PNC TJ5060 86-002(3)

Development of Equipments and Instruments for Use in Underground Research Laboratories (II)

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Shimizu Construction Co., Ltd.

1. Objectives and Significance of Development of Equipments and Instruments for Underground Research Laboratories (URL)

The second stage of R & D on HLW geological disposal includes geological survey, in-situ as well as laboratory tests and trial designing of the facility on a more concrete basis to promote the R & D program on HLW geological disposal. The second stage will call for numerous field investigations and tests. They can be summarized as follows:

1. Survey in search of potential sites for disposal (Wide-area Survey)
2. Various tests to be conducted individually for the development of techniques for evaluating the performance of the natural barrier, ascertaining the performance of the engineered barrier and techniques for in-situ tests and construction works (Tests in Existing Caverns, Investigation on Groundwater Flow System)
3. Tests for developing, verifying and establishing an overall disposal technology by utilizing different techniques such as for survey, performance evaluation, engineered barrier, and construction works that have already been developed or are under development. (Tests in URL)

4. Investigations for selecting a candidate site. (Detailed Survey or Tests in URL)

5. In-situ tests for demonstrating the safety of disposal. (URL or Proposed Site for Disposal)

The "rock mechanics measuring instrument" is the most universally used apparatus for investigating the mechanical behavior and characteristics of rocks. The "hydrogeochemical piezometric logging system" is indispensable in investigating and observing groundwater in deep formations as a means to research and evaluate the performance of the natural barrier. The present study aims at developing equipments and instruments for investigating rock mechanics as well as a groundwater logging system to promote their on-site applications and to imporve the data evaluation technique.

2. Need for Rock Mechanics Measuring Instruments and Their Required Functions

2.1 Measurement of Rock Behavior Induced by Cavern Excavation

In the vicinity of walls of a shaft or a drift, excavation works may cause deterioration of the rock and an increase in the permeability. For the evaluation of waste isolation performance, it is necessary to take into account the groundwater flow in the areas where the permeability increased, so that it is also important to elucidate the mechanism and extent of deterioration and to find out to what extent the permeability may increase in these areas. It is essential to conduct in-situ measurements of fracture behavior due to blasting and/or stress redistribution for quantitative characterization of deterioration in rocks near the wall of a cavern.

In order to determine the state of deterioration in surrounding rocks due to excavation of a shaft or a drift, use of stressmeters and strain gauges is proposed. These instruments must be capable of detecting the stress behavior with higher precision and accuracy and must allow installation in a long borehole drilled horizontally or downward.

2.2 Measurement of Hydrological and Thermal Characteristics of a Rock and Their Complex Phenomema Thereof

For designing a geologic disposal system, it is necessary to understand in advance the thermal and mechanical behaviors of a rock and the groundwater flow after the emplacement of canisters and subsequent closure of the facility. Various test methods have been devised for this purpose and different equipments and instruments are to be employed to measure various components such as the temperature, pore pressure, stress and strain in rocks. The functions required of these instruments are:

1. Highly sensitive stressmeters and strain gauges capable of detecting even minute changes in stress and strain which occur corresponding to fine changes in the pore pressure, temperature, etc.
2. Thermal-stressmeter, high heatproof strain gauge and extensometer capable of detecting thermal stress under heating and corresponding changes in strain and displacement.
3. Highly durable instruments capable of measurements over a long term under high temperature and wet environment.
4. Instruments capable of installation in a long

borehole where measurements are possible at any arbitrary point when the experimental gallery is long. Instruments should also be compact enough to measure the various components of stress, strain and displacement induced in the rock mass of a limited volume.

These are considered to coincide with the final requirements demanded in equipments and instruments to be used in the URL.

3. Existing Equipments and Instruments for Measuring the Rock Mechanics and Their Applicability

3.1 Stressmeter

Stressmeters are classified into two types: those devised for measuring the initial stress and those developed for monitoring the stress changes under the high stress condition.

Different types of instruments such as a borehole deformation gauge, a triaxial strain cell and a hollow-inclusion strain cell have been devised for the initial stress measurement. Any of these instruments enables by itself estimation of the multiple components of the stress with adequate sensitivity. However, they are not durable enough and thus not suitable for long term measurements. Further, when the surrounding rock around the points of measurement shows a non-elastic behavior, it becomes difficult to estimate the stress changes with sufficient accuracy.

Instruments developed for monitoring the stress changes are roughly classified into two types, i.e. a flexible stressmeter and a rigid stressmeter. The rigid stressmeter is to be installed directly in a borehole by utilizing a wedge mechanism. It is mainly used in hard rocks. As the rigid stressmeter is pressed directly against the borehole wall, measurement sometimes becomes impossible when cracks and fractures occurred in the rock mass surrounding the measuring points. In view of its mechanism and structure, it may be easily improved for use under high temperatures for thermal stress measurements.

As a flexible stressmeter, a flat jack type is representative which detects stress changes as changes in the hydraulic pressure of the flat jack. As mortar is used for emplacing the flat jack into the borehole, finish of the borehole or cracks in the surrounding rock mass poses little problem, making it applicable to medium hard to soft rocks. With the flat jack type stressmeter, as the increase/decrease in stress can be measured regardless of fracturing in rocks surrounding the point of measurement, it is suitable for monitoring the stress behavior under high rock pressure. However, this device is more susceptible to temperature changes and is somewhat less sensitive in respect of measurement when compared with other types of stressmeters. Also, it requires additional accurate data on the deformation coefficient for converting hydraulic pressure changes into stress changes.

3.2 Strain Gauge

Embedded-type strain gauges are recently marketed for measuring strains in concrete. Some have sufficiently low rigidity and thus can measure the strain changes including the behavior after fracture occurred in the surrounding rocks by embedding with mortar. For tests in URL, strain gauges of this type seem most suitable.

4. Development of Rock Mechanics Measuring Instruments for Use in URL

In 1984, a wedge-type rigid stressmeter was manufactured on a trial basis which is relatively durable and resistant to high temperatures. Upon performance tests under high temperatures, this stressmeter proved usable at temperatures up to 100°C. This year, the trial manufacture will be continued, with the target heat resistance set at 200°C.

4.1 Structure and Specification of Trial Stressmeter for High Temperatures

The trial stressmeter named wedge type stressmeter utilizes a proving ring of thick-walled cylinder as the stress sensor which is made of nickel-chrome-molybdenum steel and has cross-pattern strain gauges on both sides. This stressmeter is settled in a borehole by means of a wedge mechanism at a measuring position under a given pre-stress and detects the changes of one stress component in the pre-stressed direction. Fig. 4.1 shows the structure. The structure and material used for the main body are the same as those used in the trial stressmeter manufactured in 1984. By improving the heat resistance of the proving ring, the stressmeter can be used at higher temperatures.

