

SURVEY AND RESEARCH ON EARTHQUAKE(II)

March, 1986

**THE MINING AND METALLURGICAL
INSTITUTE OF JAPAN**

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Synopsis

Entrusted by the Power Reactor and Nuclear Fuel Development Corporation, the Mining and Metallurgical Institute of Japan set up a committee and conducted an "Survey and Research on Earthquake" in 1984. The committee selected Hosokura Mine in Miyagi Prefecture as the site for the installation of seismographs in order to carry out a comparative study of the influence of earthquakes at deep underground and surface locations. The committee also endeavored to design seismic observation systems.

As this study developed in 1985 into a cooperative effort between the Central Research Institute of the Electric Power Industry, and the Power Reactor and Nuclear Fuel Development Corporation, only the following tasks were assigned to the Mining and Metallurgical Institute of Japan:

- (1) Civil work for the set-up of observation systems
- (2) Planning of a survey on the observation site
- (3) Investigation of methods of studying the influence of earthquakes on the performance of geological barriers.

Because the work in (1) was civil work in the mine with Kanten Shaft of Hosokura Mine as the center, the work was carried out in contract with that mine. Prior to the civil work, meetings in the mine were held to select seismograph installation points.

After the introduction in Chapter One, this report describes in Chapter Two past earthquake occurrence in the vicinity of Hosokura Mine.

Chapter Three explains the extent of civil work performed in the mine, such as the construction of observation cottage in Hosokura Mine, the concrete

base work for seismographs, the earthquake observation system, and maintenance methods.

Chapter Four explains the earthquake observation system.

The latter section of this report - encompassing Chapters Five through Eight - describes the method of studies on the local characteristics (which is required for the analysis of earthquake observation data) and the overall plan of the study. These studies will be conducted in the next fiscal year and beyond.

Chapter Five - the first in this section - describes the geological survey plan, and a testing methods to get various rock characteristics in-situ, as the contents of a survey in Hosokura Mine.

Chapter Six takes up the observation of rock mass behavior and underground water behavior as a means of studying the influence of earthquakes on the performance of geological barriers. Actual examples of observation methods are included.

Chapter Seven also refers to the analysis of observation data, and describes methods of analysis of seismic stability and other data, and the method of generalizing observation data deeply influenced by local characteristics.

Chapter Eight yields conclusions and recommendations regarding the next fiscal year's mine survey.

* Work performed by the Mining and Metallurgical Institute of Japan under contract, with Power Reactor and Nuclear Fuel Development Corporation

1. Introduction

In 1985, the number of experts in research on earthquakes and underground water were increased and the layout of seismographs around Kanten Shaft in Hosokura Mine was reviewed. As a result, the vertical distribution of seismographs at seven positions ranging from the +1 level to the -10 level planned in 1984 was modified a little and a horizontal tripartite array was added to the plan. Three points which form a triangle with sides of about 500 m were selected on the -10 level and observation points on the -5 level were omitted, thus eight points in total were selected.

The civil work in Hosokura Mine was completed by the end of February, 1986, and the installation of seismographs and the setting up and adjustment of an observation system in an observation cottage outside the mine were performed by the Power Reactor and Nuclear Fuel Development Corporation in March. Then, training of the personnel, who were to take charge of earthquake observation work from the next fiscal year, which will be and who will be, allocated to Hosokura Mine was carried out, thus the observation organization was established.

As the contract period in this year was as short as three months, the research activity of the committee was ended with the completion of the planning of surveys and researches to be carried out from the next year.

The members of the committee in 1985 are shown on the next page. The committee continued holding study meetings five times including those in Hosokura Mine.

We would like to express our cordial thanks to the members of Hosokura Mine for their kind cooperation to the meetings in the Mine and they have executed a series of civil works mentioned in Chapter 3 of this report since the Mine was selected as the site of earthquake observations.

Members of Committee

Chairman	Koichi Sassa	: Kyoto University, Faculty of Engineering
	Umetarō Yamaguchi	: The University of Tokyo, Faculty of Engineering
	Toshikazu Kawamoto	: Nagoya University, Faculty of Engineering
	Akio Takagi	: Tohoku University, Earthquake Prediction Observation Center

