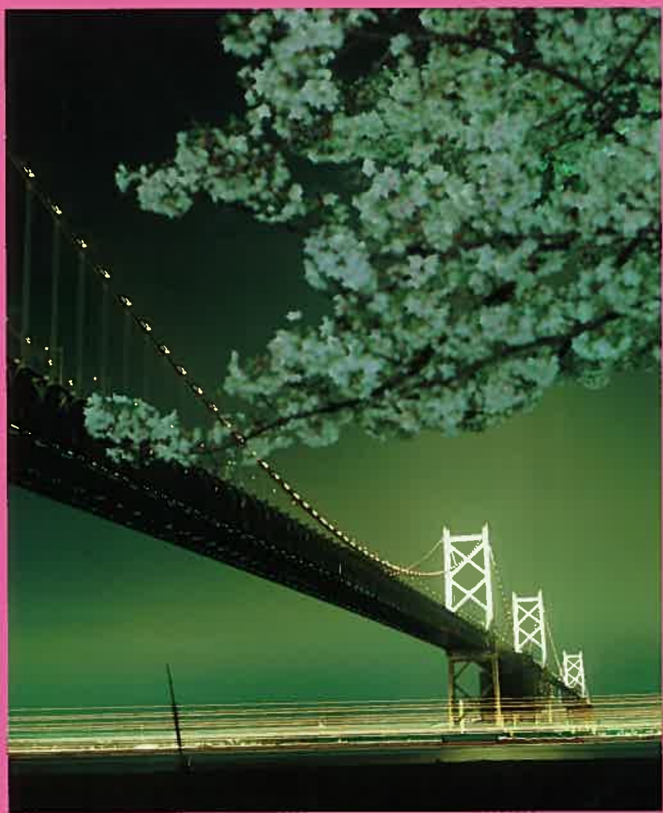
ROCK MECHANICS IN JAPAN

VOLUME VI



JAPANESE COMMITTEE FOR ISRM

1991

Mine, Nature, Artificial beauty

Large caverns in Kamioka Mine

Kamioka Mine (Gifu prefecture) was found in 720 A.D. and has been mined since then. It yields silver, zinc and lead ores.

Recently, a part of the mine is utilized for other purposes. Examples include the research on the neutorinos spectrum and nuclear decay conducted by Institute of Cosmic Rays Research, University of Tokyo, in a large cavern 1,000m below the ground. (cf. p.63)

Stalactite
Shuhodo Cave (Yamaguchi)

Shuhodo is the largest limestone cave in the western Japan It locates in Akiyoshidai plateau, which is a typical karst plateau.

Stone garden
Taizoin Temple (Kyoto)

The white sand which is given a pattern of furrows represents the sea and the rocks symbolize the islands floating on sea waves.

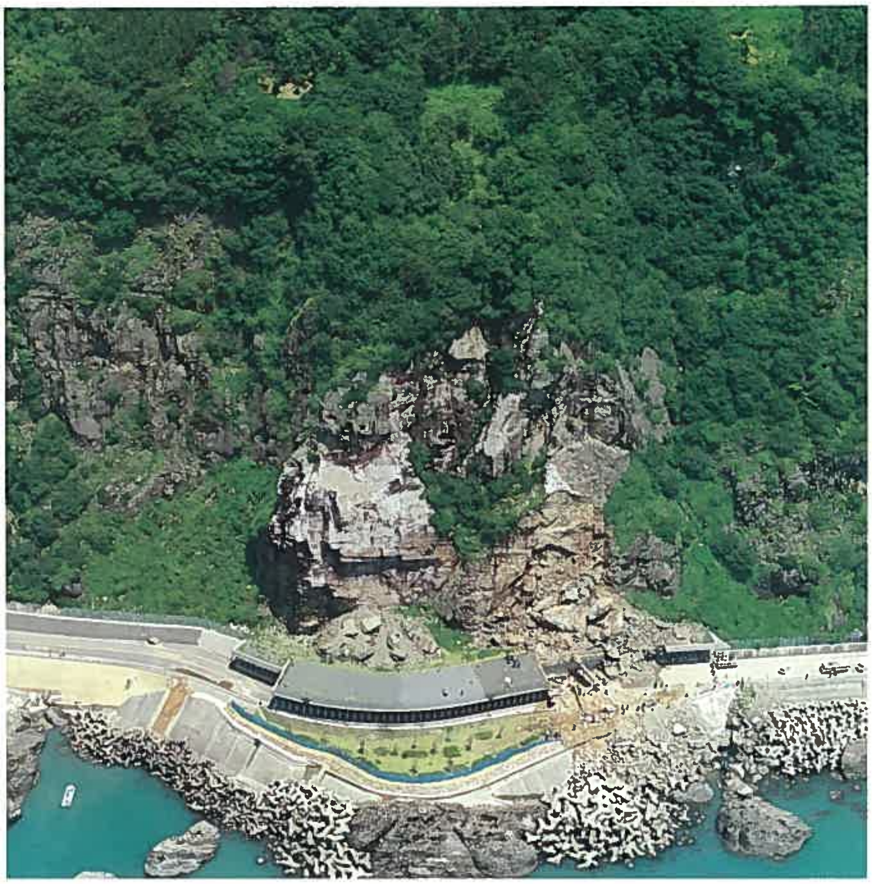
Slope

A Large Scale Slope of Limestone Open-Cut Mine in Mt.Buko

Mt. Buko which is composed of limestone and schalstein locates north-west of Tokyo.

The size of the slope is 200m in height, 800m in width and 45° in average slope angle at present. The future mining will result in a larger slop with 800m in height, 5km in width and slope angle of 60°.

Disaster due to Hillside Failure



It is an example of disaster due to the unexpected rock fall of hillside. The rock fall took place along the national highway in Fukui prefecture in 1989, and destroyed the concrete shed for shelter resulting in the loss of several lives of a tourist bus.
(cf. p.118)

Tunnel

Abo Tunnel

Abo Tunnel is 4.3km long highway tunnel passing through the high volcanic ranges in the northern Japan Alps. Various probrems have to be examined in advance, such as the excavation of intensely heated rock, stoppage of gushing hot spring water, prevention of leakage of poisonous gas and so forth.

1) Location
   border of Gifu and Nagano prefectures
2) Construction period 1989～1998

Drilling with wheel jumbos

Using eight powerful hydraulic booms, 160 to 220 holes were drilled at the face of the Kan-etsu Tunnel.

1) Location
   border of Gunma and Niigata prefectures
2) Construction period
   1977～1991
   (cf. p.96)

Center-Diaphragm Method

The Center Diaphragm Method was employed for the excavation of New Tsuburano Tunnel. This method is particularly effective in the construction for a large flat tunnel through unstable ground.

1) Location
   Kanagawa prefecture
2) Construction period
   1986～1990

(cf. p.72)

Dam

Okumino Kaore Dam

Kaore Dam, which is an arch dam, is now under construction for the upper reservior of Okumino Hydro-Power Station.

1) Location
   Gifu prefecture
2) Size
   crest height : 107.5m
   crest length : 341.2m
   dam volume : 400,000m³
3) Construction period
   1988～1994

Naramata Dam

Naramata Dam, a rockfill dam with a central impervious core, is utilized for flood control and water supply for various purposes.

1) Location
   Gunma Prefecture
   (near the boundary with Niigata Prefecture)
2) Size
   crest height : 158m
   crest length : 520m
   dam volume : 13.10 million m³
3) Construction period
   1981～1990

Dam

Kurobe Dam

Kurobe Dam was completed in 1963.

This is a dome-shaped arch dam and the highest one in Japan.

1) Location
   Toyama prefecture
2) Size
   crest height : 186m
   crest length : 492m
   dam volume : 1.58 million m^3

(cf. p.89)

Miyagase Dam

Miyagase Dam is a concrete gravity dam for flood control and multi - purpose water supply. This is now under construction.

1) Location
   Kanagawa prefecture
2) Size
   crest height : 155m
   crest length : 400m
   dam volume : about 2.00 million m^3
3) Construction period
   1987～1995

(cf. p.38)

Inground Oil Storage Plant (Vertical Type)

Bird's-eye view of the base (Akita)

Akita Oil Storage Base has twelve inground crude oil storage tanks, which has the largest size in the world.

1) Location
   Akita prefecture
2) Size of storage tank
   height : 51.5m
   inner diameter : 90m, 97m
3) Total storage capacity
   4.50 million kl
4) Construction period
   1981～1994

Reprinted from 1990. 1. 26
NIKKEI CONSTRUCTION
(photo by Yoshikazu Nishiyama)

Excavation of tank (Akita)

Underground Oil Storage Plant (Horizontal Type)

Storage cavern (Kushikino)

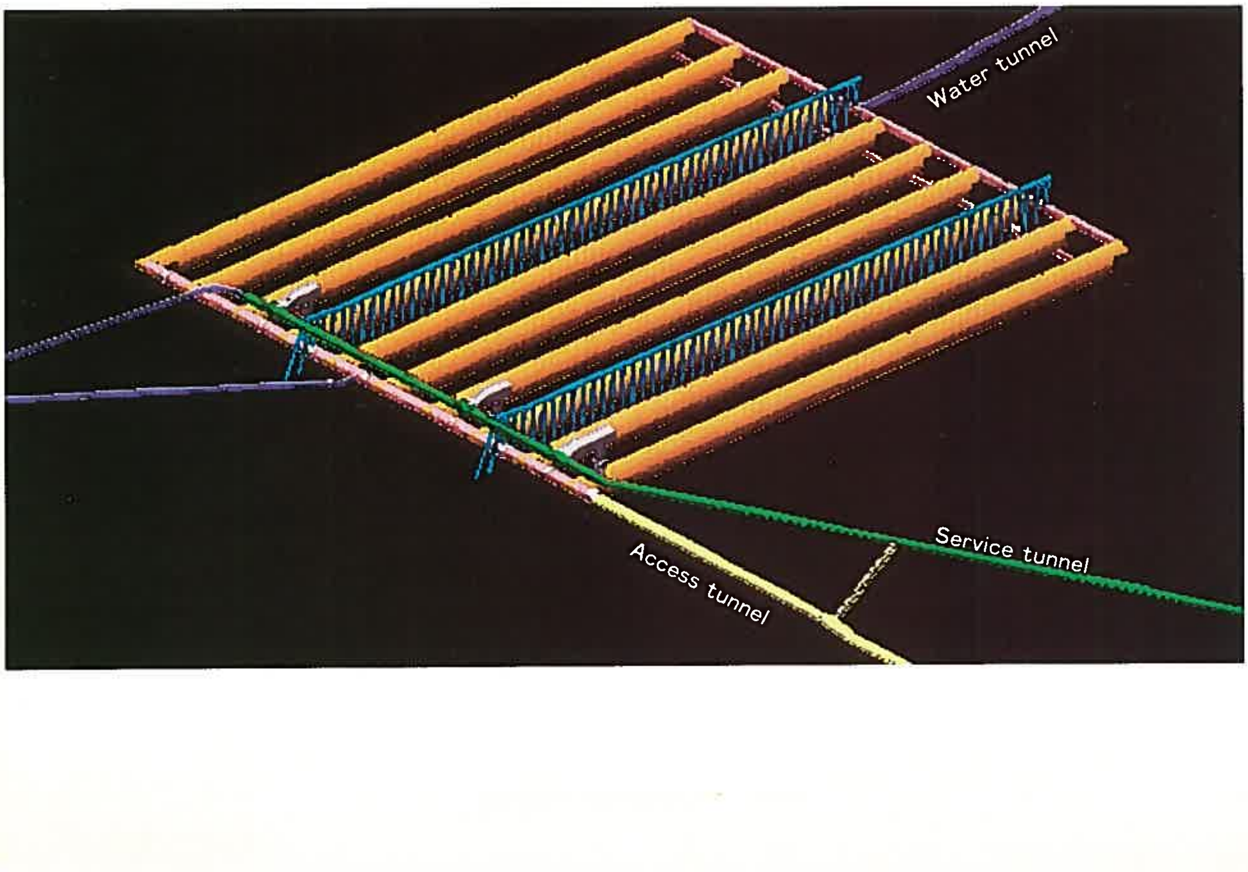
Kushikino Plant is one of the first three underground oil storage facilities in Japan.

1) Location
   Kagoshima prefecture
2) Size of storage cavern
   height : 22m
   width : 18m
   length : 555m×10 caverns
3) Total storage capacity
   1.75 million kl
4) Construction period
   1987~1992

(cf. p.31)

Illustration ELECTRIC POWER DEVELOPMENT CO., LTD.

Perspective view (Kushikino)



Underground Power Station

Sabigawa Power Station

1) Location
   Tochigi prefecture
2) Shape of cavern
   mashroom-shaped cross section
3) Size of cavern
   height : 51.4m
   width : 29.0m
   length : 165m
4) Maximum output
   900MW
5) Construction period
   1987～1994

(cf. p.40)

Imaichi Power Station

1) Location
   Tochigi prefecture
2) Shape of cavern
   egg-shaped cross section
3) Size of cavern
   height : 51.0m
   width : 33.5m
   length : 160m
4) Maximum output
   1,050MW
5) Construction period
   1979～1988

(cf. p.101)

Okawachi Power Station

1) Location
   Hyogo prefecture
2) Shape of cavern
   bread-loaf-shaped cross section
3) Size of cavern
   height : 46.6m
   width : 24.0m
   length : 135m
4) Maximum output
   1,280MW
5) Construction period
   1988～1992

(cf. p.42)

Cover Photograph
Minami-Bisanseto Bridge
Photo courtesy of Honsyu-Shikoku Bridge Authority

Back Cover Photograph
Kumamoto Castle

ROCK MECHANICS IN JAPAN

VOLUME VI

1991

Published by
JAPANESE COMMITTEE FOR ISRM
(c/o JAPAN SOCIETY OF CIVIL ENGINEERS)

PRESIDENT: Yuichi NISHIMATSU

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Preface

Rock Mechanics in Japan, Volume VI, 1991 was compiled by the Japanese Committee for ISRM in order to introduce recent research activities and technical developments in the field of rock mechanics and related industries in Japan. A volume has been published every 4 years coinciding with meetings of the International Congress on Rock Mechanics.

The Japanese Committee for ISRM is organized under cooperation of four societies; Japan Society of Civil Engineers, the Japanese Society of Soil Mechanics and Foundation Engineering, the Mining and Materials Processing Institute of Japan, and the Society of Materials Science, Japan. This Committee represents Japan as the National Group of International Society for Rock Mechanics (ISRM). In 1990, work was begun by the organizing committee of the 8th International Congress on Rock Mechanics in preparation for the 1995 meeting in Tokyo.

The volume VI of Rock Mechanics in Japan consists of two parts. In the first part, brief comment on the activity of the Japanese Committee for ISRM and reviews on the research activity of the related four academic societies from 1987 to 1990 are presented. The second part reviews recent technical developments related to rock mechanics in various construction projects and mining activities.

The volume VI indicates the enthusiasm with which rock mechanics is approached in Japan. A number of papers on rock mechanics have been published every year in Japanese and various big projects related to rock mechanics have stimulated many technical developments. Unfortunately, the language barrier disturbs mutual understanding and information exchanges between engineers who are interested in the common field of rock mechanics. It will be a great pleasure if this volume would introduce recent research activities and technical developments in Japan, the host country of the 8th International Congress on Rock Mechanics, to the world.

March 1991

Yuichi NISHIMATSU

President,
Japanese Committee for ISRM

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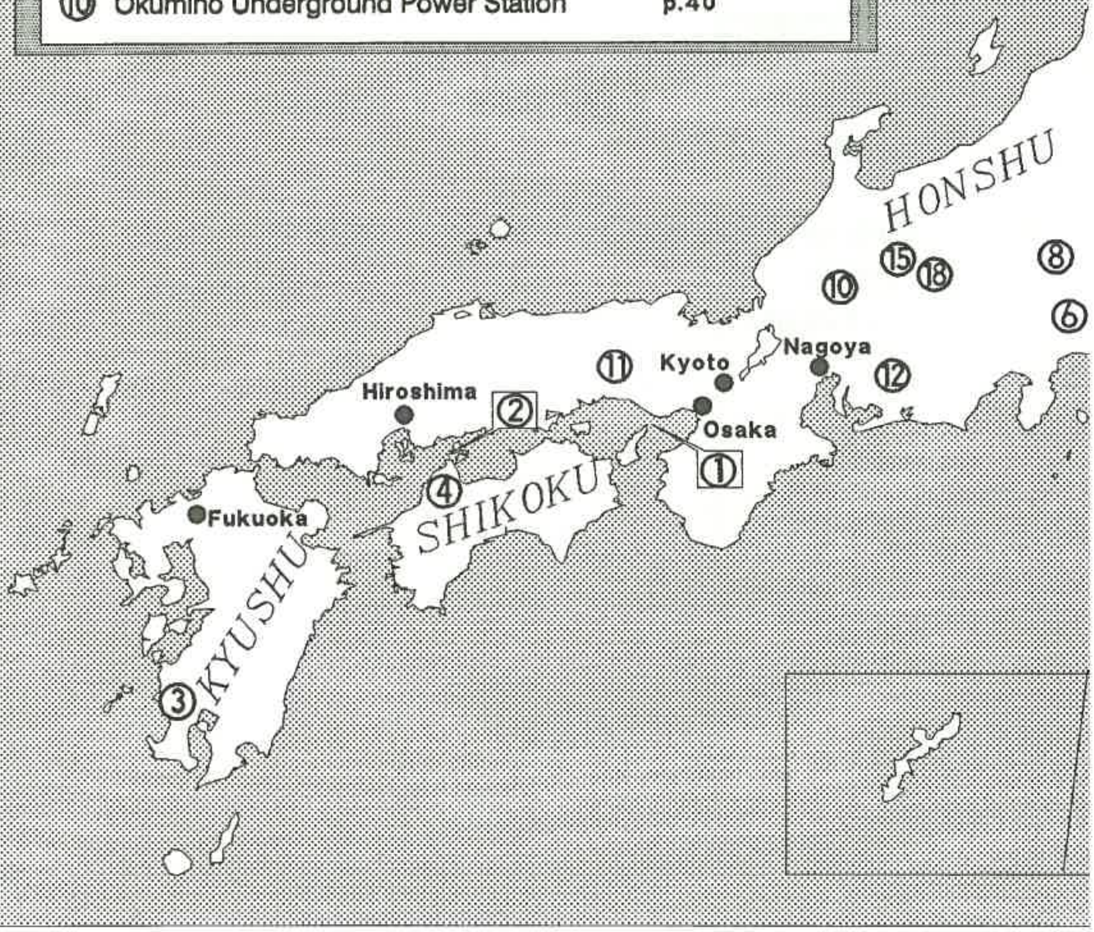

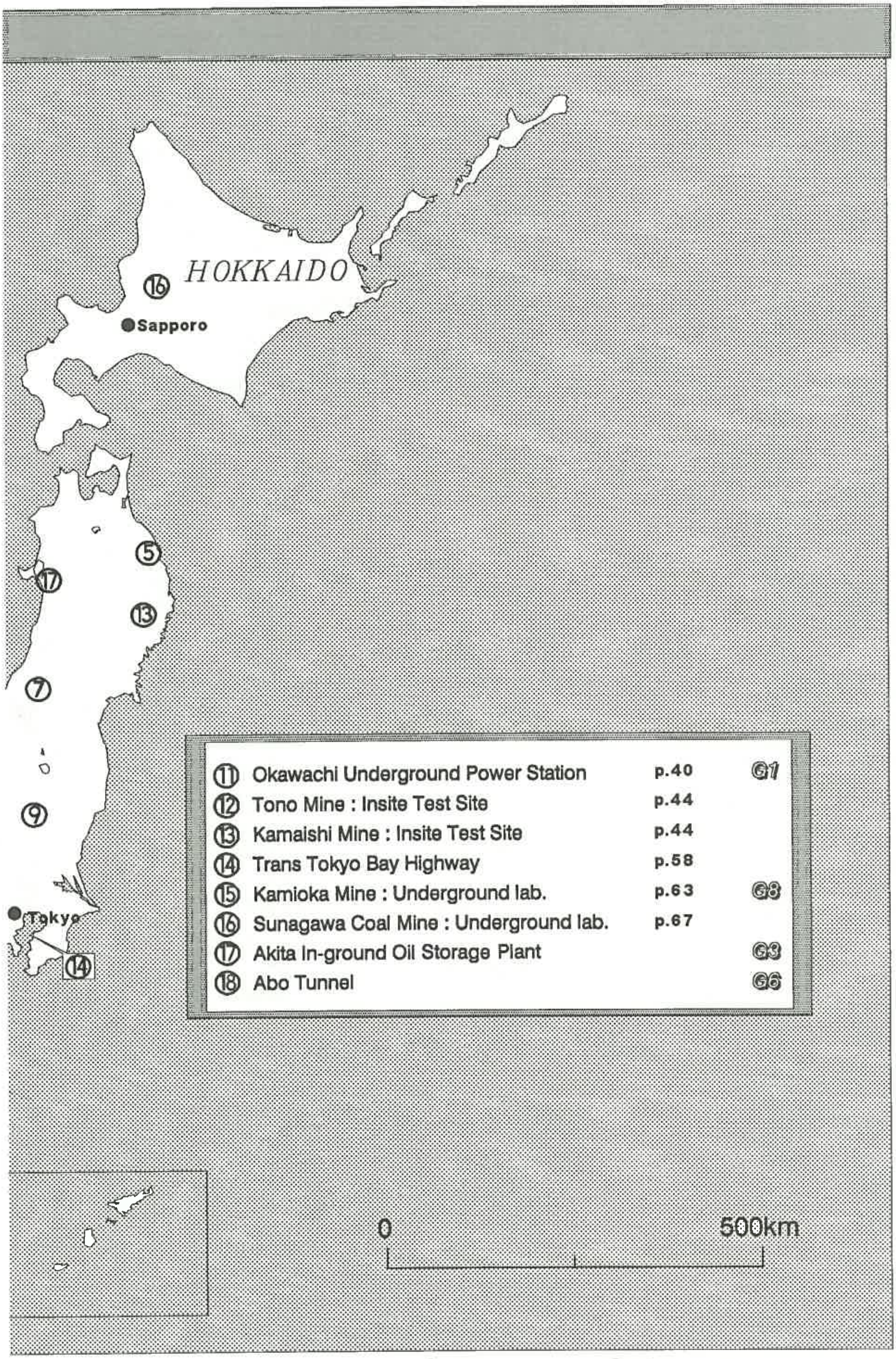

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Project Map

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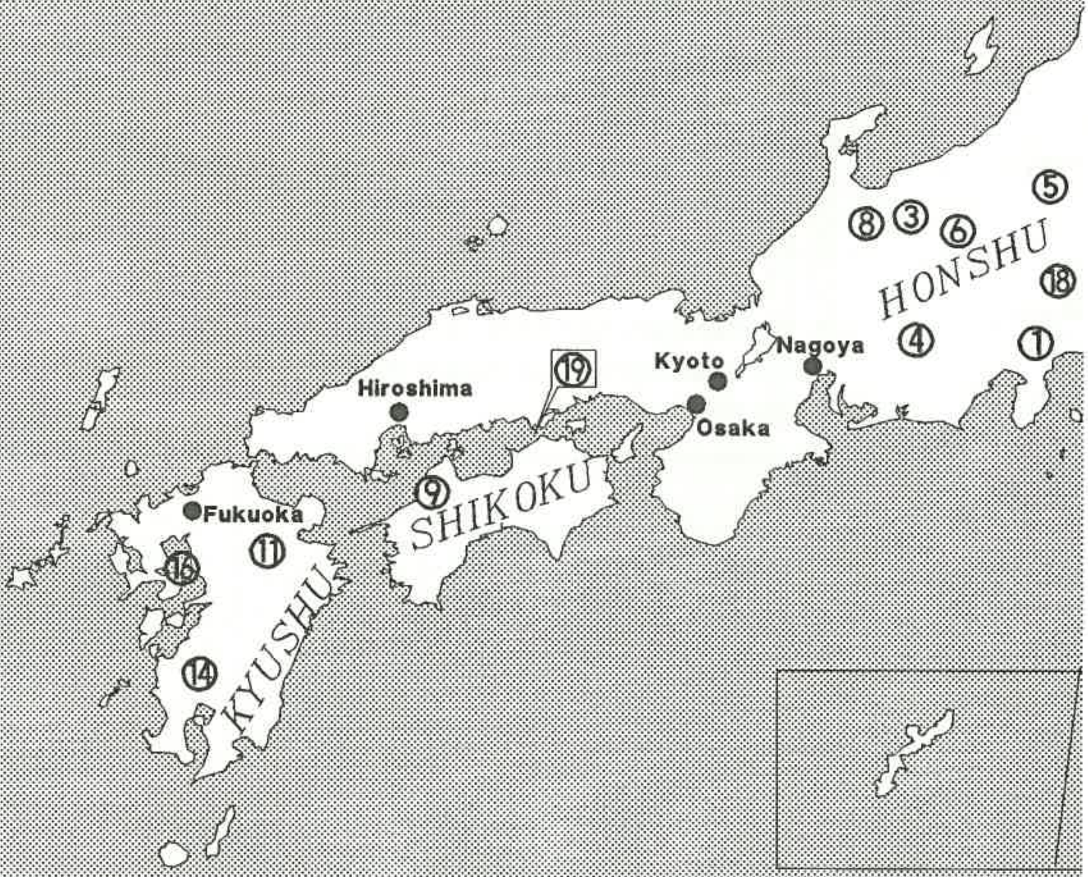

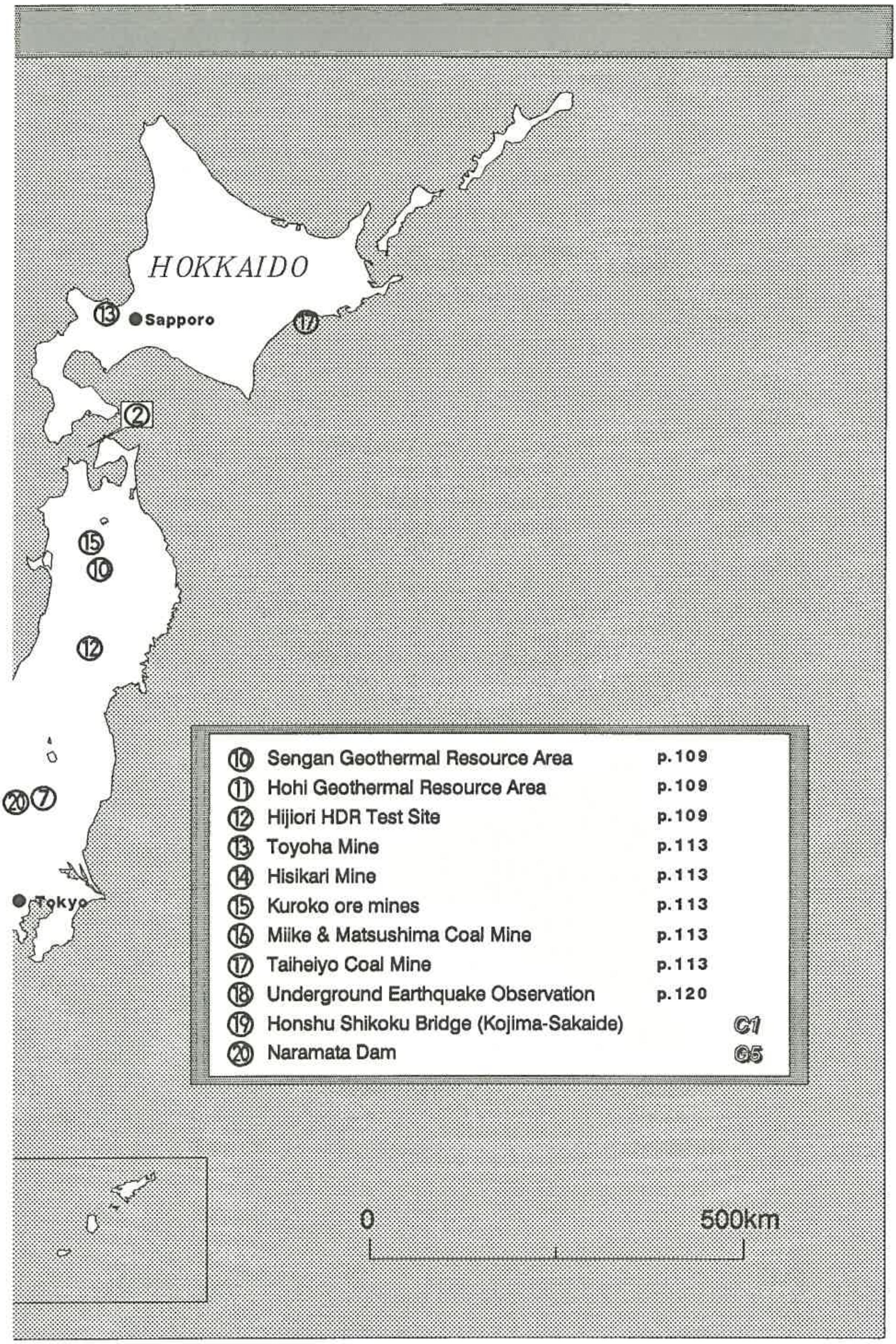

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Organization and Activities of Japanese Committee for ISRM (National Group of Japan, ISRM), and Progress of Arrangement and Welcome for the 8th ISRM Congress

Koichi SASSA

Professor of Kyoto University
Chairman of Secretarial Board, Japanese Committee for ISRM

1. Organization and Activities

Japanese National Group is composed of 303 individual members and 73 supporting member firms of ISRM, and is organized under cooperation of four following individual academic societies, that is, the Japan Society of Civil Engineering (JSCE), the Japan Society of Soil Mechanics and Foundation Engineering (JSSMFE), the Mining and Material Processing Institute of Japan (MMIJ), and the Society of Materials Science, Japan (SMSJ).

Japanese Committee for ISRM has a Board of Directors, a Secretarial Board, and following three sub-committees, those are, Publication, Testing Methods, and Foreign Affairs and Planning.

The Board of directors is composed of about 25 directors.

The Board Meeting is normally held twice a year. This meeting is a decision making meeting of the national group.

The Secretarial Board is composed of chairman of this board, 8 executive members who are named by the above four organizing societies and the chairmen of three sub- committees shown above. The Secretarial Board discusses the managements of the national group and the original bill for the Board Meeting.

Sub-committee on Publication manages the publication of the followings.

Rock Mechanic News: about 16 pages, published four times per year, the contents are activities of the national group, information from the head office of ISRM, announcement of meetings, and etc.

Rock Mechanics: about 900 pages, published annually, the contents are the papers on rock mechanics which were published in journals and proceedings of the four organizing societies during the year.

Rock Mechanics in Japan: about 300 pages, published just before ISRM Congress, the contents are the introduction of rock mechanics activities in Japan.

The Sub-committee on Testing Methods is a Japanese Committee of the ISRM Committee on Testing Methods. This committee discusses various testing methods, organizes a workshop on testing methods and technical meetings with lecture by foreign colleagues.

The Sub-committee on Foreign Affairs and Planning is responsible for the foreign correspondence, especially communication with the ISRM headquarter and members. It also discusses and proposes the future plan of ISRM national activity.

The committee organizes Japan National Symposium on Rock Mechanics, which is supported by JSCE, JSSMFE, MMIJ and SMSJ. The national symposium is normally held every three years. The 7th Symposium was held in December, 1987, and the 8th one was held in November, 1990. In both symposium, about 80 papers were presented.

The titles and authors of the papers presented in the 8th symposium are as follows.

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"Accuracy of Identification Method for Anisotropic Mechanical Constants of Rock Mass by Local Iterated Kalman Filter"
by Shunichi KADOTA, Etsuro SAITO and Shigetoshi KODA

"Analysis and Back-Analysis for Problems of Tunnel Excavation with One or Two Openings in Elastic Rock"
by Tetsutaro KAWAKAMI, Ken-ichi HIRASHIMA, Toshio FUJIWARA and Yukio

YAMASHITA
"Stress Estimation of Tunnel Lining by Convergence Data"
by Masayasu HISATAKE, Tomio ITO and Toshio MURAKAMI
"Numerical Analysis of Deformation Behavior of Jointed Rock by Equivalent Volume Defect Method"
by Katsuhiko KANEKO and Yoshiharu TANAKA
"Elasto-plastic Analysis of Rock Slopes by the Coupled Boundary Element-Characteristics Method"
by Katsuhiko SUGAWARA and Yuzo OBARA
"Estimation of Mechanical Properties of Discontinuous Rock"
by Bunsaku HASHIMOTO, Xiao Ming CHENG, Masako KAMIYAMA, Xiong MIN, Katuso HAGIHARA and Kiyoharu SUZUKI
"Studies on Mechanical Behavior o Rock Anchor"
by Yoshirou NIIMI, Seiichi KOMURA, Omer AYDAN and Seiji OKUMURA

THEME: 2 Discontinuities in Rock Masses
"The Study on Estimating and Modeling of Joints in Rock Mass"
by Yoshifumi NOGUCHI, Akio IIJIMA, Naoaki NAKAMURA, Katsaki KOIKE and Katuhiko KANEKO
"A Case Study of Rock Mass Classification and Modeling for Stratified Hard Rocks"
by Shu-ichi HASHIMOTO, Tadashi MIWA and Masa- aki ENDO
"Size Distribution of Cracks in Rock Masses"
by Masanobu ODA and Kenji KIMURA
"Estimating the Distribution of Rock Mass Discontinuities Using Scanlines"
by Tsuyoshi KIMURA, Ikuo TOHNO and Tetsuro ESAKI
"Evaluation of Geological conditions by "Drilling Logging System""
by Kenji AOKI, Takeshi INABA, Yukihiro SHIOGAMA and Yasunari TEZUKA
"Image Processing Method for the Rock Joint Abstraction and its Application to the Rock Joint Survey System"
by Bunsaku HASHIMOTO, Takashi SATO and Makoto HONDA
"An Investigation of Cracks in Granite Rock by using Ground Probing Radar"
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"Propagation Characteristics of Electromagnetic Waves Through the Cracked Rock"
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"Scale Effect in Shear Strength and Deformability of Rock Joint"
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"Roughness of Rock Discontinuities and Their Shear Behavior"
by Toshiaki SAITO and Makoto TERADA
"Roughness and Shear Behaviour of Rock Joints"
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"Correlation Between the Quantity of Discontinuities and Mechanical Properties on Rock Materials"
by Takashi ITOU, Tomoyuki AKAGI and Seiichi KOUMURA

THEME: 3 Acoustic Emission and Survey Method
"A Development of the Color Image Processing System for Optical data of Rock by Bore Hole Television-Analysis of Optical Characteristics of the Rocks-"
by Toshiaki MIMURO, Osamu TURUTA, Takeshi SASAKI, Hitoshi KURIOKA and Michihiro INO
"In-situ Experimental Study on Resistivity Tomography in Tunnel"
by Koji NOGUCHI, Shinya GOTO, Kazuo FURUYA, Masanao SHIBAMOTO and Haruhiko NISHINO
"Monitoring of Microcracking Cluster in Stressed Rock by AE and Seismic Tomography"
by Ken-ichi ITAKURA, Kazuhiko SATO and Atsushi OGASAWARA
"The Stability Monitoring during Excavation of Rock Caverns by Acoustic Emission Measurements"
by Kenji AOKI, Masaru TOIDA and Kenichi KOSHIZUKA

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by Tsuneyoshi MOCHIZUKI, Yoshinobu SAITO, Koji ISHIYAMA and Yoshitomo

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"Dynamic Response of Tunnel Caused by Blasting Vibration"
by Atsuo HIRATA, Tsutomu INABA and Katsuhiko KANEKO
"Characteristics of Ground Motions Observed in Deep Rock during Near-Field Earthquakes-Discussion on the Earthquakes in and around the Izu Peninsula-"
by Nobuo ARAI and Kazushi WAKITA

THEME: 5 Crack Propagation and Static Fracturing
"Some Stages of Stress-induced Crack Nucleation in Rock Sample"
by Yozo KUDO, Ken-ichi HASHIMOTO, Osam SANO and Koji NAKAGAWA
"Measurement of Crack Advance Behavior by AE in Three Points Bending Test"
by Manabu UTAGAWA, Masahiro SETO, Tamotsu KIYAMA and Kunihisa KATSUYAMA
"Application of Fracture Mechanics on Tunnels Blasting Design"
by Kenji AOKI, Takayuki MORI, Kouichi MURAKAWA and Kenichi KOSHIZUKA
"Study on Static Rock Breaker Using Shape Memory Alloy"
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"Development of Static Fracturing Method of Rock Mass by Using Hydraulic Pressure"
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by Mitsuhiko SHIMADA
"Deformation Behaviour of soft Sedimentary Rocks under Thermal Atmosphere"
by Tadashi YAMABE, Toshiyuki YAZAWA and Sin- ichi TANIGUCHI
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"Mechanical Behaviour and Property Changes of Rock induced by Tunnel Excavation in Granite"
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"Stability of Interpanel-Pillar and Deformation of Gateroad due to Longwall Mining"
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"Deformational Behavior of Existing Tunnels Due to Ground Surface Excavations"
by Shunsuke SAKURAI, Norikazu SHIMIZU, Hiroshi KANAZAWA and Makoto KAJIWARA
"Study on the Meaning of Tunnel Face Evaluation"
by Tikaosa TANIMOTO, Hisaya YOSHIOKA, Toshio FUJIWARA, Koji HATA, Hideo KINASI and Michio NAKAO
"Interpretations and Applications of Ground Characteristic Line to Soft Rock Tunnels"
by Takashi KITAGAWA, Ryunoshin YOSHINAKA and Daisuke INAGAKI
"Supporting Effects of Tunnel Face"
by Jiro YAMATOMI, Gento MOGI and Umetaro YAMAGUCHI
"Considerations on Rock Bolt Effects in Soft Rock Tunnel"
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by Ken-ichi HIRASHIMA, Shozo SAKUMA, Shinji KIKUCHI and Takeshi MATSUDA

"A Forward Analysis Method of Three- Dimensional In Situ Stress Determination by Absolute Displacement Measurements in a Tunnel"
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"Anelastic Strain Recovery of Rocks and Three- dimensional In-situ Stress Measurement"
by Koji MATSUKI

"Determination of In-Situ Stress State by DSCA"
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"Estimation of Rock Stress for In situ Stress Measurements and Laboratory Experiments"
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"Estimation of Geostress from AE Characteristics in Cyclic Loading of Rock"
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"Settlement-Swelling behavior of Tertiary Mudstone Induced by Effect of Drying-Wetting Repetition"
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by Hareyuki YAMAGUCHI, Yoichi MORI, Ichiro KUROSHIMA, Makoto FUKUDA and Ryoji SAKURADA

"Prediction of Long Term Strength of Soft Rock"
by Katsuhiko YAMADA, Shin-ichiro MATSUMURA and Yoshihiro NISHIGAKI

"Comparison of Testing Procedures by Cyclic Triaxial Loading for the Dynamic Deformation Characteristics of Soft Rock"
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"Rock Mechanics Investigations for the Construction of CASES Rock Cavern"
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"Strength and Deformation Properties of Mudstones in Triaxial Compression"
by You-seong KIM, Kenzo OCHI and Fumio TATSUOKA

"Strength and Deformation Properties of Mudstones in Laboratory Tests and Field Measurements"
by Kenzo OCHI, You-seong KIM, Kazuyuki NAKAMURA and Fumio TATSUOKA

"Mechanical Characteristics of Artificially Weathered NISHIYAMA Mudstone"
by Toshiaki MIMURO, Masaru YAMAUCHI, Atsushi DENDA and Kouhei WATANABE

"Characteristics of Mechanical Properties of Coal Measure Rocks and Coal and Their Application to Mining"
by Kikuo MATSUI, Masatomo ICHINOSE and Hideki SHIMADA

"Physical properties of Expanding Clay Mineral Bearing Altered Andesite"
by Shigeo DOI, Tetsuya SUZUKI and Yu HARIYA

THEME: 10 Seepage Flow

"Monitoring Fluid flow in Rock Samples by Means of P-wave Velocity Tomography and Velocity Recovery Due to Infiltration of the Fluid"
by Koji MASUDA, Osamu NISHIZAWA, Kin-ichiro KUSUNOSE, Takashi SATOH and Manabu TAKAHASHI

"Permeability of Sandstone Under Hydrostatic Pressure"
by Zi-qiu XUE, Yoji ISHIJIMA and Manabu TAKAHASHI

"Three dimensional Inversion of Spacial Distribution of Hydraulic Properties of Rock Masses Using the Transient Pressure Data Obtained in the Pulse Test"
by Hiroyuki TOSAKA, Kiyoshi MASUMOTO, Kazumasa ITOH and Yasunori OTSUKA

"A Semi-analytical Estimation of Hydraulic Conductivity from Lugeon Test Results Based upon Analytical Transient Solution and 3-D Numerical Results"
by Hiroyuki TOSAKA and Keiji KOJIMA

"Applicability of Modified DEM by Coupling with Pore Water Flow"
by Tsuyoshi NISHIMURA, Hideo KIYAMA, Hisashi FUJUMURA and Kimitomo WAKIMOTO .br
"Consideration of Gas Permeation Characteristics in Rock Bodies"
by Yositada ICHIKAWA and Isao NOTOHARA
"New Evaluation Methods of Flow Resistance Laws in Jointed Rock Foundation"
by Norihisa MATSUMOTO, Yoshikazu YAMAGUCHI and Tsutomu ANIYA
"An Example of Calculation of Permeability Tensor"
by Yuzi ENDOH, Nobuhiko WADA
"In Situ Experimental Studies on Groundwater Flow Analysis for Jointed Rock Masse"
by Kokichi KIKUCHI, Yoshitada MITO, Makoto HONDA, Toshiaki MIMURO and Jun YOSHIDA
"Application of Crosshole Permeability Test for Characterization of Hydraulic Properties of Jointed Rock Mass"
by Kenji AOKI, Yukihiro SHIOGAMA, Masaru TOIDA, Yasunari TEZUKA, Takaaki KOBUCHI and Kazuhiko MASUMOTO
"Evaluation of the Three-Dimensional Hydraulic Conductivity Tensor of a Fractured Rock Mass by Cross-Hole Tests"
by Hisashi CHOH, Yoshifumi NOGUCHI, Toshiyuki HOKARI, Tetsuo OKUNO and Yasushi KUSAKABE

2. Arrangement and welcome for the 8th ISRM Congress

The Japanese Committee for ISRM is quite happy to be able to have the 8th International Congress of ISRM in Japan. This is the first International Congress on Rock Mechanics to meet in Asia. The congress will be held during late September in 1995, as this time of year can offer some of Tokyo's finest weather.

The venue for the Congress is the Nippon Convention Center with a huge exhibition hall and hotel facilities, the Center will rank as the biggest and best convention complex in Asia. The Center lies approximately midway between Tokyo and its New International Airport at Narita.

Keynote of the Congress is Frontiers of Rock Mechanics towards the 21st Centuries.

The main session themes proposed are as follows.
(a)Geology, site exploration and testing.
(b)Physical properties and modeling of rock.
(c)Near surface excavation, stability of slope and foundation.
(d)Excavation and stability of underground openings.
(e)Heat, water flow and chemical transport in rock masses.
(f)Information system and artificial intelligence in rock mechanics.

Halls is reserved to accommodate displays relating to large-scale construction project, plus machinery, testing equipment, measuring instruments, and assorted publications.

Technical excursions will afford full day or half-day visits to such places as the Trans-Tokyo Bay Highway or Tsukuba Science City to inspect interesting rock mechanics projects and various sights.

Pre- and Post-Congress tours will last from two days to a week, and visit such places as Seikan Tunnel, the Honshu- Shikoku bridge system, underground power stations, nuclear power plants, large dams, geothermal fields, mines, volcanoes, active faults, plus a few must-see attractions like Kyoto.

Pre-Congress Tours under discussion are as follows.

A) Northern Kanto Route(4 days)

Underground power station, sightseeing in Nikko, the rock caverns of Oya Quarry, atomic research facilities at Tokai, and Tsukuba Science City

B) Southern Kanto Route(2 days)

Hakone mountain resort, Owakudani fumaroles, Tanna active faults and dams.

C) Northeastern Japan Route(5 days)

Seikan Tunnel, Showa New Volcano, Towada caldera Lake, Osarizawa and "Kuroko" mines, and Sengan geothermal development sites.

Post-Congress Tours under discussion are as follows.

D) Kansai Route(3 days)

Kyoto, old imperial capital, plus the Akashi Kaikyo Bridge.

E) Central Japan Route(6 days)

Same as (D) above, plus underground power stations, nuclear power plants, Kurobe dam and "Japan Alps"

F) Southwestern Japan Route(7 days)

Same as (D) above, plus the Honshu-Shikoku bridge system, scenic Setouchi island sea, the Himeji and Kumamoto castle, underground oil storage facilities at Kikuma, Beppu hot spa and Hohi geothermal development sites.

An Executive Committee has been organized in 1990. The member of this committee are as follows.

Chairman	Toshio Fujii
Vice-Chairmen	Ryuichi Iida
	Koichi Sassa
Members	Toshiki Aoyama
	Mizuhito Iguro
	Sadao Umeda
	Kohkichi Kikuchi
	Kiyoshi Kishi
	Takuro Kegai
	Hitoshi Koide
	Tatsutoshi Kondoh
	Syunsuke Sakurai
	Masanobu Tezuka
	Hidesuke Nakajima
	Ryunoshin Yoshinaka
Secretaries	Yuzo Ohnishi
& Members	Michio Kuriyagawa
	Tohru Tonegawa
	Masayuki Hori
	Toshinori Mizutani

Activities on Rock Mechanics in Japan Society of Civil Engineers

Isao NAGAYAMA

Chairman of Secretarial Board, Committee on Rock Mechanics
Japan Society of Civil Engineers

1. Committee on Rock Mechanics

The Japan Society of Civil Engineers (JSCE) is the biggest society in the field of civil engineering in Japan and its members include approximately 33,000 engineers and 1,200 public and private corporations. The Society has a lot of activity programs for the research and development of civil engineering. These programs are usually managed by the committees which are organized in the Society. There are about 50 committees in the Society. The Committee on Rock Mechanics is one of the most active and important committees.

The Committee on Rock Mechanics was organized in 1963 and Dr. Shunzo Okamoto, the present emeritus professor of Tokyo University, was selected as the Chairman of Committee (1963 to 1973). The Committee has contributed to the research and development of rock mechanics and related civil engineering works in Japan since then. The present Chairman is Dr. Ryuichi Iida (1986 to the present), who is the assistant Director General of the Japan Dam Engineering Center. He is the fourth Chairman of the Committee, following Dr. Tatsuo Mizukoshi (1973 to 1982) and Dr. Toshio Fujii (1982 to 1986).

The Committee on Rock Mechanics consists of 50 experts on rock mechanics from universities, government, public corporations, electric power companies, railway companies, consultants, construction companies and other related organizations.

The Committee has an executive committee and five permanent subcommittees which are responsible for the activities in individual fields. These subcommittees are:

(a) the Subcommittee on Foundation of Dams and Large-scale Structures
(b) the Subcommittee on Tunnels and Large Caverns
(c) the Subcommittee on Testing and Measure-

Table.1 History of the Committee on Rock Mechanics

Year	Event
1962	JSCE's 1st Symposium on Rock Mechanics
1963	Establishment of Committee on Rock Mechanics
1963	Following subcommittees were organized ·Subcommittee on Geology ·Subcommittee on Measurement ·Subcommittee on Application ·Subcommittee on Theory
1963	Adhoc Subcommittee for Publication of "Kawamata Arch Dam" was organized (until 1965)
1964	Subcommittee on Tunnels was organized
1964	1st National Symposium on Rock Mechanics
1966	Following subcommittees were reorganized ·Subcommittee on Dams ·Subcommittee on Tunnels ·Subcommittee on Theory and Measurement
1971	Adhoc Subcommittee for Revised Edition of "Rock Mechanics for Civil Engineers" was organized (until 1975)
1974	Subcommittee on Soft Rock was organized
1984	Adhoc Subcommittee for Education of Rock Mechanics was organized (until 1987)
1985	Subcommittee on Tunnels was reorganized to Subcommittee on Tunnels and Large Caverns
1988	Subcommittee on Slope Stability was organized
1988	Subcommitee on Dams was reorganized to Subcommitee on Foundation of Dams and Large-scale Structures

ment
(d) the Subcommittee on Soft Rock
(e) the Subcommittee on Slope Stability

Each Subcommittee has 25 to 30 experts in the respective field.

The detailed history of the Committee on Rock Mechanics is in Table.1.

2. Activities of Subcommittees

2.1. Subcommittee on Foundation of Dams and Large-scale Structures

The Subcommittee on Foundation of Dams and Large-scale Structures is one of the earliest established subcommittees. The original Subcommittee on Dams was organized in 1966 in order to make researches on rock mechanics in dam engineering. The Subcommittee, however, extended its research field to the foundation engineering of other large-scale structures in 1988 because of increased demand of construction of large bridges such as Honshu - Shikoku Bridges and Tokyo Bay Bridge.

One of the remarkable results of the activities of this Subcommittee is the publication of the book titled "Geologic Investigations for Dam Foundations" in 1977. This book was revised in 1986. The other books published by this Subcommittee include "Guideline of Foundation Grouting for Dams" (1972) and " Practice of Foundation Grouting for Dams - Case Study -" (1973).

The Subcommittee usually meets several times in a year. The Chairman of the Subcommittee is Dr. Norihisa Matsumoto. The present themes of research are :

(a) Research on Excavation Technology of Bedrock for Dams
(b) Research on Evaluation of Geology and Bedrock for Dams
(c) Research on Seepage Flow in Rock Masses
(d) Research on Rock Mechanics for Foundation of Large-scale Structures

The Subcommittee occasionally holds workshops related to research themes.

2.2. Subcommittee on Tunnels and Large Caverns

The Subcommittee on Tunnels and Large Caverns is one of the earliest established subcommittee, too. The original Subcommittee on Tunnels was organized in 1964 in order to make researches on rock mechanics in tunnel engineering. The Subcommittee, however, extended its research fields to rock caverns in 1985 because of the increased demand of construction of underground power plants, underground oil storage caverns and other large underground structures.

One of the remarkable results of the activities of this Subcommittee is the publication of the books titled "Geological Survey, Rock Tests and Field Measurements for Tunnelling" in 1983 and "Evaluation and Application of Geological Survey, Rock Tests and Field Measurements for Tunnelling" in 1987. Another book by this Subcommittee is "Developments of Tunnel Excavation Machines in Japan" (1976).

The Subcommittee usually meets several times in a year. The Chairman of the Subcommittee is Prof. Dr. Shunsuke Sakurai. The present themes of research are :

(a) Research on Behavior of Rock during Tunnel Excavation
(b) Research on Design and Construction of Deep Underground Openings

The Subcommittee occasionally holds workshops related to research themes.

2.3. Subcommittee on Testing and Measurement

The Subcommittee on Testing and Measurement is the oldest subcommittee. At the beginning (1963), two Subcommittees, the Subcommittee on Measurement and the Subcommittee on Theory, were organized. They were then combined to form the Subcommittee on Theory and Measurement in 1966. The present Subcommittee on Testing and Measurement succeeded it in 1988.

One of the remarkable results of the activities of this Subcommittee is the publication of the books titled "A Guideline for Testing Methods of Deformability and Shear Strength of In-situ Rock Masses - Commentary and Application to Design of Structures -" in 1983 and "The Present State of the Dilatometer Test" in

1988.

The Subcommittee usually meets several times in a year. The Chairman of the Subcommittee is Mr. Hayasi Sugawara. The present themes of research are :

(a) Research on Measurement of In-situ Rock Stress
(b) Research on Testing and Measurement for Deep Underground Opening

The result of research on the first theme will be published as a book soon.

The Subcommittee occasionally holds workshops related to research themes.

2.4. Subcommittee on Soft Rock

The Subcommittee on Soft Rock was organized in 1974 in order to make researches on physical and mechanical properties of soft rock.

One of the remarkable results of the activities of this Subcommittee is the publication of the book titled "Soft Rock Engineering - Fundamentals and Case Studies for Investigation, Design and Construction -" in 1984.

The Subcommittee usually meets several times in a year. The Chairman of the Subcommittee is Mr. Soichi Tanaka. The present themes of research are :

(a) Research on Survey and Testing Methods for Soft Rock
(b) Research on Evaluation of Soft Rock
(c) Research on Properties of Soft Rock under Various Environments
(d) Research on Physical Properties of Mudstone

The result of research on the first two themes will be published as books in the near future.

The Subcommittee occasionally holds workshops related to research themes.

2.5. Subcommittee on Slope Stability

The Subcommittee on Slope Stability is the newest subcommittee organized in 1988. The Subcommittee make researches on slope stability in the construction works because of increase on large slopes in the construction works.

One of the remarkable achievements of this Subcommittee is to have held a panel discussion on "Measurements of Rock Slopes to Predict and to Prevent Slope Failures" at the 22nd JSCE's Symposium on Rock Mechanics in 1990.

The Subcommittee usually meets several times in a year. The Chairman of the Subcommittee is Dr. Seishi Okuzono. The present themes of research are :

(a) Research on Measuring Technology for Rock Slopes
(b) Research on Analytical Methods of Rock Slopes

The Subcommittee occasionally holds workshops related to research themes.

3. Symposia and Workshops

3.1. Symposia

The Japan Society of Civil Engineers has held the JSCE's Symposium on Rock Mechanics since 1962. The Symposium has been managed by the Committee on Rock Mechanics since 1963 when the Committee was first organized.

The 23rd JSCE's Symposium was held in February, 1991. There were 73 papers and 411 participants attended. When the first JSCE's Symposium was held in 1962, there were only 12 papers (no data available to the number of participants). The significant increase on papers and participants in the Symposia is shown in Fig.1.

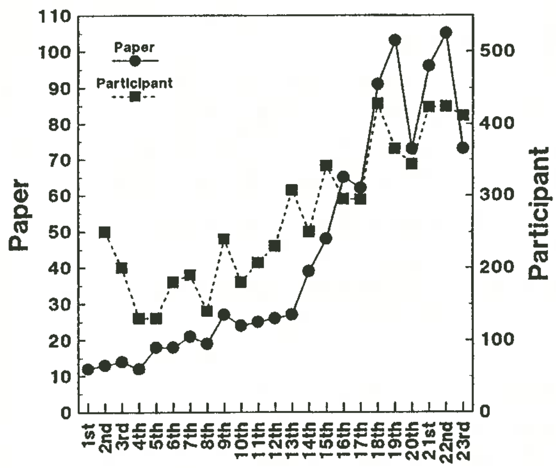

Fig.1 Number of Papers and Participants in JSCE's Symposium on Rock Mechanics

The Japan Society of Civil Engineers is one of the societies which organize the Japanese Committee for ISRM (International Society for Rock Mechanics). The Japanese Committee for ISRM has held the National Symposium on Rock Mechanics every three years since 1964.

The Japanese Committee for ISRM held the International Symposium on Weak Rock in Tokyo in 1981. The Japan Society of Civil Engineers submitted the paper titled "Soft Rock Engineering in Japan" to this International Symposium.

The JSCE's Symposium did not use to be held in the year when the National Symposium on Rock Mechanics was held. However, the JSCE's Symposium has been held every year since 1982 because of increased demand that more opportunities to present technical papers should be provided.

The Committee on Rock Mechanics has held two sessions of panel discussion at the JSCE's Symposium since 1985. The Committee has selected the up-to-date themes to be discussed in the panels. The themes at the 23rd JSCE's Symposium in 1991 were:

(a) Rock Classification for Soft Rock
(b) Loosening of Rock during Tunnel and Cavern Excavation

Five specialists in the respective field discussed each theme and about 400 engineers joined the discussion.

The themes of panel discussions in the past are listed in Table.2.

3.2. Workshops

The Committee on Rock Mechanics hold workshops of specified topics once or twice in a year. Two workshops were held in the fiscal 1990 (Apr. 1990 to Mar. 1991).

The themes of the first workshop are:

(a) Report on the International Conference of Rock Joint (June 4 to 6, 1990 in Norway)
(b) Report on the International Workshop on Scale Effects in Rock Masses (June 7 to 8, in Norway)
(c) Report on the International Conference of Mechanics of Jointed and Faulted Rock (April 18 to 20, in Austria)

Table.2 Themes of Panel Discussion

Year	Theme
1988	·Evaluation of Rock Masses in Tunnelling ·Seepage Flow in Rock Masses
1989	·Slaking of Soft Rock ·Rock Classification for Bedrock of Dams
1990	·Measurements of Rock Slopes to Predict and to Prevent Slope Failures ·The Present States of Measurement for In-situ Rock Stress
1991	·Rock Classification for Soft Rock ·Loosening of Rock during Tunnel and Cavern Excavation

Table.3 Publication

Year	Title
1965	Construction Report of Kawamata Arch Dam
1966	Rock Mechanics for Civil Engineers
1972	Guideline of Foundation Grouting for Dams
1973	Practice of Foundation Grouting for Dams - Case Study -
1975	Rock Mechanics for Civil Engineers (Revised Edition)
1976	Developments of Tunnel Excavation Machines in Japan
1977	Geologic Investigations for Dam Foundations
1983	A Guideline for Testing Methods of Deformability and Shear Strength of In-situ Rock Masses - Commentary and Application to Design of Structures
1983	Geological Survey, Rock Tests and Field Measurements for Tunnelling
1984	Soft Rock Engineering - Fundamentals and Case Studies for Investigation, Design and Construction -
1986	Geologic Investigations for Dam Foundations (Revised Edition)
1987	Evaluation and Application of Geological Survey, Rock Tests and Field Measurements for Tunnelling
1988	The Present State of the Dilatometer Test

Four lecturers made a presentation in the workshop and about 100 engineers attended it.

The themes of the second workshop are:

(a) Numerical Model for Stability Analysis of Rock Slopes and its Application
(b) Evaluation of Slope Stability of Rock Mass with Discontinuities
(c) Case Studies on Sliding of Rock Slopes
(d) Evaluation of Rock Slope Stability during Earthquake
(e) Present States of Stability Analysis of Rock Slope with Discontinuities

Seven lecturers made a presentation in the workshop. There attended about 100 engineers.

4. Publication

The Committee on Rock Mechanics has published many books. Some of them have been already referred to in Section 2. The Committee published the other books under the special sub-committee organized in the Society. One is the book titled "Construction Report of Kawamata Arch Dam" published in 1965. The other is the book titled "Rock Mechanics for Civil Engineers" published in 1966. "Rock Mechanics for Civil Engineers" was revised in 1975. The complete list of books from the Committee on Rock Mechanics is shown in Table.3.

Recent Activities on Rock Mechanics in The Japanese Society of Soil Mechanics and Foundation Engineering (JSSMFE)

Kohkichi KIKUCHI

Professor of Kyoto University
Chairman of the Research Committee on Rock Mechanics JSSMFE

This report describes recent activities on rock mechanics in the JSSMFE during the period from 1987 to 1990.

1. The Outline of Organization and Activities

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. Main activities of the JSSMFE are as followings,

(a) Publications

Bulletin of the JSSMFE "Soil and Foundation" (monthly, in Japanese).

Journal of the JSSMFE (quarterly, in Japanese and in English).

Books of the individual subjects concerning with geotechnical engineering (100 titles).

(b) Hold of conference and symposium

National conference (annual).

Symposium for the new topics on geotechnical problems.

Lecture and lecture tours.

(c) Research and investigation

20 research committee are organized.

(d) International cooperations

The result of activities on rock mechanics at JSSMFE until 1986 have already been reported in "Rock Mechanics in Japan, Volume 1-5" published by the Japanese Committee for ISRM.

2. The Activities on Rock Mechanics in the JSSMFE National Conference (annual meeting of the society)

2.1. 1987 (22th, held at Niigata city)

Outline and main subjects are as follows;

Total presented papers --- 737

Total participant members --- 1,549

Total presented papers in rock properties and rock engineering session --- 36

(a) Development for new fields, technology and methods (underground cavity for the radiational disposal material, seepage problems in rock mass, investigate and analyze of discontinuous planes in rock mass, image processing of rock surface, etc.) --- 6

(b) Properties of soft rock (strain softening, slaking, weathering) --- 12

(c) Elastic plastic analysis (FEM, DEM) --- 2

(d) Fundamental problem (geotomography, etc.) --- 16

Niigata prefecture is located in soft rock field, and presented papers concerning with soft rock are attracted in this session.

2.2. 1988 (23th, held at Miyazaki city)

Total presented papers --- 891

Total participant members --- 1,694

Total presented papers in rock properties and rock engineering session --- 32

(a) Properties of rock mass containing discontinuous planes (investigations-image processing, geophysical surveys, analysis-block theory, seepage problem) --- 12

(b) Properties of soft rock (slaking, swelling) --- 11

(c) Rock properties (plastic and yield behaviour) --- 9

One of fundamental problems of rock mass in which investigations, analysis and physical properties of discontinuous plane are attracted in this session.

2.3. 1989 (24th, held at Tokyo)

Total presented papers ------------ 746

Total participant members ------- 1,872

Total presented papers in rock properties and rock engineering session --------- 20

(a) Development of new technology and methods (semi vario gram, three dimensional processing of discontinuous planes, bore hole hammer test device) --- 3

(b) Discontinuous plane and anisotrophy of rock

mass (numerical analysis, modeling)--- 7
(c) Properties and deformability of soft rock (slaking, swelling, cyclic loading) --- 6
(d) Permeability (permeability of jointed rock) --- 4
In situ rock properties in order to apply for analytical model are attracted in this session.

2.4. 1990 (25th, held at Okayama)

Total presented papers --- 792
Total participant members --- 1,756
Total presented papers in rock properties and rock engineering session --- 22
(a) Properties of soft rock (silt rock, man made rock) --- 12
(b) Testing methods of discontinuous plane of rock --- 3
(c) Others --- 7
The mechanical characteristics of soft rock utilizing for underground space in soft rock area are attracted in this session.

3. The Activities of the Research Committee on Rock Mechanics at JSSMFE

JSSMFE has 20 research committee are organized and acting now. The recent activities of the research committee on rock mechanics during the period from 1987 to 1990 are as followings.
(a) Prediction and substance of rock mass behavior (published 1987.3).
This is investigated the prediction and the substance on rock mass behavior of rock slopes, dam foundations, bridge foundations, tunnels and underground caverns.
(b) Site investigation and testing of rock (1987.3-1988.3, published 1989.9).
This is investigated the all kind of testing and site investigation methods and collected their practical applications.
(c) Interpretation and applications of test results of rock (1988.4-1989.3, to be published).
This is investigated and pointed out between the relations test results and actual behavior of the rock structures.
(d) Research and investigation of block theory and its application for actual rock structures (1987.7-1989.3, reported).
This is investigated and evaluated the block theory and its applicabilities of rock structures.

