creep law. This is remained for future research to combine the semi-log relationships observed at in-situ and laboratory tests.

(G-4)

(179) Basic Study on the Estimation of Dynamic Stability of Large Rock Slope

Hashimoto, B. and Nissato, H.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 100, No. 1157, pp. 561–568, 1984,

This paper discusses the stability of a large rock slope at the time when seismic wave is propagated to such structure.

To examine the dynamic stability of the large slope by adopting modal analysis, we propose the technique how to calculate the vibration modes of the model by finite element method, how to calculate a maximum amplitude of every node in the model from above vibration modes, how to obtain the local safety factors by using the combined displacements to superpose the static displacements and the amplitudes, and how to estimate the dynamic stability by the distribution of the safety factors.

In this paper, a theoretical analysis of dynamic response of the rock structure, definition of local safety factor, adoption of our attempt to process a dynamic system, and the simulation to estimate the dynamic stability are discussed.

The result of this simulation shows that the stability is affected unfavorably with decrease in the order of vibration modes, and that partial sliding may occur near the toe in a large rock slope during severe earthquake of its intensity 6, and gives other various suggestions for future study.

(G-4)

(180) The Fracture of Coal Seam Due to Advance Boring – Study on Acoustic Emission Activity Due to Advance Boring in Coal Seam –

Nakajima, I., Fukai, T. and Watanabe, Y.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 100, No. 1157, pp. 569–574, 1984,

In this research, the coal fracturing activity due to advance boring was observed by the acoustic emission methods in order to obtain the informations for judging the hazard of coal and gas outburst.

Practically, one-dimensional source location were conducted from acoustic emission signals detected in the stress relief boring for coal seam. Furthermore, the amount of cuttings in addition to acoustic emission activity was measured at every unit drilled length in that boring and the shield boring designed specially to prevent the collapse of a borehole. The fracture criterion of the coal seam saturated with gas under high pressure was analyzed to explain the characteristics of the acoustic emission activity in advance boring. The main concluding remarks are as follows;

1) In many cases the acoustic emissions due to fractures of coal seam occurred near the cutting points and in some cases at a distance ahead from the region of the stress concentration associated with the bottom of a borehole.
2) In the former cases the amount of cuttings increases and decreases almost without retard of the acoustic emission activity, while in the latter cases in some retard.
3) The retard of the discharge of cuttings from the acoustic emission activity is considered to be an useful information for judging the hazard of coal and gas outburst because this retard is due to the local coal fractures which are caused by the change in gas pressure in coal seam at a distance ahead from the bottom of a borehole.

(G-0)

(181) Effects of Support Parameters in the Concrete Support Combined with Steel Rings –A Study on the Mechanism of Concrete Support Combined with Outer and Inner Steel Sets (2 nd Report) –

Matsuki, K., Kobayashi, R. and Kubo, N.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 101, No. 1169, pp. 403–407, 1985,

Effects of support parameters such as thickness of concrete lining and spacing of steel ring in the concrete support combined with steel rings are evaluated with axi-symmetric finite element method in order to contribute to the rational design of the support. In addition to the concrete support with double steel rings, other cases are analyzed for comparison including those of outer or inner steel ring alone and that where an alternate outer steel ring is removed from the case of double steel rings.

In the concrete support with double steel rings, supporting more load than outer steel rings, inner steel rings reduce stress concentration in the concrete lining more than outer steel rings as shown in Figs. 6 and 7. Thus, inner rings play more important role in the concrete support combined with double steel rings.

Equivalent relationship between thickness of concrete lining and spacing of steel ring which gives the same stress concentration in the inner wall of concrete lining or at the center of inner steel ring is proposed in Figs. 10 and 11 as a measure for determining the support parameters in the concrete support combined with steel rings.

(G-1)

(182) Gate Roaway Deformation with Advancing Longwall Coal Face

Ihara, M., Matsui, K., Ichikawa, Y. and Ichinose, M.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 101, No. 1169, pp. 409–414, 1985,

A simple and inexpensive method is adopted to measure the gate roadway deformation with advancing longwall coal face in Ikeshima Collieries of Matsushima Coal Mining Co., Ltd.

Vertical closure of the gate roadway is much greater than sides closure. It is characterized that vertical closure reaches a certain value at about 100 m distance behind longwall face.

The effects of strata and mining conditions on the gate roadway deformation are studied by laboratory tests and elastic numerical analysis. It is shown that the deeper the depth of coal seam is and the weaker the strength of the floor rock is, the greater the gate roadway deformation becomes.

It is difficult to get an empirical equation to preestimate the gate roadway deformation by statistical treatment of measuring data because of a shortage of the precise data. It becomes clear, however, that relating the results of elastic numerical analysis presented by Everling to measuring data makes it possible to preestimate the gate roadway deformation with a considerable accuracy.

(G-1)

(183) Theoretical Study on Rock Deformability — Fundamental Study on the Estimation of Rock Deformability (1 st Report) —

Obara, Y. and Omi, M.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 101, No. 1173, pp. 699–705, 1985,

This paper discusses the theoretical treatment of rock deformability by using the crack model.

In the present analysis, discontinuities in rock are assumed to be represented by elliptic-plate-cracks. Two crack cases are analyzed, one is open crack and the other is closed crack.

Expressions for effective compliances of material with a single isolated crack are given as shown in eq. (6) and eq. (15). The effective elastic moduli of material with randum oriented cracks are analyzed by using the self consistent method and expressions for them are shown in eq. (17), eq. (19) and eq. (20).

For an application of this theory, the relationship between the rock elasticity and Rock Quality Designation are discussed.

In estimating rock deformability, the density ratio of open-cracks to closed crack shares the important role with other factors, namely, the total crack density, the crack geometry and the frictional coefficient.

(G-2)

(184) Mathematical Model of Crack Growth for Sanjome Andesite

Okubo, S., Shin, K. and Nishimatsu, Y.

Journal of the Society of Materials Science, Japan, Vol. 33, No. 370, pp. 96–101, 1984,

The mathematical model of crack growth given by the following equation is proposed,

$$d(\Delta a)/dt = K^n/A(\Delta a)$$

where Δa is the crack extention and K is the stress intensity factor.

The proposed equation has been applied to the three-point-bending tests on beam specimens under the condition of a constant rate of load-point-displacement, $\dot{u}$. The results calculated showed a linear increase in K_{max} with $\dot{u}^{1/(n+1)}$. The experiments have been carried out by changing $\dot{u}$ from 10^{-6} to 10^{-1}cm/sec. The experimental results also showed a linear increase in K_{max} with $\dot{u}^{1/(37+1)}$.

Subsequently, the experiment has been carried out in order to determine the function $A(\Delta a)$. The experimental procedure starts at loading a specimen up to K under a constant $\dot{u}$, and then the specimen is unloaded measuring the compliance (COD)/(LOAD) to calculate the crack length. By changing the level of K, a total of 28 tests have been carried out. The K-Δa curve obtained indicated a rapid increase in K at small Δa, followed by a gradual decrease in its increasing rate, and finally levelling off of K above $\Delta a = 1$ cm. From this K-Δa curve, the $A(\Delta a)$ was obtained and found to increase rapidly at small Δa and level off above $\Delta a = 1$ cm.

Through various simulations by a computer, the proposed model was found to explain the behaviour of Sanjome Andesite specimen with a crack subjected to three-point-bending under the condition of a constant $\dot{u}$. It is remained for future research to verify the equation in the cases of creep and relaxation.

(G-0)

H. [Design, Construction and Behavior of Engineering Works]

(1) Seismic Behavior of a Rock Tunnel — Analysis of Observed Waves —

Nakamura, Y., Asakura, T., Yamaguchi, Y., Tsujita, M. and Wakita K.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 187–192, 1984,

In order to investigate the behavior of a rock tunnel when it is subjected to an earthquake, earthquake observations have been carried out in the Shin Usami Tunnel of JNR's Ito Line, located in Ito City of Shizuoka prefecture. For the observations, 8 accelerometers and 6 strain gauges were set up in the rock around the tunnel, and 10 strain gauges were set up on the surface of the lining concrete. The rock at the site is mainly basalt with an overburden of about 220m to 260m. The velocity of the primary wave in this area is between 2.3 km/sec to 3.2 km/sec. During the analysis of the observed waves from July 1983 to June 1984, the following results were obtained.

(1) When an earthquake wave propagates through the rock around a tunnel, the propagation of the shear wave and the primary wave in the upward direction is prominent. The frequencies at the peaks of the amplification function are constant and not influenced by the properties of the earthquake.

(2) In the horizontal plane of the rock around a tunnel, no noticeable amplification of the earthquake wave can be seen even in the vicinity of a cavern.

(3) In the cross section of a tunnel, the shearing deformation is significant.

(4) The vertical component of the earthquake wave in the rock around a tunnel tends to be as large as or even larger than the horizontal component for some frequencies. (H-5)

(2) Monitoring and Estimation of the Effects on the Properties of the Surrounding Rock Caused by the Excavation of a Cavern

Yoichi, H., Hasui, A. and Yamashita, R.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 193–198, 1984,

Due to the excavation of a rock cavern, a so-called "Relaxed Zone" will occur in the surrounding rock. In this zone, the original rock properties are changed by the excavation. Consequently, it is important to clarify the process and the behavior of the relaxation to determine this change qualitatively and quantitatively. The authors monitored the properties of the rock surrounding a cavern during its excavation in stages from beginning to end. The permeability of the rock, and the propagation velocity and the attenuation of the seismic wave of the rock, as well as the deformation measurements using extensometer, were investigated. The results were summarized as follows.

① When the excavation reached to the elevation where the monitoring devices are placed, all the above-mentioned rock properties in original were considerably affected to change.

② Among those rock properties, the attenuation of the seismic wave was remarkably changed. Conseqently, the monitoring like this seemed to be an available measure to presume the relaxed zone.

③ As a synthetic estimation, it was made clear that the rock around the cavern can be classified to three zones , that is, relaxed zone- the deterioration area of rock, stress concentration zone- the incremental area of the rock properties, and elastic zone- little change or no change of the rock properties, after the excavation was made. (H-5)

(3) Study on the Permeability Change of Rock Mass Due to Underground Excavation

Motozima, I.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 199–204, 1984,

The permeability of rock masses around the underground cavity for an electric power station is measured through the period of excavation.

Main obtained results are as follows.

1) The permeability in rock mass around the underground cavity increases due to excavation, and hundreds times at the point of about 5m distance from the underground cavity.
2) The relation between permeability and state of joint in rock mass has been obtained through measurement.

$$\Delta D = 0.774\{(N_A^2\ L_{uA})^{\frac{1}{4}} - (N_B^2\ L_{uB})^{\frac{1}{4}}\}$$

where ΔD :	change of joint width	(mm/m)
Lu:	permeability	(Lugeon)
N :	joint frequency	(jts/m)
A :	after excavation	
B :	before excavation	

3) The permeability change has a remarkable correlation with the joint frequency at before excavation. (H-5)

(4) Application of the Beam Element Method for Analysis of Interaction between Rockbolts and Surrounding Rock

Kondoh, T. and Tsuchiya, H.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 227–232, 1984,

The authors have developed a new method for analyzing the interaction between rock bolts and the surrounding rock. The method uses the bending of a cantilever arm between the rock bolt and rock. This bending corresponds to the movement of the rock. Constant shear spring coefficient is determined analytically from measurements of rock bolt axial stress and relative displacement in the rock mass. Although the rock bolt and the cross section for analysis are usually situated 3-dimensionally in relation to one another, 2-dimensional FEM analysis can be easily applied in this method.

This paper presents an example of analysis of constant shear spring coefficient using measurements of rock bolt axial stress. When the constant thus obtained is used in FEM analysis of tunnel deformation and rock bolt axial stress, the results show good agreement. (H-5)

(5) A Study on the Mine Roadway Deformation in Soft and Weak Rockmass of the Kuroko Mine

Amano, K., Asami, N., Yamatomi, J., Yamashita, S., Kawabe and Qiao C.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 257–262, 1984,

The maintenance of the underground mine roadway in soft and weak rockmass is an important and serious problem for the Kuroko mines. Since the stability of underground openings is largely affected by the fractured zone (plastically deformed region) occured in the surrounding rockmass, it is necessary to estimate the size of the plastic zone quantitatively by theoretical analyses and in situ measurements.

Several published results of in situ measurements shows that axial force induced in grouted rockbolt has distinctive distribution with peak. If the boundary of the plastic zone coincides with the peak location of induced axial force, the estimation of the size of the fractured zone will be easily performed. In order to clarify the relationship between the size of fractured zone and the location of the peak value of axial force distribution in grouted rockbolt, in situ measurement has been carried out at Matsumine mine in Akita Prefecture. The mine roadway selected as the experiment site was located about 300m below the surface and was supported by the blocked steel sets.

The Convergence of the mine roadway, movement occurred in the surrounding rockmass and axial force induced in the rockbolts increased rapidly during the roadway face advance, but the rate of increment decreased largely after the roadway face advance terminated. However the convergence and rockmass movement were steadily increasing with time and showed none of the evidence of leveling off. The major principal strain and its direction calculated from the convergence of the roadway were almost same for all measurement sections.

Although the magnitude of the peak value varied in aforementioned manner, the peak location of the measured axial force distribution unchanged with the roadway face advance and the time elapse.

The measured rockmass movement after the heading advance having terminated was much larger than the calculated value with the theory of elasticity. Therefore, the rockmass movement was caused mainly by the time-dependent deformation and increased with the plastic zone expansion.

The obtained results of in situ measurement were compared with that of so called "Trap-door" tests carried out at the laboratory. According to these results, there seems to be no relation between the size of the plastic zone and the location of the peak axial force. However, it is necessary to carry out a theoretical analyses to verify the experimental results. (H-5)

(6) A Method of Evaluating Plastic Zone around Tunnels Based on Field Measurements

Sakurai, S., Shimizu N. and Matsumuro, K.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 263–268, 1984,

Field measurements have been widely recognized as a potential tool for the rational design of tunnels and monitoring of its stability during excavation. Nevertheless, it is a difficult task to select an adequate excavation method and suitable support measures.

This paper presents a method to evaluate a plastic zone occurring around tunnels by displacements measured during tunnel excavation. The plastic zone is an important information for assessing the tunnel stability and the design of support measures. The method is based on the interpretation of strain around tunnels, i.e., the normalized initial stress (initial stress divided by Young's modulus) is back-analyzed from the measured displacements. The maximum shear strain is then calculated by an ordinary linear elastic analysis. All the analyses are carried out by finite element method. Elasto-plastic boundary can be determined by choosing one of the contour line of the maximum shear strain equal to the critical shear strain of materials which may be determined in laboratory experiments. Some numerical simulations prove that the proposed method is applicable to engineering practice. (H-5)

(7) Fundamental Study on the Stability of Large Underground Rectangular Excavation in Soft Rock

Kikuchi, K., Shimizu, H., Ono, Y., Onishi, M., Wakabayashi, N. and Michiie, T.
Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 275–280, 1984,

The Neogene Tertiary layer mainly made of soft rock is widely distributed in Japan. In the near future large underground excavation in this layer will be planned and made use of. At that time the stability will be the most troublesome ploblem.

This paper describes the numerical analysis on the stability of the large underground excavation in soft rock and its evaluation of the stability. Underground quarries in "Ohya-Stone" were analysed as typical openings in soft rock mass. These openings are situated at the depth of 100-130m and their hight are 10-50m, having been mainly excavated by room and piller method. The numerical models were determind from the results of boring and the site investigation. Material constants were evaluated from laboratory core tests and tri-axial tests. Power function criterion (Yoshinaka & Yamabe) and the another (Hoek & Brown) were used for the failure criteria to obtain the strength of "Ohya-Stone", which has non-linear failure envelop. Two dimensional FEM, three dimensional BEM and no-tension analysis were carried out. These contain shafts, single and multipule underground excavation.

According to the comparison between the results of analysis and the site investigation, adaptability and problems of the analysis and evaluation of the stability are described.

The results are summerized as folloes.

