Nuclear Safety
NEA/CSNI/R(2013)11
October 2013
www.oecd-nea.org

Seismic Observation in Deep Boreholes and Its Applications

Workshop Proceedings
Niigata Institute of Technology
Kashiwazaki, Japan
7-9 November 2012

Part 2

OECD
BETTER POLICIES FOR BETTER LIVES

NEA
NUCLEAR ENERGY AGENCY

Unclassified **NEA/CSNI/R(2013)11/PART2**

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development

28-Jan-2014

English text only

NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

Proceedings of the Second Workshop on Seismic Observation in Deep Boreholes and Its Applications

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

Hosted by Japan Nuclear Energy Safety Organisation

This document only exists in PDF format.

JT03351593

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 34 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, Chile, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Republic of Korea, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the work of the OECD.

OECD Publishing disseminates widely the results of the Organisation's statistics gathering and research on economic, social and environmental issues, as well as the conventions, guidelines and standards agreed by its members.

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 31 countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, the Republic of Korea, the Russian Federation, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission also takes part in the work of the Agency.

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."

The 2nd International Workshop on Seismic Observation in Deep Borehole and Its Applications

Presentation Materials

(Each title is linked to the presentation material)

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) Special 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 “GONAF - A 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 : case study of the Niigata Basin”
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, “Deep Borehole Seismology in Vietnam : Needs and Challenges”

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, “ISSC Information & Notification System”

(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”

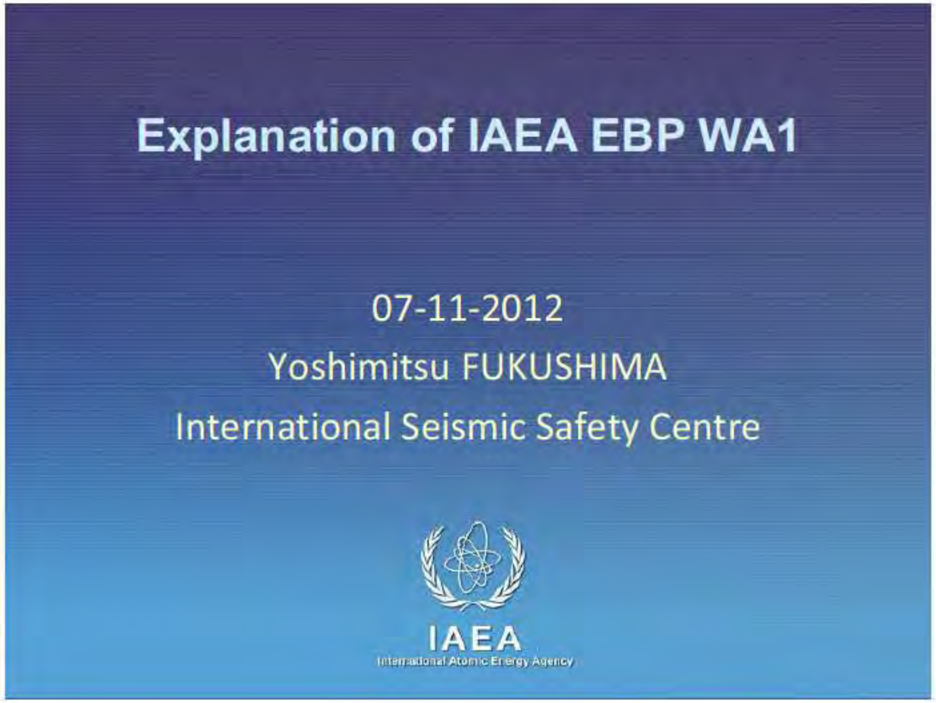
S3-06 Mitsuyuki Hoshiba/Meteorological Research Institute, “Real-time Prediction of Earthquake Ground Motion: Time-Evolutional Prediction and Real-Time Correction of Site Amplification Factors”

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”

