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SURVEY AND RESEARCH ON EARTHQUAKE

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THE MINING AND METALLURGICAL
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Survery and Research on Earthquake

The Mining and Metallurgical Institute of Japan

Synopsis

Japan is one of the salient earthquake countries in the world. Therefore, for the geologic disposal of radioactive wastes, the influence of an earthquake must be studied in relation to the performance of geologic barrier.

It is known generally that the influence of an earthquake is less empirically at underground deep point than at ground surface. Such phenomena are to be confirmed. Then, by earthquake resistance design where necessary, the safety in geologic disposal should be attained.

In the above connection, there has been set up a Committee on Earthquake Survey and Research in the Mining and Metallurgical Institute of Japan. With this committee, the influence of an earthquake at deep underground and at ground surface will be studied comparatively and thereby the data are to be acquired for achieving the seismicity in deep underground radioactive waste repositories. Observations of seismic waves will thus be made with the existing openings in deep underground, according to the schedule as follows.

1s year

(1) Studies on the survey and research Program
 a. setting up the committee
 b. survey on the state of seismic observations

(2) Selection of an observation site
 a. survey on the occurrence of earthquakes
 b. selection of an observation site (Hosokura Mine has been selected as the site)

(3) Design of observation equipment
 a. preliminary survey on the site conditions

b. design of observation equipment

2nd year

(1) Purchasing and installation of observation equipment

(2) Survey on geology and bedrock characteristics in the observation site

(3) Accumulation and analysis of observation data

3rd year

(1) Accumulation and analysis of observation data

a. analysis of observation data

b. detailed survey on geology and bedrock conditions.

(2) Installation of additional observation equipment

(3) Selection of another observation site*

4th year

(1) Accumulation and analysis of observation data

(2) Installation of observation equipment - in the mine selected in the 3rd year*

(3) Survey on geology and bedrock in the additional observation site*

5th year

(1) Accumulation and analysis of observation data

(2) Collection of the survey and research results

(3) Decision on the future schedule - concerning Continuation of survey and research

* Feasibility is studied. When feasible, the items concerned are carried out.

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

1. Introduction

In Japan, which is one of the salient earthquake countries in the world, research on earthquakes was started very early. In 1880, the Seismological Society of Japan was set up; the society observed its centenary in 1981.

Before the Second World War, however, seismic observations were made mostly by the Japan Meteorological Agency. As of about 1945, the number of weather stations with earthquake observation had been 110 for long time.

Then, in 1965, the first five-year program in the "Earthquake Prediction Program" was started. Also along with the advances in seismograph technology, the seismic observation networks were extended. Presently, besides the observation networks intended for prediction of eqrthquakes by national institutions such as universities and by the Japan Meteorological Agency, seismic observations are carried out by private enterprises. These are, however, mostly seismic observations at observation points on the ground surface. On the otherhand, seismic waves are also observed at underground for the purposes of earthquake prediction and seismicity elucidation in underground structures such as an underground power station. These observations of seismic waves at the underground are at shallow points up to about 100 m. The observation points deeper than 200 m or 300 m are very few. Characteristics of seismic motion are influenced largely by the geologic structure or the bedrock properties, so that the phenomena vary from one region to another. It is therefore necessary to make seismic observations at locations as many as possible with different bedrocks.

In the fiscal year 1984, as the first stage the present state of seismic observations and the seismic observation systems were surveyed, and Hosokura Mine was selected as a seismic observation site. Preparatory work was thus made for starting the comparative studies of seismic phenomena in deep underground and at ground surface.

In this report, in chapter 2 are described the present state of seismic observations in Japan and the examples of seismic observation at underground power stations, tunnels and mines. In chapter 3, the seismic observation systems and the observation data analysis methods generally employed are described. Then, in chapter 4 the selection of an seismic observation site and the survey made at the site for design of the observation system are described. In chapter 5 the design of the observation system is described.

Earthquake survey and research were conducted with members of the committee as follows.