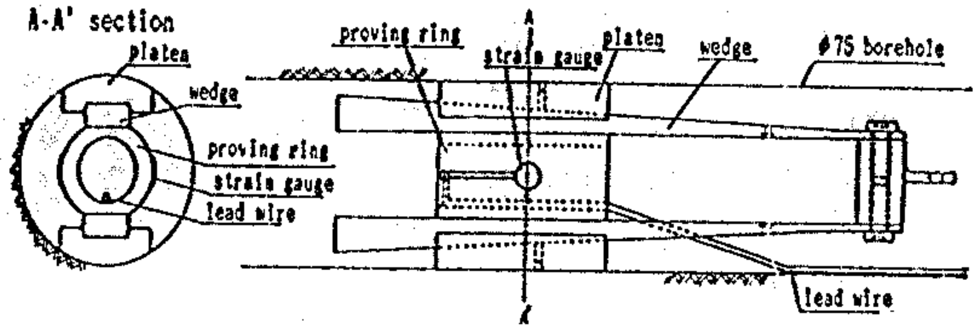

Fig. 4.1: Construction of Wedge-type Stressmeter

The materials and specification used in the manufacture of the proving ring for high temperatures are listed below:

(1) Material (proving ring) : SNCM nickel-chrome-molybdenum steel

(2) Strain gauge : Hottinger Baldwin Messtechnic GMBH 3/350 XG11 (W. Germany)

(3) Gauge adhesive: Hottinger Baldwin Messtechnic GMBH EP310 (W. Germany)

*Curing at 300°C for 1 hour was repeated for 3 cycles.

(4) Gauge coating: The adhesive, EP310, is coated in three layers for water proofing, and Fine heat-proof TFE coating (Fine Chemical Japan LTD) was further applied for impact resistance.

*After each coating step, curing at 300°C for 1 hour was conducted.

(5) Gauge lead wire: Junphrone coated wire (for high temperatures)

A 2-element-cross-pattern strain gauge is attached at the center of the proving ring on both sides to form a 4-gauge-bridge circuit. One of the axes of the strain gauge coincides with the direction for detecting the stress.

4.2 Performance of Trial Stressmeter for High Temperatures

A stressmeter was placed in a borehole in an aluminum block to determine the sensitivity characteristics. The output of the stressmeter against the stress imposed on the block was 0.38 $kg/cm^2/10^{-6}$ ($2^6 \times 10^{-6}/kg/cm^2$), demonstrating sufficient resolution.

Fig. 4.2 shows thermal characteristics of the trial stressmeter in the heating test. Because of rapid heating, a slight drift is observed in the output strain several hours after heating is completed. Thereafter the output becomes stable showing only negligible changes in the output strain even if the temperature is raised to 200°C from the room temperature. However, under the high temperature of 200°C, it takes quite some time for the output to level off at a certain value compared to 150°C. Even after the output reaches a plateau, the output still fluctuates slightly and is somewhat unstable. We therefore consider that temperatures below 200°C are the adequate range for the trial stressmeter according to the present specification.

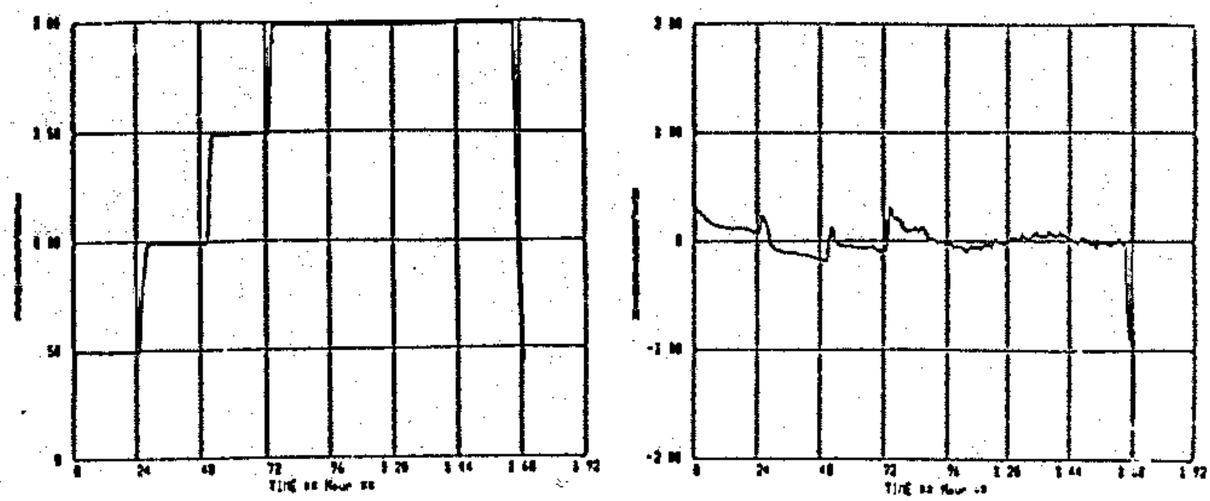

Fig. 4.2: Result of Temperature Characteristics Test

(Left: temperature-time relation,

Right: output strain of stressmeter - time relation)

5. On-site Applicability of the Rock Mechanics Measuring Instruments

In order to assure acquisition of adequate data from various tests in URL using the instruments, it is essential to conduct preliminary applicability tests under similar rock conditions and environment to verify that these instruments have the required performances.

As the first stage of the on-site application tests this year, the rock behavior during excavation was measured in tuff breccia using the wedge type stressmeter, hydraulic capsule, embedded-type strain gauge and triaxial strain cell to review the applicability of each instrument.

5.1 Outline of the Instruments for Trial Use

(1) Wedge type stressmeter

The wedge type stressmeter is identical in structure with that described in Section 4 (see Fig. 4.1).

(2) Hydraulic capsule

The hydraulic capsule is one of the flexible stressmeters of flat jack type. It is widely used in coal mines in Japan for monitoring the stress changes.

The sensor means in the hydraulic capsule comprises a flat jack which is filled with oil and is interposed between semi-cylindrical platens made of iron. The sensor selectively detects a stress component in the vertical direction if any change in the rock pressure occurs, and reads it out as a change in the hydraulic pressure. As shown in Fig. 5.1, a borehole is drilled in a rock mass to a measuring point, where the rock pressure sensor of the hydraulic capsule is embedded at the bottom of the borehole using mortar.