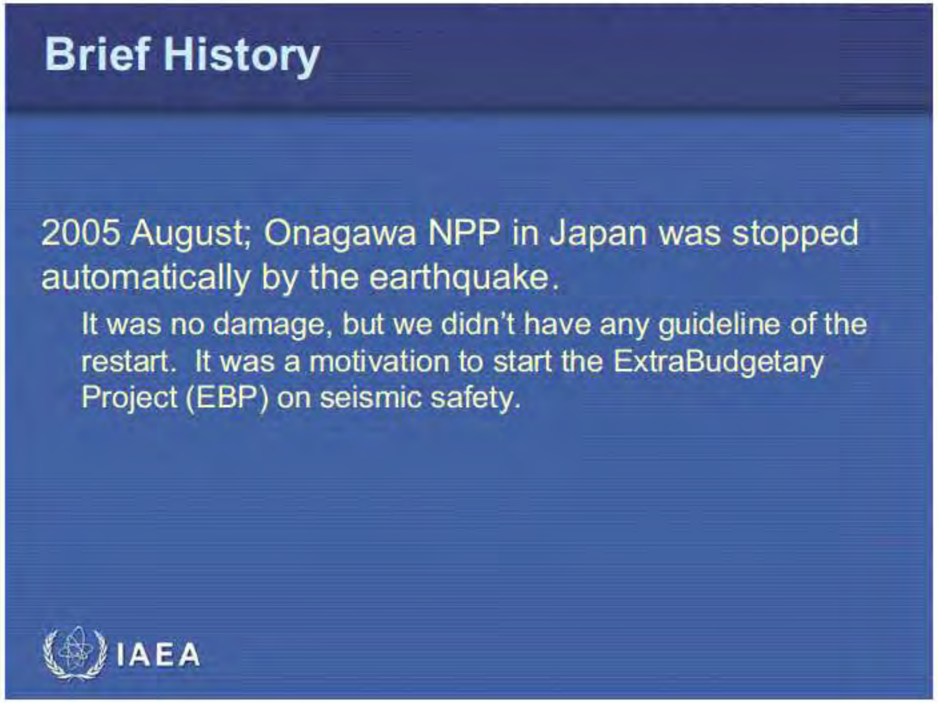


Explanation of IAEA EBP WA1

07-11-2012

Yoshimitsu FUKUSHIMA

International Seismic Safety Centre



Brief History

2005 August; Onagawa NPP in Japan was stopped automatically by the earthquake.

It was no damage, but we didn't have any guideline of the restart. It was a motivation to start the ExtraBudgetary Project (EBP) on seismic safety.

Brief History

2007; Niigata-ken Chuetsu-oki earthquake stopped **Kashiwazaki-Kariha** NPPs after the ground motion greatly exceeded the standard seismic ground motion.

This shook the technical community and IAEA immediately launched an ex-ExtraBudgetary Project (EBP) on seismic safety with the assistance of world-wide institutes.

Brief History

Meanwhile, IAEA started to update a safety standard on seismic hazard, NS-G-3.3 (SSG-9, published in 2010) and incorporated the lessons learnt.

Another EBP on Tsunamis (triggered by 2004 Sumatra earthquake) was also activated with the assistance of Japanese institute.

2008; International Seismic Safety Centre (ISSC) was established.

2010 August; the on-going EBPs were arranged in a single ISSC-EBP then split into 10 working areas.

Brief History

2010 November; 1st Kashiwazaki International Symposium on Seismic Safety of Nuclear Installations

Resolutions of Session A (Earthquake and ground motion)