Members of Committee

Chairman	Kōichi Sassa	:	Kyoto University, Faculty of Engineering
	Umetarō Yamaguhci	:	The University of Tokyo, Faculty of Engineering
	Toshikazu Kawamoto	:	Nagoya University, Faculty of Engineering
	Taiji Ueno	:	Seumitomo Metal Mining Co., Ltd.
	Kikuo Shichijima	:	Mitsui Mining and Smelting Co., Ltd.
	Takaaki Kashiwagi	:	Mitsubishi Metal Corporation
	Masatoshi Ito	:	Dowa Mining Co., Ltd.
	Koji Kojima	:	Nippon Mining Co., Ltd.
	Tooru Inoue	:	Nittetsu Mining Company, Ltd.
	Jyun Tashiro	:	Limestone Association of Japan

Members of Working Group

Chief	Hiroya Komada	:	Central Research Institute of Electric Power Industry
	Yoshihiro Sawada	:	" "
	Kazuhiko Sato	:	Muroran Institute of Technology
	Takao Sato	:	Meiho Engineering Co., Ltd.
	Hikaru Hotta	:	Construction Project Consultants Inc.
	Mizushiro Inoue	:	The Mining and Metallurgical Institute of Japan
	Hisato Kitane	:	" "

2. Survey on the present state of seismic observations

2.1 The state of seismic observations in Japan

(1) Observation of micro earthquakes

Earthquakes of magnitude up to 3, are called as micro earthquakes. The occurrence frequency of such earthquakes is very high. It is said that the occurrence of the earthquakes of a magnitude one smaller, i.e. from magnitude 3 to magnitude 2, . . ., are about eight times as many. The occurrence of micro earthquakes is related with active fault, magma activity, plate movement, or the activity of a large earthquake in the past. Watching the micro earthquakes is thus a useful means for the prediction of a large earthquake.

Micro earthquake observations are made mainly by educational institutions such as Hokkaido University, Tohoku University, University of Tokyo, Nagoya University, Kyoto University and by the National Research Center of Disaster Prevention, the Science and Technology Agency. Observations started differently with such institutions. However, full-scale observations are from about 1965.

The method of micro earthquake observations is commonly concentrated observation system by telemetering, using high sensitive velocity meters as a seismograph.

(2) Observations of small, moderate and large earthquakes

Earthquakes of magnitude 3 ∿ 5 are small earthquake, of 5 ∿ 7 moderate earthquakes and of 7 ∿ large earthquakes. Observations of these earthquakes are made solely by the Japan Meteorological Agency.

The total number of observation points is about 130, which are distributed throughout Japan. Seismographs used are various. The seismograph of highest sensitivity is a short-period velocity meter. Its magnification is 10,000 ∿ 1,000,000. The seismograph of lowest sensitivity is a strong-motion seismograph (a displacement meter) of 1 magnification. The recording method is also various, such as analog recording at the observation point or telemetering.

(3) Observations of strong motions

Observations of strong motions are made by many organs from early days. In the engineering field, however, such observations were started in 1953 with the setting of a SMAC type strong motion accelerometer. As of March

1984, a total of the 1411 strong motion accelerometers are set throughout the country. Of the total, 840, about 60%, are in buidlings and those set on the ground are 389, about 28%, most of which are on the sedimentary soil in urban areas, few on the bedrock.

Observations of seismic waves in the underground are made at 140 points in Japan as of 1982. 71 observation points are at underground depths up to 50 m, 51 at depths of 50 m ∿ 100 m, 9 at depths of 100 m ∿ 200 m, 2 at depths of 200 m ∿ 300, 1 at depths of 300 m ∿ 400 m, none at depths of 400 m ∿ 500 m, and 5 at depths beyond 500 m.

2.2 Observations of seismic waves in the underground

(1) Summary

Observations of seismic waves in the underground are made in boring holes and in underground openings such as mines, tunnels and underground power stations. Most of them, however, are at shallow depths up to 100 m. The observation at a deepest location is that with a 3510 m deep micro earthquake observation well at Iwatsuki City, Saitama Prefecture, conducted by the National Research Center of Disaster Prevention, the Science and Technology Agency, for the purpose of earthquake prediction. Observations are almost all, about 85%, for the acceleration.

