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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

Second Workshop on Seismic Observation in Deep Boreholes and Its Applications

7-9 November 2012
At the Niigata Institute of Technology, Kashiwazaki, Japan

Hosted by Japan Nuclear Energy Safety Organisation

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The mission of the NEA is:

– to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as

– to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information.

The NEA Data Bank provides nuclear data and computer program services for participating countries. In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

THE COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

"The Committee on the Safety of Nuclear Installations (CSNI) shall be responsible for the activities of the Agency that support maintaining and advancing the scientific and technical knowledge base of the safety of nuclear installations, with the aim of implementing the NEA Strategic Plan for 2011-2016 and the Joint CSNI/CNRA Strategic Plan and Mandates for 2011-2016 in its field of competence.

The Committee shall constitute a forum for the exchange of technical information and for collaboration between organisations, which can contribute, from their respective backgrounds in research, development and engineering, to its activities. It shall have regard to the exchange of information between member countries and safety R&D programmes of various sizes in order to keep all member countries involved in and abreast of developments in technical safety matters.

The Committee shall review the state of knowledge on important topics of nuclear safety science and techniques and of safety assessments, and ensure that operating experience is appropriately accounted for in its activities. It shall initiate and conduct programmes identified by these reviews and assessments in order to overcome discrepancies, develop improvements and reach consensus on technical issues of common interest. It shall promote the co-ordination of work in different member countries that serve to maintain and enhance competence in nuclear safety matters, including the establishment of joint undertakings, and shall assist in the feedback of the results to participating organisations. The Committee shall ensure that valuable end-products of the technical reviews and analyses are produced and available to members in a timely manner.

The Committee shall focus primarily on the safety aspects of existing power reactors, other nuclear installations and the construction of new power reactors; it shall also consider the safety implications of scientific and technical developments of future reactor designs.

The Committee shall organise its own activities. Furthermore, it shall examine any other matters referred to it by the Steering Committee. It may sponsor specialist meetings and technical working groups to further its objectives. In implementing its programme the Committee shall establish co-operative mechanisms with the Committee on Nuclear Regulatory Activities in order to work with that Committee on matters of common interest, avoiding unnecessary duplications.

The Committee shall also co-operate with the Committee on Radiation Protection and Public Health, the Radioactive Waste Management Committee, the Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle and the Nuclear Science Committee on matters of common interest."

EXECUTIVE SUMMARY

The Second Workshop on Seismic Observation in Deep Boreholes and Its Applications (hereinafter, the "Kashiwazaki WS") was held from 7-9 November 2012 in the City of Kashiwazaki, Niigata, Japan, and co-organized by the Japan Nuclear Energy Safety Organization (JNES), the OECD/NEA/CSNI, and the IAEA International Seismic Safety Center (ISSC).

The Kashiwazaki WS was held to develop the recommendations made at the Tsukuba WS entitled "Seismic Input Motions Incorporating Recent Geological Studies" which was held in November 2004 in Tsukuba City in Japan (hereinafter, the "Tsukuba WS"). At the Tsukuba WS, the state of the art in defining realistic seismic input for the design and re-evaluation of nuclear facilities as well as advances in seismic source characterization of fault zones using data from deep geological investigations and their possible contribution to improving seismic input definitions were reviewed. Further, the importance and necessity of cooperation between seismology and geology in order to decrease uncertainty in seismic input definition were emphasized.

After the Tsukuba WS, the Niigata-ken Chuetsu-oki Earthquake (NCOE, M=6.8) occurred near the Kashiwazaki-Kariwa NPP site. In this earthquake, a focusing effect of ground motion was observed at the Kashiwazaki-Kariwa NPP site, which caused locally amplified ground motion. Units 1 and 2 showed significantly higher responses of more than 50 percent compared to Units 3 to 7. This was thought to be caused by the fact that seismic waves were focused on Units 1 and 2 due to the irregular structure under the site.

A similar effect was observed at the Hamaoka site in the earthquake that occurred in Suruga Bay in 2009. Only Unit 5 showed a double or larger response to this earthquake, and similar phenomena were found only for events with hypocenter in the narrow direction from the site. This was also thought to be caused by the irregular geological structure under the site.

In the 2011 off the Pacific Coast of Tohoku Earthquake, the peak ground accelerations (PGA) of the Dai-ichi NPP site were about twice as large as those of the Dai-ni NPP site, although the distance between these sites is only slightly more than 10 km. Further, large differences in the PGAs were found among each of the units of the Dai-ichi NPP site. For example, the PGA of Unit 4 was only 70% that of Unit 2 at the same site.

Given these circumstances, JNES initiated the "Observation and Evaluation Study of Ground Motion Amplification" project by drilling a three-kilometer deep borehole on the premises of the Niigata Institute of Technology, which is located near the Kashiwazaki site, and proposed a series of workshops related to deep underground seismic observation and ground motion evaluation to the Seismic Subgroup of the OECD/NEA/IAGE Group at the April 2010 meeting. The first was held from 24-26 November 2010 as part of the first Kashiwazaki International Symposium on seismic safety, and the second was held on 7 to 9 November 2012.

In the second WS, 36 papers were presented by the participants from eight countries including two international organizations, and discussed in three sessions (i.e. observation technology, evaluation of the observed seismic motion and the multipurpose use).

Regarding the observation technology session, useful lessons-learned in probe development, setup and maintenance under the challenging conditions posed by great depth were described. This information from SAFORD and Kashiwazaki was thought to be particularly valuable for the planning and operation of similar facilities.

As for the seismic observations from a deep borehole, it was identified that such observations are very effective for investigation of the earthquake generating process and are important for detailed understanding of the three-dimensional underground structure. There is not yet much experience with observation and application of a deep borehole, and therefore future developments and achievements are expected. The importance of simple ground motion evaluation technology combined with geophysical exploration was also acknowledged.

Examples of multipurpose utilization and the advantage of seismic observations in deep boreholes were discussed. Multipurpose use was discussed not only for seismic design and evaluation of nuclear installations, but also for general disaster prevention and for early warning systems. The importance of data sharing was again highlighted.

In conclusion, it is recommended that the next WS summarize the state of this technology in several years, after information provided in this WS has been reflected in the GONAF project (A deep Geophysical Observatory at the North Anatolian Fault plan in the Sea of Marmara) which UNESCO supports, and the comprehensive evaluation of observed seismic data in JNES's deep boreholes in both a soft rock site and a hard rock site have been completed.

Acknowledgements

This WS on "Seismic Observation in Deep Boreholes and Its Applications" was held at the Niigata Institute of Technology and co-organized by the Japan Nuclear Energy Safety Organization, OECD/NEA/CSNI/IAGE, and IAEA/ISSC with the support of the Niigata Institute of Technology and the Tokyo Electric Power Company.

This second WS was successfully completed thanks to the efforts of these organizations and the chairpersons of each session.

We hereby express our gratitude to all of them.

Organizers:

Japan Nuclear Energy Safety Organization: K. Ebisawa, S. Horino, Y. Mamada, G. Kobayashi

International Atomic Energy Agency: S. Samaddar, Y. Fukushima

OECD/NEA Working Group on Integrity and Aging of Components and Structures (IAGE): A. Huerta

Session Chairpersons:

Opening Session

Chair: Y. Fukushima (IAEA)

Honorary and Invited Speakers session

Chair: Y. Sugiyama (AIST)

Technical Session S1: Development of Deep Borehole Seismic Observation System

Chair: H. Sato (Univ. of Tokyo), M. Bohnhoff (GFZ Potsdam)

Technical Session S2: Deep Ground Motion Evaluation (Application to Seismic Design)

Chair: C. Juhlin (Uppsala Univ.), Hongjun Si (Kozo Keikaku Engineering Inc.)

Technical Session S3: Multi-usage of Deep Borehole Seismic Observation Technology and Data

Chair: A. Gürpinar (Independent consultant), S. Nakamura (Nihon Univ.)