(1) The results of stability analysis are found to show relatively good correlation with the actual condition of the openings.
(2) The long-term stability of the opening under critical state higly depends on the rock mass characteristics of strain-softning and on moisture change, re-filling up the openings and the supporting system. (H-5)

(8) Investigation of Rock Failure Caused by Underground Excavation of Ohya Stone Quarry

Yoshinaka, R., Fujieda, M., Ohhashi, S. and Hasegawa, M.
Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 281–286, 1984,

The building stone called Ohya-Ishi (Ohya stone) has been excavated from olden times, since several hundreds years ago. The area which quarries are distributed covers about 4 x 6 km in the west of Utsunomiya City. In early days, surface or near surface excavation had been adopted, nowadays, however, deep underground excavation of room and pillar method has been adopted, and the depth of openings ranges at the level of about 60 - 130m. As well known, Ohya stone is a pumicious welded tuff and typical soft rock. Many types of rock failure in pillars, side walls, roofs and floors have been occurred according to the increase in the depth of excavation. Ohya stone is excavated from the Ohya Formation of Miocine period. Though this which yields Ohya stone has some pre-existing fractures with seam, their spacing are very wide and the rockmass is very homogenious, non-laminative and massive. So that, the openings in Ohya Formation can be regard as a model opening for the study about stability of opening in soft rock, and further the physical properties of Ohya stone have been well investigated by many researchers.

The purpose of this paper is to present the fundamental data as to the study mentioned above. The main results are as follows: geometry and distribution of underground openings being at work and abondoned, geological conditions, characterisitcs of pre-existed and induced fractures (orientation, displacement, frequency, etc.) in pillars, side-walles, roofs and floors, and some consideration on the stability of large scale underground opening in soft rock. (H-5)

(9) Behaviour of Rock Mass during Excavation of Large Cavern for Pump-Storage Powerhouse

Motojima, M. and Hibino, S.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 287–292, 1984,

About twenty underground caverns for pump-storage powerhouses have been excavated in Japan. In these sites, during construction period, many kinds of measurements were carried out around the cavern in order to check the stability.

In this paper, feature of rock behaviour around the large cavern, obtained by the results of actual measurements in many sites are described :

1) Ferro-stresses (σ_s) in arch concrete lining increase with the convergense of arch span (δ_H) caused by deformation of rock mass around the cavern, and the magnitude is related to the cavern length (L). Relation of actual results of measurements can be expressed by the following formulae

   $\sigma_s = R_c \cdot L, \quad \delta_H = R_d \cdot \sigma_s$

   and values of R_c and R_d differ between igneous rock sites and the others.
2) Difference on behaviour of rock deformation due to positions in the cavern such as roof, side walls and back wall are found by the results of multi-stage-extensometers in rock mass.
3) In the case of egg shaped cavern, the difference mentioned 2) is not so remarkable.
4) Local characteristic of geological condition around the cavern have great influence on the behaviour and stability of the part of the cavern. (H-4)

(10) A Method for Inverse Calculation of c and ϕ on a Slip Surface Based on the Janbu Method

Yamagami, T. and Ueta, Y.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 299–304, 1984,

A new method is presented for the inverse calculation of c and ϕ along a given slip surface in a landslide slope. The method, which is based on the Janbu method, satisfies the condition that the given slip surface must have a minimum factor of safety, as well as the so-called c - tanϕ relationship.

The authors have previously presented inverse calculation methods in which the Fellenius and Simplified Bishop methods were employed as the factor of safety equations. The significance of these methods has been ascertained by applying them to some problems. However, these methods can obviously handle only circular slip surface problems.

This paper deals with a further extension of the preceding methods to non - circular slip surface fields where the Janbu method is used to express the factors of safety. First, the fundamental concept and a way to determine the c - tanϕ relationship for the Janbu method are described. Then, a procedure to assume trial slip surfaces is given on the basis of polynomials. The combination of each of these trial slip surfaces with the c - tanϕ relationship gives a range within which the unknown parameters, c and ϕ, should exist. In theory this leads to nearly the exact solution.

Finally, two example problems are analysed to examine the availability of the newly proposed method. The results of the analyses show that the proposed method provides the accurate strength parameters. However, the two example problems are based only on the total stress approach. Therefore, further research in terms of the effective stress analysis may be needed for final conclusions. (H-4)

(11) Results of the Stress Measurement of Bifurcated Penstock

Horiguchi, J., Nishiwaki, Y. and Ota, T.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 323–328, 1984,

The branching type for the penstock at the Tanbara Power Station of the Tokyo Electric Power Co., Inc. is two-way branching, with a designed internal pressure of 817m. The pipe is made of HT 80 steel, with a diameter of 4,200mm and 2,900mm before and after the branching section, respectively. The branching type was determined through a hydrologic simulation using a 1/22 scale model, a design calculation using the finite element method, and stress measurement using a 1/4 scale model. Consequently, the shell branching type was adopted due to its advantages in both hydrological and structural terms. A stress gauges and other instruments were buried with the branched pipe, and measurement data of the pipe stress were compared with the above calculated values. All measurements were found to be less than the corresponding calculated values, and the actual pipe was not affected by local deformation, which had been assumed in the designing stage. These differences are considered to be due to the effect of the constraining force of the surrounding concrete and rock. (H-5)

(12) Study on Leakage in Pressure Tunnel

Fujino, K. and Hori, M.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 329–335, 1984,

Design of pressure tunnel such as headrace and tailrace tunnels in hydro power plant has a relatively long history, and the design procedure has already been properly established so far. As an appearance of pumped storage hydro power plant with relatively high head in recent years, however, the design conditions of pressure tunnel has become severe. Namely, internal water pressure tends to increase in recent power plants, and there are some cases where the alignment of tunnel has to pass through unfavorable geological condition. Therefore, prudent design and performance of construction are required from viewpoints of both structural security and water tightness. There has been reported little paper which describes design philosophy on leakage in pressure tunnel. A resolute design procedure has not been yet established concerning high pressure grouting in the surrounding rock and prestressing of concrete lining.

This paper reports firstly observation results of amount of leakage which have been measured in headrace tunnel in several hydro power plants to be owned by Electric Power Development Co. Ltd. Theoretical approach is developed to estimate an amount of the leakage, supposing that apparent average coefficient of permeability of concrete lining is determined by width and number of cracks which are caused to appear in the lining under application of the internal pressure. In this case, the average coefficient of permeability of the lining is related to deformation characteristics of surrounding rock as well as internal and external water pressures subjected to the lining. It also makes comments concerning the idea of high pressure grouting generally performed in the surrounding rock and the efficiency. (H-5)

(13) Monitoring Microseismic Activity Induced by Working Coal Seams at Great Depth

Sato, K. and Fukushima, A.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 355–360, 1984,

A digital telemetry system has been developed for monitoring microseismic activity induced by mining and for predicting large scale rock failure around mining excavation including rockburst and coalburst. The system is capable of not only recording automatically microseismic event whose Richter's scale of magnitude is in the range from -2.0 to 0.5, but also determining automatically source location and updating a database about microseismic activity in a givem mining panel. This paper describes the microseismic activity associated with fully-mechanized longwall mining that took place at 1,100 m below the surface in Horonai Coal Mine. The spatial distribution of seismic energy around coal face is discussed in order to elucidate fracture zone adjacent to coal face. Magnitude frequency relation of microseismic events and variation of seismic energy release with face advance are also taken account to description of fracture mechanics of longwall mining.

Finally the focal mechanism of microseismic event is determined from a triple dipole forces model to estimate the orientation of principal stress axes in the focal region. (H-5)

(14) Construction of In-Ground Tanks for Crude Oil at Mizushima Refinery

Konno, T., Kanbara, M., Watanabe, H. and Yanagiya, K.

Journal of the Japan Society of Civil Engineers, Vol. 69, No. 8, pp. 31–38, 1984,

The first floating roof in-ground Crude Oil tanks in the world with the volume of 260 thousand kl have been completed. This paper especially describes the method to forecast ground-water volume pumped up that is essential to maintain the pumped storage system for these tanks as well as the process of construction.

(H-5)

(15) Design of Frozen Rock Roof Method and Its Application to the Construction of Nunobiki Tunnel

Murayama, S. and Ohno, K.

Journal of the Japan Society of Civil Engineers, Vol. 69, No. 12, pp. 51–58, 1984,

The frozen rock roof method is essentially new in which a new tunnel is excavated under a frozen rock roof. The method was applied to the Nunobiki tunnel which passes fifteen meters under the existing Kobe tunnel of the Shinkansen. This report summarizes the design and the construction of the Nunobiki tunnel.

(H-5)

(16) Present Situation of Underground Fuel Stock Piling and Water-Seal System

Sato, K.

Journal of the Japan Society of Civil Engineers, Vol. 70, No. 9, pp. 48–54, 1985,

This report describes the present situation of underground stock piling in Europe and Japan. Hydraulics of underground water incomings and outgoings, water-seal system, and on-site investigation and monitoring of underground water are also mentioned.

(H-5)

(17) Observation and Study on Dynamic Behavior of Rock Cavern during Earthquake

Hamada, M., Sugihara, Y., Shiba, Y. and Iwano, M.

Proceedings of the Japan Society of Civil Engineers, No. 341, pp. 187–196, 1984,

The authors conducted an earthquake observation and study in a railway tunnel constructed in a hard rock, where the dynamic strains in the concrete lining and the earthquake motion in the surrounding rock were measured simultaneously. By analyzing the earthquake records, the following results were obtained.

1. Maximum acceleration measured in rock is from 1/3 to 2/3 of that measured at the portal in the horizontal direction, and is from 1/3 to 1 of that measured in the vertical direction.

2. Maximum acceleration in the vertical direction is from 1/3 to about 1 of the acceleration in the horizontal direction. The ratio is larger than that of other results measured in the Quaternary.

3. Maximum lining strain is not more than 2×10^{-6} for the seismic motion in rock with 30 gal maximum acceleration. This result confirms engineer's empirical knowledge that caverns excavated in sound rock are highly earthquake resistant.

4. The lining strain of the tunnel is linearly and statically related to rock strain during earthquakes. The ratio of lining strain to rock strain is dominated by the relative stiffness of the lining and rock. (H-5)

(18) State-Of-The-Art and Future Trends of Rock Cavern Opening Techniques

Mimaki, Y.

Proceedings of the Japan Society of Civil Engineers, No. 352, pp. 23–39, 1984,

Concerning the large rock caverns, the author described the state-of-the art and some future trends on the in-situ investigation on rock properties, design criteria and excavation techniques.

At first, the importance of in-situ rock tests to estimate the behavior of fractured rock mass considering stress conditions according to the excavation is pointed out. And examples of the evaluation of rock deformability using in-situ triaxial tests and stress relieving large flat jack methods are described.

Secondly, the history of design philosophy is reviewed and a few actual examples of large underground openings in Japan are introduced.

Finally, the development of excavation methods is briefly reviewed and the importance of the establishments of new techniques such as systematic investigation on various rock conditions, highly accurate and rapid excavation equipments, the actual observational construction method are states. (H-5)

(19) Theory and Design of Foundations on Slopes

Nakajima, E., Tabara, K. and Maeda, Y.

Proceedings of the Japan Society of Civil Engineers, No. 355, pp. 46–52, 1985,

Design method and problems of bridge foundations, which are constructed on slopes of mountaneous areas, are examined from practical point of view.

The types of foundations studied are shallow foundations and Sinso piles (Cast in place piles on slopes).

1. Shallow Foundation

As a practical method for calculating bearing capacity of shallow foundations on slopes, the method by Japan Highway Public Corporation is thought to be the only one available today. Sallow foundations with steps, however, are practically often used in order to decreace excavation. In this case, estimation of bearing capacity becomes quite complicated. Therefore, influence of stepes on the bearing capacity is studied and simple design method is proposed.

2. Sinso Pile

Elasto-plastic analysis has been used as a method to evaluate deformation and stability of foundations. However, it is shown that the analysis is not appropriate judging from recent is-situ tests. Therefore, A practical design method is proposed. The basic concept behind it is that the order of soil coefficient eualuation and that of analysis should properly be balanced. It is proposed to analyse deformation and stability separately; the former by elastic analysis and the latter by ultimate equilibrium analysis. The proposed method offers reasonable results judging from the past experiences. (H-1)

(20) Rapid Construction of a Long Headrace Tunnel of Shinaimoto Hydro-Electoric Power Station

Sugiki, K. and Yoshikawa, T.

Proceedings of the Japan Society of Civil Engineers, No. 355, pp. 81–90, 1985,

This article describes the epock-making rapid construction procedure employed by The Kansai Electric Power Company, Inc. ("Kansai Electric") in an effort to construct a long headrace tunnel in a shorter lead time for early completion of its 124-megawatt "Shin-Aimoto" (renamed now as "Otozawa") hydro power plant which started commercial operation in September 1985.

The headrace tunnel has a total length of 10,813 meters, and the rapid construction procedure was applied to its 5,735 meter-long segment where no access tunnels could be placed due to environmental restrictions.

The segment was divided into two parts: 2,355 meters on the upstream side and 3,380 meters on the downstream side.

On the upstream side, the long hole blasting method and NATM(New Austrian Tunnelling Method) were employed. With four-boom hydraulic gantry drifters mounted on a sliding floor, 4.5 meter-long charge holes were drilled to excavate full face of 30 square meters. The maximum tunnelling speed thus reached 258 meters per month.

On the downstream side, the pilot-reaming TBM excavation method was applied. Excavation of both pilot tunnel (3.6 meters across in diameter) and reaming (from 3.6 meters to 6.1 meters in diameter) proceeded at the speed of over 400 meters per month.

When reaming, invert concrete placement was made under beltconveyer of TBM and arch concrete placement followed 400 meters behind invert concrete placement.

For excavation of fractured zones running 500 meters long in this area, a newly developed shotcrete method and long fiber reinforced plastic (FRP) rock bolts were applied as supporting material.

The rapid construction of tunnels using TBM or long hole blasting method has been considered as inapplicable in Japan, because of its intricate and complex geological conditions. As a result of the success of this project, the authors believe that such rapid construction procedure will be accepted with high appreciation and widely employed in the similar future civil engineering projects. (H-5)

(21) Effect of Pipe-Roof in Tunnelling Method

Ohkawa, T., Yokoyama, J., Ishihara, H. and Kojima, W.

Proceedings of the Japan Society of Civil Enigneers, No. 355, pp. 100–107, 1985,

Recently the pipe-roof-method has been often carried out as tunnelling sub-system. There is an important problem, surface subsidence, for excavation of thin overburden tunnel. One of measures against the behaviours is pipe-roof-method which can suppress them fairly.

Only equilibrium, which can calculated in some ways as external forces, are taken into consideration. But the displacements are not introduced by them, while it is most important for pipe-roof-design. From measurement of displacement and pipe-roof works pipe-roof-effects are found, as follows.

1) In supported are, pipe-roof works with a support.
2) Out of supported area, pipe-roof makes displacement of rock mass small. (H-5)

(22) A Geotechnical Evaluation Method for Dam Foundation Rocks in Consolidation Grouting – Examination in Oguchigawa Dam –

Kikuchi, K., Saito, K. and Harumatsu, Y.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 186–190, 1982,

Oguchigawa Dam is a 72m high concrete gravity type dam intended for creating a reregulating reservoir of Arimine Third Power Plant developed by Hokuriku Electric Power Co., Inc. This report describes a geotechnical evaluation method applied to dam foundation rocks, in order to examine the design, execution and effect of consolidation grouting in this dam foundation.

1) With regard to the dam foundation rocks, the weathering of rocks and the distribution of cracks were investigated in detail and analyzed, to make a grade map and a crack density map, and to examine the bearing resistance and permeability of the foundation rocks. According to the results, the conditions of rocks in the access to the river bed are relatively good, while in the access to both the banks are somewhat bad.

Furthermore, the permeability of rocks showed correlation between rock compactness and crack density; the worse the condition of rocks and the higher the crack density, the higher is the permeability.