Yoshimasa Kobayashi	:	Kyoto University, Faculty of Science
Koji Matsuki	:	Tohoku University, Faculty of Engineering
Kunio Watanabe	:	Saitama University, Faculty of Engineering
Kazuhiko Sato	:	Muroran Institute of Technology
Hiroya Komada	:	Central Research Institute of Electric Power Industry
Yoshihiro Sawada	:	" "
Hitoshi Koide	:	Geological Survey of Japan
Kin-ichiro Kusunose	:	" "
Hikaru Hotta	:	Construction Project Consultants Inc.
Takaaki Kashiwagi	:	Mitsubishi Metal Corporation
Sakae Sakurai	:	Hosokura Mining Co., Ltd.
Katsuyoshi Inoue	:	Dowa Mining Co., Ltd.
Koji Kojima	:	Nippon Mining Co., Ltd.
Keizō Ogawa	:	Nittetsu Mining Company, Ltd.
Jyun Tashiro	:	Limestone Association of Japan
Takeo Yokoyama	:	Seumitomo Metal Mining Co., Ltd.
Masayoshi Nishio	:	Mitsui Mining and Smelting Co., Ltd.
Researcher Mizushiro Inoue	:	The Mining and Metallurgical Institute of Japan
Masahiro Hagimoto	:	" "

2. The Occurrence of Earthquakes in the Vicinity of Hosokura Mine

2.1 Past earthquake activity in Tohoku District

The activity of large earthquakes in the Tohoku District shows almost the same pattern of distribution throughout history, and they have occurred in almost the same areas at intervals of several tens to several hundreds of years. Earthquakes occur most frequently under the sea bed in the earthquake zone of the east coast of Aomori Prefecture to Fukushima Prefecture running almost parallel to the coast line and earthquakes of a magnitude of 7.5 or so have occurred often, but their seismic centers are deep. When the inland earthquake zones or those along the coast of the Sea of Japan are compared with those in the area shown above, the frequency of earthquakes in the former area is considerably lower than that in the latter area and the largest magnitude is up to 7.0, but their seismic centers are shallow.

2.2 Disastrous earthquakes in and around Miyagi Prefecture

An earthquake of a magnitude 7.4 occurred in 1978 under the seabed 60 km off the coast of Kinkazan, and an intensity of V was recorded in Sendai, Ofunato, Ishinomaki, Fukushima and Shinjo. In 1936, an earthquake of a magnitude 7.7 occurred in almost the same area. According to earthquake resisters, earthquakes with an intensity of V or more occur at about 10 year intervals for both Sendai and Ishinomaki. However, it does not mean that earthquakes of an intensity of V occur once per about 10 years regularly, but there seems to be a tendency that they occur concentrated in an active period.

2.3 Microearthquake activity in Tohoku District

The distribution of microearthquake activity in Tohoku District almost agrees with that of the epicenters of large earthquakes in the past. There are three main areas of significant seismic activity: under the bottom of the Pacific ocean, along the mountain range forming the backbone of Honshu and along the Sea of Japan coast. A highly active zone of small earthquakes runs almost from north to south near the inland backbone mountain range in the Tohoku District and seems to be distributed along the western edge of the Kitakami mountains. This active zone extends from the northern part of Miyagi Prefecture. The aftershocks of the Great Earthquake of 1983 in the central Japan Sea still actively occur in succession.

2.4 Microearthquake activity in and around Miyagi Prefecture

A reverse fault type earthquake of a magnitude of 6.5 occurred in the northern part of Miyagi Prefecture in 1962. In 1970, there was an earthquake of a magnitude of 6.2 in the southeastern part of Akita Prefecture, and in 1976, there was an earthquake of a magnitude of 4.7 in Onikobe, Naruko Town, Miyagi Prefecture. Furthermore, an earthquake of a magnitude of 4.7 occurred in Naruko Town, Miyagi Prefecture in March, 1985, and an earthquake of a magnitude of 4.7 occurred in the northern part of Miyagi Prefecture in June of the same year. As shown above, a highly active zone of microearthquakes exists in the vicinity of Hosokura Mine.

3. Civil Work for Installing the Earthquake Observation System

3.1 Work plan

The Committee of Survey and Research on Earthquake determined the locations where seismographs should be set up as follows in the first meeting of the committee and the meetings of the field committee in Hosokura Mine.

Seismographs were planned to be set up at eight positions of survey point 1 to 8. The extent of the positions spreads 800 m from east to west, 500 m from north to south and vertically from the +1 level to the -10 level, of which four levels are used. The deepest position is the depth of 350 m. These points form a tripartite array of observation points in the horizontal and vertical directions.

An observation cottage was built at the entrance to the +1 level, and as the instruments installed in the cottage are quite sensitive to temperature and humidity changes, an air conditioner both for cooling and heating was installed to keep the temperature and humidity in the cottage constant.