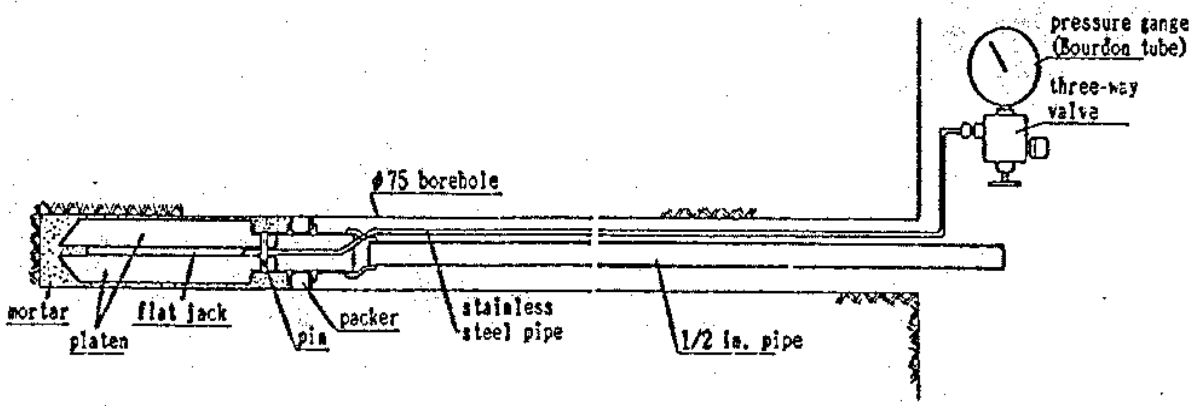

Fig. 5.1: Emplacement of Hydraulic Capsule

(3) Embedded strain gauge

Various types of embedded strain gauge are commercially available. In the present study, an embedded strain gauge manufactured by Tokyo Sokki Kenkyusho is used. For the in-situ measurements shown in Fig. 5.2, the strain gauge was attached to the tip of the hydraulic capsule to measure strain changes in the direction in which the stress changes are detected.

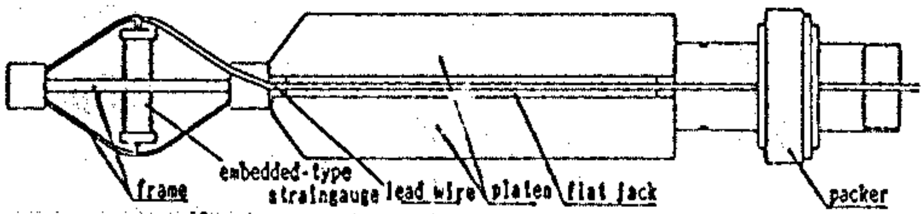

Fig. 5.2: Combination of Hydraulic Capsule and Embedded-type Strainmeter

(4) Triaxial strain cell

The triaxial strain cell we used is a simplified version of CSIR type shown in Fig. 5.3.

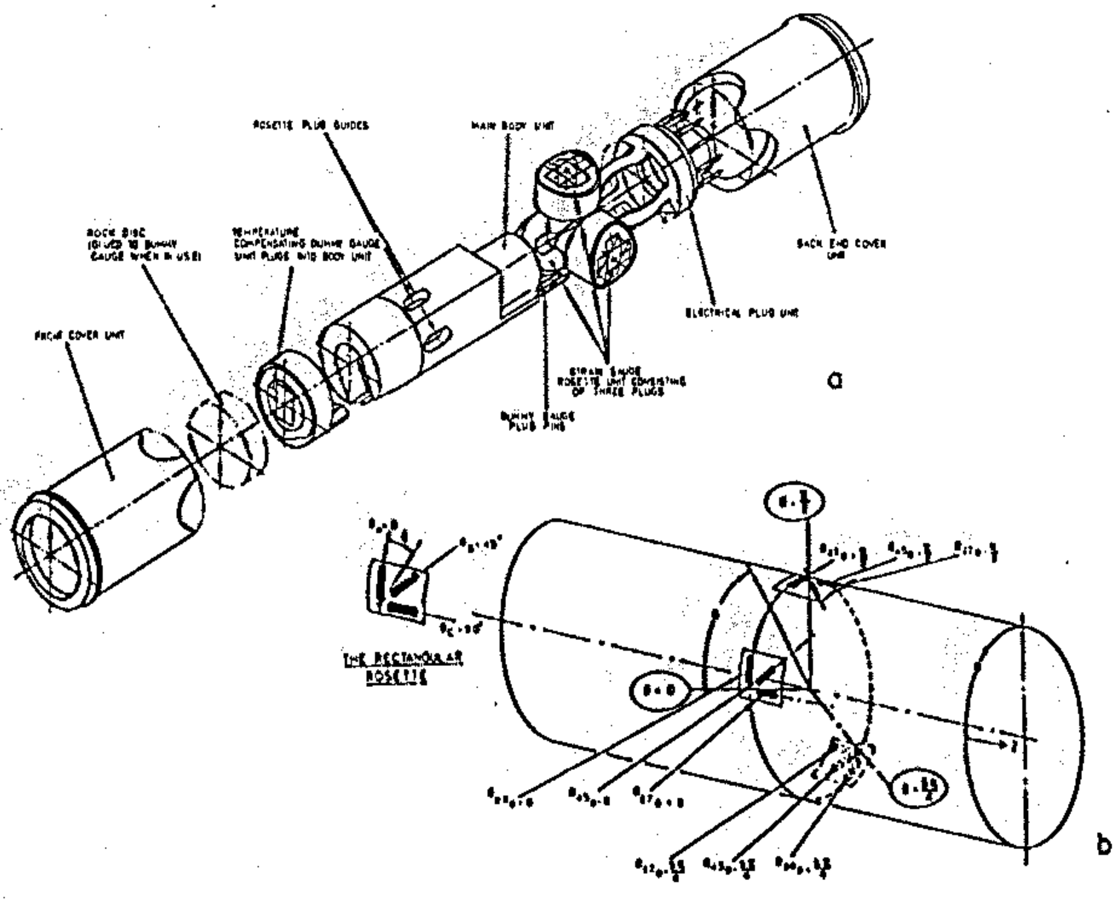

Fig. 5.3: Triaxial Strain Cell (CSIR type)

5.2 Outline and Conditions of the Measurement Site

The measurement was conducted at a site about 340m below the surface. The surrounding rock mass comprises tuff breccia. Fig. 5.4 shows the layout and contours of galleries, fracture distribution, layout of boreholes, arrangement of instruments, progress of gallery excavation, etc.

Prior to excavation of Gallery C which is under observation, boreholes were drilled from the existing Gallery A to the location of Gallery C. After the instruments were installed, Gallery C was excavated to measure the concurrent rock behavior.