Panel Discussion

Chair: Y. Sugiyama (AIST), A. Gürpinar (Independent consultant)

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1. INTRODUCTION

Several kilometers below the earth’s surface, the earth's crust is thought to have a nearly constant shear wave velocity of 3 to 3.5 km/s. This layer is referred to as “seismic bedrock.” Because its horizontal properties vary very slowly, it transmits a uniform input ground motion to the overlying strata over a large region.

When the strata above the seismic bedrock are thick and vary laterally as at the Kashiwazaki - Kariwa NPP site, it turns out that the amplification of seismic ground motion in the surface strata grows very large depending on the soil conditions. This phenomenon was observed at the Kashiwazaki-Kariwa NPP site upon the occurrence of the 2007 Niigata-ken Chuetsu-oki Earthquake.

Thus, it is important in the seismic design of nuclear installations to measure the ground motion of seismic bedrock and to accurately evaluate the amplifying characteristic in the subsurface strata.

This Kashiwazaki WS contributed to improving the accuracy of design basis ground motion by investigating the latest information on the following topics in a workshop format.

1) The latest information on seismic recording techniques that can withstand the environment (high temperature and high pressure) in deep boreholes that reaches seismic bedrock.

2) The latest information on analysis and evaluation of seismograms recorded in deep boreholes and their use

3) Information on seismic ground motion amplification by subsurface strata overlying seismic bedrock

1.1 Background of the WS

The Second Workshop on Seismic Observation in Deep Boreholes and its Applications was held from 7-9 November 2012 at the Nuclear Seismic and Structure Research Centre of the Niigata Institute of Technology. It was co-organized by JNES, IAEA/ISSC, and OECD/NEA. This second workshop followed the First Workshop on Seismic Observation in Deep Boreholes and its Applications, which was held 24-26 November 2010 and which was embedded in the first Kashiwazaki International Symposium on Seismic Safety.

Based on the lessons learned from the 2007 Niigata Chuetsu Oki Earthquake, JNES developed a ground motion observation system with vertical seismic array that was installed in a 3000-meters deep borehole at the Niigata Institute of Technology from November 2010 to February 2012. The principal objective of this observation system was to improve the evaluation method for site amplification and propagation effects of ground motion on nuclear power plants with high accuracy.

After starting trial (partial) operation of this system in February 2012, JNES started full-scale deep seismic ground motion observation in June 2012. Nearly two years have passed since the first WS, and there have been many developments in international and domestic deep seismic ground motion observation projects. Therefore, the second WS was held to consolidate information on these achievements.

1.2 Objective of the Second WS

The objective of this second WS is to exchange information about the latest technical/research progress after the first WS, to discuss them, and to get the prospects to the future on technologies and research items on the following matters which we should promote.

(i) International application and promotion of seismic observation technology in deep boreholes and technology for investigating underground structures.

(ii) Development of more practical, more reliable, more economical, and simpler technology for investigating underground structures

(iii) Utilization of this technology for the evaluation of uncertainty of 3D deep underground structures.

(iv) Application of deep seismic ground motion observation data for the seismic safety of nuclear facilities (usage to real-time automatic-scram, etc.), and promotion of international multi-purpose usage of such data.

2. WS OUTLINE

2.1 Opening, honorary and invited speech Session (7 November)

The Opening Session consisted of opening remarks (by IAEA, OECD/NEA, and JNES), a speech from the supporting institution (NIIT), an explanation of IAEA EBP activities (by IAEA and JNES), the aim and points of this workshop (by Sugiyama/WS Chair), one honorary speech, and three invited speeches.

2.2 Technical Session (8-9 November)

The following three technical sessions were held and led by their respective chairs and co-chairs.

(1) Session 1: Development of Deep Borehole Seismic Observation System

Chair: Sato (Tokyo Univ.), co-chair: Bohnhoff (GFZ Potsdam)

(2) Session 2: Deep Ground Motion Evaluation (Application to Seismic Design)

Chair: Juhlin (Uppsala Univ.), co-chair: Si (Kozo Keikaku Engineering)

(3) Session 3: Multi-usage of Deep Borehole Seismic Observation Technology and Data

Chair: Gürpinar (Consultant), co-chair: Nakamura (Nihon Univ.)

2.3 Panel Discussion and Closing (9 November)

Each chair of the technical sessions (for Session 2, the co-chair) reported a summary of presentations. Sugiyama, the workshop chair, led the discussions on each session and on topics that touched on the themes of all sessions.

3. WS PARTICIPANTS

79 persons in total, including 14 from overseas hailing from 8 countries and 2 international organizations, participated in the second WS. (A list is attached.)

4. BRIEF SUMMARY OF EACH PRESENTATION

4.1 Opening, honorary and invited speech sessions

O-01 Opening remarks (IAEA, NEA, JNES, and NIIT)

Three co-organizers (IAEA, OECD and JNES) and one supporting institution (NIIT) made welcoming addresses.

IAEA emphasized that this WS could contribute to reducing the risks of nuclear facilities through geophysical exploration and seismic observation using deep boreholes. OECD explained the historical background of this WS and its expectations related to deep borehole observation for seismic safety. JNES emphasized the novelty and significance of deep borehole seismic observation and its instrumentation technology, especially that which was developed at Kashiwazaki. NIIT explained that they are currently improving an information dissemination system that is easy to use during disasters and that they have enrolled as a donor organization of IAEA/EBP in the nuclear disaster prevention area.

O-02 Yoshimitsu Fukushima/IAEA/ISSC, "Explanation of IAEA EBP WA1"

An outline of IAEA/ISSC/EBP activities was given and the relation of this WS to those activities was explained. Deep borehole seismic observation is one of the themes in Work Area 1, and the IAEA conveyed its expectation that this WS would lead to the creation of a supplemental document for seismic hazard evaluation to be included in IAEA guide SSG-9 (Seismic Hazards in Site Evaluation for Nuclear Installations).

O-03 Changjiang Wu/JNES, "JNES's activities in the extra-budgetary programme of the International Seismic Safety Centre: WA1 Seismic Hazard"

Issues in design basis ground motion development, the study items of Work Area 1 of IAEA/ISSC/EBP, and JNES's contributions were explained. It was also noted that the discussions and resolutions of this WS would be summarized in a technical document as task 1.4 of WA1.

O-04 Yuichi Sugiyama/AIST, "Aim and points of this workshop: The Second Workshop on Seismic Observation in Deep Boreholes (SODB) and Its Applications."

The achievements of the first WS and the aim of the Second WS were explained. The purposes of this Second WS were: to re-recognize the significance of seismic ground motion evaluation based on newly added deep borehole seismic observation in addition to existing borehole investigation, geological surveys, and geophysical exploration; to acknowledge deep borehole seismic observation and geophysical exploration (hardware) as well as the site characteristic evaluation method (software) required for seismic ground motion evaluation; and to consolidate opinions on multi-purpose application of observation technology and data as well as acknowledge issues to be addressed and technological problems. The final goals of this WS were to clarify items and issues that present challenges for the future based on the discussions in this WS.

O-05 Heki Shibata/Prof. Emeritus, Tokyo Univ., "Memo on some targets of the previous meeting in 2004 and now"

The necessity of deep borehole observation was pointed out in a 2002 WS entitled "Physics of Active Faults" organized by USGS and NIED, and discussion on the utilization of deep borehole observation for design basis ground motion development was then was deepened at the 2004 OECD/NEED Tsukuba WS. In addition to this study history, a series of WSs on Seismic Observation in Deep Boreholes and its Application organized by OECD, IAEA and JNES was planned.

Prof. Shibata also explained that at the first SODB WS, he expected deep borehole observation to be used to observe the activity of specific faults with high accuracy, to detect the detailed structure of those specific faults, and to estimate the asperity distribution in order to establish a practical approach to design basis earthquakes for nuclear power plant design. Recently, however, he has come to think that SODB will help find hidden faults and help observe the conditions of old faults. He also mentioned that he believes that in the future SODB can be used for re-activity evaluation of tertiary faults and evaluation of the movement of local fracture zones.