4. The Outline of Research Work Shop on Rock Mechanics under the Research Committee on Rock Mechanics at JSSMFE

This work shop to the related held every year in the national conference of JSSMFE promoted by the research committee on rock mechanics. Selection of subject for the work shop is determined by the representative construction at the time and problems. The activities during the period from 1987 to 1990 are as followings.

4.1. 1988.16 June (1st, held at Miyazaki, participant members --- 90)

Main subject
"Prediction and substance of rock behavior".
Topics
(a) "Construction and measurements of Wasyuzan tunnel" presented by Mr. Shinichi Okamoto (Okumura construction Co.Ltd.). Fig.1 shows a section of Wasyuzan Tunnel.
(b) "Safety management on large scale excavation of soft rock" presented by Mr.Toyohiko Watanabe (Kajima corporation).
(c) "Construction of cut slope of Tenzan Dam adjustment pool" presented by Mr.Joichiro Tano (Kyushu Electric Power corporation).

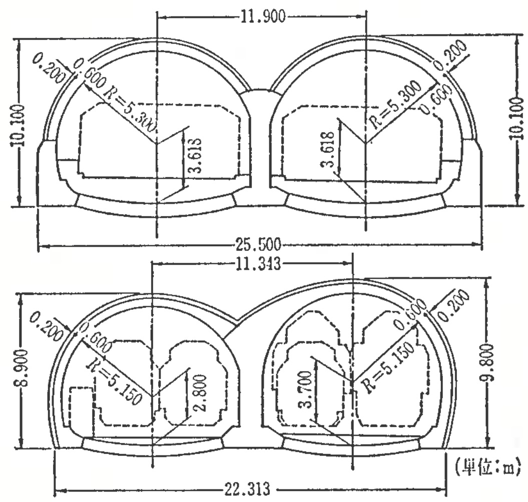

Fig.1 A section of Wasyuzan Tunnel (Okamoto, 1988)

4.2. 1989.13 June (2nd, held at Tokyo, participant members --- 170)

Main subject
"Rock behaviour and its problems of underground caverns".

Topics

(a) "A point of view of a civil engineer for the construction of Kikuma underground rock oil reservoir" presented by Mr. Naoki Takeda (Taisei construction Co. Ltd.). Fig.2 shows a section of Kikuma underground oil storage caverns.

(b) "Construction and Measurements of Akashi power station" presented by Mr. Tutomu Nishikawa (Chubu Electric Power Corporation). Fig.3 shows a layout of Akashi Power station.

4.3. 1990.13 June (3rd, held at Okayama, participant members --- 110)

Main subject

"Interpretation of rock test and examples of design, construction, measurements"

Topics

(a) "A study on in-situ shear strength of foundation rock for dams" presented by Mr.Isao Nagayama (Ministry of construction).

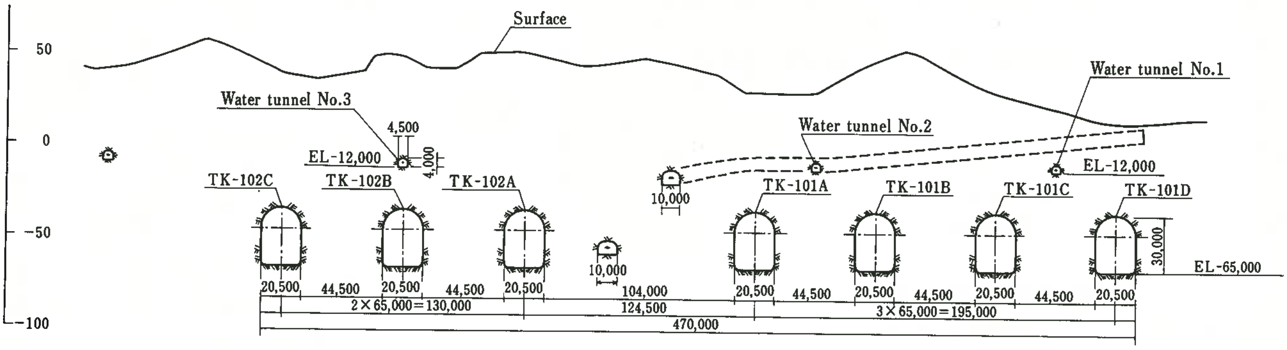

Fig.2 A section of Kikuma underground oil storage caverns (Takeda, 1989)

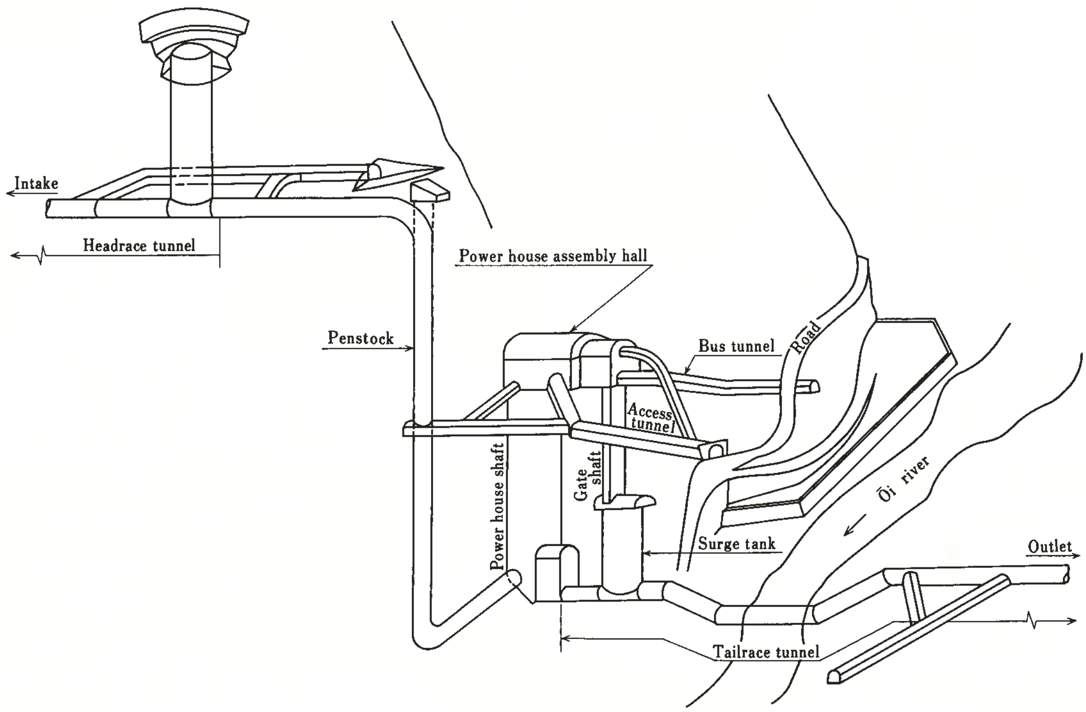

Fig.3 A layout of Akashi Power station (Nishikawa, 1989)

The relationships between the shear strength of foundation rock by in-situ shearing tests and some other physical properties such as Schmidt's rebound value, sound velocity, joints geometries of sheared surfaces and deformation modulus of rock are discussed here. Fig.4 shows a example of test result.

(b)"Tunneling in Chugoku area" presented by Mr. Hiroshi Inoue (Japan road authority). Five examples of tunnels constructed in Chugoku area are presented. The applicabilities of construction methods and its substances are discussed here.

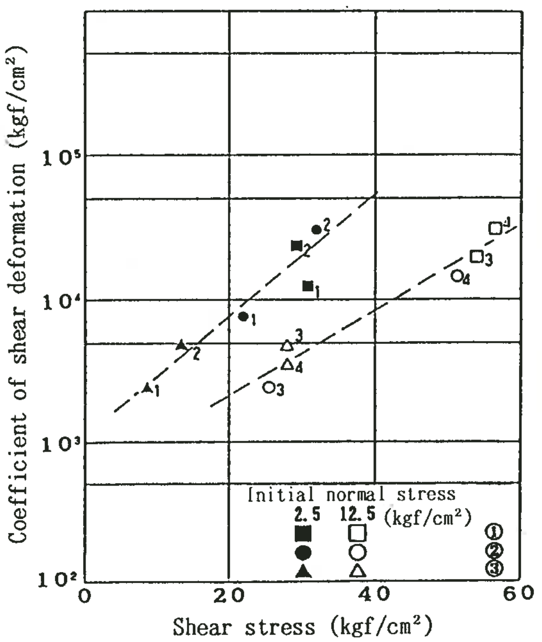

Fig.4 A example of test result (Nagayama, 1990)

5. The Activities of the Editorial Committee on Rock Mechanics at JSSMFE

This committee is organized for the publication of results and the activities of research committee on rock mechanics. The texts are intended to be a guide design/construction engineers related to rock structures.

(a) "Prediction and substance of rock mass behavior" is published in December 1988 from JSSMFE. Total pages are about 380.The text describes the rock behavior from prediction to measurement for rock slopes, dam foundations, bridge foundations, tunnels and underground caverns.

(b) "Site investigation and testing of rock" is published in September 1989 from JSSMFE. Total pages are about 540.The text consists of 8 volumes and 69 chapters which are;

Volume 1 - Planing of investigation and testing.
Volume 2 - Site investigations.
Volume 3 - Geophysical surveys.
Volume 4 - Geophysical exploration.
Volume 5 - In-situ test.
Volume 6 - Laboratory physical test.
Volume 7 - Laboratory mechanical test.
Volume 8 - Geomineralogical test.

The text is intended to be a dictionary to general engineers concerning rock works and many kind of testing and site investigation methods are explained for their practical applications.

(c) "Interpretation and applications of test results of rock" , editorial committee to be start in April 1991.The text will be consist of 4 volumes and 9 chapters which are ;

Volume 1 - Problems on rock tests and measurements.
Volume 2 - Plate load test. Rock shear test. Bore hole load test. Lugion test.
Volume 3 - Unconfined compression test. Confined compression test. Slaking test.
Volume 4 - Measurements of displacement in rock structures. Measurements of convergence of tunnel sections and caverns.

The text is intend for the guide to applicabilities and relations between the tests result and actual behaviour of the rock structures.

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Activities on Rock Mechanics in the Mining and Materials Processing Institute of Japan

Koichi SASSA

Professor of Kyoto University
Chairman, Division Society for Rock Mechanics and Engineering.

1. General Information of the Institute

The institute has established 12 Divisions or Division Societies in 1988 when the name of the Institute has been changed from the Mining and Metallurgical Institute to the Mining and Materials Processing Institute. Among the divisions or the Division Societies, activities on rock mechanics are mainly conducted in the Division Society for Rock Mechanics and Engineering with partial cooperation of Division of Mechanization and Automation, Surface Mining Division Society, Division of Construction Materials, and Division of Coal Science and Technology.

In this Institute, studies on the role of rock mechanics in mining engineering are actively conducted. Beside them, the studies on the extraction of geothermal energy, utilization of inner space, and underground repository of nuclear waste have been promoted and conducted from various points of view.

The institute publishes "The Journal of the Mining and Material Processing Institute of Japan" and also the proceedings of the annual meeting and symposium those are held annually in spring and autumn, respectively.

Research Committee on Survey and Research on Earthquake has been established in 1984. This committee is chaired by Prof. K. Sassa, and has pursued the research work on the effects of ground motion due to earthquake to deep underground radioactive wastes depositories. The work is performed under contract with Power Reactor and Nuclear Development Corporation (PNC) and under cooperation of the Central Research Institute of the Electric Power Industry. This research committee has conducted the observation of earthquake at the deep underground several locations of different depth and the ground surface. Many earthquakes have been observed, and characteristics of under ground motion due to earthquakes are discussed.

Besides the research committee shown above, research committees of which period of activity is limited to three years are also organized to promote research activities in the important and recently developing technical fields. The research committees of this type which have been organized and pursued the studies on the subjects related to rock mechanics in recent five years are shown below.

Research Committee on Application of Numerical Methods to the Stability of Rock Structure in Mines (Chairman: Prof. S. Yamashita). The period of activity was 1986 to 1988.

Research Committee on Application of AE for Monitoring the Fracturing of Rock Mass (Chairman: Prof. K. Nakatsuka). The period of activities was 1986 to 1988.

Research Committee on Developments of Ultrasonic Sensor for Measuring the Geometry of Underground Openings (Chairman: Prof. S. Higuchi). The period of activities was 1986 to 1988.

Research Committee on Application of Geotomography to Rock Characterization and Prospecting (Chairman: Prof. K. Sassa). The period of activities was 1988 to 1990.

Research Committee on Automatic Excavation System for Underground Openings in Rock Mass (Chairman: Prof. Y. Nishimatsu). The Period of activities is 1989 to 1991.

Research Committee on Expert System for Rock Engineering Practitioners (Chairman: Prof. Y. Mizuta). The period of activities is 1989 to 1991.

2. Organization and Activities of the Division Society for Rock Mechanics and Engineering

The Division Society for Rock Mechanics and Engineering (Chairman: Prof. K. Sassa) is the chief executive body on rock mechanics in the Mining and Material Processing Institute of Japan (MMIJ). The Division Society has three Committees, those are Committee on the Numerical Methods for Rock Engineering (Chairman: Prof. S. Yamasita), Committee on the Developments of the Inner Space (Chairman: Prof. K. Kojima), and Committee on Environments of the Inner Space (Chairman: Prof. Y. Mizuta).

The Division Society organizes symposium, workshop and lecture meeting, and also publishes a special issue on rock mechanics as a volume of the Journal of MMIJ. The activities of the Division Society in recent two years are shown below.

The following three sessions are organized by the Division Society as a part of the annual symposium of MMIJ which was held in October 1989 at Kyoto. The titles of the sessions and the contents are as follows.

Session: Application of Geotomography on Rock Engineering
a) Progress and Point of Caution when Applying Geotomography on Rock Engineering:
by K. Sassa.
b) Geotomography by use of Electric and Electromagnetic Prospecting Methods:
by Y. Sasaki.
c) Applicability of Electrical Prospecting Methods - Extraction and Enhancement of the Signals due to Target for Hole to Hole or Hole to Surface Solid Array System-:
by T. Sugano and K. Sassa.
d) Inspection of Rock Pillar by both P-wave and S-wave Seismic Tomography:
by J. Kawakami, H. Hattori and M. Shimo.
e) Some Application of Various Types of Geotomography for Characterization of Rock Mass:
by h. Shima and H. Kamiya.

Session: Rock Structure Design
a) Prediction Method of Deformation Characteristics of Jointed Rock Mass:
by K. Kaneko and T. Shiba.
b) Support Design for Soft Rock:
by J. Yamatomi and K. Kojima, T. Saito and Y. Ogata.
c) Application of Coupled Boundary Element-Characteristics Method to the Slope Problems:
by K. Sugawara, Y. Obara and K. Sakaguchi.
d) Conditions of Rock Mass and Applicability of Tunneling Machine:
by S. Okubo.
e) Stability of Subsurface Nuclear Power Station for Ground Motion due to Earthquake:
by S. Hibino.
f) Rock Mechanics and Long Period Stability of High Level Nuclear Waste Depositories:
by H. Koide and M. Takahashi.
g) Rationalization of Mining in Kamioka Mine based on Rock Mechanics:
by S. Saito, T. Jyougo and H. Sakai.

Session: Progress of in situ Stress Measurement
a) In Situ Stress Measurements by the Stress Relief Method:
by K. Sugawara, Y. Obara and K. Sakaguchi.
b) Measurements of Pressure acting on Tunnel Lining:
by Y. Ishijima and B. Soh.
c) Determination of Ground Stress with Consideration of the Characteristics in Strain Change in Stress Relief Method:
by T. Saito.
d) Characteristics of Kaiser Effect of Acoustic Emission:
by k. Michihiro and K. Hata.
e) Method and Results of Ground Stress Measurement by Hydraulic Fracturing Technique:
by I. Matunaga and M. Kuriyagawa, T.Yamaguchi, Y.Sato and Y.Oikawa.
f) Ground Stress Measurement by Double Fracturing Technique:
by S. Sakuma, S. Kikuchi, Y. Mizuta and S. Serata.
g) Research Activities on Ground Stress Measurement in Central Research Institute of Electric Power Industry:
by T. Kanagawa.
h) Ground Stress Measurements at Deep Location under Ground:
by T. Yamaguchi, Y. Oikawa, Y. Sato and H. Ito.

The following three sessions were organized by the Divisional Society as a part of the annual symposium of MMIJ which was held in October 1990 at Tsukuba. The titles of the sessions and the contents are as follows.

Session: Geotomography and its application
a) Seismic Reflection Tomography:
by Y. Ashida.
b) Seismic Tomography which takes into account the velocity anisotoropy:
K. Kaneko, G. Kawano and Y. Noguchi.

c) Joint Survey in Granitic Rock Mass by Seismic Tomography:
by K. Yokoi, N. Nakamura and T. Takahashi.
d) Characteristics and Accuracy of Electrical Resistivity Tomography:
by Y. Sasaki.
e) Rock Mass Characterization by Two and Three Dimensional Electric Resistivity Tomography:
by H. Shima and H. Kamiya.

Session: Recent Progress of Rock Mechanics for the Developments of Underground
a) Deformation and Failure Characteristics of Rock Layer between Coal Seam under Various Loading Conditions:
by Y. Ishijima and M. Nakata.
b) Kaiser Effectic Phenomena of Acoustical Elastic Properties of Rock:
by K. Shin and T. Kanagawa.
c) Evaluation of Time-dependent Deformation of Soft Rock Caused by Drift Excavation:
by Y. Ogata, T. Yamaguchi, M. Kuriyagawa and S. Okubo.
d) Development of Borehole Type AE Sensor and its Frequency Characteristics:
by A. Cho, K. Kusunose and N. Matsumoto.
e) Support Design foe Underground Opening in Soft Rock:
by T. Saito.
f) Groung Stress Measurements by a DSCA Method for Boring Core:
by O. Sano, O. Nishizawa, T. Yamaguchi and Y. Mizuta.
g) Application of a Stress Relief Method on Hot Dry Rock Geothermal Project:
by K. Sugawara, K. Sakaguchi, Y. Mizuochi and A. Takahashi.

Session: Inner Space Environment and Expert System
a) An Approach to Expert System:
by T. Yamada
b) An Expert System Capable of Circulation over PC Communication Network for Computer Assisted Recognition of Inner Space Environment:
by Y. Tominaga
c) Development of an Expert System for Escape Route Selection:
by M. Inoue
d) Design of Rock Cavern Ventilation and Its Actual State:
by K. Aoki
e) Some Subjects in Inner Space Development:
by S. Nishimura
f) Improvement of Underground Environment in Very Hot Working Area:
by K. Nishioka, O. Sakai and Y. Mizuta
g) Ventilated Cooling System in Hishikari Mine:
by K. Kataya
h) Sound Propagation Characteristics along Underground Airway:
by M. Kinoshita, T. Isei, H. Imaizumi and S. Kunimatsu

Workshop on the Numerical Methods for Subsurface Development was organized by the Committee on the Numerical Methods for Rock Engineering, and was held in November 1989. The contents are as follows.
a) Results of the Survey on the Applicability of various Numerical Methods for Stress Analysis of Rock Structures:
by S. Yamashita.
b) Stress Analysis around Underground Openings by Boundary Element Method:
by H. Kato.
c) Examples of the Application of FEM on the Evaluation of the Stability of Underground Openings:
by Y. Mizuochi and M. Kitahara.
d) Discussion on The Analysis of the Behavior of Rock Mass Breakage by RBSM Method with Polygonal FEM Model:
by T. Yamada and N. Takeuchi.
e) Analysis of Water Flow in Rock Mass:
by Y. Ohnishi, M. Nishigaki and Y. Takeshita.
f) Method of Analysis and Computer Program for Heat Flow in Rock around Airway and Heat Transfer into Air Current:
by Y. Mizuta.

Lecture Meetings those were organized by the Division Society were as follows.
(a) Date: 3rd October, 1989.
Title and lecturer:
"Engineering Thermophysics Activities in the Academy of Science of Ukrainian SSR"
by Prof. V. P. Chernyak
"Trend of the Studies on Rock Mechanics Presented in Recent International Conferences"
by Prof. T. Tanimoto
(b) Date: 7th February, 1990
Title and Lecturer:
"A Review of Strength Criteria for Intact Rocks

and Rock Masses"
by Mr. V. S. Vutukuri
"U. S. Hot Dry Rock Geothermal Energy Program"
by D. Michael Fehler
(c) Date: 29th October, 1990
Title and Lecturer:
"Hydro-Geomechanics in Fractured Rock Masses"
by Prof. D. Elsworth
"Weathering and Unstability of Rock in Ancient Egypt Ruins"
by Prof. C. Tanimoto

The Division Society arranged the publication of a special issue on rock mechanics. This special issue was published as Vol. 107, No. 6, 1991. The contents of this volume are as follows.

"Creep Behavior of Sanjome Andesite in Three- Point Bending"
by Katsunori FUKUI, Seisuke OKUBO and Yuichi NISHIMATSU
"Roughness of Rock Discontinuities and Their Shear Behavior"
by Toshiaki SAITO and Makoto TERADA
"Relation between Stress-induced Crack Path and Mineral Grains in Granitic Rocks"
by Yozo KUDO, Ken-ichi HASHIMOTO, Osam SANO and Koji NAKAGAWA
"Field Investigation and Modeling of Rock Joints"
by Yoshifumi NOGUCHI, Akio IIJIMA, Naoaki NAKAMURA, Katsuaki KOIKE and Katsuhiko KANEKO
"Experimental Study on Determination of In-situ Stress State by DSCA"
by Tsutomu YAMAGUCHI, Yasuki OIKAWA, Yoshiteru SATO, Michio KURIYAGAWA, Norio TENMA, Hideo KOBAYASHI and Isao MATUNAGA
"Characteristics and Mechanism of Crustal-Stress Distribution in Hard Rocks"
by Ryuji IKEDA and Hiroaki TSUKAHARA
"Ground Supporting Mechanism of the Linear Arch Formed in the Immediate Roof of an Underground Cavern"
by Gento MOGI, Jiro YAMATOMI, Umetaro YAMAGUCHI and Tetsuo NAKAGAWA
"Elasto-plastic Analysis of Rock Slopes by the Coupled Baundary Element-Characteristics Method"
by Yuzo OBARA and Katsuhiko Sugawara
"Rock Mechanics Investigations for the Construction of CAES Rock Cavern"
by Yoji ISHIJIMA, Masao NAKATA, Yukio KOSE and Masao HIRATA
"Deformation of a Rock Tunnel in an Elastic Rock Mass"
by Yoshihiro OGATA, Michio KURIYAGAWA and Shozo TANINAMI
"Measurement of the Stress in The Tunnel Lining by the Two Points Method"
by Yoji ISHIJIMA, WenZou Song and Takayuki SUGAWARA
"Dynamic Behavior of Tunnel due to Blasting"
by Atsuo HIRATA, Tsutomu INABA and Katsuhiko KANEKO
"The Stability Monitoring of Rock Caverns by Acoustic Emission Measurements"
by Kenji AOKI, Masaru TOIDA and Kenichi KOSHIZUKA
"Relation between JMA Seismic Intensity Scale and PPV or VL Induced by Blasting"
by Sunao KUNIMATSU, Takehiro ISEI, Fusanori MIURA and Koji NAKAGAWA

3. Recent Papers on Rock Mechanics Published in the regular issues of the Journal of MMIJ

The titles and authors of the papers on rock mechanics which were published in the regular issues of the journal of MMIJ in 1989 and 1990 are as follows.

Vol. 105(1989), No. 3
"Studies on Landscape of Mined-out Quarry with Planting"
by Naohiro OTSUKA and Yoshinori SEKIMOTO
"Extension of TWO Fractures with Different Characteristics by Hydraulic Fracturing -Simulation of fracture extension by hydraulic fracturing for the development of hot dry rock (2nd Report)-"
by Michio KURIYAGAWA, George ZYVOLOSKI, Sharad KELKAR, Isao MATSUNAGA and Tsutomu YAMAGUCHI

Vol. 105(1989), No. 4
"Slaking of Coal Measure Rocks -Effect of water on mechanical properties of coal measure rocks (3rd Report)-"
by Masatomo ICHINOSE, Kenichi UCHINO

and Kikuo MATSUI

Vol. 105(1989), N0. 6
"Estimation of Attenuation Characteristics of Elastic Waves by Strata Using Reflection Seismograms"
by Yuzuru ASHIDA and Koichi SASSA
"Swelling of Coal Measure Rocks -Effect of water on mechanical properties of coal measure rocks (4th Report)-"
by Masatomo ICHINOSE and Kenichi UCHINO

Vol. 105(1989), No. 7
"Elasto-plastic Analysis of a Single Rectangular Opening and Parallel Circular Openings under Bi-axial Stress Condition -Elasto-plastic analysis of rock caverns by a coupled boundary element-characteristics method (3rd Report)-"
by Toshiro AOKI and Katsuhiko SUGAWARA
"Measurement of Rock Stress in Bongmyung Coal Mine and Daesung Coal Mine of Korea"
by Kwang-Soo KWON, Sea-Hwan RO and Won-Kyong SONG
"Creep Behavior of Rock under Uniaxial Compression"
by Katsunori FUKUI, Seisuke OKUBO and Yuichi NISHIMATSU
"Controllability of Servo-Controlled Testing Machine in Creep Test of Rock under Uniaxial Compression"
by Katsunori FUKUI, Seisuke OKUBO and Yuichi NISHIMATSU

Vol. 105(1989), No. 8
"A Study on the Class II Behavior of Rock"
by Changrong HE, Seisuke OKUBO and Yuichi NISHIMATSU
"Borehole Deformation under Overcoring"
by Masayuki KOSUGI and Yoshihiro OGATA
"A Study on Core Discing with a Center Hole"
by Tsuyoshi ISHIDA and Toshiaki SAITO
"Laboratory Test of Boring in Coal Swam"
by Tatsuhiko GOTO, Tateki SATO, Yoshiaki FUJII and Yoji ISHIJIMA

Vol. 105(1989), No. 9
"Acoustic Emission in Hydraulic Fracturing of Coal Measure Rock"
by Masahiro SETO, Tamotsu KIYAMA, Takashi NARITA, Makoto KOUNO, Kanji SHIOTA, Hiroshi NABEYA and Gouta DEGUCHI
"Effect of Water Jet with Nozzle ahead of the Bit - Water jet-assisted rock cutting (2nd Report)-"
by Izumi NISHIZAWA, Seisuke OKUBO, Masao AKIYAMA and Yuichi NISHIMATSU

Vol. 105(1989), No. 10 "Permeability Tests of Rock by Transient Pulse Method"
by Fumio SUGIMOTO and Mitsumasa FURUZUMI

Vol. 105(1989), No. 12
"An Wmpirical Considaration on the Stability of Underground Openings"
by Koji KOJIMA
"Comparison of Deformational Behaviors of Roadway Driven by Shotfiring with Those by Machine Cutting - Study of maintenance of gate roadways in coal mine (2nd Report)-"
by Kikuo MATSUI and Masatomo ICHINOSE

Vol. 105(1989), No. 13
"Applicability of Displacement Discontinuity Method to Crack Problems"
by Takumi SHIBA, Katsuhiko KANEKO, Yuzo OBARA and Katsuhiko SUGAWARA
"Influence of Particles Shape on Grindability -Relationship between probability of fracture and shape index-"
by Yoshiteru KANDA, Yoshio MAKUTA and Toshihiko IMAMURA

Vol. 105(1989), No. 14
"Monitoring of Stress and Vertical Displacement Changes in a Pillar during Secondary Mining at Kamaishi Mine -A study on the method for measuring in-situ stress change with pressure cell (2nd Report)-"
by Koji MATSUKI, Sukma Saleh HASIBUAN,Tadayoshi YAMAMOTO, Yoshifumi NOGUCHI and Takashi NARASAKA

Vol. 106 (1990), No. 1
"The Effects of Driving Pressure and Traverse Rate on the Depth of Cut for Slot Cutting in Rocks with High-speed Waterjets -A study on the slot cutting in the rocks with high-speed waterjets both in air in water(1st Report)-"
by Kiyohiko OKUMURA, Koji MATSUKI, Kazuhiro SUZUKI and Cui Mo-Shen

Vol. 106(1990), No. 2
"An Empirical Formula on the Depth of Cut for Slot Cutting in Rocks with High-speed Waterjets -A study on the cutting in rocks with high-

speed waterjets both in air and in water(2nd Report)-"
by Koji MATSUKI, Kazuhiro SUZUKI and Kiyohiko OKUMURA
"Study on Flow of Ore in Large Scale Ore Pass Systems -Mechanism of gravity flow and mixing of ore in ore pass-"
by Gento MOGI and Umetaro YAMAGUCHI

Vol. 106(1990), No. 3
"A study for the Hydrofracture Breakdown Pressure Based on the Point Stress Criterion"
by Takatoshi ITO, Kazuo HAYASHI and Hiroyuki ABE
"Numerical Method for Rock Deformation Analysis Based on Equivalent Volume Defect"
by Katsuhiko KANEKO and Takumi SHIBA
"Slot Cutting in Welded Tuff with High-Speed Waterjets under High Ambient Water Pressure -A study on slot cutting in rocks with high speed waterjets both in air and in water (3rd Report)-"
by Koji MATSUKI, Hajime NAKADATE and Kiyohiko OKUMURA
"Application of Equivalent Volume Defect Method to Closed Crack Problem"
by Katsuhiko KANEKO, Takumi SHIBA and Kenji NODA

Vol. 106(1990), N0. 6
"Properties of Mortar Block Blasting -Blasting factor and effect by crater test (2nd Report)-"
by Hisao HONMA
"Numerical Simulation on the Relation between RQD and P Wave Velocity of Rock Mass"
by Toshiki WATANABE and Koichi SASSA
"Applicability of Tunnel Boring Machine and its Expert System"
by Seisuke OKUBO

Vol. 106(1990), No. 9
"Moment Tensor of Acoustic Emissions Associated with Underground Excavation"
by Kazuhiko SATO, Ken-ichi ITAKURA and Satoshi TAKATSUKA
"Study on Flow of Ore in Large Scale Ore Pass Systems (2nd Report) -Blending of ore in ore pass system-"
by Gento MOGI and Umetaro YAMAGUCHI

Vol. 106(1990), No. 10
"A New Method of Visualization and image Analysis of Microcracks"
by Takashi NISHIYAMA, Hiromu KUSUDA and Motonori KITAGAWA
"Location and Characterization of Hydrofractures Formed in Coal Measure Rock by Acoustic Emission Measurements"
by Masahiro SETO, Tamotsu KIYAMA, Takashi NARITA, Makoto KOUNO, Kenji SHIOTA, Hiroshi NABEYA and Gouta DEGUCHI

Vol. 106(1990), No. 12
"The Effect of Confining and Pore Pressures on Fracture Toughness of Rocks"
by Koji MATSUKI and Tomoyuki AOKI

Vol. 106(1990), No. 13
"Cyclic Fatigue Process of Rocks under Compression"
by Koji MATSUKI and Hiroyuki KUDO

Vol. 106(1990), No. 14
"Heat Extraction Tests and Reservoir Modeling for Hot Dry Rock Development"
by Tsutomu YAMAGUCHI, Yoshiteru SATO, Michio KURIYAGAWA, Isao MATSUNAGA, Yasuki OIKAWA, Yoshiko MITSUNAGA and George ZYVOLOSKI

Activities on Rock Mechanics in the Society of Materials Science, Japan

Koichi SASSA

Professor of Kyoto University
Chairman, Rock Mechanics Committee

The Society of Material Science, Japan, is one of the organizing societies of Japanese Committee for ISRM. The committee on Rock Mechanics in the Society of Material Science, Japan was organized in 1963. Since then, the activities on rock mechanics and rock engineering in this society are mainly conducted by this committee. In 1971, a subcommittee specialized in comminution was set up in the committee on rock mechanics.

The committee on rock mechanics is quite interesting academic group. Because the members of the group have an academic background of wide variety, namely, civil engineering, mining engineering, geology, geophysics, geodesy, seismology etc.

This committee hold a regular meeting about every three months. The main part of this meeting is two lectures and discussions thereon. Beside the regular meeting, lecture meeting, training course and field inspection are also organized. Furthermore, this committee has published many special issues on rock mechanics as the volumes in regular issues of the Journal of the Material Science, Japan.

The contents of recent two special issues on rock mechanics are as follows.

Vol. 35, No. 392, May 1986.
"Distinct Element Analysis and Model Test of Granular Ground --Ground Movement due to Shallow Tunneling---"
by H. Kiyama, H. Fujimura and T. Futagi
"Damage Mechanics Analysis of Underground Opening in Jointed Rock Mass"
by T. Kyoya, T. Ohashi and T. Kawamoto
"Effects of Griffith Cracks and Inclusions on Fracture Criteria under a General Triaxial Stress State"
by H. Koide, M. Takahashi, S. Kinoshita, Y. Ishijima and A. Nakamura
"Long-Term Creep of Rocks-Experimental Results with Large Specimens Obtained in 27 Years and Those with Small Specimens in 10 Years"
by N. Kumagai, H. Ito and S. Sasajima
"AE and Thermal Expansion of Oshima Granite during Slow Cyclic Temperature Change between 210K and 370K"
by S. Ehara, T. Yanagidani and M. Terada
"Petrographical Investigation on Alkali- Reactive Aggregates in Japan"
by T. Shibuya, K. Fujisaki, H. Yamamoto, F. Imadate and S. Horiuchi

Vol. 38, No. 426, March 1989.
"How to Evaluate the Principal Axes for Anisotropic Rocks"
by Y. Kudo, K. Hashimoto, O. Sano and K. Nakagawa
"Loading Rate Dependency of Class II Rock under Confining Pressure"
by C. He, S. Okubo and Y. Nishimatsu
"Rock Stress Measurement by Sleeve Fracturing Technique"
by Y. Obara, K. Sugawara, H. Araki and Y. Ariga
"Reproducibility of the Property of Rock by Compression Test on Hard Rock"
by O. Sano, Y. Kudo, K. Furukawa, K. Nakagawa and Y. Mizuta
"Determination of Optimum Tunnel Shape Based on Three Dimensional Back Analysis"
by M. Hisatake, T. Inaba and A. Hirata
"Rapid Excavation of a Headrace Tunnel and Loosening in Rock Mass in Shin-Aimoto Power Station Project"
by C. Tanimoto, T. Yoshikawa and A. Hohjo

The titles of the lectures presented at the committee's regular meetings which were held from February 1986 to March 1991 are as follows.
"Laboratory Measurements of Spatical Fluctuation and Attenuation of Elastic Waves by Scattering due to Random Heterogeneities"
by Koji MATSUNAMI
"What We Have Learned from S-Wave Polarization Anisotropy"

by Masataka ANDO
"Effects of Low Velocity Thin Layers on Elastic Waves"
by Koichi SASSA
"Three-dimensional Structure beneath Subduction Zones revealed by Seismic Tomography"
by Kazuo HIRAHARA
"Seismic Tomography and its Application to Rock Engineering"
by Koichi SASSA and Toshiki WATANABE
"Application of Reflection Seismic Techniques to Ultrasonic Inspection Method"
by Yuzuru ASHIDA
"Tectonic Structure of Median Tectonic Line by Reflection Seismic Land Survey"
by Yoshinori IWASAKI and Soji YOSHIKAWA
"Tectonic Structure of Osaka Bay Basin by Reflection Seismic Airgun Survey"
by Yoshinori IWASAKI
"Resistivity Image Profiling for Geoengineering Survey"
by Tatsukichi TANAKA
"The Application of an Underground Radar System for Ancient Relic Survey"
by Tonouchi SHOJI
"A New Method of Visualization and Image Analysis of Microcracks"
by Takashi NISHIYAMA
"Fracture and Deformation of Rocks under High Confining Pressures"
by Mitsuhiko SHIMADA
"Combined Stress Hypothesis for Mixed-Mode Fracture Toughness Criterion"
by Chikayoshi YATOMI
"Experimental Observation of the Dynamics of Frictional Instability"
by Takashi YANAGIDANI
"Experimental Study for The Kaiser Effect of AE(Acoustic Emission) on Ground Material"
by Kazutoshi MICHIHIRO
"Distinct Element Models in Geomechanics"
by Hideo KIYAMA
"Latest Trend of Rock Stress Measurement"
by Katsuhiko SUGAWARA
"In-situ Stress Measurement Using a Conical-shaped Borehole-gouge"
by Shoichi KOBAYASHI and Tohru YOSHIKAWA
"Simulation of a Fault Rupture Process and Mechanism by Finite Element Method"
by Kenzo TOKI
"Density of Sedimentary Rocks and its Increasing Ratio with Depth"
by Koichi NAKAGAWA
"An Approach to Mechanics for Discontinuous Rock Masses"
by Masanobu ODA
"Recent Development in Rock Hydraulics"
by Yuzo OHNISHI
"Permeability Measurement Techniques for Rock Mass"
by Michito SHIMO
"In-situ Experimental Studies on Groundwater Flow Analysis for Joined Rock Masses"
by Toshiaki MIMURO
"Rock Classification Based on Several Observed Parameters in Tunneling"
by Shyuichi FUJITA
"A Study Preceding Displacement of Nou-Tunnel"
by Toshio KUMETA
"Rapid Excavation of Highway Tunnel Utilized Large Construction Machines"
by Hisaya YOSHIOKA
"The Present Status of Eurotunnel Construction"
by Chikaosa TANIMOTO
"Scientific Problems Associated with Radioactive Waste Management"
by Michito SHIMO
"Report on the Activities of the Commission on Testing Methods-Working Group on Suggested Methods for Seismic Testing within and between Boreholes"
by Koichi SASSA
"Report on 6th ISRM Congress in Montreal"
by Toshiaki SAITO
"Report on attending International Symposium on Underground Engineering (New Delhi)"
by Shun-suke SAKURAI
"Report on ECRF(Engineering in Complex Rock Formation) Symposium in Beijing and Introduction of Rock Mechanics in China"
by Toshikazu KAWAMOTO
"Report on 2nd International Symposium on Field Measurements in Geomechanics (Kobe)"
by Shun-suke SAKURAI

The following various types of meetings were held under auspices of this committee during 1987 - 1990.

Field Inspection:
a) Construction sites of Rokko Island and Seishin New Town. Those are big quarry and

reclamation work.

b) Construction site of Ookohchi Electric Power Station. This power station under construction is a large underground hydraulic power station.

Lecture Meeting:

a) "Rock Mass Characterization and Numerical Modeling for Tunneling"
by Dr. N. Barton.

b) "Recent Blasting Techniques and Research in Australia"
by Dr. G. C. Sen.

c) "Rock Hydraulic Testing for Underground Nuclear Waste Depositories and Stress Measurement at Underground Research Laboratory, Canada"
by Dr. T. Doe.

"Electric Power Station in North America"
by Mr. H. Butsuhara

d) "Hydro-Geomechanics in Fractured Rock Masses"
by Prof. D. Elsworth

"Weathering and Unstability of Rock in Ancient Egypt Ruins"
by Prof. C. Tanimoto

Rock Mechanics and its application to the Akashi-kaikyo Bridge

Takeo ENDO and Mamoru YAMAGATA***

* ; Director, Honshu-Shikoku Bridge Authority
** ; Project Manager, Honshu-shikoku Bridge Authority

1. Introducion

The Akashi-kaikyo Bridge has been constructed since 1988 and its completion is scheduled for 1997. The foundations needed appropriate application of rock mechanics for design and construction since they are founded on soft rocks.

This report describes the outline of geological investigation and design for substructure in terms of geomechanics.

2. Akashi-kaikyo Bridge

The Akashi-kaikyo Bridge ,as illustrated in Fig.1, is one of the bridges in the group of Honshu-Shikoku Bridge complex connecting the Main Island (Honshu) to the Shikoku Island of Japan and it is a suspension bridge stiffened with trusses of three-spans, two-hinged. It's total length is 3910m, and its center span is 1990m.

This bridge composes of foundation (1A, 2p, 3p, 4A), towers, cables and girders as shown in Fig.2.

The bed rocks are different at each foundation, in which 1A and 3p are founded on sedimental layers consisting of alternating of sandstone and mudstone. While 2p is in the stratum comprising Pliocene-pleistocene congromerate and 4A is designed on weathered granite.

3. Geotechnical Investigation and Design of Foundations

Fig.3 illustrates the design flow through the geotechnical investigation, in which three items are considered relevant to foundation design, i.e.,

(a) determination of analitical methods of foundation stability and displacement
(b) modelling of the founding strata

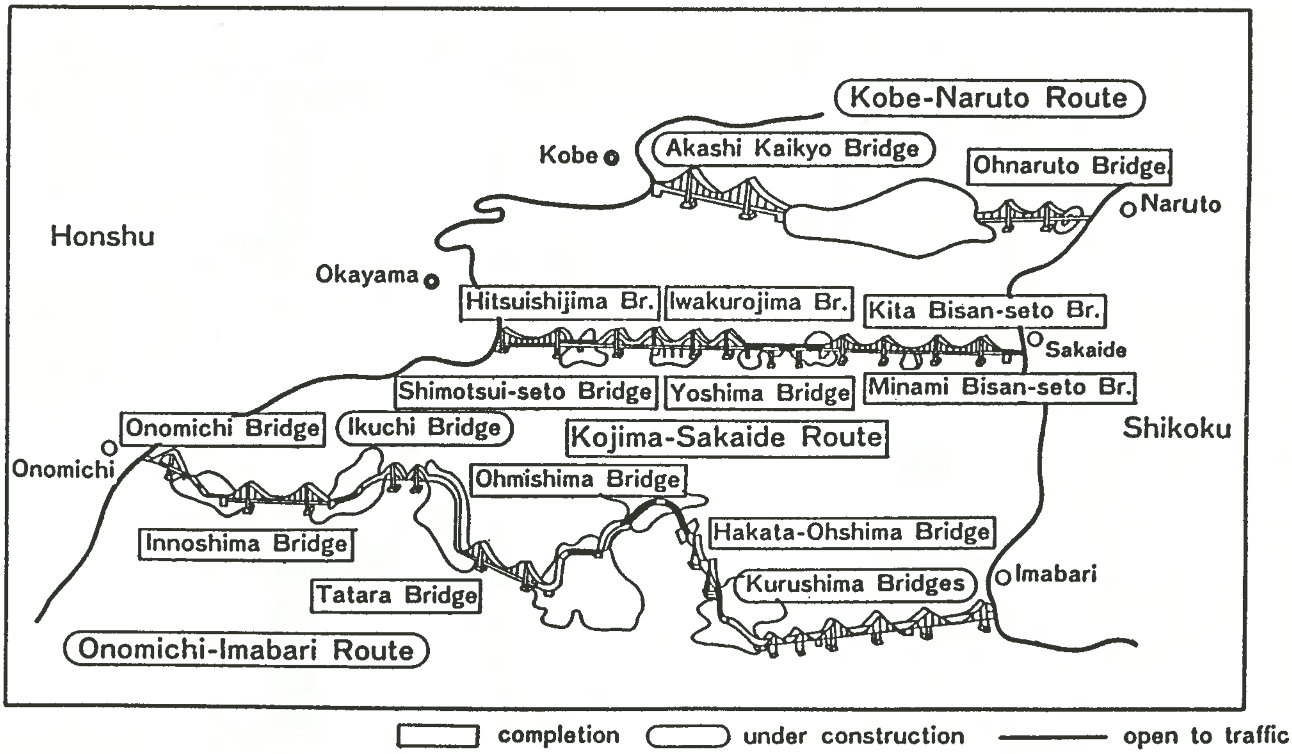


Fig.1 View of the Honshu-Shikoku Bridge Complex

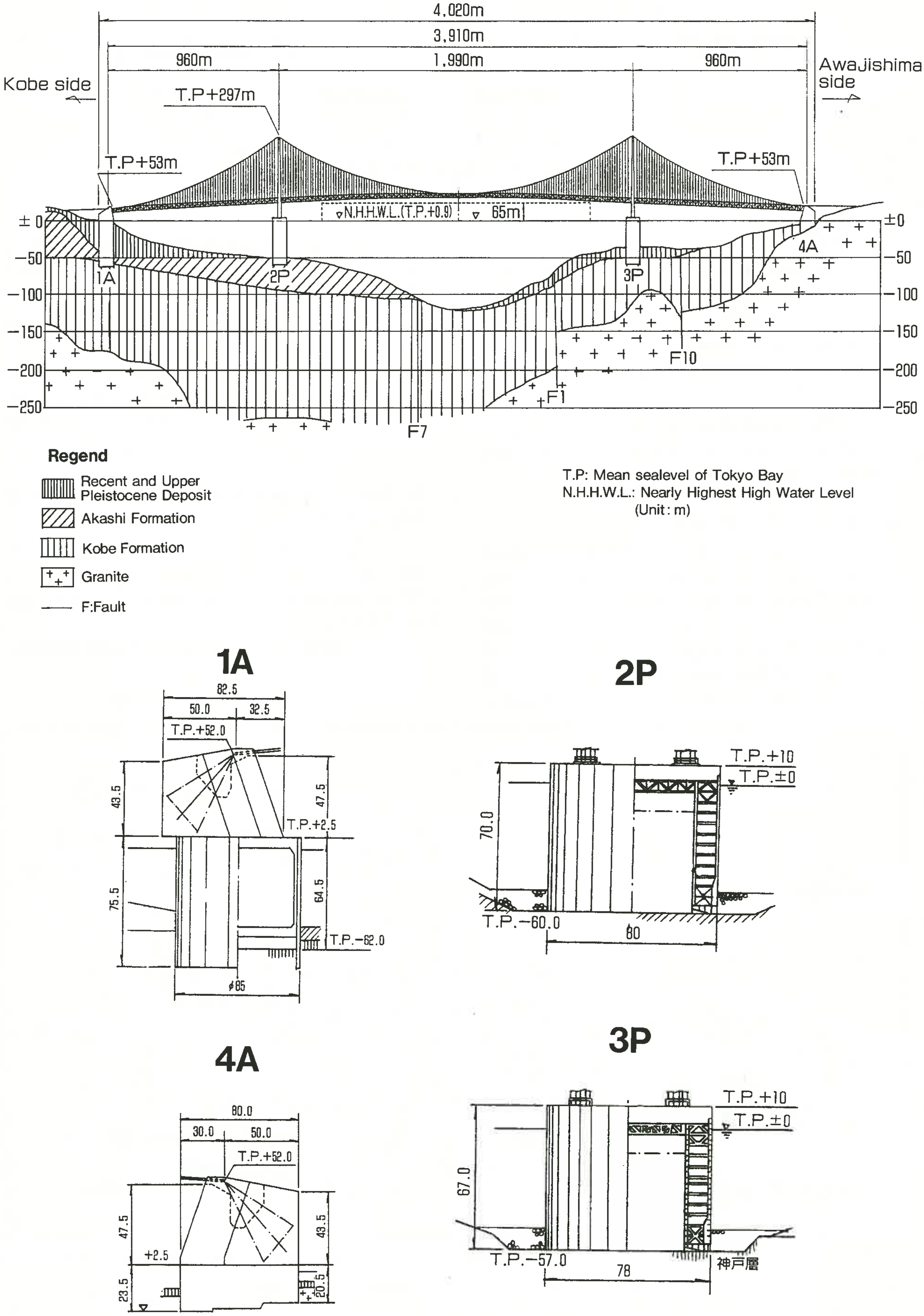


Fig.2 Geologic Profile along Akashi Kaikyo Bridge

(c) determination of design paramenters.
The geotechnical investigation was carried out to execute these action programs. In Table 1, the geotechnical explorations performed to this date is shown. Exploration were accomplished in a phased sequence as follows:
(a) Comprehensive exploration
(b) Preliminary investigation
(c) Detailed investigation (Phase 1 and 2)

In phase 2, exploration was done by a variety of methods, the principle ones being (a) core-drilling, (b) geophysical logging, (c) pressuremeter test, and (d) core testing. Core-drilling was achieved with a triple tube sampler of 360mm in diameter for Akashi formation which contains the graval from 50mm to 100mm or more. While in the Kobe group and weathered granite,a triple tube sampler with 116mm in diameter was used.

The geophysical logging consists of three methods, seismic, electrical resistivity and density. Such geophysical explorations supplied useful information for bedrock profiling and on engineering properties of foundation rock.

The pressuremeter tests were performed to get the deformation properties of soft rock with the hydrostatic pressure up to 100 kgf/cm^2.

The laboratory tests used borehole samples were conducted under the triaxial condition. The shearing properties were obtained from a consolidated undrained or drained triaxial compression test.

3.1. Determination of the Analytical Methods of Foundation Stability and Displacement

Large plate loading tests were performed in order to reveal the mechanism of failure and deformation of bedrock. The analytical methods of foundation stability was determined on the modified Bishop method and the Rigid Bodies Spring Model method based on test results.

The deformation of strata occures at various stages during/after construction. In particular, creep effects are significant when a foundation rests on a poor rock. The finite element method was applied to the deformation analysis using the deformation parameters obtained from

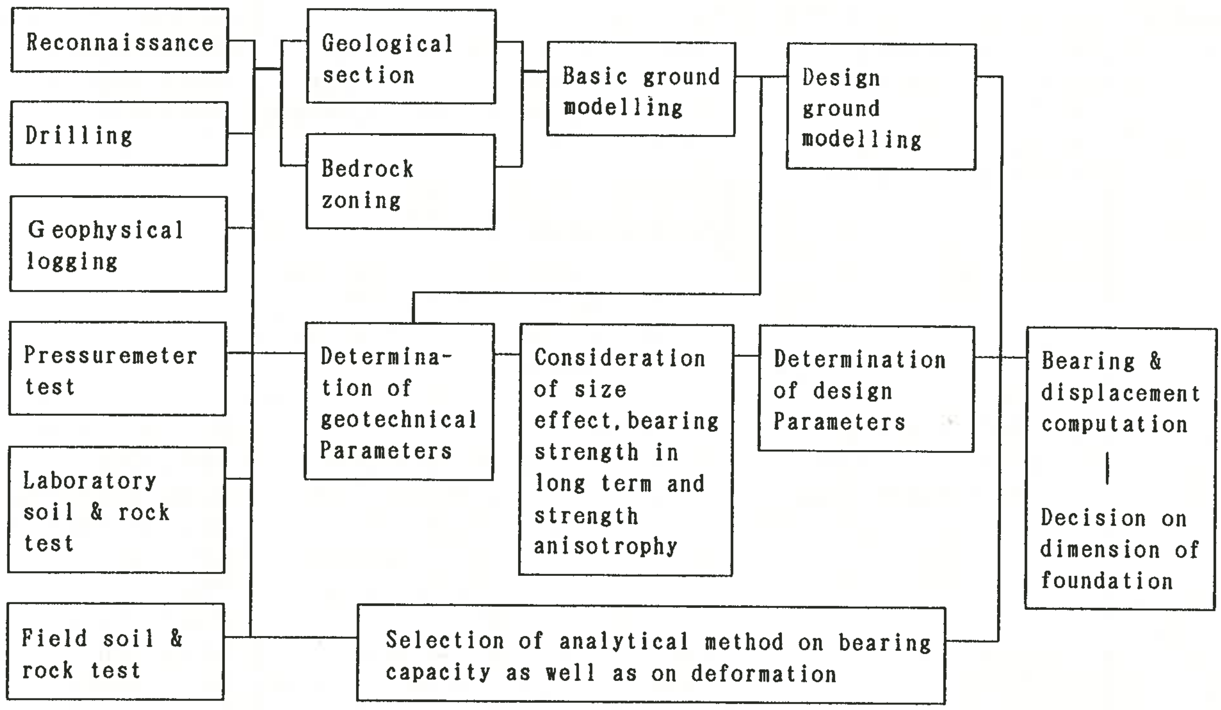


Fig.3 Foundation design flow chart

Table 1 Phased geotechnical explorations performed for the Akashi Kaikyo Bridge

Investigation			Items	Results
Comprehensive exploration		Overall Data Collection for comparison/selection of feasible routes.	#Bathymetric Survey and Topographic Survey for islands in straits. Sonic Prospecting, Geologic Reconnaissance, Echo-Sounding, Bottom Material Sampling by Dredging, Sea Floor Observation by Submarine Vessel, Aerial photographing	·Classification Map of Topography ·Bathymetric Map
Preliminary investigation		To obtain basic data for route recommendation and design/construction plan	#Drilling Core Drilling, Geophysical Logging, Pollen Analysis, Diatom Analysis, Foraminifera Analysis, Standard Penetration Test, Soil Test, Rock Test #In-Situ Rock Test Direct Shear Test, Static Loading Test. Rapid Loading Test, Geophysical Prospecting, Soil Test, Rock Test #Seismic Risk Survey	·Geologic Map ·Geohistory ·Contour Map showing surface boundary of Kobe Formation ·Aerophotograph
Detailed Investigation	Phase 1	Selected Drilling for revealing ground conditions at all substructure sites and for establishment of investigation standards	#Drilling Core Drilling, Geophysical Logging, Pressuremeter Test, Soil Test, Rock Test, Standard Penetration Test #In-Situ Rock Test Direct Shear Test, Creep Test, Static/Dynamic Loading Test, Triaxial Compression Test on ϕ 30cm Samles	·Geologic Profile ·Establishment of investigation Standards
Detailed Investigation	Phase 2	Detailed Drilling for securing rock cores and rock/unit classification	#Drilling Core Drilling, Geophysical Logging, Pressuremeter Test, In-Situ Permeability Test, Soil Rock Test·Unit weight, Grain Size Analysis, Pulse Velocity, Unconfined Comression Test, Triaxial Test·CU·CD·UU, Cyclic Triaxial Test, Dynamic Triaxial Test, Creep Triaxial Test, Simplified Slaking Test	·Geologic Model at each site. ·Shear Strength, Bearing Capacity Deformation Characteristic of Akashi/Kobe Formation ·Geotechnical Parameter for each unit

triaxial creep tests. In earthquake resistant design, the behaviour of poor rock under cyclic loading is of great importance e.g. the respones to cyclic loading such as is of relevance to rock-foundation interaction under earthquake loading. Values for shear modulus and damping ratio of rock were decided from the cyclic triaxial test, as well as the in-situ dynamic loading test.

3.2. Modelling of the Founding Strata

Modelling of the bedrock is a valuable tool for design. Such a modelling can be done by geophysical loggings, as well as by performing tests on part of core obtained from the exploration program. The modelling is based on soil types, weathering, strength, deformability and on the degree of crack present in the core.

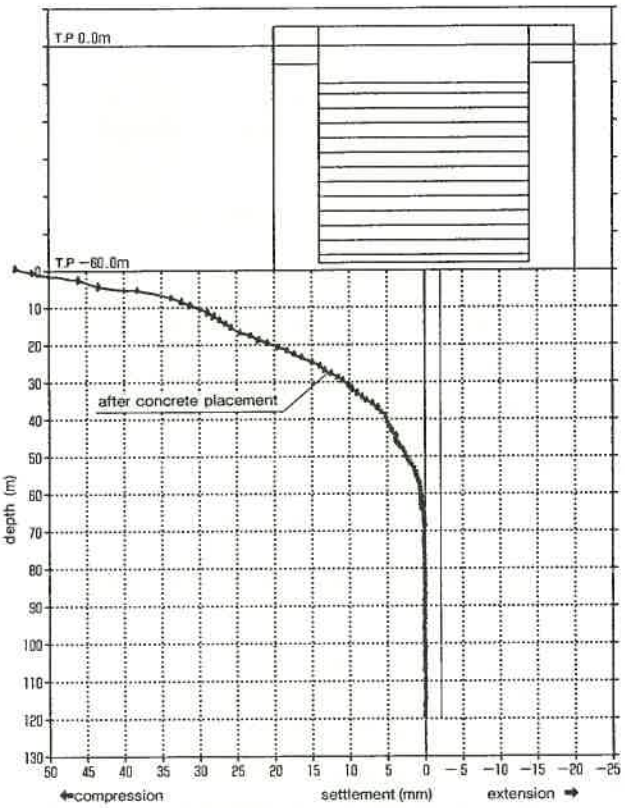


Fig.4 Settlement distribution (2p)

3.3. Determination of Design Parameters

The engineering parameters employed in the performed analyses are given in Table 2. The design parameter were fixed based on the geotechnical parameters obtained from various tests shown in this Table, considering anisotropy of strength, long-term strenght, etc.

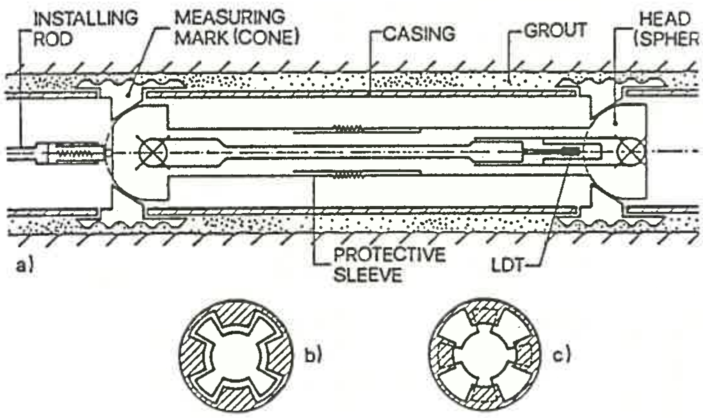
4. Monitoring of Foundation

In view of uncertainties in prediction, it was decided to monitor foundation performance using surface settlement markers, and sliding micrometers in the layer. The settlement distribution beneath the foundaion is plotted in Fig.4. The measured distribution of settlement with depth revealed that the compression of the layers was concentrated almost entirely in the top 30m.

Fig.5 illustrates the measuring equipment.

5. Aknowledgements

The authors are grateful to the support of the committee on seismic and foundation design.



a) schematic view , b) sliding position , c) measuring position

Fig.5 Sliding Micrometer-ISETH

Table 2 Geotechnical Design Parameters and Their Testing Method

		Geotechnical Parameter		Testing Method
Static Parameter	Strength Parameter	Akashi F. Kobe F.	C_d ϕ_d	Triaxial Test on CD Conditions
		Granite	C_d ϕ_d	In-situ Rock Test
	Deformation Parameter	E_s		Pressuremeter Test or Triaxial Compression Test
		ν_2		Triaxial Compression Test
	Creep Parameter	G^X		Triaxial Drained (undrained) Creep Test
		G_3		
		η_3		
	Unite Weight	γ' γ_t γ_{sat}		Physical Property Test
Dynamic Paarameter	Strength Parameter	Akashi F. Kobe F.	C_{cu} ϕ_{cu}	Triaxial Test on CU Conditions
		Granite	C_d ϕ_d	In-situ Rock Test
	Deformation Parameter	G_D (G_o)		PS Logging
		G		Cyclic Triaxial Test
	Damping Parameter	D		Cyclic Triaxial Test
	Unite Weight	γ' γ_t γ_{sat}		Physical Property Test
At Typhoon/ Vessel Collision	Strength Parameter	Akashi F. Kobe F.	C_{cu} ϕ_{cu}	Triaxial Compression Test on CU Conditions
		Granite	C_d ϕ_d	Shear Strength by in-situ Rock Test
	Deformation Parameter	E_0		2×Es (Es: Static Parameter)
		ν_0		Same as Static Parameter
	Unit Weight	γ' γ_t γ_{sat}		Physical Property Test

Outline of Underground Oil Storage Plant in Japan

Toshiaki MAKITA, Yoshiharu MIYANAGA** and Akira FUKUHARA***

* ; Japan Underground Oil Storage Co.,Ltd
** ; Electric Power Development Co.,Ltd

1. Introduction

Althogh Japan is a major consumer of petrroleum, it depends almost completely on imports from abroad. In 1973, the year of so-called oil crisis, Japan was seriously affected by the shortage of oil supply. Since that time, Japanese Government has been forced to establish the means to maintain the storage of enough amount of crude oil within the country.

This paper presents a report on the outline of underground oil storage plants under construction in Japan.

2. Outline of the Project

The first underground oil storage plants in Japan are now being constructed by Japan Underground Oil Storage Co.,Ltd. at three locations, Kuji, Kikuma and Kushikino. The locations of the three plants are shown in Fig.1.

The total storage capacity at these three plants is 5 million kl divided into 1.75 million kl at Kuji and Kushikino respectively and 1.50 million kl at Kikuma. The total project cost is about 180 billion yen.

An outline description of each plant is shown in table 1. And the layout of the Kikuma plant is shown in Fig.2.

3. Outline of the Design

3.1. Water Seal Effect

The average permeability of rock mass is

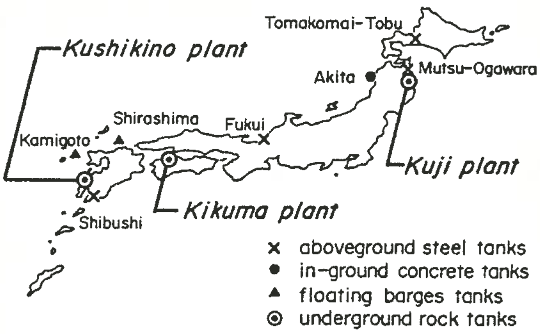


Fig.1 Location of Japan's National Petroleum Stockpile Facilities

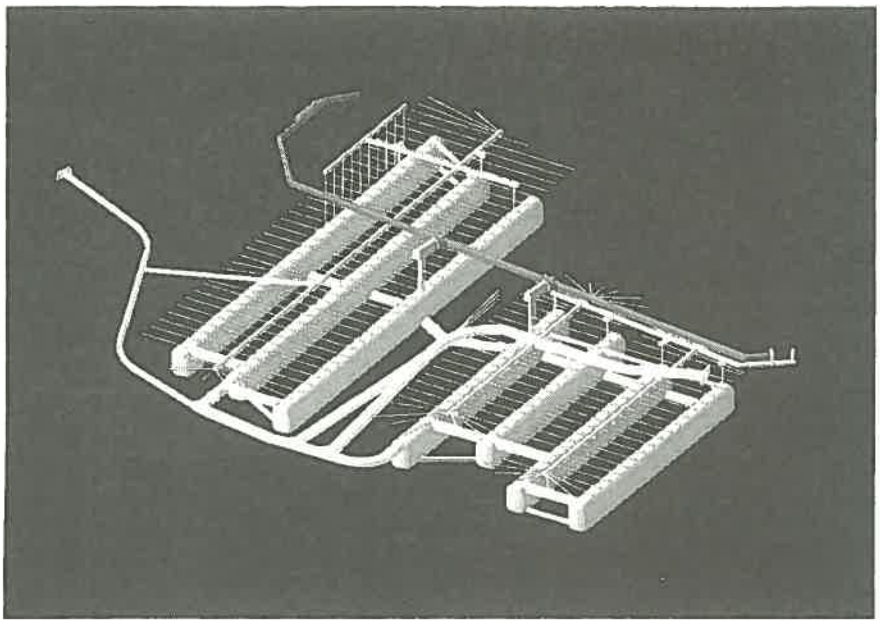


Fig.2 Layout of The Kikuma Oil Storage Plant

7.6×10^{-8} at Kuji and 8.7×10^{-9} m/sec at Kikuma respectively, and the ground water level will be possible to drop to crown of storage caverns. Therefore, the artificial water barrier system was employed at Kuji and Kikuma plants.