2) As for the design and execution of the consolidation grouting of the dam foundation rocks, "rock property" numerically expressing the quality of rocks was contrived to evaluate the rocks, and to select the locations of grouting. In the case under consolidation grouting, the access to the river bed on which a large force would act from the dam, shows that "2" or more points of the rock property rock needed grouting in principle, while the access to both banks shows that "3" or more points needed to be treated as aforesaid. According to the permeability tests carried out in consolidation grouting, the results show that the coefficients of permeability of rocks with a rock property index of "1" is equal to $5.^{0} \times 10^{-5}$ cm/sec. or less, and of rocks with a rock property index of "2" is equal to $1.^{0} \times 10^{-4}$ cm/sec. or less respectively. These results are surmised to support that the above selection standard is almost proper. Furthermore, according to the result of consolidation grouting, the rock property index showed correlation with the quantity of cement grout. The larger the rock property index, the larger the quantity of cement grout. This means that the rocks are improved.

Comprehensively judging from the above, it can be said finally that the evaluation in reference to the rock property index is very effective in examining the design, execution and effect of consolidation grouting. (H-1, K-4)

(23) Behavior of Rock Mass around Large Caverns During Excavation Works

Hibino, S. and Motozima, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 66–70, 1983,

This paper describes the mechanical feature of rock behaviour during excavation, obtained from the results of measurements at many sites of pump storage power station.

By the comparison of the measured values of stress in arch concrete lining of each cavern, and observation of the difference on the time history and distribution of displacements bitween measurement and calculation, The followings were disclosed:

(1) The values of stress in arch concrete lining varied with the kinds of rock mass; ratio between the values in sedimentary rock and igneous rock is about 1 : 2 ~ 1 : 3.

(2) Stress in arch lining is mainly caused by the displacements of rock mass neiboring side walls of the cavern.

(3) Actual displacement of rock mass is caused by strain of rock and joint opening, and the latter is larger than the former.

(4) Joint opening depend on extent of surface of the cavern wall. (H-5)

(24) On Bahavior of Tunnel Supporting System Applied to Shallow Overburden Tunnel in Soil

Yokoyama, A., Terado, Y., Kimura, K. and Ikeda, H.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 71–75, 1983,

It is well - known that there are differences between ground behaviour caused by shallow overburden tunnel and that by ordinary tunnel. So we think that supporting system with shotcrete, steelrib and rockbolts applied to shallow overburden tunnel in soil behaves characteristically.

The authors had a chance to measure stress, strain of support members to each phase of tunnel excavation.

In this paper the authors want to introduce the result and its consideration.

Consepuently two conclusions which are as follows are given

1) Shotcrete, steelrib, and rockbolts behave sensitively to each phase of tunnel excavation. Particularly shotcrete and rockbolts are strongly influenced by lining but this phenomenon is very temporary.
2) In spite of very small dimension of supporting system, supporting system could fill its function effectively.

(H-5)

(25) On the Displacement Measurements of Surrounding Rocks during the Excavation of Two Shield Tunnels under the Bridge Structures Temporarily Supported

Sawada, J., Tasaki, K., Kondoh, T., Tsuchiya, H., Mori, T. and Abe, T.
Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 76–80, 1983,

During the excavation of two subway tunnels under the bridge structures, displacement measurements were carried out by Sliding-Micrometer developed by Kovari for vertical direction and Inclinometer for two horizontal directions.

The data of displacements of which measuring points were set 0.5 or 1.0m in each intervals in the borehole have been obtained through the periodes from when the tunnels came near the measuring section beforehand, to the far distances forwardly.

As a result, the deformation behavior of the surrounding rocks during excavation are shown in this article.

The authors show that these behaviors will be based on the inhomogeneity of rocks, considering the correlation of actual distribution of displacements to the results of numerical calculation by FEM in which the rock condition is assumed to be isotropic, homogeneous and elastic one.

(H-5)

(26) Measurement and Analysis of Tunnel Excavated in Expansive Stone

Hirano, I., Takeda, N., Honma, N. and Sato, M.
Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 81–85, 1983,

A lot of trouble has been experienced in tunnelling in expansive ground, such as Hiburi, Noshiro, Akakura, Nabetate and Nakayama tunnel. Advanced studies have been carried out to solve those troubles, however the mechanism of expansion has not been explained clearly. There needs a proper method of design and tunnelling for the expansive ground.

Authors show a tunnel excavated in expansive mud stone by NATM. Measurement results show a typical time-dependent deformation behavior, and it is assumed that this behavior is due to the plastic flow with time-dependent decrease of strength. According this idea, a numerical model of expansive ground is proposed and a numerical simulation of NATM is carried out.

Analyzed results show a good agreement with measured one. (H-5)

(27) Ground Behavior during Thin Overburden Soil Tunnel Excavation

Yokoyama, A., Fujimori, F., Hirano, I. and Kamemura, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 86–90, 1983,

In designing and excavation of thin overburden soil tunnel, it is very important to understand 3 dimensional ground behavior around tunnel face. This report describes a part of investigated results of field measurements at Horinouchi Tunnel that is excavated in soft sedimentary, and cohesionless soil with thin overburden.

According to the results of these measurements, the following are concluded.

1) Ground behavior during thin overburden tunnel excavation is mainly subjected to the longitudial peripheral deformation around tunnel face. For the safely and efficiently tunnelling, it is very important to know this deformation.
2) Ground surface settlement is occured in about 0.5D before tunnel upper face, where D is equal to 10.7m, which means a diameter of cross section. It is recognized that about 20-30% of total ground surface settelment occurs by this time.
3) It is possible to excavate thin overburden tunnel in soft sedimentary and cohesionless soil under macroscopic elastic ground condition with early supporting system by shotcrete.
4) It is recognized that ground arch effect is developed in the case which overburden thickness is more than 0.5D. (H-5)

(28) Coupled Boundary-Finite Element Analysis of Structures on Multi-Layered Strata

Mitsui, Y., Ichikawa, Y., Obara, Y. and Kawamoto, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 111–115, 1983,

A boundary element analysis coupled with finite elements is proposed to simulate structural behaviours of a footing on horizontal multi-layers. The analysis involves two types of finite elements, that is, the constant strain triangle(C.S.T.) and the Goodman's joint. The Goodman's joint elements are built in between layers, then contacted behaviours of layers can be easily culculated. That is, shearing slips between layers are aptly described by this procedure under several conditions of the filled interface materials.

The major advantages to use the Boundary Element Method (B E M) is that it requires only boundary discritization of each homogeneous zone, and it is able to account for an infinite region. On the other hand, the Finite Element Method(F E M) is possible to specify the local properties of Materials which are even nonlinear. Thus the coupling of two methods ennables us to solve quite large fields of engineering problems.

Further investigations are expected for nonlinear analysis of the layer and the interfacial materials. (H-1)

(29) Optimal Location of Measurement Points in Underground Openings in Connection with Back Analysis of Measured Displacements

Shimizu, N. and Sakurai, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 175–179, 1983,

This paper presents a method of back analysis for the interpretation of field measurements in underground openings, and discusses the optimal location of measurement points for obtaining accurate results from the back analysis.

In the first half of the paper, a back analysis method is formulated using the Boundary Element Method, which assumes the rock mass in which the underground openings are excavated to be homogeneous, linear, isotropic, and elastic. Assuming the values of Poisson's ratio and the vertical component of initial stress, the method yields a complete initial stress field and Young's modulus from a set of displacements measured during the excavation of underground openings.

In the second half of the paper, the optimal location for displacement measurements is investigated using the results of numerical simulations for illustrative examples.

The conclusions are as follows:

1) Borehole extensometers should be installed not only in vertical and horizontal directions, but also in a diagonal direction, to get a better estimation of initial stress and material parameters.
2) The measurement lines of convergences should form at least one triangle. (H-5)

(30) Estimation of Loosening around Mining Face of Shallow Overburden Tunnel in Soil

Yokoyama, A., Fujimori, F., Terado, Y. and Kimura, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 180–184, 1983,

As tunnelling meathod with shotcrete and rockbolts has remarkably utilized in Japan,we have a tendency to apply it to urban tunnel which is in demand very much . Generally urban tunnel is very expensive. There is a possibility that tunnelling method with shotcrete and rockbolt enables us to make up cheap urban tunnels.

We had a chance to excavate some tunnels in soil with shallow overburden . Geological condition of these tunnels is as same as that of urban tunnel and brings us danger of collapse.

In this paper authors deduce collapse of tunnel whose support is composed of shotcrete and rockbolts from behaviour of ground caused by tunnel excavation, and shows one effective index which is calld S_A-value and is derived from ground settlement to estimate loosening around mining face.

(H-5)

(31) The Failure Criterion for Rock Surrounding Tunnel and the Support Design — Approach to the Usefull Design Method for Tunnel —

Okabayashi, N., Inou, M. and Ohno, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 185–189, 1983,

We have made a study of the method to determine upon a failure criterion for the rock mass surrounding tunnel and analysis of rock - support interaction.

A failure criterion for the rock depends upon the relationship between the strength of the rock and the stress condition in it. On the basis of failure theories proposed by Griffith, Mhor and Coulomb, we have used the following empirical failure criterion.

"The failure criterion"

$$\sigma_1 = \sigma_3 + \sqrt{m\sigma_c \sigma_3 + s\sigma_c^2} \qquad (1)$$

where,

σ_1 is the major principal stress at failure

σ_2 is the minor principal stress at failure

σ_c is the uniaxial compressive strength of the intact rock

m and s are material constants which depend upon the properties of the rock

While, the failure criterion for a jointed rock mass may be determined by the same relationship to equation (1) to decrease the values of m and s according to the classification of rock masses. In order to check the applicability of the failure criterion, we have used about 1,000 data of uniaxial and triaxial tests.

Tunnel support has been designed on the theory that dead weight load acts on it. But actual support pressure is not only influenced by in situ stresses and the strength of rock,but also the stiffness of support and the timing of setting.

We have expressed the failure criterion for the elastic and plastic rock masses surrounding tunnel on the equation (1), and have explained about rock - support interaction analysis.

(H-5)

(32) Equivalent Modulus of Elasticity of Shotcrete Tunnel Lining

Shinji, M. and Sakurai, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 190–194, 1983,

Many privious works of tunnel analysis are based of the assumption that the irregularity of shotcrete linings is ignored. In fact, we aware of the fact that the analysis based on this hypothesis did not result in any agreement with field measurement and the effect of irregularity of shotcrete tunnel lining on the results of analyses was not investigated.

Considering these circumstances, in the present works, an equivalent modulus of elasticity is proposed by means of computer(F.E.M) simulation in order to evaluate the effect of irregularity of shotcrete lining.

It is concluded in this study that the irregularity cannot be ignored, so that the tunnel analysis must be done by introducing the equivalent modulus of elasticity proposed here, in order to take into account the effects of the irregularity.

(H-5)

(33) Inclined Shaft for Spillway of Arima Rockfill Dam

Fukushima, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 210–214, 1983,

Both right and left banks and shores at the location of Arima dam-site are very steep and the construction of the open channel spillway is so difficult that an inclined shaft type spillway was chosen.

The salient features of the spillway system with the inclined shaft are as follows;

Maximum discharge		720 m^3/sec
Length of inclined tunnel section		102 m
Angle made by the tunnel with horizontal		47°
Length of subsequent horizontal tunnel section		355 m
Maximum cross-section of tunnel excavations	27M x 15M ellipse	$A \approx 270m^2$
Minimum cross-section of tunnel excavations	ϕ 8.70M	$A \approx 70m^2$

(Minimum applies the bottom part of the inclined shaft and all subsequent horizontal section)

Rock conditions: Alternative strata of chert and slate, but these rocks had been badly shattered due to fault.

Tunnel driving was executed according to the New Austrian Tunnelling Method (NATM), but in our case some points were improved in comparison with ordinary NATM.

(1) Owing to its very large cross-section, the ring closure time, which is normally recommended as less than one month from starting excavation of the part, was assumed to exceed six months, therefore we paid special attention to choose a type and dimensions of the supports.

(2) To prevent from loosening of the surrounding ground, very low bench height (1.6m) was chosen. (Normally 4 - 5m is applied.)

(3) Long bench length was chosen to enable effective tunnel excavation. Heavy bulldozer with ripper was adopted to excavate centre portion of the tunnel rapidly at first.

Above mentioned measures were taken in order to avoid loosening of the surrounding ground. We believe that very low bench height particularly contributed much to avoid ground loosening and to carry out effective work.
Thus, with improved NATM, we were able to excavate this large inclined tunnel successfully, safely and economically. (H-5)

(34) Cause of the Crack in Inner Lining of the Tunnels Excavated by NATM

Fukushima, K. and Chikahisa, H.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 215–219, 1983,

Recently, the New Austrian Tunnelling Method (NATM) has been adopted at many tunnelling sites in Japan.

This method is aimed at supporting the ground pressure by the surrounding ground itself which shall be reinforced by outer lining (shotcrete, anchor bolts, etc.).

Inner lining mainly has an intention to finish the smooth inner surface of the tunnel with nice outlook reducing the resistance of waterflow as well as for the convenience of attaching ceilings, lamps, signals, etc..

However, in many tunnels many cracks on the surface of inner linings occurred which mar the workmanship and allow the glow of icicles.

These phenomena have been rare in the case of conventional tunnel driving method, therefore it is assumed that a statical behavior of the tunnel executed by NATM could be the main cause.

The authors proposed that cracks were caused by certain point load due to local contact between outer and inner linings and the residual settlement of surrounding ground.

Certain observations, measuring data, calculation formula and calculation results of stress and displacement of inner lining are attached. (H-5)

(35) Statistic Analysis of Measured Results under NATM

Yoshikawa, K., Asakura, T., Hiyoshi, S. and Endoh, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 220–224, 1983,

On the tunnel construction, it has been emphasized every time that the importance to reflect the measured results to its designing and execution. However, it might be hard to say at present that the practical application of the measured results for the construction works is thoroughly carried out. Because there are no indications of practical feed back methods or control criterias.
Originally, the techniques of feeding back and the control criterias for supporting pattern have to be determined based on the results of measurements and observations with each tunnel. However, it would be required to establish some control criterias as a standard during designing and at the early stage of construction work.
This study aimed to establish a standard control criterias based on the actual measurements and observations to meet the above-mentioned purposes, is a description regarding the convergence on the static results of measured values over the 821 measuring sections in 50 tunnels constructed by NATM.

1) The data used for this analysis are classified into 5 stages from the lighter to the heavier based on the supporting pattern.
2) When the boundary to the specially classified pattern is placed to the point where the ratio between the diameter of tunnel and the convergence ($\Delta D/D$) changes less than 1.5% and the pattern I and II are classified by convergence, the criterias in controlling construction pattern will be shown in the following Table.

	V~II (mm)	I (mm)	Special Pattern(mm)
Single Track	Less than 25	25 - 75	More than 75
Double Track	Less than 50	50 - 150	More than 150

3) In order to predict the final convergence at the stage as early as possible during construction works, the relative relation between the maximum deformation velocity ($\delta vmax$) and the maximum convergence (δmax) will be shown by the following equation:

$$\delta max = m \cdot \delta vmax$$

Where,

Excavation Width	Excavation Method	m	Correlation Coefficient
Single Track	Full Face	2.04	0.93
Double Track	Full Face	2.82	0.79
Single Track	Bench Cut	5.01	0.64
Double Track	Bench Cut	7.24	0.89

(H-5)

(36) Management of Tunnelling by NATM with Strain Softening Behaviour

Kadota, S. and Ishii, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 225–229, 1983,

An excavation pattern is one of the main management items of tunnelling by NATM. Especially, the careful management is demanded for bedrock with bad ground condition as strain softening or swelling phenomena. Managed suitable control for excavation like this, it is not only necessary for measurements of rock behaviour by excavation, but also for knowledges of difference one by some different excavation patterns.

This report describes, for use of management, the results of the parametric analysis that varied factors had an effect on rock around excavated zone, and excavation patterns.

The contents can be summarized as follows.

1). There is a large difference in plastic zone and deformation mode by some different excavation patterns.

2). The distribution concerned with bearing force is changed by some different excavation patterns.

3). The progress of the residual zone is one of the problems of stability bedrock. It is greatly affected with the coefficient of lateral pressure.

(H-5)

(37) Result of Measurement on the Bearing Part of the Rock of Internal Hydraulic Pressure in Penstock

Miyake, K., Horiguchi, J., Nishiwaki, Y. and Ota, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 265–269, 1984,

Tanbara Power Station is of a pure pumped-storage type with ultimate total output of 1,200 MW (300 MW × 4), owned and constructed by the Tokyo Electric Power Co. at the upstream of Tone River. On December 17, 1982, the 1st term units of 600 MW (300 MW × 2) were put into initial operation.