3.2 Setting up

The weight of signal cable is 425 g/m, so the weight of cable required to hang up a length of 350 m in the shaft is about 150 kg. Therefore, the cable was fixed at 2.0 ~ 6.0 m intervals to the timber props using IV cord. In the horizontal direction, messenger wire was stretched and cable was fixed to the wire. The base for each seismograph was made by digging at the drift floor so as to expose about 1 m² of base rock and then placing a 50 cm cube of concrete on the base rock. This block of concrete had anchor bolts for fixing the seismograph on its upper surface. The observation cottage is of a prefabricated construction with a floor space of 18 m² and heat insulation materials were installed. Power is taken from a switchboard used for underground slim filling plant and supplied to the measuring instruments via a voltage stabilizer.

4. Earthquake Observation System

4.1 Composition of system

An observation system is constructed mainly of detectors and observation instruments. The detectors are velocity feedback type accelerometers, including six three-component types and two one-component types. The main part of the observation instruments consists of an amplifier, an A/D converter, a delay device, a processor, a digital data recorder, a D/A converter, an analog recorder, a time signal generator, etc. When a seismic vibration of a level above a optional threshold level is detected, the vibration is recorded by the data recorder and the maximum value of the vibration is printed out by a printer. When required, it is also possible to output the waveform with a pen recorder.

4.2 Specification and exterior of system

The specifications of the system are as follows.

measurable acceleration range:	± 1000 Gal
measurable frequency range	: (0.05 ~ 30 Hz) $\pm 10\%$
A/D converter	: 16 bit
sampling frequency	: 100 or 200 Hz
dynamic range	: 86 dB or more
trigger circuit	: level judgement, optional setting 3-ch AND/OR
signal delay time	: 5.12 or 10.24 sec.
size of mount rack	: 1130 mm W x 680 mm D x 1650 mm H

Control switches are all setted on the front panel and input and output terminals are setted on the rear panel.

4.3 Recording format

A recording time chart, a magnetic tape record channel table, the analog recording format, the printing-out format, the display format and the MT recording format are illustrated and explained.

4.4 Test results of instruments

The results of tests of overall performance and individual performance are shown and the test results have all been judged as good. In addition, a list of the frequency characteristics of the seismograph and the amplifier, the trigger frequency characteristics detector sensitivity and the table of visible record sensitivity are shown.

4.5 Organization for earthquake observations

Observations in the mine are entrusted to Hosokura Mine, and ordinary checks and measurements at the time of earthquakes are performed by the staff of the Mine. The seismographs and cables are checked twice a month and the measuring instruments are checked twice a week. Data records on checked items are sent to the Central Research Institute of the Electric Power Industry at regular intervals. When an earthquake occurs, three operations are carried out, i.e., (1) to take out a magnetic tape from the digital data recorder and load a new tape, (2) to take out printed paper from the digital printer and (3) to take out recorded paper from the monitoring pen recorder. These records are sent to the above institute together with the data records on checked items. If problems occur, it is immediately reported to the Mining and

Metallurgical Institute of Japan, the Institute contacts the Power Reactor and Nuclear Fuel Development Corporation and also the Central Research Institute of the Electric Power Industry, and then the problems are dealt with appropriately.

4.6 Photographs of setting up works

The photographs of laying cable, the observation cottage, installation of the seismographs, earthquake observation instruments, etc., are shown.

5. Survey Plan on Observation Sites

5.1 Survey plan on geology and underground structure

Each level on which a seismograph has been setup and the space within a radius of about 300 m around Kanten Shaft will be surveyed to prepare detailed geological maps on a scale of $1/1000 \sim 1/3000$ and geological sectional maps in four directions with Kanten Shaft as the center. In addition, the positions, sizes, etc., of goafs with fillings will be surveyed and noted as precisely as possible. Furthermore, level layout maps will be prepared and in the maps the distribution of faults, cracks, etc., will be shown as required.

5.2 Survey plan on elastic wave propagating characteristics

As the rock around Kanten Shaft has comparatively complicated structure, it is indispensable to clarify the influence of the non-homogenous rock on the propagation of seismic waves. Accordingly, a survey plan on elastic wave propagation characteristics was studied, but the plan is still in a conceptual stage and must be put into practical form before it can be put into practice by studying methods, time, effect, etc., in more detail.