The rock mass of Kushikino is low in permeability ranging 10^{-9} and 10^{-10} m/sec. At the Kushikino plant, the natural water seal system was employed primarily, but the artificial water barrier system was employed in part as a vertical water barrier to prevent migration of crude oil between caverns.

Confirmation of securance of the ground water level is performed by inference by finite element seepage analysis using past investigation data from each facility site.

3.2. Cross Sectional Configuration of Storage Cavern

The cross sectional configuration of the caverns is determined from consideration of stability of the caverns, economy and ease of construction.

At Kuji and Kushikino which have the complex geological conditions, the egg-shaped type (18m×22m) was employed considering the mechanical stability of the cavern and ease of meeting a fault and poor rock. The horseshoe type (20.5m×30m) was employed at Kikuma, because of its good geological condition. The cross sectional configuration of the three plants is shown in Fig.3.

3.3. Supports System

In order to secure the safety of the storage caverns, the system of support by rock bolts and shotcrete employed in this design is minimum requirement under the geological conditions of Japan. The method used in the design of rock bolts is to assume the length and pitch of the bolts with consideration of the loosened zone and then verify the assumed length and pitch by FEM and other analytical methods.

The example of cavern support at the Kushikino plant is shown in Fig.4. The standard supports system at the Kushikino plant, which is corresponding with the rock classification, is shown in Fig.5.

4. Outline of the Field Measurement

4.1. Convergence Measurement

In order to administrate the safety of the caverns, the convergence measurements are carried out every 30m during the construction. Generally, a convergence measure is utilized in that measurement, but in this project, convergence measuring system, consisted of the combination with total station and resettable prisms,

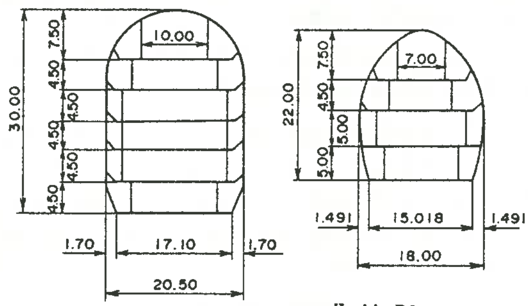


Fig.3 Cross Section and Excavation Division

Table 1 Outline Description of The Three Plants

Item	Kuji Plant	Kikuma Plant	Kushikino Plant
Rock Type	Granite	Granite	Andesite
Water Injection facility	Yes	Yes	In part
Storage Capacity (in million kl)	1.75	1.50	1.75
Storage Caverns			
Distance between caverns (m ctc)	50	65	50
Depth (arch crown)			
From sea level (m)	Approx.-20	Approx.-35	Approx.-20
From ground surface (m)	Over -100	Over -65	Over -100
Operating Units			
Number	3	2	3
Width ×Height×Length (m)	18×22×1100~2200	20.5×30×1030~1313	18×22×1100~2220

is developed in order to carry out safely and quickly.

In this system, the convergence is calculated using the measurement data by measuring the distance between total-station and prisms and taking the included angle by looking through a total-station. By that system, it is able to measure the convergence of 3 or 4 sections in a measurement as shown in Fig.6.

4.2. In-situ Stress Measurement

In this project, in-situ stress measurements are carried out by double fructuring system in some boreholes at the stage of arch in caverns. In-situ stress and modulus of deformation are obtained by evaluating the relation between loading pressure and diametral deformation of a borehole measured by this borehole loading test. In-situ stress and modulus of deformation are used for the monitoring of the caverns' stability.

5. Outline of Construction

The construction schedule of the three plants is shown in Table 2.

The sequence of excavation of the Kushikino plant's storage cavern is shown in Fig.5. First, the part of arch is excavated, and the main body is excavated by bench cut with benches 4.5m and 5.0m in height.

In the performance of the construction, in addition to standard performance, change in the rock classification, increased in rockbolts and

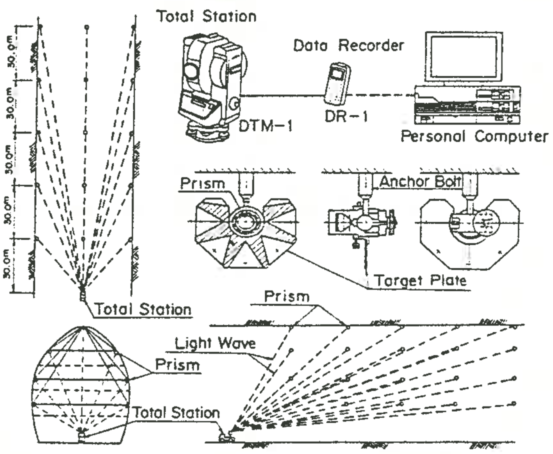


Fig.6 Convergence Measuring System

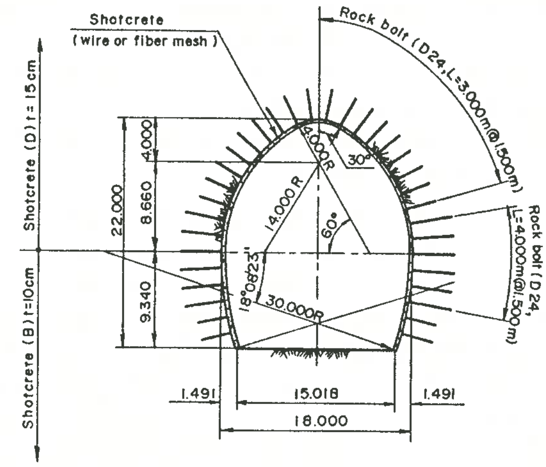


Fig.4 Example of cavern support at The Kushikino Plant

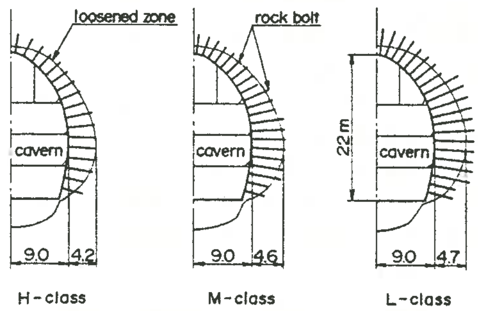
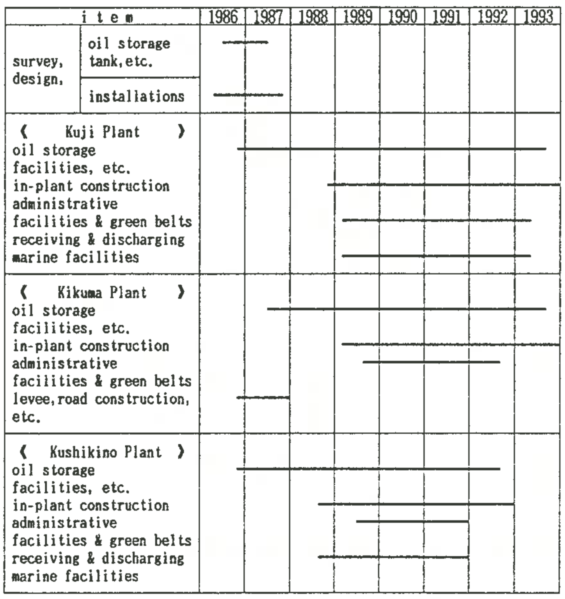


Fig.5 The Standard Supports System at The Kushikino Plant

Table 2 Construction Schedule of The Three Plant



increase in shotcrete are performed in a ccordance with construction control criteria on the basis of the results of the excavated surfaces and instrumentation monitoring, and variation in the cross section also is considered as the subject of design variation.

A personal computer has been set up at the construction site and the monitoring and prediction of the caverns' stability are being carried out using the back analysis program by the Boundary Element-Finite Element coupled method which was developed by proffessor Sakurai.

6. Conclusion

At the Kushikino plant, the excavation work has been finished and the pipe laying work is the height of prosperity now. At the Kuji and Kikuma plants, the excavation work of storage cavern has reached 80% of the whole. And besides, the non injection clay grouting (the clay suspension permiate into the cracks of rock mass around the cavern and fill the narrow gap) is being carried out at the Kuji plant in order to prevent the water table dropping and decrease leakage water. The result of the non injection clay grouting will approximately become clear after a year.

Finally, as the chain of energy storage, underground LPG storage test plant is now being constructed at Mizushima in Okayama prefecture. The various tests will be started in next year at this plant.

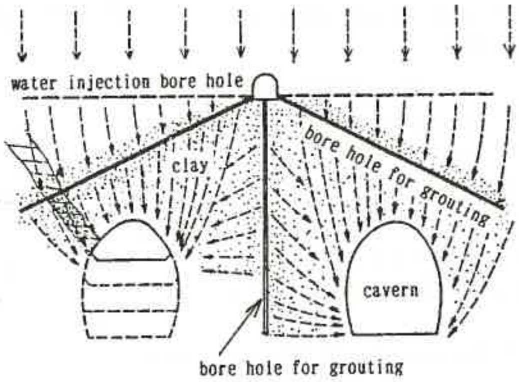


Fig.8 Non Injection Clay Grouting Method

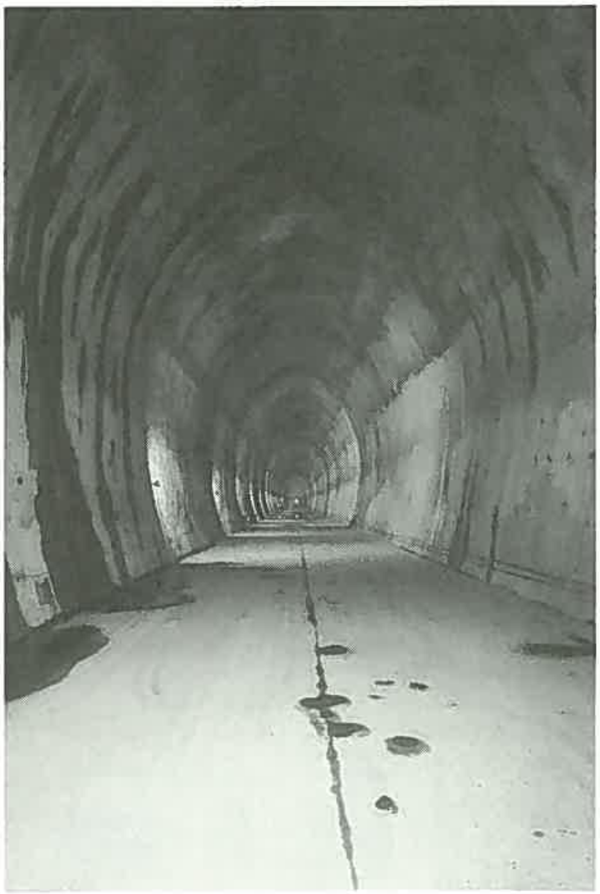


Photo.1 Storage Cavern Excavated Completely

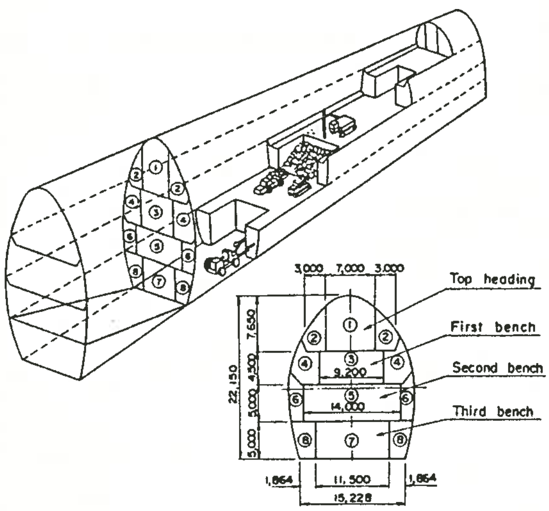


Fig.7 Sequence of Excavation at The Kushikino Plant

Reference

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Constructions of Multi-purpose Dams in Japan

Development Division, River Bureau,Ministry of Construction
Dam Department, Public Works Research Institute

1. Introduction

Japan is the country of islands with steep mountains and the most of population is concentrated in the narrow plains. It is therefore necessary to construct a large number of dams for flood control and water supply. The most popular type of large dams in Japan is a concrete gravity dam because of high resistance against overtopping of flood and the adaptability to various geographical and geographical features. More than 300 dams have been completed, and another 400 are under construction or planning by the Ministry of Construction of Central Government, and by local government and Water Resource Development Public Corporation under the technical supervision of the Ministry. However, it is getting more and more difficult to find a damsite with tight bedrock. The comprehensive geological survey have to be conducted to understand mechanical and water-tight feature of the bedrock in advance of the design and construction of these dams. The Ministry also makes various researches for rapid and economical construction of dams. The remarkable result of the research is the development of the RCD (roller compacted concrete for dams) construction method.

In this paper, the brief outlines of the construction technology of dams in Japan are described.

2. The Survey and Test for The Bedrock of Dams

In Japan, comprehensive geological surveys and test are executed for bedrock of a dam in advance of its design and construction. These include seismic prospecting, core drilling, exploratory adits, in-situ shear tests, in-situ deformation tests, and permeability tests (Lugeon tests). After these results, three types of maps of the bedrock are drawn and are used in the design of the safe and economical dam, and in the planning of the foundation treatments. These are geological maps, rock classification maps and permeability maps.

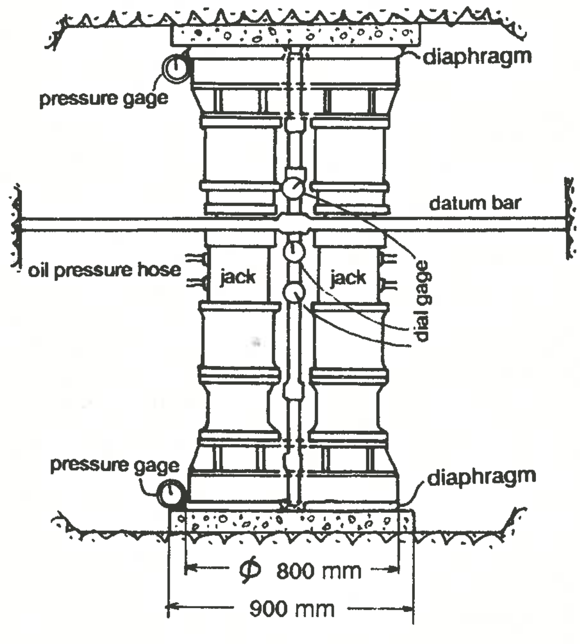


Fig.1 In-situ Deformation Test

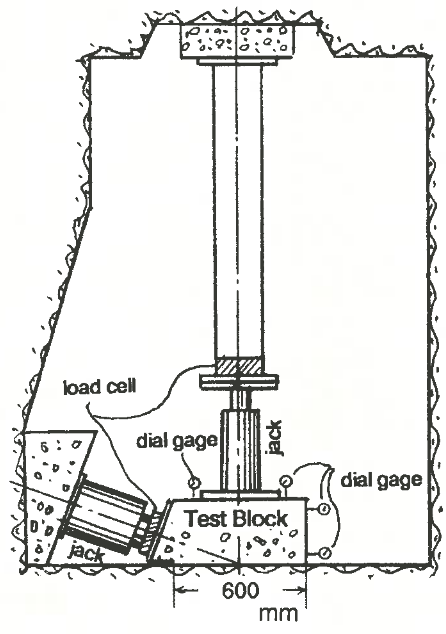


Fig.2 In-situ Block Shear Test

In the survey of the bedrock, rock classifications are used in Japan to evaluate and classify the properties of rock. The most popular method of rock classification is the combined one by Public Works Research Institute and by Central Research Institute of Electric Power. In the rock classification, three indices are generally used. They are stiffness of the rock, spacing and conditions of the joints. The bedrock at the damsite is classified into several ranks by these indices. The mechanical features of the typical rock are examined through in-situ rock tests and the design properties are thereby determined. The distribution of the rock properties can be estimated from the rock classification maps.

The permeability maps or "Lugeon maps" from the in-situ permeability test (Lugeon tests) in drilling holes are used in determining the area of curtain grouting or other seepage control treatments.

Table 1 Survey and Test at Miyagase Dam

Test Item	Total Amount
Elastic Prospection	5,300 m
Core Drilling	87 holes (10,299 m)
Permeability Test	73 holes (1,864 times)
Exploratory Adits	19 adits (2,963 m)
In-situ Deformation Test	16 points
In-situ Shear Test of Rocks	25 points

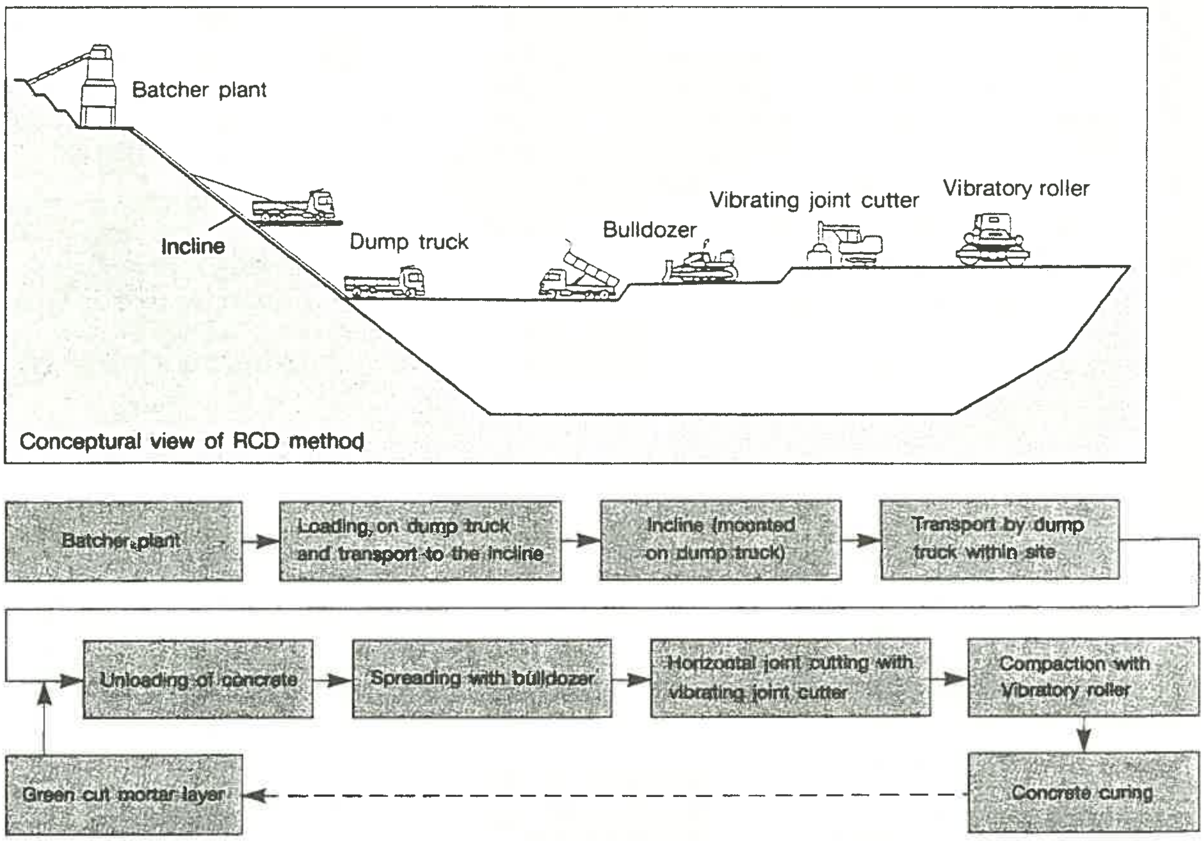


Fig.3 Construction Flow of RCD Construction Method at Miyagase Dam

3. Outline of The RCD Construction Method

Nowadays, in less favorable geological conditions of the damsites, the larger cross-section of dams is required in designing the safe concrete gravity dams. Under these conditions, the RCD construction method has been developed as the economical and rapid construction of concrete dams by the technical supervision of the Ministry of Construction.

In the RCD construction method, lean zero-slump concrete is used, and compacted by vibrating rollers. The RCD construction method has following advantages.

a) the use of large earth-moving machineries
b) the variety in choice of the way of concrete transportation
c) shortening of construction period
d) construction economy
e) The safety of a concrete dam construction because of wide and horizontal construction area without high lift difference
f) high quality of concrete almost equivalent to that of conventional concrete

The RCD construction method has been first adopted at Shimajigawa Dam completed in 1980 and many dams have been constructed by the method since then. The RCD construction method is getting world-wide evaluation as the rapid, economical and safe construction method.

4. Large Dams Under Construction in Japan

Many dams are under construction in Japan, The following are some of these dams.

Miyagase Dam is to be build across the Nakatsu River, a tributary of the Sagami River, about 50 km west to Tokyo. The dam is being constructed by the Ministry of Construction for flood control, municipal and agricultural water supply and preservation of normal river flow. It has a maximum height of 155m and a crest length of 400m with a total volume of 2,000,000 m^3 of concrete as the largest one in Japan. It reduces the flood discharge of 1,700 m^3/s by 1,600 m^3/s.

The bedrock of the dam consists of pyroclastic rock, and the main bedrock of the dam is lapilli tuff of Miocene. There is a relatively high permeable zone near the river bed.

The RCD construction method has been adopted at Miyagase Dam for the economical and the rapid construction of huge volume of concrete. The concrete will be transported from the mixing plants at the right abutment at the crest level of the dam onto the dam by two inclines, which is suitable to the steep gorge of the site. Crashing aggregate is used for concrete mix. The aggregate is lapilli tuff and volcanic breccia, and transported through the glory hole from the quarry.

Gassan Dam is at the Bonji River of the Aka River system in Yamagata Prefecture. This concrete gravity dam is 122m high, 393m long with a volume of 1,130,000 m^3. The dam is constructed by Ministry of Construction for flood control, water supply and preservation of normal river flow. It controls 2,900 m^3 as the basic design flood discharge by 1,000 m^3.

The geology of the damsite corresponds to the Tertiary pyroclastic rock called "Green Tuff", which covers mostly Tohoku Region. The bedrock consists mainly of andesite, while andesitic tuff breccia is located at some parts. River deposit of a thickness of 25 or 30 m exist at the damsite. The foundation has some

Table 2 Mixture of RCD Concrete

Dam Name	MSG (mm)	VC Value (sec)	Air (%)	Unit Weight (kg/m^3)				
				Water	Cemente	Flyassh	sand	gravel
Miyagase	150	20±10	1.5±1	95	91	39	644	1574
Gassan	80	20±10	1.5±1	90	91	39	621	1624
Urayama	150	20±10	1.5±1	85	91	39	681	1600

relatively high permeable area near the river bed and both sides.

Gassan Dam is located in the region of cold climate with long winter season, so that the RCD construction method is adopted as the effective and rapid construction method. The belt conveyer system will be adopted for transportation of the concrete. The aggregate mainly consists of the diorite.

Urayama Dam, owned by Water Resource Development Public Corporation, is situated on the Urayama River of the Ara River system. The dam is 155 m high, 400 m long, with a volume of 1,900,000 m^3 , one of the largest concrete gravity dam in Japan. The purposes of the dam include flood control, water supply, power generation and preservation of normal river flow. It will cut 890 m^3/s of 1,000 m^3/s flood discharge.

The bedrock consists of chert, slate and greenrock of Paleozoic and Mesozoic age. The rock is fresh and hard in general, whereas chert and slate has some permeability. On either abutments, the rock is relatively high permeable because of the existence of open cracks, but beneath the part, it is little pervious.

Urayama Dam is so large that the RCD construction method is selected to achieve the rapid pace of construction. The crashed sandstone nearby the damsite is used for aggregate.

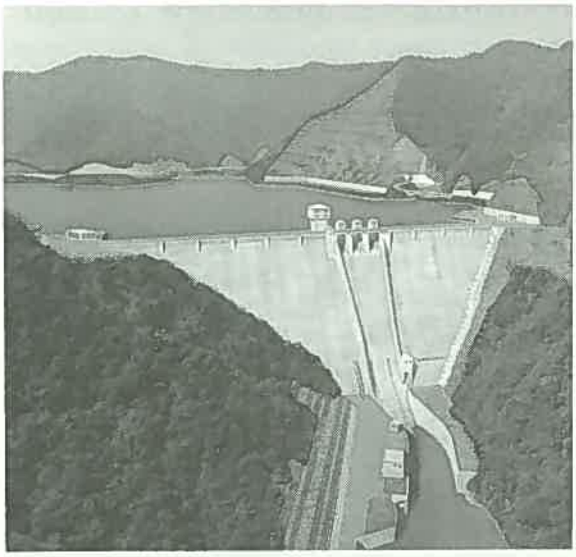


Photo.1 Miyagase Dam at **Completion**

5. Summary

The comprehensive research of the geological survey and test of the bedrock is being engaged in Japan. It will be able to construct much safe and economical dams. It will further contribute to more safe and economical dam construction in Japan.

Photo.2 Gassan Dam at Completion

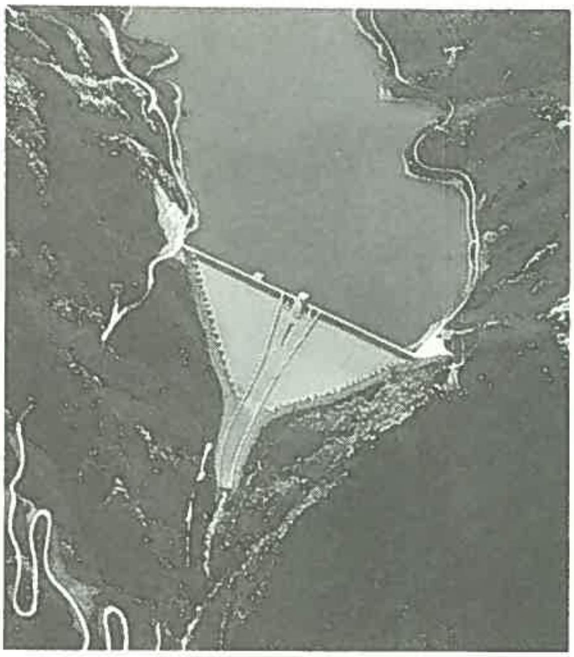


Photo.3 Urayama Dam at Completion

Underground Pumped Storage Power Stations Planned and Currently under Construction in Japan

Kenji AOKI

Kajima Corporation

1. Introduction

With the introduction of nuclear power generation from 1955, demands for a more efficient power supply in Japan resulted in the construction of a considerable number of new underground pumped storage power stations. The scale of the excavated caverns required for these power stations have become larger since around 1975. During the same period, various efforts have been made in the field of rock mechanics to study the mechanical stability of these caverns. Developments of new testing methods, numerical analysis of ground behavior during excavation have also established with actual design and construction.

Geology and rock mechanics are playing important roles in the planning of shape, orientation and layout of caverns. Considerable efforts have also been made to develop better analytical methods and geological evaluation methods.

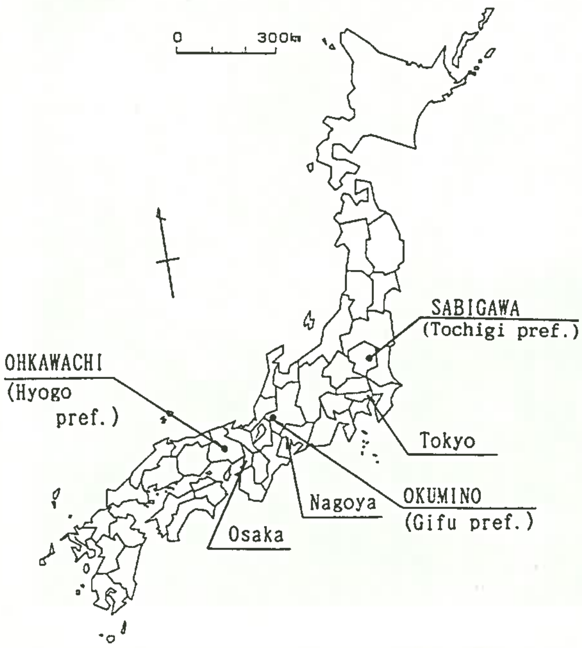


Fig.1 Locations-map

However, because of the limited land space and the growing number of construction sites in Japan, it is becoming increasingly difficult to locate favorable construction sites. This has often resulted in some compromise over geological conditions of the chosen construction sites. Consequently, in order to secure mechanical stability of the caverns, the importance of cavern behavior measurement during construction is growing.

2. Three Major Sites Under Construction

There are three ongoing construction projects of underground pumped storage power stations whose start-up dates are scheduled for around 1995 (see Fig.1). There are also some projects being planned at several other sites. The three sites for the above power stations under construction were described below:

2.1. The Sabigawa Site

The Sabigawa Underground Power Station (Fig.2a, Photo.1) is being constructed in Tochigi Prefecture by The Tokyo Electric Power Co., Ltd. Equipped with three 300MW generators, the power station is capable of generating a total of 900MW. The cavern for this power station has a mushroom-shaped with arch concrete

Photo.1 Sabigawa power station

structure. This cavern contains both the generators and transformers to ensure cost effectiveness. The geology of the site consists mainly of rhyolite, which is interspersed with tuff breccia and porphyrite. The geology of this site is characterized by well developed joints in the rhyolite, and four major faults that run across the cavern. Of primary concern are the 10-200cm thick fracture zones and clay fillings in the faults. Careful construction and support work have been carried out along these faults.

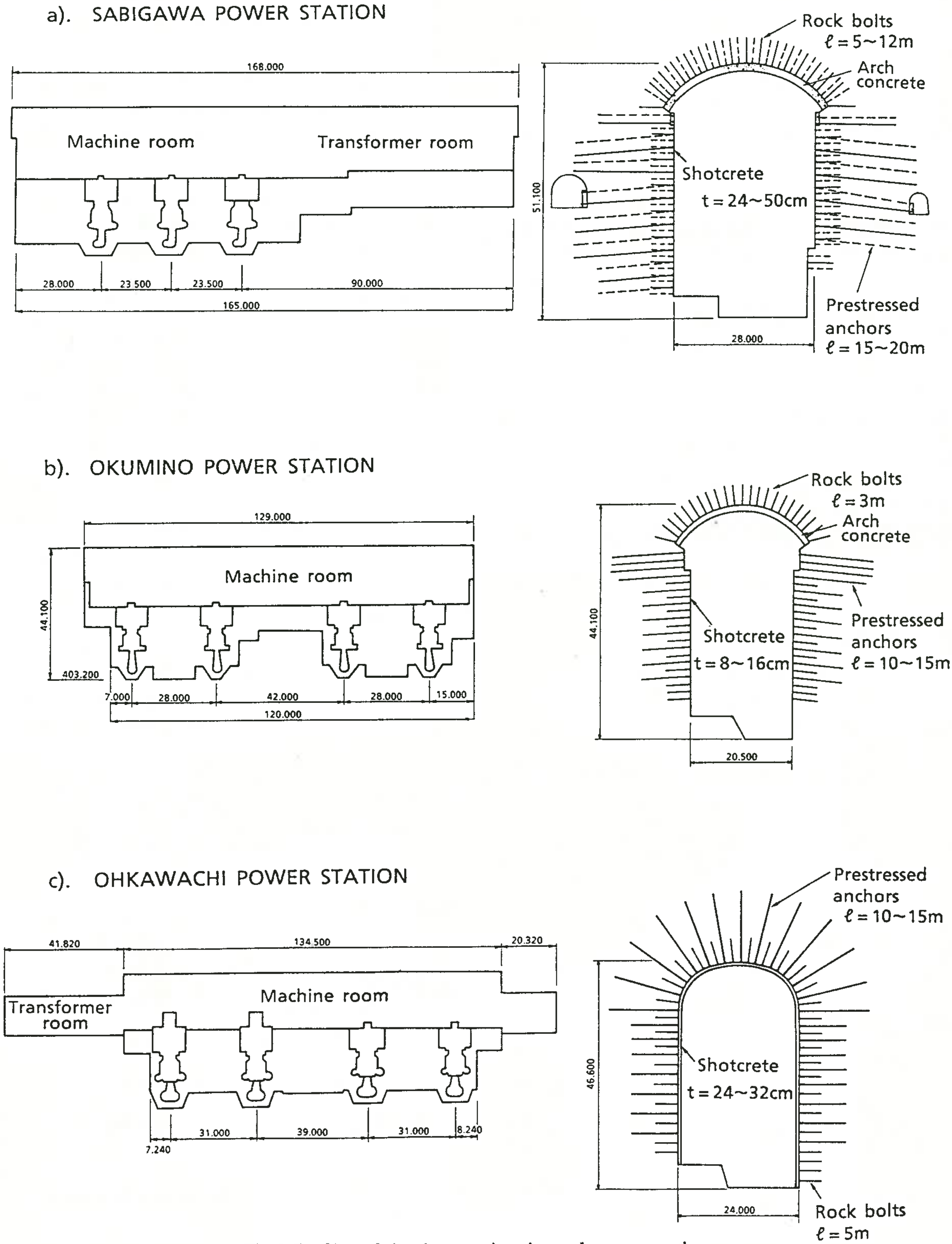


Fig.2 Profiles of the three major site under construction

2.2. The Okumino Site

The Okumino Underground Power Station (Fig.2b, Photo.2) is being constructed in Gifu Prefecture by Chubu Electric Power Co., Ltd. Equipped with four 250MW generators, the power station is capable of generating a total of 1,000MW. The cavern for this power station also has a mushroom-shaped with arch concrete structure.

This power station have a separate generator cavern and a transformer cavern. This type of layout is conventional one in Japan. The geology of the site consists of very intact rhyolite.

Photo.2 Okumino power station

2.3. The Okawachi Site

The Okawachi Underground Power Station (Fig.2c) is being constructed in Hyogo Prefecture by The Kansai Electric Power Co., Ltd. Equipped with four 320MW generators, the power station is capable of generating a total of 1,280MW.

The geology of the site consists mainly of porphyrite, which has few joints and is thus very hard. The cavern has a bread-loaf-shaped structure without the arch concrete, and is supported with shotcrete, rock bolts and prestressed anchors around the whole cavern.

The integrated cavern contains both the generators and transformers, and it has small transformer rooms on both sides for cost reduction purposes.

The generation system used is characterized by a continuously variable rotating speed control for two out of the four turbines.

3. Newly Developed Construction Techniques

New construction techniques are being implemented extensively to improve stability and quality in the underground power stations currently under construction. This section describes some developments relating to monitoring and construction techniques.

3.1. Observational Technique

As mentioned before, site conditions for recent construction projects are often less favorable than they used to be.

It is difficult to fully predict ground conditions from preliminary surveys, especially at sites where the geology is complicated. In order to compensate for the limits of the preliminary

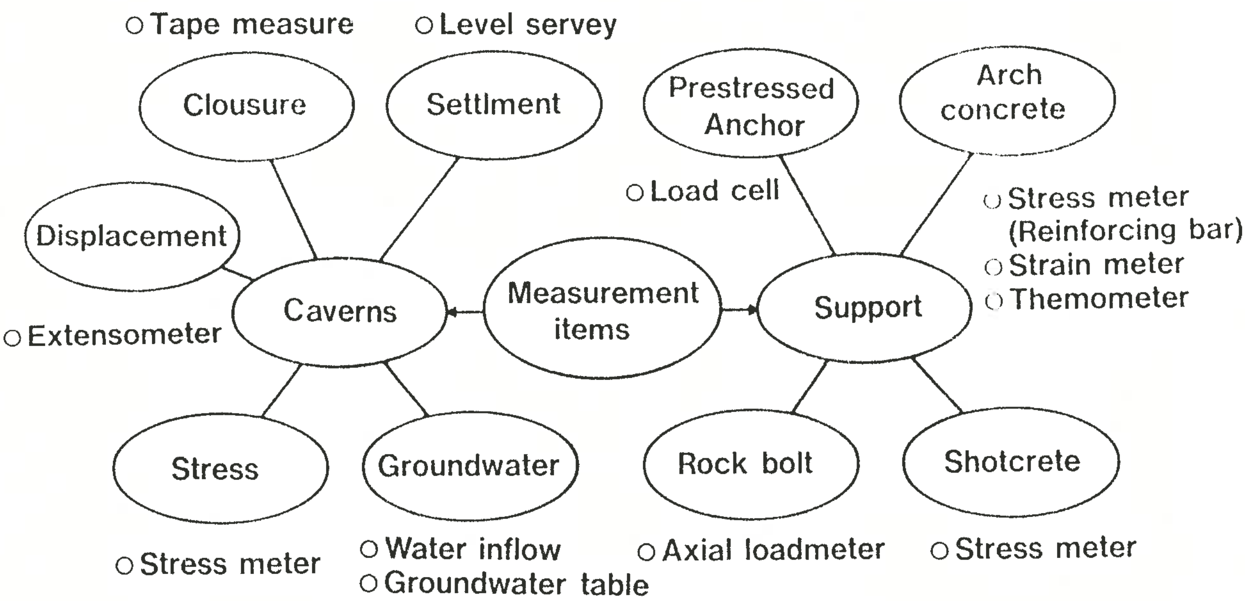


Fig.3 Measurement items of monitoring

surveys and the difficulty in behavior prediction, and thus secure the safety of the caverns, there is a growing demand for better observational techniques.

In conventional methods, data acquisition has been already automated. The subsequent data processing, however, has consequently heavily depended on manual work, and analysis has had to have been performed on a larger computer off site. Thanks to recent developments in computer technology, a series of steps (data acquisition, data processing, prediction analysis and design review) can now be efficiently performed on a computer system, at the construction site (Fig.4).

Measurement items for underground power stations can largely be divided into one group relating to "cavern behavior" and one relating to the "effects of supports," as shown in Fig.3.

Measurement for these items comprises of routine measurements and step measurements. The routine measurements involves measuring daily behavior of the caverns so that proper actions can be taken if required. The step measurements technique involves cavern behavior prediction and support design reviews based on the measured data accumulated during a certain period of excavation.

These measurement are efficiently performed on a computer system set up at the field office. Modification of supports can be handled quickly by the effective use of computer-based systems.

3.2. Automatic Construction Techniques

Major requirements of the construction techniques are the improvement of construction efficiency and productivity, and the achievement of quality and safety.

An important goal regarding the excavation is attaining a smooth wall finish, along with improved construction efficiency, which will reduce damage to the surrounding rock, thus minimizing reinforcement work and improving overall economy. Promising measures along this line include non-blasting excavation methods including TBMs and partial face excavation machines, as well as limited-blasting methods.

Other requirements include safety and comfort for workers in view of the current labor shortage and special underground working environments; and in addition quality improvement by robotization of construction machinery and introduction of automatic shotcrete machines and prestressed anchoring machines. Development of robots for more various applications is expected in the future.

4. Conclusion

In keeping pace with the recent increase in power demand, both seasonal and regional load curves are being disrupted.

Besides conventional pumped-storage underground power stations, schemes for energy-storage are being studied in order to maintain the standardization of load curves. Such methods as CAES (Compressed Air Energy Storage) and SMES (Superconducting Magnetic Energy Storage) are being implemented.

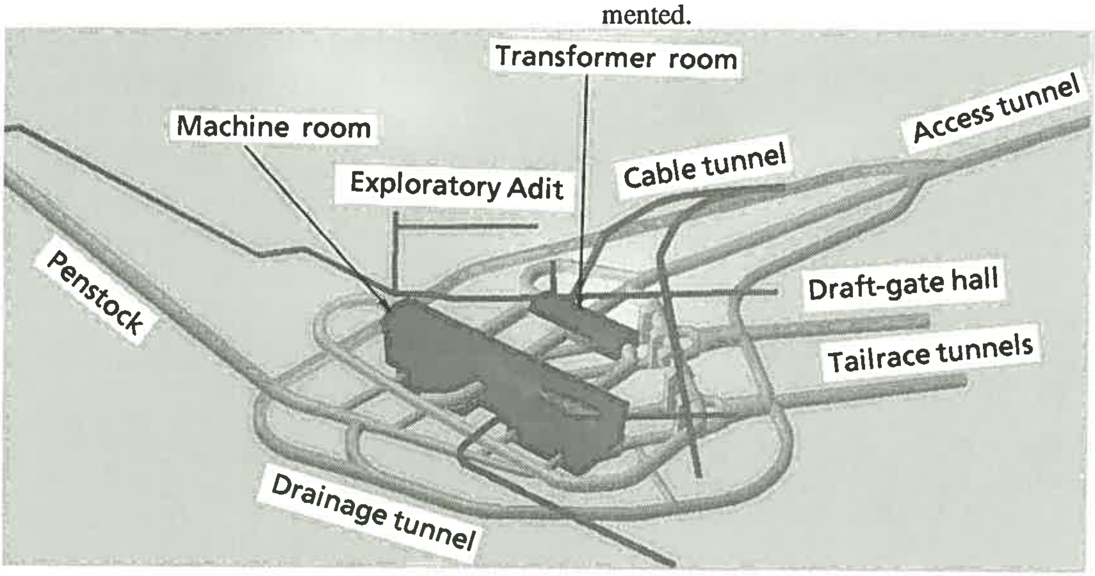


Fig.4 Isometric view of Okumino P/S (drafted by CAD)

Status of PNC's In-situ Experiments

Power Reactor and Nuclear Fuel Development Corporation

1. Introduction

PNC (Power Reactor and Nuclear Fuel Development Corporation) is a leading organization for R&D of High-level radioactive waste (HLW) management in Japan. Several experiments related with PNC's HLW programme have been carried out since 1985 at old mines. The main objectives of experiments are to understand phenomena in deep geological formation and to develop installations technics as well as to obtain geochemical and hydrogeological properties.

Although we have not yet decided any candidate geological formation for HLW disposal, we focused on two major rock types, crystalline rock and sedimental rock.

In-situ experiments are carried out at Tono mine for sedimental rocks located in the middle part of main island and at Kamaishi mine for crystalline rocks located in the northern part of main island as shown in Fig.1.

This paper introduces current activities which have been done and are on going at the above areas.

2. Tono Mine In-situ Experiment

2.1. General Geology

Fig.2 shows geological map and section of Tono area. In-situ experiments are extended at Seto and Mizutani Group with about 200m thickness.

2.2. Shaft Excavation Effect (SEE) Experiment

Objectives

SEE experiment has been carried out since 1988 including planning phase in order to evaluate disturbed zone caused by excavation and to develop prediction model. Main objectives of SEE experiment are as follows,

(a) to understand excavation effect with focusing on the change of mechanical properties and hydraulic condition around the shaft,

(b) to verify regional hydrogeological model which was created based on the pre-investigation,

(c) to obtain the change rate of geochemical properties due to the shaft excavation,

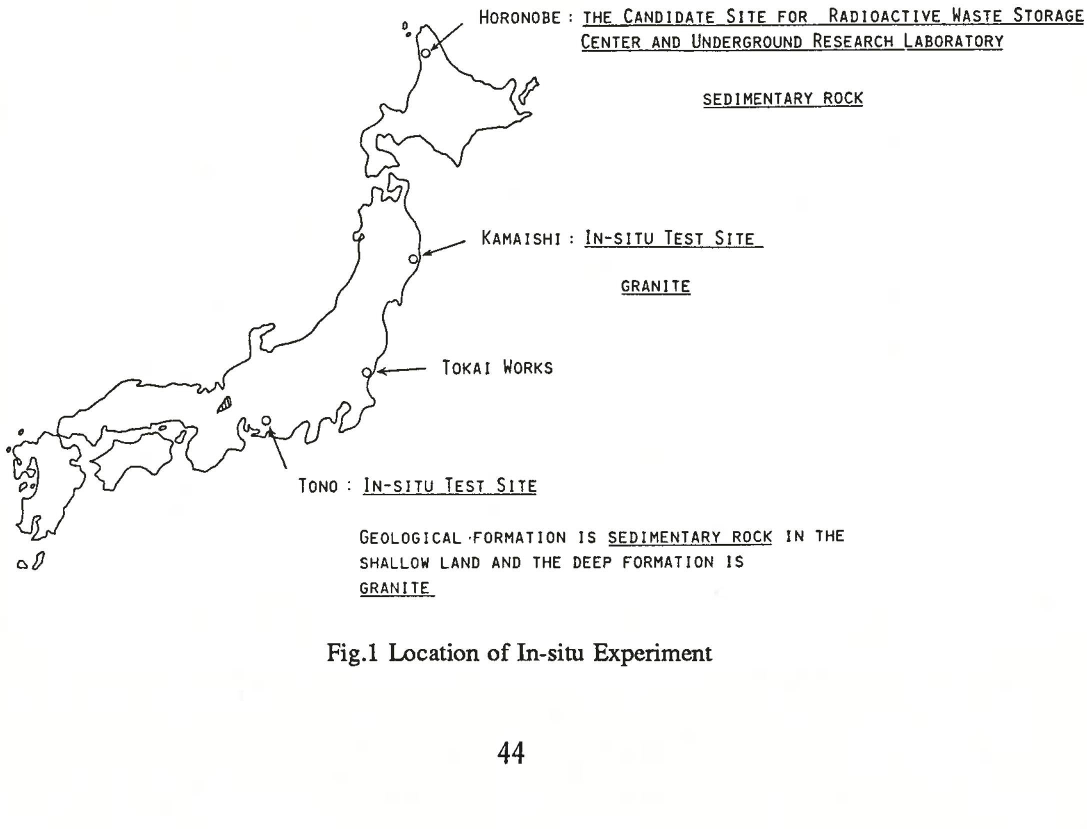


Fig.1 Location of In-situ Experiment

(d) to evaluate prediction methodology, eg. displacement and stress exchange rate which were calculated by the finite element method,
(e) to apply new installations and to evaluate their effectiveness,
(f) to develop mathematical models which can estimate excavation effects from the hydrogeological and rock mechanical point of views.

Scale

A schematic overview of SEE experiment is shown in Fig.3. A shaft with 6m diameter and 150m depth has been excavated by short-step excavation method. Excavation is separated in the three phases of GL-50m, GL-100m and GL-150m. At the depth of 50m and 100m, two horizontal drifts with 15m length are prepared in order to set up installation for pre-investigation. After finishing shaft excavation, a horizontal access drift to the existing gallery will be constructed.

Contents of Experiment

Fig.4 shows measuring section in the shaft and Table 1 presents measuring items. 4 major objectives have been carried out; geological structure exchange, stress behavior, property exchange before and after excavation as well as during excavation.

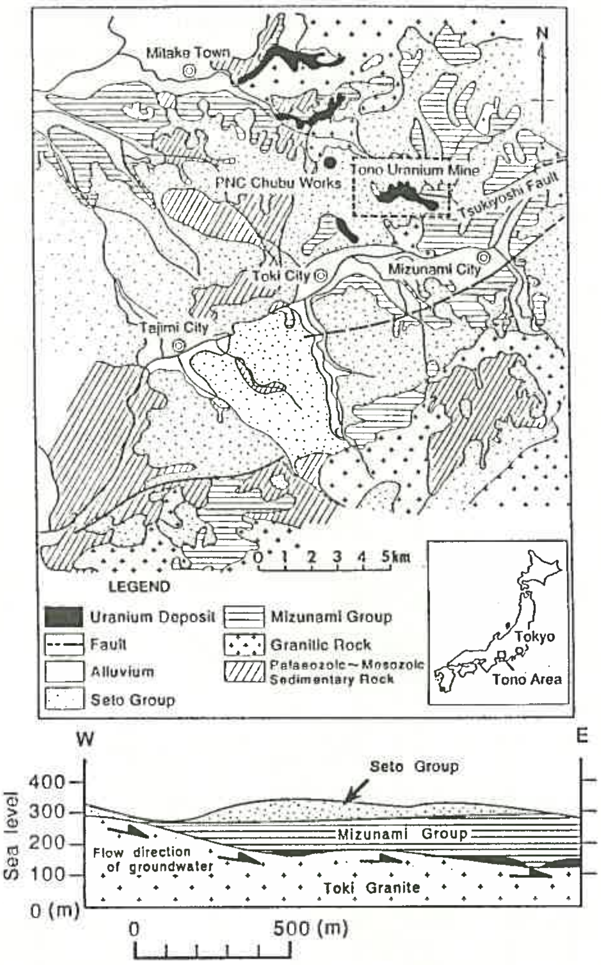


Fig.2 Geology of Tono Area

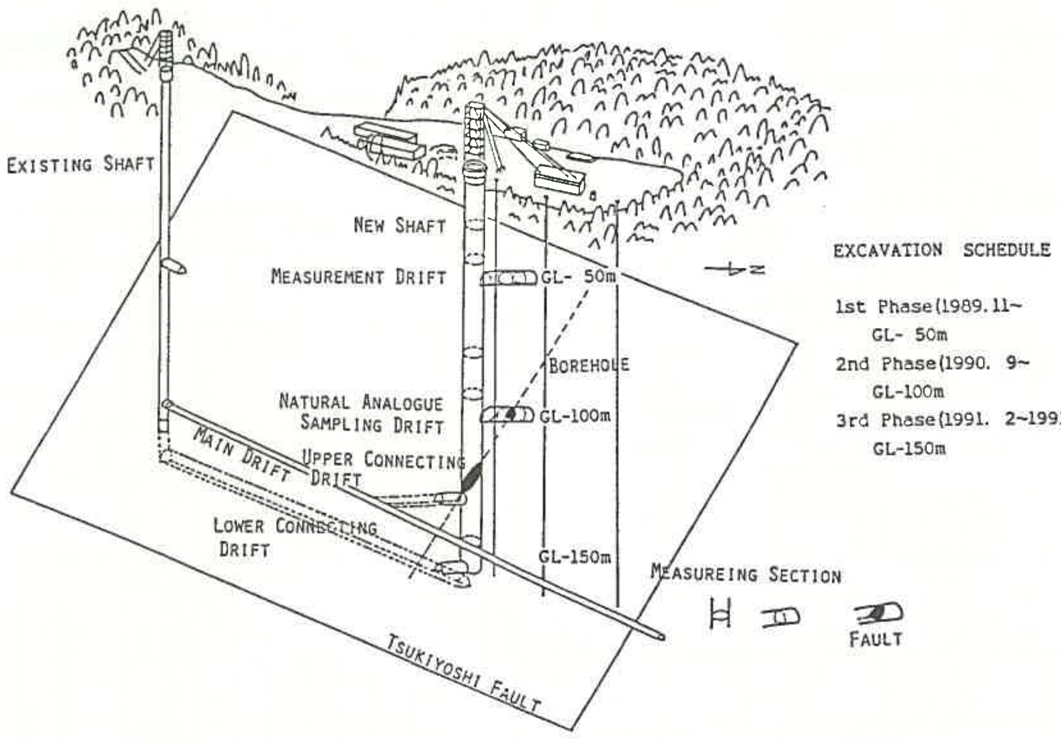


Fig.3 Schematic of SEE Experiment

At the pre-investigation stage, 10 boreholes were constructed with 200m depth each.(show Fig.5) From the core observation and seismic surveys, we predicted geological structure around the shaft and also estimated expected displacements and stress distribution at the following 3 stages.

In order to evaluate hydrogeological characteristics around the shaft, we installed multi-packering systems in the each borehole and monitor during excavation. Shaft excavation is also a big scaled pumping test which gives us a chance to estimate heterogeneous hydrogeological properties. Fig.6 presents one of hydrogeological modelling.

During the excavation, unsaturated zone can be observed around the shaft. We are measuring hydraulic conductivity of unsaturated zone using a developed instrument.

SEE experiment will be continued until end of June in 1991. Further information can be obtained from K. Sugihara,

Waste Isolation Research Section, Chubu Works, PNC,
959-31, Sonobe Teirinji, Izumi-cho, Toki-shi, Gifu prefecture 509-51, JAPAN
Tel:81-572-54-1271, Fax:81-572-55-4114

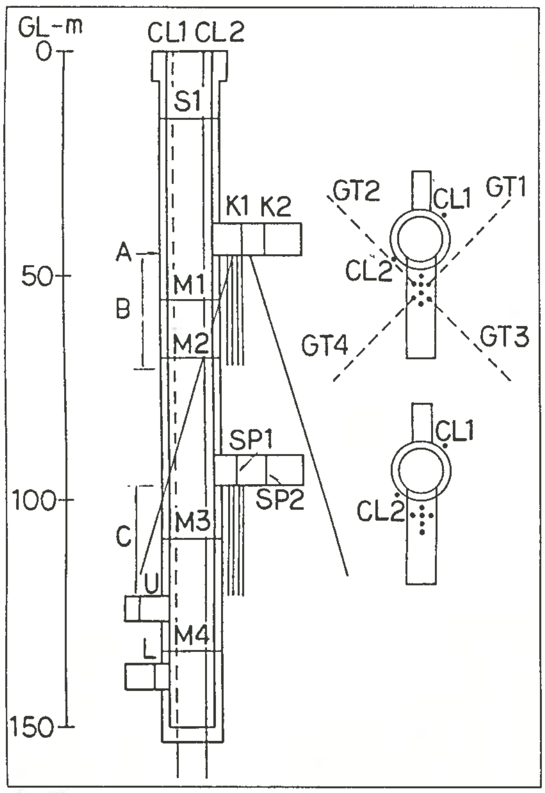


Fig.4 Measuring Section

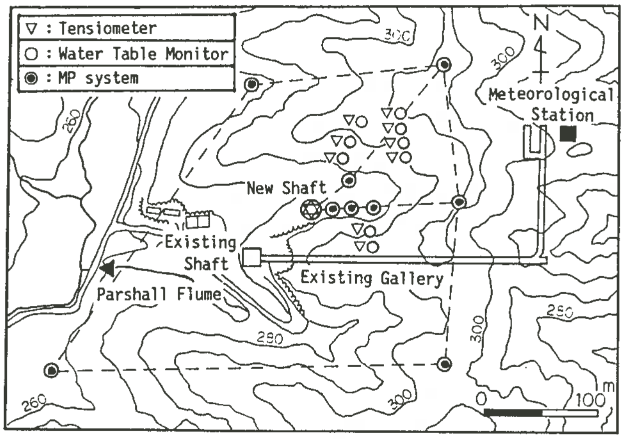


Fig.5 Monitoring System of Groundwater

Table 1 Measuring Items

OBJECTIVE	ITEM	MEASUREMENT	M1	M2	M3	M4	S1	K1	K2	SP1	SP2	U	L	A	B	C	GT1~4	CL1	CL2	Surface
Geological Structure		Seismic Survey																		○
		Geological Wall Mapping																		
Displacement	Rock Mass	Convergence						○	○	○	○	○	○							
		Extensometer	○	○	○	○					○									
		Clinometer																○	○	
Stress	Rock Mass	Hydraulic Fracturing Method																		○
		Stress Change														○				
	Support	Steel Set Stress				○	○			○	○	○	○							
		Concrete Stress	○	○	○	○	○													
		Radial Stress					○													
Property	Core	Laboratory Test												○	○	○				
	Deformation	Borehole Jack Test												○	○	○				
	Permeability	Injection Test												○	○	○				
	Seismic Wave	Crosshole Measurement													○	○				
		Tomography															○			
		Ultra-sonic Log												○						
	Electromagnetic Wave	Crosshole Radar														○				
	Fracture	Borehole TV												○	○	○				

3. Kamaishi In-situ Experiment

3.1. General Geology

The in-situ experiments in crystalline rocks have been carried out at Kamaishi old iron mine since 1988 due to 5-year experiment programme. The main experiments are extended at the site of 4 km inner the entrance and of 550m elevation with about 300m overburden (show Fig.7). Kamaishi mine area is composed of Palaeozoic and Mesozoic sedimentary rocks, skarn, granodiorite and so on. Experiment site consists of Cretaceous granodiorite (120 Ma).

3.2. Contents of Experiment

Experiments are mainly extended at both new drifts and the existing drift. Fig.8 presents whole experiment items which have already carried out. They are summarized as follows,

Investigation of Rock Properties

(a) Investigation of fracture and geological structure

Measuring the fracture distribution by geological survey of drift walls, core observation, borehole scanning and laser tomography.

(b) Rock pressure measurement

Measuring three-dimensional rock pressure condition by the over-coring method with borehole diameter measures.

(c) Drift excavation effect experiment

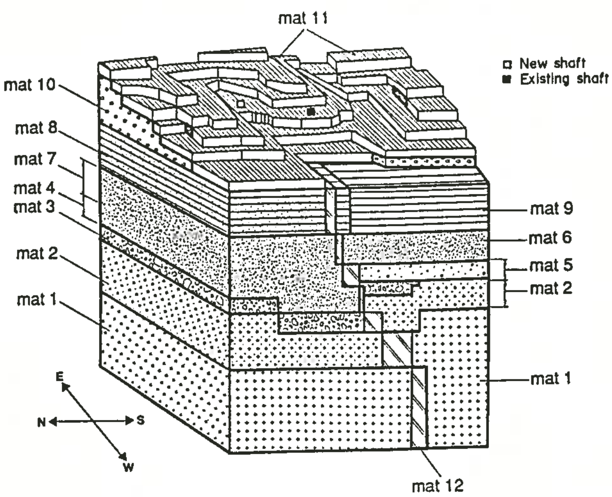


Fig.6 Hydrogeological Model

Measuring the hydraulic conductivity and Young's modulus near the drift wall before and after excavation.

Measuring rock pressure and strain during excavation. (Fig.9)

(d) Observation of seismic activities

Installing seismograph's net work system at the three different depth and monitoring.

Monitoring the dynamic behaviors of the hydraulic conditions (hydraulic pressure, in flow rate) caused by earthquakes. (Fig.10)

Investigation of Underground Hydraulic Condition

(a) Hydraulic conductivity measurement of single hole

Monitoring the pore pressure and measuring hydraulic conductivity. (Fig. 11)

(b) Cross-hole hydraulic experiment

Estimating three dimensional hydraulic conductivity tensor by cross-hole injection measurement. (Fig. 12)

(c) Evaporation measurement

Measurement seepage volume of a relatively dry rock mass by the ventilation test.

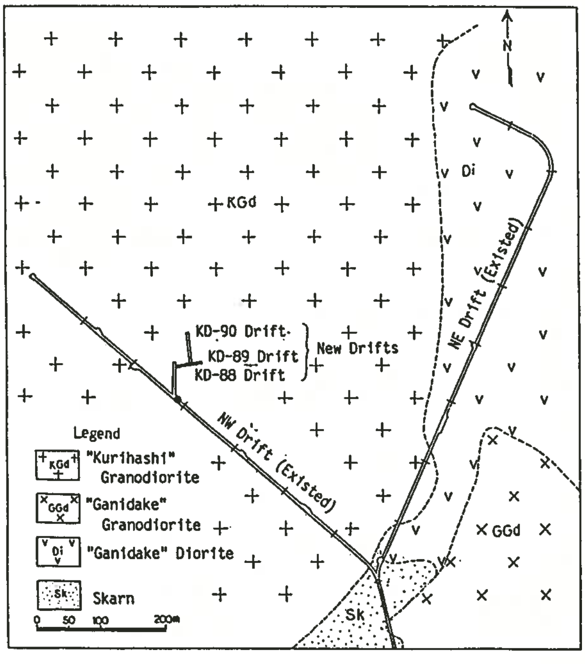


Fig.7 Geological Horizontal Section of 550m In-situ Experiment Site

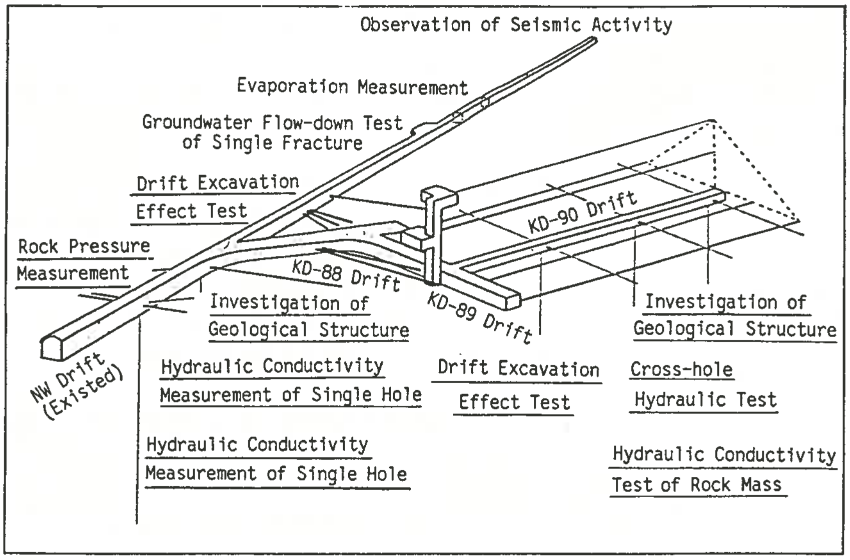


Fig.8 Test Area Arrangement

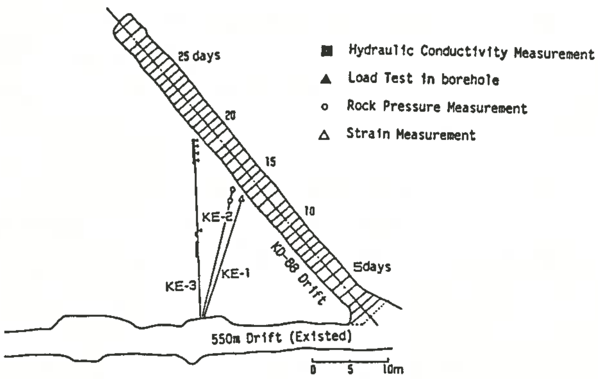


Fig.9 Drift Excavation Effect Test

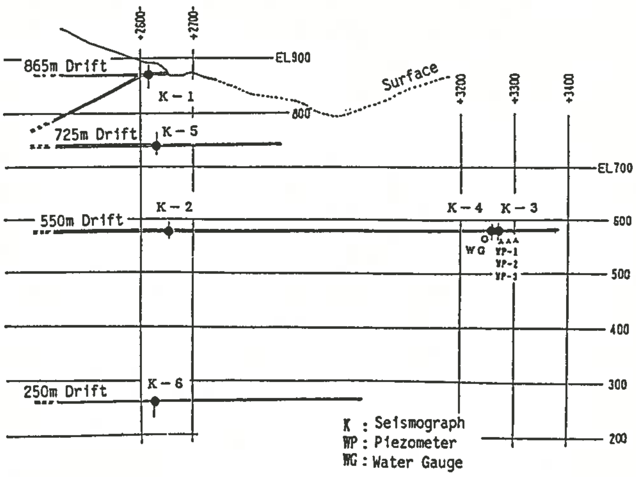


Fig.10 Observation of Seismic Activity and Underground Hydraulic Change

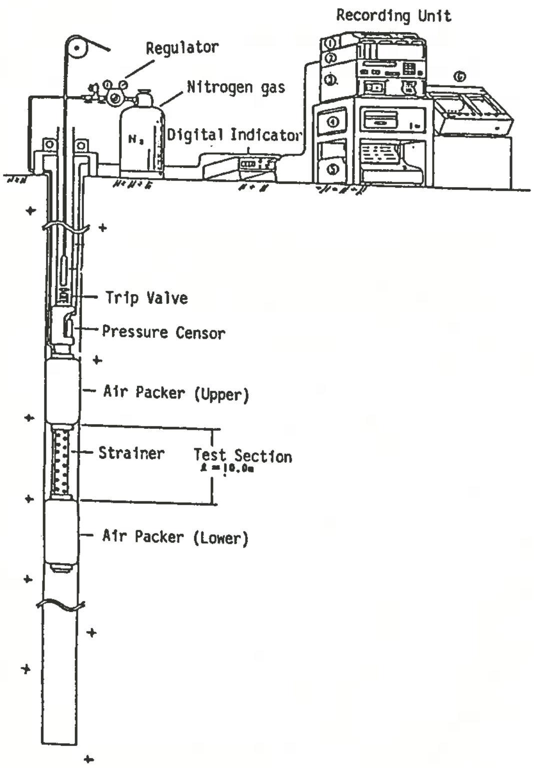


Fig.11 Hydraulic Conductivity Measurement of Single Hole (Johnson's Formation Test System)

Evaluating the saturation ratio of the rock mass during the ventilation test by the evaporation measurement and resistivity survey. (Fig 13)

(d) Single fracture flow test

Observing single fracture flow mode using tracer.(Fig.14)

(e) Investigation of hydrochemical properties

Monitoring groundwater chemical components and analyzing their origins and variety.