O-06 Marco Bohnhoff/GDF Potsdam, "Borehole seismology: Fundamentals and applications"

Because boring in itself is very expensive and instrumentation is required to endure high temperatures and pressures, deep borehole observation was accompanied by an economic risk. However, it has great advantages with respect to micro-earthquake observation, which is enriched with a short period vibration signal, because deep borehole observation greatly reduces short period noise. These kind advantages were explained by referring to the relationship between earthquake size and frequency range. Examples of seismic observation in a borehole in a geothermal field in El Salvador and a CO2 confinement project in the western part of Canada were introduced.

O-07 Kojiro Irikura/Prof. Emeritus, Kyoto Univ., "Seismic safety of NPPs based on the lessons learned from the 2011 Tohoku earthquake"

The 2011 off the Pacific coast of Tohoku Earthquake measured as large as M9.0-class, which had not been assumed in Japan's long-term predictions.

According to the forward modeling of source models to simulate seismic motion in a short period, the strong motion-generating area consists of five locations that lie west of the epicenter and downdip edge of the source fault. In addition, period-dependence of the rupture process was found; in other words, a shallow zone along the trench axis east of the hypocenter showed a large slip and the deeper zone west of the hypocenter generated a short period.

Strong ground motion in a period range of 0.1 to 10 seconds, which is important for engineering, can be estimated with a characteristic source model using outer-fault parameters and inner-fault parameters.

O-08 Aybars Gürpinar/Independent consultant, "Effective use of deep underground observation for NPP seismic hazard analysis"

The requirements of site vicinity investigation to obtain detailed knowledge to provide information on the properties of foundation materials to be used in site response analysis are described in IAEA Safety Guide SSG-9, but there is a limitation in this adaptability when taking into account recent earthquakes. Large differences in peak ground acceleration were observed among each unit of the Kashiwazaki-Kariwa site upon the Niigata-ken Chuetsu-oki Earthquake in 2007; the same kind of phenomenon was observed at the Fukushima Dai-ichi NPP and Dai-ni NPP sites, which are only about 10 km apart, upon the 2011 off the Pacific coast of Tohoku Earthquake.

These suggest that ground motion cannot be definitely evaluated by the conventional method at sites with shear wave velocity of less than around 1,000 m/s.

There is a need to examine the site vicinity and site area scales holistically; deep borehole observation is a promising method to address this issue.

4.2 Session 1 presentations

S1-01 Genyu Kobayashi/JNES, "Construction of a system for Seismic Observation in Deep Boreholes (SODB) -Overview and achievement status of the project"

The seismic responses of each unit at the Kashiwazaki-Kariwa NPP differed greatly during the 2007 Niigata-ken Chuetsu-oki Earthquake; the deep sedimentary structure around the site greatly affected these differences. To clarify underground structure and to evaluate ground motion amplification and attenuation effects more accurately in accordance with deep sedimentary structure, JNES initiated the SODB project.

Deployment of a vertical seismometer array in a 3000-meter deep borehole was completed in June 2012 on the premises of NIIT. Horizontal arrays were also placed on the ground surface.

Experiences and achievements in the JNES project were introduced, including development of seismic observation technology in deep boreholes, site amplification measurements from logging data, application of borehole observation data to maintenance of nuclear power plant safety, and so on. Afterwards, the relationships of other presentations in this WS, were explained.

S1-02 Hiroshi Sato/The Geological Society of Japan, "Significance of geophysical and geological investigations of deep structure for safety evaluation of nuclear power plants"

The faulting process and subsurface deformation as well as the complicated underground structure of the Niigata area in relation to ground motion were explained, which was followed by an explanation of the importance of the following items.

- Understanding geological history to construct the current geological structure,

- Construction of an integrated ground model by geophysical exploration; topographical, geological, and morphological data; and boring data, and
- Confirmation of model validation by simulation.

S1-03 Yutaka Mamada/JNES, "Construction of a system for Seismic Observation in Deep Boreholes (SODB) -Development of multi-depth, high-temperature/ pressure resistance seismometers-"

The development of a high quality system for seismic observation in deep boreholes, the installation process at the NIIT site, and the data sharing plan for this observation were explained.

The key points of the development were high temperature resistance (150 degrees Celsius), high pressure resistance (30 MPa), and a high dynamic/wide frequency range seismometer which allows for observation of microtremor to strong motions as well as a cascade-connection-type borehole seismometer, which allows multiple probes to be set at several depths in a single borehole. The developed system consists of broadband (0.1-50 Hz) and high dynamic range (up to 1000 gal) seismometer with electronic parts on the ground and only the pendulum part in the borehole (it became a servo-type seismometer). Durability and maintenance may be issues in the future.

S1-04 Satoru Wada/Tokyo Sokushin Co., "Construction of a system for seismic observation in deep boreholes (SODB) – Development of the Deep Borehole Seismometer"

The design and specifications of the seismometer specially developed for the SODB project were explained in detail. The seismometer used in SODB is a servo-type velocity seismometer, of which only the pendulum parts are placed in the borehole, and the electronic parts are placed on the ground. Seismometer probes were set at three depth levels in a cascade connection. In addition, an outline was given of several field experiments and in-house tests required for system development. Electric noise reduction at a high frequency range (above 10 Hz) is an issue in future and the durability of the optical fiber cables connecting the pendulum with the electronic parts under a high temperature environment (above 150 degrees Celsius) are required to be watched carefully.

S1-05 Marco Bohnhoff/GFZ Potsdam, "GONAF: A Deep Geophysical Observatory at the North Anatolian Fault"

An outline was given of the GONAF (Deep Geophysical Observatory at the North Anatolian Fault Zone) project operating at the Marmara seismic gap of the North Anatolian Fault Zone. The Princes Island Segment is a part of the North Anatolian Fault Zone in Marmara seismic gap. This segment is a remaining part of the recent rupture of the North Anatolian Fault. Further, the rupture of this part is predicted to occur in the near future. The primary objectives of the project are to collect seismograms of small earthquakes with magnitudes less than zero using borehole observations with low noise, to gain new insight into the physical states of critically stressed fault segments during and after large earthquakes, and to monitor progressive damage evolution at fault asperities. There were explanations about the seismic network in the region, the recent microearthquake observation, and the project's PIRES (Princes Islands Real-time Permanent Seismic Network). For the GONAF project, a network of eight borehole arrays with five-level seismometers, including a ground surface of 300-m boreholes, is planned. Horizontal arrays on the surface of an island in the Marmara Sea have also been deployed. In addition, deployment of a permanent ocean bottom seismometer is planned as part of the GONAF+ plan in 2014.

S1-06 John Townend/Victoria Univ., "The Deep Fault Drilling Project, Alpine Fault, New Zealand: Preliminary results, future plans, and affiliated seismological research"

The current progress and plan of the deep drilling project at the Alpine Fault in New Zealand were presented. New Zealand is located at the plate boundary of the Australian and Pacific plates. The boundary runs offshore of the North Island transversely and the South Island longitudinally. The South Island boundary is known as the Alpine Fault, which has oblique movement with a high slip rate of more than 20 mm/yr., one-third of which is vertical and two-thirds of which is horizontal, but there have been no earthquakes for the past 300 years. The primary objective of the project is to understand the fundamental geophysical-rheological process of faulting, such as discrimination of stable/unstable friction, earthquake nucleation and predominant slip, and fluid over-pressure and shear zone evolution. The project consists of two stages (first leg DFDP-1: successfully completed in 2011, second leg DFDP-2: now funded and planned for 2014). In the DFDP-1 project, two holes were drilled at the intersection of two plates for core sampling, geophysical logging, and setting of permanent monitoring facilities (depths: 100 meters for hole A and 150 meters for hole B).

S1-07 Peter Malin/Auckland Univ., "Outline and prospects of the SAFOD Project"

SAFOD is a project to investigate and understand the rupture process of the San Andreas Fault through an investigation of material composition of the fault zone; observation to reveal underground structure; and measurement of physical properties, such as stresses on and around the fault, permeability, and pore pressure, etc. at Parkfield. In addition to observation by a seismometer and tilt-meter which were installed at a depth of about three kilometers in a borehole in the fault zone, core sampling and geophysical logging were carried out as part of this project. High quality data, such as that on guided waves (special seismic waves that propagate in the fault zone) and repeated earthquakes (earthquakes with very similar waveforms) were acquired. Such data can be very useful in understanding the fault rupture process.