(1) DSHA/PSHA

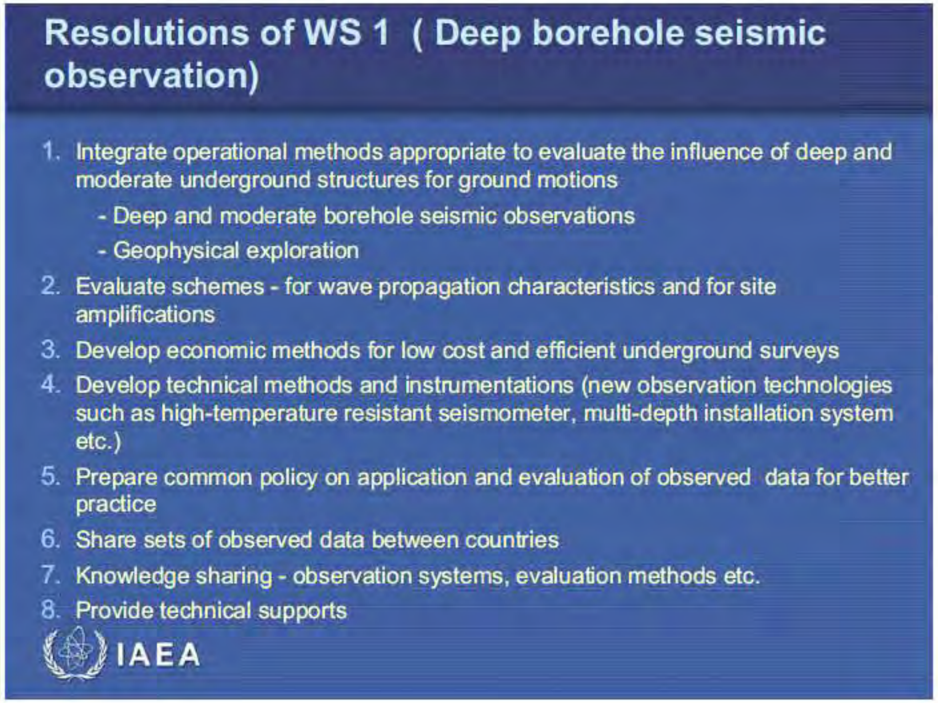
(2) Near-source ground motions

(3) Diffuse seismicity

(4) Quantification and Reduction of uncertainties in SHA

(5) Damage Indicators

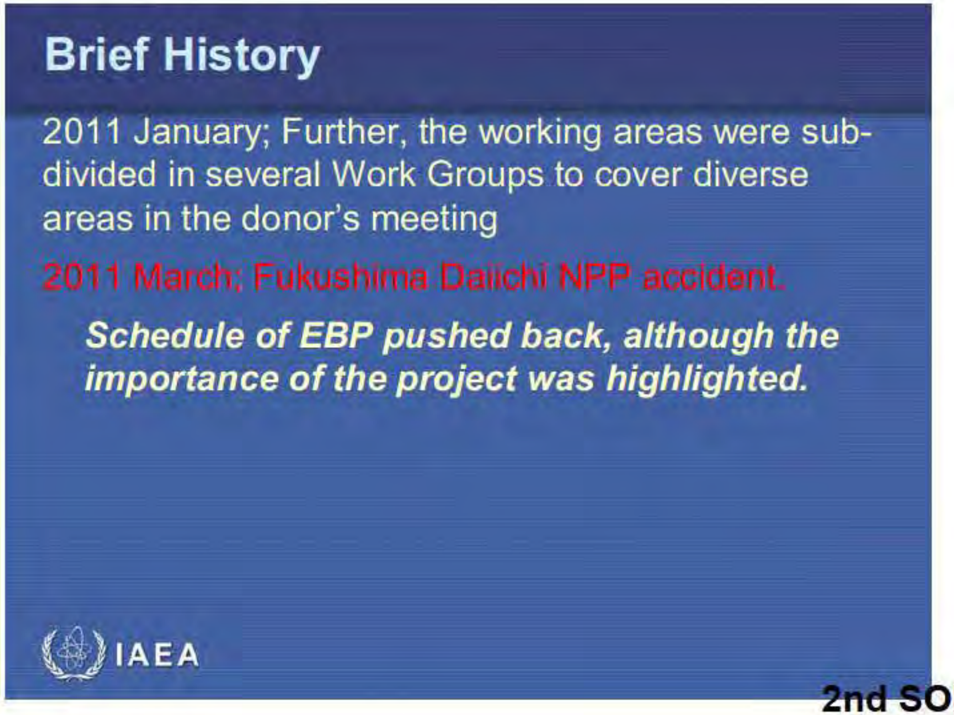
IAEA



Resolutions of WS 1 (Deep borehole seismic observation)

1. Integrate operational methods appropriate to evaluate the influence of deep and moderate underground structures for ground motions
   - Deep and moderate borehole seismic observations
   - Geophysical exploration
2. Evaluate schemes - for wave propagation characteristics and for site amplifications
3. Develop economic methods for low cost and efficient underground surveys
4. Develop technical methods and instrumentations (new observation technologies such as high-temperature resistant seismometer, multi-depth installation system etc.)
5. Prepare common policy on application and evaluation of observed data for better practice
6. Share sets of observed data between countries
7. Knowledge sharing - observation systems, evaluation methods etc.
8. Provide technical supports

IAEA



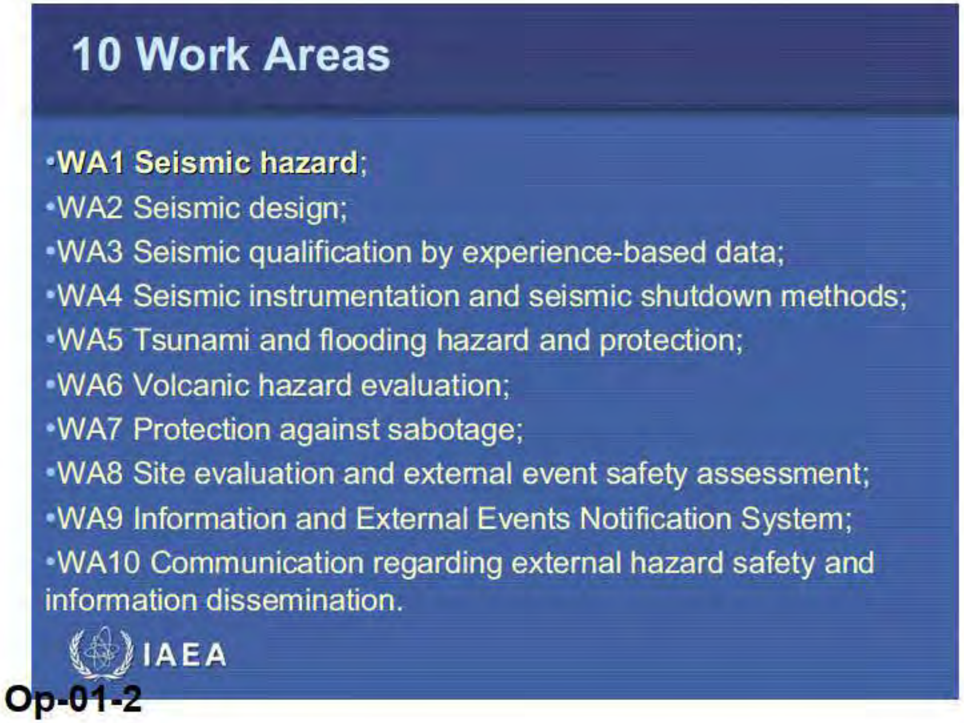
Brief History

2011 January; Further, the working areas were sub-divided in several Work Groups to cover diverse areas in the donor's meeting

2011 March; Fukushima Daiichi NPP accident.

Schedule of EBP pushed back, although the importance of the project was highlighted.