Kamaishi in-situ experiment will be continued until end of the fiscal year of 1992. Further information can be obtained from K. Niimi,

Radioactive Waste Management Project, PNC Head Office,
1-9-13 Akasaka, Minato-ku, Tokyo 107, JAPAN
Tel:81-3-3586-3311 ; Fax:81-3-3586-2786

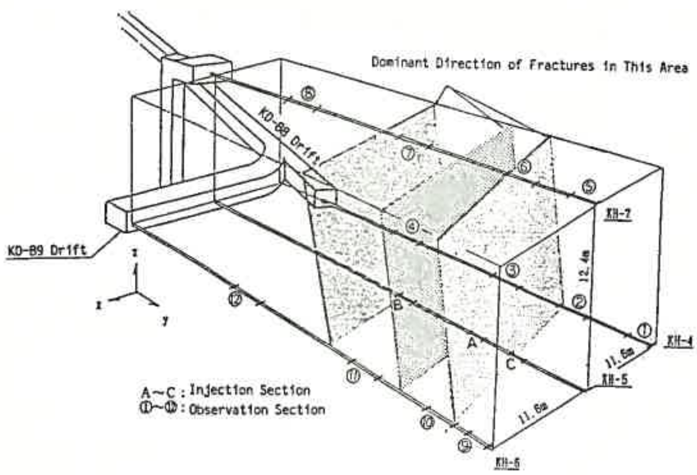


Fig.12 Cross-hole Hydraulic Test

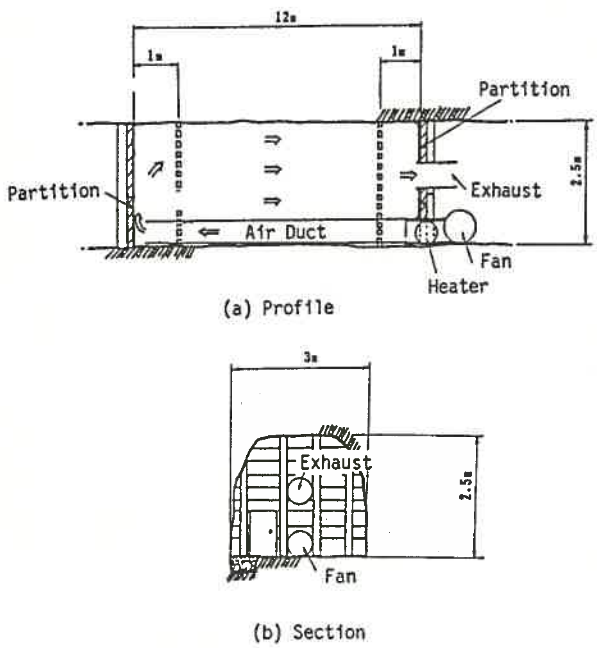


Fig.13 Ventilation Test

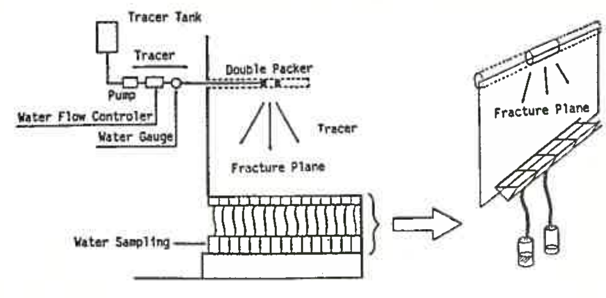


Fig.14 Layout in Groundwater Flow-down Test of Single Fracture

Rock Mechanics of Compressed Air Energy Storage and Supermagnetic Energy Storage in Japan

Masao HAYASHI

Dept. of Civil Eng., Tokai University

1. Introduction (Fig.1 and Fig.2)

Increases of peak demand of electric power and populative concentration in urban area are looking for advanced economic CAES.

2. Long Term Development (Table 1)

a) Ministry of Trading & Industry has kicked off a conventional CAES in hard sand stone in wasted coal mine for environmental assessment which is led by the New Energy Development Fund in corporation with Electric Power Companies, Electric Power Development Co., and Central Research Institute of Electric Power Industry from 1990 as SUNAGAWA Program[1].

b) CRIEPI has begun bore hole tests in hard granite at KONGO[2] and in soft mud stone at SODEGAWRA[3] from 1989.

c) The author has proposed in 1989 advanced concept of CAES regarding to high economic common use CAES Gas Turbine for peak & middle powers[4] and submerged CAES tank in soft rock in urban area[5] in 1989 on submerged rock mechanics.

d) SMES has been studied by Prof Masuda H. and several groups including JSCE[6], and MITI has begun the research of electric equipment of SMES from 1990.

3. Geologic Condition of Japan (Fig.3)

a) Northern half of Japan Islands are covered by soft rocks of The Tertiary & Quarternery in where Tokyo, Yokohama and Nagoya are located[7]. Therefore urban CAES should be developed based on the advanced concept of rock mechanics of water sustained cavern[8] in soft rocks.

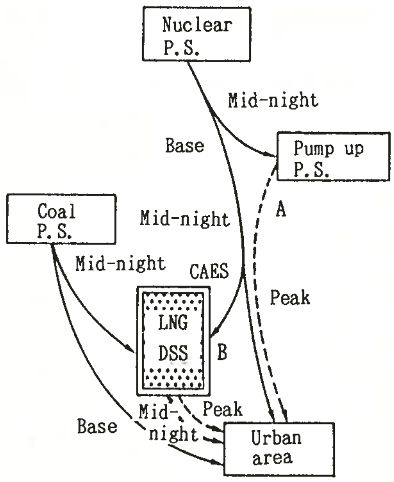


Fig.2 Urban CAES-GT using LNG[4]

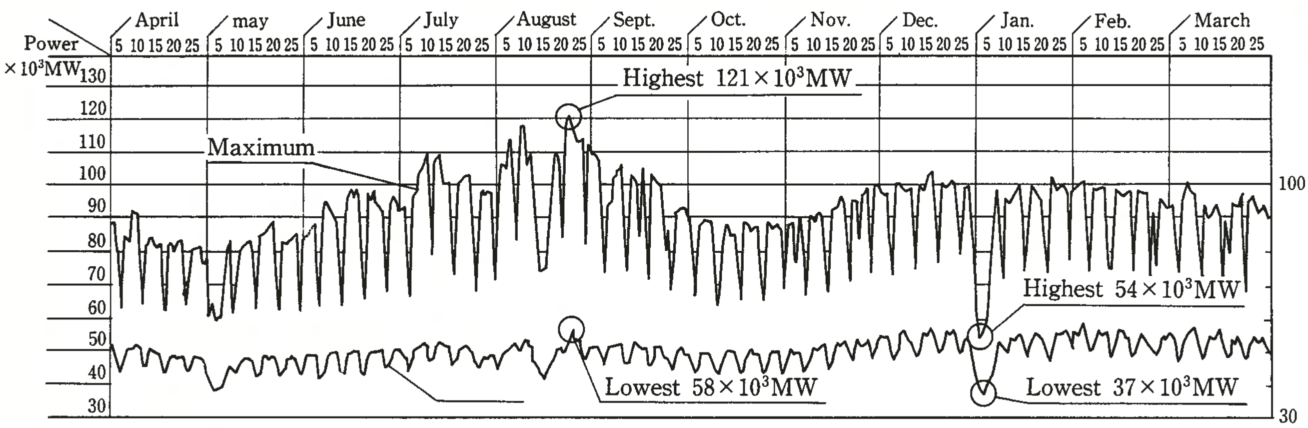


Fig.1 Annual Variation of Electric Power Demand in Japan(1988): MITI

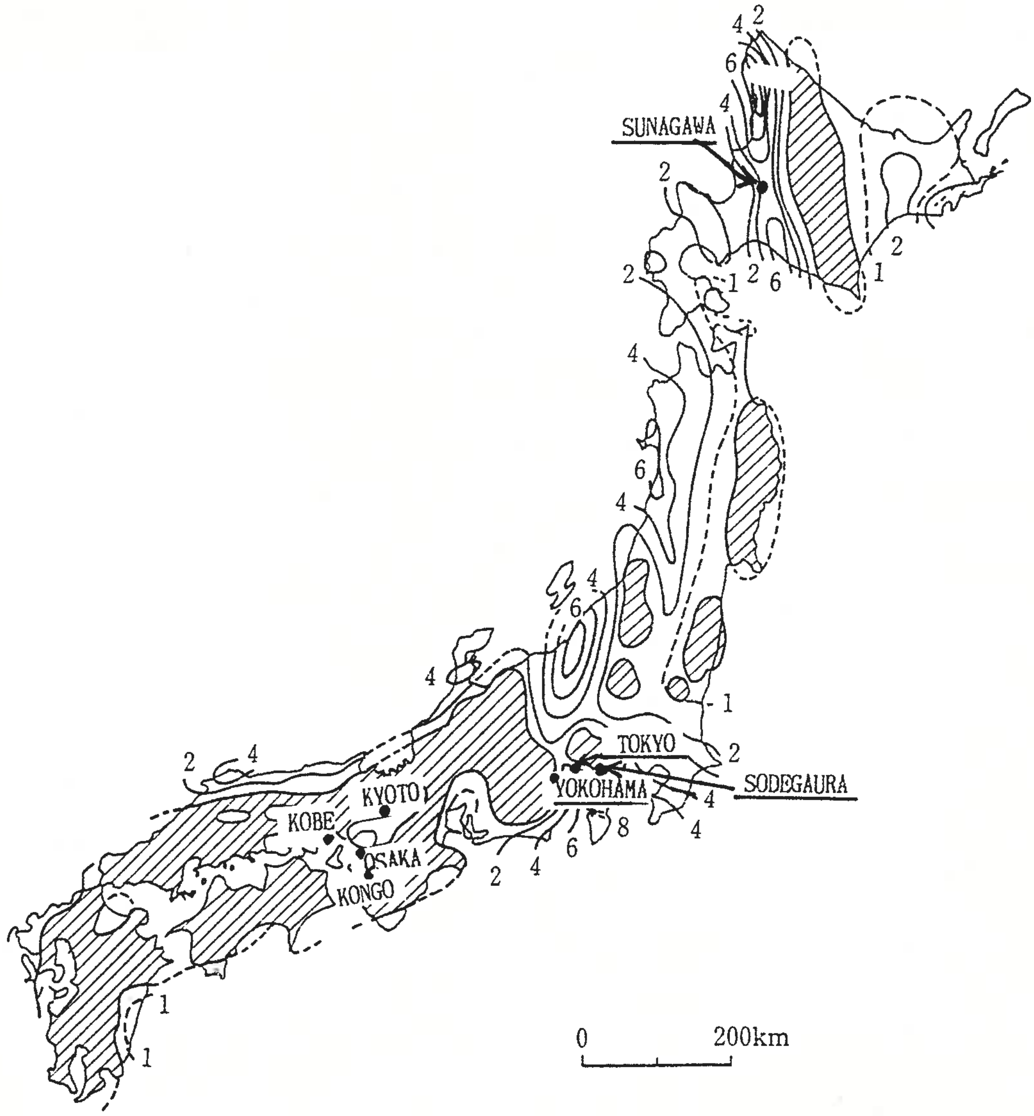


Fig.3 Depth in kilometer of Neotertiary and Quarternery Sedimentations[7]

Table 1 Scope of Development of CAES-GT in Japan(M. Hayashi, 1990)

Target	Object		1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 (Year)
Environmental assessment	National pilot plant at wasted coal mine		30MW; National project (bar 1990–1999)
High efficient G.T.	Expectation of high efficient G.T. (Steam injection and heat storage)		F/S; (Expectation) (dashed bar 1992–2000)
Urban CAES-GT	Hard rock tank	Water sus-tained	F/S (bar 1990–1993); Expectation (dashed bar 1993–2000)
	Water sustained air tank	Panto trencher in harder soft rock	F/S; (Expectation) (dashed bar 1991–2000)
		Pre-lining in soft rock	F/S; (Expectation) (dashed bar 1993–2004)
	Air tank in sea bed	Submerged construction	F/S (bar 1990–1993)

b) Western half of Japan Islands are occupied by harder rocks of aged era in where Kobe, Hiroshima and Fukuoka are located. Therefore "Urban CAES" would be easily constructed in the Western half up to 2000 in corporative with government assessment at SUNAGAWA Program.

c) SMES will be expected in far future 2030.

d) Geo-tomography of deep rocks will be developed in corporation with SUNAGAWA Program[1].

e) Seismic safety will be assessed by means of dynamic FEM and BEM , and observation in existing pumped hydro power stations[9].

4. Design Concepts of CAES-SMES in Japan

a) Following CAES are promising in Japan.

(a) Hard rock cavern (TBM , rock bolt and slush concrete)

$H\text{-}w_u$: watersustained cavern unlined (Fig.4)

water permeability $k_w <$ about 10^{-5}cm/s

(quasi constant pressure tank).

$H\text{-}w_l$: watersustained cavern lined

cavern will be commonly used for CAES

and deep aeration of sewage[10]

$H\text{-}d_l$: lined dry cavern[1]

variable pressure tank with line will be

experimented in SUNAGAWA(Fig.6).

$H\text{-}d_{ls}$: dry lined shaft

This is studied of common use for CAES

and Sewage Treatment[10]

(b) Soft rock cavern (submerged Robot excavation & lining)

$S\text{-}w_{ls}$: watersustained lined shaft

under feasibility study[11]

$S\text{-}w_{ld}$: watersustained lined dome

under feasibility study(Fig.5)[10]

b) Specific Volume of CAES Cavern (Table 2)

Required volume will greatly depend on thermal efficiency of CAES gas turbine system[4]. The author recommends high efficient CAES-GT with steam injection[4].

c) Design Concept of SMES in Japan

High rigidity of rock mass is required for SMES. Large plant will be economic.

It is under the first phase of metallic industry prior to the rock mechanics.

5. Rock Mechanics of CAES and SMES

a) Air Tight Tests of Hard Rock

(a) Dry chamber test has been experimented by Ichikawa Y. and Notohara I.[12] applying repeated pressure by helium gas(Fig.7, Fig.8).

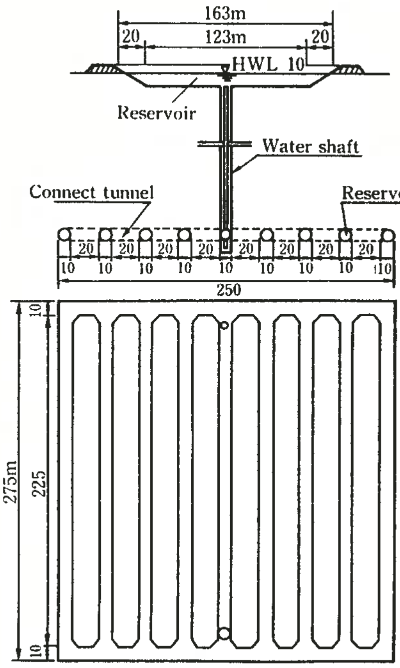


Fig.4 Compressed Air Tank in Hard Rock (Schematic)[11]

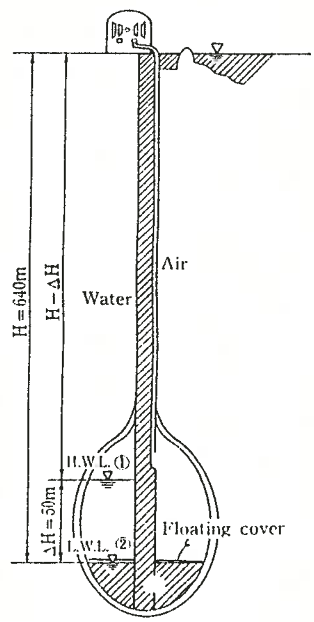


Fig.5 Submerged Geo-Spacing for CAES in Deep Soft Rock[4),5]

Table 2 Specific Volume of CAES Cavern in about 600m Depth

	Gas Turbine	Past Design		Commercial Design		Near Future Design (1995-2000)		
	Project Name	Huntorf	Middle South Service	MF 111 1250 C	MW 701 1150 C	AGT 297 1300 C	AGT 240 1300 C	AGT STEAM 416 1300 C
COMPRESSOR	duration	h 8	h/w 58	h 8	h 10.7	h 8	h 4	h 7
	power	MW 58	MW 110	MW 22.4	MW 195.6	MW 125	MW 100	MW 143
	energy	MWH 464	MWH 6160	MWH 179.2	MWH 2086	MWH 1000	MWH 400	MWH 1001
GENERATOR	power	MW 290	MW 220	MW 38.7	MW 387	MW 297	MW 240	MW 416
	duration	h 3.5	h 40	h 6	h 8	h 8	h 7	h 7
	energy	MWH 1015	MWH 8800	MWH 232	MWH 3096	MWH 2376	MWH 1680	MWH 2912
CAVERN	flow rate (kg.f/cm²)	416	300	37.4	347	240	250	240
	volume m³	208 806 (320 000)	1 498 378 (1 600 000)	18 100	224 500	120 700	62 900	105 600
	specific volume m³/kwh	0.21 (0.31)	0.17 (0.18)	0.078	0.074	0.051	0.037	0.036

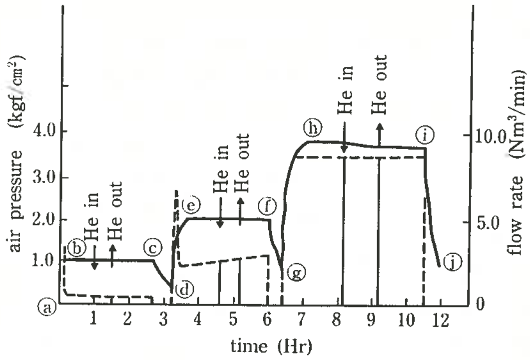


Fig.7 Air supply[12)]

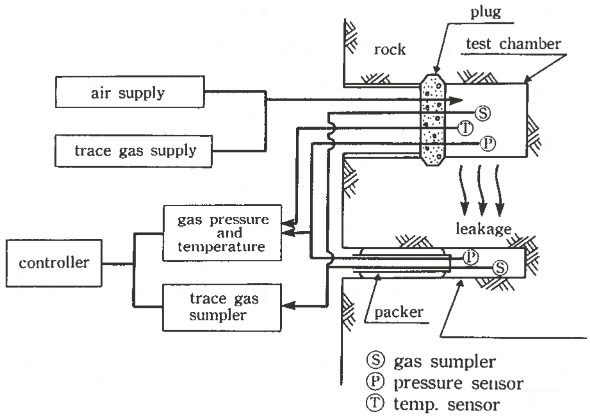


Fig.8 Air Permeability Test[12)]

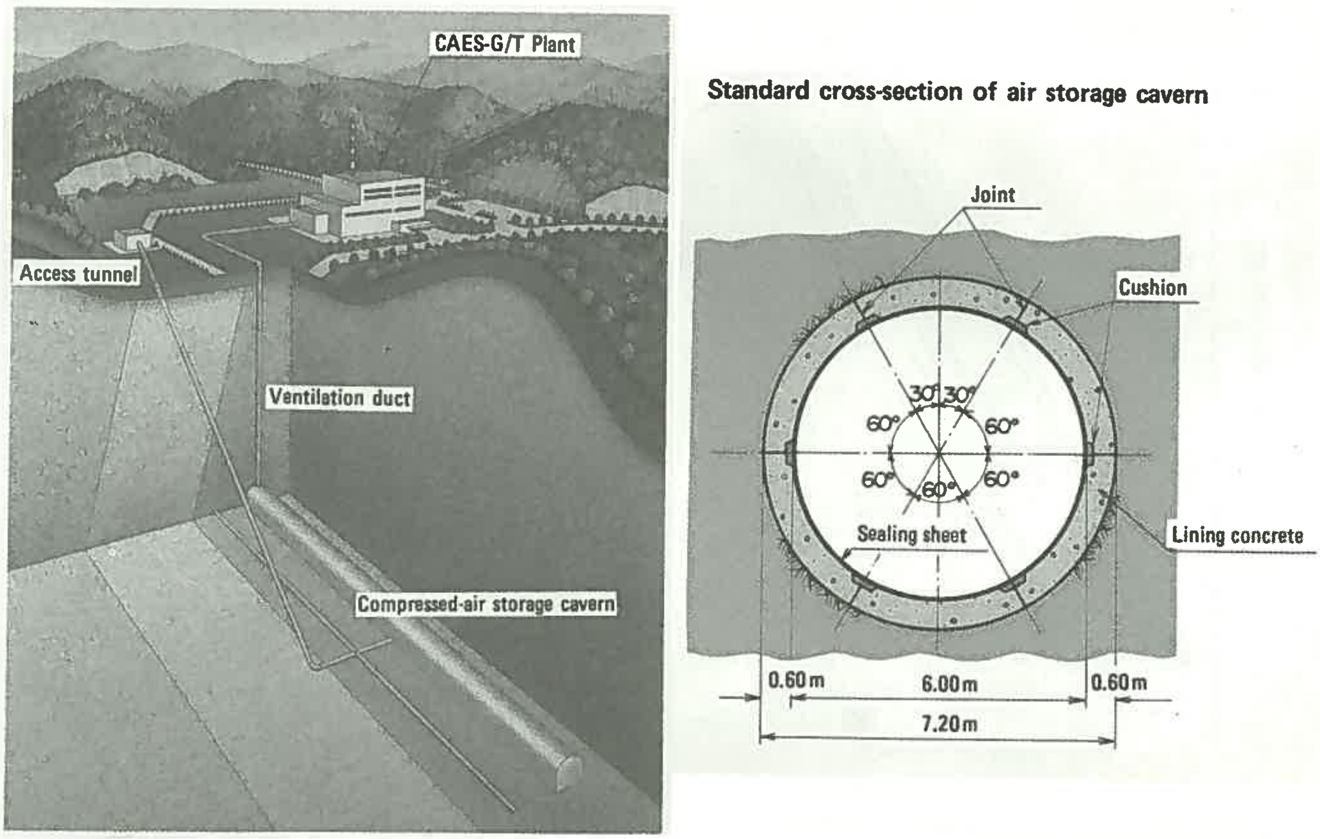


Fig.6 Schematic drawing of CAES-G/T system in SUNAGAWA[1)]

Analysis of the results show the square rule between inner pressure and leak rate(Fig.9).

(b) Water sustained bore hole test has been experimented for air tightness[2](Fig.10). Result shows any shortage of air tight pressure in comparison with nominal hydro static pressure in specific case(Fig.11).

b) Loadings of Soft Mud Stone

(a) Stress-Strain, Strengthes and Consolidation Failure of deep mud stone in Tokyo Bay.

Nishi K. and Kawasaki S.[3] experimented of deep mud stone as shown in Fig.12-15. Soil mechanics of few consolidated clay would be able to apply to deep soft rock.

(b) Repeated fatigue failure of mud stone

Submerged CAES cavern must be stable for long term creep. Nakayama T., Hirai M. and Iwashita N. have systematically experimented such several strengthes as peak, creep, repeat and residual conditions[14]. Fig.16 suggests the design criterion of submerged CAES tank on the creep and repeated load : Design by residual strength will be sound or conservative base for long term stability.

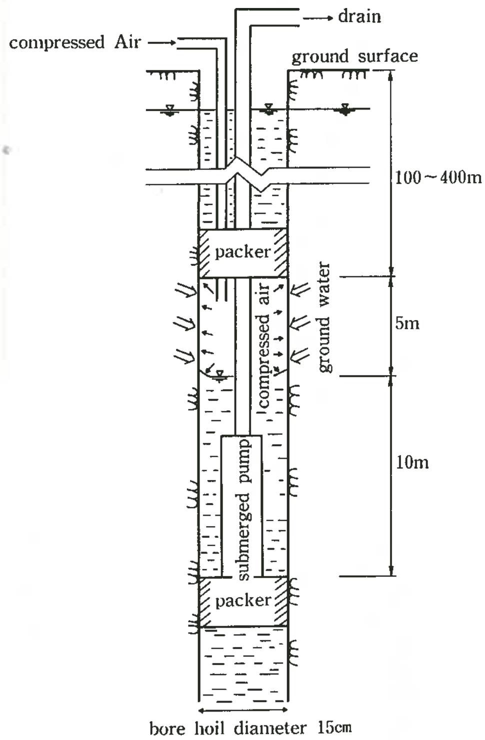


Fig.10 Air Tight Test in Bore Hole[2]

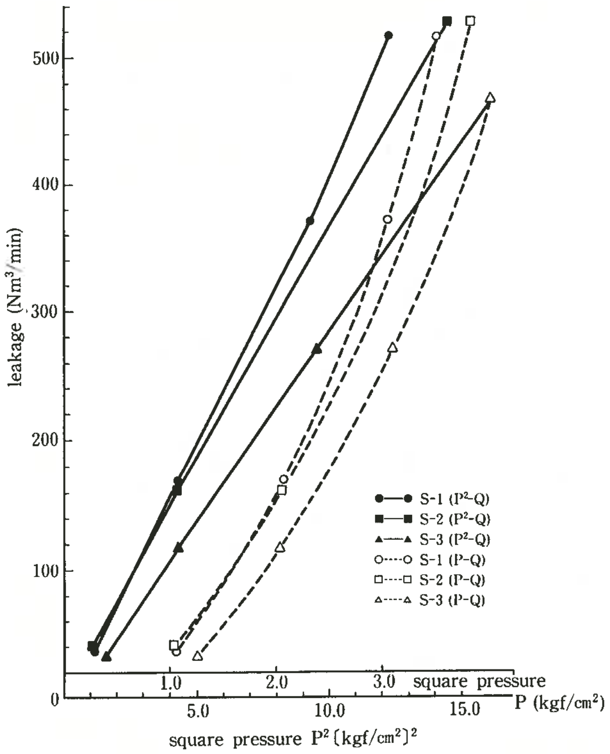


Fig.9 Pressure and leakage (S series)[12]

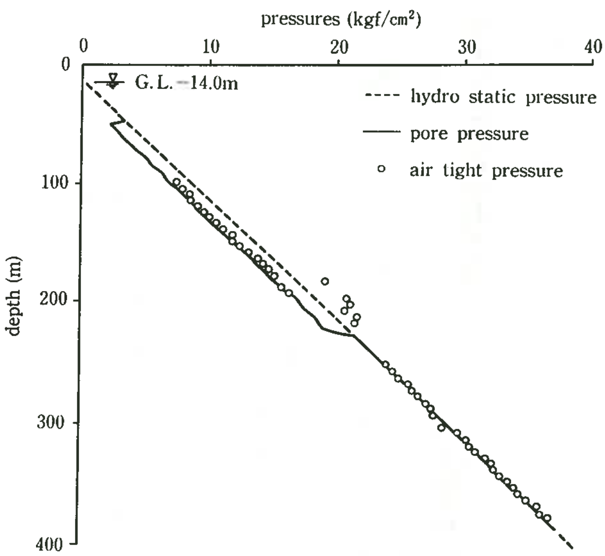


Fig.11 Air Tight Test at Depth 370-375m of Granite[2]

(c) Robot construction of submerged cavern in deep soft rock

Apart from the conventional rotating excavation, the author has proposed the Panto Trencher system for large submerged dome and Tubular lining forms and Convex Rail Slide Cutter system[8] (Fig.17 and Fig.18).

These systems will be tested primarily in laboratory and then in field test.

(d) Stress and deformation analysis of submerged CAES cavern in soft rock

Preliminary analysis of advanced concept of submerged construction has shown the sound local safety and few nonlinear deformation around the concrete lining[8](Fig.19 and Fig 20). Small pilot plant will be experimented in total system in the near future in shallow depth at first.

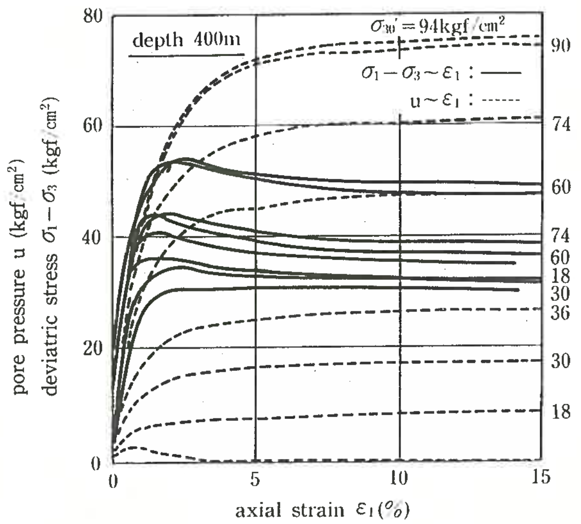


Fig.12 Stress-Strain-pore pressure of Tertiary mud stone[3),11)]

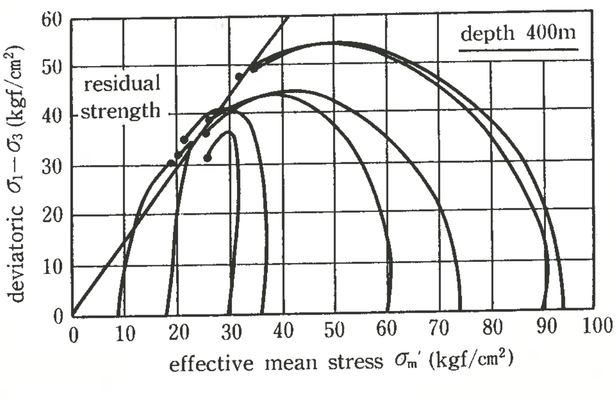


Fig.13 Effective Stress Path of Tertiary mud stone[3),11)]

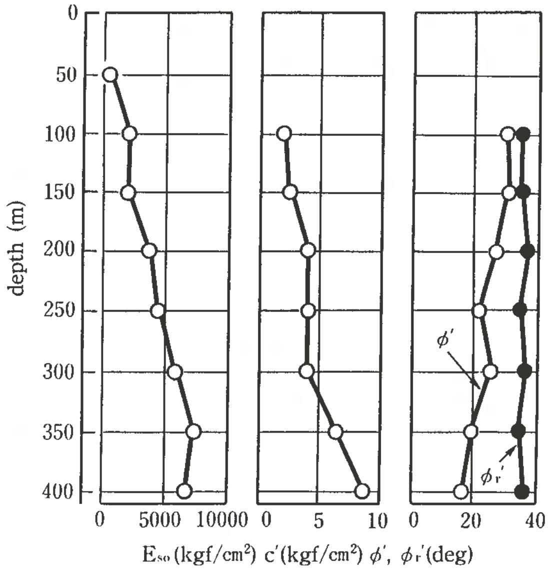


Fig.14 E_{50}, C', φ', Residual ϕ_r'(C_r'=0) at various Depth[3),11)]

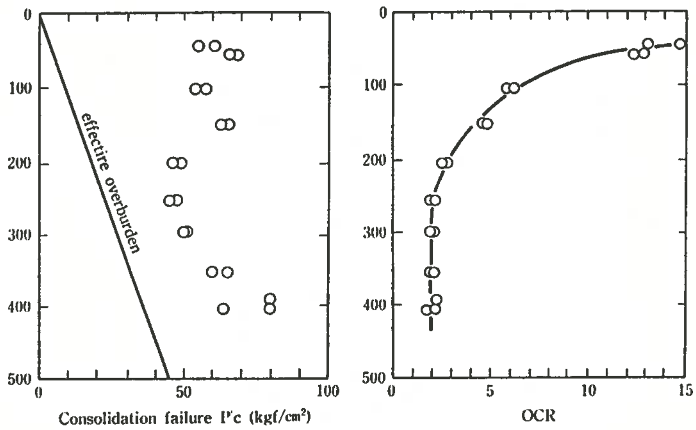


Fig.15 Consolidation Failure P_C' and Over Consolidation Ratio at Varcous[3),11)]

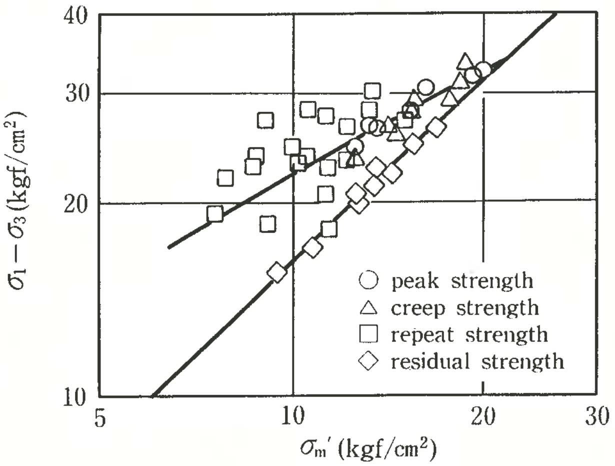


Fig.16 Failure Conditions of mud stone[13)]

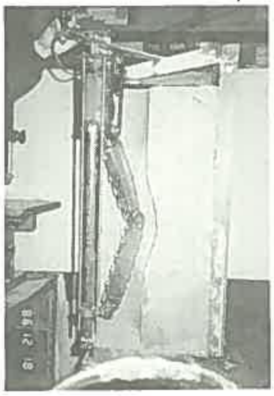


Fig.17 Model of Panto-Trencher with Chain Saw for Cavern Construction(1986)

Fig.18 Model of Tubular Form(1989)

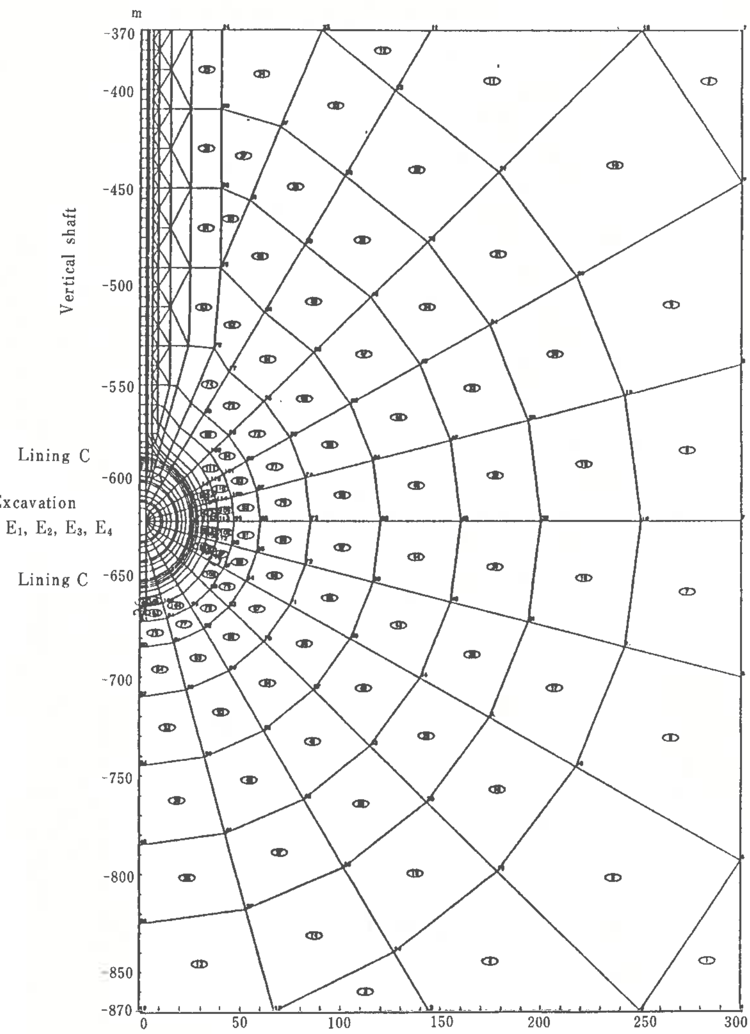
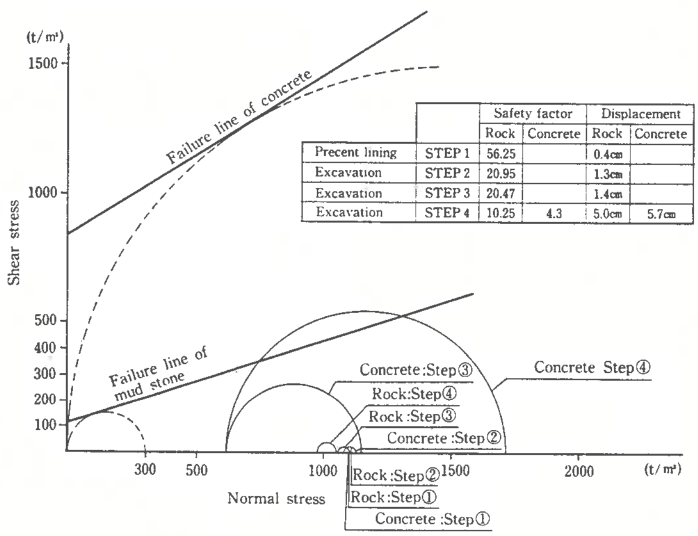


Fig.19 Nonlinear FEM Model for Excavation Analysis



		Safety factor		Displacement	
		Rock	Concrete	Rock	Concrete
Precent lining	STEP 1	56.25		0.4cm	
Excavation	STEP 2	20.95		1.3cm	
Excavation	STEP 3	20.47		1.4cm	
Excavation	STEP 4	10.25	4.3	5.0cm	5.7cm

Fig.20 Stress Path in Precedent Lining Method

c) Stress around SMES tank

(a) Electro Magnetic Load[6]

Electro magnetic forces are illustrated in Fig.21.

(b) Tensile stress domains by excavation an electro magnetic forces are illustrated in Fig.22.

6. Near Future Development (conclusion)

Conventional CAES in hard rock will be constructed successively following to MITI Sunagawa pilot plant for environmental assessment. Advanced Robot Construction of urban CAES of submerged tank in deep mud stone will be carefully experimented from small size pilot plant to larger one, around 2000.

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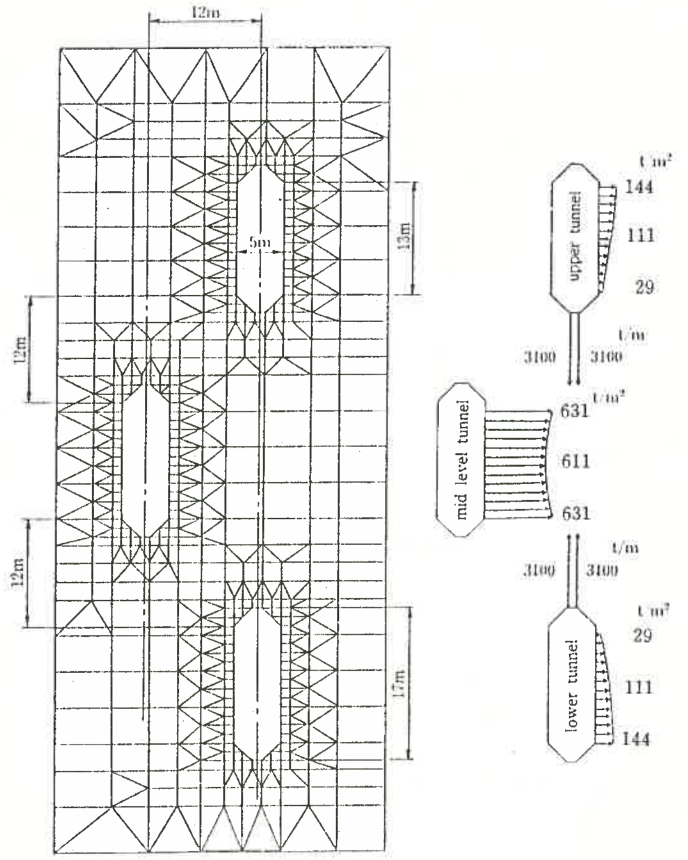

Fig.21 Model around Cavern for SMES

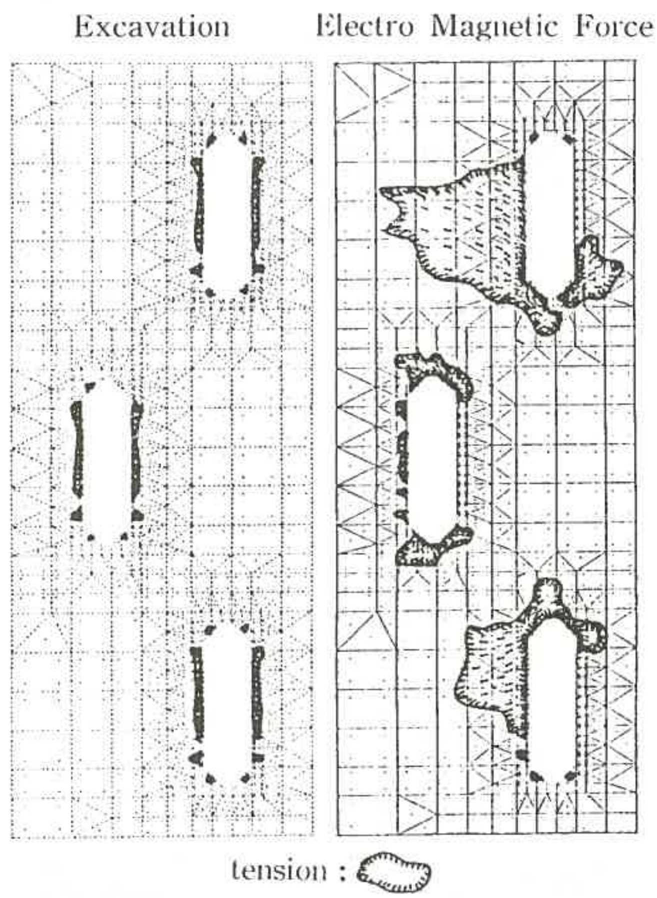

Fig.22 Tensile Stress

Present and Future of Underground Space Use in Japan

Yuzo OHNISHI

Subcommittee on Use of Underground Space, JSCE

1. Introduction

Japan has been moving towards a highly advanced country to establish safe, wealthy and comfortable society with more social and economic stock to face the change of international relationship in the 21st century. The use and development of underground space is attracting people's attention because it is thought to be a key issue to accede to demands for various infrastructures to improve existing urban traffic, flood control, telecommunication and other public utilities in these decades. The metropolitan areas such as greater Tokyo, Osaka and Nagoya districts have been suffering from unexperienced centralization of economic activities and steep increase of population.

Shortage of land and uprising land price due to overcrowded urban area, especially in the center of cities, have made it difficult to proceed with construction and renewal of infrastructures, as the uprising of land price necessitates proportionally huge amount of payment to landowners not only for the taking of land, but also for the ordinary underground use right. In addition, numerous underground facilities, e.g. various lifelines as well as traffic facilities formerly laid without comprehensive underground use planning sometimes obstruct necessary underground construction works. Under these circumstances, a few years ago, governmental ministries and agencies urgently inaugurated legal, institutional and technical researches on deep underground space use as the most drastic measure to meet with recent needs of big and fundamental public works in metropolitan areas. Side by side with those researches, numerous private sectors have presented various ideas concerning deep underground space development; there appeared a boom named "Geo-front Concept".

However, the natural condition of Japan is not favorable to the use and development of underground space. Japan is mountainous country and most of the cities are located on the land of the alluvial formation. It has some seasons with a lot of rain, which keeps the groundwater table relatively high. Occurrence of earthquakes is also observed all around the country. Japan had to stand with these difficulties. The Japanese technology of excavating the soft ground has been at the top level in the world, which allows proper underground construction in the densely inhabited city.

For further use of underground, many research subjects are left unsolved as follows; the grand design concept of underground use in the urban development, systemization of underground space use, regulation for underground development, safety and environmental conservation, and the psychological and mental effect of underground environment to human being. In addition, the construction technology such as the inventive and automated construction technology should also be developed to promote the underground use.

2. Underground Construction Technology

Although Japan continued to import construction technology from abroad between the 1950's and 1970's, many original techniques for construction especially in soft soils eventually has been cultivated from late 1960's. Followings are some of the typical Japanese underground construction technologies developed in recent decades.

2.1. Slurry Walls

The underground slurry wall developed in the 1960's was imported and first used in dam construction. It was also used to build cut-off walls, retaining walls, and structural walls for building foundations, as well as inground tanks. In the 1970's, Japan developed its own slurry wall, called the soil-cement wall. In addition, the Japanese developed methods for incorporating the previously temporary slurry wall into the permanent walls of structures as basements or underground floor walls. Another development that occurred as an outgrowth of the imported slurry wall was the self-hardening bentonite wall, creating a wall without the use of concrete.

Up until this time, slurry walls had typical depth of up to 100 meters and thickness up to 2 meters. In 1985, Japan developed machinery which allowed the construction of slurry walls on an increased scale, with depths ranging from 135 to 160 meters, and thicknesses from 2.4 to 2.8 meters. These slurry walls are being used for the construction of the man-made island with the Trans-Tokyo Bay Highway Project.

2.2. Shield Tunnelling

The shield tunneling method had advanced tremendously owning to its applications in some of Japan's urban areas which contained many soft soils. Two of the major development that were made involved two methods, namely the slurry shield, and the earth pressure balance shield tunnels. The slurry shield method uses disc cutters to advance while the tunnel is prevented from collapsing and water inflow by using pressurized bentonite slurry between the excavating face and the bulkhead. The earth pressure balanced shield also advances using disc cutters. The chamber between the ground face and the bulkhead is always filled with excavated soil that is then treated with some admixture which helps to prevent water inflow and retains the tunnel opening.

2.3. Large Scale Underpinning

Underpinning is a common technology used to support existing structures while underneath excavation takes place. Large scale underpinning in Japan is an outgrowth of modern underpinning technology, and various techniques have been successfully completed in Japan.

3. Underground Space Use: Examples

Underground development is mainly concerned with three categories; underground resources, underground energy facilities and underground space development. As land space available for development is diminished, underground space might be developed in a variety of ways; to enhance urban life, to supply management and production, to solve the traffic problem and to reduce natural disasters. Several types of underground development would be requested to make the proper use of underground space for a human being.

In the case of designing the underground space of people, the greatest care must be taken to decide the environmental state such as "direct natural light", "fresh air", and "a feeling of being liberated". Underground space has to be developed to create the comfortable environment for a human being. Thus, what is important is how to deal with the natural potential.

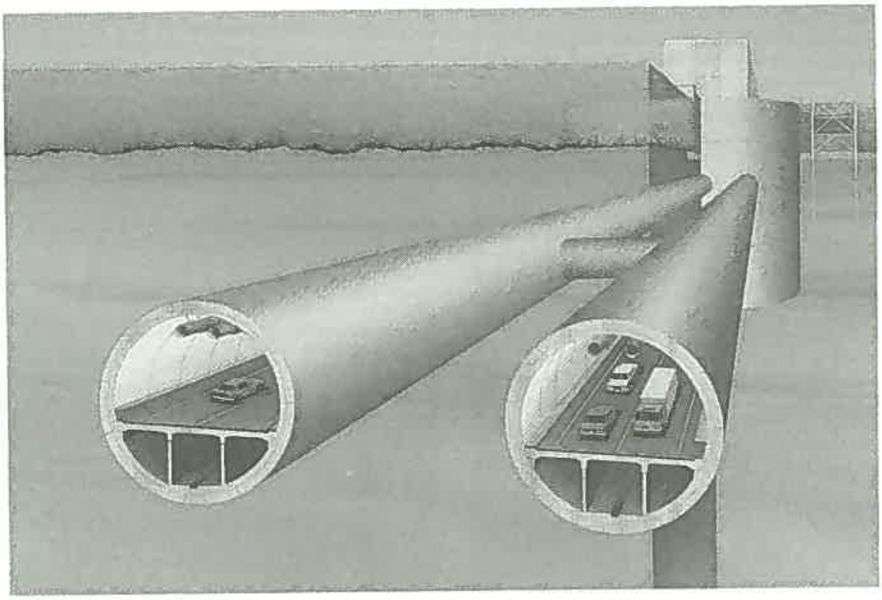

Fig.1 Planning tunnels of the Trans-Tokyo Bay Highway

As examples of underground space use, especially in metropolitan area, some of major underground facilities in Japan are shown in the following figures and photos.

a) Trans-Tokyo Bay Highway[1)]

The Trans-Tokyo Bay Highway is a 15km route connecting Kawasaki city (Kanagawa prefecture) with Kisarazu city (Chiba prefecture) by tunnels (shield tunnel: inner diameter: 12.9m, average depth from the surface: 43.5m in Fig.1), bridge and man-made island (slurry wall: 135-160m deep, 2.4-2.8m thick) across Tokyo Bay. It is connected to other major highways in order to conform an expansive trunk highway network.

b) New Deep Subway System[2)]

The existing subways have almost been constructed under public lands such as roads to avoid the compensation expense for private land owners. The subways in the center of Tokyo have a tendency with deepening year by year.

Nagata-cho Station of the Hanzomon Subway Line in Tokyo is a deep underground structure of GL-37m, and also NTT's tunnel for telephone cables at GL-47m. If new subways are constructed below those, they must be settled at deeper level. As passengers, in this case, will stay in a deep closed space, the very deep subway has to be designed with the countermeasure against emergency.

One of the most important subjects for underground development is disaster prevention. Disasters in a very deep subway may be caused by fire, earthquake, flooding and so on. In particular, the fire tends to cause terrible damage and loss. Contermeasures for disasters are of critical importance (Fig.2).

c) New Tokyo Station of Keiyo Metropolitan Line[3)]

The Keiyo Metropolitan Line connecting Tokyo Station with Shinkiba is a subway of 7.4km long. The formation level difference of route line between Tokyo Station and Sumida River is more than 30m below the ground surface. The underground space including Tokyo Station and specially designed station has been constructed by using the latest civil engineering technology called the dual-cylinder type shield: the tunnels between Tokyo Station and Kyobashi were excavated using a slurry shield method (sectional area: 76.1 m^2, Photo.1).

d) Underground River in Tokyo[4)]

In order to handle the unexpectedly heavy rain fall and to achieve a higher safety margin against flood without purchasing expensive lands, a highly motivated flood control scheme based on underground water channelling was recommended. The four river systems in the

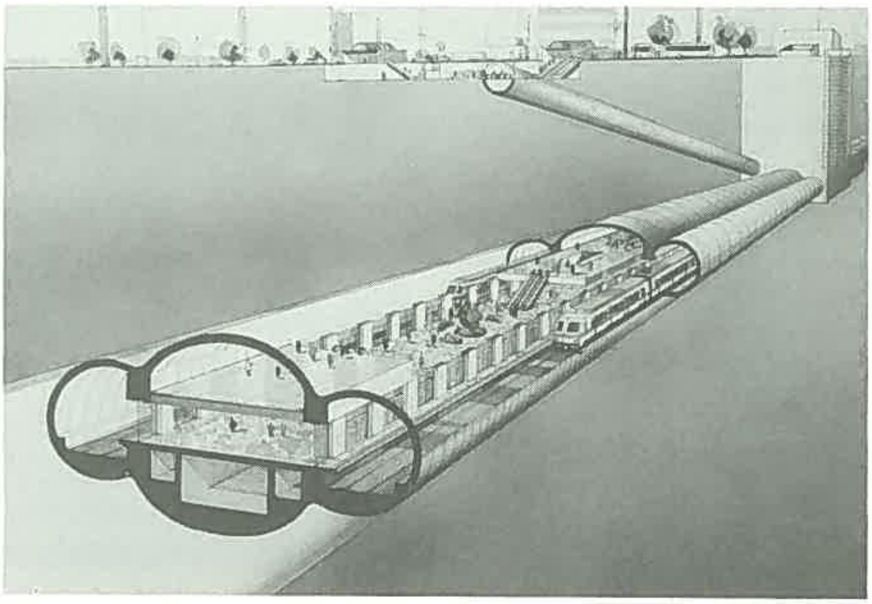

Fig.2 Image Picture of a deep subway station by courtesy of Railway Technical Research Institute

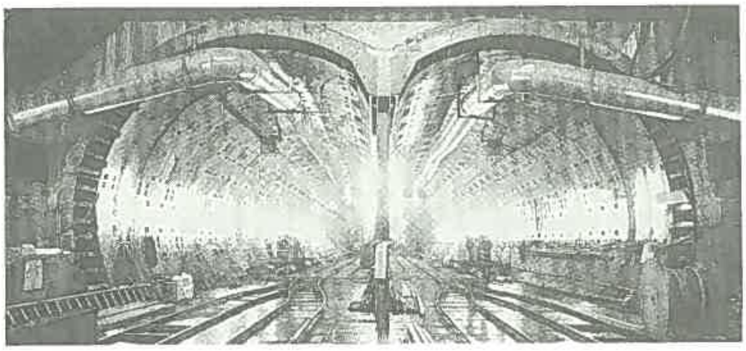

Photo.1 Dual-Cylinder Type Shield Tunnel of the Keiyo Metropolitan Line (courtest of East Japan Railway Co.)

Yamanote River basin through Tokyo are comprised of ten rivers (including the main sewerage system), and the underground rivers under the Loop Road 7 will unite these ten rivers to collect a part of the flood water from branches of these rivers during a period of heavy rainfall. The collected overflow water is then to be led down to Tokyo Bay so as to drain off the flood water into the sea by means of a pumping systems located at the lowest part of the channel flow (Fig.3). Underground river beneath Loop Road 7 is planned to be provided at a very low depth of some 40 meters below ground level.

e) National Diet Library Annex[5)]

The underground National Diet Library Annex is planned on the following three reasons:

a) Preserve landscape around the Nation Diet Building and the Supreme Court

b) Need stack rooms with large capacity

c) Save construction expense

Fig.3 Image picture of underground river system in Tokyo

The national Diet Library is a closed system, it has an advantage over above ground library in being more easily operated by a few staffs (Photo.2). In addition, underground atmospheric temperature at the depth of 15m or below is kept at 16°C to 17°C all the year round, it can be operated with less energy consumption for air conditioning compared with an ordinary above ground building.

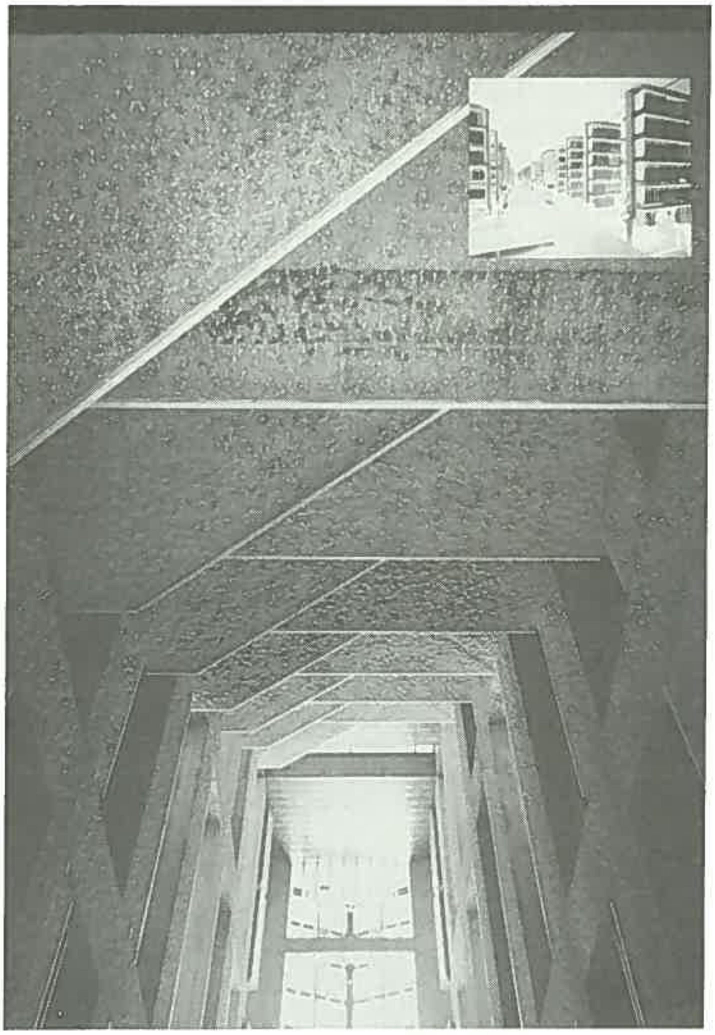

Photo.2 National Diet Library Annex

4. Conclusion

In the history of civil engineering in Japan, the underground technology for excavation and construction has greatly advanced after the Meiji era of 19th century and the World War II. With the development of excavation methods and machines, the underground space has been recognized to be more valuable for the city infrastructures, satisfying with the demand from the better life. In harmonizing both urban development and public acceptance, it is necessary for an ideal underground use to advance the technology in terms of sustainable development and the environment.

(This article is rearranged and summarized from the original paper "UNDERGROUND SPACE USE IN JAPAN[6]" written by Sato,K. (Chairman, subcommittee on Underground Space Use, JSCE), et. al.)

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Mining Methods and the Use of Inner Space at Kamioka Mine

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1. Introduction

Kamioka Mine comprises two mines - Tochibora and Mozumi. Its history is very old and goes back to 1400's when it was started as a silver mine. Currently, it is producing silver, lead and zinc ores. Daily ore output of Tochibora is 4,000t (grading 20g/t Ag, 0.3% Pb and 4.2% Zn) and Mozumi, with a daily output of 450t of ore (grading 18g/t Ag, 0.4% Pb and 7.0% Zn). Although the ore grade is low, the mine is blessed with natural conditions. In each case the mines are in the high mountains flanking the valley, a circumstance which enables all mine drainage to be by gravity, and allows for natural ventilation. Country rocks are generally very stable in the mine and uniaxial compressive strength shows 1,500-2,500kg/cm^2. Thanks to these conditions, both Tochibora and Mozumi mines are now worked entirely by trackless mining methods and promoting further mechanization. High labor productivity of 47 tons per manpower enables to

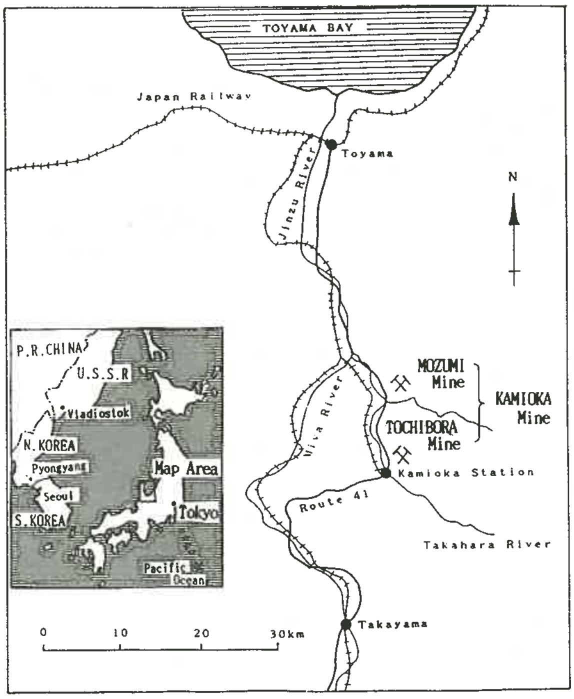

Fig.1 Location of the Kamioka Mine

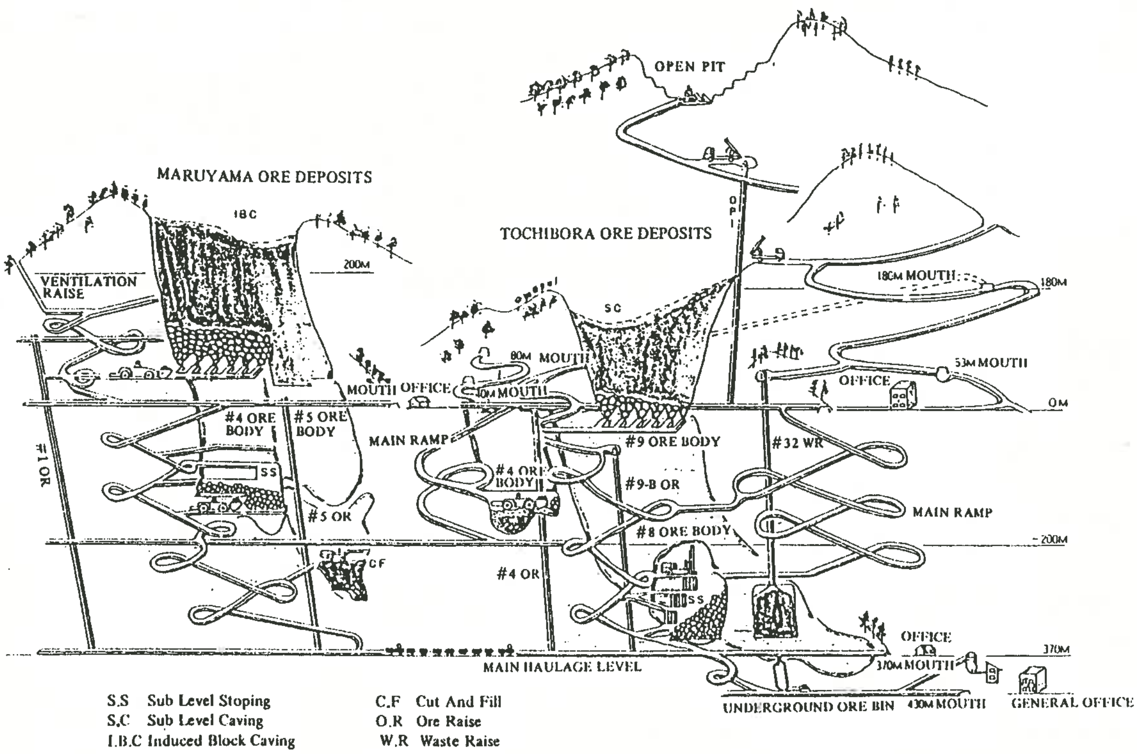

Fig.2 Schematic Underground Structure of Tochibora Mine

operate the mine competitively even though its ore grade is generally low.