(2) Seismic observations at underground power stations

Seismic observations are conducted at the following underground power stations.

i. Shiroyama Power Station
ii. Numappara Power Station
iii. Shimogo Power Station
iv. Ochiai Power Station
v. Ikehara Power Station
vi. Kinugawa Power Station

Seismic observations at the respective underground power stations will be described briefly below.

i. Shiroyama Power Station

Size of the opening is length 110 m x width 20 m x height 40 m. Depth from the ground surface (covering) is 200 m. Geology is slate and sandstone. Accelerometers are set on the ground surface and in the underground. For the period of eight years from July 1976 to July 1984, 170 earthquakes were observed. Seismic observations are continuing at present. Maximum amplitude, transfer function and response spectrum on the ground surface are compared with those at the underground.

ii. Numappara Power Station

Size of the opening is length 131 m x width 22 m x height 46 m. Depth from the ground surface (covering) is 250 m. Geology is granodiorite. Velocity meters are set on the ground surface and in the underground. For the period of five years from December 1977 to December 1982, 46 earthquakes were observed. Seismic observations are continuing at present.

iii. Shimogo Power Station

Size of the opening is length 171 m x width 22 m x height 46 m. Depth from the ground surface (covering) is 100 m. Geology is granodiorite. For the period of two years from July 1981 to July 1983, 11 earthquakes were observed. Seismic observations are continuing at present. Maximum amplitude and response spectrum at the ground surface are compared with those at the underground.

iv. Ochiai Power Station

The power station is semi-underground. Its excavation is diameter 15 m, 22 m deep. Geology is greenschist. For the period of six months from February to August 1983, 27 earthquakes were observed. Seismic observations are continuing at present. Accelerometers are used. Maximum amplitude, spectrum intensity and transfer function are compared with those at the underground on the ground surface.

v. Ikehara Power Station

Size of the opening is length 122 m x width 20 m x height 43 m. Depth from the ground surface (covering) is 20 m. Geology is siliceous plate. Velocity meters and displacement meters are set on the ground and at the underground. For the period of five years and eight months from April 1977 to December 1982, 59 earthquakes were observed. Seismic observations are continuing at present. Maximum amplitude on the ground surface is compared with those at the underground.

vi. Kinugawa Power Station

Size of the oepning is length 195 m x width 46 m x length 35 m. Depth from the ground surface (covering) is 67 m. Geology is liparite and tuff-breccia. Not only on the ground and in the underground power station, accelerometers and velocity meters are also set in the shaft leading from the ground surface to the underground power station and in the boring hole about 15 m away from the shaft at various underground depths. The relation between the amplitude and the underground depth and also the relation between the waveform and the underground depth were revealed.

(3) Seismic observations in mines

i. Hitachi Mine

Seismic observations were made by use of the mining adit. Locations observation point were four points on the ground surface and three at the underground of which depths 150 m, 350 m and 550 m. Geology is mainly tuff, greenschist and siliceous schist. With accelorometers set at the observation points, for the period of five years from 1976 to 1981, 52 earthquakes were observed. Seismic observations were suspended and are not made at present. Maximum acceleration, velocity response spectrum, Fourier's spectrum, frequency transfer function, etc. were observed comparatively between on the ground surface and at the underground. These results obtained are the most substantial.

ii. Seimsic observations in coal mines

In the Mitsui Sunagawa Coal Mine and in the Hokutan Horonai Coal Mine, there are set numerous seismographs on the ground surface and at the underground depth about 1000 m. The earthquakes of interest are extremely micro earthquakes called "mountain rumbling." These are produced by cracking in bedrock caused by mining. Purpose of the seismic observations is safety in mining.

(4) Seismic observations in tunnels

Seismic observations in tunnels are made in the Ishizuka Tunnel, the Shin-Usami Tunnel and the Seikan Tunnel. In this report, however, seismic observations in the Ishizuka Tunnel and in the Shin-Usami Tunnel will be described.

i. Ishizuka Tunnel

Ishizuka Tunnel exists in Sakari Line of National Railways. There are several observation points at the portal of tunnel and 580 m ∿ 650 m from the portal. Geology is slate. Accelerometers are set at the respective observation points. There are also set strain gauges to measure strains in the tunnel lining. Observation of seven earthquakes were reported.