Each of penstock lines No. 1 and No. 2 has a total length of about 920 m. It is buried in the inclined shaft over a length of about 420 m. In this section, a part of internal hydraulic pressure is burdened to the rock-bed in the relatively stabilized condition for a length of about 200 m.

Rock in this pressure-burdened section is graded within a range of CH to B, consisting of conglomerate in the Tertiary, though it partially contains fracture zones.

The Formula in the Technical Standards for Hydraulic Gate and Penstock was used in designing the bearing part of the rock. Furthermore, study was conducted by use of the two-layer model of relaxed zone and sound zone in the state of plane strain.

In the meanwhile, external pressure was calculated by application of the E. Amstutz under the Technical Standards for Hydraulic Gate and Penstock. Rock properties used for design were determined finally with consideration to the results obtained from plate bearing test, water chamber test and seismic test.

In order to identify the acceptability of the designed coefficient of the bearing part of the rock, instruments were installed for measurement on both of No. 1 and No. 2 penstocks, each at selected positions from both relatively poor and good rock properties within the pressure-burdened section.

The results of comparison between designed and actually measured values are as follows:

(1) The actually measured results on the coefficient of the bearing part of the rock with relatively poor rock properties were averaged at 40 percent within a range of 32 to 50 percent for No. 1 and averaged at 33 percent within a range of 25 to 51 percent for No. 2, while the designed coefficient of the bearing part of the rock is 19 or 20 percent for No. 1 and 20 or 21 percent for No. 2 respectively.

(2) The actually measured results on the coefficient of the bearing part of the rock with relatively good rock properties were averaged at 63 percent within a range of 45 to 73 percent for No. 1 and averaged at 56 percent within a range of 40 to 68 percent for No. 2, while the designed coefficient of the bearing part of the rock is 31 or 32 percent for both No. 1 and No. 2 alike.

As identified from those results of measurement, the actually measured values of the bearing part of the rock exceed far above those originally designed at each measured point.

It is therefore intended that by further analysis of such measured values the result of analysis should be incorporated into the design to seek the more reasonable coefficient of the bearing part of the rock.

(H-5)

(38) Mechanical Behavior of Rock around Cavern of Shimogo Underground Power Station after Completion of the Excavation

Hori, M. and Washizawa, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 270–274, 1984,

The dimension of the underground power station in Shimogo pumped storage hydro plant project is 171 m in length, 45.5 m in height and 22 m in width. The rock surrounding this cavern is consisted mainly of diorite, and partly of the formation of sandstone and shale lying underneath the diorite deposit. The excavation of the cavern has started on November, 1978 and finished on July, 1980, taking a period for about one and half years.

With aim of observation of mechanical behaviors of rock during excavation, rock movements and stresses in arch concrete were monitored. It was known from the results of measurement that the compressive stress of steel reinforced bar in the arch concrete increases linearly with convergence of the span in the cavern. Moreover, a relatively large rock movement was observed, 130 mm at maximum. After the cavern has beeen completely finished, the measurements are still continued up to now, in order to observe behaviors of the cavern after completion of the excavation.

According to these measurements, some interesting facts are found as follows; the change of arch concrete lining stresses is caused by a seasonal change of tempereature in the cavern. The change of temperature in the arch concrete is about 10°C in a year. And, rock displacements in side walls almost ceased as the excavation works was completed, and the change of rock displacement is actually zero. (H-5)

(39) The Deformation of Dam Abutment and Change of Permeability Due to the Fill Placement in Embankment Dams

Matsumoto, N. and Yamaguchi, Y.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 206–210, 1985,

Fill placement works on the dam foundation as overburden loading. This loading influences the stress states in the foundation resulting in the change of strain and permeability in the underground. At the 16th Symposium on Rock Mechanics of J.S.C.E. , one of the authors showed the observed results of the change of deformation and permeability in the dam abutment due to the fill placement. These results indicate that the tensile strain occurs temporarily in the abutment and then it turns to compressive strain in accordance with the decrease of permeability. These phenomena correspond to the stress and strain change obtained from computation.

This paper describes the measured results of these mechanisms in case of hard rock foundation, as compared with the case of soft rock foundation in the previous paper. The authors tried to confirm the fact that the decrease of permeability occurs even in the hard rock foundation in despite of small deformability.

Measured results indicate that permeability changes due to fill placement even in hard rock foundation as in case of soft rock. However, the change of permeability occurs while the fill placement reaches to five meter, and does not occur after that.

The authors feel that these results are very helpful for the determination of effective grouting and seepage control design in the foundation of filldams. (H-4)

(40) A Method on Rock Classification and Standard Supports System for NATM

Nagao, T., Takahashi, T. and Kawakita, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 226–230, 1985,

NATM has been rapidly spread for tunnelling method in last ten years in Japan. However,the methods for constructing tunnel economically and stablly at NATM,namely,ground evaluation method,standard design process and the means of controlling excavation by mesurements etc, are ont fully established now.

In this paper,we proposed the classification of rock masses and the standard supports system by analyzing the results of labolatory and in-situ tests,which were perfomed from the class of hard rock down to the one of squeezed or loosed ground, and further rearrenging various classification suggested to date.

The main results of analysis are follows,

1) Dynamic elastic modulus(E_d) vs. static one(E_s) relation:

$$E_d = k_1 \cdot E_s^{k_2}$$

where k_1 and k_2 is the constants dependent and independent on rock.

2) Static elastic modulus vs. compressive strength(σ_c) relation:

i) $\sigma_c \leqq 40 \sim 50$ (kg/cm^2) ; $E_s = \alpha \cdot \sigma_c^{\beta}$ ($\because \beta > 1$)

ii) $\sigma_c \geqq 40 \sim 50$ (kg/cm^2) ; $E_s = \alpha \cdot \sigma_c$

where α, β are constants.

3) The equation of estimation about compressive strength(σ_{cR}) on a jointed rock mass:

i) $\sigma_{CR} \geqq 43$ (kg/cm^2) ; $\log(\sigma_{CR}/V_P^2) = V_P/2,7 + k_{R1}$

ii) $\sigma_{CR} \leqq 43$ (kg/cm^2) ; $\log\sigma_{CR} = 1.3\log V_P + k_{R2}$

in which, V_P ; P wave velocity

k_{R1}, k_{R2}; constants dependent on compressive strength of rock specimen and elasic wave velocity of specimen or rock mass.

According to the results of analysis above mentioned, we attempted to make the table of rock classification for NATM from a viewpoint of practical use.

Furthermore, the standard supports system for every rock grade were also considered by meas of FEM etc. and discussed as to applicability of the system to a tunnel constructed by NATM.

Consequently, it is clear that the rock classification and standard supports system in this study is applicable to NATM tunnel. (H-5)

(41) Evaluation of Long Term Stability of Rock Cavern

Ishii, T., Fukuda, K., Izumiya, Y., Araya, S. and Mishima, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 231–235, 1985,

For the purpose to cralify the methods for evaluating a long term stability of rock cavern, an in-situ investigation was conducted utilizing roadways in existing old mines where factors injuring the long term stability acted in a complex manner. In-situ investigation was carried out in the total of 84 site including roadways of more than 100 years old after excavation in 7 mines. Main research items include uniaxial compressive strength, rock pressure strength ratio, Bieniawski's RMR, Q-value by Barton and stability index which was devised on trial bases for the present investigation.

From the relation between the stability index value and the elapsed time after the excavation, it was shown that the cavern would be maintained for more than 100 years when the stability index value was over 65. Because the lower limit of RMR value and conpressive strength which satisfying the stability condition is settled as the stability index value indicating the long term stability condition is provided, RMR value and uniaxial compressive strength is promising to evaluate the long term atability of rock cavern. (H-5)

(42) Theoretical Studies on the Design of Rockbolting in Tunnels

Saito, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 246–250, 1985,

The axial stress distributions in rock bolts induced with the tunnel face advance are analyzed theoretically, after they are installed close at the tunnel face. At first, the rock displacements around the circular tunnels with the advance of the face are caluculated under the three dimensional stress state. The axial stress in the rock bolts are induced through the fundamental interaction between rock mass and rock bolts accompanied with these rock displacement. The results obtained seem to be very useful as one of the standards to examine the measuring data.

Further, the fundamental design method for rock bolting based on the total amount of strain energy stored in the rock bolts is proposed. According to this method, the length and density of rock bolting can be estimated roughly. (H-5)

(43) Influence of the Inclined Diversion Tunnel on the Main Tunnel

Ito, F., Takeda, N. and Kamemura, K.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 261–265, 1985,

At the intersection area of the main tunnel and inclined diversion tunnel, the ground arch around the main tunnel is sliminated by the excavation and main tunnel yields unstable state. The ground around the main tunnel show the three dimensional behaviors of the stress and displacement.

Hence, at the intersection area, there are many complicated problems. However, these problems are not solved clearly and the excavation results of this kinds of tunnel intersection are very few.

Under these circumstances, authors have carried out the three dimensional FEM elastic analysis in order to clarify the three dimensional behaviors of the ground. The model for the analysis is shown in Figure 1, and the result of this analysis is shown in Figure 2, which means the consentration of the stress on the ground around the intersection. Based on the results of analysis, important points for design and excavation at the intersection are summarized as follows.

1) The concentration of the stress is 1.6 in the case of the inclined diversion tunnel and 1.2 in the case of tunnel at right angle.
2) The influential region is 2D in the case of the inclined diversion tunnel and 1.5D in the case of tunnel at right angle.
3) The distribution of the displacement is almost same in both cases and the vertical displacement is dominaut.

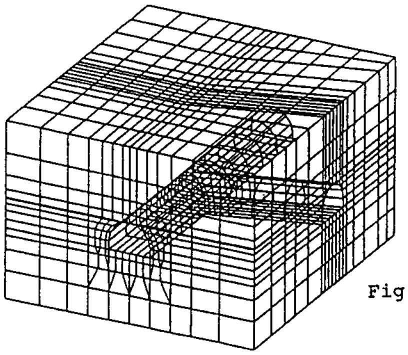


Fig.1 Three dimensional model for FEM analysis

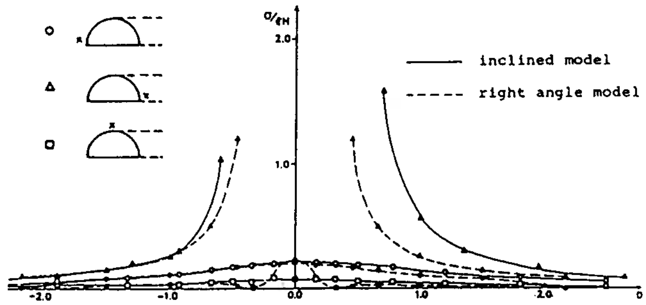


Fig.2 The concentration of the stress around the intersection ($\sigma h=\sigma v$, increment stress)

(H-5)

(44) Ground Behavior around the Tunnel Intersection

Mohri, M., Yamakawa, T., Mine, T. and Okada, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 266–270, 1985,

On the Myozin tunnel which is a part of highway crossing Shikoku island,longitudinal flow ventilation system has been adopted. In order to introduce this ventilation system, it is nessessary to construct electric bagfilter chamber beside the main tunnel.

This chamber is linked to the main tunnel by connecting tunnel, which has the same cross-section as the main tunnel. When the connecting tunnel is constructed, complicated re-distribution of stress in the natural ground in the vicinity of the main tunnel is anticipated to occur.

In the design of electric chamber and connecting tunnel, the followings are to be evaluated.

- The range of main tunnel affected by connecting tunnel driving.
- The distance along the connecting tunnel from the main tunnel beyond which connecting tunnel driving does not affect to the main tunnel.
- The required stiffness of supports of the connecting tunnel.

In this paper, We discuss the above mentioned items based on the results of measurements.

(H-5)

(45) Examples of Measurement and Analysis of Stress on Shotcrete Tunnel Walls in Sandy Ground

Uchiyama, C., Kurata, T., Kondoh, T. and Tsuchiya, H.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 271–275, 1985,

When using NATM in sandy ground, it is necessary to continually prevent erosion of the ground when concrete is sprayed and insure the successful adherence of the concrete.

The authors attempted to deal with these problems in the construction of a large water conduit by driving steel sheet piles into the ground before excavation. It was feared that the use of the sheet piles would weaken adherence between the shotcrete and the natural ground. However, measurement of stress on the shotcrete established that the load was born by both the shotcrete and the ground.

This paper describes the use of the steel sheet piles and the measurement of stress on the shotcrete by a Curvometer and a Deformeter. (H-5)

(46) The Base Friction Model Apparatus for the Simulation of the Ground with Cavity

Nishida, T., Esaki, T., Kameda, N. and Kakigawa, Y.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 276–280, 1985,

The base friction principle permits the replacement of gravity in the plane of a two dimensional physical model by drag forces acting along its base. In Egger's base friction apparatus, we have a trouble of strecting of endless belt in case of very large base friction forces.

The authors have improved a new base friction apparatus which has the very high stiff plate with uretan instead of the endless belt and its plate can move with very slow speed (10mm/min). So we can easily observe the behavior of ground deformation and failure.

This paper describes some experimental studies on the mechanism of cave-in by this apparatus.

The conclusions are summarized as follows:

1) By this technique, the progressive development of a settlement crack or roof collapse can be arrested and examined at any stage.

2) The behavior of failure of the model is simulated to the ground with cavity in gravity field when proper air pressure on the model is supplied and geometric scale and the scale factor for stresses is satisfied. So, we can predict the behabior of the ground including collapse by this procedure. (H-5)

(47) Fundamental Study for Action and Effect of Rockbolt in a Rock Joint

Yoshinaka, R., Sakaguchi, S., Shimizu, T. and Arai, H.

Proceedings of the Symposium on Rock Mecanics, JSCE, 17th, pp. 281–285, 1985,

Recently, tunnels and underground openings tend to be constructed by New Austrian Tunnel Method, so that opportunities to use rockbolts in jointed rock mass have increased. But it is not enough to explain the mechanism of bolt action and it is much difficult to evaluate their effect quantitatively. So we performed a series of laboratory experiments by using mortar specimens, each of which contain single joint reinforced by fully grouted rockbolt, as a first step to investigate the mechanism of bolt action and bolt effect.

The size of specimens is 80cm x 40cm x 20cm and surface of the joints is flat or have regular asperities whose dilatancy angle i=10° or 20°. Rockbolts are installed intersecting the joint at the angle of 45°, 90° and 135°. The shear tests is performed by three dimensional test rig under plain strain condition. The normal stress of the joint is held constant at the value of 20 or 40 or 60kg/cm^2 during the tests.

From the test results we can get following observations.

(1) There are three types of Shear stress-Shear displacement relations. They are, (i)Constant or Gradually increasing, (ii)Softening, (iii) Gradully increasing and Softening. They depend on normal stress and dilatancy angle. Softening occur when asperities of joint are sheared off.

(2) Bolt effect on shear strength depends not on normal stress but on bolt angle α. In the cases when α=135°, bolt effect is relatively small, especially for residual shear strength. This is considered since compressive stress arise in bolt which reduce the effect of bolt on shear strength by dowel action.

(3) There are three types of bolt stress, and they depend mainly on bolt angle α. They are, (i)Tension (α=45°), (ii)Bend (α=90°), and (iii)Compression (α=135°). (H-5)

(48) Three Dimensional Model Test on an Unlined Tunnel under Large Pressure of Overburden

Kanto, K. and Washizawa, E.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 286–290, 1985,

In order to verify the earth pressure phenomena around the vicinity of a tunnel excavated in large mass of overburden of soft ground , three dimensional model tests have been carried out.

The ground motion phenomena around the vicinity of proceedingly excavated face of tunnel has been observed and studied. Then the experimental results have been compared with data obtained from the actual measurement carried out in the field. Thus the followings are verified;

1) The stress conditions around a tunnel is closely not only depending on the characteristics of soft materials, specially by internal friction angle ϕ, but also relating to phenomena such as the fluidity of soft materials, deterioration of strength by water, increase of strength with consequent compression in soft materials and so on.
2) In the cases of initial stress is large and soft materials in front of tunnel face yields to the stress, the displacement of soft materials around a tunnel excavated is occuring very large in front of the face. This displacement appears as the squeezing displacement from the face and displacement by compression (consolidation)in soft materials.
3) Though convergence measurement is simultaneously related to $C/\gamma H$ and $\tan\phi$, in the case of utilizing the results in the field practically, it becomes one of the problems from now on how the physical properties are estimated.