An elastic wave velocity distribution survey was planned by dividing it into an elastic wave prospecting on the ground surface, a seismic testing within drifts, a seismic testing between drifts and other surveys. The elastic wave prospecting on the ground surface is to be carried out to find out the thickness of the surface strata and the velocity characteristics near the ground surface. As a seismic source explosive are used for P waves and board striking for S waves. Survey lines of about 1 km are proposed. In the seismic testing within drifts, P and S wave velocities along drifts are to be measured and also the thickness of loose zones, which are supposed to have occurred near the surface of openings is estimated. This survey is to be used especially for surveying the distribution of P and S wave velocities corresponding to kinds of rock. The seismic testing between drifts is to be carried

out so as to understand the entire underground structure. When the number of survey lines becomes large, more detailed velocity structure can be obtained by using the technique of geotomography. Other items of surveys are the measurement of P and S wave velocities of the fillings in goafs and the measurement of the attenuation properties of elastic waves. The measurement of velocities of the fillings is to be carried out by setting survey lines which cross the goafs with fillings or by setting short survey lines on the surface of the fillings. The survey on attenuation properties to be carried out using Kanten Shaft.

5.3 Survey plan on in-situ rock property tests

To investigate the influence of an earthquake at the deep underground at the point of interests, it is necessary to carry out boring first at the point and judge the characteristics of rock mass in the region. Therefore, plans to carry out borings of a depth of 40 ~ 200 m in Hosokura Mine and to carry out various strata analysis, core observation, tests in the bore hole, and permeability tests in the bore hole were studied and the results of the studies are shown.

5.4 Rock property test plan

A plan is shown to carry out laboratory tests on 15 items by collecting rock samples from eight locations near each earthquake observation point, more than five locations of typical rock with few cracks, more than five locations in fault fracture zones such as Syoko Fault and more than three locations of fillings in mined out veins.

6. Investigation of Method to Estimate Earthquake Influence on the Performance of Geologic Barrier

6.1 Method of observing rock movement

The measurement of the static relative displacement, especially the elongation or contraction and inclination of rock, which may be caused by earthquakes, is an important subject in investigating the performance of geologic barrier. The method of measuring elongation or contraction, which is commonly used at present, is a method using bar type extensometers set in levels and volume strain gauges set in bore holes. For the bar material, molten crystal or super invar alloy is used, and for detecting displacement, a differential transformer is used. The minimum measurable limit when using a bar of 10 m long is a change of strain of $10^{-9} \sim 10^{-10}$. On the other hand,

the volume strain gauge is a stainless steel vessel filled with silicone oil. This gauge is fixed in a bore hole by using expandable cement. Its minimum measurable limit is 3×10^{-11} .

For the measurement of inclination, a water-tube inclinometer is used. This consists of a set of two vessels filled with water which are connected by a pipe. Therefore, the levels in the vessels change when rock is inclined. The minimum measurable limit of this inclinometer is $10^{-9} \sim 10^{-10}$ radian.

In addition, noise sources in strain and inclination observations are explained and the main results obtained in the earth crust movement observations carried out by Tohoku University are shown.

6.2 Plan of observing ground water flow characteristics

Substances are transported through rock by ground water flow. Therefore, when examining the safety of a deep underground storage space against earthquakes, it is important to check the change of ground water flow around the cavity. The most basic method to observe the change of ground water flow is to measure the quantity and quality of water permeating into the cavity. Ground water flow in rock is influenced by crack systems, and permeable routes are formed. If the crack systems are modified by an earthquake, the quantity of water changes accordingly. This modification of crack systems is not uniform but varies considerably between different places. Therefore, it is important to carefully measure the quantity of water continuously leaking out of a particular crack. Together with the water quantity, water quality is also an important factor. Survey items on water quality include those which indicate the overall water quality such as electrical conductivity, pH and turbidity, and major ion concentrations. It is necessary to measure and record these survey items on water quality at each point for checking ground water.

7. Analysis for Observed Data

7.1 Data analysis

1) Confirmation of earthquake data

The occurrence time of earthquake, the location of the epicenter, the hypocenter depth, the magnitude and the seismic intensity at various places of the observed earthquake will be confirmed.

2) Arrangement of observation records

Seismic wave records will be arranged and edited under the following

items:

- Playback of earthquake records
- Noise eliminative processing
- Distribution of the maximum acceleration

3) Frequency analysis

On suitable waveforms of observed earthquake records, Fourier spectrum analysis, auto-correlational and cross-correlational analysis and vibration property analysis will be carried out and also particle velocities and displacements are determined by integrating seismic data. From these results, seismic movement characteristics will be determined.

4) Property of propagation of seismic waves

Separation of the kinds of waves, the incident angle of seismic waves, direction, etc., will be examined in order to understand the characteristics of underground seismic movements.