Aseismicity of the structures in rock is examined.

ii. Shin-Usami Tunnel

Shin-Usami Tunnel, 3000 m long, exists in Ito Line of National Railways. Seismic observations are made at several points at the tunnel portal and at the middle part of the tunnel. The depths from ground surfaces (covering) at the observation points are 220 m $\sim$ 260 m. Geology is alteration basalt. Along with the accelerometers, there are also set strain gauges so that the behavior of a tunnel at the time of an earthquake is examined. Seismic observations were started in July 1983 and in the period of one year up to June 1984 ten earthquakes were observed.

(5) Results obtained so far by underground observations of earthquakes

Following are the results revealed by underground observations of earthquakes.

i. The maximum acceleration at underground depths beyond 200 m is about 1/2 that at ground surface. The ratio in maximum acceleration, however, differs with observation points and with the vertical or the horizontal motion.

ii. In the ground with a soft surface layer, the amplification in seismic motion becomes large.

iii. The underground attenuation effect increases when the hypocentral distance is smaller.

iv. In the seismic motion spectrum as observed at underground, the predominant component in short period range observed at ground surface no longer exists; the form of spectrum is thus flattened as compared with that at ground surface.

3. Survey on observation systems

(1) Summary

Observation systems used for measuring strong seismic motions were surveyed. Survey was first made of the observation instruments. Seismographs, recorders and attached equipments were thus surveyed concerning the respective specifications by the manufacturers. Then, typical observation systems were selected. Their major functions and also the methods of data processing and analysis were surveyed.

(2) Observation instruments

i. Seismographs

Seismographs recently used for seismic observations in the field of engineering are almost all accelerometers. The accelerometer is a seismograph of which output signal is proportional to the displacement acceleration in ground vibration. It is of the following two types.

a) Velocity feedback type accelerometer

This type of accelerometers are manufactured in Japan by Akashi Seisakusho Co., Ltd., Katsushima Seisakusho Co., Ltd. and Tokyo Sokushin Co., Ltd. In the respective accelerometers, the frequency range where the sensitivity is uniform is 0.1 Hz ∿ 50 Hz; the dynamic rnage is 0.1 gal ∿ 2000 gal.

(b) Servo-type accelerometer

This type of accelerometers are manufactured in Japan by Japan Aviation Electronic Industry, Ltd. and Akashi Seisakusho Co., Ltd. The measurable frequency range is DC ∿ 250 Hz or DC ∿ 400 Hz. The dynamic range is 0.1 gal ∿ 2000 gal.

ii. Recorders

In recent years, due to high stability and low cost of the A-D converter, the method of recording is a digital recording method. In this method, the vibration phenomena for the duration of about 10 seconds from prior to the start to the vanishing are recorded. The A-D converted signals are recorded in magnetic tape.

iii. Attached equipments

a) Oscillograph

The digital signals are converted back to the analog signals by D-A converter. The waveform is then observed by the oscillograph. An oscillograph of the heat pen type is the most suitable.

b) Concentrated observation system

An earthquake is a sudden phenomenon. And, there do not occur many earthquakes for short period of time. In the concentrated observation system, therefore, routine check is made automatically each day or each week to ensure that the system is in proper operation to record an earthquake at any time.

c) Non-shutoff power supply equipment

At the time of a large earthquake there is the possibility that the commercial power supply will fail. A non-shutoff power supply equipment is used in this case to enable normal operation of the system. It is essential as attached equipment.

(3) Examples of observation system

Typical seismic observation systems will be described.

i. Seismic observation systems for the ground and structures

Seismic observation system in a nuclear power station will be described. For the seismograph, a servo-type accelerometer is used. Using an A-D converter, the signals delayed for 10 ∿ 20 seconds are recorded in a digital data recorder.

ii. Horizontal array seismic observation on ground and observation systems

Recently, seismic observations by a horizontal array of seismographs in the vicinity of ground surface, are made for detailed observations of the seismic wave propagation and also for obtaining informations on the hypocenter.

As an example of such seismic observation, the vertical array observation system conducted by Research Committee on Earthquake Observation with the Vertical Array in the Rock in the Kanto district will be described. For the seismograph, an accelerometer is mainly used. Along with this, a velocity meter and a displacement meter are also used.