S1-08 Wade Johnson/UNAVCO, "Engineering analysis of recovered SAFOD borehole instrumentation"

The basic data set was acquired during 18 instrumentation setting tests conducted from 2004 through 2007 as part of SAFOD. Active hydrocarbon-rich water invaded the borehole because the borehole had not sealed at the bottom. For this reason, the water in the casing reached the cable head and caused a malfunction. Attempts were made to use better O rings, Krytox oil, and epoxy seal, but all failed. In most of these deployments, standard wire-line was used and the average failure time was two weeks.

Based on design review, many improvements such as stainless tube encapsulate electric cables, all-metal seals, and swageloks were applied. Setting of improved downhole instrument packages was carried out in the autumn of 2008. Still, these instruments could not endure the high temperature environment of 120 degrees Celsius for a long period of time, and all were offline in less than a month.

A SAFOD engineering subcommittee was established in 2010 to investigate the problems caused through an examination of the removed instruments. It became clear that fluid including active hydrocarbons had invaded the stainless tubing from the seal part and caused all instruments to fail.

Based on the above-mentioned experience, recommendations for the future are as follows.

- Perform strict oversight of subcontractors.
- Perform robust risk analysis and prepare a risk mitigation plan.
- Multiple checks should be performed on points of failure by different people.
- If possible, avoid the use of active electronics in environments like those in SAFOD.
- Components must be rated for use in the temperature range of the environment in which they are to be used.
- If a failure occurs, remove the instrumentation in a timely manner.
- The SAFOD POD design was not inherently flawed but poorly implemented.

S1-09 Haruhiko Suzuki/OYO, "Estimation of S-wave velocity structure of deep sedimentary layers using geophysical data and earthquake ground motion records"

The preliminary results with an outline of array observation for microtremor and natural earthquakes around the NIIT site were explained. Phase velocity estimated from a horizontal array of strong motion observation agrees with that from the microtremor survey. Estimation results are consistent with other literature, such as PS-logging data and gravity maps. Further improvement of the three-dimensional modeling by using microtremor surveys and horizontal array observation is planned for the future.

S1-10 Toru Kajiwara/OYO Seismic Instrumentation Co., "Development of a simple borehole seismometer"

Progress at the second site of the JNES SODB project was explained. The second site has hard rock up to nearly ground surface and 1,000 meter borehole was already drilled and a simple serial connection probe has been developed for this site because of less severe temperature and pressure conditions than those at the first site. (Please refer to the Attachment 2)

This lightweight system consists of cables protected by metal sheathes can be used in a cascade connection similar to the observation system introduced in presentation S1-03. This system was developed for installation in a borehole with five-inch probe casing.

Since the required temperature and pressure were not as high as those in presentation S1-03, improvement efforts focused on how to use existing seismometers in a cascade connection for a SODB project hard rock site. The seismometer used is a force balance servo accelerometer of around +-4g dynamic range. This instrumentation system was already installed at the site.

S1-11 Susumu Abe/JGI, Inc, "Experimental investigation on multidisciplinary geophysical characterization of deep underground structure using multi-scale, multi-mode seismic profiling for the evaluation of ground motion and seismic model building"

Recent advancements in data acquisition and velocity estimation for multi-mode, multi-scale seismic exploration were explained along with the basic concept of strategic geophysical surveys for NPP siting assessment.

Then, as a case study using this concept, multidisciplinary geophysical characterization results pertaining to the deep underground structure beneath the JNES Kashiwazaki Center were explained in detail.

At the site, reflection/refraction surveys and magnetotellurics/gravity surveys were also conducted. It was shown that these surveys can be used complementarily because at the upsurge part, where clear images cannot be obtained by reflection/refraction surveys, magnetotellurics /gravity surveys can be used to obtain clear images.

4.3 Session 2 presentations

S2-01 Genyu Kobayashi/JNES, "Evaluation of near-surface attenuation of S-waves based on PS logging and vertical array seismic observation"

As a result of the lessons learned from the experience of Kashiwazaki-Kariwa NPP due to the 2007 Niigata Chuetsu Oki Earthquake, it has become clear that a rational method of near-surface attenuation characteristics covering a depth range from engineering bedrock to seismic bedrock urgently needs to be established. JNES performed PS logging and vertical array seismic ground motion observation at a soil ground site (SODB 1st site), sedimentary rock site, and an igneous rock site (SODB 2nd site), and proposed an evaluation method of attenuation characteristics (site characteristics) for the deep underground.

S2-02 Hiroaki Sato/CRIEPI, "Site-response estimation by the 1D Heterogeneous Velocity Model using borehole logs and its relationship to the damping factor"

In the Niigata area, which suffered from several large earthquakes such as the 2007 Chuetsu-oki earthquake, geographical observation that elucidates the S-wave structure of the underground is advancing. Modeling of S-wave velocity structure in the subsurface is underway to enable simulation of long-period ground motion. The one-dimensional velocity model by inverse analysis of microtremors is sufficiently appropriate for long-period site response but not for short-period, which is important for ground motion evaluation at NPP sites.

The high-frequency site responses may be controlled by the strength of heterogeneity of underground structure because the heterogeneity of the 1D model plays an important role in estimating high-frequency site responses and is strongly related to the damping factor of the 1D layered velocity model.

S2-03 Yoshihiro Sugimoto/Dia Consultants, “Development of a new modeling technique of 3D S-wave velocity structure for strong ground motion evaluation - Integration of various geophysical and geological data using joint inversion”

A restricted stripe-like zone suffered major damage due to the 1995 Hyogo-ken Nanbu earthquake, and ground motion of the south side of the Kashiwazaki NPP site was much greater than that of the north side in the 2007 Niigata-ken Chuetsu-oki earthquake. One reason for these phenomena is thought to be the focusing effect due to irregularly shaped sedimentary basins (e.g., basin-edge structure, fold structure, etc.) This indicates that precise evaluation of S-wave velocity structure is important. A calculation program that was developed to make S-wave velocity models using the joint inversion method was presented. This program unifies various geophysical and geological data and can make a complex structure model for evaluating strong ground motion with high precision.

S2-04 Hiroshi Sato/Earthquake Research Institute/Tokyo Univ., “Estimation of seismogenic source faults by seismic reflection profiling: Case study of the Niigata Basin”

The tectonic evolution and geological features of the Niigata basin were explained with reference to historical major earthquakes in the area, which is compressed by the subducting Pacific plate and form fold-and-thrust belt. P-wave structures have been investigated since about 2009 using dense seismic velocity profiles, including sea areas. 18% of compression and sedimentation caused from subsidence happened in the northwest-southeast direction since 5Ma in this area, and a complicated underground structure was composed. The inverted, failed rift structure and deep geometry of the active fault have been demonstrated well by CMP seismic reflection profiling and refraction tomography. This Miocene rift structure strongly controls the geometry of seismogenic source faults.

S2-05 Christopher Juhlin/Uppsala Univ., “3D seismic imaging of the subsurface for underground construction and drilling”

3D seismic imaging of underground structure has been carried out in various parts of the world for various purposes. Examples shown below were introduced in the presentation.

- CO2 storage in Ketzin, Germany
- Mine planning at the Millennium Uranium Deposit in Canada
- Planned Forsmark spent nuclear fuel repository in Sweden
- Exploring the Scandinavian Mountain Belt by Deep Drilling: the COSC drilling project in Sweden

He explained that seismic methods provide the highest resolution images (5-10 m) of deeper (1-5 km) sub-surfaces in the sedimentary environment, but further improvement is required in crystalline rock environments, and the integration of geology, geophysics, and drilling will provide an optimal interpretation.”