(H-5)

(49) Study of the Control Methods with Driving Tunnels

Gomi, M.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 291–295, 1985,

The displacement of the bedrocks surrounding tunnels accompanying tunnel excavation is different according to the geological features, earth covering, the strength of the bedrocks, the shape and size of excavated section, excavating method and so on. In order to reflect to the safety and economical efficiency of construction, it is necessary to measure the displacement as early as possible after the excavation of tunnels. It is the present status to carry out the forecast of convergence and loosening area among the displacement of bedrocks with the examples of the actual measurement of tunnel displacement under similar geological condition, with the results of analyzing displacement on the basis of preliminary geological investigation, by the method of excavating pilot tunnel, by the method of determining the procedure while excavating tunnels and so on. Moreover, recently as the method of reflecting to the design and construction accompanying tunnel excavation, the back analysis method utilizing the actually measured data has been studied.

In this paper, the measured data in about 60 places among the tunnels constructed so far were summarized in terms of convergence and loosening area, and proposal was made on how to reflect these results to the execution control.

(H-5)

(50) Approach to Measuring Controls in Tunnel Construction

Chikahisa, H., Gotoh, T. and Kawabata, Y.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 296–300, 1985,

There are in-situ measurements in tunnel construction classified into two groups called the followings;

- Measurement A ...... for daily construction controls.
- Measurement B ...... for geological interests.

The authers propose the measuring control procedure whitch combines Measurement A (composed of convergence measurements, geodetic measurement of the roof and face sketchings), statistical technique (quantification theory) and back analysis. The adaptation of this utility procedure is discussed which allows tunnel engineers to analyze and forecast final tunnel behaviors of that cross-section on sketching face conditions. And it is discussed how to estimate control limit of Measurement A (except face sketching data) based on practical measuring results.

(H-5)

(51) A Method of Forecasting Ulimate Displacements around a Tunnel by Using Field Measurement Data in Early Stage

Shinji, M. and Sakurai, S.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 301–305, 1985,

At the construction of tunnels and underground powerhouses, it must be emphasized that the feedback of field measurement data to design and execution of structures is of primarily importance. Nevertheless, no reliable method of feedback has been developed yet in practical monitoring system.

This paper deals with a method of forecasting ulimate displacements around underground openings from field measurement data in early stage. The method consists of two phases. The first is a back analysis of measured displacements in which the value called "normalized Initial stress" is obtained. The second phase is a forcast of ulimate value of normalized initial stress from its value in early stage. We reveal that the velocity of normalized initial stress is proportional to the remainder of normalized initial stress. Therefore, the following equation is proposed.

$$\sigma_r = C(\Delta\sigma/\Delta t) + \sigma$$

where σ and σ_r are the present and ulimate value of normalized initial stress, respectively. $\Delta\sigma/\Delta t$ is the velocity of normalized initial stress at present. C is constant depending on geology, tunnel shape and support measures. Considering previous field measurement data, the constant C ranges from 6 to 8.

A case study on UJI Tunnel shows that the proposed method has a good accuracy for forecasting the ulimate value of normalized initial stress. This then provides the maximum displacement and the maximum strain distributions around tunnel.

(H-5)

(52) Prediction of the Behavior of a Cavern Side Wall Due to Excavation by Using the Back Analysis Method

Hasui, A., Yamashita, R. and Yoichi, H.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 306–310, 1985,

During the construction of underground structures such as tunnels and caverns. it is important from the aspect of their safety and economy to predict the behavior of the rock around the cavern with the progress of the excavation as well as to examine the existing state.

The Direct Back Analysis method proposed by Sakurai et al. has been applied a number of underground openings to estimate the stability of them during excavation. This method evaluates the strain distributions in ground media near underground openings, which can be obtained from the observed(measured) displacement data.

Described in this paper are the modified Back Analysis Method by considering the progress of the excavation and its application to an underground rock cavern. In this study, the cavern was located in a sound granitic rock mass at a subsurface depth of 200 m. The displacement data adopted were only the values obtained by the extensometer which had been setted horizontally in one direction.

Though the above-mentioned condition were unfavorable to the analysis, the study was successfully performed by supposing that the horizontal stress would be equal to the vertical stress in the initial state, reffered to a large number of stress measurement data obtained in the existing underground cavern sites.

As a result, the following items were confirmed.

(1) Even in case that the measurements were carried out only in one direction, the Back Analysis Method has significant meanings from the engineering point of view by supposing the initial stress state.

(2) Even in the above-mentioned situation, the prediction of the behavior with the progress of the excavation was confirmed to be practicable from the technical judgement.

(3) Also, the displacements previous to begin measurements could be reproduced satisfactorily by the Back Analysis Method with considering the progress of the excavation. (H-5)

(53) Examples of Cutting and Stabilizing Slopes Having Fresh Faults

Okuzono, S., Haneda, H. and Yasukawa, M.

Tsuchi-to-Kiso, JSSMFE, Vol. 30, No. 3, pp. 33–38, 1982,

This report introduces the examples of failures and repair works in cut slopes with comparatively fresh, including active faults. After investigations for the actual state of slope failures at these fault spots along highways, the report also presents the results of detailed studies on the effects of such factors on the slope stability as degree and width of the crushing, relative position between slope and fault, and ground water conditions. (H-2)

(54) Problems of Dam Foundations

Joujima, S.

Tsuchi-to-Kiso, JSSMFE, Vol. 32, No. 4, pp. 5–10, 1984,

Dams have been constructed by many organizations in Japan. On large dams the numbers of dams for power generation have gradually been decreasing, while quite a number of dams for flood control and water supply are to be constructed. About 300 multipurpose dams are now being constructed in this country. With the increase in the number of dams, dams have to be constructed at the site where it has been previously considered to be difficult geologically. This paper outlines about the present state of problems of concrete gravity dam foundation and zonetype fill dam foundation and the matter for further research. (H-4)

(55) The Design and Construction of Rock-Fill Embankment for Expressways

Sezai, T., Mishima, N. and Iguchi, T.

Tsuchi-to-Kiso, JSSMFE, Vol. 32, No. 7, pp. 9–14, 1984,

Accompanied with the change of the construction site of expressways in the mountains, such case tends to increase that rock materials, e.g. cobbles and boulders, are used for embankment. Therefore, the method of effective and economical use of these materials were standardized.

The design, construction and quality control of rock-fill embankment are described in this paper with it's typical case histories. (H-4)

(56) Evaluation of Earthquake-Induced Sliding in Rockfill Dams

Watanabe, H., Sato, S. and Murakami, K.

Journal of the Japanese Society of Soil Mechanics and Foundation Engineering, Vol. 24, No. 3, pp. 1–14, 1984,

The relation between the factor of safety obtained from dynamic response analyses on arbitrary potential sliding surface of a rockfill dam and the one obtained from conventional method such as slice method has been made clear by introducing a concept of equivalent instantaneous seismic coefficient.

Throughout many numerical experiments of dynamic response analyses conducted on a typical rockfill dam section with sinusoidal ground motions of various kinds of accelerations and periods, a simple expression for the sliding permanent displacements has been obtained as a function of maximum equivalent instantaneous seismic coefficient and duration of sliding which is independent of the scale and location of sliding surface, the period of ground motion and the amplitude of ground acceleration. This formula has been applied to the simplified evaluation for the sliding permanent displacements in the cases with the ground motions of recorded accelerograms.

Acceleration response spectra of many recorded accelerograms have been calculated and the ratio of each maximum value to peak ground acceleration has been plotted against corresponding predominant period. With this diagram the amplitude of equivalent sinusoidal ground acceleration has been specified as 0.5 to 0.6 of peak ground acceleration in conservative side.

Combining above formula with the magnification factors of the equivalent instantaneous seismic coefficients in the potential sliding circles near crest, an expression for the relationship between the amplitude of above equivalent sinusoidal ground acceleration and the earthquake-induced sliding displacement at near crest has been derived. Giving certain amount of allowable permanent displacement, an earthquake-resistant design diagram for rockfill dams concerning with the equivalent sinusoidal ground acceleration has been proposed. (H-4)*

(57) Elastic Analysis of Tunneling under the Inclined Surface

Kiyama, H., Fujimura, H. and Moriki, S.

Journal of the Japanese Society of Soil Mechanics and Foundation Engineering, Vol. 24, No. 4, pp. 163–170, 1984,

The two dimentional theory of elasticity is adapted to studies of shallow tunneling in the inclined ground. Analytical solutions of stress and displacement are obtained in which full consideration is given to the conditions at both the boundary of a free circular hole and a free inclined surface of the solid under the action of gravity. Their expressions are given in terms of simple infinite series.

The solution of stress is strictly exact throughout the tunnel ground, but the solution of displacement has two serious terms; one tends to infinity at a far distance from the tunnel and another is a rigid displacement term of theoretical indetermination for lack of the unmoved point near the tunnel.

In order to prove the applicability of the solution the displacements are calculated for wide variation of the inclination of surface, the depth of tunnel and the poisson's ratio of ground, and the chracteristics of displacements such as the distributions of displacements, the surface subsidence curves and the deformations of tunnel circumference are discussed.

In results it is concluded that the solution putting the rigid motion term equal to zero is exact in practical use for the displacements around the shallow tunnel in the inclined ground. (H-5)

(58) Effect of Shotcrete on Preventing Settlement of Ground Surface in Tunnel Excavation

Morita, K., Maki, M. and Mori, Y.

Journal of the Society of Materials Science, Japan, Vol. 31, No. 341, pp. 125–131, 1982,

The ground condition of the Kongō-gawa Tunnel from its entrance to the 100 m-depth is severe, *i. e.*, the earth covering is thin (15 m), the upper layer of the ground consists of talus, and besides the clay layer under the tunnel is short of bearing power.

To cope with this site condition, the silot tunnel method, the chemical grouting method, and the shotcrete method were adopted.

As a large amount of settlement arose after excavation of silot tunnels, it was feared that the settlement would increase much more in excavating the upper half section. But by using the shotcrete method in excavating the upper half section, the settlement could be held down to a comparatively little amount.

This paper reports the construction outline. Furthermore, the results of elastic FEM analysis for the upper half section excavation showed that the settlement of ground surface using the shotcrete method model became half as large as that of using the conventional method model. (H-5)

K. [Construction Methods and Equipment]

(1) Consideration on Analysis and Control of Foundation Grouting of the Dam

Nagayama, I., Yoshinaga, T., Tsugaki, A. and Tashiro, T.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 311–316, 1984,

It is important to understand characteristics of grouting for foundation rock of the dam in order to design and control foundation grouting properly.

Therefore, using the data of grouting for foundation rock of the certain dam site, this report explains the process of improvement of Lugeon value, the relation between Lugeon value and amount of grout injection per meter of a grout hole, and the estimate of improvement of impermeability of foundation rock by the amount of grout injection. (K-2)

(2) Study on Geotechnical Evaluation Methods for Consolidation Grouting of Dam Foundation

Shiratsuchi, H., Oka, N., Kikuchi, K. and Harumatsu, Y.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 317–322, 1984,

The consolidation grouting of the dam foundation is performed to improve the rock properties of the foundation and to restrict the seepage into the foundation.

The detail geological condition of the dam foundation has to be grasped to perform the consolidation grouting rationally and effectively. The study of the area and methods of grouting and effects after grouting have to be made based on this research.

This report summarizes the conception and application example of the geotechnical evaluation in the study of the consolidation grouting design and grouting effect of the dam foundation, furthermore, shows the results of the study concerning the Oguchigawa dam (concrete gravity type) and the Niikappu dam (rock fill type) executed in the detail geological investigation for the grouting steps by the writer and others as the application example. (K-4)

(3) Quasi-Static Fracturing of Rock – By Hydraulic Fracturing and by Injection of Special Expansive Material –

Ishijima, Y. and Kinoshita, S.

Proceedings of the Japan Symposium on Rock Mechanics, 6th, pp. 361–366, 1984,

Rock fracturing by the two methods, one is fracturing by injection of the special expansive material and the other is hydraulic fracturing, progresses quasi-statically and fractures initiated from the hole surface in rock develop to the several number of distinguished open type cracks. Investigation is made to clarify their fracturing mechanisms based on the linear fracture mechanics.

Two dimensional stress analysis of the crack problems is conducted by using the body force method developed by Nishitani(1)-(3). Seepage flow analysis, required to simulate hydraulic fracturing, is conducted following the method belonging to the category of boundary element method, which is essentially to distribute the line source flow along the boundary to meet the given conditions.

At the early stage of crack development, induced by injection of the expansive material, two symmetrical cracks are expected to appear from a single hole(Fig.2). With pressure increase they are replaced by the four symmetrical cracks. The attainable crack length is limitted by the power of the expansive material which is represented as line a in Fig.3. It is anticipated that cracks parallel to the free surface of a semi-infinite plate should develop from holes distributing along the line parallel to it(Fig.4).

Coupled model combining the flow and the mechanical phenomena is used to simulate the hydraulic fracturing process. Typical breakdown is presumed to occur when the rock permiability is small(Fig.7). However, under the increasing permiability this phenomenon disappears(Fig.8). Shut-in behavior is also simulated: Pressure drops sharply just after the shut-in, then it decreases gradually and converges to the level equal to the rock pressure after sufficient time elapse(Fig.7).

(K-2)

(4) Foundation Treatment of Ohuchi Dam

Watanabe, K.

Proceedings of the Japan Society of Civil Engineers, No. 355, pp. 38–45, 1985,

Ohuchi dam is a rockfill dam with vertical clay core of 102m in height. The bedrock at the dam site is composed of tuff. At the river bed there is a fault running roughly along the valley. The bedrock at the left abutment has been subjected to crushing due to the influence of the fault which has closely developed cracks over roughly the entire area. Weathering has resulted in deterioration and the rock is generally soft. This bedrock was treated to control underseepage by grouting.

A grout blanket was performed over the entire core base to ensure watertightness in the vicinity of the core-bedrock contact, and a grout curtain was arranged along the axis of the dam. Since the bedrock was soft, grouting could not be done under high pressure.

Since drillholes in the vicinity of the ground surface caved in easily, grouting of the main portions above the gallery was performed with the sleeve grouting method that is usually performed for the deposits.

Fry ash cement was used as the main grout material, and a 4% bentonite and 0.25% water reducing agent were admixed to reduce bleeding and viscosity.

The dam was embanked after the completion of the grout blanket and curtain above the gallery. The base of the core deformed a maximum of 10cm due to the load of the dam. The properties of the bedrock such as permeability coefficient, modulus of deformation and critical pressure changed due to these load and deformation. (K-2)

(5) Experimental Study on Thin Flexible Tunnel Support System

Adachi, T., Tamura, T. and Yashima, A.
Proceedings of the Japan Society of Civil Engineers, No. 358, pp. 47–52, 1985,

The mechanical efficiency of a thin flexible tunnel support system such as shotcrete lining and rock bolts is investigated on the basis of experimental works. At first, model tests of tunnel excavation in which shotcrete lining and rock bolts were simulated by thin papers were carried out in a dry sand ground. As the results, it is found out that even if so flexible thin paper closed ring lining has a remarkable effect on the tunnel stability and that the effect of rock bolts appears only when they are placed to get into the outside of a plastic zone developed in the surrounding ground. Secondary, a circular tunnel excavation was simulated by shrinking a metal ring in an aluminium rod mass and the development of a loosened zone in the ground due to tunneling was discussed. (K-11)

(6) Undersea Construction Works of Bridge Foundation (Construction of South and North Bisan-Seto Bridge)

Sugita, H.

Proceedings of the Japan Society of Civil Engineers, No. 361, pp. 11–20, 1985,

This paper discusses the undersea foundation works for South and North Bisan-Seto Bridge (twin suspension bridges) of Honshu-Shikoku Bridge Project.