IAEA



10 Work Areas

- **WA1 Seismic hazard**;
- WA2 Seismic design;
- WA3 Seismic qualification by experience-based data;
- WA4 Seismic instrumentation and seismic shutdown methods;
- WA5 Tsunami and flooding hazard and protection;
- WA6 Volcanic hazard evaluation;
- WA7 Protection against sabotage;
- WA8 Site evaluation and external event safety assessment;
- WA9 Information and External Events Notification System;
- WA10 Communication regarding external hazard safety and information dissemination.

IAEA

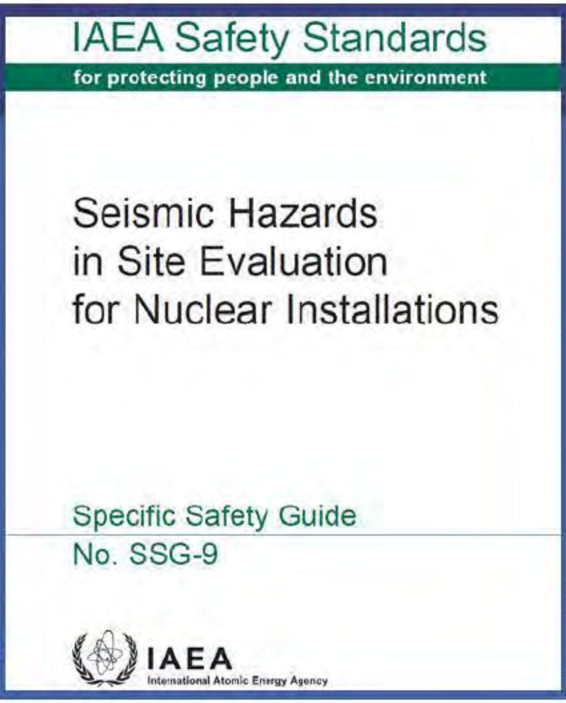
IAEA Safety Standards

IAEA

Safety Requirements (NS-R-3)
Specific requirements for earthquakes

1. **Seismological, geological & geotechnical** conditions shall be evaluated.
2. **Information** shall be collected (prehistorical, historical, instrumental, etc.).
3. **Seismotectonic model** shall be performed to determine seismic hazard.
4. **Seismic hazard assessment** shall be done taking into account seismotectonic model and site conditions. **Uncertainty** analysis shall be done.
5. Potential **surface faulting** shall be assessed.
6. A **fault is capable** if:
   a) Evidence of past movements
   b) Structural relationship with known capable faults able to produce movement at or near the surface
   c) Maximum magnitude is sufficiently large to produce movement at or near the surface.
7. Surface faulting is an **exclusion criterion**.

IAEA


IAEA Safety Standards
for protecting people and the environment

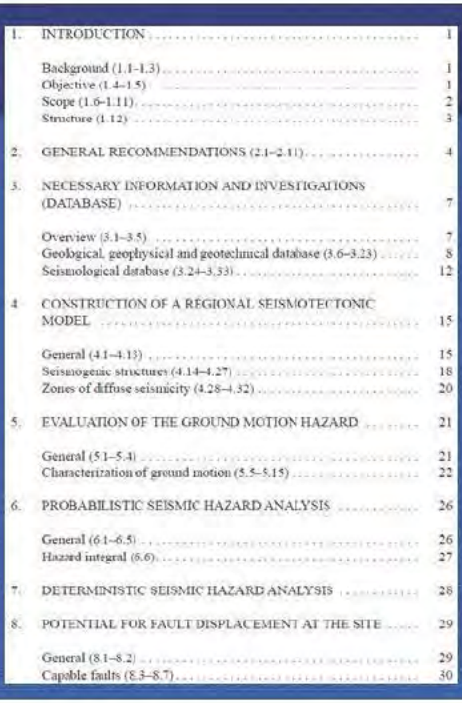
Seismic Hazards
in Site Evaluation
for Nuclear Installations

Specific Safety Guide
No. SSG-9

IAEA
International Atomic Energy Agency

IAEA

Contents


1. INTRODUCTION 1

Background (1.1-1.3) 1
Objective (1.4–1.5) 1
Scope (1.6-1.11) 2
Structure (1.12) 3