Japan has an area of 373,000km^2, of which 81,000km^2 is habitable. From a viewpoint of effective land use, utilization of underground is driving attention. Research has been conducting to construct a underground facility which has a merit to be located underground. Reflecting such demand, Kamioka Mine is planning to construct an inner space laboratory project at Kamioka Mine.

2. Mining Methods

Tochibora Mine consists of 60 orebodies scattering over in area of 7.5 km^2 and within height of 600m. Each orebody is connected by a ramp system. Presently, four mining methods are used in Tochibora Mine. Orebodies close to the surface of the earth are worked by the open pit method. The caving method is employed for large orebody comprised by weak rock. While the sub-level stoping is applied for large orebody consisting of stable rock. Other medium and small scale orebodies are mined by the mechanized cut and fill method. Untill 1980's, both the caving and sub-level stoping were mainly used. However, the mechanized cut and fill now accounts for 80% of the ore produced at Kamioka.

3. Mining Equipment

Kamioka Mine introduced a trackless mining in 1968. Since then, ripping of smaller dimension tunnel and drifting of rampway were conducted. Development of the trackless system was completed in 1978. The equipments for trackless mining are shown in Table 1.

Table 1 Mining Equipments

drilling	8*	TAMROCK minimatic 2 boom
	2*	FURUKAWA hydraulics 1 boom
	2*	FURUKAWA hydraulics for long hole
	1*	FURUKAWA pneumatic 2 boom
blasting	7*	KAMIOKA AN-FO truck 150kg
	2*	GETMAN AN-FO truck 270kg, 400kg
		central controlled blasting system
transport	11*	KAWASAKI M12 6.5m^3
	3*	KAWASAKI M9 3.8m^3
	1*	KAWASAKI M6 3.3m^3
	5*	electric loco, 7t GRANBY CARS
supporting	2*	TAMROCK robolt
	2*	shot creting
utility	3*	scaler
	2*	diamond coring
	2*	GETMAN crane 3t,5t
	1*	GETMAN TRANSIT MIXER
	41*	TOYOTA trucks

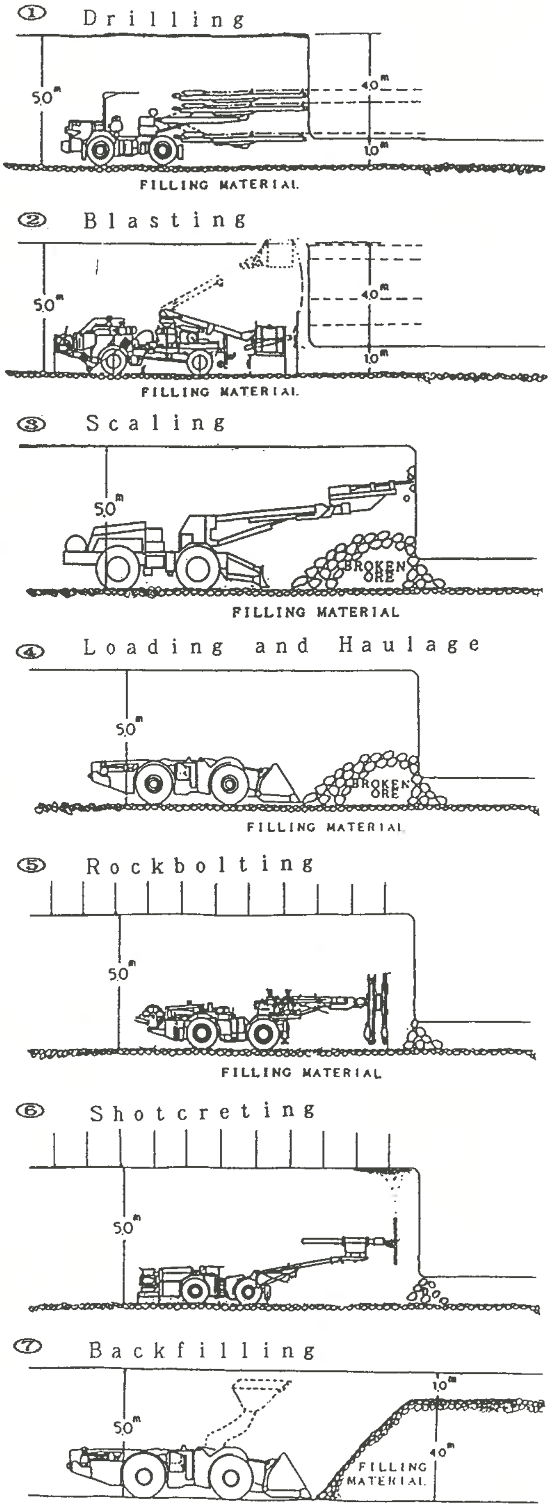

Fig.3 Mechanized Cut and Fill Method

4. Inner Space Laboratory

Utilization of underground space at Kamioka goes back to 1956 when an underground air receiver was constructed. In the present day, underground caverns are going to be used for experimental work of compressed air energy storage (CAES), performance test of explosives, experimental station of excavation method and physics.

4.1. Underground Air Receiver

Underground air receiver was constructed in 1956 to meet peak- and intermediate period demands and reduce a capacity overload of compressors. The receiver was installed at the level of 180m from the surface. Storage method of compressed air is water compensation system that keeps air pressure constant.

4.2. Experimental Work of CAES

Basic design of CAES consists of compressor, generator serving also electromotor, gas turbine and cavern storing high pressure air as shown in fig. 5. At the process of producing high pressure air, a clutch between generator and compressor is connected. At the process of generating electricity, a clutch between generator and gas turbine is connected and compressed air released from cavern is burnt out. Kamioka Mine is conducting a basic study to research a gas leakage from cavern and confirm a safety of gas tight sealing.

4.3. Explosives Experimental Station

Having a request from an explosive manufacturer, experimental station is being constructed to test a perfomance of explosives. The station consists of a dome, 20m wide and 18m in height and a tunnel of 230m. Experiment of underwater explosion is conducted in the dome by installing a water tank (10m height). Firing explosive test is conducted in the tunnel. Underground experiment excels in sound and vibration protection.

4.4. Experimental Station of Excavating Method

For the utilazation of the inner space,studies are underway for investigating underground character, developing of rock excavating method and testing rock excavating equipments.

4.5. Experimental Station of Physics

Tank will be installed filling 50,000t of pure water in the dome space of 40m wide and 54m in height at the level of 1,000m from the surface. The Institute of Cosmic Rays Research,

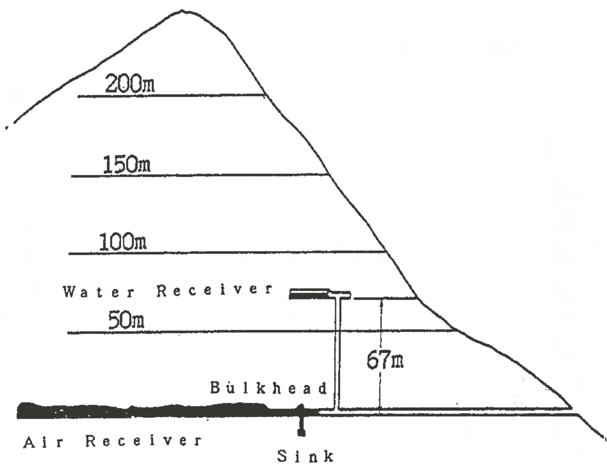

Fig.4 Air Receiver

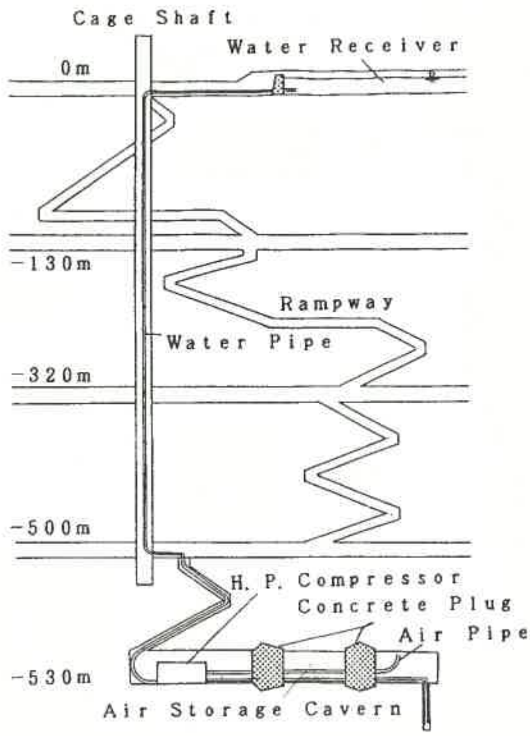

Fig.5 Basic Design of CAES System

University of Tokyo, will begin an experimental work about neutrinos spectrum research and nuclear decay. Construction of the cavern is starting in September 1991. This is tenfold larger than the existing tank (19m wide and 16m in height with 4,900t capacity) which was installed in 1983.

5. Conclusion

Mozumi Mine was used to be producing 1,800t per day of ore at the height of prosperity. It has been reducing output as the ore reserves decrease and plans to discontinue the operation in 1994. Even after the discontinuance, Mozumi Mine functions as an inner space laboratory and seeks for other potentialities for such inner space utilizaton as underground storage, underground plant and industrial waste disposal. Kamioka Mine is planning to utilize the mining technology which was accumulated in the past.

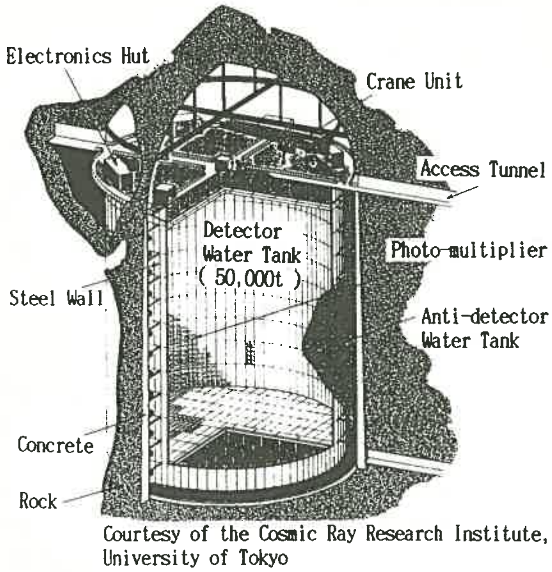

Fig.7 Super Kamioka Neucleon Decay Experiment

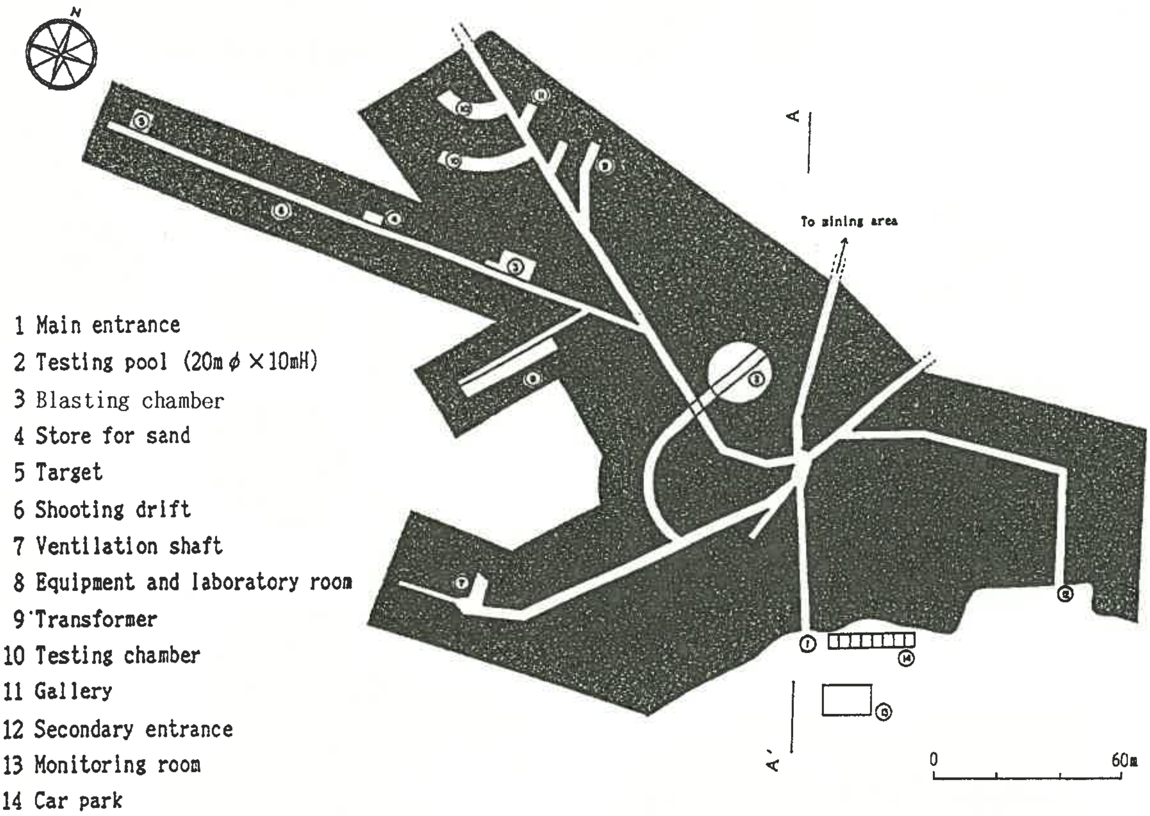

Fig.6 Underground Experimental Station

A Review on New Underground Experiments Utilizing Mines

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1. Introduction

The object of this paper is to introduce representative underground experimental facilities in Japan, which are installed in mines.

Underground has several merits for installation of the experimental facilities for special purposes. Screening effects for the cosmic rays and the above-ground sounds or vibrations, easy maintenance of the security are examples of such characteristics of underground. Easiness to construct large caverns to store the large-sized experimental apparatus is another merit.

Many kinds of underground experiments can be conducted in the abandoned and/or active mines. In this case, they are put into practice in shortest preparation time and with least financial investment, by making use of the following characteristics:

(a) There are several deep mines in Japan, which indicates that the quick access to an arbitrary depth is possible utilizing the mine frame. Some part of the mine frame might be directly applied for the new purposes by making small modification to adapt to the new usage.

(b) Geological, hydrostatical and geothermal conditions, as well as the stress field are known to some extent. At the same time, informations on the rock mechanics conditions are accumulated. These data could contribute to save the investigations on the strata and to quickly start planning work.

(c) Surface infrastructures such as electricity and roads, as well as underground facilities such as ventilation, transportation and water pump-up system are available.

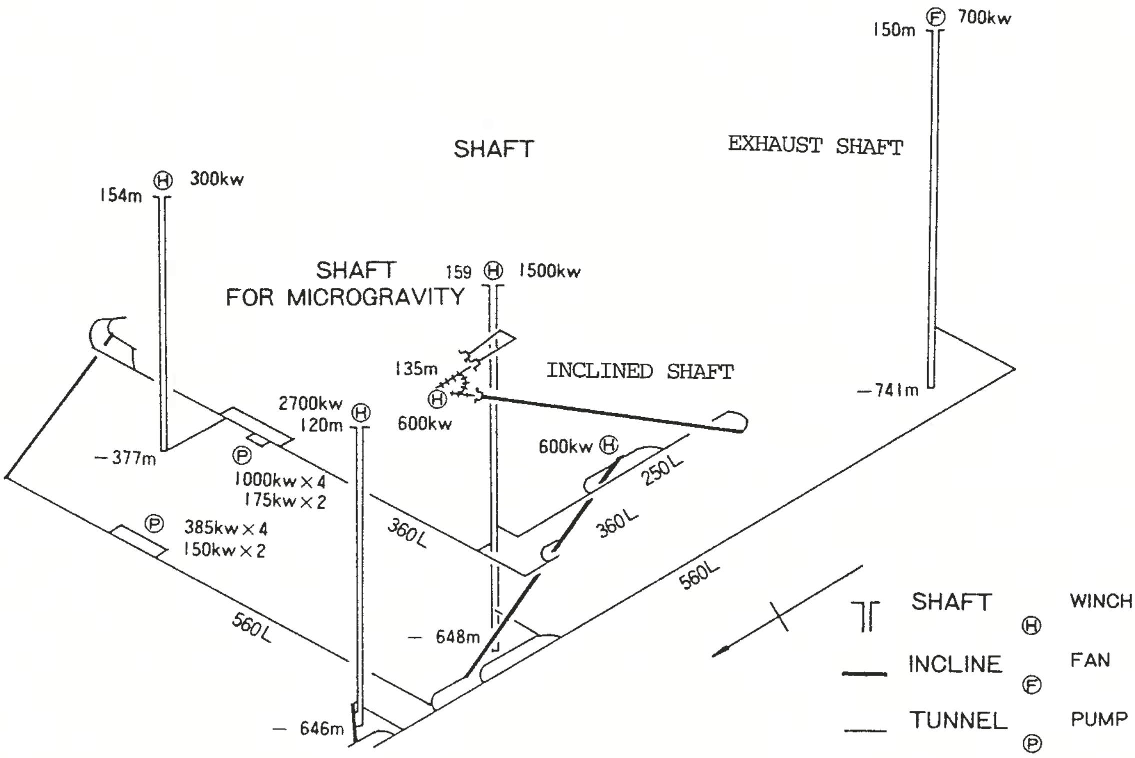


Fig.1 Schematic diagram of pit frame of Sunagawa Mine

There are two mines where the underground experimental facilities have been introduced. One is Sunagawa Coal Mine, closed in 1987, where four long shafts and roadways at two levels have been maintained(Fig.1). The rock mass is composed mainly from the shale of the Tertiary, whose compressive strength is from 50 to 80 MPa. The roadway maintenance is fairly good. Difficulties accompanying the construction of the cavern will be expected to be little. The only problem is that the rock is rather sensitive to water since it contains a small amount of expansive clay minerals. However, this should not bring serious problems since the rock mass is in dry condition owing to the drainage level located at the deepest level.

Another is Kamioka Metal Mine which is still active, producing 4000 t zinc ore every day. Most of the host rock, composed mainly of gneiss, belong to the category of hard rock, having compressive strength of from 150 to 200 MPa and large cavern can be maintained with little support. In addition, since the site is located at depth under the steep mountains, it requires short distance to access from the highway to the test area covered by the rock having thickness of 1000 m.

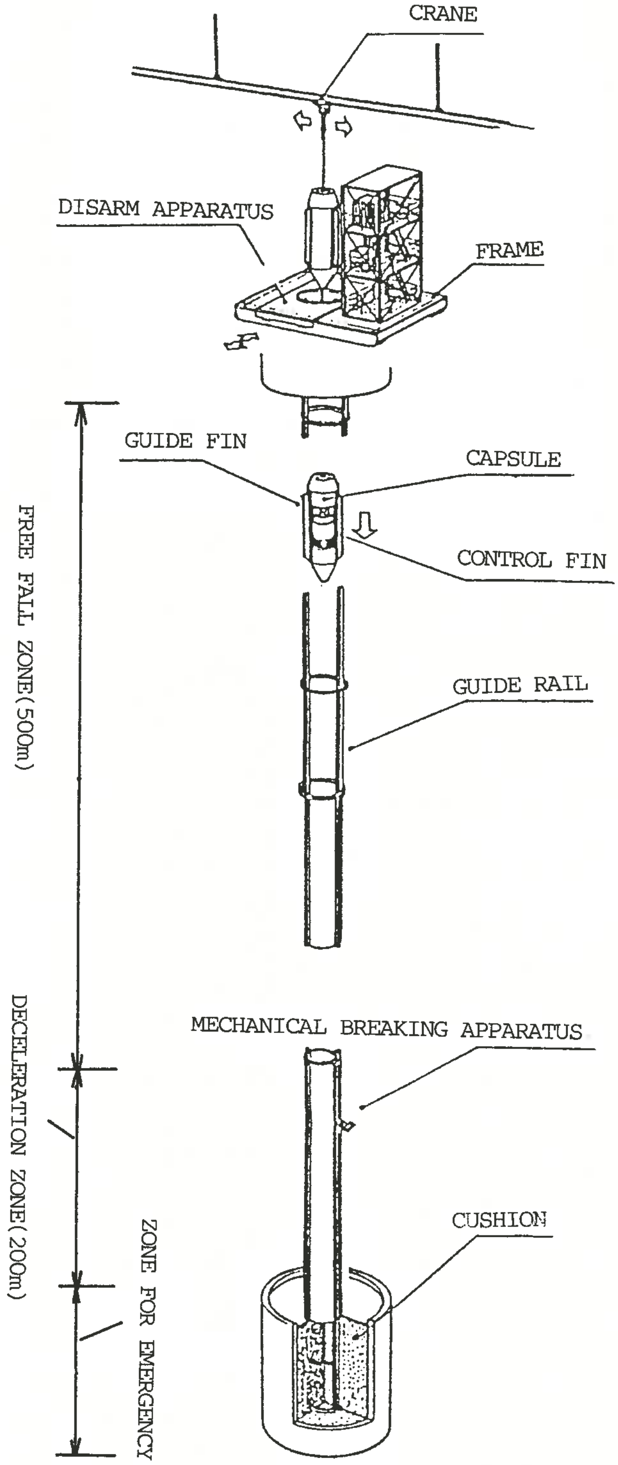


Fig.2 Micro-gravity drop tube utilizing the mine shaft

2. Micro-gravity Drop Tube

One of the shafts of Sunagawa mine, of 4.8 m in inside diameter and of 776 m in length, has been converted to a microgravity drop tower(Fig.2). Two parallel guide rails

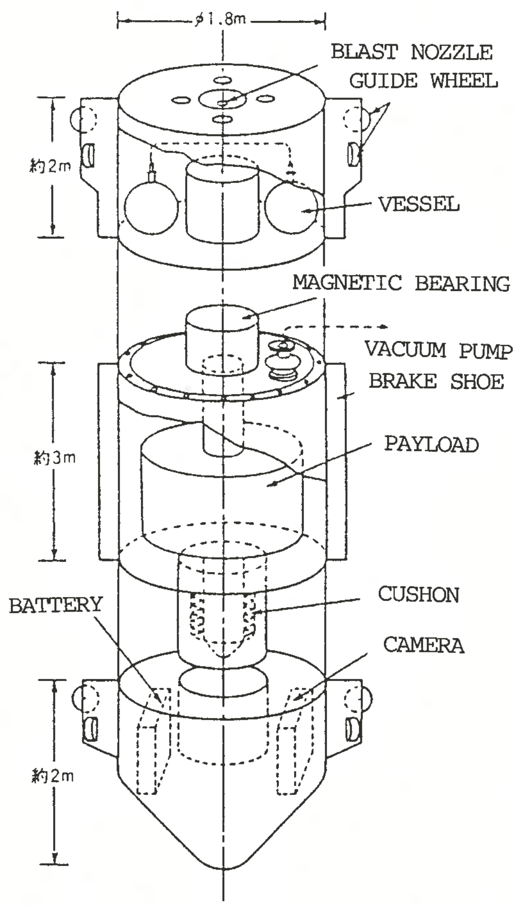


Fig.3 Capsule to be dropped

was newly laid, which were fastened to the buntons spaced at 3.6 m along the shaft. The capsule, of 1.3 m in diameter and 1.4 m in length as shown in Fig.3, has ability to carry 1 t payload during its free fall along the guide rails for a distance of about 500 m. Falling speed is controlled by the gas-jet equipped at its rear part. Inside the capsule, micro-gravity condition of 0.1 mG in quality is realized during the fall which continues about 10 seconds.

In the bottom part of the shaft, control tube of 200 m in length is equipped to decrease the speed of the falling capsule until the standstill condition, by the combined mechanisms of air-damping and mechanical brake.

Tests utilizing this facility will start from this year.

3. Pilot Plant for CAES

Full scale test for the compressed air energy storage/gas turbine system (CAES system) has started in Sunagawa Mine from 1990(Fig.4). To produce 35 MW electric energy, the gas-turbine generator will consume compressed air of 3 to 8 MPa in pressure to be delivered from the 30,000 cubic ms cavern which is located at a depth of 450 m from the surface.

Test conducted in the sedimentary rock is expected to be helpful to access the practical uses in the urban sites whose geologies are mostly weak sediments.

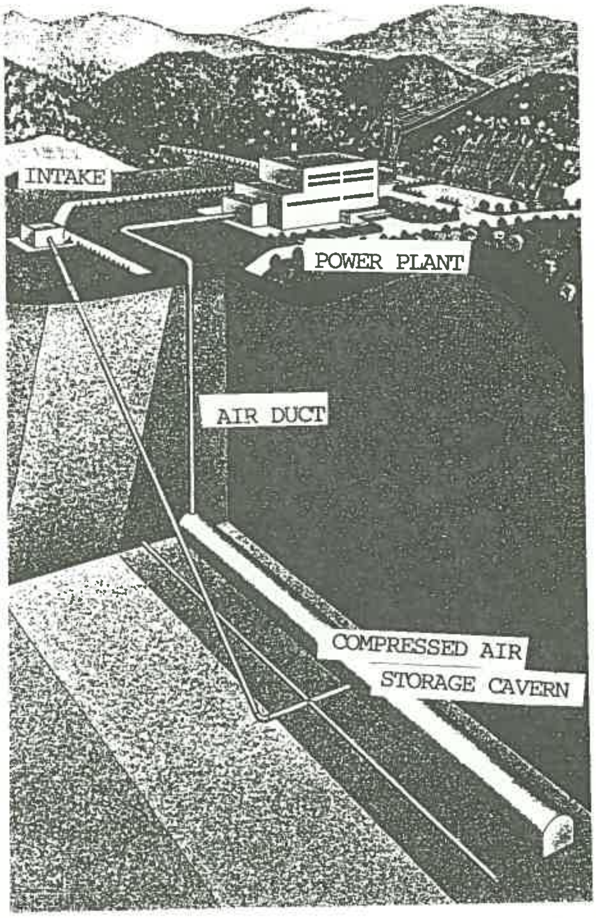


Fig.4 Schematic diagram of the CAES project

4. Climate Simulator Tower

An idea to utilize the shaft to create the clouds to study the climate will be put into practice in the Sunagawa Mine. It is well known among the miners that the rain of small scale often falls in the exhaust shaft through which rising current of humid and warm air is existing.

By controlling the velocity, humidity and temperature of the air in the shaft, atmospheric conditions which generate clouds and rains can be simulated(Fig.5). Several ideas on the facility of the climate simulating tower utilizing the shafts are now discussed under the name of "magic monky project".

5. Kamiokande

Most of the cosmic rays coming from the outside of the earth cannot penetrate deep into the rock mass. Therefore the density level of the cosmic rays is fairly lower in underground than

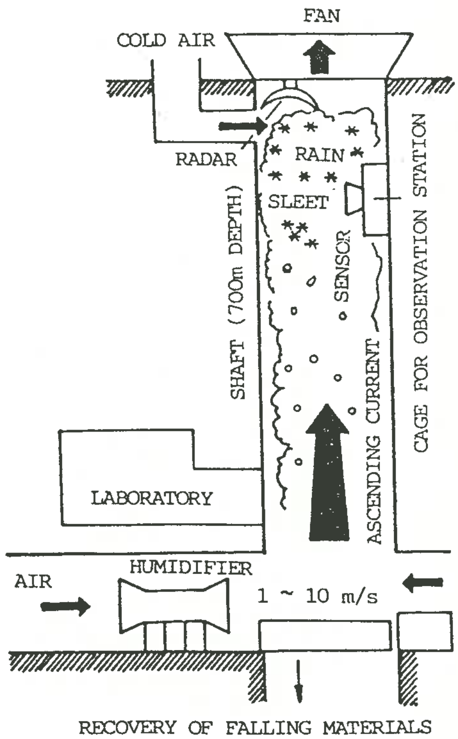


Fig.5 Shaft simulator to study clouds

on surface. Underground experimental facility in Kamioka Mine located about 1000 m below surface utilize this circumstances.

Main facility set up in the cavern, having a size of 19 m in diameter and 23 m in height, is the cylindrical tank, 16 m in diameter and 16 m in height, filled with pure water. On its inside wall, a thousand of highly sensitive photo-sensors are fastened.

In 1987, new trinos emitted accompanying the burst of a super-nova in the Magellanic Clouds were firstly detected by this apparatus.

Another aim is to confirm the hypothesis of the disintegration of the proton, whose phenomena can be observed by a infinitesimal quantity of light emitted accompanying its disintegration. However, there has been no result during the time of observation started from 1983 until now. According to the scientists, this is attributed to the underestimation of the lifetime of the proton.

So a new project equipped with the tank larger than the present one with the capacity to store 50,000 t of pure water has started this year(Fig.6).

In this cavern, cold fusion experiments have also been conducted utilizing the high quality of screening effect.

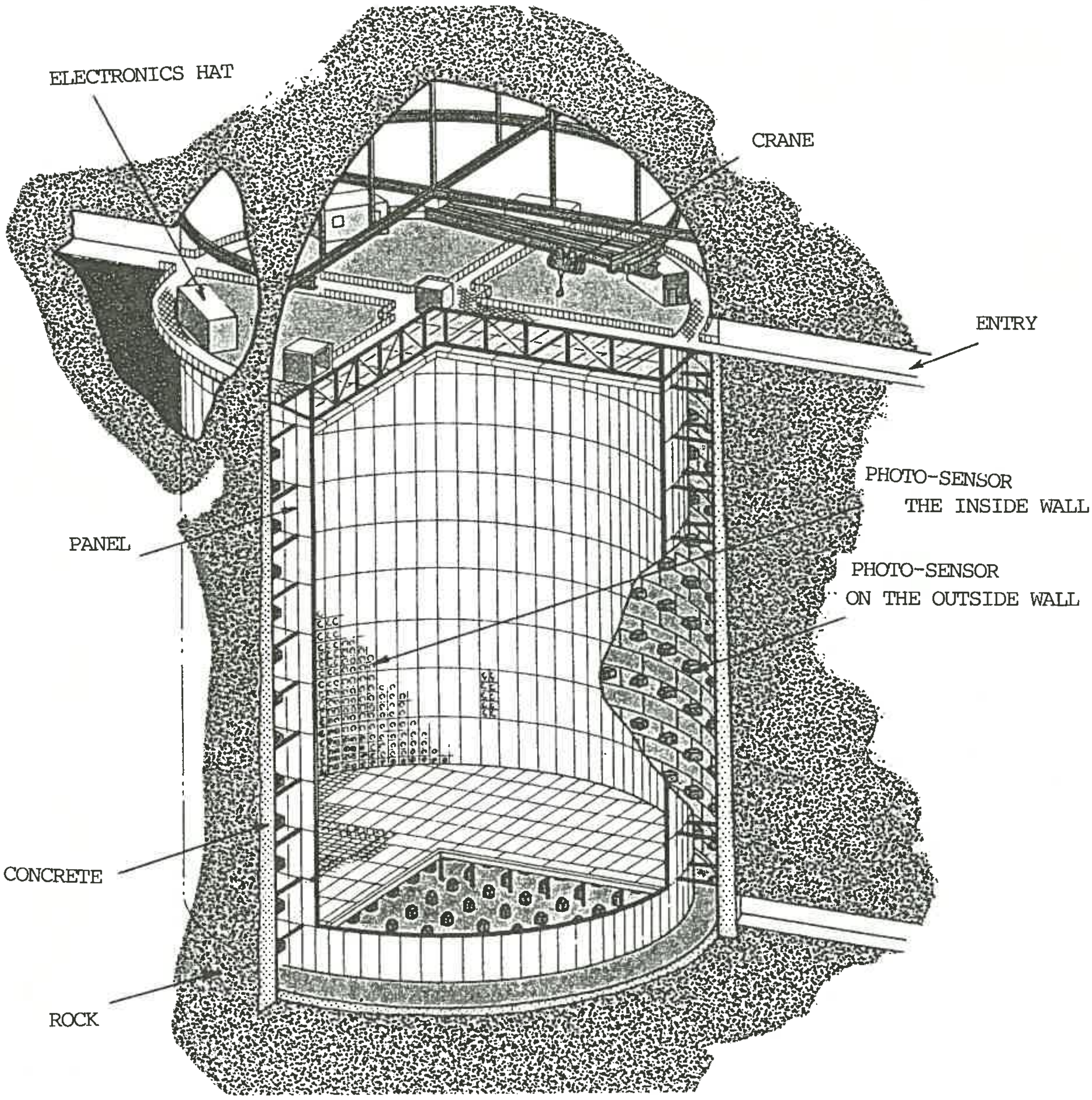


Fig.6 Kamiokande

Intelligent Tunnelling

Mitsuaki HIGO, Motohisa TAKAMI

Civil Engineering Division, HAZAMA Corporation

1. Foreward

The land is small and mountainous in our country and the proportion of tunnels used in road and railway networks is quite high. The total length and number of tunnels we have in Japan is at a world top-level. Moreover, tunnel construction is increasing every year and ever thriving to a greater and higher degrees.

Our land is made up with varieties of geologies. It is quite normal to have plural number of soil layers or geologies in construction of a tunnel. It is almost impossible to grasp beforehand the detail of the geology from the preliminary study since a tunnel is a linear structure. Therefore, for safe and economic tunnelling, so called an "intelligent construction", in which measurement is made during the construction to grasp the nature of the ground and the information is fed back to the construction, becomes necessary. At present, NATM is mainly employed in Japan and the importance of the measurement during construction is very high from the viewpoint of the basic idea of the method as well.

Here, the outline of the measuring works applied in our tunnelling work and an example thereof employed in the construction of a very large-section tunnel, New Tsuburano Tunnel, are introduced.

2. Outline of Measuring Works

The purpose of the measuring works performed during tunnelling is to grasp the behavior of the surrounding ground caused by the tunnelling and the effectiveness of each support member to ensure the safety and economy of the construction works. To be more specific, the measuring works include the one to be carried out during a routine supervision of the construction (Measuring Work A) and another to be performed in addition to the Work A according to the geologic feature of the ground (Measuring Work B). The Measuring Work A is applied in almost all the tunnelling works while the Work B is additionally employed in comsiderable

Table 1 Items to be Measured

	Item \ Ground condition	Hard rock	Soft rock	Soft rock with high plastic strain	Soil
Measuring Work A	Observation (inside the tunnel)	◎	◎	◎	◎
	Convergence	◎	◎	◎	◎
	Crown settlement	◎	◎	◎	◎
Measuring Work B	Sampling test	△	△	△	◎ Soil test
	Underground displacement	△	△	◎	○
	Rock bolt axial force	△	△	◎	△
	Pull-test of rock bolt	△	△	△	○
	Stress of lining	△	△	○	△
	Settlement of ground surface and subsoil	△	△	△	◎
	Elastic wave velocity (inside wall of tunnel)	△	△	△	△

◎ : always measured ○ : usually measured △ : measured if necessary

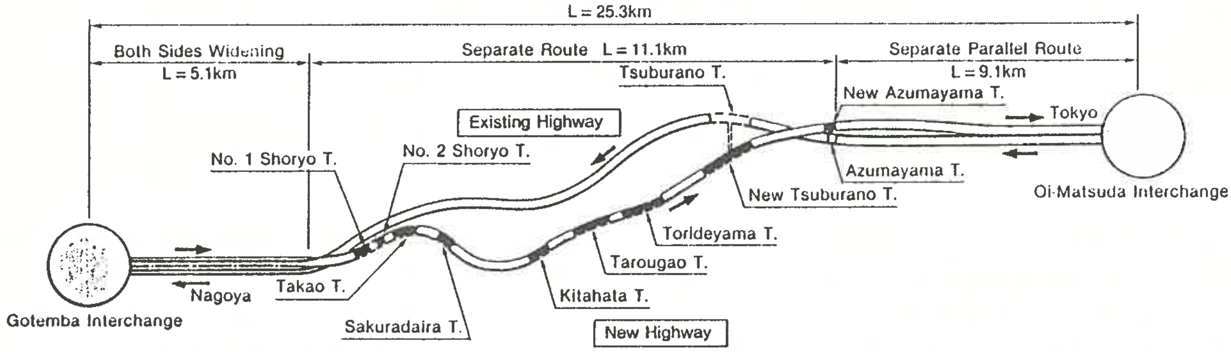


Fig.1 Plan of Tomei Expressway Improvement Project

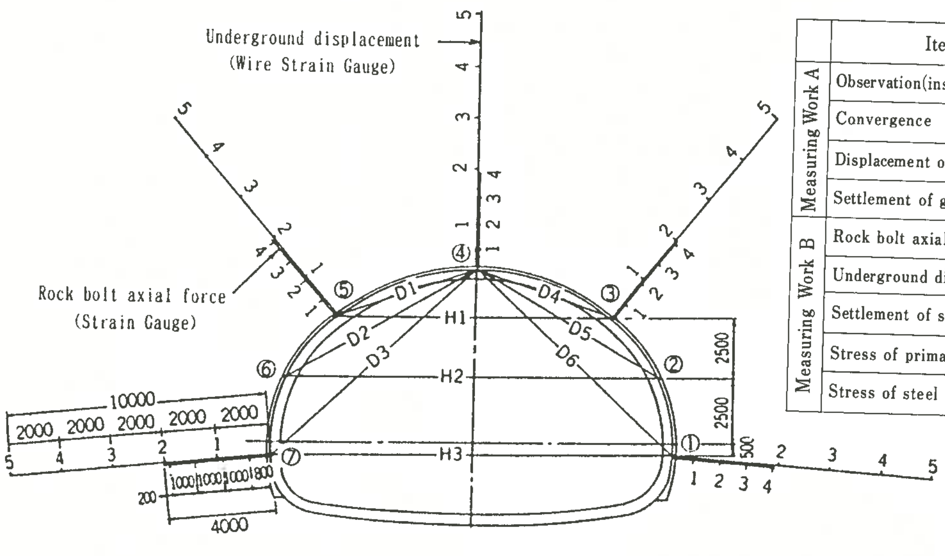
number of tunnelling works, although the cross-sections measured are small.

3. Example Employed in New Tsuburano Tunnel

Tomei Expressway is a major highway with the total length of 347km connecting Tokyo and Nagoya. The traffic(volume of the Expressway) has increased greatly due to the rapid development of our economy causing the chronic traffic snarl. To solve this, an expansion and renovation of the Expressway has been carried out since 1986 in the portion of Oi-Matsuda to Gotemba ICs, 25.3km. New Tsuburano Tunnel is one of the nine tunnels to be newly constructed in the project(see Fig.1). It is 1,715m long with a large-flat excavation cross-section of $130m^2$with 3-lanes. The geology is mainly of conglomerate and mudstone and the portal portion is covered with scoria layer.

In the same way as in the cases of ordinary tunnelling works, the Measuring Works-A were performed for every 5 to 30m during the construction and the Works-B, at the typical locations in each support pattern, the portal or thinly covered portions and locations where problems were likely. The typical cross-sections are as shown in Fig.2.

The covering of the construction pattern as shown in Fig.3 is as thin as 11m. This was the one adopted in the portion where a road was on the ground. The geology was of weathered conglomerate and stability of the face and settlement of the ground were problems, and supplemental methods such as the center diaphragm method or urethane injection forepoling, etc. were employed. In this part of the tunnel, not only the Measurement A but also Measurement B was employed. Table 2 shows the result of



	Item	Location
Measuring Work A	Observation(inside the tunnel)	——
	Convergence	D_1~D_6, H_1~H_3
	Displacement of crown, toes	①~⑦
	Settlement of ground surface	——
Measuring Work B	Rock bolt axial force	①③④⑤⑦
	Underground displacement	①③④⑤⑦
	Settlement of subsoil	——
	Stress of primary lining	①③④⑤⑦
	Stress of steel supports	①~⑦

Fig.2 Measurement Pattern (Standard)

the measurements. The tunnel was excavated with no collapse and almost no effect to the road on the ground as the max. settlement of the ground surface was 4mm.

4. Afterward

In our country, the "intelligent tunnelling", i.e. supervision and management of construction by "measurements during-construction" is regarded to be of vital importance. Especially, under the circumstances that construction of tunnels by NATM in city-areas where the soil is soft and weak, buildings and roads are on the ground and very large-section tunnels of 3- or 4-lanes of roads are increasing, the imortance of the "intelligent tunnelling" is increasing ever so much. Advance in the development of measuring technology is also remarkable and highly accurate measuring devices are being developed and the "Fuzzy Theory" and AI technologies are also being introduced.

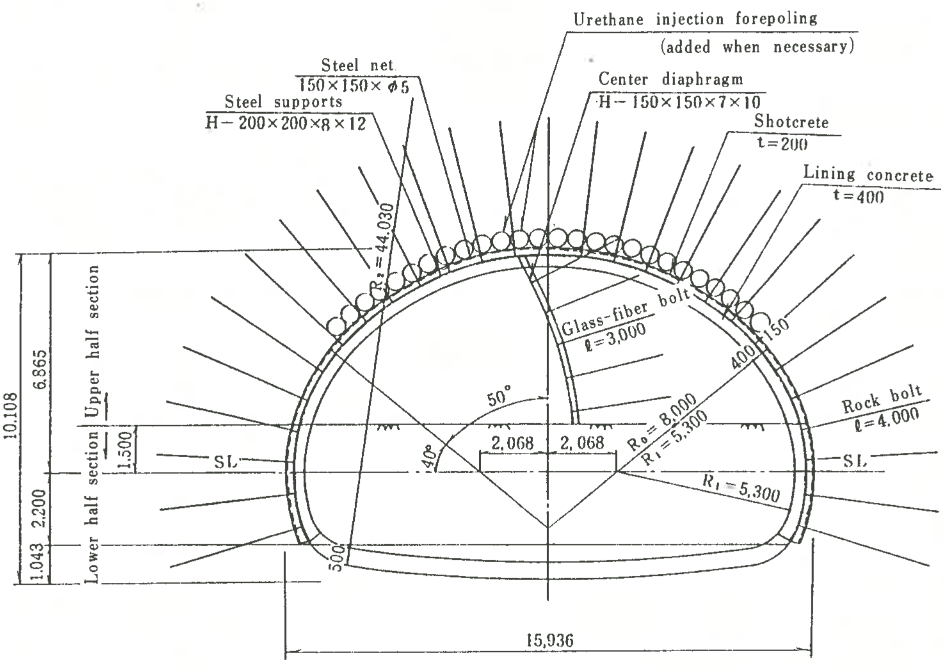
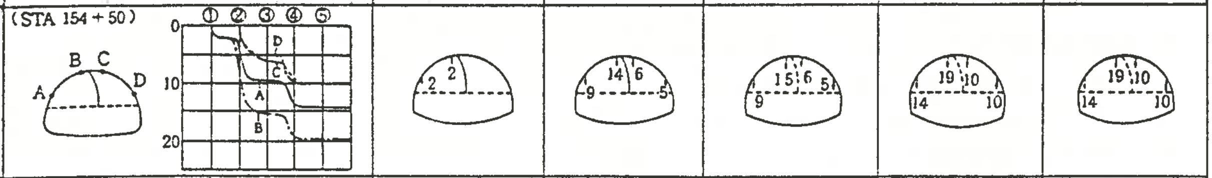
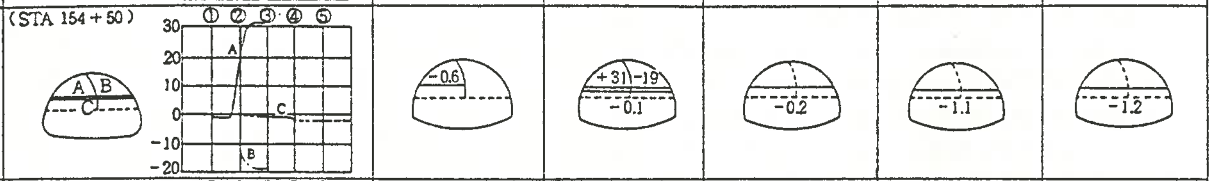
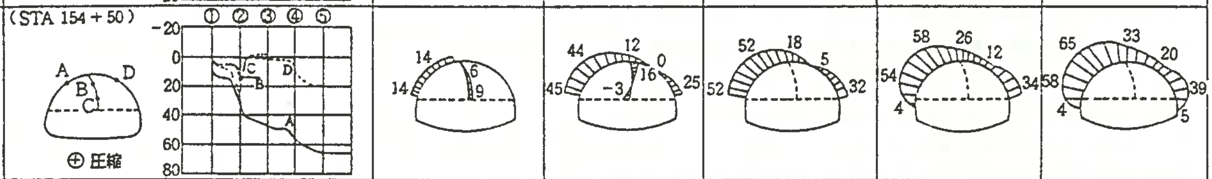
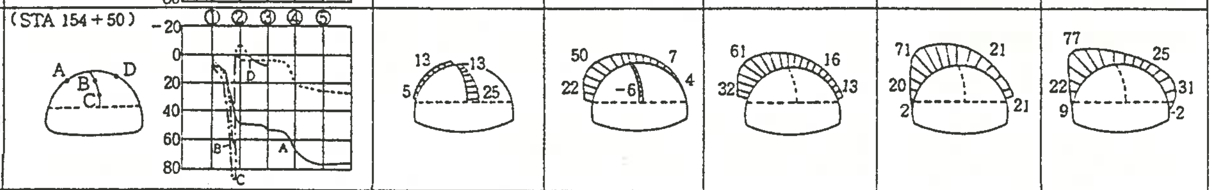
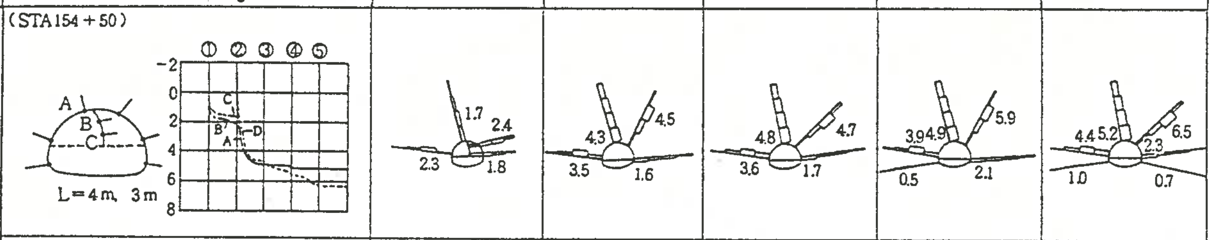
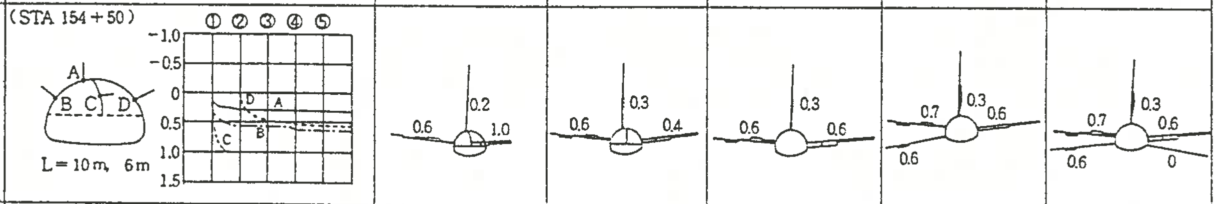
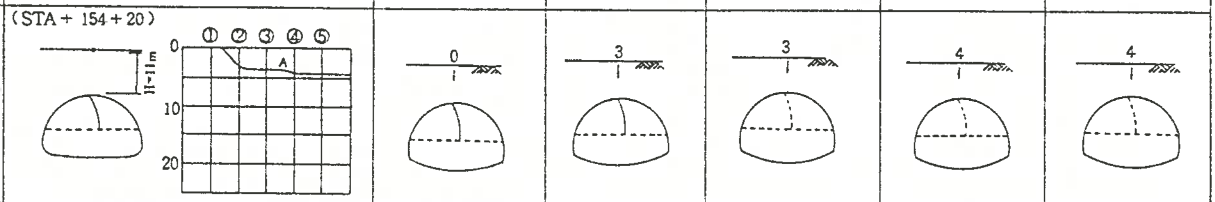
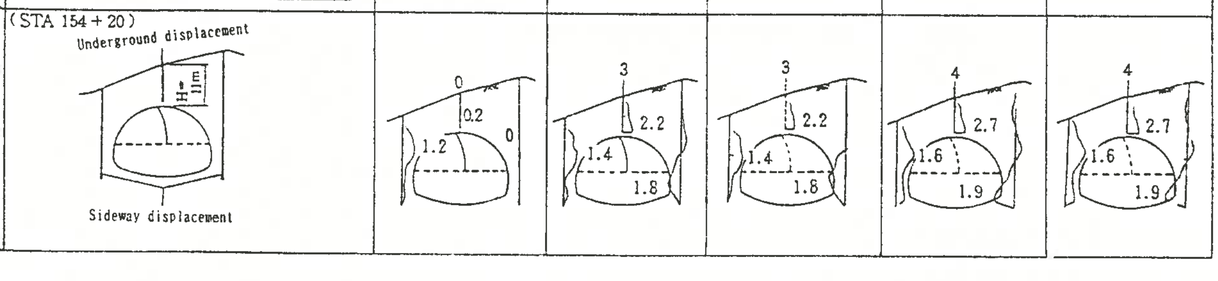


Fig.3 Outline of Countermeasure

Table 2 Result of Measurement

Item	Result	① Upper quarter heading (Jan. 9)	② Upper half heading (Feb. 5)	③ Removal of center diaphragm (Feb. 23)	④ Lower quarter heading (Mar. 4)	⑤ Lower half heading (Mar. 11)
Crown settlement (mm)						
Convergence (mm)						
Stress of steel supports (t)						
Stress of shotcrete (kg/cm²)						
Rock bolt axial force (t)						
Underground displacement (mm)						
Settlement of ground surface (mm)						
Underground displacement (mm) Sideway displacement (mm)						

Recent Progress in Shield and TBM

Akiomi SHIMAZU

Director, Information Management Division, Japan Construction Information Center (Former Director, Construction Method and Equipment Department, Public Works Research Institute, Ministry of Construction)

1. Introduction

Advanced technology of tunnelling in Japan mostly lies in Shield Tunnelling recent days. This comes from the circumstances of which alluvial deposits cover deep and wide in most flat area of Japan. Due to the spreading social economic activities, utilization of underground spaces for subway net, sewage line, power supply etc. has been accelerated and Shield Tunnelling Method has mostly applied for such construction in urban areas owing their features of not affecting surface traffic of social activities comparing with other excavation methods. Recently, deeper and larger underground spaces for road, river, sewage facilities etc. have been planned considering future social demands. Responding to such movements, another technological improvements of advanced shield methods have been progressed.

As for the tunnelling in mountainous area, number of application of NATM(New Austrian Tunnelling Method) is predominant over ordinary rock supporting system. On the other hand, mechanical excavation system for total cross section(so called TBM: Tunnel Boring Machine) has sometimes used for efficient and safety excavation in relatively sound rock tunnels. Due to complicated formation of geological condition in most cases, TBM applicable in alternating geology with alluvial deposit has also being developed.

In this chapter state of the technical development in Shield and TBM is introduced.

2. Development of New Shield

Shield Tunnelling Methods have been used as one of the most important measures for underground tunnel construction in urban areas. Recently shield tunnelling method are expected to meet more difficult technical conditions for increasing social demands developing the following several efforts.

2.1. Improvement in Cutting Mechanism

As for the types used the majority is closed face type machines applied to collapsy and complicated soil layer of alluvial and some diluvial deposits comparing with few use of pneumatic type machines(or open face type). Among the closed face type, slurry circulation type and earth pressure balanced type have been ordinarily used. Recently improvements in combination of cutting face structure and slurry material have been tried to meet various soil and rock condition. For example, the bubble contained slurry shield has developed to cover wide soil condition. The heavy density slurry shield has developed for permeable soil layer with large cobble stones.

2.2. Free Shape Cross Section

The cross section of conventional shield method has been circular shape for mechanically efficient and economical excavation. However, increase in diameter and recent congestion

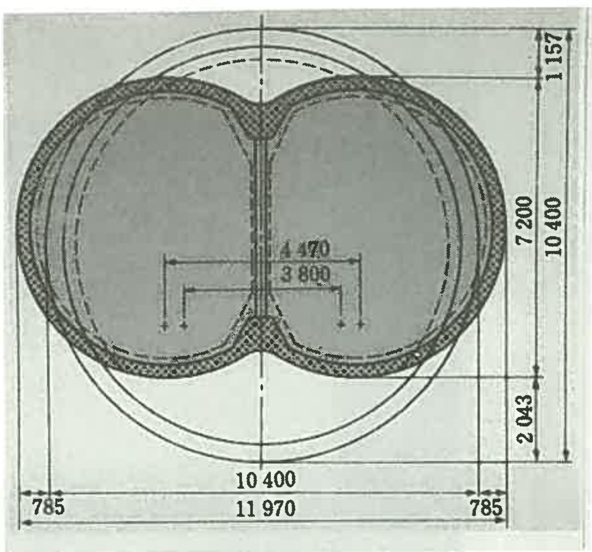


Fig.1 Comarison of Cocoon Section with Regular Circular Cross Section (Unit : mm)

of underground use have produced another demands to excavate designed shape cross section other than circular shape. This avoids waste of space use as shown in Fig.1 and reduces volume of excavated soils which treatment is one of the social environmental problems in urban areas. Responding such demand, several type of shield methods such as MFS, DOT, H&V, the planetary cutter, etc. have been developed and recently applied in actual construction.

The MFS(multi-face shield method) consists of two circular ordinary machines overlapped and set back in small distance each other as shown in Fig.2. This enable to excavate cocoon like shape cross section. The MFS succeeded in first application of actual excavation of this kind of rail way tunnel(7.4m in dia.x 2) as shown in Fig.3. The MFS of three or four tubes are also planned for large scale space construction such as subway station.

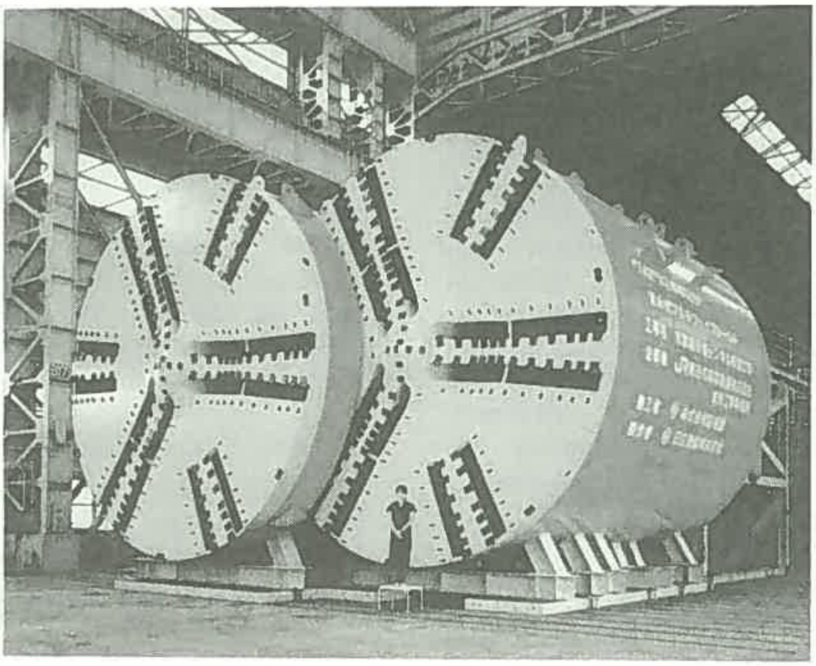


Fig.2 MFS Shield

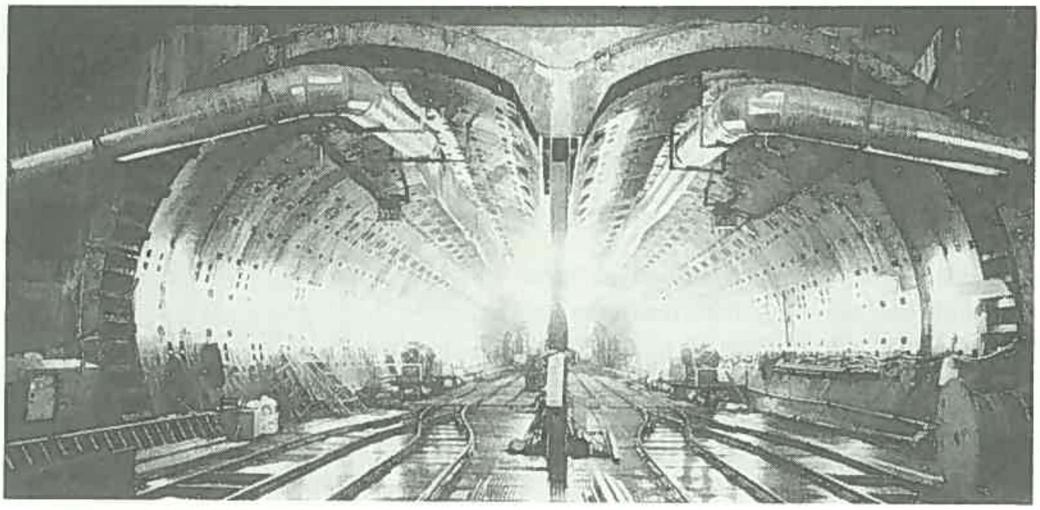


Fig.3 Completed Work by MFS Shield

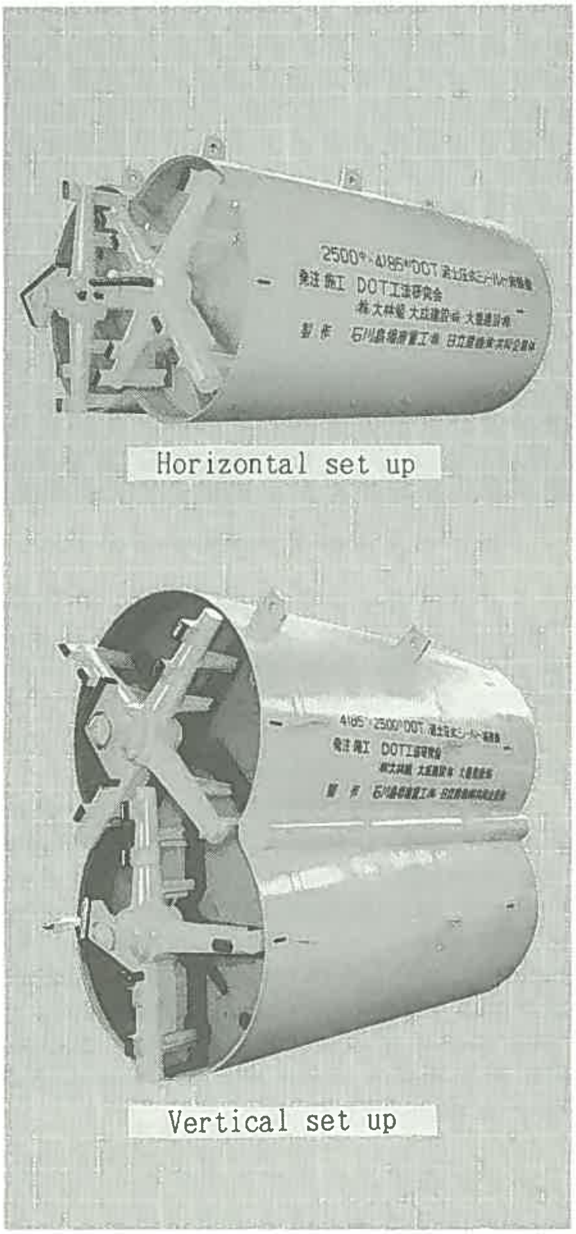


Fig.4 Horizontal and Vertical Set up of DOT Shield

The DOT(double-o-tube method) also has two overlapped circular tubes with synchronized cutter faces to excavate cocoon cross section. Fig.4 shows horizontal and vertical set up of the machine. The DOT is now applied to the subway tunnel(6.1m in dia. x 2) of New Transport System in Hiroshima City.

The other methods have also been developed. The H&V shield method consists of articulate double tubes. This, as shown in Fig.5, gives continuous twist of double cross section in horizontal formation to vertical formation or vis-a-vis, facilitating space saving in limited space portion at complicated nodes of underground net. The planetary cutter shield method is newly developed for excavating free shape cross section with singular tube by means of planetary gear cutter as shown in Fig.6. This gives rational tunnel shape for its purpose as shown in Fig.7.

Fig.5 Twisted Segment of H&V Shield

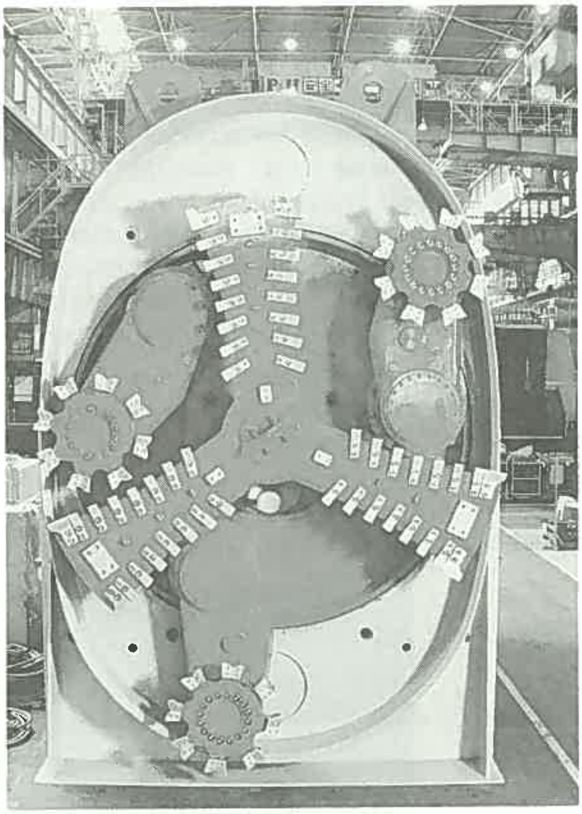


Fig.6 Planetary Cutter Shield

Apart from the free shape, technique of partial enlargement of cross section has been developed for installing man-hole section along power supply line shield. The method uses secondary shield of larger diameter(7.9m) in the part of enlargement distance(24m) along over primary shield(6.6m in dia.) of ordinary method. Fig.8 shows the part of enlargement.