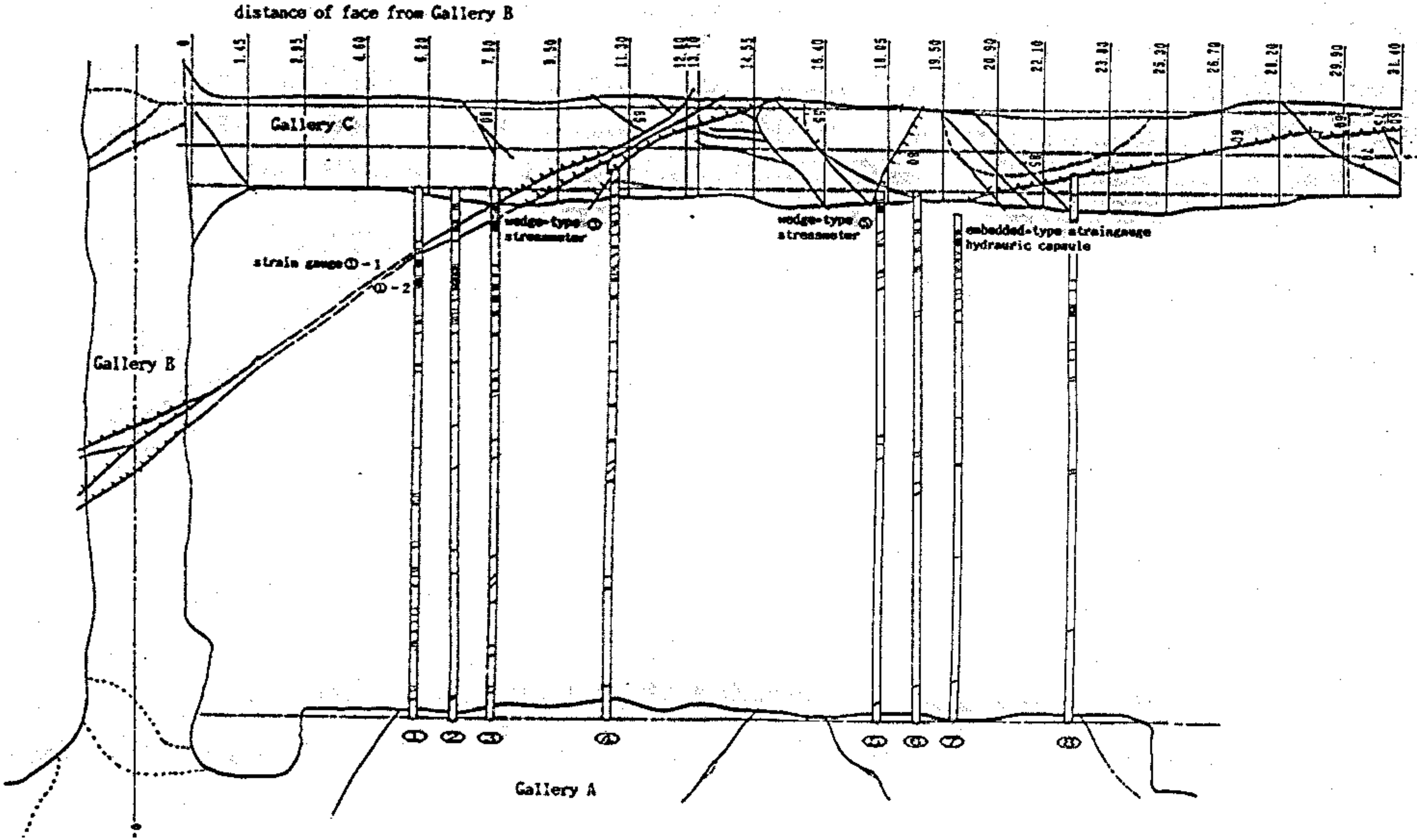

Fig. 5.4: Outline of Measurement Site

5.3 Numerical Analyses of Stress Changes Induced by Gallery Excavation

FEM analyses were conducted using elasto-plastic axi-symmetrical models to elucidate stress status in the surrounding rock during excavation.

Fig. 5.5 shows the models used for calculation as well as the results. According to the results of calculation, a compressed state which is termed as an abutment stress occurs in both components of σr in the direction of the cavern diameter and $\sigma\theta$ in the tangential direction near the front of the face when the rock mass is under elastic conditions. In the regions extending on both sides of the face, the stress component $\sigma\theta$ comes under still greater compression whereas the component σr shows a marked decrease as the stress is released by the gallery excavation.

Under an elasto-plastic condition which produces plastic zones in the rock mass beyond the face, an abutment stress is observed in front of the face where no fracturing has occured, as is also the case under the elastic condtion. However, increase in stress is greater here than the case under the elastic condition. The tendency in the stress changes in the region stretching on both sides of the face varies depending on the distance from the gallery wall. In the plastic zone near the wall, the stress change