2. GENERAL RECOMMENDATIONS (2.1–2.11) 4

3. NECESSARY INFORMATION AND INVESTIGATIONS (DATABASE) 7

Overview (3.1–3.5) 7
Geological, geophysical and geotechnical database (3.6–3.23) 8
Seismological database (3.24–3.33) 12

4 CONSTRUCTION OF A REGIONAL SEISMOTECTONIC MODEL 15

General (4.1–4.13) 15
Seismogenic structures (4.14–4.27) 18
Zones of diffuse seismicity (4.28–4.32) 20

5. EVALUATION OF THE GROUND MOTION HAZARD 21

General (5.1–5.4) 21
Characterization of ground motion (5.5–5.15) 22

6. PROBABILISTIC SEISMIC HAZARD ANALYSIS 26

General (6.1–6.5) 26
Hazard integral (6.6) 27

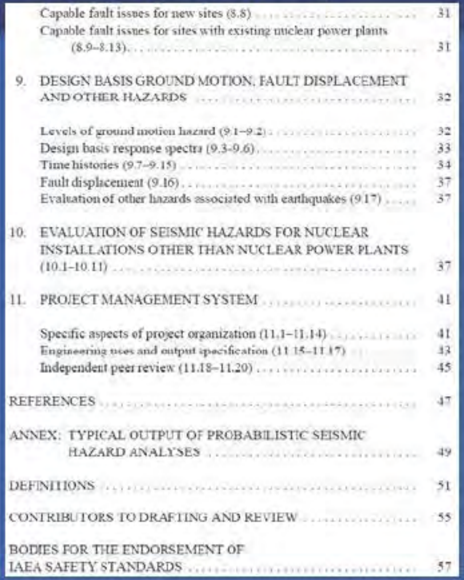
7. DETERMINISTIC SEISMIC HAZARD ANALYSIS 28

8. POTENTIAL FOR FAULT DISPLACEMENT AT THE SITE 29

General (8.1–8.2) 29
Capable faults (8.3–8.7) 30

IAEA

Content of SSG-9 (continue)



Capable fault issues for new sites (8.8) 31
Capable fault issues for sites with existing nuclear power plants (8.9–8.13) 31

9. DESIGN BASIS GROUND MOTION, FAULT DISPLACEMENT AND OTHER HAZARDS 32

Levels of ground motion hazard (9.1–9.2) 32
Design basis response spectra (9.3-9.6) 33
Time histories (9.7–9.15) 34
Fault displacement (9.16) 37
Evaluation of other hazards associated with earthquakes (9.17) 37

10. EVALUATION OF SEISMIC HAZARDS FOR NUCLEAR INSTALLATIONS OTHER THAN NUCLEAR POWER PLANTS (10.1–10.11) 37

11. PROJECT MANAGEMENT SYSTEM 41

Specific aspects of project organization (11.1–11.14) 41
Engineering uses and output specification (11.15–11.17) 43
Independent peer review (11.18–11.20) 45

REFERENCES 47

ANNEX: TYPICAL OUTPUT OF PROBABILISTIC SEISMIC HAZARD ANALYSES 49

DEFINITIONS 51

CONTRIBUTORS TO DRAFTING AND REVIEW 55

BODIES FOR THE ENDORSEMENT OF IAEA SAFETY STANDARDS 57

IAEA

Goal of WA1

Specific Safety Guide (SSG) -9 on seismic hazards was published in 2010, which provided a comprehensive coverage of seismic hazard issues.

We anticipate that this guide will be useful to MS's in developing site specific seismic hazard assessments. However, for new comers, who are embarking on nuclear programs for the first time or expanding their nuclear energy capacity, more specific guidance will be required. WA1 of this EBP will develop supplemental guidance for the application of SSG-9.

Reflection of Tohoku earthquake

IAEA

Objectives/activities under WA-1

To carry out activities to develop detailed guidance for implementing IAEA Safety Standards Series SSG-9, "Seismic Hazards in Site Evaluation for Nuclear Installations",

Covering the areas relating to;

- ✓identified source or diffuse seismicity,
- ✓ground motion prediction equation and site response,
- ✓deep borehole observations,
- ✓slope stability and soil liquefaction,
- ✓and 'environmental seismic intensity and paleoseismology'.
- ✓Finally, the guidelines/methodologies will be compiled in documents of Safety Report Series and Technical Documents levels.