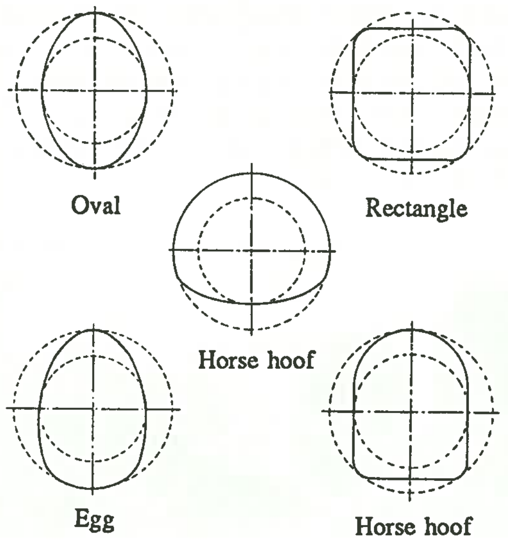


Fig.7 Various Free Shape Cross Sections by Planetaty Cutter Shield

2.3. Large Scale Cross Section

The demand to construct large scale space in deeper ground has accelerated development of large scale shield machines in which several technical improvements have carried out in mechanism of cutting face, transportation in pieces and field assembling of machines, soil stabilization mechanism around cutting front, automatic assembling of tunnel segments, etc..

The largest application is now under way in the underground river project in Metropolitan Tokyo where slurry circulation type shield machine of 13.94m in dia. is to used to excavate 2km long tunnel at 60m below the ground. The photo of the machine is shown in Fig.9.

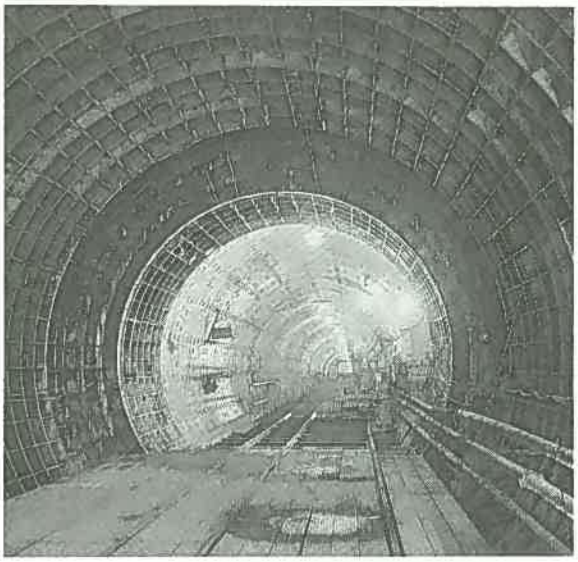


Fig.8 The Enlarged Cross Section (front side)

The large scale tunnel project of Trans-Tokyo Bay Highway has started and will soon use 14m in dia. class shield along 9.5km long undersea tunnel in alluvial layer.

2.4. Sharp Curve Alignment

Due to the congestion of underground facilities and limitation of shaft installation sites, necessity of tunnel alignment with sharp curvature has increased. Articulate type shield machine, as shown in Fig.10, is used for this purpose and recent practice has realized minimum radius of 10 meters. This owes to improvement of articulate angle, soil stabilization technique in curved side wall, reaction balance on segments part, etc..

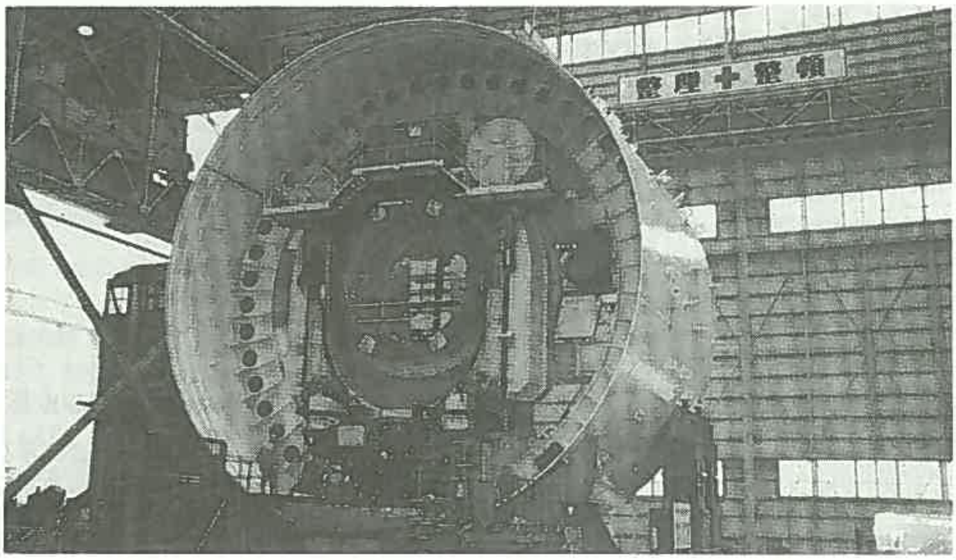


Fig.9 The Shield of Large Scale Cross Section(13.94m in dia.)

Fig.10 Articulate Shield for Curve Setting

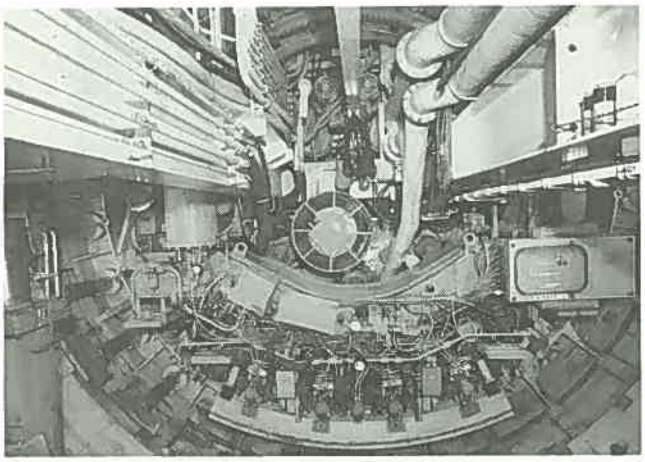


Fig.11 Automatic Assembling of Segments

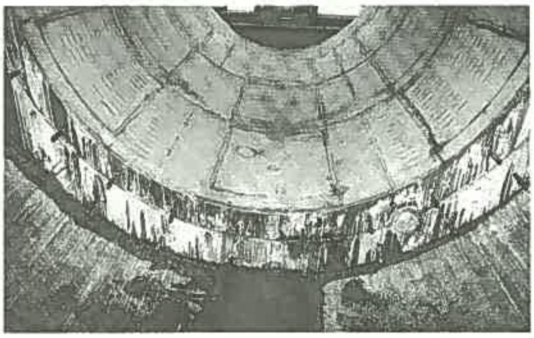


Fig.12 ECL Experiments

2.5. Automatic Control of Shield Excavation

Thrusting forward the shield on the planned alignment is quite skillful work and needs experiences in changing geological condition. Owing rapid progress of computer and advanced measurements technology, automatic thrusting control has, in most cases, been applied in recent thrusting practices. In the automatic system, positioning of the shield machine is measured by gyrocompass and LASER light and thrusting is followed by computerized jacking pattern based on the information of position difference from the planned line, past accumulated thrusting data with geology, jacking stroke, load gauge data, earth pressure gauge data, etc..

Face front condition is also important in automatic excavation. Recently detecting system on face front collapse has been devised by measuring the difference in electric current between slurry material and far front object. Detecting of obstacles has also been done by means of deflection and Rayleigh wave analysis.

2.6. Progress in Segment Installation

Assembling and installation of segments and backfill grouting are heavy work to be improved into automatic operation. A practice of automatic assembling and installation of segments to form tunnel structure has been done successfully as shown in Fig.11. Direct concrete placing instead of segment assembling has been tried aiming at more efficient work. This is called ECL(extruded concrete lining) and an example is shown in Fig.12.

3. Development of TBM

In recent tunnel excavation TBM has been noticed as economical and rapid execution of relatively small tunnel in the circumstances of pursuing highly mechanized construction. TBM in Japan has been improved much in working efficiency to meet its complicated and alternating geological condition. Main feature of the improvements is the introduction of combination of shield methodology with the ordinary TBM of rock excavation. For wide range of geological condition such as sound rock caught by smashing zone or soft rock/soil zone, thrusting by ordinary gripper reaction in rock portion and thrusting by segment reaction in soft rock/soil portion are possible with only one machine. This enable TBM to allround excavation. However, application of this TBM has lied within some range such as small diameter in long distance excavation by cost consideration. One application is shown in Fig.13. Usually excavated material is transported outside by mechanical belt conveyer or by slurry flow in case slurry circulation cutting face is used.

Fig.13 TBM for Wide Geological Range

Investigation and Estimation on Discontinuity (including Geotomography)

Kohkichi KIKUCHI

Professor of Kyoto University

1. Introduction

Recently, in Japan, the trend of civil engineering constructions expressed by three words such as "divergence", "enlargement" and "complication". Therefore, it is necessary to grasp the properties of rock masses as the foundations of the constructions more exactly. The phisical properties of massive hard rock masses, the main kind of foundations, are storongly infulenced by those of discontinuities which is distributed in rock masses, because intact rock of such rock masses is very hard, not deformable and impermeable. Thus, it is very important to analyze, examine and design the structure based on the model which is made using discontinuity data. Considering above, several Japanese organizations concernedwith civil engineering and mining, are making reserches on discontinuity. In this chapter, the author introduces the activities of Japanese reserchers on discontinuities, and also introduces the reserches on geotomography which is one of the noti ceable method in order to survey discontinuity distribution effectively.

2. Researches on Discontinuity

The theme of the researches on discontinuity rock masses are divided into the following three:
(a) Estimation of phisical properties
(b) Estimation and modelling of distribution
(c) Analysis considering phisical properties and distribution

2.1. Estimation of Phisical Properties

The theme of researches on estimation of phisical properties of discontinuity rock masses are divided into the following two:
(a) phisical properties of single discontinuity
(b) phisical properties of discontinuity system
Dividing such reseaches into mechanical reseaches and hydraulic researches, the author introduces them in the following section.

2.1.1. Mechanical Property

2.1.1.1. Phisical Property of Single Discontinuity

Several laboratoly testings were made in order to examine the mechanical properties of single discontinuity. Most of researches were carried out for estimating the shearing properties of single discontinuity. Many research groupe such as Ryunosin YOSHINAKA et al., Toshiaki SAITOH et al., Ryoukichi HAMAJIMA et al., Chikaosa TANIMOTO et al. and Kohkichi KIKUCHI et al., are making such reseaches considering roughness of discontinuities.

Especially, YOSHINAKA et al. studies the scale effect of discontinuities and rock bolting. SAITOH et al. discusses the change ofthe discontinuity roughness profile and dilat-ancy when shearing.

On the other hand, as the activities on nomal stress - nomal strain, YOSHINAKA et al. reported the relation between the nomal stiffness of single discontinuity and contacting area between discontinuity walls.

2.1.1.2. Phisical Property of Discontinuity System

Becase of difficulty of the testings, most of the researches on phisical properties of discontinuity system are theoretical studies which are carried out by Masanobu ODA et al., Toshikazu KAWAMOTO and Takashi KYOYA et al., Ryoukichi HAMAJIMA et al., and so on.

ODA et al., suggests "Crack tensor" method which is the estimation of the mechanical properties such as elastic compliance and so on using "Crack tensor" based on geometrical information of discontinuity distribution.

KAWAMOTO and KYOYA et al. suggest "Damage tensor" method. this method also estimates themechanical properties using relation between stress field, strain field and "damage field" which replases the mechanical effects of the discontinuity system.

2.1.2. Hydraulic Property

2.1.2.1. Hydraulic Property of Single Discontinuity

The laboratoly permeability testings using the simple discontinuity plane - model, the artificial discontinuity plane and the actual discontinuity plane (borehole size) were carried out by Kunio WATANABE, Kuniaki SATOH, You ITOH, Yuzo OHNISHI and so on.

Considering the roghness pattern of the discontinuity profile, WATANABE made the parameter study by carrying out the hydraulic testing using the various models and the artificial discontinuity planes. SATOH, ITOH and OHNISHI made the hydraulic experiments under the certain stress and examine the relation between stress and permeability.

The field testing was only carried out by Kohkichi KIKUCHI et al.. In-situ single discontinuity plane was tested and the channeling in the discontinuity plane investigated. As the results, the flow through the actual discontinuity obeys Darcy's flow and its channel is very complicated like blood vessels (Fig.1).

Fig.1 The Channel through the In-situ Single Discontinuity (KIKUCHI et al.)

2.1.2.2. Hydraulic Property of Discontinuity System

Becase of difficulty of the testings, most of the researches on hydraulic propertiesof discontinuity system are also theoretical studies or the interpretations of permeability testings which are carried out by Kunio WATANABE, Yuzo Ohnishi, Masanobu ODA, Keiji KOJIMA, You ITOH, Michihito SHIMO, Kenji AOKI and so on. Most of these studies aim at the disposal problem of radioactive wastes and the relation-between stress and permeability is frequently studied.

Kohkichi KIKUCHI et al. made in-situ experiments and investigated the channels through discontinuities at two sites where the single discontinuity set and discontinuity system are distributed respectively. As the results, the flows through the actual discontinuity set and discontinuity system obeys Darcy's flow and the channels are very conplicatedlike blood vessels as well as the actual single discontinuity (Fig.2).

2.2. Estimation and Modelling of Distribution

It is impossible to grasp the 3 dimensional discontinuity distribution determinately because A lot of discontinuities are frequently distributed at the objective region for analysis in general. Therefore the stochasitic approach considering the nature of discontinuity population is an only method to estimate the distribution. As the methods of sampled survey, several methods were suggested.

Discontinuity distribution is regulated by the several parameters (discontinuity characteristic elements). It is very important for the statistical investigation and the stochastic estimation of distribution to examine the nature (probabilistic space) of such parameter distributions. The distributional natures of orientation, persistence, density, aperture and so on were reported by several authors. For roughness, Quantitative approaches were also carried out by several authors using Fractal geometry and so on.

Kohkichi KIKUCHI et al. suggested the stochastic estimation method for discontinuity distribution based on the statistical data sampling. This method covers the point and interval estimation of discontinuity distribution using probabilistic space model of 7 discontinuity parameters (orientation, persistence, density, aperture, filling, roughness, conductivity) which regulates the distribution, and the 3 dimensional discontinuity analog model can be generated using the results of such estimation.

Except for Kohkichi KIKUCHI et al., Kenichi KANATANI et al. suggested the estimation method using stereology.

The estimation methods in a single population of discontinuity are described above. In the case that the locational variance of nature of distribution is high in a population, it can not be to express the local distribution of discontinuity effectively, as estimating distribution stochastically. Considering above, KIKUCHI et al. and WATANABE et al. suggest the area-division method which is the preliminary procedure before detail estimation in order to express the local distribution.

Recently, the automatic sampling systems for discontinuity data using the portrait treatment technique are developed by several researchers, because the discontinuity survey is apt to need a detail work and a lot of time in general. Most of them are the methods inputting the geometric discontinuity data rapidly from the photograph and the video film by the portrait treatment procedures. The high quality borhole televison is also developed in order to obtain the discontinuity data at the bore hole more effectively.

2.3. Analysis Considering Phisical Properties and Distribution

2.3.1. Mechanical Analysis

The parameter studies are frequently carried out. Finite element method, boundary element method, distinct element method, block-theory and so on are mainly examined as the mechanical analysis of discontinuous rock masses.

As the analysis using continuum model, the crack tensor method by Masanobu ODA and the damage tensor method by Toshikazu KAWAMOTO and Takashi KYOYA are often studied. Shunsuke SAKURAI studies the slope problems and the tunnel problems of discontinuous rock masses using the inverse analysis method. The joint element often studied by Toshihisa ADACHI and so on.

On the other hand, as the analytical studies using discontinuum model, Parameter study

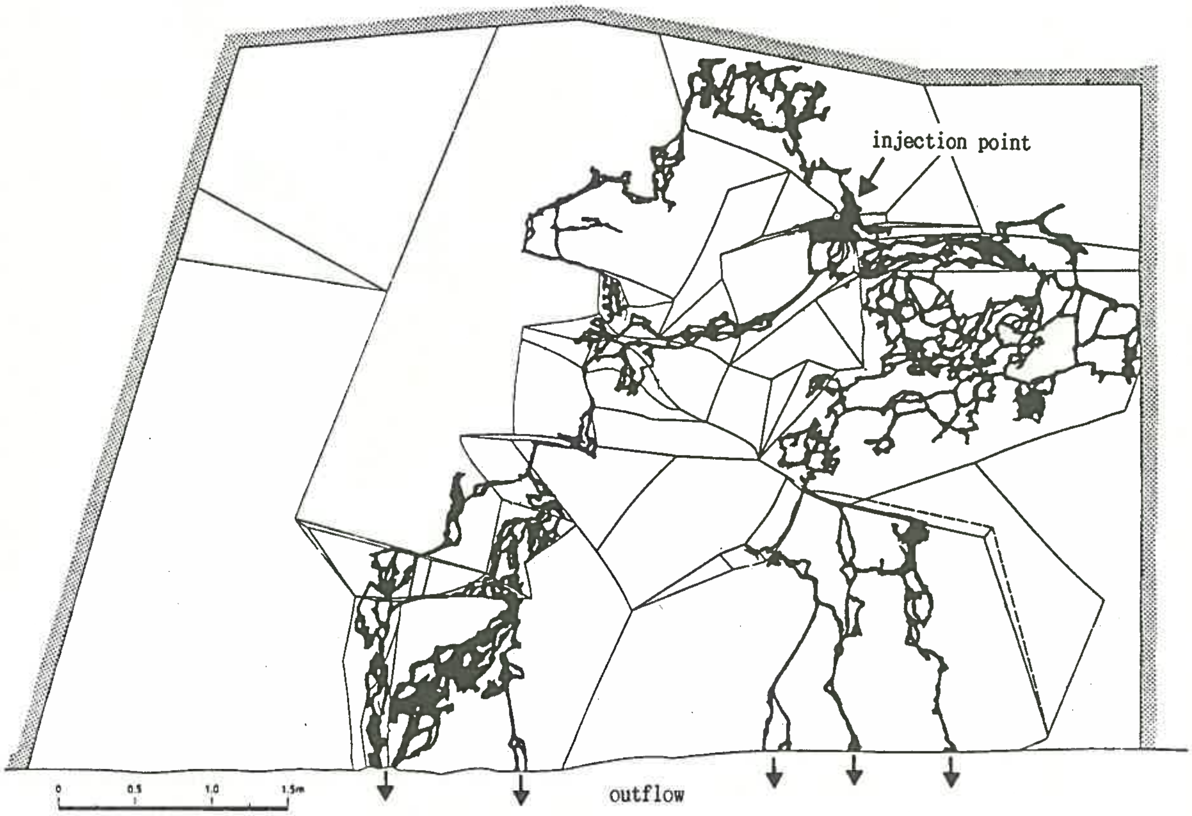


Fig.2 The Channel through the In-situ Discontinuity Set (KIKUCHI et al.)

of distinct element method and the extension of block theory are carried out by several authors.

Tadahiko KAWAI suggested "Rigid Body - Spring Model"(RBSM) method. THis model is composed of rigid body elements (block) and two springs which have nomal and shear resistence respectively. The deformation and stress of rock masses expressed by the deformation and stress of two springs using this model.

2.3.2. Seepage Flow Analysis

Analysis using continuum model such as finite element method, boundary element method, and analysis using discontinuum model such as network model analysis, rock block model analysis, double porosity model analysis and so onare examined as the seepage flow analysis of discontinuous rock masses.

Continuum model analysis are studied by Kunio WATANABE, Masanobu ODA and so on and discontinuum model are studied by Kunio WATANABE, Yuzo OHNISHI, Makoto NISHIGAKI, You ITO and so on.

Kohkichi KIKUCHI et al. analyzed the in situ experiments results using 3 dimensional channeling network model which is generated using the data of joint distribution only. Fig.3 shows the schematic model of this analysis. As the result of the analysis, it is clear that the velocity of seepage flow is very high and is distributed log-normally.

Kunio WATANABE also developed channelling model through discontinuity system, and analyzed in situ seepage flow using it.

3. Researches on Geotomography

Velocities and attenuations of elastic waves and also electrical resistvities can be used effectively as indices to important characteristics of in-situ rock and soil, such as phisical and mechanical properties, degrees of wethering and fracturing etc.

"Seismic velocity tomography","Seismic attenuation tomography" and "Electrical resistivity tomography", those are called as Geotomography, are utilized to obtain two dimentional distribution of propagation velocity and attenuation characteristics of elastic waves and electrical resistivity. A demand for these three tomographies supposed to be increased greatly in future. Among them,seismic velosity tomography is most developed and most frequently used. The recent main objects for which seismic velocity tomography testings are applied are as follows; site characterization for dam, tunnel, large underground openings and safety inspection of rock structures.

Seismic attenuation tomography is now being investigated actively towards practical applications.

Electrical resistivity decreases with increace of fracturing. Up to the present, electrical resistivity tomography is mainly utilized for evaluation of rock in construction site such as dam, tunnel and also for investigation of injected water flow through fracture zone in hot dry rock geothermal energy extraction project.

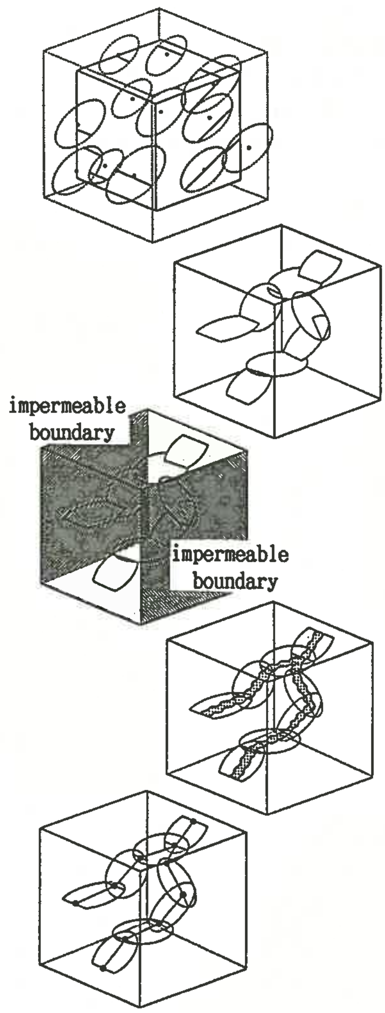


Fig.3 The Schematic Model of Permeability Analysis (KIKUCHI et al.)

Rock Mechanics in the Seikan Tunnel

Yutaka MOCHIDA

Suncoh Consultants Co., Ltd

Japan is located at the westen end of pacific Ocean and the eastern end of Eurasian Continent with Japan Sea (Fig.1). and the Japanese Islands consist of four majar islands named Hokkaido, Honshu, Shikoku and Kyushu from the North.

Since the Japanese Islands are boundary of the continent and the ocean, many tectonic actions have been occurred for a long time, according to the theory of Plate Tectonics. In other words, it can be said the Japanese Islands were generated by these geotectonic movements.

Therefore the area of the Seikan Tunnel is also affected by such movements, though, Japanese Islands are located between two supposed tectonic lines which run from north to south on the other side (Boundary of Plates around the Japanese Islands is shown in Fig.2). Although Fig.3 shows the Geology of the Seikan Tunnel, it is almost composed by volcanic, pyroclastic and sedimentary rocks of Miocene of Tertiary. This area is one part of northeastern mountain range which is structual component of the Japanese Islands including western Hokkaido(Oshima peninsula and middle part of Northeast Honshu)

As we predicted,since large amount of water-ingress had been occurred on a excavation works of undersea portion of this long tunnel, we always carried out exploratory horizontal drillings from tunnel face to investigate geological conditions including water-ingress. Consequentry we decided to grout before excavation works of the tunnel. While these grouting works were carried out, almost of each times of grouting, we found that grouting quantity per minute was increased when grouting pressure was beyond some certain level of pressure. (I named this pressure as the "critical grouting pressure" as shown in Fig.4).

This critical grouting pressure was affected by the total gravity of overburdended rocks, water depth from sea surface and perhaps by tensile strength of rock which were grouted. Although this phenomena may be called as one

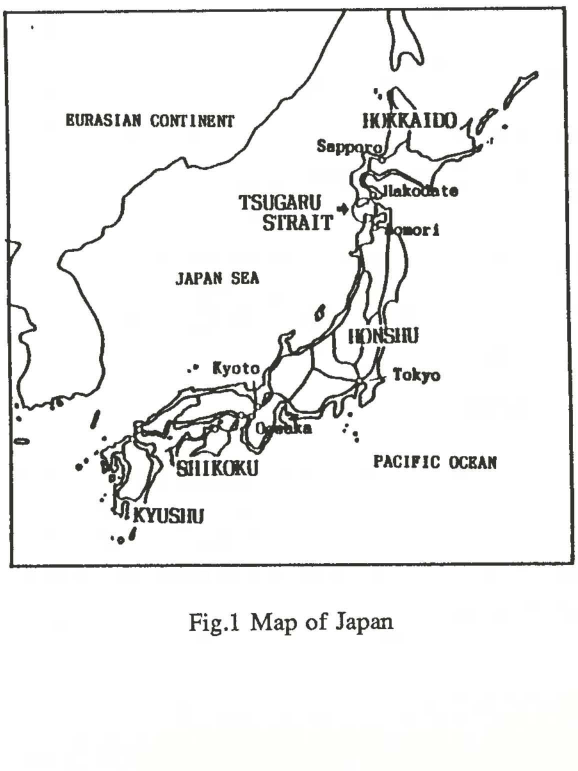


Fig.1 Map of Japan

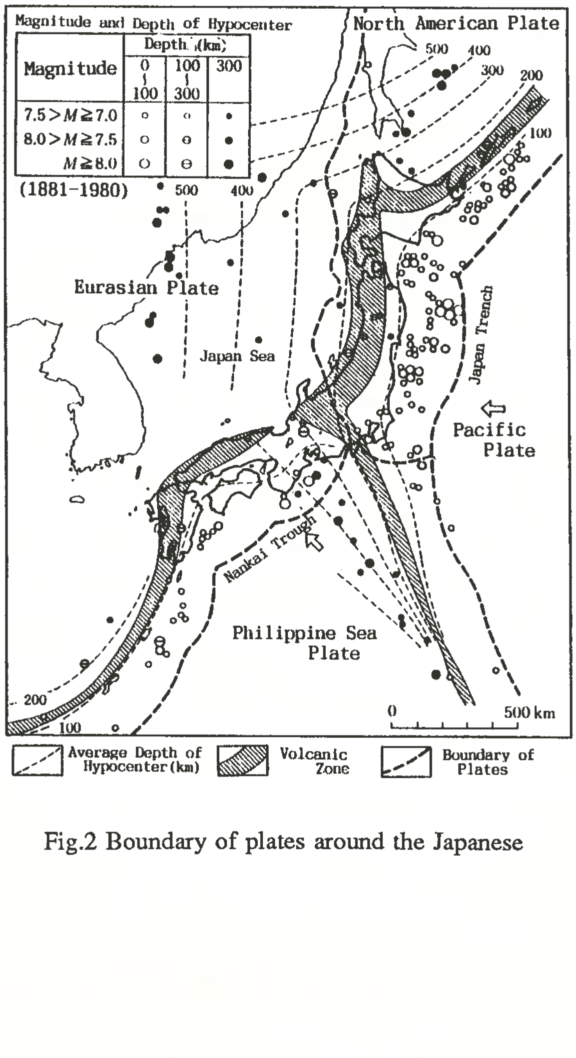


Fig.2 Boundary of plates around the Japanese

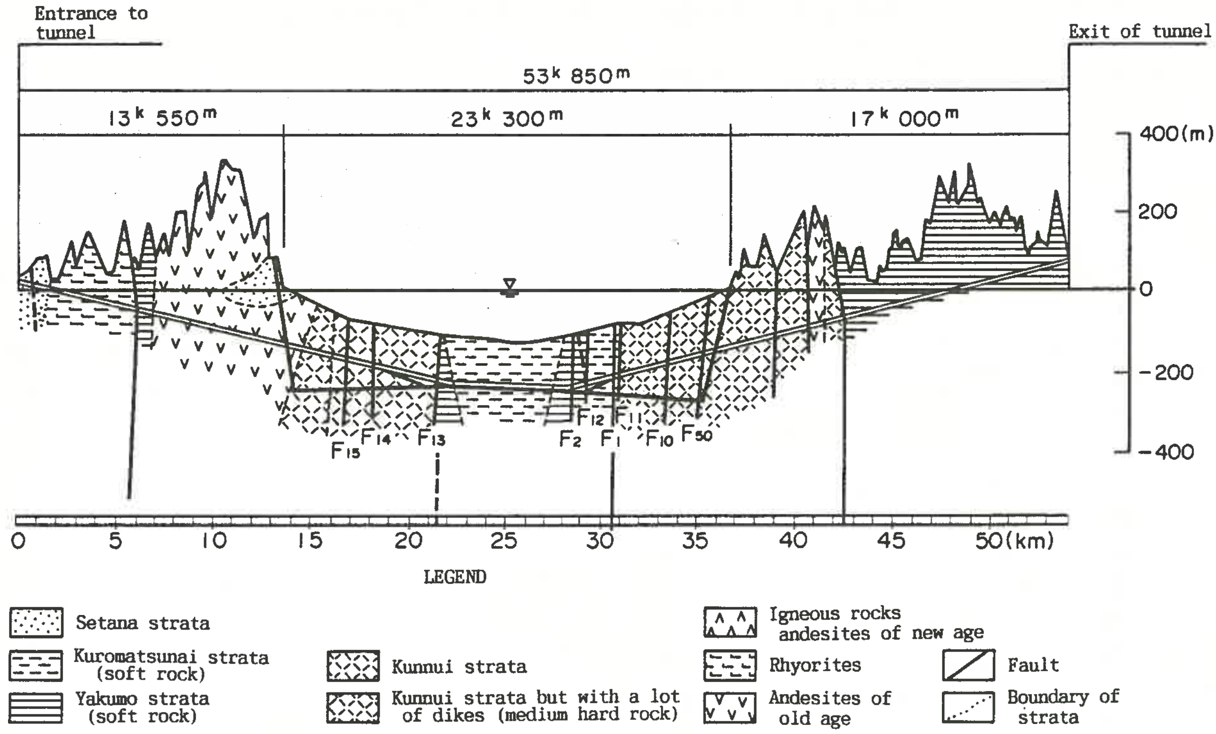


Fig.3 Geological profile of the Seikan Tunnel

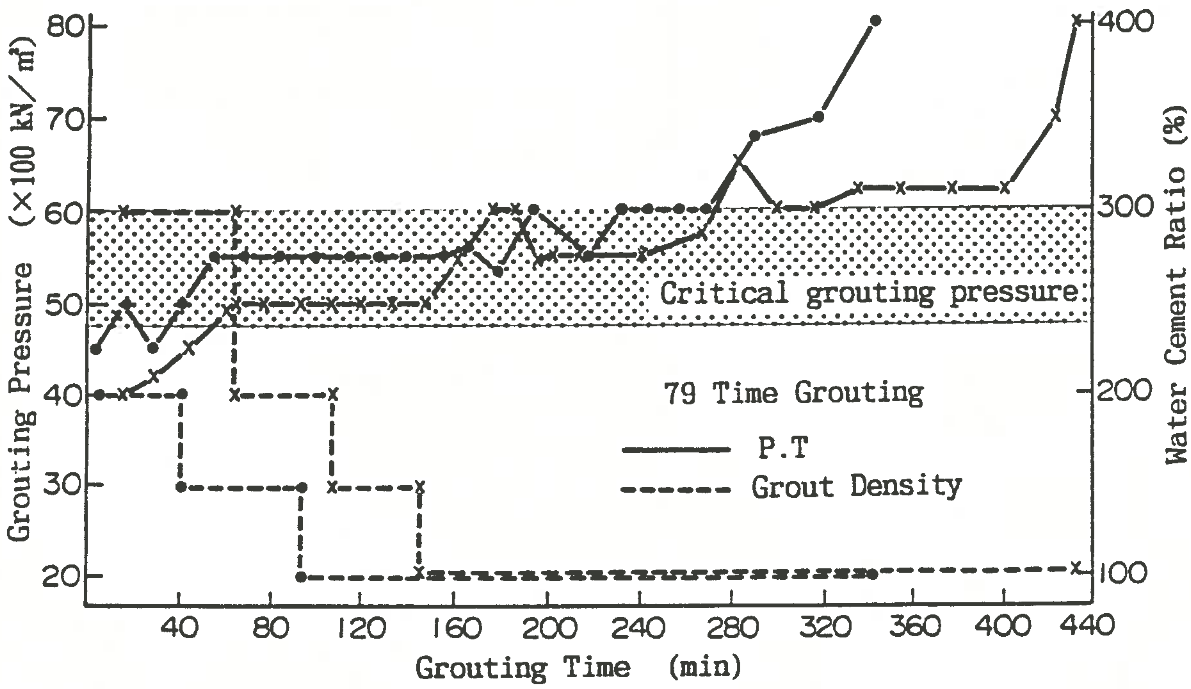


Fig.4 Critical grouting pressure

kind of hydrofructures, in this time, I established some guidelines when grouting the tunnel as follows (A grouting mode curve is shown in Fig.5).

(a) In case of hard rocks where water-ingress flows into the tunnel through fissures of rocks, some 70% of the predicted total quantity shall be grouted so that it is not beyond the critical grouting pressure.

(b) In case of soft strata i.e. fault zone, soft rocks and other bad geological conditions, 70% of the planned grouting quantity may be grouted, after it is beyond critical grouting pressure.

Based on this method, thick veins of hard consolidated grouting materials were made inside the ground. This is one kind of effects for consolidation of ground and consequently geological conditions might be changed becoming more stable than before. This grouting method was very effective not only to seal the most of water-ingress but also to stabilize soft grounds.

In order to analyse such effects, measurements of initial stresses under the ground were carried out inside the Seikan Tunnel by overcoring method and Acoustic Emission method. Table 1 shows the outline of their results though, as you can see in this table, the highest initial stresses were made in horizontal direction, and it seems those directions were harmonized with geotectonic movements between the ocean and the continent, on the other hand, it also shows that total horizontal earth pressure is superior to vertical earth pressure at the measurement points during actual excavation works in fault zone (see Fig.6).

Not only in the Seikan Tunnel, we sometimes faced to the similar result of geotectonic movements at actual constructions of many tunnels in Japan

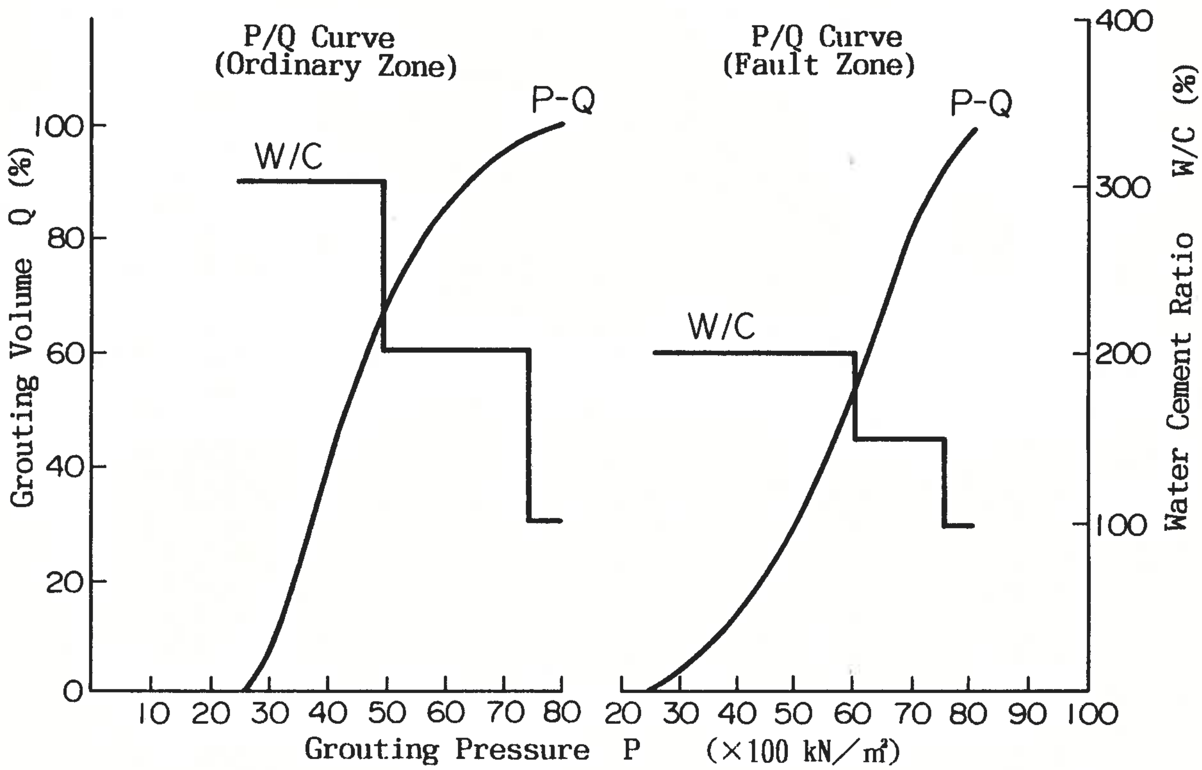


Fig.5 Grouting mode curve

Table 1 Initial stress

	Initial Stress (kg/cm²)	Direction
Main Stress ($\sigma 1$)	100～150	N36° W(Horizontal)
Vertical Stress(σZ)	50～ 70	

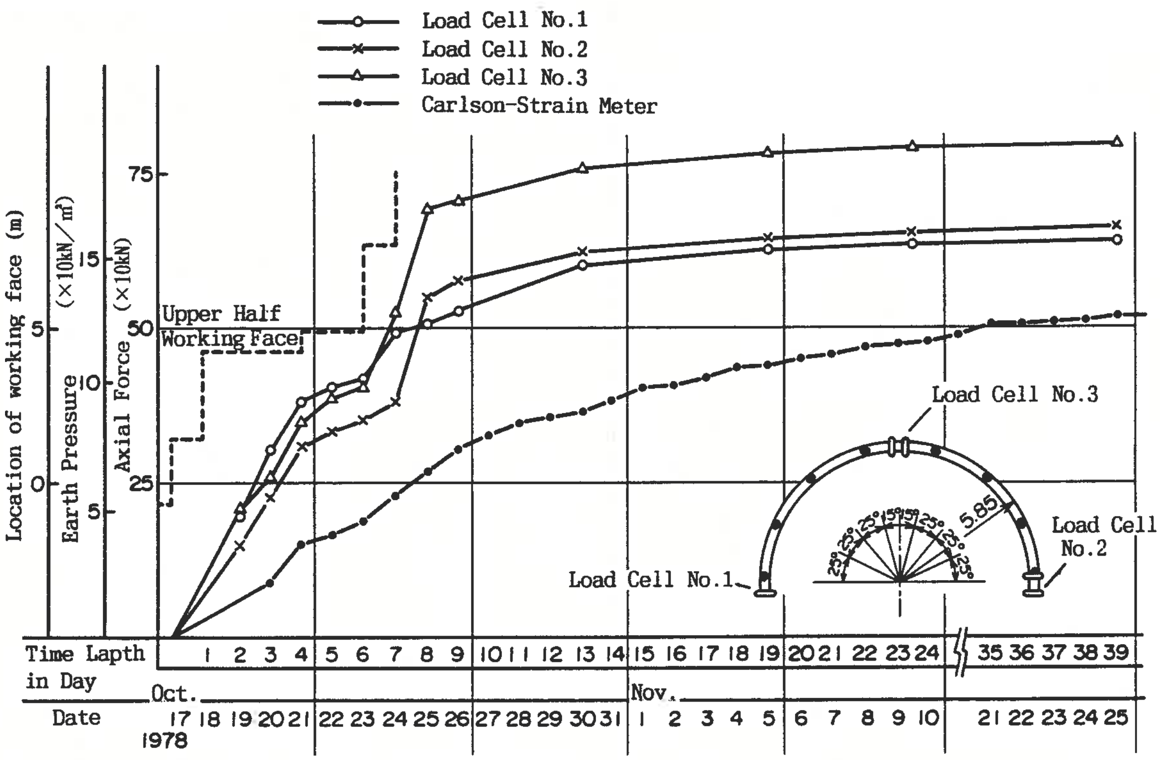


Fig.6 Measured result of earth pressure in upper half

Power Development of The Kurobe River Sysytem and History of Dams

Construction Department.
The Kansai Electric Power Co., Inc.

1. Power Development of the Kurobe River System

The Kurobe River flows from the peaks of the Northern Japan Alps, the most rugged and steepest mountain ranges in the central mainland of the Japanese Archipelago. The river threads its way northward between these peaks, and finally discharges into the Japan Sea. The river has a water course of 86km, a catchment area of 768km^2, and an average gradient of 1/40.

With an annual average precipitation on the basin of about 4,000mm due to extremely heavy snowfall and rainfall, the Kurobe River and its tributaries abound with water flow all year round, and exhibit favorable conditions for extensive hydro power development. Therefore, the Kurobe River had long been considered to be a favorable river system for large-scale hydro power development.

The development program of the Kurobe River system began in 1927, with the construction of the Yanagawara Power Plant in the lower reaches of the river. The development program continued to build power plants upstream in succession. Kurobegawa Power Plants Nos.2, 3, and 4 were thus constructed one after another, with the most upstream plant, No.4, finally completed in 1961.

With the completion of the Kurobe Dam, which is part of the Kurobegawa Power Plant No.4project, it became possible to make the fullest use of the extremely high head available from the main stream of the Kurobe River system. Creation of a large man-made lake with an effective storage capacity of some 150,000,000m^3 also made it possible to redevelop the entire river basin, as it markedly improved the flow conditions in the river.

The redevelopment program of the river system was initiated in 1960, starting from the upper reaches of the river. Shin-Kurobegawa Power Plants Nos. 3 and 2 and the Otozawa Power Plants were constructed in succession, each next to the existing power plants located in tiers along the river. The redevelopment program was finalized in 1985 with the completion of the most downstream Otozawa Power Plant.

After completion of the program, the Kurobe River system became one of the biggest power sources in Japan, as it now comprises 15 peak-load power plants having a combined installed generating capacity of about 910MW.

The power development program of the Kurobe River system was carried out successfully through an all-out effort to overcome the hardships caused by extremely severe natural conditions of the region, while at the same time, exercising all possible environmental considerations in preserving the scenic beauties of the Japanese Central Alpine National Park. This achievement was made possible only by utilization of state-of-the-art technologies and methods available at the time of each phase of the development program.

Of all the hydro power plants and associated facilities built along the Kurobe River system, two major dams, Kurobe and Dashidaira, are both the most interesting and the most representative, containing the features described below.

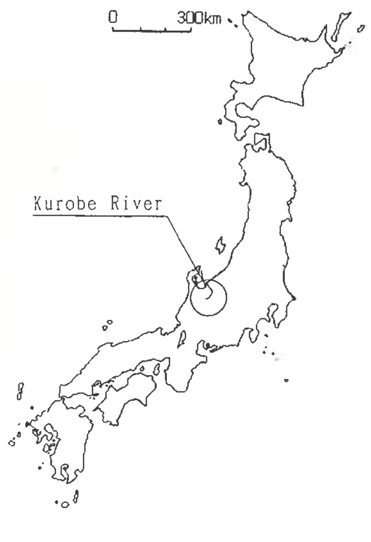


Fig.1 Location of the Kurobe River

2. Kurobe Dam

Kurobe Dam is a 186m high dome-shaped arch dam containing 1,580,000m^3 of concrete. The geological survey of the dam site consisted of a large-scale surface reconnaissance and a massive subsurface exploration. The exploration was carried out by (1)construction of 49 horizontal adits with a total length of 2,700m, (2)drilling of 67 boreholes with a total length of 5,000m, and (3)driving one horizontal adit under the river bed. All these were properly arranged as required in a grid-like fashion.

In parallel with the geological survey, extensive measurements were carried out to determine various characteristics of the rock masses considered to be essential for the design of the dam and associated structures. Field measurements of the modulus of elasticity of the rock masses were extensively implemented by means of static loading and seismic prospecting tests. Laboratory rock tests were also conducted on a large number of borehole cores, mainly to determine the compressive strength of the rock.

It should be mentioned that, as part of the geological survey of the site, a great number of unprecedentedly large-scale in-situ rock tests were carried out. The purpose of these tests was to determine the specific rock behavior important for the design of the structures. The program for these tests was established on the basis of consultations with the Technical Advisory Board appointed for the project by the International Bank for Reconstruction and Development. At that time, the tests were on the greatest scale in the world in terms of their scope, content, and methodology. Even today, they are, in principle, quite comparable with the level and type of rock tests currently in use. Fig.6 and Table 2 illustrate the arrangement of the rock chambers for the in-situ tests and the testing methods used.

It should also be mentioned that various measuring instruments and devices were installed in the dam and in its foundations and abutments to provide information on the behavior of the dam and foundations during the impounding activities. It was ascertained by continuous measurement that the behavior of the foundations and the abutment rock had a great influence on the displacement of the dam structure. For this reason, extensive measurements with high precision instruments have been conducted continuously over a period of about 30 years since the dam was completed.

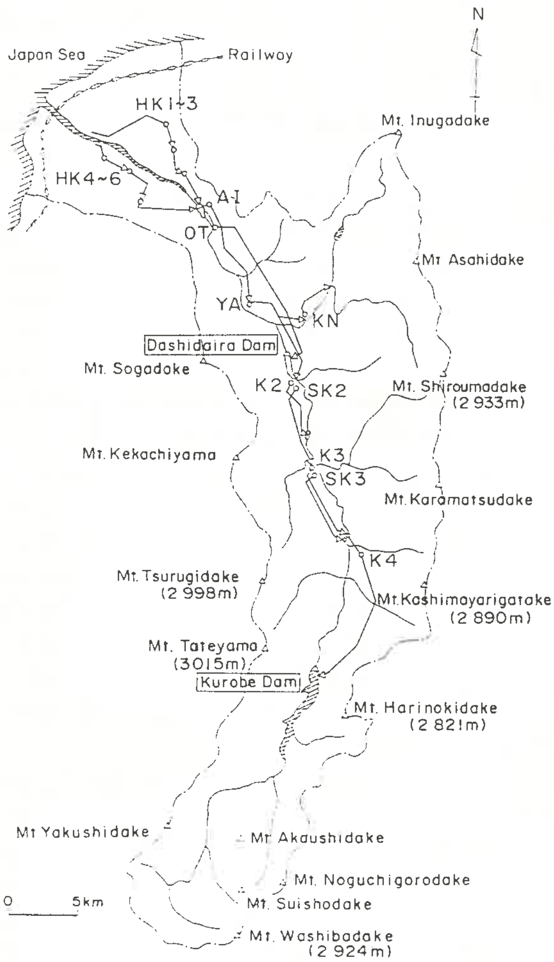


Fig.2 Power Development of the Kurobe River System

Table 1 Hydro Power Plants in the Kurobe River System

Power Plant	Installed Capacity (kw)	Maximum Discharge (m³/sec.)	NetHead (m)	Start of Operation
Kansai Electric				
(K4) Kurobegawa No.4	335.000	72.00	545.50	1961
(SK3) Shin-Kurobegawa No.3	105.000	48.00	269.00	1963
(K3) Kurobegawa No.3	81,000	33.60	278.33	1940
(SK2) Shin-Kurobegawa No.2	74,200	46.00	189.80	1966
(K2) Kurobegawa No.2	72,000	47.20	177.02	1936
(YA) Yanagawara	54,000	50.92	124.58	1927
(KN) Kuronagi No.2	7,600	6.20	152.55	1947
(AI) Aimoto	29,700	50.09	71.52	1936
(OT) Otozawa	124,000	74.00	193.50	1985
Nine Plants	882.500			
Hokuriku Electric				
(H.K) Six Plants	28,280			1926-1936
Total	910,780			

Photo 1 Kurobe Dam - Panoramic View

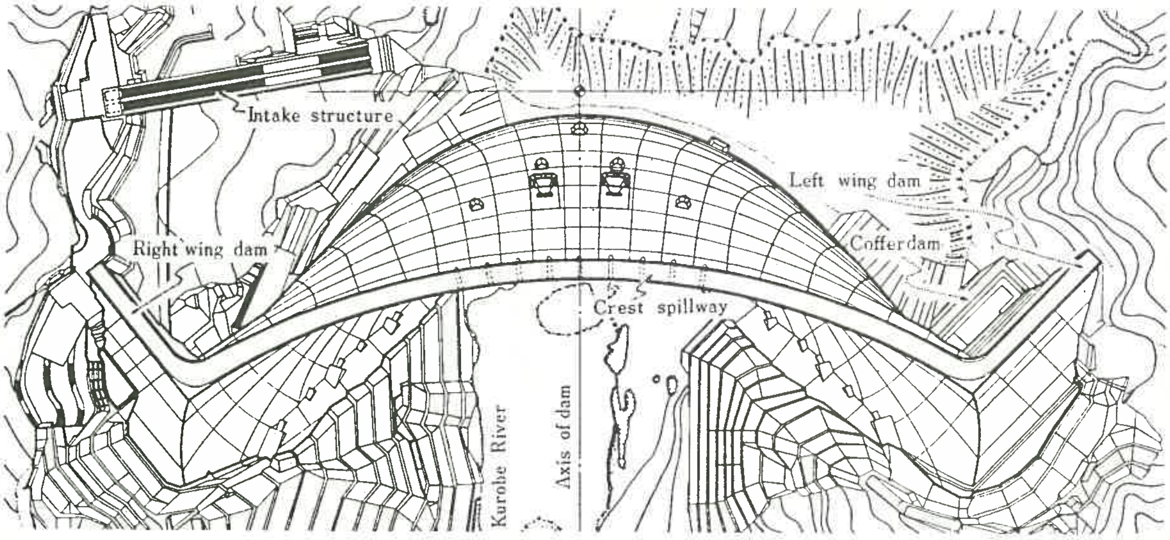


Fig.3 Kurobe Dam - General Plan Outlet Conduit

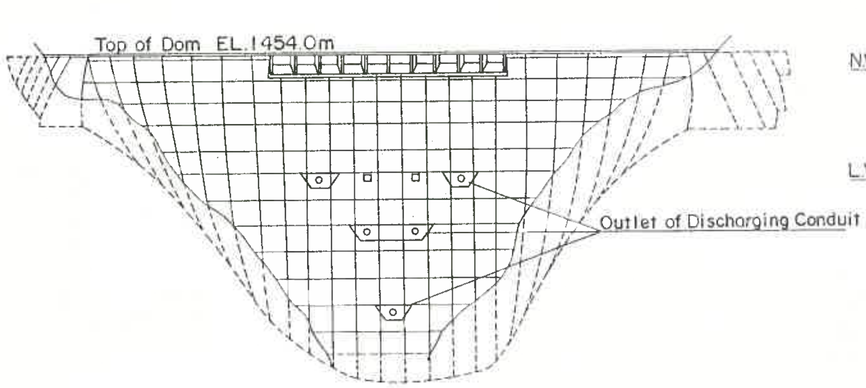


Fig.4 Kurobe Dam - Downstream View Outlet Conduit

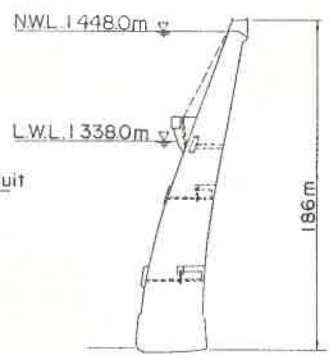
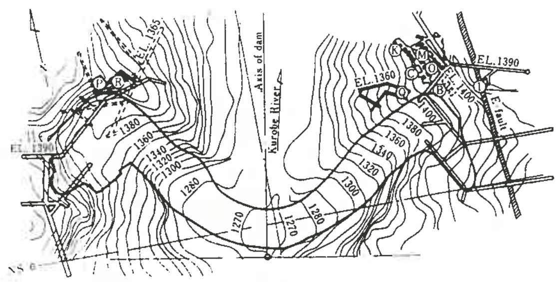


Fig.5 Kurobe Dam - Typical Cross section Outlet Conduit



Chamber	Elevation	Type of test
B	1405 (m)	Block shear test
C	1390	Block shear test
I	1390	Fault triaxial test
K	1390	Fault shear test
M	1390	Rock shear test
O	1390	Rock triaxial test
P	1390	Rock triaxial test
Q	1360	Rock triaxial test
R	1365	Rock triaxial test

Fig.6 Arrangement of Rock Chambers for the In-Situ Tests at the Kurobe Dam Site

Table 2 In-Situ Tests of Rock Behavior at the Kurobe Dam Site

Chamber	Type of test	Principle of test	Location	Number of blocks
B.C	Block shear test		Right bank : EL.1390 EL.1405	6
M	Rock shear test		Right bank : EL.1390	2
K	Fault shear test	Fault	Right bank : EL.1390	2
O.P Q.R	Rock triaxial test		Right bank : EL.1390 EL.1360 Left bank : EL.1390 EL.1365	12
I	Fault triaxial test	Fault	Right bank : EL.1390	3

3. Dashidaira Dam

Dashidaira Dam is a concrete gravity structure, 76.7m high with a concrete volume of 203,000m3. The dam was constructed in the lower reaches of the Kurobe River to create a regulating reservoir for the Otozawa Power Plant.

The most outstanding features of the dam are two sediment dislodging facilities, the largest in scale and the first such type of structures built in Japan. The purpose of these facilities is to ensure undisturbed functioning of the reservoir, by removing silt and sand deposited in the reservoir, which is subjected to heavy sedimentation from the inflow of large quantities of sediment from the upper reaches of the river.

The facilities consist of three different types of gates, a slide gate, a roller gate, and a radial gate, all 5m in width and 4.9m - 5.5m in height. Since the dam has only recently been completed, these facilities have not as yet had an opportunity of removing large volumes of silt and sand.

Another matter which should be mentioned in connection with this project is the speed with which the headrace tunnel, 10.8km long and 5.3m in diameter, was excavated. A distance of 3.4km in the tunnel was excavated at a record-breaking pace of about 400m a month on the average, by utilizing a pilot-reaming-type tunnel-boring machine of German WIRTH manufacture.

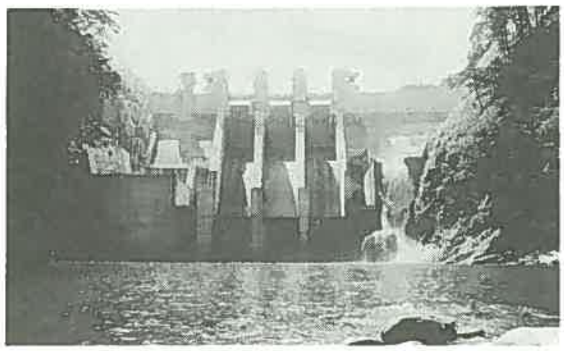


Photo 2 Dashidaira Dam - Downstream View

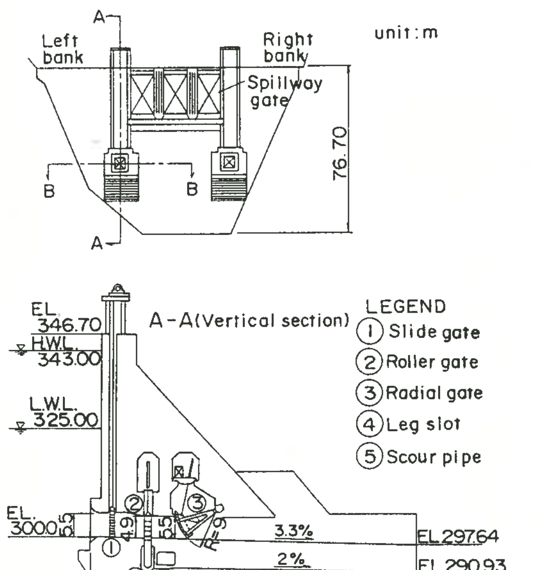


Fig.7 Dashidaira Dam - Typical Cross Section Sediment Dislodging Facilities

Enasan Tunnel of Chuo Expressway

Japan Highway Public Corporation
Taisei Corporation

1. Introduction

The Enasan Tunnel is about 8.5 km in length, penetrates the Central Alps (maximum overburden 1000 m) toward their narrowest portion between Nagano Prefecture and Gifu Prefecture (Fig. 1). Although the Enasan tunnel consists of twin tubes, phased construction was adopted from the viewpoint of economical investment and to meet increased demands of traffic volume. The first tunnel was completed in August 1975 and took eight and a half years while the second tunnel was opened to traffic in March 1985 after seven years of construction.

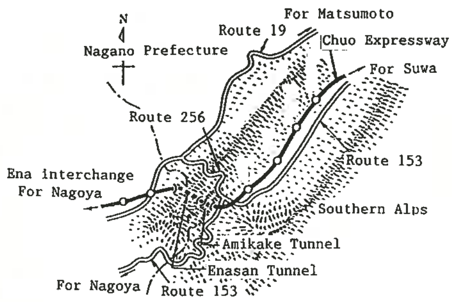


Fig.1 Location map of Enasan tunnel

A drain effect was expected on the second phase but there was still a lot of water inflow. For the ventilation system of Phase 2, a longitudinal flow ventilation system was applied instead of the lateral flow ventilation system used in Phase 1.(Fig.2)

2. Geotechnical Considerations

2.1. Introduction

The Enasan Tunnel is located near the eastern extremity of the Atera fault (active) and to the west of the Median Tectonic Line. The maximum overburden is about 1000 m and the ground water head is also high (Fig.3).

The presence of these conditions means special measures had to be taken to handle water inflow at a maximum pressure of 50 bar, and plastic pressure reaching 100 tf/m^2.

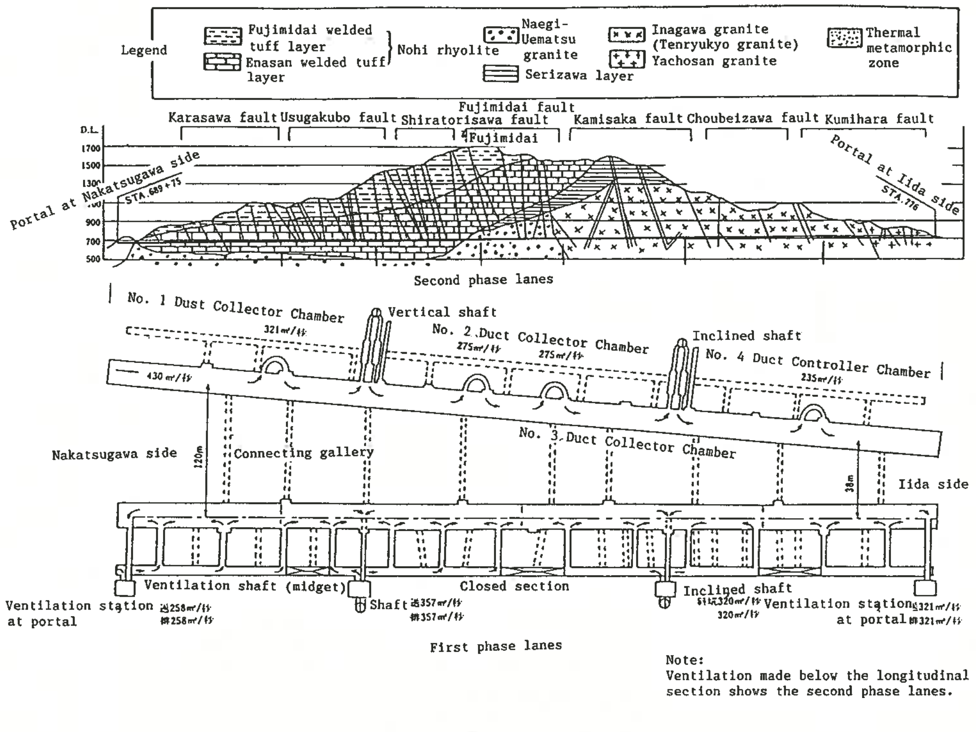


Fig.2 Ventilation system

2.2. Seismic Prospecting and Tunnelling

Rock classification, part of the preliminary survey, was mostly achieved by seismic prospecting, using the refraction method from the ground surface, and the results did not always match the conditions encountered at the time of execution. For this reason, seismic prospecting fan shooting method, well shooting method, and others were carried out using to investigate the cause of difference between them and made Fig. 4 as a result.

This approximately matches the elastic wave velocity obtained prior to the work assuming that the Vf of the material (water and crushed rock) filling the fissures is about 2000 m/sec. It also meant that the value would decrease to less than half after dewatering result from tunneling excavation. In other words, in order to explain the actual conditions encountered during excavation, most of sections are crushed zone which velocity is less than 2000 m/sec.

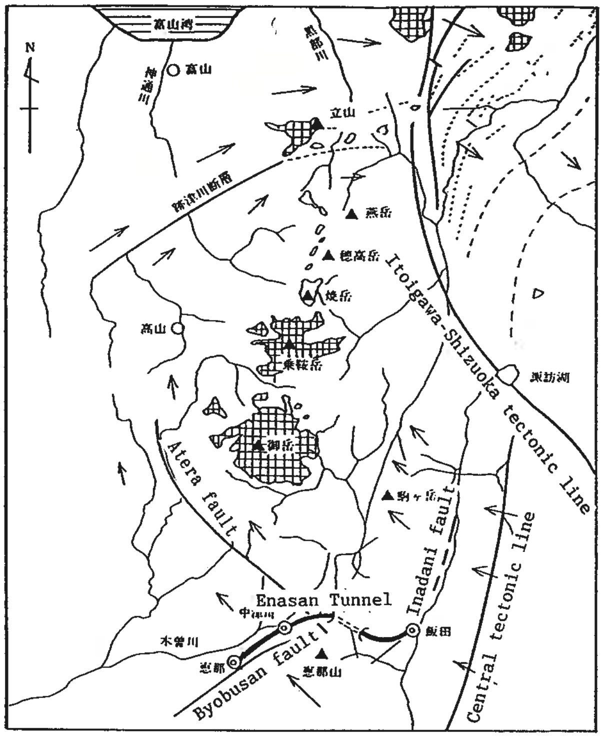


Fig.3 Geology of Enasan Tunnel and its peripheral areas (Yoshio NISHINA :Block upheaval of Hida Mountains and Adera fault)

$$\frac{1}{Vt} = \frac{n}{Vf} + \frac{1-n}{Vm}$$

n : mixing ratio (%)
Vt : measured sound speed (km/sec)
Vf : velocity of material filling fissures (km/sec)
Vm : velocity of original rock (6.0 km/sec)

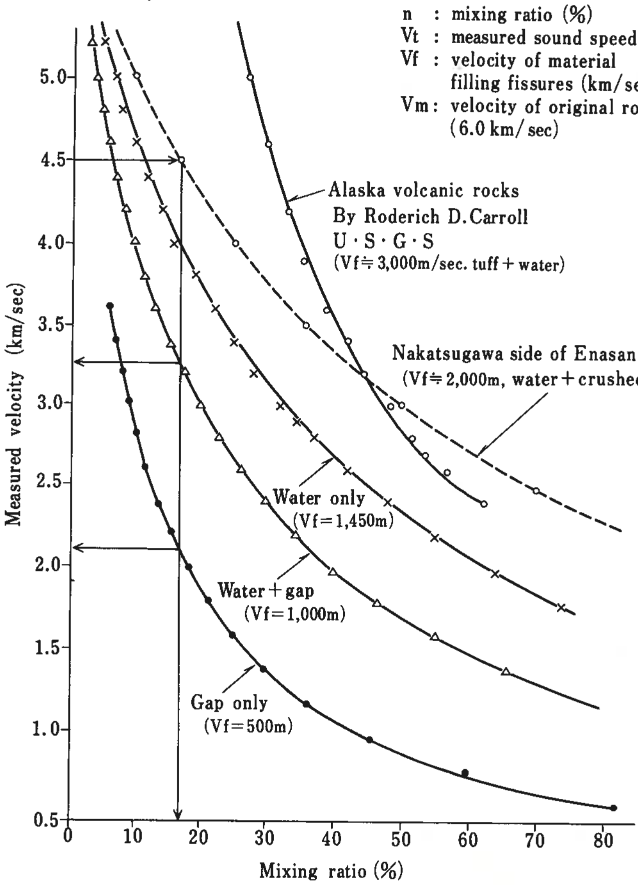


Fig.4 Sound speed-mixing ratio

The conditions at the Nakatsugawa side of the first tunnel is now described. Since the ground water head reached a maximum of 50 bar, when water was not well drained from the pilot drift, faces and surrounding walls collapsed frequently. This led to liquefaction of the collapsing earth and rock and a debris flow in the tunnel.