S2-06 Peter Malin/Auckland Univ., "Evaluation of three-dimensional underground structure in the SAFOD Project"

In the SAFOD project, the imaging of the fault zone was implemented using data acquired by a pilot hole array of a vertical depth of 2km and then a main hole was drilled using these data. The trajectory of the main hole below vertical depth of 1.5km was angled toward/through the fault zone up to a vertical depth of 3km. An sensor array was located in the hole.

As a result, the hypocenter locations of small earthquakes within the fault zone were determined with high accuracy (location error within 10 meters) and the location of the fault zone was able to be identified with high accuracy.

Using this data, high resolution underground structure around the San Andreas fault zone was obtained. It was reported that this underground structure revealed the deep structure of the San Andreas Fault at the Parkfield site as well as the branch fault.

S2-07 Tran Thi My Thanh/ Institute of Geophysics (IGP), VAST, "On ground motion evaluation and geophysical surveys in Vietnam"

The seismicity around Vietnam during the past 100 years and the current state of seismic observation in Vietnam were explained. Since seismicity in Vietnam is very low and few seismograms from natural earthquakes are available, it is difficult to predict strong ground motion. Given this situation, a comparison of a synthetic seismogram prepared by the empirical Green function method and the observed seismogram was shown for the 2001 Dien Bien earthquake (M5.3). Afterwards, it was noted that although the stochastic Green function method is desirable for predicting strong motion in low seismicity areas such as Vietnam, issues remain regarding how to set the parameters required for the method.

4.4 Session 3 presentations

S3-01 Nguyen Hong Phuong/Institute of Geophysics(IGP), VAST, "Deep borehole seismology in Vietnam : Needs and challenges"

The deep borehole seismic observation technique has never been used in Vietnam except in the field of oil and gas exploration; however, sharing thoughts on the possibilities of applying Deep Borehole Seismology in Vietnam is desirable for urban seismic risk assessment in Hanoi City. After an explanation of how faults are distributed over the land and seas around Vietnam, the state of human risk evaluation in Hanoi was explained using a database of 46 faults. The necessity of a simpler method for subsurface structure evaluation in Vietnam was also noted.

S3-02 Hisanori Matsuyama/OYO & Hiroyuki Fujiwara/NIED, “Construction method and application of a 3D velocity model for evaluation of strong seismic motion and its cost performance”

Based on experiences of making subsurface structure models for seismic strong motion evaluation, the advantages and disadvantages in terms of convenience and cost for several methods used to make such models were reported. As for the details, gravity and microtremor surveys were considered to be highly valid in terms of convenience and cost. However, stratigraphy and seismic velocity structure are required to make accurate 3-D subsurface structures. To realize these, methods for directly examining subsurface ground or using controlled tremor sources (at high cost) are needed. As a result, it was summarized that in modeling subsurface structures, some sort of plan including both types of methods is desirable and that several methods must be combined to match one’s intended purposes and budget.

S3-03 Nebi Bekiri/IAEA/ISSC, “ISSC Information & Notification System”

The Information & Notification System carried out in WA9 of IAEA/ISSC/EBP was explained. This system is comprised of two parts, a database of earthquakes, tsunami, and volcanoes as well as a notification system for these phenomena. Data and systems from USGS, NOAA, JNES, ISPRA, and USNRC are utilized. The system can automatically display supposed effects on NPPs near a hazard source when an earthquake or tsunami occurs. Seismic observation data from the deep borehole at Kashiwazaki, which is operated by JNES, is planned to be added to the ISSC database using this information system.

S3-04 Hongjun Si/Kozo Keikaku Engineering Inc., “Application of seismic observation data in boreholes for the development of an Attenuation Equation of response spectra on bedrock”

Ground motion data on seismic bedrock is important, but it is very difficult to obtain such data directly. The data from KiK-net and JNES/SODB is valuable and very useful in developing the attenuation relationship of response spectra on seismic bedrock. NIED has approximately 200 observation points on seismic bedrock with S-wave velocity of more than 2000 m/s in Japan. Using data from observation at these points, a Ground Motion Prediction Equation (GMPE) is under development.

S3-05 Masashi Matsuoka/Tokyo Inst. of Tech., “Seismic intensity maps triggered by observed strong motion records considering site amplification and their service based on the Geospatial International Standard”

Instrumental seismic intensity measurement is carried out at approximately 4,200 points in Japan, but the correct values at points without seismometers cannot always be provided because seismic motion depends on geologic and geomorphologic features. Quick provision of accurate information on seismic intensity distribution over wide areas is required for disaster mitigation. To estimate seismic intensity at specific points, it is important to prepare ground amplification characteristics for local areas beforehand and use an interpolation algorithm. The QuiQuake system (quick estimation system for earthquake maps triggered by using observation records from K-NET and KiK-net that have been released by the National Research Institute for Earth Science and Disaster Prevention), which uses these, was developed; it can be started up automatically using seismograms and can immediately display a seismic intensity distribution map. The calculation results are sent to IAEA and JNES in the form of strong motion evaluation maps with a mesh size of 250 x 250 m. These maps are also sent to the general public via social networking websites.

S3-06 Mitsuyuki Hoshiba/Meteorological Research Institute/JMA, "Real-time prediction of earthquake ground motion: Time-evolutional prediction and real-time correction of site amplification factors"

At present, the Japan Meteorological Agency predicts seismic intensity using pre-calculated ground motion for magnitude (M) and hypocenter distance (D); M and D are estimated based on observed seismic motions, but this system has limitations regarding prediction accuracy. To resolve these limitations, JMA is now developing a "time evolutional prediction system" which uses real-time records from points neighboring the point in question. In this system, ground motion characteristics (site amplification characteristics) at the point in question and neighboring points are evaluated in advance.

Real-time seismic intensity estimation at the point in question is carried out using time-evolutional observed motion via the following procedure:

- Step 1: Collect data on observed ground surface motion at neighboring points.
- Step 2: Estimate seismic bedrock motion at neighboring points.
- Step 3: Estimate seismic bedrock motion at the point in question by theoretical wave propagation evaluation from the seismic bedrock at neighboring points to that of the point in question.
- Step 4: Evaluate ground surface motion at the point in question.

S3-07 Katsunori Sugaya/JNES, "Development and examination of a real-time automatic scram system using deep vertical array seismic observation system"

In Japan, observed seismic motions in reactor buildings are currently used for seismic scram, but installing a seismometer at a great depth at the site may possibly shorten scram initiation time. JNES proposed a scram system with a seismometer set at a depth of 3,000 m on the premises of the Niigata Institute of Technology based on preliminary results for a scenario earthquake and is now planning quantitative evaluation.

S3-08 Katsuhisa Kanda/Kobori Research Complex Inc, “Practical application of a site-specific earthquake early warning (EEW) system”

The development of an on-site warning system was reported. This system improves the timing of warnings and reduces the number of false alarms by improving the method of estimating the JMA seismic intensity using earthquake early warning system information based on site-specific data. Moreover, the development of an application for practical use in a construction company and an integrated system for realizing system shutdown was also reported.

The concept of this system is based on the following. Seismic intensity is not distributed concentrically, and the attenuation relationship cannot explain the distribution of seismic intensity precisely. The standard method of seismic intensity prediction is construed as "attenuation relationship + soil amplification factor," but this may be improved in the reformulation “original attenuation relationship for each site + correction factors dependent on the epicenter location and depth” using a seismic intensity database that includes data on recent and historical earthquakes.

S3-09 Yukio Fujinawa/Genesis Inc., “Utilization of real-time seismic hazard information to make facilities more resilient”

Though the JMA early warning system (EEW) has been in operation for a long time, there are some shortcomings. Most people receive only EEWg (general public) alerts, but these do not reach those in places near the epicenter in time because issuing even the first alert requires three to five seconds. This presentation explained a hybrid seismic hazard evaluation system that uses regional EEW as well as on-site vertical and horizontal seismic observation data. A hybrid alert system using on-site instrumentation that detects initial small tremors and EEW can provide alerts much earlier than use of EEW alone. This system has been in practical use in a semiconductor factory since 2005.