IAEA

Deliverables and Target dates

Safety Reports

1)Ground motion assessment by fault rupture model 2Q/13

2)Ground motion assessment under diffuse seismicity 4Q/13

Technical Documents

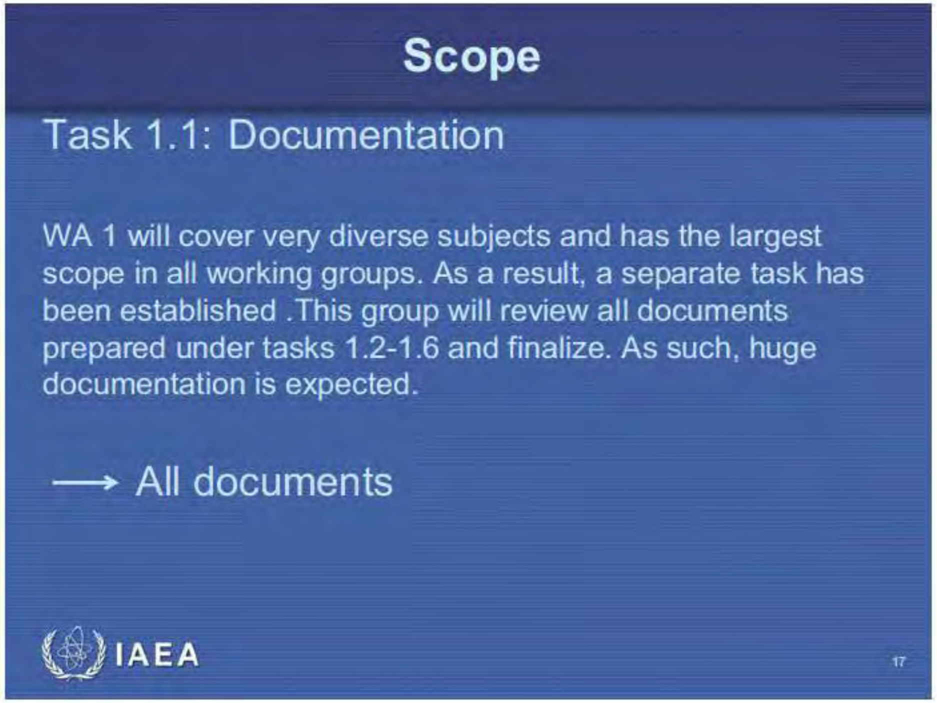
1)Site response and ground motion prediction equations 1Q/14

2)**Deep borehole** seismic observation technology and site response database 2Q/16

3)Assessment of seismic source potential from paleoseismological data 4Q/12

Database of environmental seismic intensity 1Q/13

IAEA

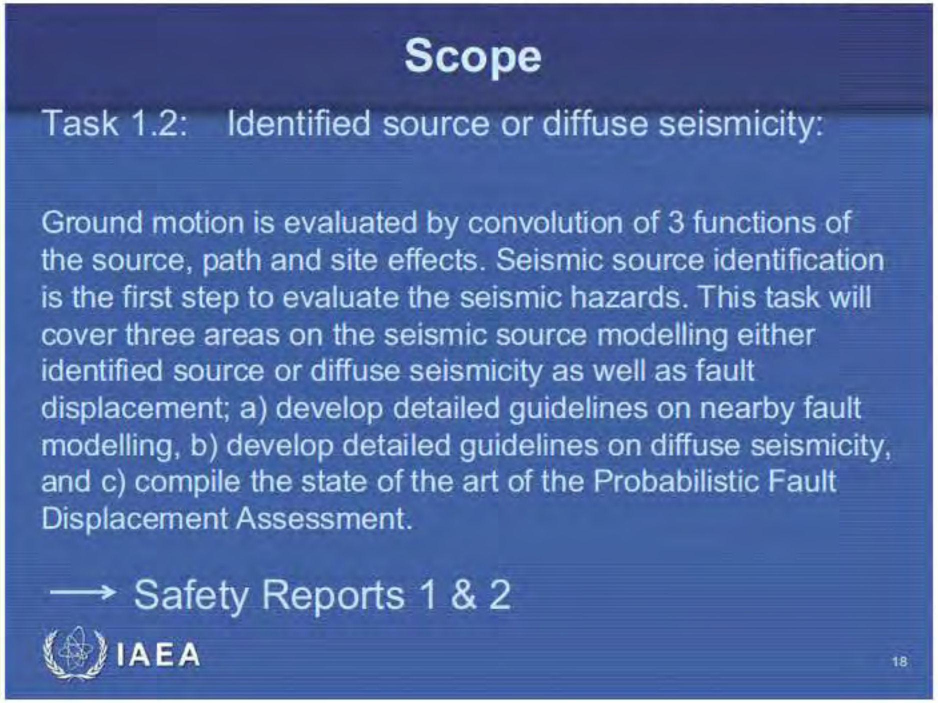


Scope

Task 1.1: Documentation

WA 1 will cover very diverse subjects and has the largest scope in all working groups. As a result, a separate task has been established .This group will review all documents prepared under tasks 1.2-1.6 and finalize. As such, huge documentation is expected.