Although it was originally planned to precede with a pilot tunnel and perform drain boring, it actually became necessary to provide a drain tunnel (small section) in the pilot tunnel as the water pressure rose and, additional drain tunnels had to be excavated when conditions were very poor.

2.3. Plastic Pressure

The ratio (qu/γh) between VCS of rocks surrounding tunnel and overburden in the Choubeizawa fault was found to be much smaller than anticipated, and plastic flow was encountered. The overburden h was 240-350 m (trial calculation assuming γ = 2.1 tf/m^3, γh would be 504 tf/m^2 - 735 tf/m^2).

On the other hand, the uniaxial compressive strength of the ground, qu, was 200 tf/m^2 - 300 tf/m^2, from which the value of qu/γh is calculated as follows:

(a) h = 240 m qu/γh = 0.4 to 0.6

(b) h = 350 m qu/γh = 0.27 to 0.4

The design of the lining through the Choubeizawa fault differed between the two phases because of advancements in technology (Fig. 5).

In the case of the first tunnel, abnormal rock pressure loaded on the support. To sustain the huge vertical load on arch shaped structure, a primary lining (700 mm in design thickness), a secondary lining (500 mm in design thickness), and the side drift substitution method was used. However, as disturbances such as settlement of the arch crown occurred during excavation, the secondary lining was replaced with SFRC as one of the various measures taken (steel fiber 118 kg/m^3, cement 600 kg/m^3). For the second tunnel, NATM was applied for a trial section. The original design had 6 m long rockbolts. Since the deformation did not stop, 9 m and 12 m long rockbolts were added.

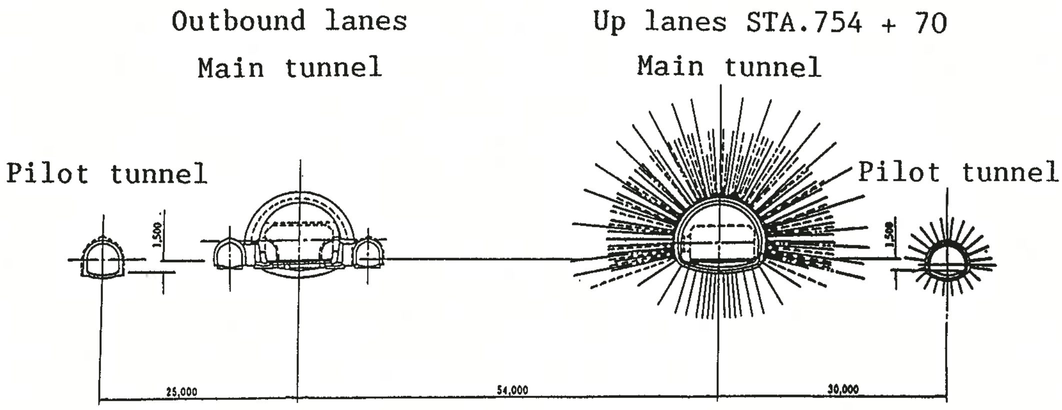


Fig.5 Layout of second tunnel and first tunnel of Choubeizawa fault

Kan-etsu Tunnel, the Longest Highway Tunnel in Japan

Japan Highway Public Corporation
Taisei Corporation

1. Summary

The Kan-etsu Expressway is an approximately 300 km long national highway which connects Niigata and Tokyo. (Fig. 1)

Because the border between Gunma and Niigata prefectures is very mountainous, construction costs were very high so this section was initially put into service with just two lanes. Traffic jams were common at the point where 4 lanes narrowed down to two on Sundays and holidays when the traffic volume peaked. So for this reason, construction of Phase II lanes (11,010 m) of the Kan-etsu Tunnel commenced in June 1986. Completion is scheduled for November 1991 and work has progressed smoothly, so the final stage of finishing work has been reached.

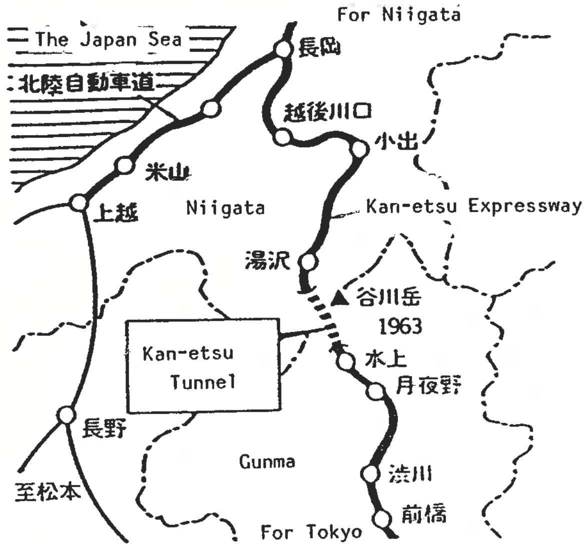


Fig.1 Location map

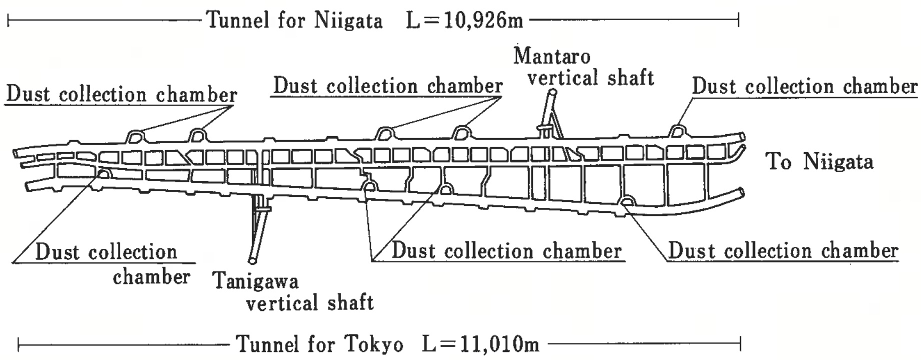


Fig.2 General plan of the tunnel

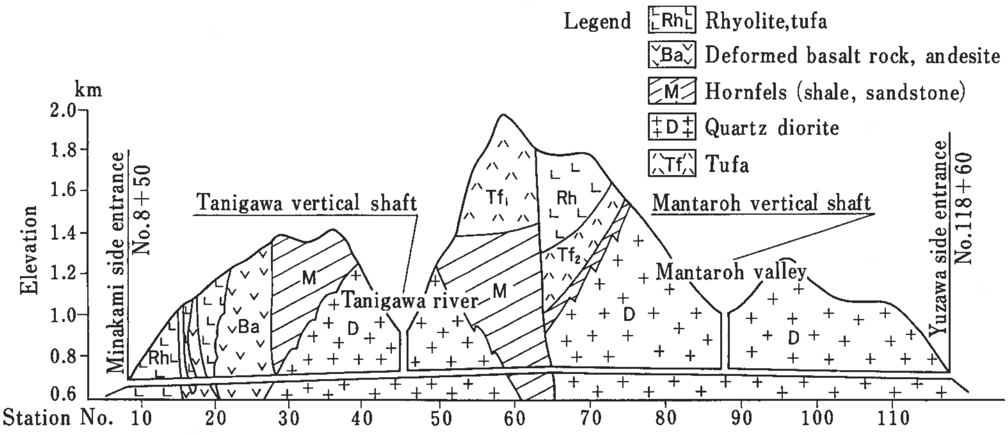


Fig.3 Geological vertical chart

2. Geology of Kan-etsu Tunnel

The geological formation in this area consists largely of quartz diorite and hornfels (shale, sandstone with thermal meta-morphism). (Fig. 4)

As the rockbed sustained complex orogenic movement, it was thought that considerable stress still remained in the ground, and this was verified by the occurrence of rockbursts as seen in the case of Daishimizu Tunnel.

3. Ventilation Design

In the Phase I tunnel, a vertical shaft feed and vertical exhaust flow ventilation system using electric dust collectors was adopted for the first time to reduce construction and maintenance costs. The same ventilation system was adopted for the new tunnel except that the number of dust collection chambers is reduced by one. (Fig. 5)

4. Tunnel Excavation

Excavation of the Phase I tunnel took about 4 years and 6 months. But in the Phase II tunnel, excavation was completed within 3 years.

A full-face driving method same as Phase I was adopted. While in the case of the Phase I tunnel the conventional support system based on rockbolts with wire mesh or steel supports was used, the NATM with shotcrete and rockbolts was adopted for the Phase II tunnel.

In Phase I, mucking was done by large dump trucks and the muck was temporarily stayed in the tunnel, but in Phase II, the container method was adopted to improve workability and the working environment. It was decided to use a wheel loader (4.2 m^2) for loading and large capacity containers (21 m^3) for haulage.

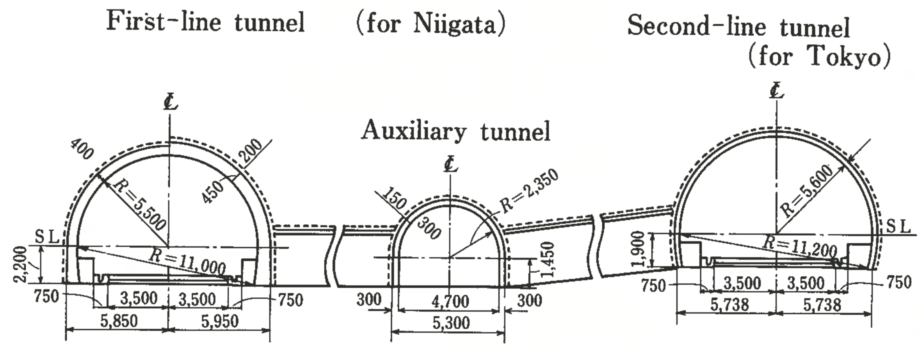


Fig.4 Typical cross section

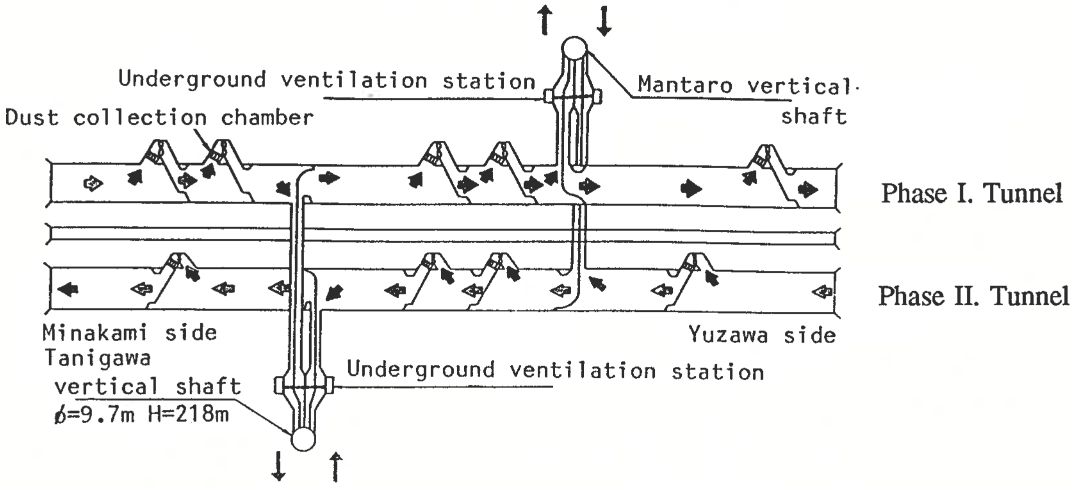


Fig.5 Ventilation plan

5. Measures to Cope with Rockbursts

In the section between 4,300 m and 5,400 m from the portal on the Yuzawa side, rockbursts were experienced in the Phase I work. At that time, the overburden was approximately 700 m.

In the case of the Phase II work, AE measurements were taken for the purpose of predicting rockbursts. This is a method which predicts the magnitude of rockbursts by detecting the minute breaking vibration in the rockbed which precede rockbursts using a a high-sensitivity accelerometer. The frequency of breaking vibration is used as a measure. The accelerometer was installed in a borehole drilled toward the main tunnel from the auxiliary tunnel and the cable was led to the Contractor's office and connected to a recorder for automatic monitoring. A correlation was seen between the magnitude of breaking vibration and rockbursts, thus helping in the prediction of rockbursts.

The magnitude of the predicted rockbursts was classified into 3 stages. At the face where the rockbursts were predicted to be the greatest in magnitude, face shortcrete (t=5cm) and friction type rockbolt (length=4m, 22 pieces/face) were executed on the face, carrying out full face excavation with one advance length 2 m.

Support system consisted of steel fiber shotcrete (t=5cm) and rockbolts for rockbursts section was successfully accomplished.

6. Ventilation System for Construction

Although measures were taken to reduce the needed ventilation volume, such as adopting the container method of mucking, ventilation of about 3,000 m^3/min of the face and totally 5,000 m^3/min in the tunnel was needed. It would be practically difficult to supply such air volume using ventilation tube duct, fresh air from the auxiliary tunnel was used for ventilation.

7. Vertical Ventilation Shafts

Two ventilation shafts were constructed in the Phase I work. The diameter of each was 9.7 m and they were 220 m and 230 m deep, respectively. The pilot tunnels for these shafts were excavated upwards using an Alimak climber and then enlarged from the top downwards. Using this method, it became possible to excavate ventilation shafts by hauling out muck through the auxiliary tunnel and main tunnel without constructing of access roads in the National Park.

8. Development of Phase II Work

The average advance rate of the main tunnel was about 150 m/month. The reasons for this good progress can be summarized by:

(a) The operation of the large equipments was smooth as planned.

(b) The water inflow at the face was less than anticipated.

(c) There were relatively little down-time at the face work because the excavation work and the mucking were done by different teams.

(d) The rockburst section was successfully excavated, almost without interruption.

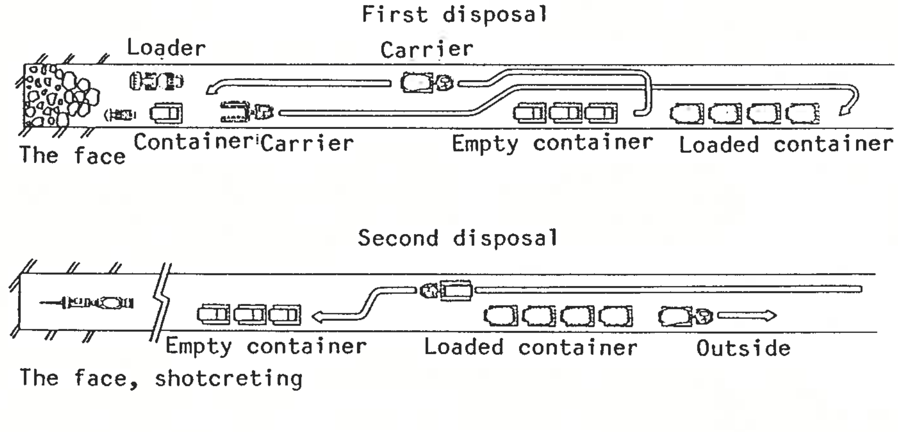


Fig.6 Mucking illustration

History of Underground Power Stations

Tokyo Electric Power Co.

1. Introduction

The history of underground power stations in Japan began with the 51MW Uryu Power Station of The Hokkaido Electric Power Co., which began construction in December 1937 and was completed in August 1943. In the ensuing 53 years until now, underground power stations have been or are being built at 51 sites (see Fig. 1, Table 1).

These 53 years from 1937 to 1990 can be divided into the four periods shown in Fig. 2.

The first period covers the years from 1937 to around 1950, the pre-war and chaotic early post-war years.

In the second period, potential electric power sources were eagerly sought to meet the anticipated demand for power that would support economic restructuring and trigger the explosive economic growth that followed. The power stations constructed during this period were conventional hydro-electric types which grew larger with time. This period covers the timeframe from 1950 to around 1965.

The third period is characterized by the rapid economic growth of Japan. The escalating demand for electric power and the predominant construction of thermal power plants made the introduction of many pumped storage power stations reasonable to take advantage of the excess night-time capacity. Most of the large hydro-electric power stations built during this period were of the pumped storage type, which became progressively larger in size. This period ran from around 1965 to 1975.

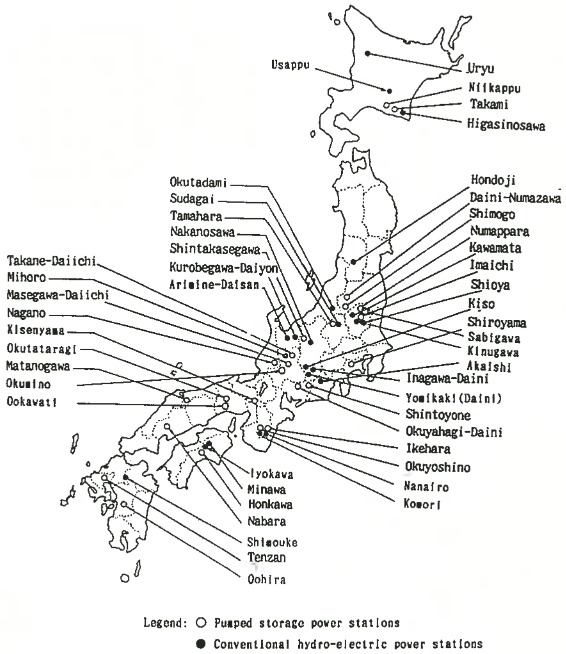


Fig.1 Locations of Underground Power Stations

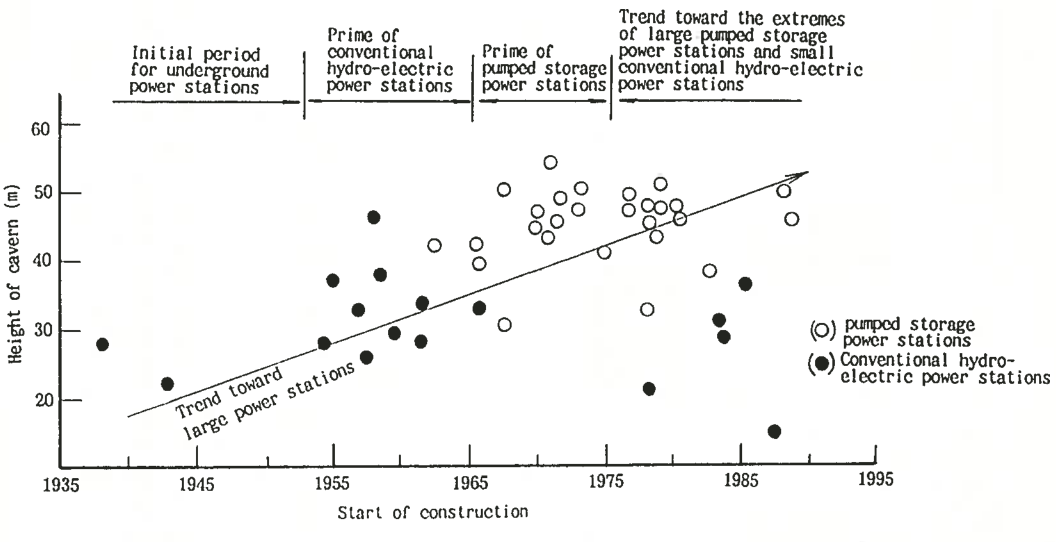


Fig.2 Changing Height of the Underground Cavern

Table 1 Outline of Underground Power Stations

(1) Pumped Storage Power Stations

Name of Power Station	Installed Capacity ($\times 10^3$ KW)	Shape of Cavern (※1)	Size of Cavern (m)			Volume of Excavation (m3)	Depth of Over burden (m)	Start of Constructi-on
			Height	Width	Length			
Shiroyama	250	MS	38.0	20.0	133.0	100000	200	1961.12
Ikehara	350	〃	42.5	20.3	122.0	94000	71	62.3
Nagano	220	〃	42.3	20.1	70.1	61000	147	65.4
Takane-Daiichi	340	〃	40.4	19.4	89.0	50994	120	65.5
Kisenyama	466	〃	51.0	25.6	60.4	77816	250	67.3
Shintoyone	1125	〃	46.5	22.4	140.5	140000	220	69.11
Numappara	675	〃	45.5	22.0	131.0	97000	250	69.12
Niikappu	200	〃	43.4	19.8	50.8	43000	110	70.8
Oohira	500	〃	45.4	22.0	82.8	79100	280	71.5
Okutataragi	1212	〃	49.2	24.9	133.4	145200	240	71.6
Shin-Takasegawa	1280	〃	54.5	27.0	165.0	211700	250	71.11
Nabara	620	〃	47.7	25.0	85.6	81900	180	72.11
Masegawa-Daiichi	288	〃	50.6	23.2	57.4	57700	117	73.2
Okuyoshino	1206	〃	41.6	20.1	157.8	128200	180	75.1
Tamahara	1200	〃	49.5	26.6	116.3	143970	240	76.7
Okuyahagi-Daini	780	〃	47.8	22.4	103.3	101301	340	76.8
Daini-Numazawa	460	〃	47.6	26.0	96.5	91800	160	77.8
Shimogou	1000	〃	45.5	22.0	171.0	133000	120	77.12
Honkawa	600	〃	47.4	24.3	98.0	89700	270	78.10
Takami	200	〃	43.3	21.5	55.0	44950	220	78.12
Imaichi	1050	HS	51.0	33.5	160.0	197400	400	79.10
Tenzan	600	MS	48.0	24.0	89.0	95200	500	79.12
Matanogawa	1200	〃	46.2	23.5	155.0	157000	350	80.3
Okumino	1000	〃	37.8	17.5	126.0	102300	350	85.3
Sabigawa	900	〃	51.1	29.0	165.0	191100	200	87.9
Ookawachi	1280	WH	46.7	24.0	134.5	122600	263	88.3

(2) Conventional Hydro-electric Power Stations

Name of Power Station	Installed Capacity ($\times 10^3$ KW)	Shape of Cavern (※1)	Size of Cavern (m)			Volume of Excavation (m3)	Depth of Over burden (m)	Start of Constructi-on
			Height	Width	Length			
Uryu	51	MS	28.0	15.0	51.0	25200	20	1937.12
Iyokawa	6	〃	23.3	7.3	14.5	4600	20	42.2
Sudagai	46	〃	28.3	15.0	54.3	21500	74	53.11
Okutadami	360	〃	37.8	17.5	85.6	70500	110	54.12
Kurobegawa-Daiyon	335	〃	33.9	22.4	119.4	101200	160	56.8
Minawa	7	CD	25.9	12.0	12.0	5600	13	57.5
Mihoro	215	MS	45.8	22.5	78.0	58700	243	57.6
Yomikaki(Daini)	70	〃	38.1	17.6	33.8	22448	100	58.11
Usappu	25	〃	29.9	14.4	22.4	9610	20	59.5
Shioya	9.2	CD	28.6	17.2	17.2	6395	43	61.4
Kawamata	27	MS	34.1	17.1	33.2	13090	80	61.4
Kinugawa	127	〃	35.0	19.5	46.2	28481	63	61.4
Kiso	116	〃	33.6	16.9	39.0	21800	220	65.5
Ootumata	38	〃	28.4	19.0	19.0	14909	90	65.12
Nakanosawa	42	〃	32.7	15.6	25.6	12900	105	77.12
Arimine-Daisan	20	HS	20.8	14.6	30.0	7400	63	78.4
Hondouji	75	MS	38.7	19.8	38.0	21200	150	82.5
Inagawa-Daini	21.6	HS	31.7	16.5	25.1	11400	200	83.5
Higashinosawa	20	MS	29.4	26.0	15.0	11250	39	83.7
Akaishi	39.5	〃	14.9	15.0	27.0	18548	70	87.3

(※1) Shape of Cavern MS :Mushroom-shaped CD :Circular dome-shaped
HS :Horseshoe-shaped WH :Warhead-shaped

The fourth period came after the prime of constructing underground power stations. Few suitable sites were left in Japan for hydro-electric generation, and the growth of power demand had tailed off. These facts resulted in a temporary standstill for the construction of power stations during this period. The newly constructed power stations could be clearly grouped into the large pumped storage type and small conventional hydro-electric power stations.

2. Trends in Size and Shape of the Underground Caverns

Typical caverns employed to accommodate the underground power stations in the first and second period had a height of 30 to 40 meters, a cross-sectional area of 400 to 1000 square meters, a depth of over burden of up to 150 meters, and were usually in the shape of a mushroom.

The years from the third period till now saw large caverns having a height of 40 to 50 meters and a cross-sectional area of 800 to 1400 square meters. A typical underground power station constructed in this period is the 1280MW Shintakasegawa Power Station, which, with work commencement in 1971, is as yet the greatest in output and size in Japan with a 54.5-meter-high cavern and 210 thousand cubic meters of rock excavated for it (see Fig. 3).

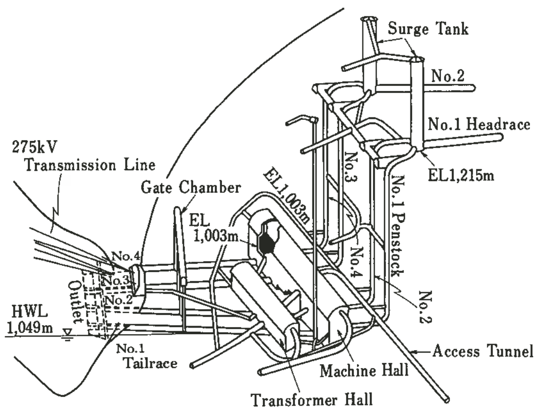


Fig.3 Perspective of Underground Power Station (Shintakasegawa)

As cavern sizes were increasing -- involving 100-to-500-meter-deep over burdens and high initial stress -- thorough studies were required to ensure stability of the cavern. Advancement these years in procedures and techniques for analyzing geologic behavior during cavern excavation work as well as PS anchors and shotcrete of higher reliability as a result of advanced construction techniques have made larger horseshoe-shaped caverns with higher dynamic stability viable, such as the Arimine No. 3 Power Station and Imaichi Power Station. Fig. 4 shows the difference in results of FEM visco-plastic analysis depending on the cavern shape: the horseshoe-shaped cavern shows a smaller displacement and a narrower loosened zone, and therefore higher stability than the mushroom-shaped cavern does. How the size and shape of caverns of Tokyo Electric Power Co. have changed over time is shown in Fig. 5.

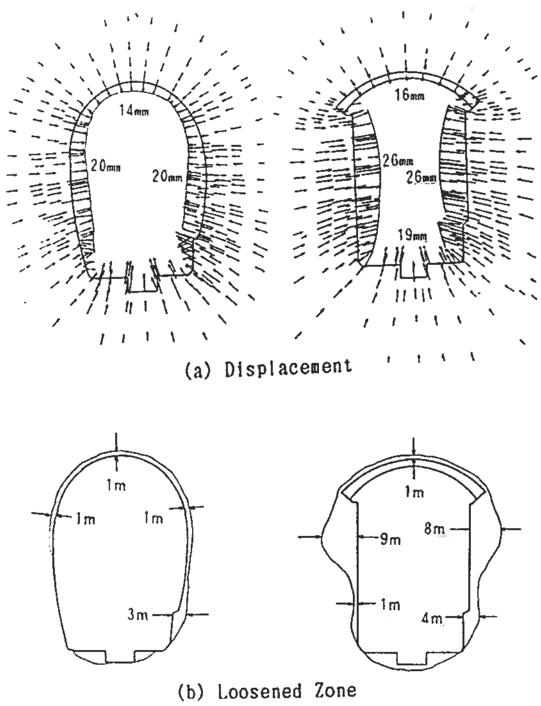


Fig.4 Results of FEM Analysis

In the fourth period, there were few sites left in Japan with uniform geological conditions over the whole site which were suitable for constructing underground power stations. Some sites available for power stations today may be accompanied by abrupt changes in geological conditions and others by unexpected faults. The extremely complicated geology of Japan often necessitates extensive measurements to be conducted during excavation work. Thus, displacements of the bedrock and concrete lining expected based on prior FEM visco-plastic analysis to occur during excavation work are compared in many cases with measurements taken during the work to successively review the pattern of PS anchors. Such a careful check system today contributes greatly to higher stability of the cavern and smoother progress of construction work, e.g. for the Sabigawa pumped storage power station now under construction.

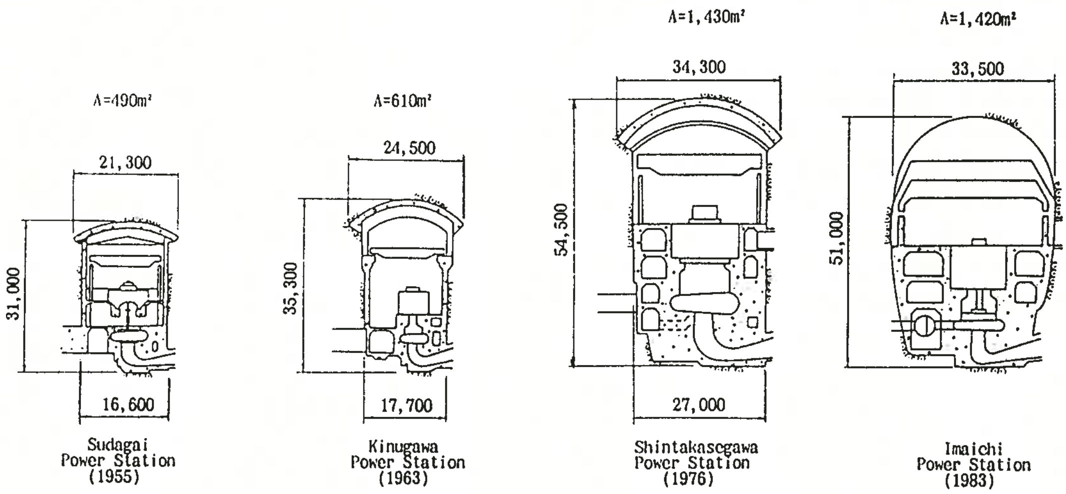


Fig.5 Underground Power Stations of Tokyo Electric Power Co. of Increasingly Larger Size

An Investigation of Geomechanics and Hydoraulics at Kikuma Underground Crude Oil Storage Demonstration Plant

Kuniichiro MIYASHITA *, *Kenji AOKI* **, *Tetuya HANAMURA* † *and Takehiko TAKADA* ††

* Shimizu Corporation, ** Kajima Institute of Construction, † Taisei Corporation, †† JGC Corporation

1. Introduction

In order to investigate the applicability of underground petroleum storage system in Japan where the geological structure is rather complex, a demonstration plant was constructed in Kikuma, Ehime prefecture from March, 1980 through December, 1981. The plant comprises a horizontal water curtain type underground crude oil storage cavern of 25,000 kl in capacity. The operation of receiving and loading crude oil for the cavern was conducted from April, 1982 through October, 1984. A series of investigations on geomechanics and hydoraulics was carried out at the plant from the begining of the construction to December, 1990, which lasted no less than 6 years after the operation of crude oil. Various data on mechanical and hydraulic behavior of the bedrock surrounding the storage cavern were obtained. This paper shows the results of the investigations.

Fig.1 The Location of The Demonstration Plant Site

2. Outline of the Investigation

The demonstration plant is located at the northern end of Takanawa Peninsula, northwest of Shikoku Island (Fig.1). The northern half of the Takanawa Peninsula, which includes the site, belongs to the Ryoke metamorphic belt, and most of the area consists of granitic rocks. The fresh rock is hard and fine grained. There are no major faults and fracture zones in the area, the largest being about 50 cm in width. There are two predominant fractures in the NE-SW and NW-SE strikes respectively at a steep angle of 50-90^{0} dipping toward NW and SW. The boundary between the weathered and fresh zones is located at EL +15m to -6m gently dipping towads the sea in the direction of west to southwest. The underground water level runs within the weathered zone substantially parallel to the boundary.

The storage cavern is 15m W × 20m H × 112m L and located at the depth of EL -42m to -62m. The water tunnel and the water borings

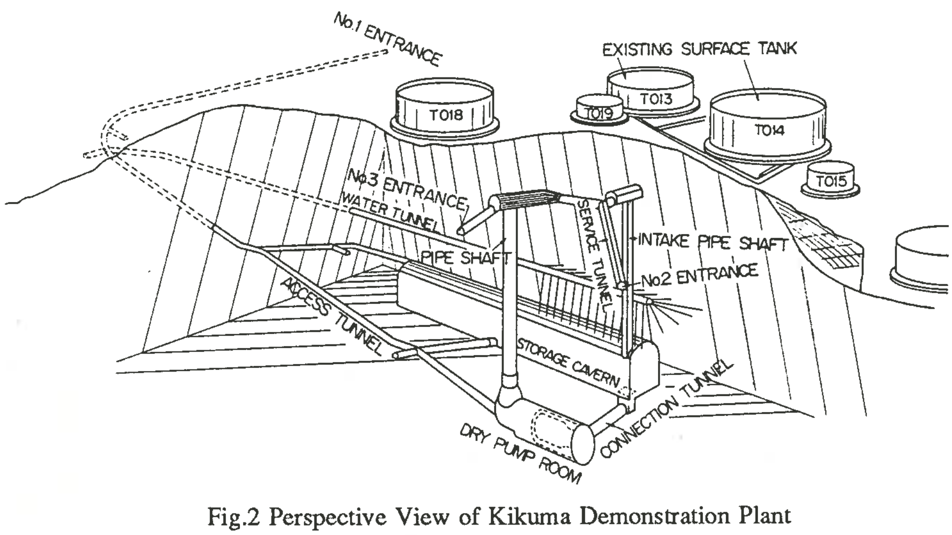


Fig.2 Perspective View of Kikuma Demonstration Plant

were designed to prevent the lowering of the groundwater level and to confirm the effect of the water used to confine the oil. The water tunnel is 4.0m W × 4.0m H and the floor is located at EL -25.8m (Fig.2).

The investigations were roughly divided into three stages. The first is the preliminary studies which were conducted prior to the excavation of the cavern. The second is those conducted during the construction and the operation, and the last is those conducted after the operation of oil.

The preliminary studies include various loggings and tests using the boreholes around the storage cavern and in-situ shear tests, deformation tests and initial stress measurements in the test tunnel branching from the access tunnel.

The second studies include continuous measurements of the ground water level and pore pressure around the cavern using the same boreholes, geological observations and measurements of convergence, deformation of rock, axial stress of rock bolts and permeability of rock around the storage cavern.

The last studies include continuous measurements of the ground water level and pore pressure around the cavern, and measurements of deformation of rocks and axial stress of rock bolts.

Table 1 List of Investigation Items and Quantities

Object		Items	Actual Quantities	Purposes & Content
Preliminary investigation	Boreholes	Electric logging	11 holes , total of 822m	Weakened and crashed zones and aquifer bedrock
		Seismic logging	5 holes , total of 390m	Seismic wave velocity and find out hardness of bedrock
		Density logging	5 holes , total of 437m	Bedrock density and the degree of crashing
		Sonic wave logging	3 holes , total of 272m	Development of fissures , and presence of crashed zones
		Radioactivity logging	3 holes , total of 271m	Argillized and crashed layers of bedrock
		Caliper logging	3 holes , total of 274m	Location of crashed zone of bedrock
		Observation by borehole TV	11 holes , total of 325m	Thickness of weathered layer , and find out distribution of density & direction of fissures
		Measurement of groundwater velocity & direction	3 holes , total of 55 points	Direction and velocity of groundwater
		Seepage measurement	1 hole , total of 6m	Permeability and pore pressure applied on bedrock
	Test tunnel	Rock shear test	4 blocks	Shear strength , angle of friction and residual shear strength of rock
		Rock deformation test	3 places	Modulus of deformation and creep factor of rock
		Measurement of initial stress in rock (O.C.method)	3 directions , total of 9 points	Initial stress of bedrock for determination of cavern arrangement
		Measurement of initial stress in rock (A.E.method)	3 directions , total of 90 test pieces	
Investigation during construction	Boreholes	Observation of groundwater level	20 holes	Groundwater level and its monitoring
		Observation of pore pressure	15 holes , 53 points	Pore pressure of bedrock , and to monitor if predetermined validity of water curtain is obtained or not
	Crude oil cavern	Measurement of convergence of the cavern	3 cross sections , total of 15 lines	Relative displacement inside cavern walls , and to study its stability
		Measurement of rock displacement	3 cross sections , total of 74 points	Displcement of rock around the cavern , and to study its stability
		Measurement of rock bolt axial stress	2 cross sections , total of 44 points	Axial stress in the rock bolts , and to study arrangement and length of rock bolts
		Permeability test	7 holes , total of 35 sections	A limit of loosening zones around the cavern , and to study its stability
Investigation during and after operation	Boreholes	Observation of groundwater level	20 holes	Groundwater level and its monitoring
		Observation of pore pressure	15 holes , 53 points	Pore pressure of bedrock , and to monitor if predetermined validity of water curtain is obtained or not
	Crude oil cavern	Measurement of rock displacement	1 cross sections , total of 24 points	Displacement of rock around the cavern , and to study its stability
		Measurement of rock bolt axial stress	1 cross sections , total of 36 points	Axial stress in rock bolts , and to study stability of the cavern

Table 2 Results of In-situ Shear Test and Deformation Test

Rock shear test	Shesr strength τ_R		40 - 50 (kg/cm²)
	Angle of internal friction ϕ		55 - 60°
Rock deformation test	Modulus of Elasticity	Tangent modulus E_T	12.4×10^4 (kg/cm²)
		Cutting modulus E_S	6.5×10^4 (kg/cm²)
	Deformation modulus D		6.8×10^4 (kg/cm²)
	Creep coefficient	α	0.109
		β (1/hr)	0.250

Items, objectives and methods of measurements of these studies are shown in Table 1.

3. Preliminary Studies

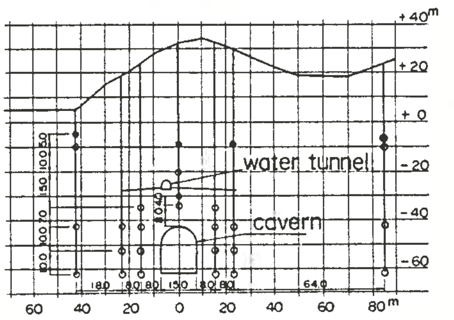
The results of each logging show good correspondence with one another; the geology gradually improves between EL 0m and -10m, and substantially stable and favorable rock conditions continue below EL -10m.

The permeability around the cavern was predominantly 10^{-5} - 10^{-7} cm/sec, althogh a permeability in the order of 10^{-4} cm/sec was observed in several sections.

The results of rock shear tests and rock deformation tests are shown in Table 2. Overcoring measurements of initial stresses which were carried out in the test tunnel located at EL -47.0m, show that the maximum principal stress was 56.3 kg/cm^2, intermediate principal stress was 47.3 kg/cm^2, and the minimum principal stress was 47.2 kg/cm^2 indicating that the stress components in the horizontal E-W direction are somewhat predominant.

4. Studies on Hydraulics

Study on the hydraulic behavior of the bedrock around the cavern is extremely important because this plant introduces an artificial water curtain type storage system. As for the ground water level, 20 boreholes were used for observation. The pore pressure was measured in several boreholes of them. Pressure detectors of strain gauge type were installed in each borehole to measure the ground water level and pore pressure, which were automatically recorded by a mini-computer in the observation room. Installation of these pressure gauges is illustrated, for example, in Fig.3.



o Pore pressure gauge

• Groundwater level gauge

Fig.3 Cross-Section of Hydraulic Observations

Chronological changes of the water level are shown in Fig.4. Fig.4-1 shows the level before excavation; ground water flow can be seen from N-E to S-E. Fig.4-2 and Fig.4-3 clealy show that there are regions where the water level drops below EL ± 0m. Fig.4-4 shows the level after the water tunnel has been supplied with water; it is seen that the regions below EL ± 0m are divided into upper and lower sections and that the ground water level is recorded by a certain degree. These upper and lower sections correspond with the regions found in the preliminary studies where the permeability is higher and fractures exist more frequently. Fig.4-5 and 4-6 show the level during the time when vertical shafts were constructed. The water level was not recovered in such areas.

Fig.4-7 shows the state after all the facilities were completed and the access tunnel and vertical shafts were supplied with water. It is seen that the regions where the ground water level dropped has completely disappeared. Fig.4-8 shows the state during the crude oil operation; the ground water is extremely stable up to such levels as observed in Fig.4-2 or 4-1.

Fig.4-9 and 4-10 show the states several years after the crude oil operation. In this stage the supply of water to the water tunnel was stopped, while the pressure inside of the cavern was kept under 0.5 kg/cm^{2}G, thus a quasi-natural water condition was made, and it was tested if the water level should be dropped down. It is seen that the ground water keeps on the stable level as those of Fig.4-7 or 4-8, though the level was slightly dropped in several years.

Thus, although the ground water level dropped to a certain degree due to underground excavation, supply of water to the water curtain thereafter helped to recover almost its original level. And in case of a quasi-natural water condition in this demonstration plant, it was shown that the supply of ground water around the cavern was balanced to some degree with water seepage into the cavern, so the water level could be kept stable at some level.

Fig.5 shows the chronological changes of pore pressure distribution in the middle cross section of the cavern. Lowering of the pore pressure around the cavern is seen as excavation proceeds. As shown in Fig.5-3, when the water curtain is supplied with water, the pore pressure in rock above the water curtain is recovered. However, the pore pressure around the cavern remains unchanged because of the atmospheric pressure in the cavern. Fig.5-4 shows the state when the excavation of the cavern has almost been completed. The pore pressure in the rock at the left of the cavern is relatively well recovered while it still remains lowered at the right because of the access tunnel. Fig.5-5 was taken at the time when the tightness test of the cavern was conducted with a pressure of 2.2 kg/cm^{2}G after the access tunnel had been supplied with water. The equipotential lines of pore pressure shows a closed curve centering

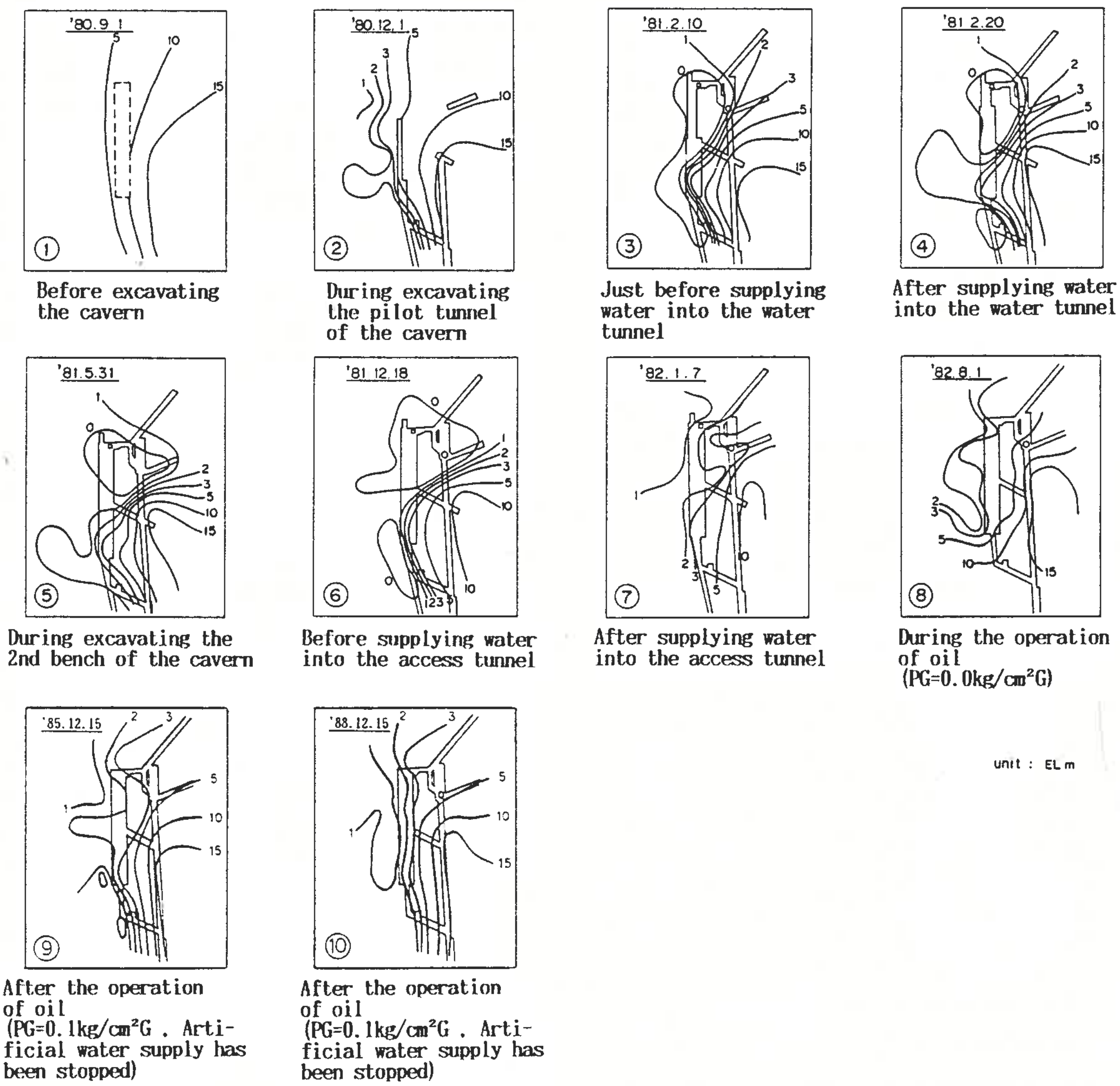


Fig.4 Plan Distribution of Ground Water Level Transition

around the cavern, indicating that the cavern is airtight. However, the area at the access tunnel side where the pore pressure became lowered is somewhat large. This coinsides with the findings that the rocks at the left of the cavern have more fractures and higher permeability than those at the right side. Fig.5-6, 5-7, and 5-8 show the states after the crude oil operation. It is seen that the pore pressure around the cavern keeps on the stable condition.

In this investigation, we also carried out two dimensional steady seepage flow analysis by FEM. Although in the analysis rocks were assumed to be isotropic and homogeneous, the results showed nearly good correlation to those of measurements above mentioned.

Furthermore, the tightness test also indicated that there was no leakage of air from the cavern. Thus it was clarified that a little uneven distribution of pore pressure being due to heterogeneity of rock would not affect the confining performance.

5. Studies on Geomechanical Behavior of Rocks

Stability of rocks around the cavern during excavation was confirmed by chronological measurements as shown in Table 1. Three cross sections in the axial direction of the cavern were selected in which measurements were arranged as shown in Fig.6 Convergence was measured using a tape extensometer. A 5-stage deformation gauge was used to measure deformation of rocks. For axial stress measurement, a rock bolt was grooved and attached with strain gauges at 4 different points.

Table 3 shows comparison of the results between measurements and analysis with respect to the changes in convergence and deformation of rocks at each stage of excavation. Visco-elastic program of FEM was employed for the analysis, using mechanical properties obtained in the preliminary studies. As is shown in the table, it can be said that the changes themselves

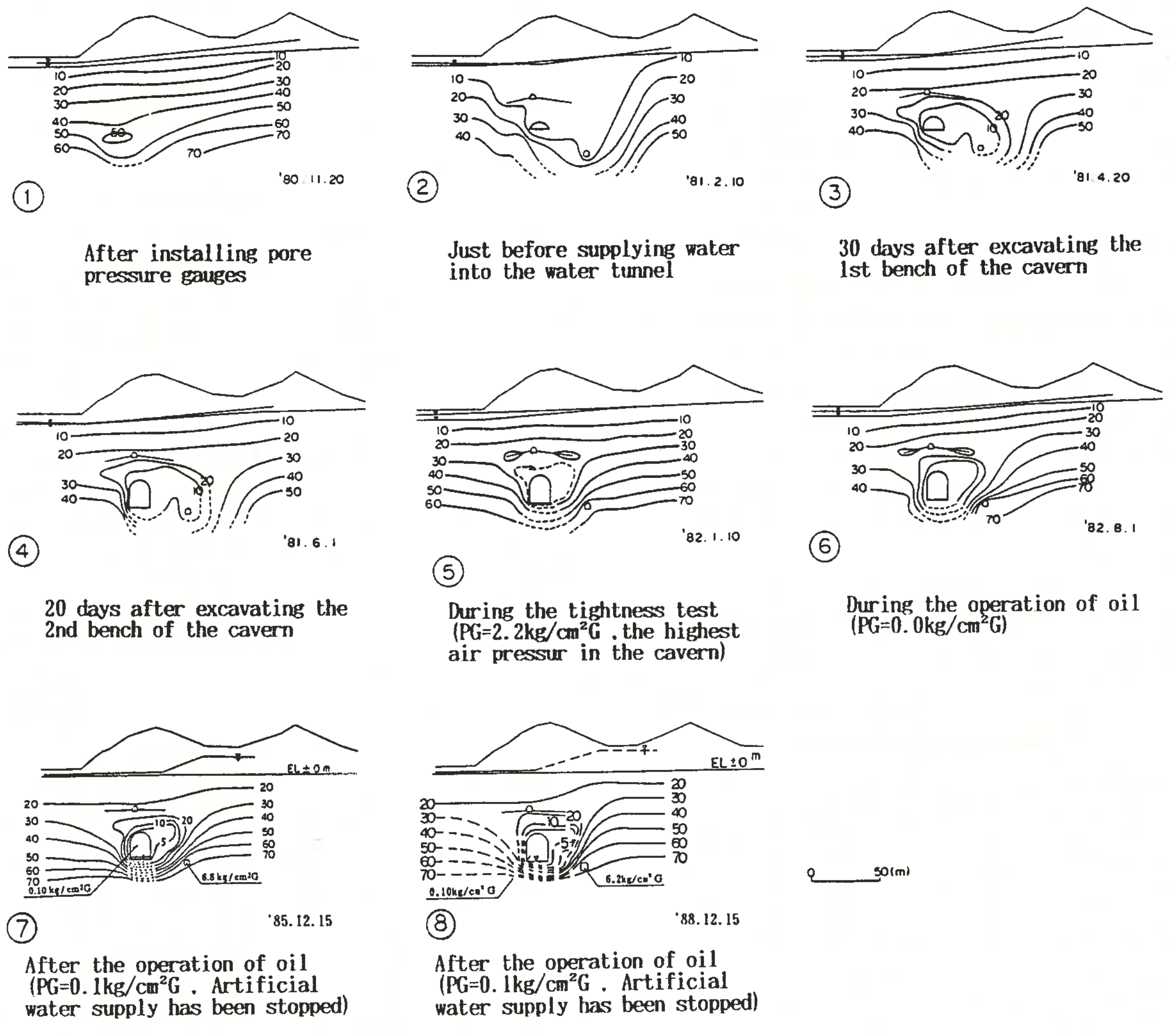


Fig.5 Chronological Changes of Pore Pressure Distribution

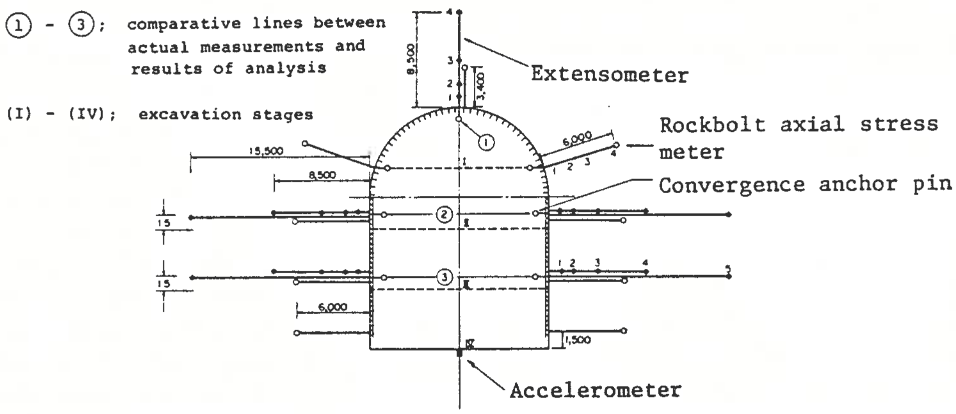


Fig.6 Measurements Inside the Cavern (the middle cross-section)

are small and they are generally in good agreement, although there are several disagreements between the measured and analytical values.

During the crude oil operation and for several years after that, deformation of rocks and axial stress of rock bolts were continuously measured in the middle cross section of the cavern. As a result of the measurements, we found no remarkable movement of rocks, and the stability of the cavern for a long term (for more than 9 years after construction) was confirmed.

Thus, concerning the stability of rocks around the cavern, it was confirmed all through the stages of the investigation.

6. Conclusion

From various studies and investigation above mentioned, The following results were obtained:

(a) The ground water level around the cavern may drop down to a certain degree due to excavation, but it can almost be recovered to the original level by supplying water for artificial confinement of oil. And the water level could be kept stable at some level even in a quasi-natural water condition because of the equilibrium of the supply of ground water around the cavern and the seepage amount into cavern.

(b) Measured pore pressure showed a slight disagreement with the results of steady seepage flow analysis in which rocks were assumed to be homogeneous and isotropic. However, the disagreement was small enough to disregard its influence on confining performance.

(c) Rocks around the cavern were extremely stable during the investigation. Thus, mechanical stability of a petroleum storage of this scale can be sufficiently maintained if suitable bedrock was selected.

(d) Findings of the preliminary studies on rock conditions and hydraulics corresponded well with the results of other studies conducted at latter stage.

(e) Mechanical and hydraulic behavior of rocks around the cavern was extremely stable for several years after the crude oil operation. Thus, it can be said that crude oil can be stored in the cavern for a long term in safety, under such good conditions of rocks.

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Table 3 Comparison of Analytical Values and Actual Measurement

Comparison of convergence

Excavation Steps	Lines of measurement	Analytical values	Actual measurement values
III	1 2	- 0.4 6.8	2.8 5.4
IV	1 2 3	- 0.5 4.8 8.6	- 1.9 2.8 - 2.8

unit : mm

Comparison of rock deformation

Excavation Steps	Lines of measurement	Analytical values	Actual measurement values
I	1	3.2	- 0.28
II	1	0.1	0.01
III	1 2	- 0.1 5.4	- 0.03 1.15
IV	1 2 3	0.0 1.8 5.6	0.0 0.61 4.18

unit : mm

Geothermal Energy Development

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1. Introduction

Japan locating in the circum-Pacific volcanic belt, is considered as one of the world's prominent volcanic countries with promising geothermal resources. Potentially, there are four types of geothermal resources in Japan such as natural dry steam, high enthalpy thermal water in volcanic areas, low enthalpy thermal water in sedimentary basins in non-volcanic regions, hot dry rock and volcanic heat[1]. Among these, the high enthalpy thermal water in volcanic areas has been of great interest and ten geothermal power plants using this type of geothermal resource are in operation as shown in Fig.1.

Developments of geothermal power plants are carried out by private enterprise, and research and developments of geothermal energy are conducted by Sunshine Project Promotion Headquarters, AIST, MITI, New Energy Development Organization (NEDO), National research Institutes and several universities.

Today's research activities on rock mechanics

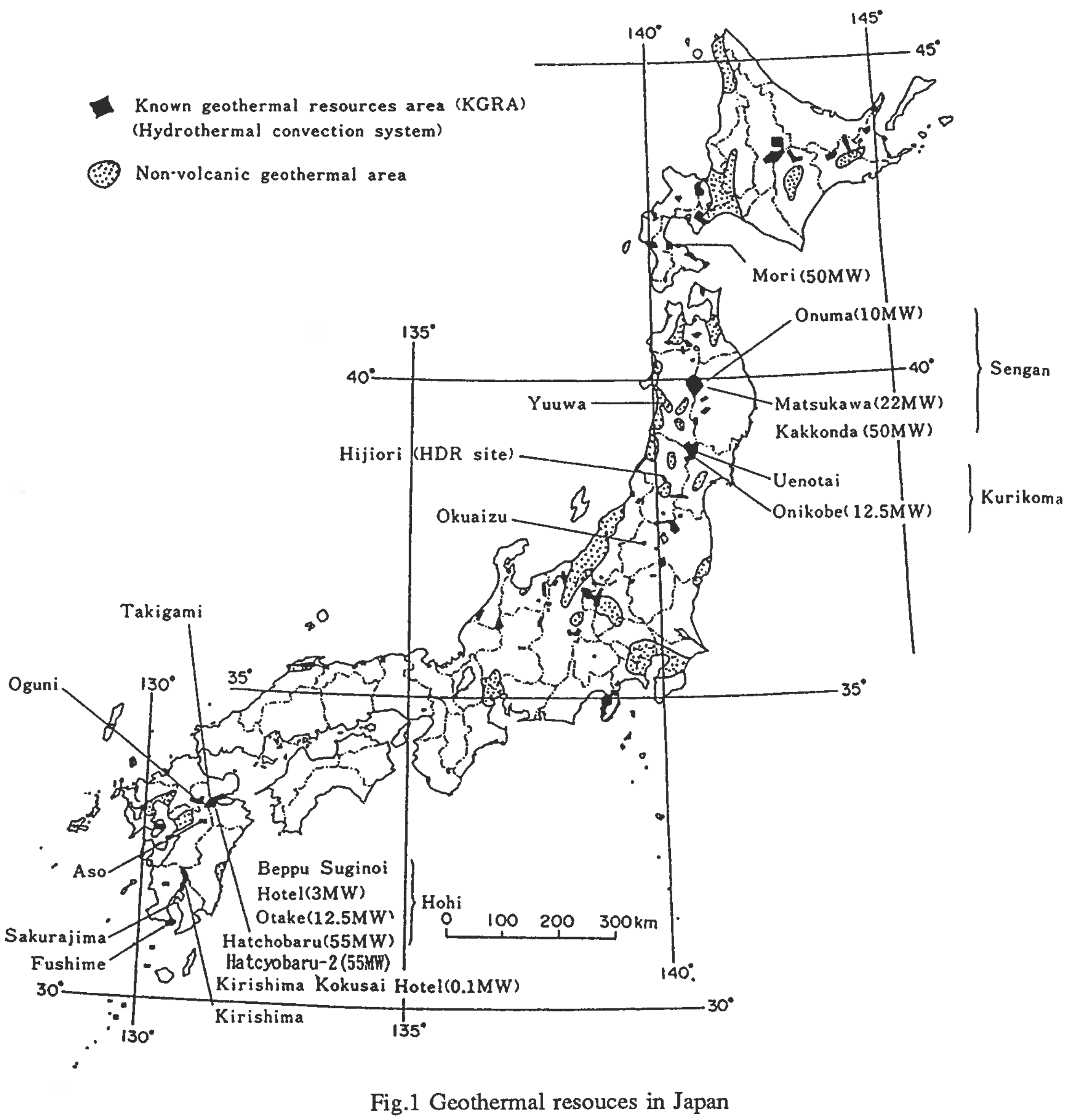

Fig.1 Geothermal resouces in Japan

as to geothermal energy development are as follows;

a) rock properties under geothermal conditions
b) drilling technology for hot and hard rocks
c) hydraulic fracturing techniques for heat extraction
d) development of fracture detection tools under geothermal conditions

In this paper, present geothermal energy utilization, recent research activities in the four categories listed above and general information of several impressive research projects on geothermal energy development are presented.

2. Electrical Update of Japan[2)]

The first commercial power plant using natural dry steam was completed at Matsukawa in 1966. Success in power generation using separated steam from flashing thermal water in New Zeland in 1958 had a great impact on exploration and development activities in Japan, then Otake and Onuma power plants using flashing steam were inaugurated in 1967 and 1973 respectively.

Today, we have ten geothermal power generating plants and their total installed capacities are 270 MW as is shown in Table 1. Several other power plants are going to be constructed in this decade.

Table 1 Geothermal power plants in Japan

(As of March, 1991)

Name of power plant	Location	Constructed Year	Power Generation Type	Installed Capacity (MW)
Matsukawa	Iwate	1966, Oct	Dry Steam	22.0
Otake	Akita	1967, Oct	1-Frash	12.5
Onuma	Akita	1973, June	1-Flash	10.0
Onikobe	Miyagi	1975, March	1-Flash	12.5
Hatcyobaru	Oita	1977, June	2-Flash	55.0
Kakkonda	Iwate	1978, May	1-Flash	50.0
Suginoi Hotel	Oita	1981, Aug.	1-Flash	3.0
Mori	Hokkaido	1982, Nov.	2-Flash	50.0
Kirishima H.	Kagashima	1984, Feb.	1-Flash	0.1
Hatcyobaru-2	Oita	1990, June	2-Flash	55.0
				270.1

3. Rock Properties under Geothermal Condition

Fracture toughness tests were performed on rock sample 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 rock fracture toughness were given through experiments using pre-notched cylindrical specimens in the presence of pressurized water, ranging from 0.1 to 30 MPa at a maximum temperature of 224 degree C. The rock fracture toughness was defined by critical stress intensity factor of the crack tip region at the onset of the main crack propagation, which corresponded to an abrupt increase in the sum of released AE energy before the maximum differential pressure was reached. This kind of work are performed mainly by GEEE group in Tohoku University[3)].

The estimation of stress state in conventional geothermal energy development is not so popular but is very important to design a underground circulation system for hot dry rock development and to expect directions of artificial fractures. The differential strain curve analysis(DSCA) method and AE method are being applied for oriented drill cores from geothermal wells.

4. Drilling

Geothermal wells must be penetrated into formations such as a) complex geology, b) high subsurface temperature, c) hard, fractured and abrasive rocks, d) fractured rock resulting in frequent loss of drilling fluid circulation.