All of the foundations rest on bedrock (granite) and built in predredged caissons. The largest foundation is 75 × 59 m in plan and the depth to bedrock is 50 m below the water surface.

The procedure of this predredged caisson method is;

1) Seabed at the foundation site is blasted and dredged until sound bedrock appears, and then the surface of bedrock is evenly finished. During this seabed dredging, whole shape of a steel caisson is fabricated and assembled at a shipyard.
2) The steel caisson is towed to the site, and then is sunk and rested on the finished bedrock.
3) The caisson is filled with prepacked concrete, and then the foundation is completed.

It was very difficult to confirm the result of undersea foundation works by visual observation from the surface of the sea.

However, it was necessary to make sure whether the finished bedrock was stable or not, so that the foundation could be rested firmly on the bedrock.

Therefore, engineers themselves dived to the seabed to observe the bedrock and confirmed characteristics of rocks and existence of faults all over the surface of bedrock. (K-12)

(7) Development of "Injection Type Rock Bolt"

Yamamoto, M. and Kigawa, T.

Proceedings of the Japan Society of Civil Engineers, No. 361, pp. 86–94, 1985,

"Injection type rock bolt" has been finally succeeded in actual use after repeating tests and improvements under many kinds of the natural ground at the tunnel construction sites.

The principal components of this rock bolt are the bolt provided with a cloth bag fitted on one end of the bolt, injection tube and ventilation tube.

Advantage of "Injection type rock bolt" ① Even long size bolt can be used. ② The grout can be filled into the hole without any void. ③ It can be checked easily. ④ A high pullout resistance can be obtained quickly. This is explanation for the process of the development, component of the rock bolt, injecting material, grout pump units (both in the manual and automatic method), the pullout test, the working procedure and the execution. (K-11)

(8) Wear of a Rock Excavating Tip and Its Counterplan Due to Hardfacing

Muro, T. and Fukagawa, R.

Proceedings of the Japan Society of Civil Engineering, No. 364, pp. 87–95, 1985,

As an important problem of construction machinery, it is necessary to study the boundary region of mechanical properties between metal and rock mass to get a rational maintenance of rock excavating tip. Here, the amount of wear and wear length of pure rippertip and hard surfaced one by means of spraying or welding were measured respectively at several different ripping operation sites of land reclamation. It was clarified that the amount of wear of pure tip is fairly correlated to the index of rock mass strength for wear, and the wear resistance and self-sharpness of tip coated by carbide composite welded metal presents to be higher than the other metals. And also, the effect of hardfacing of sprayed metal can not present under high contact pressure, but develops considerably under low pressure. (K-4)

(9) Behavior of Rockbolts Found in the Experiments of Two Lowering Panels

Yamamoto, M. and Ohno, K.

Proceedings of the Japan Society of Civil Engineers, No. 364, pp. 143–152, 1985,

Although the rockbolts are used very often as a main member of supports in NATM, the fact is that there are various understanding of the effects of rockbolts and that there has been no specified way of design. It is because the effects of rockbolts have been recognized mainly through experiences and also because there is no good way of investigation of them.

This study of rockbolts by two lowering panels is a method of examining more positively the mechanical properties of rockbolts presented by our authors, following the previous study by one lowering panel. This series of the experiments by two lowering panels were made to examine the mechanical properties of a group of rockbolts while the experiments by one lowering panel were made to examine the effects of a rockbolt.

This report describes the behavior of rockbolts found through the experiments of two lowering panels including theoretical consideration. And it also describes our view of design of rockbolts. (K-11)

(10) Reduction of Blasting Vibration and Noise (Pre-Blasting)

Hori, Y., Harada, J. and Ueda, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 136–140, 1982,

Generaly, there are two kinds of method in breaking the hard rock, one is ripping and the other is blasting. In the hard rock with seismic velocity 3000 (m/s) or higher, the ripping production is reduced extremely. At right near houses and buildings, the ground vibrations and noises generated by blasting must by reduced not to do damage to structures and humen being.

This report is the instance combined excellently ripping with blasting. Field conditions were as follows.

Seismic velocity is nearly 5000 (m/sec)
Minimum horizontal distance is about 45 meter from the field to the house.

In consideration of these conditions, we adopted "Pre-Blasting" in breaking the hard rock. The maximum permissible value of vibration and noise generated by pre-blasting was as follows.

vibration : 0.2 kine (cm/sec)
noise : 80 dB

The bedrock was loosened by pre-blasting, and enabled to break by ripping of D10 tractor. And the production of D10 tractor was 400 (BCM), nevertheless the seismic velocity was nearly 5000 (m/sec) before pre-blasting. We measured the vibrations and noises generated by pre-blasting, the result was as follows.

vibration : 0.1 kine (cm/sec)

noise : 74 dB

Both the results of measurment was satisfied the maximum permissible value. By adopting pre-blasting, we could carry out the breaking hard rock near houses without trouble. (K-4)

(11) Excavation of Inclined Tunnel by Tunnel Boring Machine and Design of Steel Lining

Hori, M. and Kawashima, Y.

Proceedings of the Symposium on Rock Mechanics, JSCE, 14th, pp. 146–150, 1982,

In the project of Shimogo pumped storage hydro power station of 1,000 MW, a tunnel boring machine was employed to excavate the inclined tunnel as the penstock. The tunnel has been completed with 5.8 m diameter and 37° inclination angle. This performance was the first success in Japan in the excavation of an inclined tunnel by TBM.

The use of the machine has brought not only a good performance of excavation even in bad geological condition, but also several advantages in the design of the steel lining in the penstock.

It is found out throughout the investigation of the tunnelling performances that there exists a linear relationship between the ratio of thrust force to torque acting on the boring head and the ratio of uniaxial compressive strength to tensile strength of the rock excavated. The surrounding rock is not almost loosened by the excavation if TBM is employed. The thickness of the loosening zone generated in the circumferential area of the tunnel was measured by a seismic prospecting in the field. From the results, the thickness was found to be 0.3 m at most, which was relatively small in comparison with those caused by the conventional blasting method. Consequently, for the sake of the reduction of the loosening zone by the use of TBM, a design of the steel lining in the penstock becomes economical. The cost of the steel lining saved by about 17% compared with a cost required for a case when the conventional blasting method would be employed. (K-4)

(12) In-Situ Measurement on the Effect of Rock Bolt Support in Comparison with that of Arch Support

Ohkubo, S. and Nishimatsu, Y.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 16–20, 1983,

Civil and Mining industries are now evaluating the rock bolting as an excellent support method with its significant advantages:reduced storage and handling requirements,improved ventilation,immediate effect of supporting and so on. This study has been started to reveal the advantages and disadvantages of the rock bolt support over the conventional arch support and examine its applicability on the basis of in-situ measurement carried out at Fukazawa mine in Akita.

The rock bolts were installed in a square grid at 1 m interval. The convergence,of roadway cross-section,radial extension of rock wall and axial force of rock bolt have been measured. Up to this date(400 days after installation),measured values have been continuously increasing, and some are of the considerable amount. For example,convergences are in the order of 50-70 mm against the roadway of 3.3 m height and 4.5 m width. However,rate of increase is decreasing monotonously and no trend of roof fall or wall spalling is observed.

At the roadway supported by the arch support,convergence and radial extension of wall were measured. Up to this date,convergence and radial extension at the arch supported roadway are considerably larger than those of the bolt supported roughly by the factor of 1.5 to 2.0. A temporary conclusion may be that the rock bolting is superior to the arch support. Especially in the very early stage,say,within a few days after installation,rock bolting is favored for its immediate effect, while the effect of arch set is delayed until firm contact of arch set or timber lagging with rock wall is established.

The convergence and radial extension at both rock bolt and arch supported roadways follow the semi-log relationship,linear increase with log time. Interestingly enough,the specimen obtained at the test-site also follows the logarithmic creep law. This is remained for future research to combine the semi-log relationship observed at in-situ and laboratory tests. (K-11)

(13) Large Scale Model Tests on the Effects of Rock Bolts as Tunnel Support in Soft Rock

Tsuchiya, T., Yasuda, N., Tazawa, Y. and Sudo, H.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 31–35, 1983,

For the purpose of studying the effect of rock bolts as tunnel support in soft rock, model tests using a large scale testing device were carried out.

Artificial rock cubes of 2.5×2.5×2.5 m were made of bentonite mortar, and a bore hole(tunnel) of 60 cm in diameter was provided at the center of the cube. Around the circumference of the hole, rock bolts support of 20 cm or 40 cm in length was installed.

From the experimental studies, the following results were obtained.

1. Radial deformation(convergence) of the tunnel is reduced by the installation of rock bolts.
   Deformation behaviour and failure mode of the tunnel are signifficantly influenced by the supporting conditions such as length(L) and number(n) of rock bolts.
2. In the case of no support, radial stress around the tunnel(σ_r) is reduced as a failure of the tunnel wall progresses.
   However, when rock bolts support is installed, no considerable reduction of σ_r takes place.
3. With an increase of the load, the tension of the rock bolts(T_b) increases. Peak points of T_b shift with the supporting conditions such as L and n of bolts.
4. In the case of rock bolts support, the cracking zone around the tunnel after the test is reduced in comparison with the case of no support.
   This behaviour tends to agree well with the experimental results of the other factors such as tension of the rock bolts, stress and strain distribution around the tunnel.
5. In the case in which the total length of the rock bolts($L \times n$) is equivalent, for improving their stabilizing effects, it seems to be very useful to increase the number(n) of rock bolts.

In order to work out more effective supports, further researches on the influence of loading conditions and of the tunnel face will be conducted. (K-11)

(14) Effects of Guide Hole on the Smooth Blasting Contour Formation of Rocks Containing Discontinuities

Nakagawa, K., Ono, Y., Nishida, T. and Sakamoto, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 155–159, 1983,

Since rock mass contains the geological discontinuities it is very difficult to make a smooth contour by blasting. The guide hole effects on the smooth blasting contour formation are sometimes discussed. In order to simulate the propagation of cracks from the blast holes with guide holes and the formation of smooth blasting contour in rocks containing discontinuities, blasting tests were conducted by using cement mortar specimen which contains discontinuity plane.

Through the blasting tests, the following conclusions are summarized.

1. The blasted contour which connects the adjacent blast holes usually consists of blast cracks and pre-existing discontinuity plane.
2. When the blast hole without guide hole is adjacent to the discontinuity plane, the cracks propagate radially from the blast hole and form crater against the plane. When the hole is distant from the plane, only one crack may propagate perpendicular to it.
3. With the guide holes placed near the blast hole, the cracks in the guide hole direction propagates adding to the other cracks.
4. The unevenness of the contour can be effectively reduced by the cracks in the guide hole direction. The reduction of the over break by the use of guide hole, however, is not so evident.

(K-4)

(15) Effects of Grouting Material on Rockbolting

Hata, S., Tanimoto, C., Kariya, K., Noguchi, T. and Iwasaki, Y.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 195–199, 1983,

Rockbolt is one of the principal member of the tunnelling supports and is widely used for various rocks. Also many researches on interaction between rockbolts and rock have been made. It is essential that the rockbolts are used suitably for characteristics of the ground. From the measurements of the axial force distribution of the bolts on construction site, it was note in some rockbolts that slip occurred between rockbolts and ground, and the effects of the bolts are not sufficiently achieved. In the grouting material which play an important role combining rockbolt and ground, shear and tensile stress develop with the increase of the axial force of bolts. When their stress exceed the strength of the grouting material, the slip occurrs. In this paper, the effects of the rockbolts are discussed in relation to the characteristics of the grouting materials through numerical analysis and laboratory tests. The shear stress distribution on the surface of the bolt and cause of slip are also discussed.

In the numerical analysis, it is assumed that the grouting materials is elastic, and the axial force and the shear stress acting on the fully bonded bolt is calculated for various characteristics of the grouting material by F.E.M.

Laboratory tests are carried out in 105 x 105 x 105 mm mortar blok in which ϕ 10 mm reinforcement is inseted and cement milk of various consistency is grouted. The block is laterally confined and compressed in plane strain condition. The relation between residual compressive strength and consistency of grouting materials is discussed.

Following are the results of this study.

(1) The rockbolt becomes effective according to increase of elastic modulus of the grouting material. However, when elastic modulus of the grouting material exceeds that of the ground, the increase of the effects of the bolt is not expected.
(2) The strength of the grouting material can be measured by pull-out test of the bolt. On this test, it is neccessary to shorten the bonded length so that the bolt is not broken before the grouting materials is broken.
(3) In case that the rockbolts are applied to soft rock which relatively shows large deformation, the grouting material which has low strength and low elastic modulus is suitable.

(K-11)

(16) Three Dimensional Model Tests on Tunnelling with Rock Bolts in Squeezing Ground

Inokuma, A.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 200–204, 1983,

The purpose of the tests is to know the stress distribution around a tunnel supported with rock bolts and to clarify the difference of the effects due to the difference of rock bolt length.

The method of the experiments is as follows. The first step is to fill the earth tank with the model earth material. The second step is to give 68kPa pressure to the model earth. The third step is to excavate a 17.5 cm diameter tunnel 2.5 cm in length at a time and then to push 16 model rock bolts per section into the earth uniformly around the tunnel. The third step is repeated until the model tunnel becomes 50 cm long. The fourth step is to rise the pressure from 68kPa to 196kPa

Two cases are done. Case 1 is the test of 3 cm long rock bolts. Case 2 is the one of 15 cm long rock bolts. The friction angle and uniaxial compressive strength are about 3 and 49 kPa each.

The results are as follows.

(1) The distribution of the vertical stresses around the tunnel face is not so different between Case 1 and Case 2. But the distribution of the radial stresses is quite different between Case 1 and Case 2 in the stage of 68 kPa loading pressure.

(2) The convergence is not so different between Case 1 and Case 2 at 68 kPa pressure level but quite different at the pressure higher than 98 kPa.

(3) Consolidation is observed in the earth near rock bolts.

(K-11)

(17) Comparing Calculations Regarding Tunnel Reinforcement Effect of Systematic Rockbolts with Results of Large Model Tunnel Tests

Tuchiya, T. and Yasuda, N.

Proceedings of the Symposium on Rock Mechanics, JSCE, 15th, pp. 205–209, 1983,

We have made some tunnel model tests on reinforcement and non-reinforcement with systematic rock-bolts. The results are reported at this sysmposium and published in another paper. In the present paper, we compare calculations using 3 kinds of material non-linear models i,e, Hibino & Shoji's non-linear model, bi-linear model, tri-linear model.

The results obtained are summarized as follows.

1) About Hibino & Shoji's non-linear model

Deformations of tunnel wall calculated with proper values of Eo and n, approximately ageree with measured results. But distribution of stresses in artificial rock medium differs from measured results.

2) About bi-linear, tri-linear models

Strain and stress distributions on artificial rock medium in calculatation approximatery agree with measured results. But behavior of deformation is almost linear, and differs from non-linear behavior in measured results.

3) The results of calculations using slide joint elements agree better with measured deformation and bolt axial force than the results not using such elements.

4) We have not discovered any model as yet in which the all kinds of measured values coincide , and we think it apropriate to use Hibinos & Shoji's non-linear model, because deformation is related to stress of lining, and so it is important for design.

5) Tri-linear one, however would provid, an ideal tool, when coupled in future with a dilatancy model or a cracking model which could better represent strain of neighbour zone of wall.

(K-11)

(18) Experiments and Analyses on Confining Effect to Rock Bolt Considering Mortar and Rock (Part 1)

Tei, K., Obara, Y., Ichikawa Y. and Kawamoto, T.

Proceedings of the Symposium on Rock Mechanics, JSCE, 16th, pp. 280–284, 1984,

The supporting effect of rock bolts used in Tunnel excavations is considered to be a lateral confinement on the Tunnel walls which caused a triaxial state of stress,increasing the stability of Tunnel excavations. The confinement effect of the bolt is largely influenced by the interaction between bolt and surrounding medium. However,this phenomena is not still well known. The confinement effect of the bolts depend upon many factors such as rock mass properties,state of stress,bonding of bolts and rock mass and their relative movements,etc.

Of these,the bonding of rock bolts and rock has been studied by carring out some push out test in this reserch. Push out test on the rock bolts which installed with cement mortar in a hole in the centre of Oya-Tuff specimens of 120mm in diameter and 200mm in length.