5) Identification of optimum rock structure

The influence of mined-out zone, fracture zones and the topography on observed seismic waves will be investigated.

6) Investigation of aseismatic stability of deep underground structure

The aseismatic stability of deep underground structures will be investigated by understanding the relationship of seismic movements observed with the ground property around the observation point.

7.2 Generalization of observation data

It is necessary to examine the influence of the local properties at the observation point on the observed seismic movement data and eliminate the influence if required to generalize the data observed. If the observed data will be used for estimating the influence of earthquakes at other places without generalizing, there is the possibility of considerable error. Therefore, a plan to study a method of computer simulation was established to examine the influence of local properties contained in observed data.

8. Conclusions

For the purpose of investigating the long-term aseismatic stability of a deep underground cavity, into which high level radioactive wastes will be disposed, and surrounding rock, surveying and research were started in the last year and many useful results have been obtained. Following the last year, surveys and research on the following items have been carried out this year.

- (1) Determination of earthquake observation points
- (2) Setting up earthquake observation systems
- (3) Surveying the occurrence of earthquakes in the vicinity of the observation sites
- (4) Making a plan to survey observation sites
- (5) Investigating a method to estimate the influence of earthquakes on the performance of geologic barrier
- (6) Plan of analysis for observed data

The main results obtained are as follows:

- (1) Determination of earthquake observation points

According to the results of surveys and research in the last year, the vicinity of Kanten Shaft in Hosokura Mine was selected as an earthquake observation zone, and in this zone, eight earthquake survey points were selected. These are as follows: one survey point (3-component) at the +1 level mouth and one survey point (3-component) in the same level, two survey points (3-component) on -3 level, one survey point (3-component) on -7 level, one survey point of 3-component and two survey points of 1-component of vertical movement on -10 level. These survey points have been arranged like this so that 3-dimensional tripartite array observations are possible.

- (2) Setting up earthquake observation systems

After setting a seismograph base at each survey point, a seismograph was fixed on the base with bolts and a signal cable from each seismograph was laid up to the mouth of +1 level via the shaft. On the +1 level, an observation cottage, for setting up seismic observation recording instruments, was built. A set of observation instruments was housed in the cottage. Seismographs and the observation recording instruments were connected and the entire system was adjusted so that earthquake observations could be carried out, thus the earthquake observation system has been completed.

- (3) Survey the occurrence of earthquakes in the vicinity of the observation site

Last year, the occurrence of earthquakes in and around the Japanese Islands was surveyed to get the information for selection of an observation site. Since the observation site has been determined, the earthquake occurrence in the vicinity of Hosokura Mine was surveyed in this year and data were

obtained to estimate the extent of earthquakes that may occur in the future.

(4) Making a plan of surveying observation sites

To generalize observation data, it is necessary to examine the influence of local properties contained in the observation data and generalize the data by eliminating the influence of local properties. For this purpose, local properties must be known. Accordingly, a survey plan of underground structure, geological characteristics and velocity characteristics of the observation zone was made and also a survey plan was described on the attenuation characteristics of rock, which greatly influences the amplification and response analysis of seismic waves.

In addition, a plan to carry out Strata analysis using underground borings and a laboratory test of rock samples were made as surveys concerning the property of in-situ rock.

Various survey plans described above are conceptional and it is necessary to make more detailed and practical working plans before carrying out the surveys.

(5) Investigating a method to estimate the influence of earthquakes on the performance of geologic barrier

To estimate the performance of geologic barrier in underground disposal areas, it is important to observe rock behavior such as the static relative displacement of rock caused by earthquakes, the changes of fine cracks and weak strata of rock accompanied by the displacement, and to observe the change of underground water flow which governs substance transfer around the deep underground disposal cavity, i.e. ground water behavior. Therefore, methods and plans to observe these items were investigated.

(6) Analysis plan for observed data

An analysis plan was made by investigating methods to process and analyze observed data and methods to generalize observed data.

According to the above research results achieved in this year, we would like to propose that we carry out the research work described below from next year.

- 1) Accumulation of earthquake observation data
- 2) Advice on the processing and analysis of earthquake observation data
- 3) Survey on the geological characteristics and underground structure of the observation zone.

- 4) Survey on the velocity structure of the observation zone
- 5) Selection of survey points for estimating the influence of earthquakes on the performance of geologic barrier and preparation of a practical survey plan
- 6) Investigation of a method for generalizing observed data

In consideration of the budget, the rock property tests, etc., will be started in the fourth year, but the order of priority, practical working plans, etc., of various surveys mentioned above will be discussed at the beginning of committee meetings held in 1986.