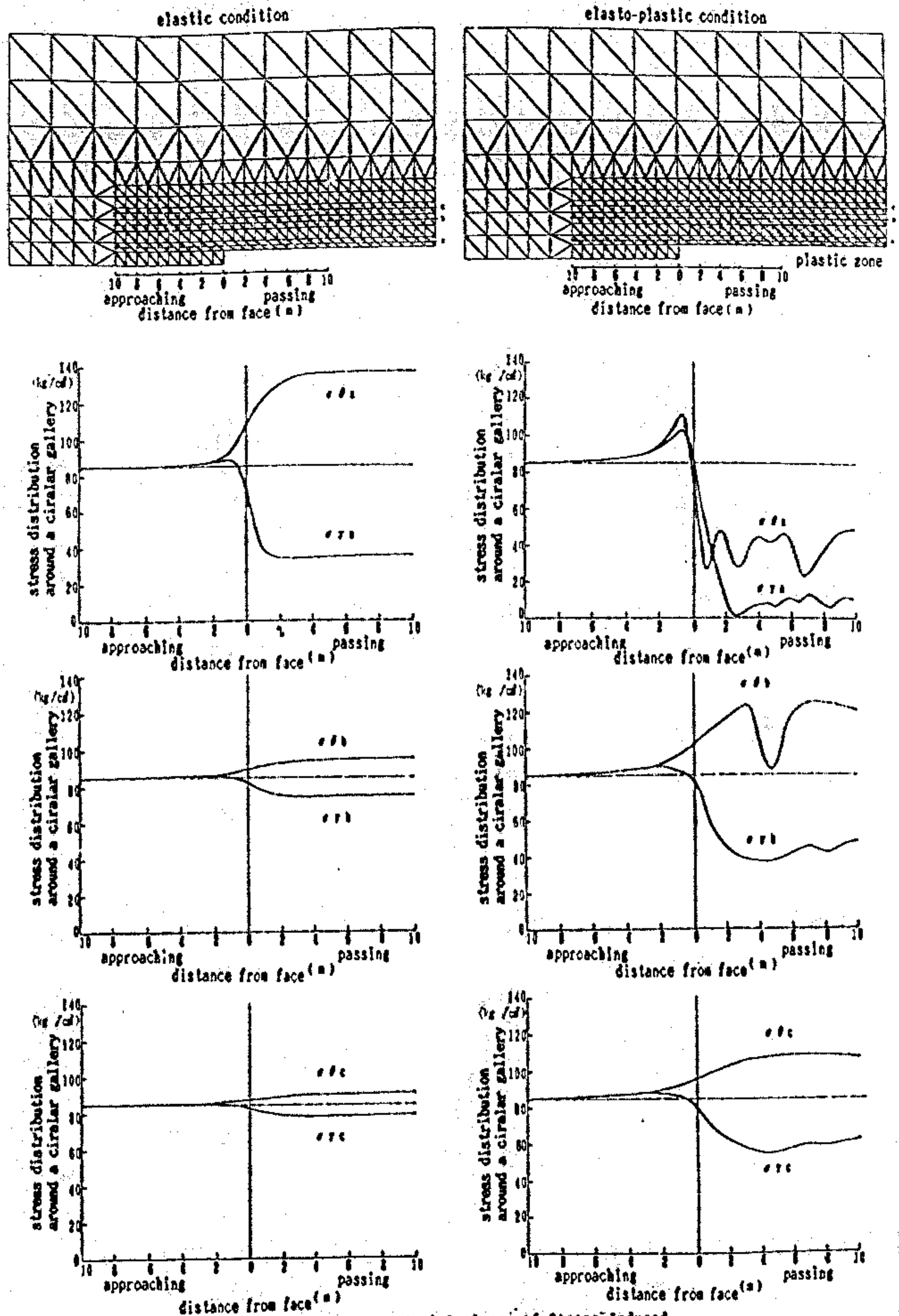

Fig. 5.5: Numerical Analyses of Stress Induced in the Vicinity of a Circular Gallery

shows a completely different pattern and both the components $\sigma\theta$ and σr are released greatly. Along the line C where there is no fracturing, the stess changes show substantially similar tendency as under the elastic condition except that the degree of change is greater. In other words, when a plastic zone appears near a gallery, the effect of stress changes propagates more extensively.

5.4 Result of Measurements and Applicability of Instruments

The result obtained from the measurements using the instruments can be interpreted, in view of the geological structure, by comparing with the result of numerical analyses of the rock behavior under elasto-plastic conditions. No abnormal behavior was observed. This essentially indicates that the instruments we employed have correctly detected the stress behavior caused by gallery excavation.

(1) Wedge type stressmeter

The results of measurements shown in Fig. 5.6 indicate that the increase in stress caused by face advancing is detected at high sensitivity. The wedge type stressmeter is suitable for use in hard rocks, but these results suggest that this stressmeter can be adequately used in medium hard rocks like the one found at this site. Although its long term applicability is still unknown as the measurement was interrupted by blasting, only a slight rusting was observed on the body of the stressmeter recovered 2.5 months after installation, indicating potential applicability in long term measurements.

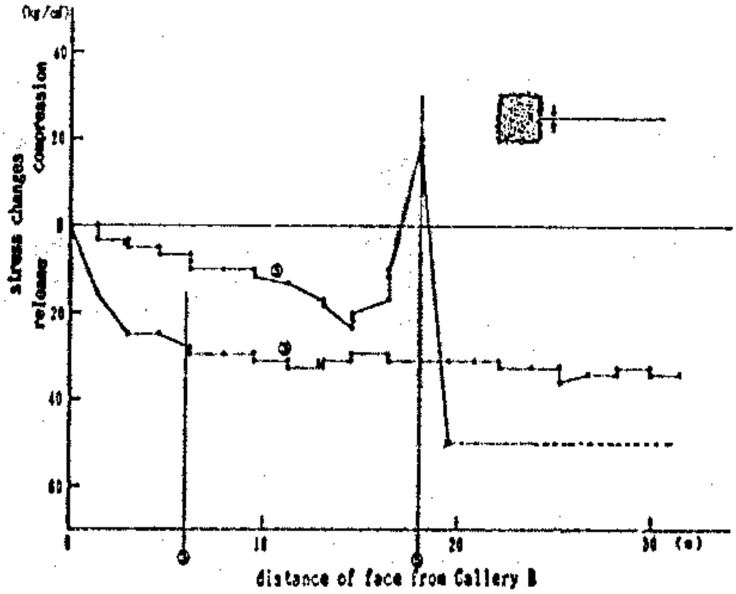

Fig. 5.6: Measurement Using Wedge-type Stressmeter

(2) Hydraulic capsule and embedded type strain gauge

As these apparatuses are completely embedded in the rock mass using mortar, they can probably withstand long term measurements with stability. In the present measurements which lasted for more than 5 months of gallery excavation, widening at the side wall and expansion of the crown, they operated smoothly and normally. As shown in Fig. 5.7, the rock behavior such as increase/decrease in stress caused by advancing/passing of the face is accurately detected. After the face passed through the measuring point, a fractured zone occurred in the vicinity of the gallery and it seems the measuring point was contained in this zone. However, the stress behavior in the fractured zone could also be monitored. This leads us to conclude that these apparatuses are suitable for accurately detecting the tendency in the stress changes even if fractures occur in the rock mass due to significant changes in the rock pressure during measurement.

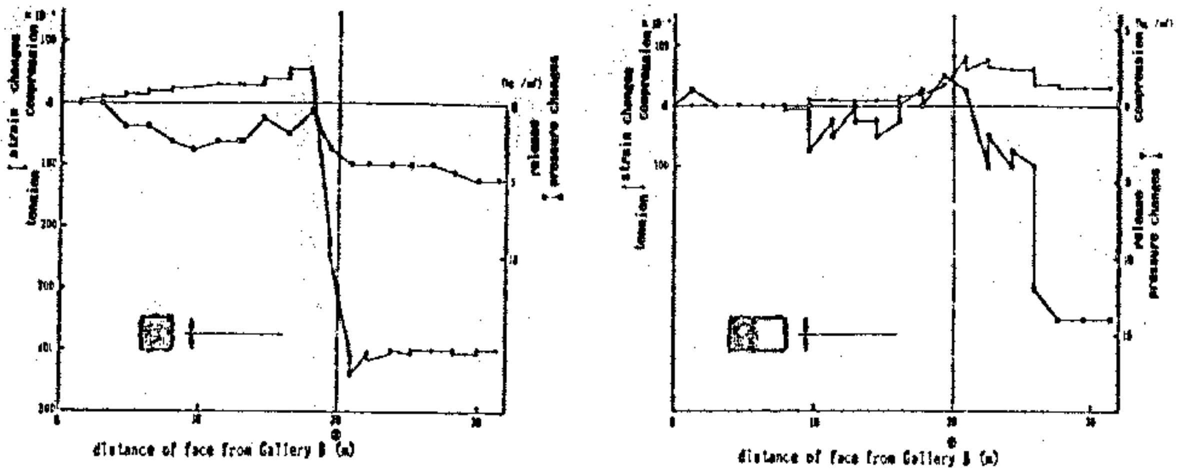

Fig. 5.7: Measurement Using Hydraulic Capsule and Embedded-type Strainmeter

(Left: at the time of Gallery C excavation

Right: at the time of expanding the side wall of Gallery C)