The results obtained from the experimental studies are;

1) Bonding strength of the deformed bar is grater than the bar which has smooth surface.

2) The ratio of the diameter of bolt to the diameter of the hole has also effect on the bonding strength.

3) As the bonding of the bolt - mortar - rock decrease with increased deformation the Dilatancy of the mortar and wedge action comes into effect.
This Dilatancy and wedge action cause lateral pressure which give a strength between bolt and rock,though bonding has been destroyed.

(K-11)

(19) On Pulling Resistance of Rock Anchor in Cut Slope Composed of Schist

Tano, J., Tokudome, Y. and Etoh, Y.

Proceedings of the Symposium on Rock Mechanics, JSCE, 17th, pp. 131–135, 1985,

This paper describes the pulling resistances of rock anchor in the cut slopes around Tenzan reservoir. Tenzan reservoir is the upper one of Tenzan Power Station of pure pumped storage type (600MW) and its effective storage capacity is 3,000,000 m^3.

In this site , because of narrow valley and steep gradient of the river ,it is necessary to get the greater part of effective capacity of the storage by cutting hillsides around the river .

As a result of the cuttings , extensive cut slopes consisting of weathered schists are made around the reservoir and these slopes need to be reinforced or to be protected against slide and weathering according to weathered degree . After various examinations , as measures of slope reinforcement under full reservoir level , rock anchor structure system is selected . Besides , most parts of slopes above the reservoir are mainly protected with vegetative cover in addition to an extensive surface drainage system .

Therefore , as a fundamental study for reinforcements , the in-situ tests were performed at the rocks of the weathered schists , the same ones of the cut slopes. These tests contain the pulling tests of rock anchors and the drilling tests of anchor holes.

The results of these tests have been applied to the design and the execution of the rock anchor works.

The contents of this paper are as follows ;

(1) Some trials in order to improve accuracy of measurement on the pulling tests of the rock anchors.

(2) The relations between the pulling resistances and the characteristics of compressive strength of the undisturbed specimens.

(3) The application of the results of the pulling tests to the system design of the rock anchors.

(4) Some skills of the estimation for the classification of rock grades at the fixed part of the anchors under construction and their applications to quality controls of the execution of the anchor works.

(K-11)

(20) Monitoring and Evaluation of Deformation of Side Walls during the Construction of Underground Pumped-Storage Power Plant

Takahashi, Y., Takeda, Y. and Yoichi, H.

Tsuchi-to-Kiso, JSSMFE, Vol. 30, No. 11, pp. 41–47, 1982,

On the construction of a large cavern such as an underground pumped-storage power plant, the measurement under excavation is important as well as the stability analysis in design period.

The authors describe the processes and procedures for evaluation of cavern stability referring the case of deformation monitoring executed in the construction of Numazawa No. 2 power plant, and emphasize that it is significant to establish the criteria of estimation for safety.

(K-4)

(21) Cutoff Construction Methods for Underground Dams

Okamoto, R., Sugawara, H., Kuwahara, K. and Nakamura, Y.

Tsuchi-to-Kiso, JSSMFE, Vol. 31, No. 3, pp. 25–32, 1983,

This paper describes selection procedures of various cutoff construction methods for underground dams in consideration of particular conditions at the planned construction site, such as geology, transportation, temporary works, environments and so forth.

The paper also reports experimental results of grouting by two methods-the double tube double packer method and the high speed water jet method-in a stratum of sand and gravel, which is considered to be one of the most suitable underground dam aquifers.

The cutoff construction methods and their effects of the underground dam at Nomozaki in Nagasaki prefecture are briefly introduced.

(K-10)

(22) Effect of Insertion of Steel Bars on Slope Stabilization

Kurose, M. and Kimura, M.

Tsuchi-to-Kiso, JSSMFE, Vol. 31, No. 9, pp. 47–53, 1983,

Soils can be reinforced by inserting steel bars. This paper describes the experimental studies on the influence of the diameter, length and spacing of the steel bars inserted on the reinforcement effect. Practical applications of this earth reinforcement method are also reported. Although the method has been successfully used so far, further studies and field observations are considered to be required.

(K-11)

(23) Model Tests and Practical Examples of Excavated Slope Reinforced with Steel Bars

Okuzono, S., Terashima, H., Noritake, K. and Yasukawa, M.

Tsuchi-to-Kiso, JSSMFE, Vol. 31, No. 9, pp. 55–62, 1983,

Recently a method to stabilize in-situ excavated slopes by driving steel bars into the slopes has widely been in use, while studies on stability analysis of these slopes are currently in progress to provide a theoretical basis for the effectiveness of the method.

This paper describes two types of model tests; one is to examine the influence of the number and length of steel bars on the reinforcement effect, the other to investigate the mechanism of the rainfall induced failure of the excavated slopes reinforced with the steel bars.

Three practical examples are also reported, together with touching on some technical problems of this method.

(K-11)

(24) A Big Fault on the Rive-Bed and the Foundation Treatment of Dondo Dam

Hasegawa, K. and Kawahara, M.

Tsuchi-to-Kiso, JSSMFE, Vol. 32, No. 4, pp. 51–59, 1984,

The Dondo Dam, which is under construction on the Yamada River belonging to the Kakogawa River system, is designed to be a concrete gravity dam of 71.5m height. On the geological survey at the Pre-construction stage, a big fault (with a wide fractured zone of 30-60 m in width) was found along the river-bed. At the construction stage, this fault aroused suspicion of the Takatsukayama Fault known as an active fault. For this reason, various geological investigations (such as ① bibliographical survey, ② areal geological survey, ③ geological survey of terrace by trenching, ④ geological survey by drilling, and ⑤ analysis of quartz sampled from the fault materials,) were additionally carried out at the cost of suspension of dam construction works. As the result, the fault proved neither the Takatsukayama Fault nor any active fault. Then, intensive rock tests were conducted to grasp the dynamic characteristics of the fault.

To cover the shortage of elastic deformation and shearing strength of the base rock a 15 m thick concrete mat was placed on the river-bed of the fault zone to construct the conventional gravity dam. (In addition, the consolidation grouting system was carried out up to 30 m depth.) (K-2)

(25) Availability of Mudstone as a Fill Material — A Case of Kanori Pondage Dam —

Akazu, T., Kanzaki, Y., Takahashi, Okabe, H., Nakazaki, H. and Ueda, T.
Tsuchi-to-Kiso, JSSMFE, Vol. 32, No. 7, pp. 15–20, 1984,

Kanori dam for agricaltural pondage use located at Iwaki city was constructed as a homogeneous earth dam using mudstone. This fill material is pervious under ordinary construction method. Therefore, a new method is necessary to ensure the impermeability of embankment. Then, laboratory tests, insitu compaction tests, and insitu permeability tests were conducted, prior to actural construction, in order to investigate the availability of mudstone as a fill material. Through these tests, it was made clear that an appropriate combination of weathering and comminution by a compactor was effective to reduce the permeability as of 10^{-5}cm/sec. (K-5)

(26) The Influence of Coarse-Grain Component on Compaction Properties of Soft Rock Muck

Goto, S., Miyamoto, T. and Tamaoki, K.
Tsuchi-to-Kiso, JSSMFE, Vol. 32, No. 7, pp. 45–52, 1984,

Large scale compaction tests were conducted with mudstone muck for investigation of compaction characteristics of soft rock. Its compaction properties is strongly influenced by grain size distribution of samples, that is, as the coare-grain component increases the dry density of muck is decreased. Multiple regression analyses gives accurate estimation (standard error is 0.023g/cm^3) of dry densities. Extiapolation of kuno's formula to coarse-grain component gives more accurate estimation (standard error is 0.018g/cm^3) of compaction curves. (K-5)

(27) Calculation of Hydraulic Effect Due to Grouting

Sato, K.
Tsuchi-to-Kiso, JSSMFE, Vol. 32, No. 12, pp. 47–52, 1984,

Grouting has often been employed for ground improvement and for reducing groundwater seepage during tunneling and underground works. This paper proposes formulae to express the quantitative relationship between permeability of ground and required grout volume. These formulae were derived from several laboratory experiments and actual measurements taken from the Seikan Undersea Tunnel project. Appropriate grout injection volume can be calculated by employing the said formulae once design permeability and grouting radius are established. (K-2)

(28) Holding Fore Acting on a Ring Held between Two Belts

– Study on Development of Vertical Double-Belt Conveyors (4th Report) –

Kondo, K. and Hokao, Z.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1139, pp. 13–18, 1983,

A vertical double-belt conveyor conveys material by holding it between two belts. The magnitude of the holding force depends on such parameters as the belt tension, the idler arrangement and the mechanical characteristics of the belt.

This paper deals with experimental investigations carried out to reveal the relations between the magnitude of the holding force and such parameters.

First, tensile tests of the belt are carried out to identify its mechanical characteristics. The results of the tensile tests are as follows;

1) From the rhoeological point of view, the belt can be described as a 3-element solid.
2) From the point of view of anisotropic elasticity, the belt can be regarded as orthotropic.

Second, the holding force is measured under various conditions on an experimental stand. The stand has four sets of carrier rollers and a pair of belts (double-belts) to simulate the straight part of a vertical double-belt conveyor. Between the double-belts are held small rings (2cmϕ) on which strain gages are stuck to show the holding force.

The main results are as follows:

1) The holding force increases with the increase of the belt tension.
2) The holding force becomes quite large when the ring comes to just onto an idler.
3) The relation between the holding force and the degree of offset of the idlers depends on the trough angle.
4) The holding force decreases with the increase of the trough angle.

(K-4)

(29) Finite Element Analysis of the Double-Belts

– Study on Development of Vertical Double-Belt Conveyors (5th Report) –

Kondo, K. and Hokao, Z.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1140, pp. 93–98, 1983,

In order to obtain such technical data as are required for designing vertical double-belt conveyors, the authors carried out a stress-strain analysis of the double-belts through a non-linear finite element method. In the analysis the conveyor belt is assumed to behave as a membrane.

The main results are as follows;

1) The non-linear finite element model expresses the holding mechanism of the double-belts well.
2) When a particle is held between the belts just on an idler, local tensile stress which is 2 or 3 times larger than the mean value generates in the outer belt.
3) When the belt width is small, the condition that no local loosening should occur in the belts determines the minimum operational tension, while when the belt width is large, the equilibrium of the forces acting on the conveyed material determines it.

(K-4)

(30) Adaptive Control for Feed-Control System of Rock Drill

Takahashi, Y., Obinata, G., Nagashaku, K. and Watanabe, Z.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1145, pp. 555–559, 1983,

In this study, a new feed-control system, which was composed of electro-hydraulic servo valve, servo amplifier, oil motor, gears, ball screw, encordor, hydraulic power unit and rock drill, was designed and tested experimentally.

By changing various parameters, the dynamic characteristics of elements of the above system were examined and this result indicated that the frequency response of the system was mainly influenced by that of the actuator system which was composed of oil motor, gears, ball screw and rock drill.

From the results of the load test, it was realized that the system equipped with a speed-change unit and a backward feed-control circuit could be fed automatically in all cases of rocks tested in this study.

Consequently, it was confirmed that an adaptive control could be used for the feed-control system of a rock drill.

(K-4)

(31) Improvement in the Rock Headings at Mikawa Mine, Miike Colliery

Sakayori, N. and Yoshinaga, T.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1146, pp. 634–638, 1983,

The rock heading in Miike Colliery is a matter of great importance recognizing the fact of increased heading meters per thousand tons of coal produced, 9.54 m in 1972 and 12.7 m in 1981, and that the innovative progresses in this field have been required. The conventional heading techniques are based on the short hole firing system where the V-Cut using portable leg drills is prevalent for the pattern of centre cut. Miike Colliery, therefore, has made practical collaboration with the Coal Mining Research Centre in Mikawa Mine on the subject applying the long hole firing system. This report presents the improvements in drilling, blasting and loading techniques realized so far.

(K-4)

(32) The Development of the Large Diameter Boring by Ring Cutter in Sumitomo Akabira Colliery

Okuyama, N.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1146, pp. 638–641, 1983,

The development of the large diameter boring by ring cutter was required for the alternative safety construction method of large diameter holes to compensate the lack of skilled labours for raise and drift construction, and other various relevant aspects. Conventional large diameter borings require to break all rocks within the hole, which means high cost requirements and less effective operations consequently.

Sumitomo Akabira Colliery introduced the large diameter boring by ring cutter to avoid the demerits of conventional methods. In July 1978, the first test of 550 mm diameter was carried, then 770 mm diameter test was tried progressively. Through the test, the disking phenomenon which has no direct relations with joints or cracks of strata was confirmed. This disking phenomenon occurred expectedly in the practical operations, which made possible for the smooth improvement of further larger diameter boring. However, no disking phenomenon was recognized in some area exceptionally, where wedge-shaped breaker was fitted additionally to the cutter to obtain sufficient results. Now, large diameter borings of 1,500 mm diameter are possible and the flexible selection of diameters is applied according to the purpose, that is, ventilation holes for decreasing the underground high temperature caused by mine deepening, effective countermeasures for gas outburst, etc.

Recently, horizontal large diameter borings upto 30 m has been possible using this method, and further horizontal long boring operation is possible if high power machine is introduced.

Regarding the cutting width of the ring part, it is fixed to 40 mm width and single cone rotary bits are applied in stead of hard metal bits to decrease the cutting losses. The method is also applied for the advanced boring in the drift sinking operation. Thus the wide range of usages of this method is hopefully expanded to various ways.

(K-4)

(33) Dinting Machines

Takagi, S. and Naitoh, H.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1146, pp. 685–688, 1983,

We developed 4 type of small dinting machines, which has some feauture to get high efficiency and reduction of labor.

Then, we put to use them at some pit in fact and investigated about following points

(1) Ability of dinting
(2) Suitability of machines
(3) Durability of machines
(4) Application to subsidiary work

In findings, every machine made higher efficiency by a large marginly than human efforts. And they can raise it moreover by improvement of way.

About suitability of machines, they have no difficulty on space where we planned.

Also they can answer to operations to make the most of each feauture.

About durability of machines, each was dammeged partly, but there were no defect in structural. We can find some of subsidiary work with them.

We expect that they could raise the overall efficiency on maintenance of roadway.

(K-11)

(34) Abstract of Bolt Setters

Saya, M. and Yamazato, H.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 99, No. 1146, pp. 688–691, 1983,

In the Coal Mining Reserch Centre, Japan, we developed five "Bolt Setters" for the purpose of preventing emergency and improving efficiency at Bolting works.

First one has tracks and two hydraulic rotation moters for drilling and Bolting, which is operated by electric moter.

Second one has a percussion drill which is installed on the simple wheel. It is operated by human power. Third one has tracks and hydraulic rotary percussion drill, which is operated by air motor (4 kg/cm^2 pressure).

Fourth one has tracks and hydraulic rotary percussion drill, which is operated by electric moter.

Last one has tracks, hydraulic rotary percussion or rotary drill and special mechanism which is able to choice rotary or rotary percussion drilling methods. It is operated by air moter (4 kg/cm^2 pressure).

(K-11)

(35) On the Effect of Rake Angle of Drag Bit in Rock Cutting

Nishimatsu, Y., Akiyama, M., Okubo, S. and Yoshida, T.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 100, No. 1161, pp. 1063–1067, 1984,

A series of rock cutting tests is conducted by drag bits of various geometries. In order to evaluate the effect of rake angle of bit as well as mechanical properties of sample rock on the cutting force, the equation of cutting force P given in previous paper $P = (a \cdot t/B+b) \cdot t \cdot B + c$ is applied to the test result, where t is the depth of cut, B is the blade width of bit, a, b and c are parameters as functions of the rake angle of bit and mechanical properties of rock. It is concluded that

(a) Parameters a and b decrease with increase of the rake angle of bit.
(b) When parameters a and b are assumed as proportional to the shear strength of rock, both of them depend upon the angle of internal friction of rock as well as the apparent angle of friction between bit and rock. The latter angle is not independent of the rake angle of bit.
(c) Parameter c is approximately proportional to the shear strength of rock, and independent of the rake angle of bit. Furthermore, on the basis of the test result, it is indicated that
(d) The ratio of thrust to cutting force decreases with increase of the rake angle of bit.
(e) When the cross-section of cut groove A is expressed as $A = (d \cdot t/B+1) \cdot t \cdot B$, the parameter d is independent of the rake angle of bit.