In addition, seismic hazard forecasts using deep borehole data and the possibility of just-before prediction of earthquake occurrence by detecting electric field pulses in the subsurface were also mentioned in this presentation.

S3-10 Hiroshi Ishii/Tono Research Institute of Earthquake Science, “Multi-component observation in deep boreholes and its applications to earthquake prediction research and rock mechanics”

The Tono Research Institute of Earthquake Science (TRIES) has developed a multi-component instrument that can be operated in deep boreholes (e.g., those one km in depth). It is equipped with stress meters, strain meters, tilt meters, seismometers, magnetometers, and thermometers; in addition, these sensors can be arbitrarily combined. The stress meters, which were developed recently, can observe stress and strain; in the future, data obtained from these sensors will offer new information on seismology and rock mechanics.

The size of typical probe is 12 cm diameter 7.8 m total length and 290 kg total weight. It consists of many meters in tandem connection.

5. SUMMARY

5.1 Summary of each session

The session chairpersons summarized the presentations in each technical session as shown below.

(1) Session 1

- Long-term operation of downhole instrumentation is an ambitious task.
- There is a substantial need to foster R&D to design simple but robust seismic downhole instrumentation for long-term operation under conditions of very high temperatures/ pressure in partly aggressive fluid/gas environments. Recent efforts are promising but need to be further extended.
- Given high drilling costs, there is a need to define the target depth based on project-specific needs.
- There exists a general consensus on the high benefits of using (deep) downhole seismic instrumentation: low-noise conditions, imaging vertical structures, depth-depending ground motion investigations, and high-frequency recordings.
- There is a need to conduct multidisciplinary efforts to get good structural models from state-of-the-art (geophysical) methods involving high resolution 2D/3D reflection and refraction seismics, gravity, magnetotellurics, microseismic monitoring, tomography, microtremor studies, and ambient noise studies.
- Projects involving deep drilling and long-term downhole monitoring require strict oversight by advisory panels.

(2) Session 2

- Seismic observation in deep boreholes enables the attenuation evaluation of seismic waves in surface geology based on seismic and logging records. The results show that such methods are effective for evaluating high frequency seismic waves.
- The results also show that the heterogeneity of surface geology plays an important role in enhancing estimation of high frequency site response.
- 3D seismic imaging methods have been proven in sedimentary environments, and integration of geology, geophysics, and drilling provides the optimal interpretation.
- In imaging of 3D velocity structures, investigation of the characteristics of active faults is also an important issue.
- Drilling and seismic observation in deep boreholes provide opportunities for accurate estimation of 3D velocity structure. The SAFOD project can be seen as a successful case.
- Successful experiences in estimation of strong ground motion and imaging of 3D

velocity structure will prove helpful for newly developing countries.

(3) Session 3

- Seismic observation in deep boreholes enables us to investigate the important problems shown below; we expect to obtain valuable results in the near future.
  - Development of GMPEs at seismic bedrock
  - Seismic scram system based on deep borehole (P wave arrivals) observation. Further research on this topic will be needed.
  - Earthquake prediction research
  - Utilization of real-time seismic hazard information to make facilities more resilient Utilization of real-time seismic hazard information not only to make facilities more resilient but also to realize disaster prevention for residences around NPPs
- Comparative evaluations of effectiveness and cost for various geophysical methods (e.g., seismic refraction, reflection, gravity, borehole observation, etc.) were shown. It is necessary to consider an appropriate combination of survey methods to obtain underground structure with the required accuracy in consideration of cost and performance.
- For newcomer countries, although considerations of cost and performance are required, it is necessary to choose survey methods having appropriate accuracy after learning about and experiencing the various techniques.
- From the perspective of international sharing of seismic observation in deep boreholes, there were interesting presentations of intensity estimates by Quickmap (quick estimation system to make seismic intensity maps from observation records from AIST), which is expected to be used for disaster handling measures. We expect not only to apply seismic observation in deep boreholes to such systems but also to propagate that to site-specific earthquake early warning systems.

5.2 Discussions

The following three aspects were extracted from the presentations during this WS and discussed in the panel as the key issues to be resolved.

The results were summarized as the resolutions of the second SODB workshop and are shown in section 5.3.

(1) Issues and agenda to be resolved in consideration of the recent technological developments in deep seismic observation

We participants recognized the achievement of multi-depth seismic ground motion observatory construction in high-temperature (150 degrees Celsius) and high-pressure (40 MPa) environments. We also recognized the technological difficulties and recent achievements in observation under high-temperature and high-pressure environments from the example of observation instrument installation problems under similar temperature and pressure conditions. Future problems and usage of developed technologies were discussed in this session.

(2) Necessity of developing economical, practical, and reliable underground structure investigation technology

Based on newcomer countries' needs (e.g., Vietnam) for underground structure investigation technology, we consolidated information on how to apply developed advanced technology as well as economical, realistic investigation technology (seismic observation technology and exploration technology) in the international nuclear power community, including in newcomer countries. Future directions for such technologies were also discussed.

(3) International sharing and multi-purpose usage of deep seismic observation technology hardware/software

Application of deep seismic observation data to empirical seismic ground motion evaluation of seismic bed-rock, real-time automatic-scram, earthquake early warnings, and earthquake prediction as multi-purpose usage were discussed as well as international sharing of such data.

5.3 Resolutions

Based on the above discussions, the following items were adopted as the resolutions of this WS.

(i) We participants of the WS acknowledge the value of the deep underground and multi-depth observation; we resolve to promote its international usage.

(ii) We promote the practical usage of simpler, more reliable, and more economical underground structure investigation technology. Such technology is available to the international nuclear power community, including newcomer countries.

(iii) We acknowledge the value of site effect evaluation by geophysical exploration and seismic observation data on seismic evaluation. We will examine the design method of the degree of uncertainty inherent in establishing reliable ground motion estimates.

(iv) JNES has proposed a possible application of seismic observation in deep boreholes in a real-time automatic-scram system to improve the seismic safety of nuclear plants. We also encourage future international multi-purpose usages of these achievements.

(v) We acknowledge the value of the Kashiwazaki Seismic Safety Center and the continuation of deep seismic observation at this facility for the international community.

Attachment 1

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OUTLINE OF THE MULTI-PURPOSE OBSERVATION PROJECT ON DEEP SEISMIC MOTION OF JNES

Attachment 2

In the 2007 NCO earthquake, the seismic ground motion greatly exceeded the design basis ground motion; in addition, the influence of wave propagation through the irregular structure (not the stratified geological layer) was identified as a great contributor.

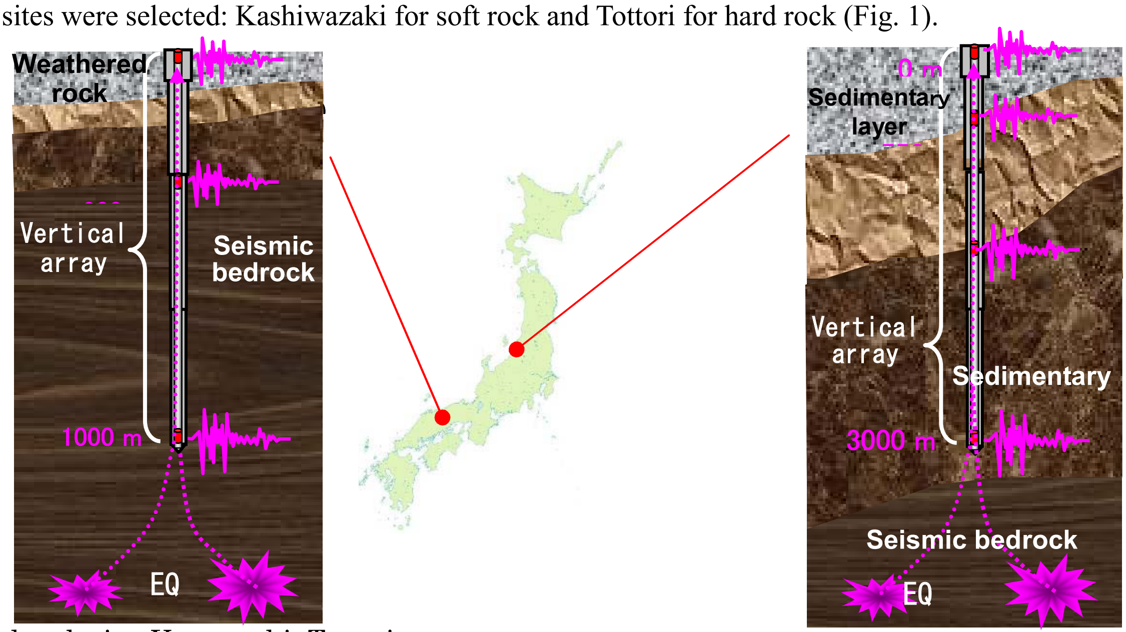
Seismic records of deep boreholes that reach the depth of seismic bedrock will contribute to elucidating the details of ground amplification characteristics. The seismic observation project using deep boreholes was initiated by JNES in 2009 to investigate this phenomenon and a series of WSs was proposed to OECD/NEA/IAGE to share and improve technologies in related areas.