In the amplifier there is incorporated an auto gain control apparatus (AGC) so that, when signals beyond the set range enter to the amplifier, the gain is changed over instantaneously and automatically.

In recording, using an A-D converter, the signals delayed for five or ten seconds are recorded with a digital tape recorder.

iii. High dynamic range seismic observation

In the system shown above i and ii, digital recording is used. The A-D converter used, however, is of 12 bits so that the dynamic range is up to 66 dB.

High dynamic range seismic observations are made with an extended dynamic range in order to faithfully record from a large earthquake to a micro earthquake. For the purpose there is a binary gain amplification

(BGA) system, in which the dynamic range is increased largely to 90 dB ∿ 100 dB.

(4) Data processing and analysis

i. Format conversion

Recorded earthquake data are processed by computer. Format conversion is thus necessary. The data is made up of the header in ASCII or BCD code and earthquake data in binary code. These are converted to EBCDIC dode or IEEE floating point standard.

ii. Fourier's spectrum

Fourier's spectrum calculation methods were surveyed. Calculation is generally by fast Fourier's transformation (FFT) at present.

iii. Power spectrum

Power spectrum calculation methods were surveyed. Power spectrum is useful for a review of the predominant frequencies in the waveform.

iv. Transfer function and coherence

Transfer function and coherence were examined. To observe reliability of a transfer function, the study of a coherence in a frequency region having peaks of the transfer function is useful.

v. Window

In spectrum calculation, it is necessary to apply a window. The window is of Parzen, Hanning or parabola type.

vi. Response spectrum

Response spectrum was studied. For the period, it is suitable to divide the period of 0.04 ∿ 5 seconds in about 100 parts, and in damping constant, it is suitable for 0, 2%, 5%, 10% or 20%, or all of them.

4. Selection of an earthquake observation site

(1) Summary

In the selection of a seismic observation site to examine the influence of an earthquake on an deep underground opening and the surrounding bedrock, the following should be taken into consideration.

a) The relation between seismic motion, waveform and the depth from ground surface is obtained up to underground depth of 300 m at least.

b) The relation between seismic motion, waveform and the properties of a geologic formation is obtained.

c) At the observation site, both shallow earthquakes and deep earthquakes are observable in high frequency.

d) The influence of topography on the seismic observation is little.

e) The bedrock at the observation site is hard rock or semi-hard rock. Geologic structure is relatively uniform.

With the above items of criteria, a survey was made and Hosokura Mine was concluded to be a suitable seismic observation site.

(2) The state of earthquake occurrence

To obtain many data in a short period of time, the earthquake observation points must be set at a site with high frequency of earthquake occurrence. For the purpose, the state of earthquake occurrences was surveyed. It was found that the frequency of earthquake occurrence is high along the coast on the Pacific from the Kanto district to the Tohoku district and further that there occur in this area both shallow and deep earthquakes.

In Sendai City about 60 km away from Hosokura Mine as a prospective seismic observation site, for the period of one year in 1984, there occurred two earthquakes of seismic intensity III, eight earthquakes of seismic intensity II and nine earhtquakes of seismic intensity I.

(3) Hosokura Mine

Hosokura Mine is owned by Hosokura Kogyo Co., Ltd., a subsidiary of Mitsubishi Metal Co. It is located in Uguisusawa Town, Kurihara District, Miyagi Prefecture.

The ore deposits are in pitch veins, containing principally lead and zinc. Geology is andesite, quartz-andesite and tuff in the tertiary period.

In a survey in the area, it was concluded that the vicinity of the Kanten shaft in the middle east of Hosokura Mine is the most suitable site of seismic observation.

(4) Survey at the site

In the vicinity of the Kanten shaft selected as a prospective seismic observation site, the following items were surveyed for the purposes of design of the seismic observation system and selection of the seismic observation points.

a) Normal micro tremors (noise) and predominant frequences in the bedrock where seismographs are to be set.

b) P-wave and S-wave velocities in rock at the site.

c) Voltage fluctuation in an AC 100V power supply.

The above items a and b were surveyed near the Kanten shaft at upper No. 1 level, lower No. 3 level and lower No. 10 level in the vicinity of prospective seimsic observation points.