→ All documents

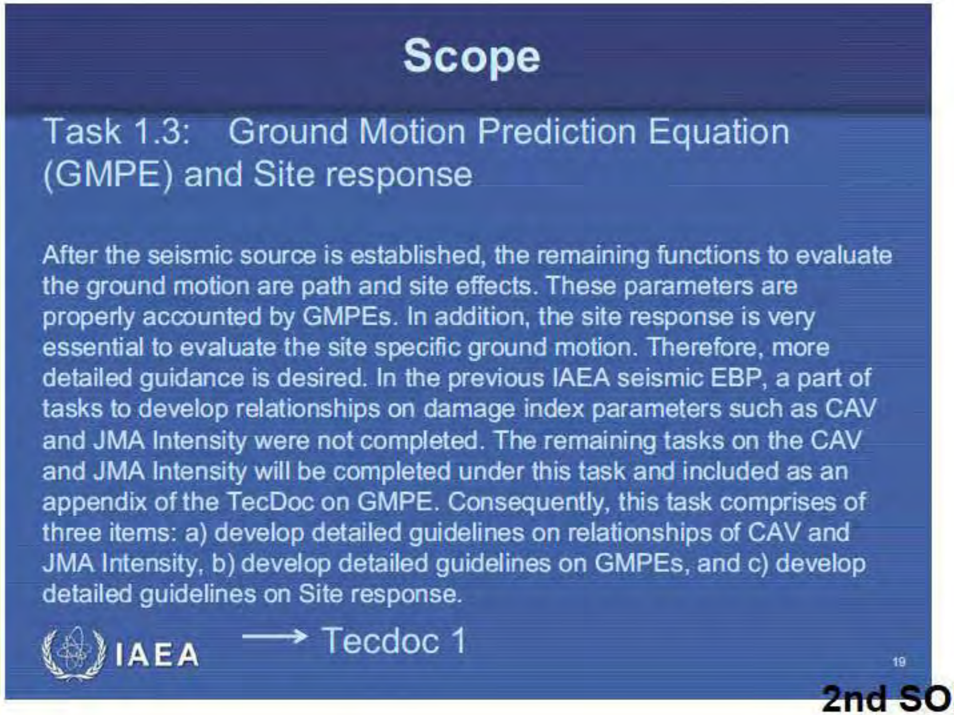


Scope

Task 1.2: Identified source or diffuse seismicity:

Ground motion is evaluated by convolution of 3 functions of the source, path and site effects. Seismic source identification is the first step to evaluate the seismic hazards. This task will cover three areas on the seismic source modelling either identified source or diffuse seismicity as well as fault displacement; a) develop detailed guidelines on nearby fault modelling, b) develop detailed guidelines on diffuse seismicity, and c) compile the state of the art of the Probabilistic Fault Displacement Assessment.