This attachment shows the current progress of the JNES project.

1. Key characteristics of the JNES project of investigation

■ Deep borehole seismography at/near soft and hard rock sites

- Two sites were selected: Kashiwazaki for soft rock and Tottori for hard rock (Fig. 1).



Hard rock site: Yonago-shi, Tottori

Soft rock site: Kashiwazaki-shi,

Fig. 1 Locations and Images of the JNES Deep Borehole Observation Project

- **Soft rock site** (Kashiwazaki): A borehole of 3,000 m depth was completed in March 2011. Installation of seismometers was completed in February 2012. After checking the observation system, seismic observation has been in progress since June 2012.
- **Hard rock site** (Tottori): To acquire data to evaluate the site amplification and attenuation features at different geological sites, a hard rock site was chosen and an

installation for seismic observation in a borehole of 1000 m depth was completed in November 2012. Although this depth (1,000 meters) is slightly more shallow than that of the top of the seismogenic layer (roughly 3,000 meters), high quality data from the borehole can contribute to evaluation of the attenuation feature in the base rock and analysis of the predominant parameter (fmax) for ground motion prediction. Seismic observation has been in progress since December 2012.

■**Horizontal array seismic observation**: At the Kashiwazaki site, seismic observation by horizontal arrays is underway. Installation of a seismometer on the surface was completed in 2011. The arrays consist of two types: a wide array in which seismometers are distributed over a 20 by 50 km rectangular area and a small array with an aperture of 20 m to 3.5 km in a square 4 by 4 km centered around the deep borehole site. The numbers of seismometer locations are 15 and 19 for the wide and small aperture arrays, respectively.

[Observation at the near-site area] [Observation over the wide area]

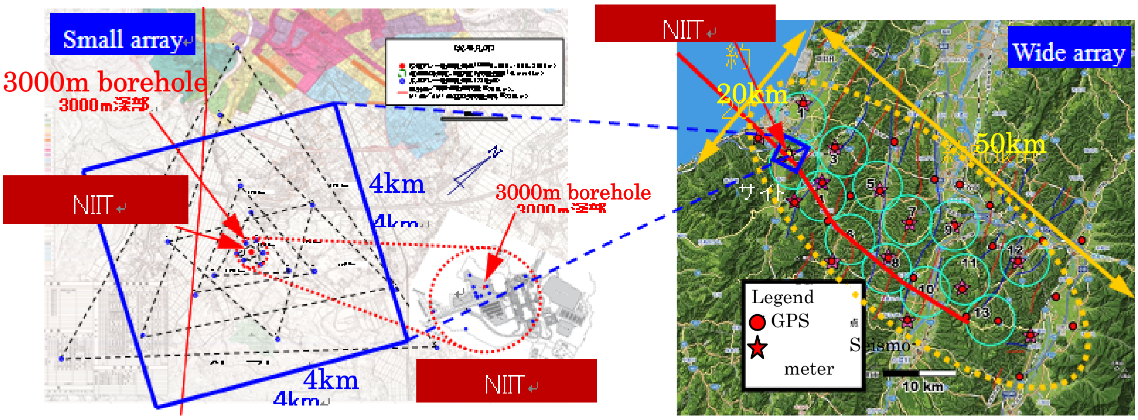


Fig.2 Horizontal array seismic observations for small (left) and wide (right) areas. Seismometer locations are represented by blue dots (left) and red stars (right).

■ Pursuit of multi-purpose utilization

- The scope of this study is multi-purpose utilization of data for normal and emergency situations. Given this scope, earthquake event data at the Kashiwazaki site has been provided to the National Research Institute for Earth and Disaster Prevention in Japan since October 2012.

2. Preliminary results obtained from data analysis of borehole observation

■Kashiwazaki soft rock site

- The Q value is a factor that is inversely proportional to seismic attenuation. Q at the subsurface (shallower than a depth of 3000 meters) estimated from PS logging data is nearly equivalent to that from seismograms of small earthquakes at the frequency band around 15 Hz, when the time window for Q estimation is selected so that only direct S waves are included. Frequency dependence of Q at the frequency band of 3 to 20 Hz is likely to be very weak.
- A three-dimensional velocity structure model is under construction around the Kashiwazaki site. In constructing a preliminary model, PS logging data was used to constrain the model. Although such a model is likely to be fine, it is necessary to check the validity of the model using observed seismograms obtained from the vertical array in the borehole.

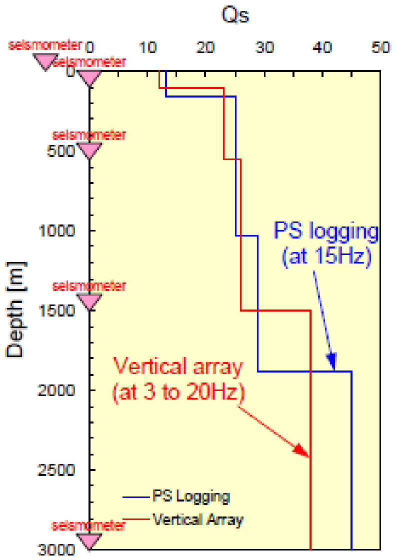


Fig. 3 Comparison of Q values from PS logging and vertical array seismic observation

■Tottori hard rock site

- The Q value at the subsurface (shallower than a depth of 1000 meters) estimated from PS logging data is 34; this value is very small for general seismological knowledge. One of the reasons for this is the velocity fluctuation due to the heterogeneity of the rocks.

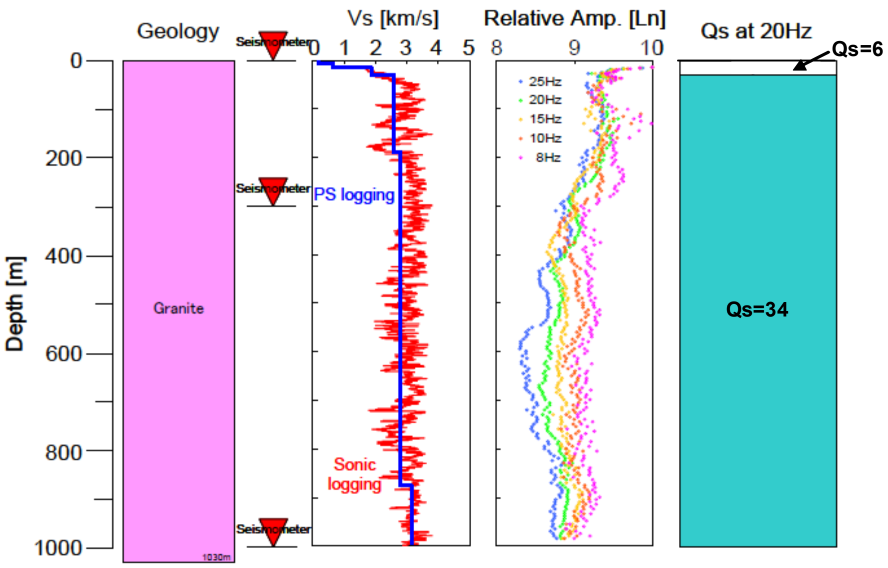


Fig.4 Profile of geology, PS logging, and estimated Q values

Progress of the project

	Hole Depth	Objective	2009	2010	2011	2012	2013	2014	2015
Soft rock site (Seis. bedrock depth : 5-7 km)	~3 km	- To ascertain the deep underground structure and attenuation feature (Verification of 3-D model)	Preparatory study	Boring	Installation	Observation			
Hard rock site (Seis. bedrock depth : 0.2-0.3 km)	~1 km	- Same as above - To ascertain attenuation and site amplification characteristics at high frequency by ground motion observed on seismic bedrock			Preparatory study Boring	Installation	Observation		
Evaluation of records and WS				First WS		Second WS	Evaluation	Final WS	