(3) Strain in borehole wall

Direct measurement of strains in the rock mass is, in theory, the most sensitive method. However, it is difficult to securely attach the strain gauge. Moreover, measurements often become rapidly unstable because of alteration of the rock at the borehole wall due to weathering or because of deterioration of the adhesive and the strain gauge itself due to moisture absorption. We were able to obtain data which indicate a certain tendency in the strain changes this time, it is probably because the measurement lasted only for about 1 week. However, as several measurements conducted while the face remained at one point, varied values were obtained. This suggests that the triaxial strain cells should be used in tests which require highly precise measurements within a short period of time in a favorable environment.

As has been described in the foregoing, there is no single apparatus among the rock mechanics measuring instruments which can be universally used for all kinds of tests. It is therefore recommended to thoroughly review the features of each appartus to select and combine optimum apparatuses for a given measurement object.

6. Technology for Investigating the Groundwater Flow

Among various equipments and instruments used in URL, the development of those used for investigating the groundwater flow should be given the top priority. Fig. 6.1 is a flow chart for investigation and estimation of the groundwater flow in the vicinity of a repository. The groundwater flow can be estimated more accurately if a numerical simulation using the data that have been collected (hereinafter referred to as "estimation of

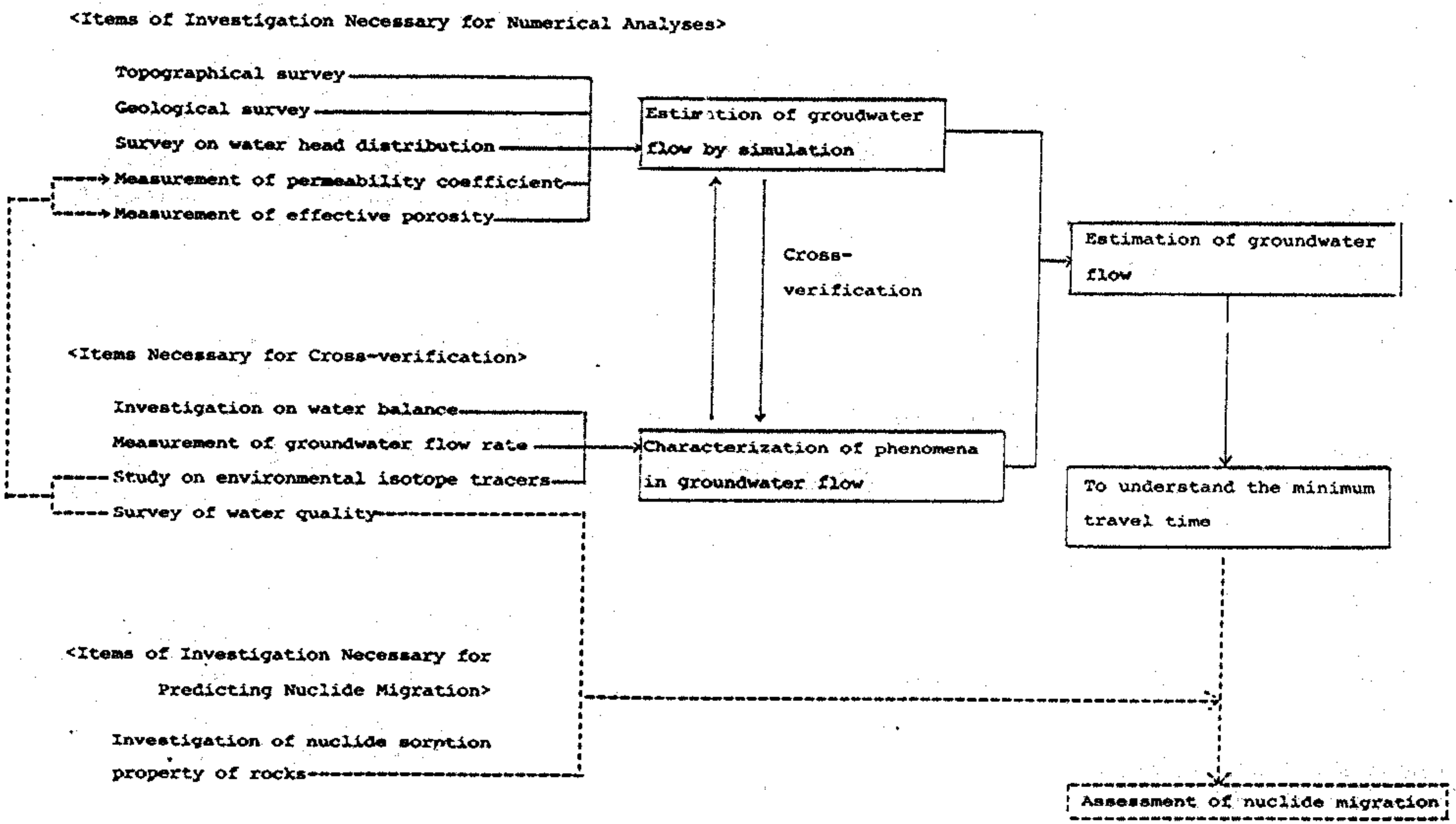

Fig. 6.1: Flow Chart for Investigation/Estimation of Groundwater Flow in Geologic Disposal

groundwater flow by simulation") and "characterization of phenomena in groundwater" are conducted in parallel for comparison and cross-verification. The latter process includes studies on the water balance, groundwater quality, and environmental isotope tracers as well as direct measurement of the groundwater flow. Cross-checking of the results of "estimation by simulation" and "characterization of phenomena" enhances the reliability and may lead to improvement of the simulation models.

The estimation by simulation is a process in which the behavior of groundwater flow is deduced on the basis of data obtained from simulated models and hypothetical conditions. The characterization of phenomena in the groundwater flow is, on the other hand, a process in which the overall groundwater behavior is induced from individual observations. It is therefore preferable to collect data as extensively as possible both in quantity and quality. Because insufficient data may lead to an inaccurate conclusion, carefully planned investigation must be conducted to collect well examined data in bulk and to demonstrate the accuracy of estimation to complement uncertainty inherent in the estimation by simulation.