Average noise levels are 0.05 gal in the vertical component at upper No. 1 level, and about 0.1 gal at other levels. However, there occur spike noises of about 0.3 ∿ 0.4 gal at intervals of about 0.5 ∿ 1.0 second.

Vibrations due to blasting in the pits were measured. But it was shown that the vibrations would not interfere with seismic observation.

In power spectra of the micro tremors, there are not detected predominant frequencies in the frequency range of 0 ∿ 30 Hz. Therefore, the micro tremors can be regarded as white noise.

The velocities of p-wave are generally 3000 m/s ∿ 3600 m/s. At lower No. 10 level the velocity of S-wave is 2000 m/s.

From the above, in the vicinity of the prospective observation points the bedrock will be semi-hard rock of C_H class.

The voltage fluctuation in an AC 100V power supply was examined in the former hoist room at upper No. 1 level. In the period of from 10:40 a.m. on March 12th to 1:30 p.m. on 14th, average maximum voltage was 101V and average minimum voltage was 78V. Accordingly, for the power supply to be used, an automatic constant voltage power supply unit will be required.

(5) Design of the observation system

The seismic observation system with the items below incorporated was specified in block diagram, and the specifications for its major components were given.

a) Velocity feedback type accelerometers (for three components) are set at seven underground observation points.

b) For the recorder, a digital data recorder is used.

c) Data recording is all made in an observation room to be installed on the site.

d) The delay device is of the specification:

- Delay time, 10 sec or 15 sec.
- Sampling frequency, 200 Hz

e) For trigger, the vibrations are examined in respective 34 channels. Trigger is then by OR and AND circuits in each channel. Trigger levels are 0.1 ∿ 10 gal. Level setting is made individually in the respective channels.

5. Conclusions

In connection with aseismicity of a deep underground opening and the surrounding bedrock in the geologic disposal of high level radioactive wastes, the following were performed:
(1) survey on the state of seismic observations, (2) survey on seismic observation systems, (3) selection of a seismic observation site, and (4) design of the seismic observation system. Following results are achieved.

(1) Survey on the stage of seismic observations

Seismic observation systems and observation results were described in six underground hydraulic power stations, three mines and two tunnels in Japan where seismic observations are conducted in the underground opening and the surrounding bedrock. General knowledge and information could thus be obtained of the underground seismic motions so far.

(2) Survey on seismic observation systems

The present state of seismic observation instruments and data processing and analysis methods, and also some example of the seismic observation system, were described for the purpose of design of the seismic observation system.

(3) Selection of a seismic observation site

With earthquake occurrence frequency, topography, geology and observation point underground depths as criteria, Hosokura Mine was selected as a seismic observation site. Hosokura Mine is located in the north of Miyagi Prefecture and there exist no steep hills around it. The bedrock is of andesite, quartz-andesite and tuff in good state. The maximum depth of the observation point proposed is about 380 m. Micro tremors in the bedrock around the selected observation points were measured; average noise level was found to be about 0.1 gal. Vibrations caused by blasting in mining were also measured, which are on the normal noise level.

(4) Design of the seismic observation system

The proposal was made that in Hosokura Mine, accelerometers (for three components) are set at seven observation points in the vicinity of the Kanten shaft and data recording is made in an observation room to be set on the ground close to the top of the shaft.

The seismic observation system proposed is an ideal arrangement of seismographs for the observation of underground seismic motions; the observation instruments are also with most advanced functions. In the future, it is necessary to restudy problems in aseismicity concerning the geologic disposal of high level radioactive wastes, thereby define the objectives of research and study further such as the arrangement of seismographs. Detailed survey on the bedrock concerned is also necessary.

As above, in the 2nd year the following works should be conducted.

1. Installation of the seismic observation equipment in Hosokura Mine.

i. Detailed design of the observation system and its purchasing

ii. Conclusion of a seismic observation contract with Hosokura Mine

2. Survey on the geology and the bedrock properties at the observation points

3. Accumulation of observation data

i. Accumulation of observation data obtained

ii. Collection of existing deep underground seismic observation data

Analysis of the observation data will be started in the 3rd year.