Recent topics of geothermal well drilling are developments of polycristaline diamond compact(PDC) bit available for hard rocks (Fig.2). Up to now, PDC bits have been widely applied for drilling of homogeneous soft formation in oil/gas fields, but they have never been used for heterogeneous hard formations encountered in geothermal fields due to spoiling and chipping of PDC cutters. To overcome this restriction, improvements of PDC bits have been carried out by NRIPR.

Through laboratory tests, PDC core bits were designed for field application. PDC core bits of 8-15/32in. diameter are tested in actual geothermal well drilled into granodiorite, at the depth of about 1,800m and formation temperature of around 250 degree C.

The performance of PDC core bits is two or three times higher than that of the conventional surface-set diamond core bits, and PDC bit life are rather longer than conventional bits[4)].

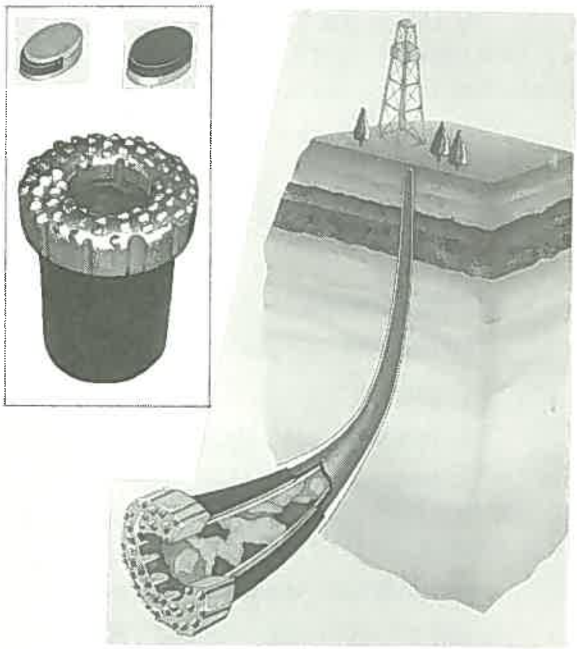

Fig.2 PDC core drill bits

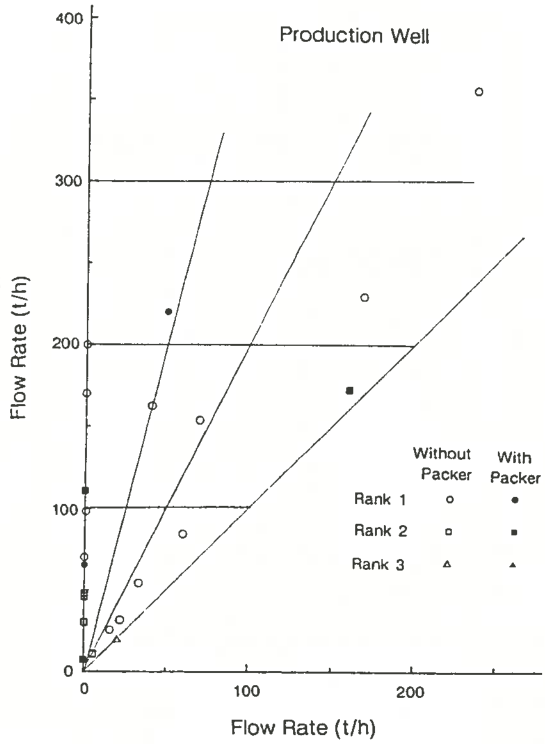

Fig.3 Increase of production by hydraulic stimulation

5. Hydraulic Fracturing

Research and development on hydraulic fracturing for the geothermal energy development have been carried out with two different objectives. The one is to make flow paths between well and natural reservoir for stimulation of the well and the other is to create artificial geothermal reservoirs of HDR subsurface system.

Application of the hydraulic fracturing for conventional geothermal developments was conducted at Nigorikawa field in 1973 for the first time in Japan. Up to now, hydraulic stimulation have been carried out for about 50 geothermal wells in Japan. Fig.3 shows the performance of these stimulation. Longitudinal and horizontal axis represent production rate of steam after and before these stimulations. Data plots located in a area above the line which inclination is 45 degrees means that stimulation improve the production rate for these wells[5)].

At Hijiori hot dry rock test site, the project being carried out by NEDO and NRIPR, twice a massive hydraulic fracturing has been conducted in 1986 and 1988 in a geothermal test well at a depth of 1,800m and a temperature of some 250 degree C. For each test, the maximum injection rate was $6m^3$/min and the total amounts of water injected were 1,000ton and 2,000 ton respectively. By these fracturing the fractures extended to an area of about 400x300x50m. Injection pressure at the well head ranged from 12 to 16 MPa depending on the flow rate of 2 to 6 ton/min[6)].

6. Fracture Location by AE

A detailed analysis has been made of acoustic emissions detected during build-up tests in a geothermal production well in Kakkonda geothermal power plant in 1982, 1984, and 1985. The three dimensional structure of the hydrothermal reservoir in the field and its dynamic behavior have been investigated. The shape and location of the cracked reservoir, fluid paths and degree of communication between the reservoir and the geothermal wells, have been revealed to some extent by this analysis[7)].

At Hijiori HDR test site, AE observations using a surface microseismic AE observation network and a triaxial geophone double sonde installed in a well have been carried out to identify the extension of the artificial reservoir by analyzing AE events occurred during the hydraulic fracturing and the circulation test, and at the same time, to study the mechanism generating the AE events by analyzing wave forms. Fig.4 shows the location of AE events occurred during hydraulic fracturing of the tst well. Taking into acccount locations of AE, two produc-

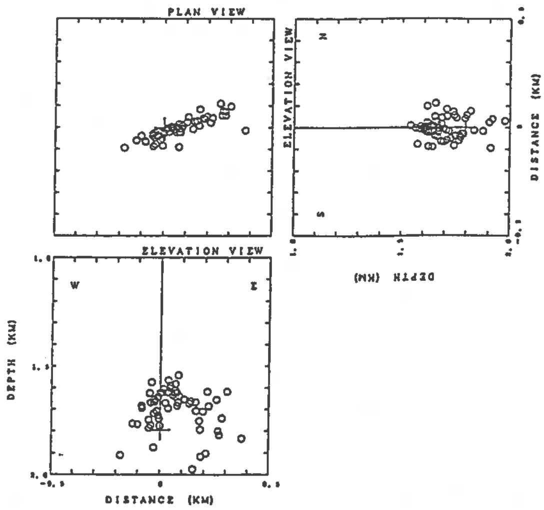

Fig.4 AE location occurred during a hydraulic fracturing at Hijiori

tion wells were drilled to intersect the fractues, then an artificial circulation system was formed and hot water of around 170 degree C was recovered from the hot dry rock body[6].

7. Development of Fracture Measurement Tools for Geothermal Conditions

To obtain information on fractures along the wall of geothermal wells, borehole Televiewer (BHTV) surveys were carried out in several geothermal field.

A electromagnetic borehole radar sonde available for geothermal condition is being developed for measuring fractures in and around wells as a part of Hijiori HDR project.

8. Some Impressive Projects on Geothermal Energy Developments

a) Gamma Project (1982-1987)

*design methodology of artificial crack-like reservoir for HDR geothermal energy extraction

*by Tohoku University

*at Higashi-hachimantai test site and Kakkonda geothermal field

b) Development of Hot Dry Rock Power Generation Technology (1984-today)

*creation of artificial fracture

*development of fracture detecting tools

*simulation of heat extraction

*by New Energy Development Organization

*at Hijiori test site, Yamagata pref.

c) Development of Technology for Increasing geothermal Energy Recovery (1989-today)

*make flow path between well and reservoir

*use magnetic fluid for tracer to detect fractures

*fracture design

*by New Energy Development Organization

*at Yunomori near Matsukawa geothermal power plant, Iwate pref.

d) Hot Dry Rock Experiment in Tuff and granite at Akinomiya (1987-today)

*new hydraulic fracturing method to make a multi-stage fracture system in a well without using open hole packers

*by Central Research Institute of Electric Power Industry

*at Akinomiya, Akita Pref.

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Japanese Mining, Now and Future

Umetaro YAMAGUCHI

1. Recent Japanese Mining Activities

Japanese mining has a long and glorious history. However, now, it is placed in lower position in Japanese national economy. Easily discovered and preferably minable deposits had been exhausted in early stages in her history and a recent atmosphere surrounding the mining is very severe in comparison with these newly developed modern industries like electronics, automobiles, and other soft-ware industries. In particular, recent changes of world economy have seriously influenced to Japanese mining industries. During this decade, 65 metal and 37 coal mines in 1974 have rapidly decreased to 25 and 28 mines. Total amount of mineral and fuel productions and the number of employee have also sharply decreased in these same years.

Non-metallic mineral mining industries have been mostly followed on the same way and now have been in hard situations. In these situations, only limestone quarrying has tremendously developed in Japan. Japanese limestone is very good in quality and sufficiently fills in quantity the huge amount of national demand for cement, iron and steel making, chemicals and others. Japan's annual production of limestone is now reached to 200 million tons and ranked higher in the world.

Huge amount of common rocks like sandstone, granite, andesite and so on are also produced as a crushed stone mainly used for construction works.

Although the crushed stone industry is legally controlled by the Stone Mining Law which is a different law with the Mining Law and the Mine Safety Law regulating metal, non-metal, coal and petroleum mining industries, it is now the largest mining industry of Japan and produces annually 500 million tons of rocks from a hill and a mountain. Crushed stone is mainly used for the active and vigorous construction works going in the country.

2. Mining Technology

Mining technology of Japan has kept the qualified technical level under the difficult economical situations. Some parts of these technologies have been appreciated as to be an unique style and highly qualified from the other countries.

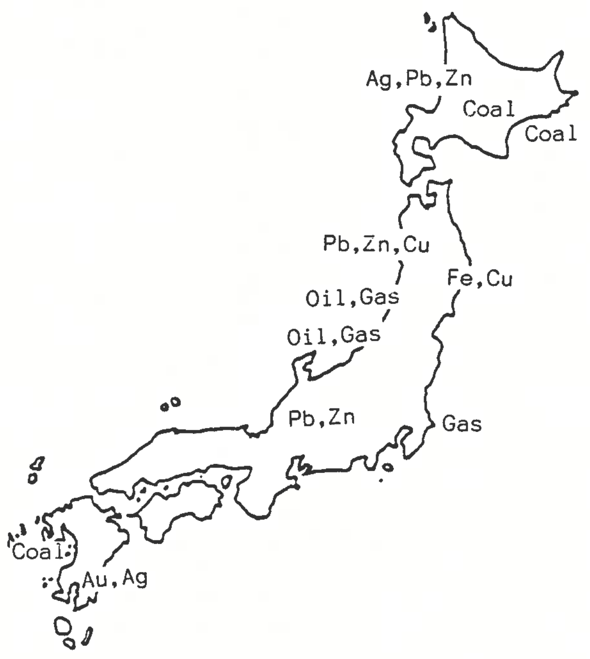

Fig.1 Mining Districts in Japan

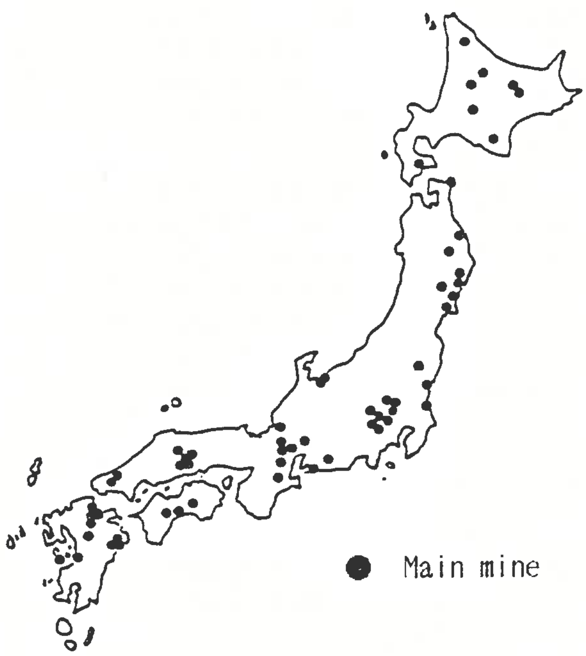

Fig.2 Limestone Mines in Japan

Generally speaking, all of Japanese active metal mines are underground mines and work for their high grade ore. Therefore, fine and qualified mining technologies are necessarily required for obtaining high productivity and to survive in these difficult situations. Toyoha mine in Hokkaido is a silver-lead-zinc mine and the vines are very excellent in the grade and in the reserve. However, the mine has been faced to temperature problem that the wall rock temperature will be over 100°C if it leaves without any treatment, because the mine is located in the volcanic region. Under the difficult working conditions, all kinds of technical effort have been made for keeping the high productivity. Well known high grade gold mine, Hishikari mine of Kyushu is also a hot temperature mine which is necessarily required to take strict measures against the 60°C hot water gushing underground.

Kuroko ore mines like Matsumine, Fukazawa and others in Akita prefecture have produced high grade zinc, copper, lead ore containing silver and gold from their blocky, seam like and lenticular ore bodies in clayey soft rock which is difficult to treat. Sophisticated underhand cut-and-fill method with artificial roof has been developed and employed for mining to their difficult ore bodies.

Kamioka in Gifu and Kamaishi in Iwate are relatively large scaled mines in Japan and are mining lower grade skarn ore from their irregular shaped ore bodies in hard rock. In these years, both mines have positively studied the application of underground space, beside the ore production, and have already had interested results.

Except of few small operations, all of Japanese coal mines are underground mines and have struggled against the difficulties of which the working places have been deep and far from the entrance of mine. It is particularly severe for Miike and Matsushima in Kyushu and Taiheiyo in Hokkaido which are undersea coal mines. In these three mines, natural and man-made islands and man-made sea-shores have been well used for their transportation and ventilation.

Coal getting system at coal face is very much rationalized and sophisticated, and some of these systems are adopted and are active in foreign countries.

Due to the quality of the Tertiary age coal and the geological conditions, deep mines,

Table 1 Japanese Metal Production (1979)

Metal		Productions	
Au	(Content)	g	3,463,516
Ag	(Content)	kg	270,725
Cu	(Content)	t	56,743
Pb	(Content)	t	46,259
Zn	(Content)	t	268,598
Pyrite	(Concent.)	t	576,163
Sn	(Content)	kg	661,459
Fe	(Concent.)	t	453,893
Mn	(Concent.)	t	92,375
Cr	(Concent.)	t	9,051
W	(Concent.)	kg	1,985,370
Mo	(Concent.)	kg	137,616

Table 2 Japanese Metal Production (1989)

Metal		Productions	
Au	(Content)	g	5,787,333
Ag	(Content)	kg	129,270
Cu	(Content)	t	9,403
Pb	(Content)	t	18,439
Zn	(Content)	t	132,633
Pyrite	(Concent.)	t	126,736
Sn	(Content)	kg	0
Fe	(Concent.)	t	30,810
Mn	(Concent.)	t	0
Cr	(Concent.)	t	X
W	(Concent.)	kg	432,873
Mo	(Concent.)	kg	0

Table 3 Coal from the Japanese Coal Mines

1979	17,641 X 10^3 t
1989	10,187 X 10^3 t

particularly in Hokkaido, are usually faced with hazardous situations of gas explosion or outburst. Gas drainage is strengthened by advanced boring or gas drainage tunnel. A centralized supervision and control system which consists of the control room in the main office, sensors and actuators of the mine, has been developed and widely employed in Japanese coal mines.

Most of limestone quarries and non-metallic mineral mines are open pit mines in contradiction to underground operations of metal and coal mines. Especially, 98 percent of limestone production comes from open-pit mines including several large scale mines which produce more than 10 million tons of limestone annually.Limestone production is very rationalized and qualified to be highly productive to be that 200 million tons of limestone is produced by only 10,000 employee.

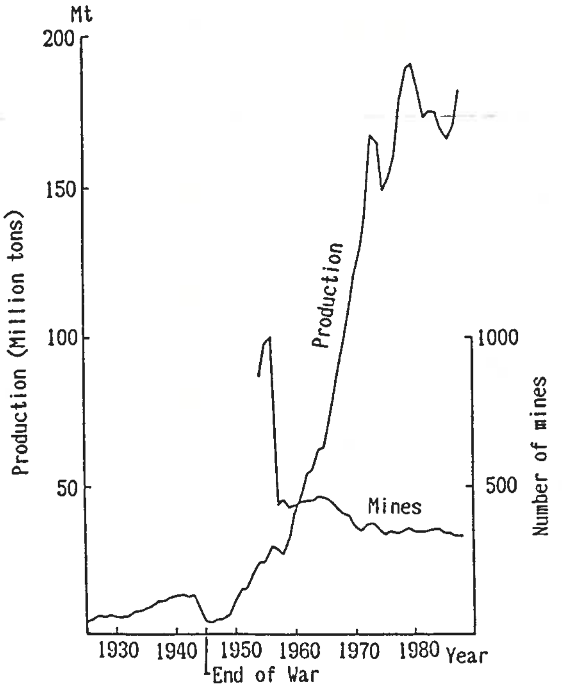

Fig.3 Japanese Limestone Production and the Number of Mines

Table 4 Top Twenty Largest Limestone Quarry of Japan (1988)

	Mine	Productions (1000 t)
1	Todakatsukumi	11,222
2	Torigatayama	10,920
3	Isa	10,553
4	Higashitani	7,916
5	Shuhou	6,299
6	Onodatsukumi	6,049
7	Nittetsutsukumi	5,356
8	Hachonohe	4,884
9	Nagaiwa	4,836
10	Sekinoyama	4,824
11	Shiriya	4,333
12	Buko	4,308
13	Tsukumi	3,975
14	Garou	3,759
15	Fujiwara	3,740
16	Minowa	3,735
17	Hikawa	3,002
18	Oumi	2,997
19	Ubekarita	2,772
20	Kawara	2,695

Table 5 Production of Crushed Stone of Japan (1987)

Rock	Productions * (1000 t)
Granite	77,895
Diorite	6,500
Gabbro	1,959
Peridotite	3,405
Porphyry	8,570
Porphyrite	2,691
Diabase	15,999
Liparite	24,100
Andesite	121,739
Basalt	18,644
Conglomerate	9,113
Sandstone	164,368
Shale	13,310
Slate	29,553
Tuff	12,649
Gneiss	5,123
Serpentinite	3,510
Crystalline schist	14,184

* including dimentional stone

In the crushed stone industries of Japan, there are various grades of the mining matter, the size, the technical level, and so on. Typical crushed stone quarry is that the mine site is located near the city or a construction work like a highway construction, dam and so on, the rock is good, the mining method employed is a bench cut employing high productive big machines, a modern crushing plant is in the mine site, and quality controlled crushed stone is regularly shipped to customers by truck fleets.

Japan is well-developed and densely populated. Therefore, environmental problems are very much serious. In some extreme cases, it had happened that mining operation had to be suspended due to the pollution it caused. In any case, sufficient consideration of environmental protection is necessary. Mine water treatment and the problem of waste disposal are receiving urgent attention, because Japan is well cultivated, particularly for rice making.

3. Rock Mechanics Researches in Japanese Mining Technologies

Frankly speaking, Japanese mining activities are now in depressed. However, the technology has been still kept on high level. Mining technology researches are actively done by universities, institutions and private mining corporations. Rock mechanics is one of the fundamentals of mining technologies. Many professors, students and engineers are engaged with rock mechanics researches.

Followings are research items recently interested and concentrated from the Japanese rock mechanics engineers in mining.

a) Soft and weak rock mining in Kuroko ore mines
b) Large scale excavation in high stressed deep mine
c) Hydrology in deep mine
d) Slope stability for large scale limestone open pit
e) Rock breaking researches for cutting tools and blasting
f) Geo-tomography researches.

For these researches, sophisticated electrical instruments and computer technologies are widely employed.

4. Future Scope

As the aforementioned, Japanese mining activities are now depressed, but the technical level has been still preserved in high and progressed. And while, it is true that Japan's present prosperity is supported by the importation of huge amount of mineral resources from all over the world. This situation will be unchanged for further. It should be emphasized the necessity to maintain mineral and fuel resources for ourself. With the situation, our technology is very significant.

Japanese mining enterprises are mostly intending to strengthen over-seas activities more than today and carrying forward a scheme to progress technologies for mining development. Japanese mining technology is also very much attractive, particularly for Asia and South and Central America. Many mining engineers from these countries come to Japan to study Japanese mining technology.

It is difficult to say, to tell the truth, the future of our Japanese mining industries is so bright, but it can to say there is a prospect and they will extend based on their technical progression. Particularly, limestone and crushed stone industries shall be important in our industries in future.

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Disasters Due to Hillside Failure and Landslide

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1. Introduction

Of the natural disasters taken place in Japan, debris flows, landslides and hillside failure, geological hazards in general term, triggered by a torrential rainfall and snow-melt, earthquake etc. have required heavy loss of lives and property damage. Figure 1 gives the number of casualties due to natural disasters and well reflects the effects of successful implementation of disaster prevention practices.

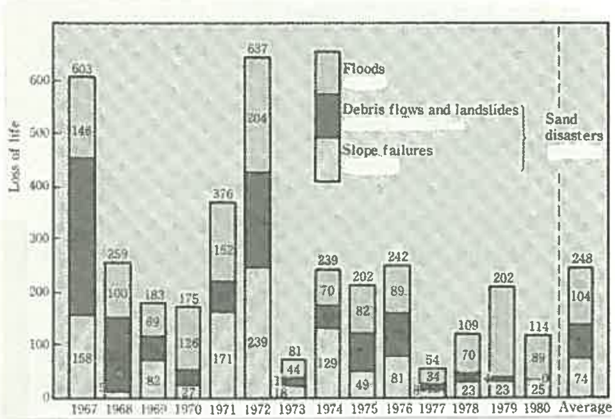
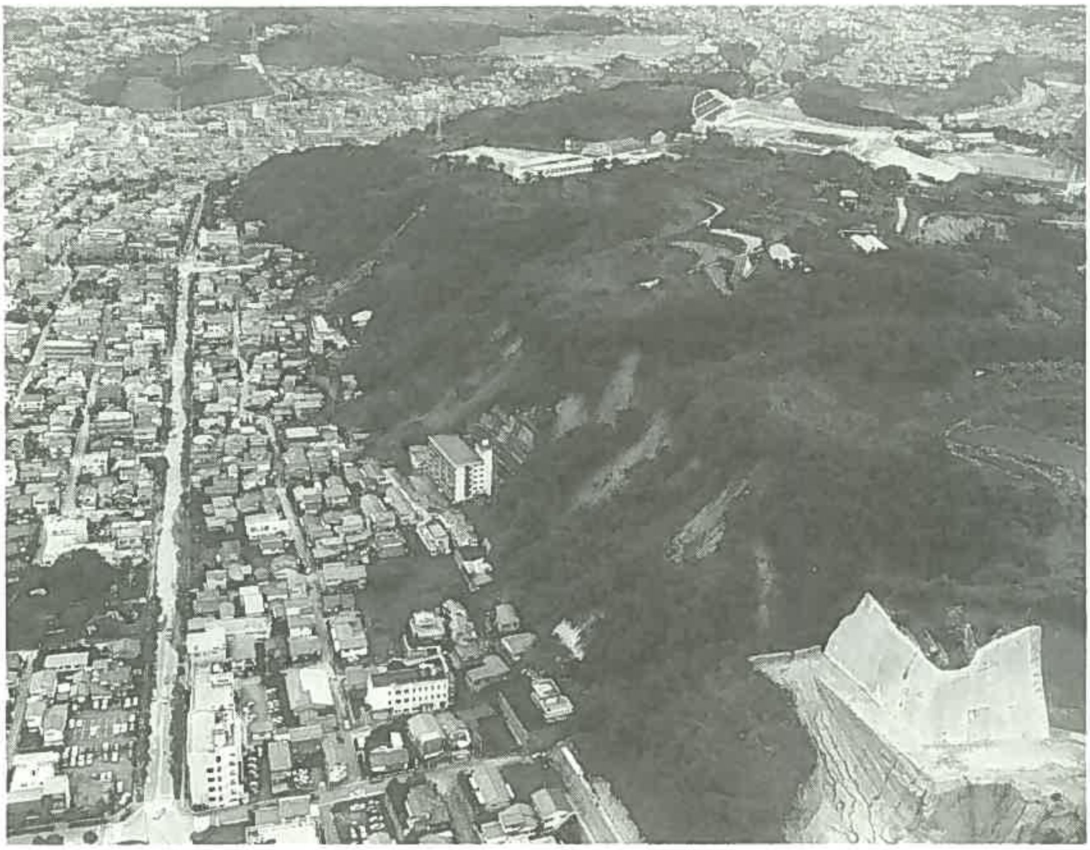


Fig.1 Loss of lives due to natural disasters, differentiated by causes

2. Hillside Failure

The slopes at risk are widely distributed all over the territory, and the number of the slopes with potential danger amounts to some 70,000.



Photograph 1 A queue of hillside failures at the flank of a terrace consists of pyroclastic deposits on the sea bed

The correlation between the geomorphological environment and landuse is of vital importance. Photograph 1 gives a typical case in Kagosima prefecture. The dominant geology in that case is pyroclastic deposit on the sea bed.

Another category of the disaster due to hillside failure takes place after a deformation of profile of hillsides along roads and in the area developed for housing. The gravure photograph gives a striking case taken place in Fukui prefecture in 1990.

3. Landslide

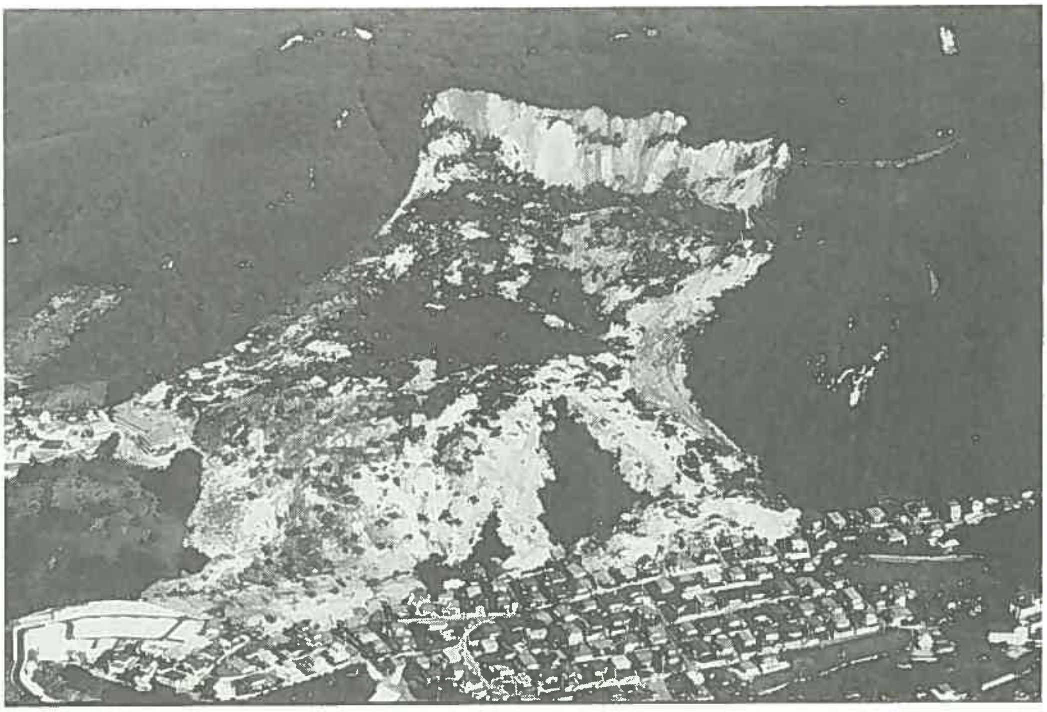
Landslide-prone areas distribute widely in the regions along the Japanese sea coast, the Fossa Magna and the Median Tectonic belt. The number of landslide-prone areas amounts to 19,000. Earthquake and quick change in water level of dam reservoir, as well as rainfall and snow-melt, are the major agents which trigger landslides. Photograph 2 illustrates a landslide at Jitukeyama, Nagano, taken placein 1985 due to repeated rainfall and snow-melt.

4. Countermeasures against Hillside Failure.

An institutional system based on a law "Act of Hillside Failure" was established in 1969. The law gives a governor of prefectural government a power to excercise the following undertakings;

a) designation of hillsides at risk
b) delineation of hazard areas due to hillside failure
c) restriction of activities which may result in a failure
d) instruction for safety measures to community peopole
e) installation of early warning mechanism

Both central and local governments are responsible for finance which amounts to 80% of the total cost for structural measures.



Photograph 2 Jitukeyama landslide

5. Countermeasures against Landslide

Landslide prevention law was enacted in 1958. The law permits a governor of prefectural government to delineate areas at risk in which nobody is allowed to make any change which may result in landslides. The central government is responsible for a two-thirds of the total cost for structural measures.

6. Research Work

Intensive research work has been carried out focusing on the following items;

a) mechanism of an initiation of hillside failure
b) dynamic properties of a mass sliding and falling
c) early warning for hillside failure and landslide
d) assessment of potential danger of the slopes at risk in case of torrential rainfall and earthquake
e) structural measures against rockfall, hillside failure and landslide
f) comprehensive system for monitoring and administrative management of the slopes at risk

Study on Earthquake Resistance of Large Underground Caverns

Hiroya KOMADA

Central Research Institute of Electric Power Industry

1. Introduction

As with underground siting of nuclear power plants, compressed air energy storage, geological disposal of high-level radioactive wastes, etc., studies have been conducted on accommodating energy facilities within underground caverns in bedrock. To accommodate these important facilities, these caverns require much greater earthquake resistance than conventional bedrock caverns such as underground hydraulic power plants, tunnels, etc.

Here, with the object of evaluating the earthquake resistance of underground caverns, the results of earthquake observations conducted at the underground caverns, mine tunnels, etc. of existing facilities in Japan are discussed and at the same time case studies on evaluating the earthquake resistance of large underground caverns are indicated.

2. Examples of Underground Earthquake Observations in Japan

With the object of identifying the earthquake motions in bedrock of a deep underground part as well as the behaviors of underground caverns during earthquake, the underground earthquake observations are conducted at the points shown in Fig. 1. The results of observations obtained at the principal points among them are described below.

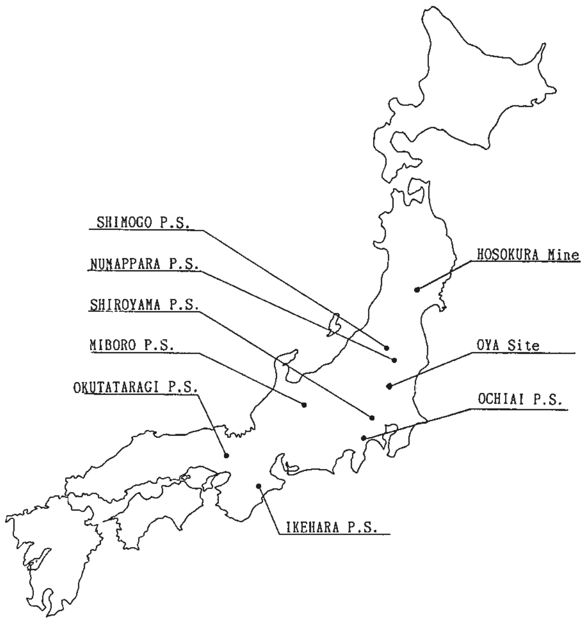


Fig. 1 Site of underground earthquake observations in Japan

2.1. Shiroyama Hydraulic Underground Power Station (Fig. 2.) [Komada,H., 1986]

Observation results obtained in the underground cavern of 20 m wide, 40 m high and 110 m length located about 240 m under the ground are as follows:

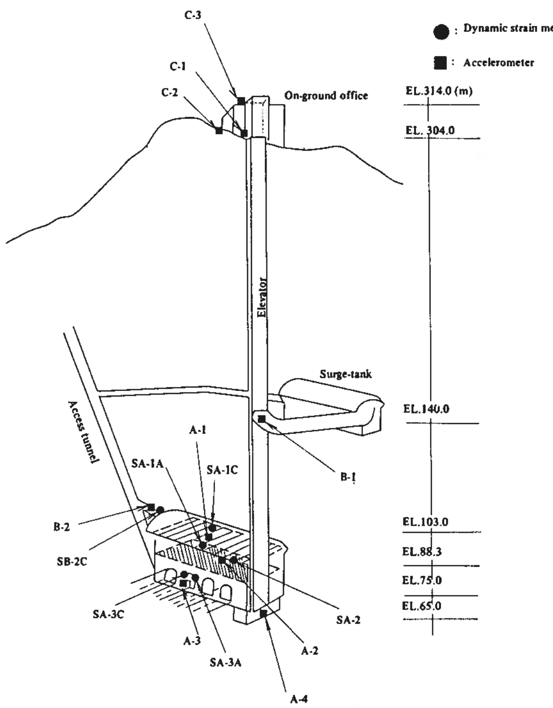


Fig. 2 Location of observation points at Shiroyama p.s.

(a) The ratios of maximum acceleration at the underground cavern bottoms located about 240 m under the ground to that at the ground surface is almost in the range of 1/3 to 1, and is concentrated especially at about 1/2 (Fig.3).

(b) The maximum accelerations in side wall in the medium higher part of the underground cavern and the bottom of the underground cavern are almost the same so far as observed values higher than about 2 gal are concerned,

and it can be considered that there is little amplification in acceleration in the underground cavern (Fig. 4).
(c) Predominance period of the seismic response spectrum on the ground surface is recognized clearly, while the response spectrum in the underground cavern has a considerably levelled shape. Moreover, the response spectrum value of the underground cavarn is reduced as the epicenter distance becomes shorter as compared with the ground surface. This phenomenon shows that, considering the present situation where the shorter the epicenter distance like near earthquake type the more damage is liable to occur, underground structures are more advantageous than on-ground structures so far as aseismic design is concerned (Fig. 5).

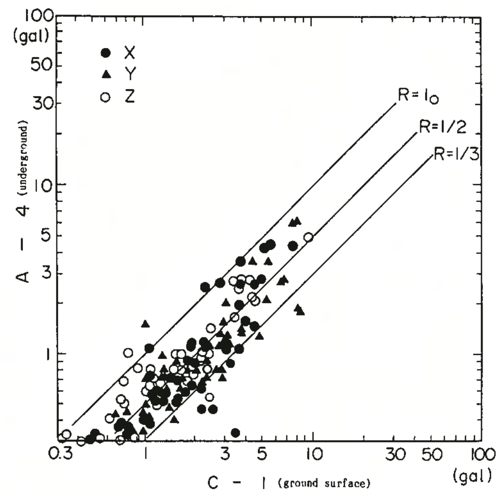


Fig. 3 Relation between maximum acceleration on the underground cavern bottom and that on the ground surfase at Siroyama p.s.

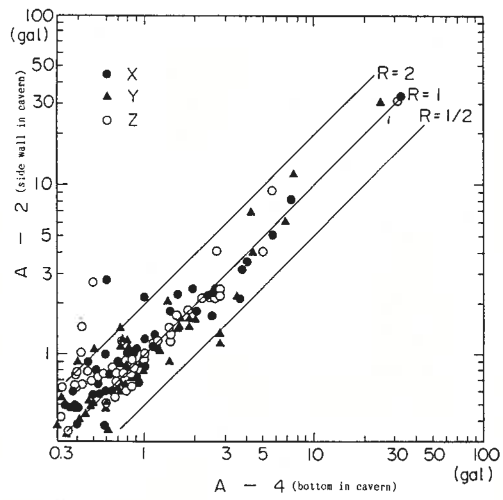


Fig.4 Relation between maximum acceleration on the cavern bottom and that in side wall at Shiroyama p.s.

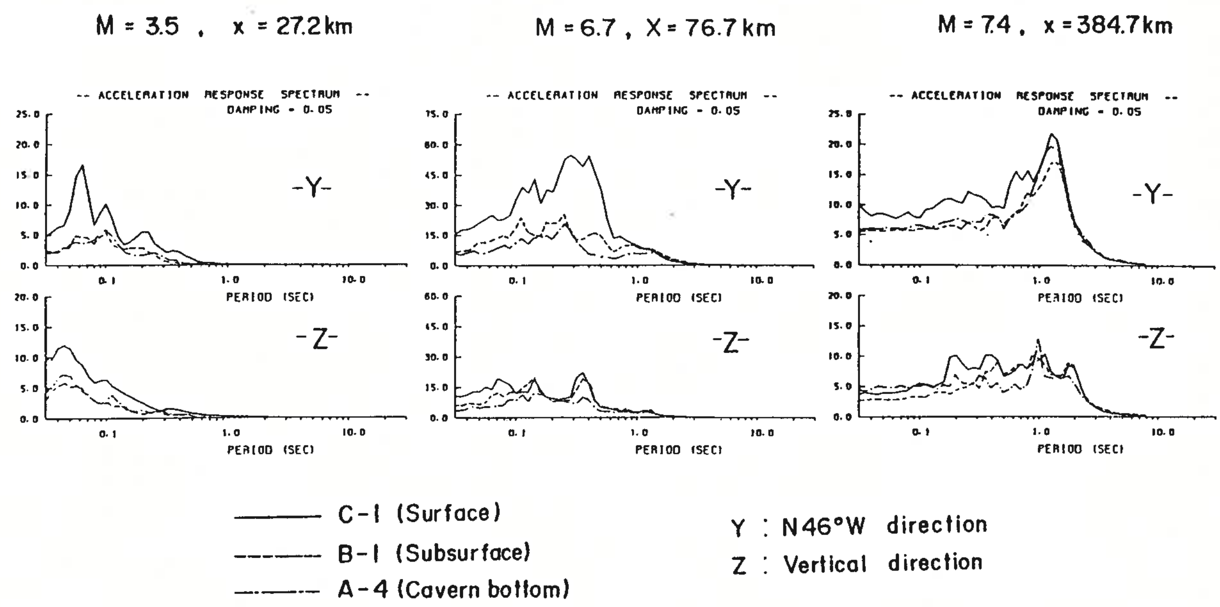


Fig.5 Response spectrum of observed spectrum of observed seismic waves at Shiroyama p.s.

2.2. Ochiai Hydraulic Underground Power Station (Fig. 6) [Komada,H., et al, 1987]

The results of observations conducted in the underground cavern of 14 m in diameter and 22 m in depth, which is a cylindrical pit type cavern excavated from the ground surface, are as follows:

(a) Ratios of subsurface maximum accelerations to surface maximum accelerations are concentrated at 1/2 to 1 (Fig. 7). This shows that the accelerations are declined at underground. From this phenomenon, it can be considered that in the underground structures whose foundation is placed at a depth of several 10 m from the ground surface, there is a possibility that the seismic input into the structures is mitigated in comparison with the on-ground structures.

(b) The normalized response spectrum at the subsurface is similar to that of the surface. For example, the more the epicenter distance increases part the longer the periods of the spectrum at the surface becomes like the surface.

2.3. Hosokura Mine (Fig. 8) [Komada,H., 1989]

Three-dimensional array seismic observations were conducted in bedrock of up to about 400 m under the ground, and the following results were obtained.

(a) Maximum accelerations on the underground at about 180 m depth from the surface decreases to about 60 percent in the horizontal and about 70 percent in the vertical to that near the ground, but in the part deeper than that a tendency to decrease further is little recognized. This phenomenon is the almost same result as that obtained at other observation points so far. The analytical result also indicates that the phenomenon approximately agrees with the proposed equation on the horizontal underground seismic distribution (Fig. 9). [Sato,K., et al, 1986]

(b) The directins of seismic wave incidence in the deep underground part was analyzed from the records of three-dimensional array observations. The horizontal direction of seismic wave incidence almost agrees with the epicenter direction from the observation point. On the other hand, the vertical direction of seismic wave incidence is in the range of about 3^{o} to 35^{o} determined from the crust-structural theory (Fig. 10). Accordingly, for aseismic design input

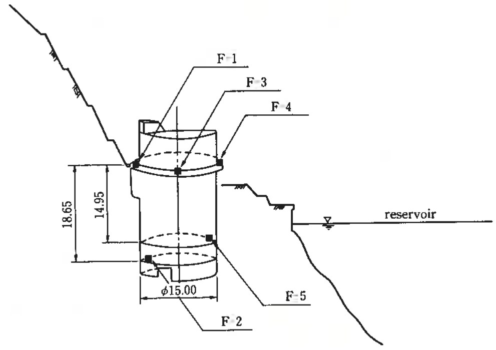


Fig.6 Location of observation points at Ochiai p.s.

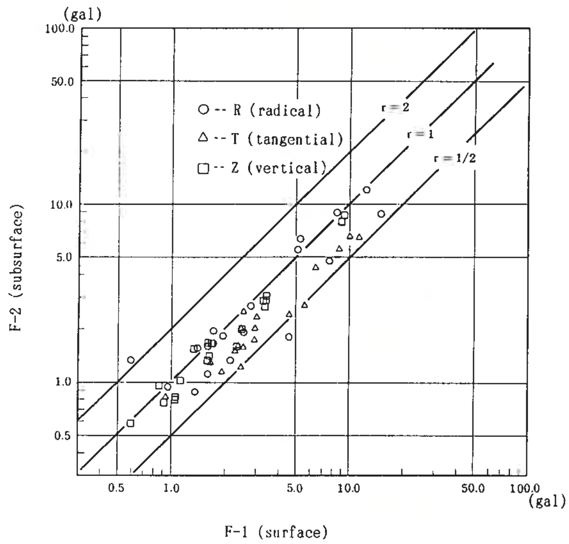


Fig.7 Relation of maximum acceleration between surface and subsurface

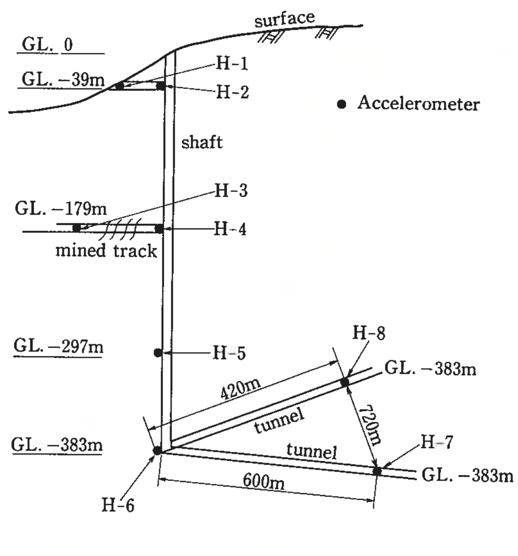


Fig.8 Location of observation points at Hosokura mine

to the deep underground structures, it was suggested as necessary to conduct study with the direction of seismic wave incidence as a parameter.

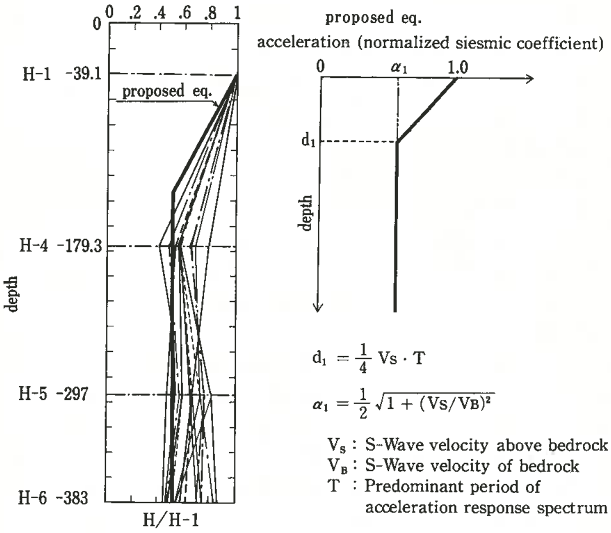


Fig.9 Proposed equatin on the horizontal underground seismic distribution

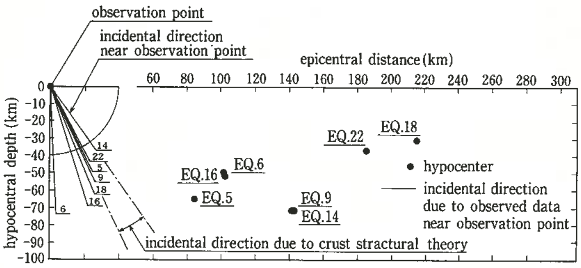


Fig.10 Vertical directions of seismic wave incidence analyzed from three-dimensional array observations

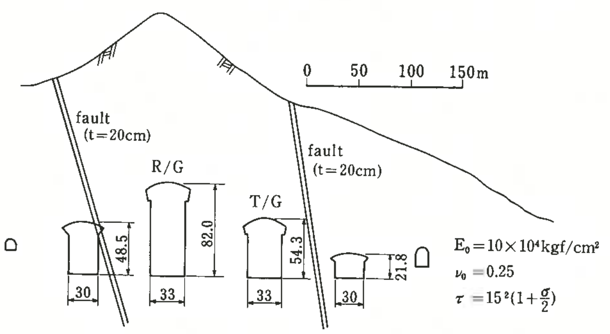


Fig.11 Model of seismic stability for underground nuclear power plant caverns

3. Examples of Studies on Seismic Stability of Underground Caverns [Kodama,H., 1990]

Dynamic or static analytical methods may be used to evaluate the seismic stability of underground caverns. The dynamic analytical method is a technique closer to the actual behaviors of underground caverns, so it is desirable to use the dynamic analytical method to evaluate the earthquake resistance of underground caverns. However, to make detailed study of underground cavern configuration during earthquake or to study the reinforcement for underground caverns, the dynamic analytical method requires complicated analytical procedures, thus making it necessary to use the static analytical method which can rationally simulate the results of dynamic analysis. It was identified that the static analysis by equivalent seismic intensity determined from the maximum shear force distribution in the analytical result of dynamic response in one-dimensional layer bedrock has the best applicability as a method of analyzing the seismic stability of underground caverns. As a case study, the seismic stability for underground nuclear power plant caverns shown in Fig. 11 was examined. First, the distribution of stresses during excavation

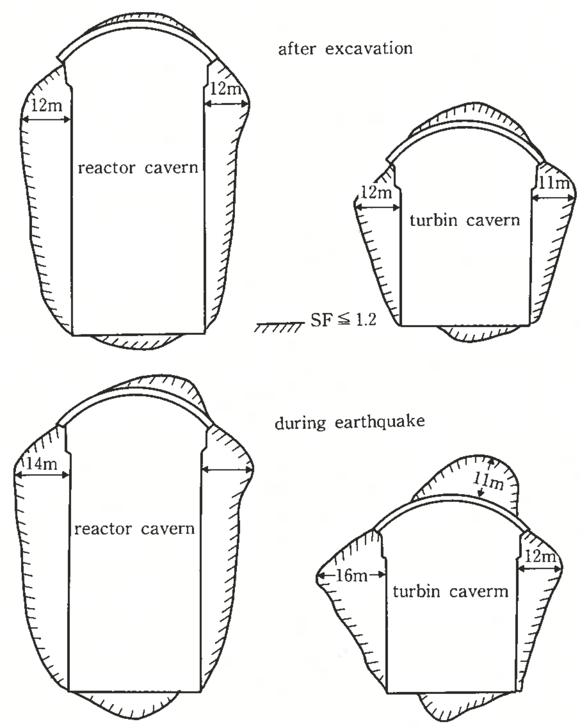


Fig.12 Distribution of loose zones around caverns during excavation and during earthquake

considering the initial earth pressure and the distribution of loose zones around the caverns were analyzed. Moreover, the evaluation on the seismic stability was conducted by the above-mentioned static equivalent seismic intensity method.Meanwhile, for input seismic motions, seismic waves which are now used in aseismic design of on-ground type nuclear power plants in Japan were used. In Fig. 12, the distributions of safety factor 1.2 during excavation and during earthquake in bedrock around the reactor cavern and the turbine cavern are shown. It is evident that the region of less than 1.2 of safety factor spreads to about 16 m during earthquake while it is about 12 m during excavation. This extent of looze zone can be fully rainforced by means of lock anchors, lock bolts and shot concrete work.

4. Conclusion

The underground earthquake observations conducted with the object of evaluating the earthquake resistance of underground caverns and the case studies by numerical analysis have been discussed. In the future, efforts will also be made to accumulate observation data by continuing the seismic observations and prepare a guide line for aseismic design on underground caverns.

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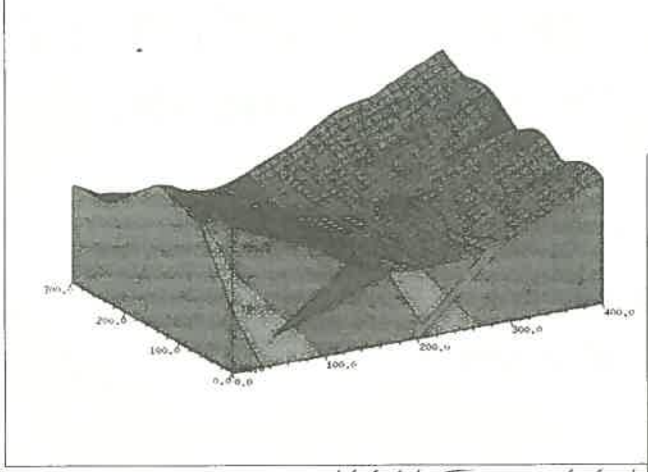
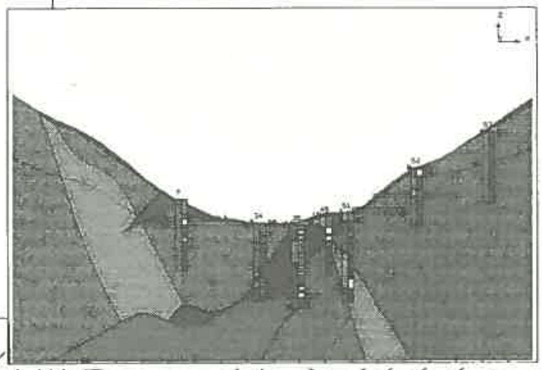
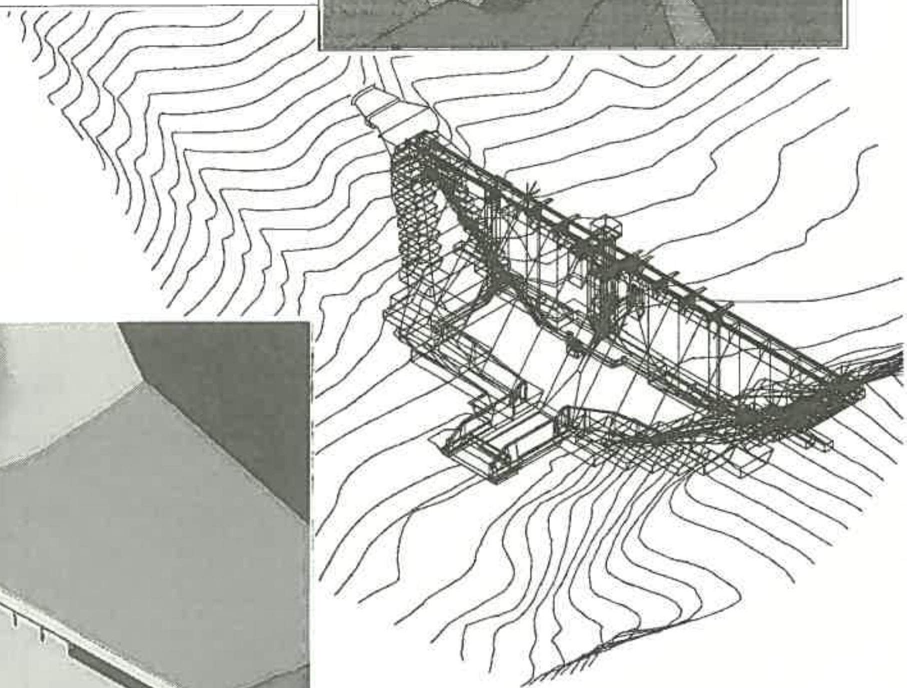
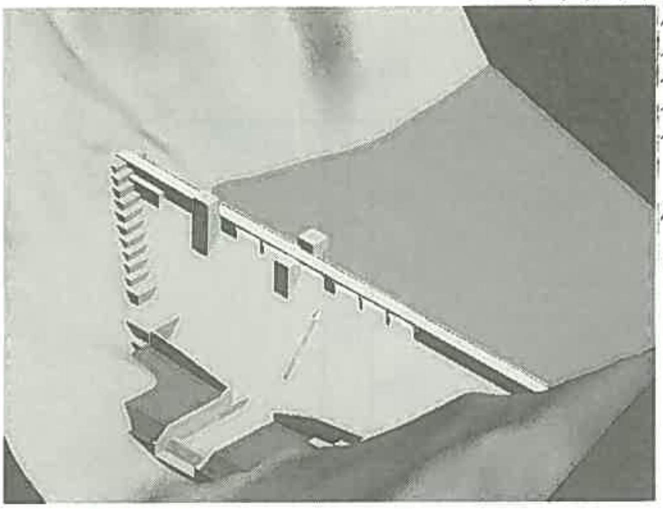
4) Sato,K., et al, Reduction of Underground Seismic Motion, CRIEPI Report No.U88022, 1988
5) Komada,H., Seismic Stability Estimation of Underground Nuclear Power Plant, Proceedings of the 22nd Symposium on Rock Mechanics in Japan, PP.277-282, 1990









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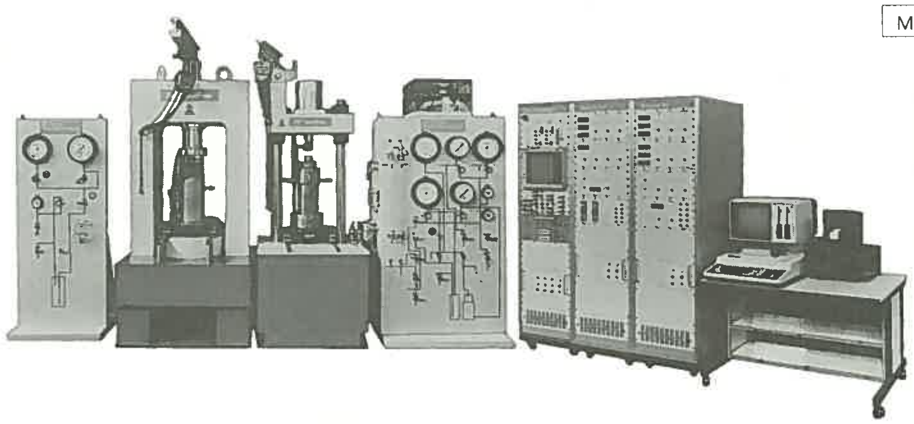

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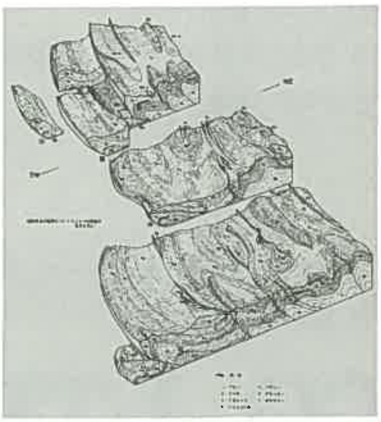

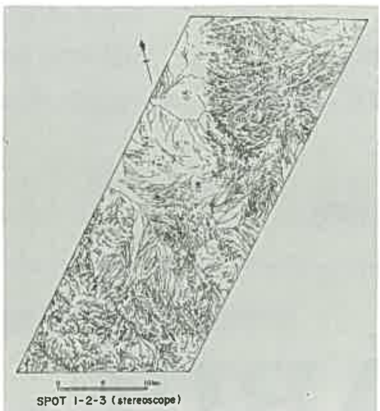

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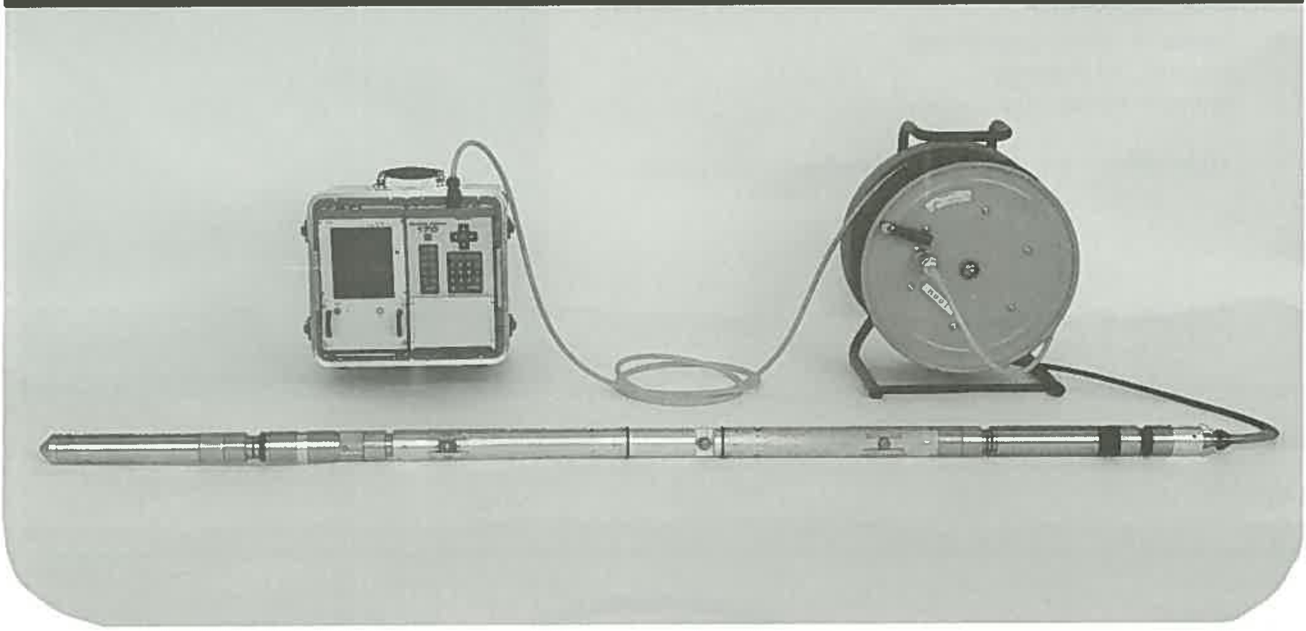

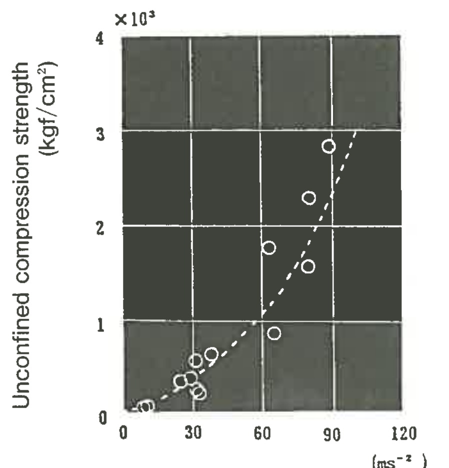

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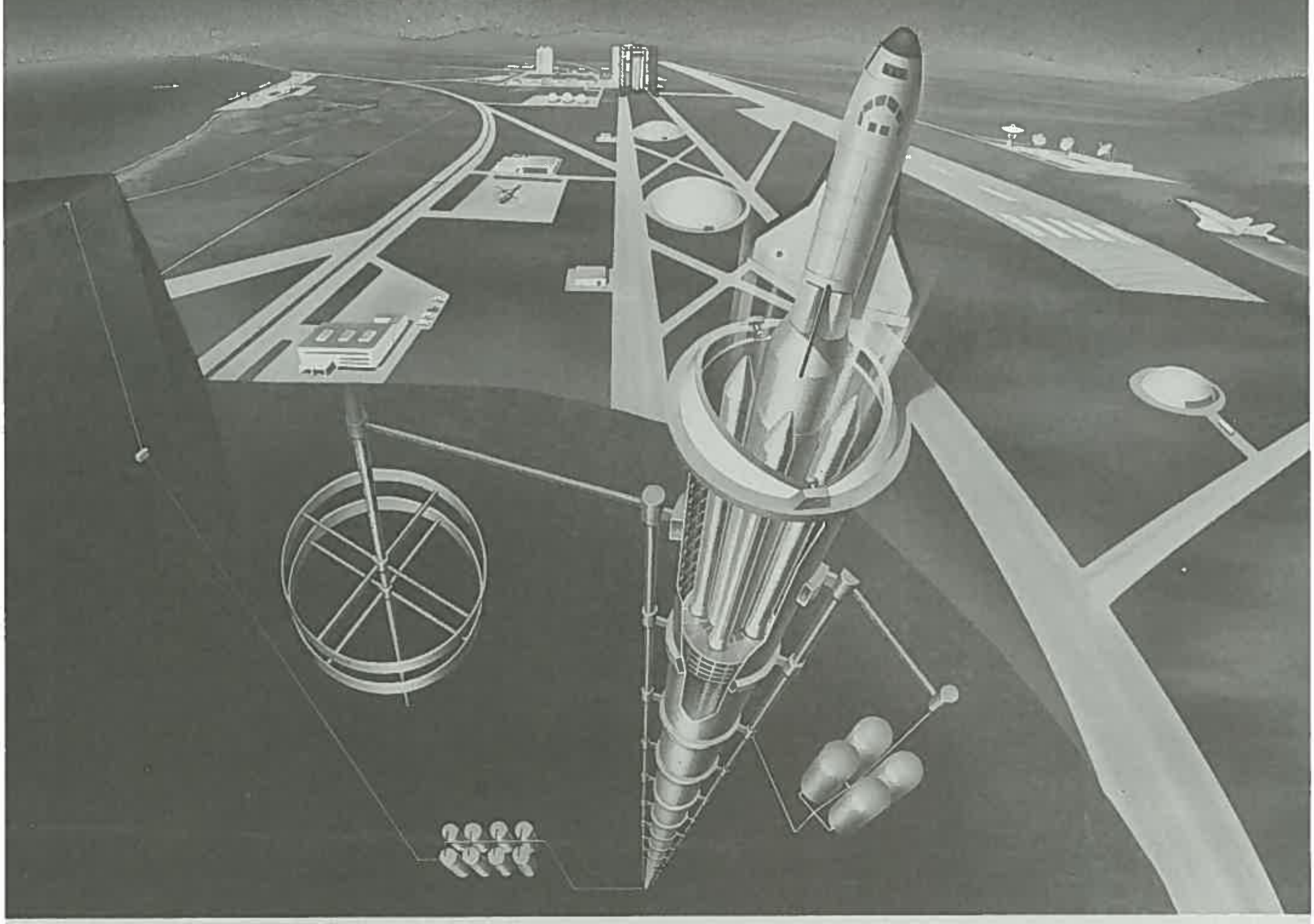

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