Items necessry for characterizing the phenomena of the groundwater flow include water balance study, measurement of flow rate, study on environmental isotope tracers, survey on the quality of groundwater and surface water. Although these items are not necessarily essential for estimation, it is always preferable to collect as much data covering as many items as possible.

Characterization of the groundwater flow by investigating the environmental isotopes, quality of water, etc. is an effective method to explain the performance of the natural barrier. At the same time, the water balance which focuses on the observations at the surface is important as backup data. Direct measurement of the direction and rate of groundwater flow is also useful as it offers first-hand data on the subjects for which it is rather difficult to obtain macroscopic characterization data.

Items for the groundwater logging system required in the future study include the following:

* Borehole instrument for in-situ measurement of groundwater pressure (depth: 1000 m range)
* Instrument for determining permeation characteristics (depth: 1000 m range)

  Packer test equipment which is reliable at least at 1000 m depth is necessary. However, it is preferable that the instrument is capable of determining the permeation characteristics (permeability coefficient, effective porosity, storage coefficient, etc.) of the rock as a massive medium without polluting the groundwater.

* Borehole instrument for groundwater sampling (depth: 1000 m range)

  Apparatus capable of continuous sampling and in-situ measurement of water quality is preferable. It is also desirable that the groundwater be sampled in a target zone without being polluted by the groundwater entering the zone from elsewhere.

* Test apparatus for analyzing groundwater

  Apparatus capable of effective general chemical analysis and isotope analysis is preferable.

* Borehole instrument for in-situ measurement of direction and flow rate of groundwater (depth: 1000 m range)

  Multi-hole artificial tracer test is not effective for rocks in deep formations and having low permeability. Measurement should be conducted using a single borehole without polluting the groundwater.

* Apparatus for monitoring borehole walls (depth: 1000 m range)

  Apparatus capable of monitoring the fracture distribution in deep formations from boreholes such as borehole TV, acoustic televiewer and dip-meter is necessary. Borehole TV is especially desirable as it allows direct monitoring.

The groundwater logging system in the present study is intended for use both in measuring the pressure and quality of groundwater (groundwater sampling in boreholes and in-situ measurements).

7. Development of Hydrogeochemical Piezometric Logging System

One of the principal objectives in URL is to elucidate the flow characteristics and water quality of groundwater as well as the permeability of the rock mass. For site selection or for various investigations, it is necessary to develop a technology for simplified groundwater logging using boreholes. As a continued study from last year, measurement probes were manufactured for assembly of an apparatus capable of measuring the pressure and quality of groundwater in deep formations and of collecting samples.

7.1 Objectives in the Development of Hydrogeochemical Piezometric Logging System

The objectives can be summarized into 4 categories:

* To grasp the distribution of groundwater potential in deep formations
* To collect in-situ water samples for the analysis of groundwater quality and environmental isotopes.

* To conduct reasonable in-situ measurement of grounwater quality as the composition of the water may change after the water is pumped to the surface. (pH, Eh, electric-conductivity, water temperature)
* To grasp the changes in the pressure and quality of groundwater over a long period of time in one specific borehole, and to adapt the appartus to different measurement sites.

7.2 Specifications of Hydrogeochemical Piezometric Logging (HPL) System

Table 7.1 shows the specifications for HPL system. Eh sensor excluded in the 1984 study is included in this study as SKB of Sweden recommends in-situ measurement by Eh sensor in boreholes.

7.3 Schedule of Development

In the 1984 study, we prepared the basic design of the system, purchased sensors, and manufactured cables and trial probe heads. This year, we plan to manufacture the probes and test their pressure resistance performances, etc. When the surface apparatuses are completed next year, we will be able to conduct on-site application tests. As certain defects are expected to be found during trial operations in the fields, actual measurements using the system can only be implemented in 1987 at the earliest.

As the surface apparatuses and cables manufactured

Table 7.1: Specifications for Groundwater Logging System

	target location	tentative specification	targets for improvement
type of rocks	rock mass (not suitable for soft and weak formations)		
depth	250 - 1000 m	450 m (total length of the cable 500 m)	1000 m (total length of the cable 1200m: drums to be added)
groundwater sampling	capable of continuous sampling at 100 - 200 ml/min	50 ml/min	50 m³/min
measurement of pore water pressure	in-situ	piezometer 0 - 50 kgf/cm² precision ±0.2% FS temperature for use ∿60°C pressure resistance 600 m	piezometer 0 - 100 kgf/cm² precision ±0.2% FS temperature for use ∿60°C pressure resistance 1200 m
pH measurement	in-situ	pH sensor 2 ∿12 pH precision ±1% FS temperature for use ∿50°C	improve pressure resistance for pH sensor ∿1200 m
Eh measurement	in-situ	ORP sensor ±700 mV (Eh sensor) precision ±2% (minimum calibration 20 mV) temperature for use ∿60°C	improve pressure resistance for ORP sensor ∿1200 m
electroconductivity, water temperature	in-situ	sensor for electroconductivity 0 ∿ 1000 μS/cm precision ±5% FS temperature for use ∿45°C pressure resistance 300 m ∿	improve pressure resistance to ∿1200 m make the measurement range variable between 0 ∿ 100,000 μS/cm
features	• convenient in point samplings during the Wide-area Survey • applicable to a certain extent for a long term observation during a detailed survey if the number of points to be measured is few		

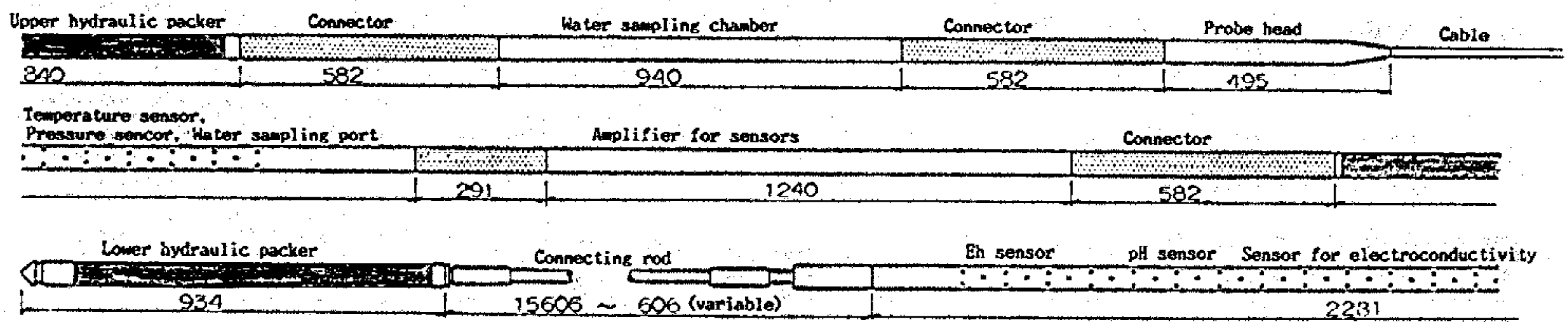

Fig. 7.1: Construction of the Probe for Groundwater Logging System

for the logging system can be adapted for permeability tests in boreholes, they will provide an efficient system for groundwater investigation if a separate probe for permeability test can be manufactured.