: Completed : Planned (As of March 2013)

Fig.5 Timetable of Deep Borehole Observation Project

THE 2ND INTERNATIONAL WORKSHOP ON SEISMIC OBSERVATION IN DEEP BOREHOLE AND ITS APPLICATIONS

Attachment 3

PRESENTATION MATERIAL LIST
(PLEASE REFER TO CD-ROM FOR THE DETAILS)

Opening Session

(Chair: Yoshimitsu Fukushima/IAEA)

Op-01 Explanation of IAEA EBP WA1 (Yoshimitsu Fukushima/IAEA/ISSC)

Op-02 JNES 's Activities in the Extra-budgetary Programme of the International Seismic Safety Centre: WA1 Seismic Hazard (Changjiang Wu/JNES)

OP-03 Aim and points of this workshop: The 2nd Workshop on Seismic Observation in Deep Borehole (SODB) and its Applications (Yuichi Sugiyama/AIST)

(1) Honorary Speech

OP-04 Heki Shibata/Prof. Emeritus, Tokyo Univ., Memo on Some Target of Previous Meeting in 2004 and Now

(2) Invited Speeches

Op-05 Marco Bohnhoff/GDF Potsdam, "Borehole Seismology: Fundamentals and Applications"

Op-06 Kojiro Irikura/Prof. Emeritus, Kyoto Univ., "Seismic safety of nuclear power plants based on the lessons learned from the 2011 Tohoku earthquake"

Op-07 Aybars Gürpinar/Independent consultant, "Effective Use of Deep Underground Observation for NPP Seismic Hazard Analysis"

Technical Session S1 【Development of Deep Borehole Seismic Observation System】

(Chair: Hiroshi Sato/Earthquake Research Institute, Marco Bohnhoff/GFZ Potsdam

(1) Development of new Observation Technology (high temperature and high pressure resistant seismometer, multi-depth seismometer installation method)

S1-01 Genyu Kobayashi/JNES, "Construction of System for Seismic Observation in Deep Borehole (SODB) -Overview and Achievement Status of the Project"

S1-02 Hiroshi Sato/The Geological Society of Japan, "Significance of Geophysical and Geological Investigations of Deep Structure for Safety Evaluation of Nuclear Power Plants"

S1-03 Yutaka Mamada/JNES, "Construction of System for Seismic Observation in Deep Borehole (SODB) -Development of Multi-depth, High-temperature/pressure resistance seismometer"

S1-04 Satoru Wada/Tokyo Sokushin Co., "Construction of system for seismic observation in deep borehole (SODB) -Development of Deep Borehole Seismometer"

S1-05 Marco Bohnhoff/GFZ Potsdam "Deep Geophysical Observatory at the North Anatolian Fault"

S1-06 John Townend/Victoria Univ., "The Deep Fault Drilling Project, Alpine Fault, New Zealand: Preliminary results, future plans, and affiliated seismological research"

S1-07 Peter Malin/Auckland Univ., "Outline and Prospects of SAFOD Project"

S1-08 Wade Johnson/UNAVCO, "Engineering Analysis of the Recovered SAFOD Borehole Instrumentation "

(2) Development of economical and realistic investigation method of deep underground structure

S1-09 Haruhiko Suzuki/OYO, "Estimation of S-wave velocity structure of deep sedimentary layers using geophysical data and earthquake ground motion records"

S1-10 Toru Kajiwara/OYO Seismic Instrumentation Co., "Development of Simple Borehole-Seismometer"

S1-11 Susumu Abe /JGI, Inc, "Experimental investigation on multidisciplinary geophysical characterization of deep underground structure using multi-scale, multi-mode seismic profiling for the evaluation of ground motion and seismic model building"

Technical Session S2 【Deep Ground Motion Evaluation (Application to Seismic Design)】

(Chair: Christopher Juhlin/Uppsala Univ., Hongjun Si/Kozo Keikaku Engineering Inc.)

(1) Evaluation of attenuation characteristics at deep underground

S2-01 Genyu Kobayashi/JNES, "Evaluation of near-surface attenuation of S-waves based on PS logging and vertical array seismic observation"

S2-02 Hiroaki Sato/CRIEPI, "Site-response Estimation by 1D Heterogeneous Velocity Model using Borehole Log and its Relationship to Damping Factor"

(2) Evaluation of 3D underground structure

S2-03 Yoshihiro Sugimoto/Dia Consultants, "Development of a new modeling technique of 3D S-wave velocity structure for strong ground motion evaluation - Integration of various geophysical and geological data using joint inversion"

S2-04 Hiroshi Sato/Earthquake Research Institute/Tokyo Univ., "Estimation of seismogenic source faults by seismic reflection profiling"

S2-05 Christopher Juhlin/Uppsala Univ., "3D seismic imaging of the subsurface for underground construction and drilling"

S2-06 Peter Malin/Auckland Univ., "Evaluation of Three Dimensional Underground Structure at SAFOD Project"

S2-07 Tran Thi My Thanh/ Institute of Geophysics (IGP), VAST, "On Ground Motion Evaluation and Geophysical Surveys in Vietnam"

Technical Session S3 【Multi-usage of Deep Borehole Seismic Observation Technology and Data】

(Chair: Aybars Gürpinar/Independent consultant, Susumu Nakamura/Nihon Univ.)

(1) Proposal of simple underground structure exploration method for practical application at nuclear newcomer countries

S3-01 Nguyen Hong Phuong/Institute of Geophysics(IGP), VAST, ("Needs for Underground Survey Technologies as a New Developing Country") (Tentative)

S3-02 Hisanori Matsuyama/OYO & Hiroyuki Fujiwara/NIED, "Construction method and application of 3D velocity model for evaluation of strong seismic motion and its cost performance"

(2) International sharing of seismic ground motion observation data

S3-03 Nebi Bekiri/IAEA/ISSC, "International Sharing of Observed Seismic Data" (Tentative)

(3) Current status of application of seismic ground observation data, sharing and application (of data) for safety of nuclear facility

S3-04 Hongjun Si/Kozo Keikaku Engineering Inc., "Application of Seismic Observation Data in Borehole for the Development of Attenuation Equation of Response Spectra on Bedrock"

S3-05 Masashi Matsuoka/Tokyo Inst. Of Tech., "Seismic Intensity Map Triggered by Observed Strong Motion Records Considering Site Amplification and its service based on Geospatial International Standard"

S3-06 Mitsuyuki Hoshiba/Meteorological Research Institute, "Real-time Prediction of Earthquake Ground Motion: Time-Evolutional Prediction and Real-Time Correction of Site Amplification Factors"

S3-07 Katsunori Sugaya/JNES, "Development and Examination of Real-time Automatic Scram System Using Deep Vertical Array Seismic Observation System"

S3-08 Katsuhisa Kanda/Kobori Research Complex Inc, "Practical Application of Site-Specific Earthquake Early Warning (EEW) System"

S3-09 Yukio Fujinawa/Genesis Inc., "Utilization of real-time seismic hazard information to make facilities more resilient"

S3-10 Hiroshi Ishii/Tono Research Institute of Earthquake Science, "Multi-component observation in deep boreholes, and its applications to earthquake prediction research and rock mechanics"