(K-4)

(36) Experimental Study on the Effectiveness of Sidewall Boring for Mine Roadway Maintenance

Ihara, M., Matsui, K. and Ichikawa, Y.

Journal of the Mining and Metallurgical Institute of Japan, Vol. 101, No. 1168, pp. 345–350, 1985,

Sidewall boring technique for the improvement of mine roadway stability is based on the transfer of the high stress concentration further away from the roadway sides. This technique seems to be a simple, effective and practical method compared with that of sidewall cutting slots.

In this study the effectiveness of sidewall boring for roadway maintenance is investigated by means of scale model tests, using a sand-plaster mixture as model rock. The results of this study are summarized as follows:

1) The optimum sidewall borings reduce mine roadway deformation.
2) The optimum length, diameter and spacing of the boreholes are about 100%, 10% and 20% of roadway width respectively.
3) Spalling of sidewall rock occurs easily because of high stress concentration between boreholes. However, the stabilities of the roof and floor are improved remarkably.

(K-0)

III. LIST OF LITERATURES

The listed literatures on rock mechanics and related fields are picked up from twenty eight periodicals[1)] published in Japan, from the beginning of 1982 to the end of 1985.

The symbols, A–1, A–2, ---- which can be seen at the end of each literature are those of classification of I.G.C.. The details are described after[2)].

The following superscripts marked at the end of each literature mean the kinds of written language:

no-marked	;	in Japanese
*	;	in English
**	;	in French
***	;	in German

NOTE

1)

(1) Proceedings of the Japan Symposium on Rock Mechanics
(2) Journal of the Japan Society of Civil Engineers
(3) Proceedings of the Japan Society of Civil Engineers
(4) Proceedings of the Symposium on Rock Mechanics, JSCE
(5) Tsuchi-to-Kiso, JSSMFE
(6) Journal of the Japanese Society of Soil Mechanics and Foundation Engineering
(7) Journal of the Mining and Metallurgical Institute of Japan
(8) Journal of the Society of Materials Science, Japan
(9) Bulletin of the Geological Survey of Japan
(10) Chinetsu (Journal of the Japan Geothermal Energy Association)
(11) Civil Engineering Journal
(12) Electric Power Civil Engineering
(13) Geophysical Exploration
(14) Journal of the Geothermal Research Society of Japan
(15) Journal of the Japan Society of Engineering Geologys
(16) Journal of the Japanese Society of Irrigation, Drainage and Reclamation Engineering
(17) Landslides (Journal of Japan Landslide Society)
(18) Large Dams (Journal of the Japanese National Committee on Large Dams)
(19) Mining and Safety
(20) Railway Technical Research Pre-Report
(21) Railway Technical Research Report
(22) Report of the Public Works Research Institute, Ministry of Construction
(23) Technical Report of Central Research Institute of Electric Power Industry
(24) The Dam Digest
(25) The Journal of the Geological Society of Japan
(26) Transactions of the Japanese Society of Irrigation, Drainage and Reclamation Engineering
(27) Tunnels and Underground
(28) Zisin (Journal of the Seismological Society of Japan)

2) I.G.C.: International Geotechnical Classification System

A General

A-1 Foundation, Soil and Rock Engineering-Scope
A-2 Historical Aspects
A-3 Bibliographies and Literature Classification
A-4 Textbooks, Handbooks and Geotechnical Periodicals
A-5 Nomenclature
A-6 Companies, Institutes, and Laboratories
A-7 Societies and Meetings
A-8 Professional Ethics and Legal Requirements (incl. Codes of Practice)
A-9 Education

B Engineering Geology
[Including Descriptions and Case Records of National Phenomena.]

B-0 General
B-1 Soil Formation
B-2 Ground Water
B-3 Mass Movements and Subsidence
B-4 Natural Catastrophes (incl. Earthquakes, Floods)
B-5 Permafrost and Frozen Ground
B-6 Submarine Geology
B-7 Structural Geology
B-8 Extraterrestrial Geology
B-9 Geomorphology
B-10 Mineralogy and Petrography

C Site Investigations

〔**Equipment and Techniques of Exploration, Sampling, Field Testing (excluding Engineering Properties), and Preconstruction Field Observations.**〕

- C-0 General (incl. Planning of Site Investigations)
- C-1 Airphoto Surveys
- C-2 Geophysical Surveys
- C-3 Probing (Soundings)
- C-4 Exploratory Excavations
- C-5 Boring Technique and Equipment and Recording of Results
- C-6 Sampling, Handling of Samples
- C-7 Measurement of Field Conditions (incl. Groundwater, In Situ Stress)
- C-8 Field Testing (excl. Tests for Engineering Properties, see Groups D and F)
- C-9 Reports on Site Investigations

D Soil Properties: Laboratory and Field Determinations

〔**Concepts, Theories, Methods of Determination, Equipment and Results.**〕

- D-0 General (incl. Laboratory Supplies)
- D-1 Classification and Identification
- D-2 Physico-chemical Properties (incl. Corrosion, Thixotropy)
- D-3 Composition, Structure and Density (incl. Porosity)
- D-4 Permeability and Capillarity
- D-5 Compressibility (incl. Consolidation and Swelling)
- D-6 Shear-Deformation and Strength Properties (incl. Pore-water Pressure)
- D-7 Dynamic Properties
- D-8 Thermal Properties (incl. Freezing)
- D-9 Compactibility
- D-10 Properties of Soil Additive Mixtures

E Analysis of Soil-Engineering Problems

〔**Theoretical, Empirical and Practical Methods of Analysis.**〕

- E-0 General
- E-1 In Situ Stresses caused by Gravity and Applied Loads and Excavations
- E-2 Deformation and Settlement Problems (incl. Piles)
- E-3 Bearing Capacity of Soils
- E-4 Bearing Capacity of Piles
- E-5 Earth Pressure Problems (incl. Silos)
- E-6 Stability of Slopes, Cuts and Excavations
- E-7 Seepage and other Hydraulic Problems (incl. Erosion)
- E-8 Dynamic Problems
- E-9 Frost Action and Heat Transfer Problems
- E-10 Behaviour of Base Courses and Pavements
- E-11 Soil-vehicle Interaction (Trafficability)

F Rock Properties: Laboratory and Field Determinations

〔**Concepts, Theories, Methods of Determination, Equipment and Results.**〕

- F-0 General (incl. Laboratory Supplies)
- F-1 Classification and Identification
- F-2 Physicochemical Properties (incl. Weathering Resistance)
- F-3 Composition, Structure and Density (incl. Porosity)
- F-4 Permeability and Capillarity
- F-5 Compressibility and Swelling
- F-6 Shear-Deformation and Strength Properties
- F-7 Dynamic Properties
- F-8 Special Properties of Rock (incl. Thermal, Electric and Magnetic Properties)

G Analysis of Rock-Engineering Problems

〔**Theoretical, Empirical and Practical Methods of Analysis.**〕

- G-0 General
- G-1 In Situ Stresses caused by Gravity, Tectonics, Applied Loads and Excavations
- G-2 Deformation Problems
- G-3 Bearing Capacity of Rock
- G-4 Stability of Slopes, Excavations and Openings
- G-5 Seepage Problems (incl. Drainage)
- G-6 Dynamic Problems
- G-7 Frost Action and Heat Transfer Problems.

H Design, Construction and Behaviour of Engineering Works

〔**Descriptions; Case Histories; Syntheses of Investigations, Design, Construction (incl. Equipment and Materials) and Behaviour.**〕

- H-0 General (incl. General Contracts and Specification)
- H-1 Foundations of Structures (Buildings, Bridges, Tanks, etc.)
- H-2 Retaining Structures and Cutoff Walls
- H-3 Unsupported Excavations
- H-4 Earthworks, Embankments, Fills and Dams (for Compaction see K-5)
- H-5 Underground Structures (incl. Tunnels, Conduits and Shafts)
- H-6 Base Courses and Pavements of Roads, Railroads and Airfields
- H-7 Harbours, Canals and Coastal Protective Works

K Construction Methods and Equipment
〔Including Improvement of Soil and Rock Conditions.〕

- K-0 General
- K-1 Dewatering and Drainage
- K-2 Injection Processes (incl. Grouting)
- K-3 Preloading and Soil Replacement by Blasting
- K-4 Soil and Rock Excavation, Processing and Transportation
- K-5 Compaction
- K-6 Soil Stabilization (incl. Mechanical, Chemical, Thermal and Electrical Methods)
- K-7 Piles and Pile Driving
- K-8 Caissons and Deep Piers
- K-9 Underpinning
- K-10 Slurry-assisted Construction of Foundations and Cutoff Walls
- K-11 Anchorages, Tied-back Walls, Reinforcement, Linings and other Supports of Soil and Rock
- K-12 Deep-water Construction Methods and Equipment (incl. Dredging, Barge Dumping, etc.)

S Snow and Ice Mechanics and Engineering

- S-1 Snow and Ice Cover
- S-2 Properties of Snow and Ice
- S-3 Snow and Ice Engineering

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Transportation Engineer	91
Regional & Urban Planner	27
Hydraulic Engineer	52
Hydrologic Engineer	118
Irrigation & Drainage Engineer	24
Soils & Foundation Engineer	20
Electrical & Mechanical Engineer	14
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Economist	13
Others	113
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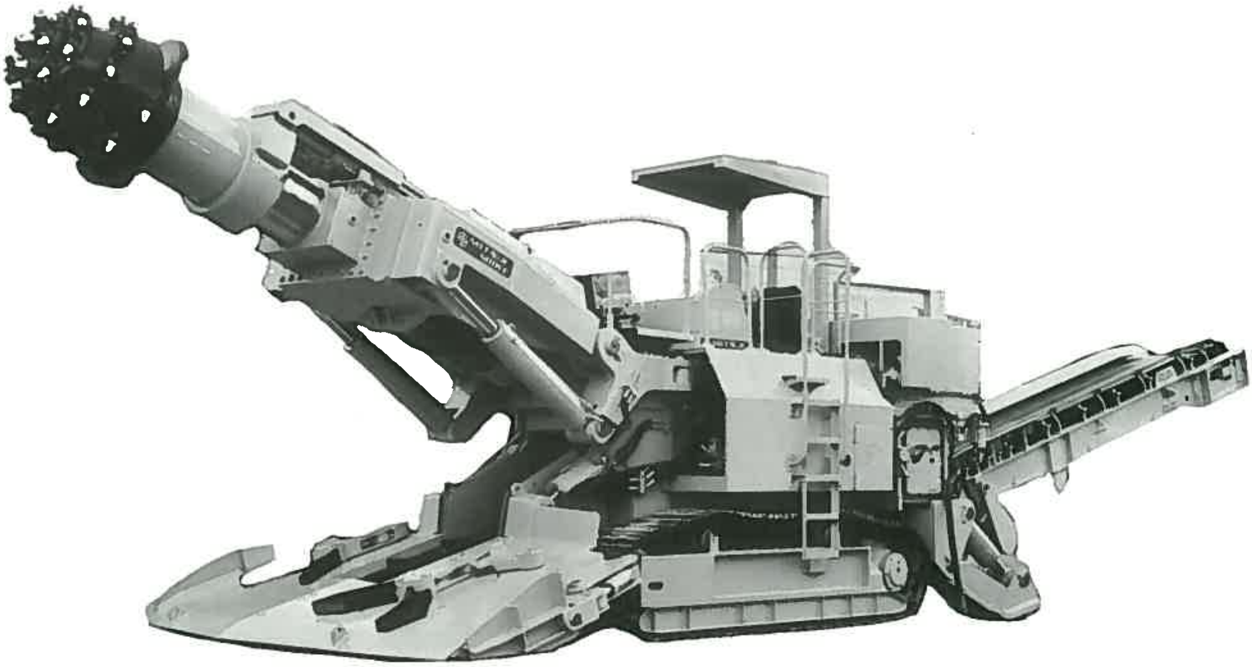

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Total Height : 3.0 m
Total Width : 3.6 m
Cutting Height : 6.0 m
Cutting Width : 6.4 m
Cutting Motor : 200/110kw-4/8P
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Director	Yoitsu Oguma
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Director	Masahiro Kita
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Civil Engineers	12
Drilling Engineers	38
Mining Engineers	7
Other Technicians	16
Administrative Staff	19
Total	135

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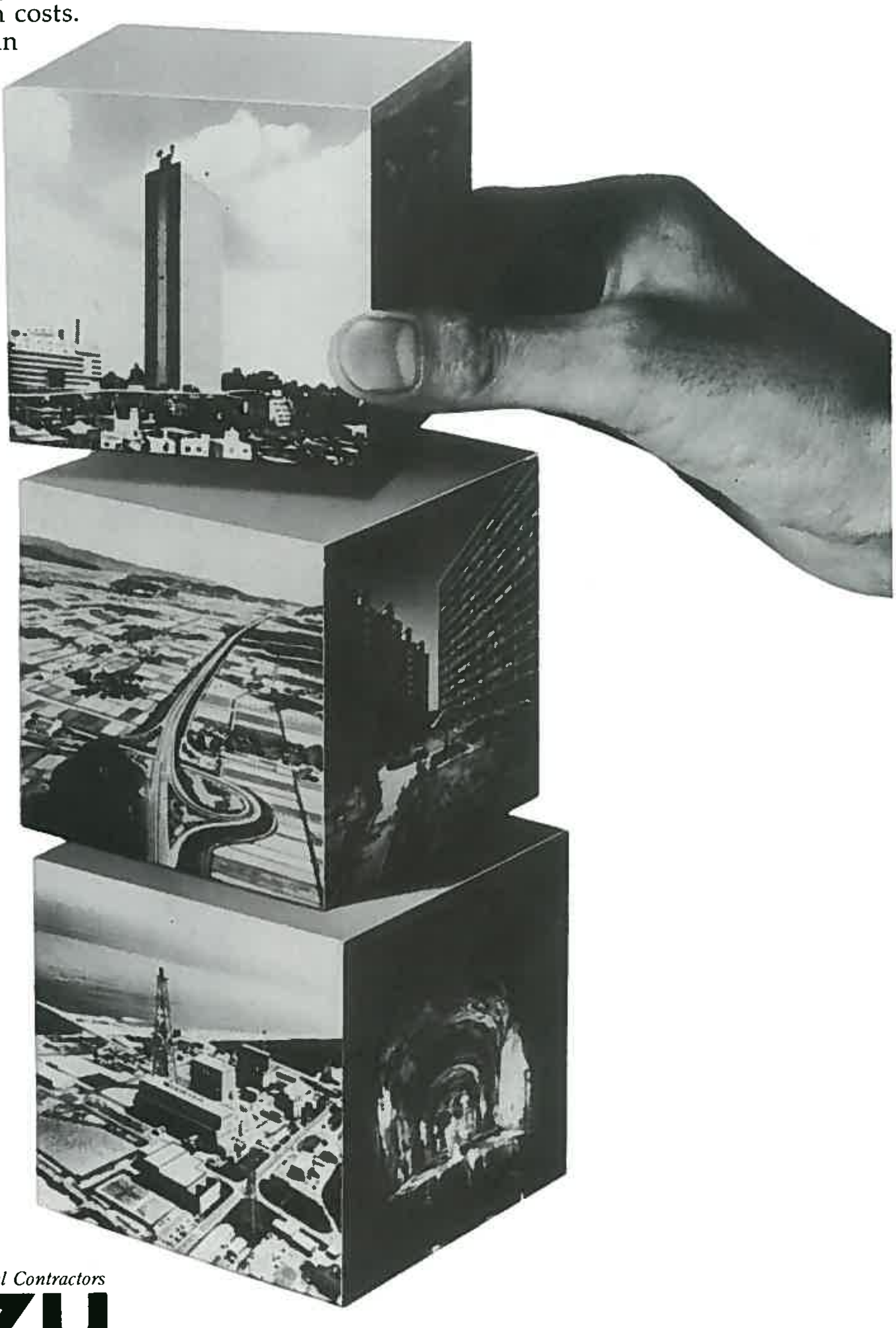

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