7.4 Probe Performance Tests

(1) Sound performance test for its water pressure resistance

It is necessary to use a pressure resistant container (sound) for protecting those components of a probe which are susceptible to water such as electronic parts and which are less resistant to pressure such as pipes. In order to place sensors, wirings, pipings and electronic circuits in a sound or to allow maintenance thereof, the sound must be divided into several sections so that they can be assembled or dismantled by means of connectors and joints. Water immersion tests were conducted to confirm the water resistance of the sound. Defective parts were improved and the performance test was repeated.

(2) Packer leakage test

After installation of a probe within a borehole, it is necessary to protect the probe at its top and bottom with packers against seepage in the borehole. Leakage test was conducted to confirm the performance of the packers in preventing seepage from other regions mixing with the water to be collected. When the pressure difference between the packers and the sound exceeded 4 kgf/cm^2 leakage was likely to occur and no abnormal signs in the packer strength were observed even when the pressure difference reached 20 kgf/cm^2. On the basis of these findings, the pressure difference of 10 kgf/cm^2 is selected as the normal pressure.

(3) Performance test of water sampling pump

We designed and manufactured a water sampling pump of a completely new type last year. The maximum discharge and delivery pressure were confirmed to improve any defects.

The pump according to the final specifications was operated on trial basis using nylon tubes (inner diameter 4 mm) connected to a length of 200 m. The result is given below. As the supplied voltage was 11.6 V, the output will increase if the rated voltage of 18 V is used.

Flow rate in the tube: 47 min/200 m

Discharge: Qmax = 44 ml/min (at the tip of the 200 m tube)

Delivery pressure: Pmax 30 kgf/cm^2 (at the discharge opening)

8. Future Objectives

8.1 Future Objectives in the Rock Mechanics Measuring Technology

(1) Heat-resistant stressmeter for hard rocks

Development of stressmeters for hard rocks used at high temperatures has been completed.
We expect to carry out the heated block jack test (test on deformation characteristics of in-situ rocks under high temperature conditions) as a part of the application tests. The test is expected to bear significance when carried out in an existing cavern, or an underground research laboratory which is eventually completed.

(2) Stressmeter for measuring thermal stress

Although it is desirable to measure the thermal stress in a rock mass using a stressmeter for hard rocks, it is not clear at this point whether the thermal stress can be correctly measured under fluctuating temperatures. It is therefore necessary to improve the materials for the stressmeter and conduct laboratory tests on the basis of preliminary theoretical studies using numerical analyses. These tests will require some 3 years. Measurement technology should be established before the heater tests can be carried out.

(3) Other rock measurement instruments

The following items must be developed in addition to stressmeters for hard rocks.

① Heat-resistant stressmeter for soft rocks

② Heat-resistant strain gauge

③ High precision convergence-meter

Development of item ① is quite difficult because of its structure. The next item on the development schedule is the heat-resistant strain gauge.

(4) On-site applicatiion test of the rock mechanics measuring instruments

If deformation, stress and strain of a rock mass can be accurately measured at a number of points, the basic mechanical behavior of the rock mass can be characterized. However, since the individual measurement techniques are not yet perfect, it is impossible to put the instruments to practical application unless the measurement instruments and evaluation technique are firmly established as a system. Such a system can only be realized through repeated tests, improvements and training. The rock measurement instruments developed each year in our study must be improved for their long term durability, performance in the field and method of installation. At the same time, the technique for interpreting and evaluating the obtained data must be improved for accumulation of in-situ data in Japan.

(5) Instruments for evaluating the mechanical properties of rocks

In addition to the rock mechanics measuring/evaluating system mentioned above, it is necessary to establish a technique for delineating the mechanical properties and deterioration of rocks in respect of such problems as: to what extent the mechanical properties of rocks deteriorte by excavation; to what extent the deterioration of rocks can be prevented by improving the construction tehcnique; and what measures can be employed in monitoring the gallery stability. Apparatuses for the borehole jack test, permeability test and ultrasonic detection should be reviewed for their applicability as a means for evaluating the long term stability and deterioration behavior of rocks, and for their improvement.

8.2 Future Objectives Relating to the Investigation Technique for Groundwater Flow

(1) Development of groundwater logging technique

As we finished developing measurement probes last year, the groundwater logging system will be completed in 1986 if a winding machine and control devices are designed and manufactured. The system, when completed, still remains to be tested for its on-site applicability for further improvements.

(2) Apparatus for permeability test in deep formations

Although Lugeon test (packer test) is the most typical method for determining permeability of rocks, much remains to be solved and improved for accurate measurement of permeability in deeper formations or in a rock mass where the interval between fractures is great. As the winding machine and measurement cables used in the groundwater logging system can be used in the Lugeon test as well, packer tests in deep formations can be conducted when the probes are developed.

(3) Technique for measuring effective porosity of rocks

Safety of a disposal site is evaluated on the basis of the concentration of nuclides migrating in groundwater. It is therefore essential to measure the amount of infiltration, dissipation and sorption property of groundwater. As the attenuation due to decay of nuclides is governed by the travel time of the groundwater, it is indispensable to understand not only the permeability but the effective porosity of rocks. The future objectives in this area include development of various methods and instruments for measurement using core samples and boreholes for in-situ tests and back-analysis from the environmental isotope tracer study.

(4) Method for understanding the fracture distribution in rock mass

As the groundwater in deep formations flows through fractures, it is important to develop borehole observation apparatuses for understanding the fracture distribution in the rock mass and to study the technique for analyzing the data obtained.

(5) Technique for measuring the direction and rate of groundwater flow

For more comprehensive studies to obtain more accurate data or for verification of estimations by numerical analyses based on the investigation results, it becomes necessary to obtain data from direct measurement of the groundwater flow rate in addition to those from the tracer tests and the environmental isotope tracer study. The existing apparatuses cannot measure the flow rate as small as several meters per year, nor are they applicable to measurements in deep formations. Use of tracers in these measurements is not desirable. Much remains to be studied in these respects.

(6) Investigation of groundwater flow mechanism through on-site application tests

Technique for safety evaluation of a disposal facility can be established when the precision in measurements, models for numerical analyses and technique for verification and interpretation of data are improved through comprehensive studies utilizing various instrumentations discussed above as well as predictions by numerical analyses. We must exert our efforts in improving the system for investigating the groundwater flow mechanism and in accumulating data on groundwater flow in deep formations in Japan.