→ Safety Reports 1 & 2

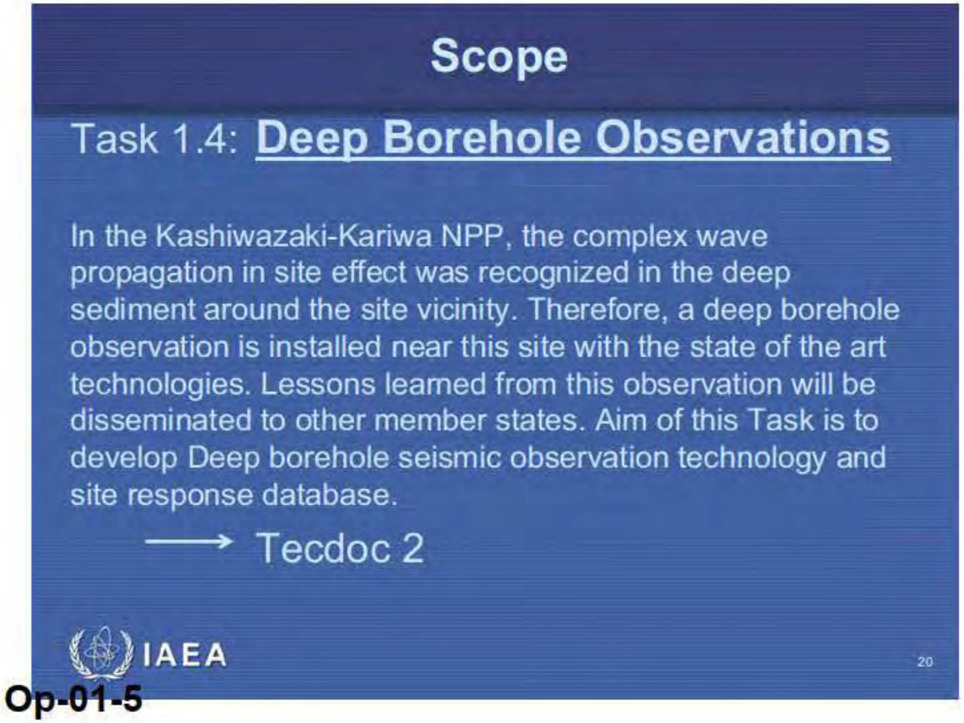


Scope

Task 1.3: Ground Motion Prediction Equation (GMPE) and Site response

After the seismic source is established, the remaining functions to evaluate the ground motion are path and site effects. These parameters are properly accounted by GMPEs. In addition, the site response is very essential to evaluate the site specific ground motion. Therefore, more detailed guidance is desired. In the previous IAEA seismic EBP, a part of tasks to develop relationships on damage index parameters such as CAV and JMA Intensity were not completed. The remaining tasks on the CAV and JMA Intensity will be completed under this task and included as an appendix of the TecDoc on GMPE. Consequently, this task comprises of three items: a) develop detailed guidelines on relationships of CAV and JMA Intensity, b) develop detailed guidelines on GMPEs, and c) develop detailed guidelines on Site response.

→ Tecdoc 1



Scope

Task 1.4: **Deep Borehole Observations**

In the Kashiwazaki-Kariwa NPP, the complex wave propagation in site effect was recognized in the deep sediment around the site vicinity. Therefore, a deep borehole observation is installed near this site with the state of the art technologies. Lessons learned from this observation will be disseminated to other member states. Aim of this Task is to develop Deep borehole seismic observation technology and site response database.

→ Tecdoc 2

Scope

Task 1.5: Slope Stability and Soil Liquefaction

This task was agreed in the donors meeting in Jan 2011, but currently suspended by the donor institutions

IAEA

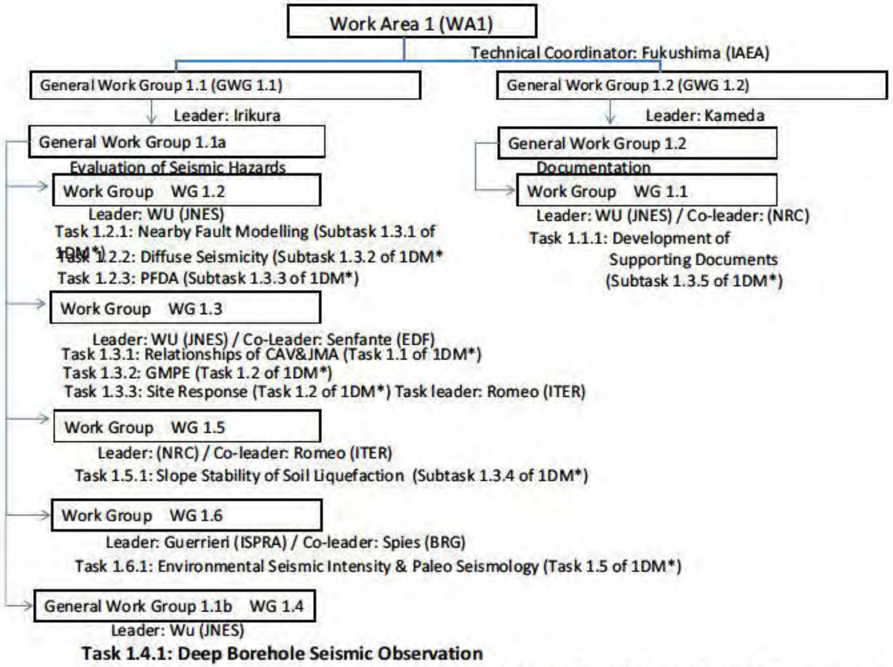
Scope

Task 1.6: Environmental Seismic Intensity and Paleoseismology

In the light of the Fukushima Daiichi NPP accident, importance of paleoseismology was again highlighted. By paleotsunami investigations, some tsunami deposit layers were detected, and the tsunami deposit of the 896 Jogan earthquake was discovered at the same location of the 11 March Great Tohoku earthquake took place. Objective of this Task is therefore to develop and disseminate the Environmental Seismic Database, and to develop detailed guidelines on Paleoseismology.

→ Tecdoc 3 & Database

IAEA



Work Area 1 (WA1)

Technical Coordinator: Fukushima (IAEA)

General Work Group 1.1 (GWG 1.1)

Leader: Irikura

General Work Group 1.1a

Evaluation of Seismic Hazards

Work Group WG 1.2

Leader: WU (JNES)

Task 1.2.1: Nearby Fault Modelling (Subtask 1.3.1 of 1DM*)

Task 1.2.2: Diffuse Seismicity (Subtask 1.3.2 of 1DM*

Task 1.2.3: PFDA (Subtask 1.3.3 of 1DM*)

Work Group WG 1.3

Leader: WU (JNES) / Co-Leader: Senfante (EDF)

Task 1.3.1: Relationships of CAV&JMA (Task 1.1 of 1DM*)

Task 1.3.2: GMPE (Task 1.2 of 1DM*)

Task 1.3.3: Site Response (Task 1.2 of 1DM*) Task leader: Romeo (ITER)

Work Group WG 1.5

Leader: (NRC) / Co-leader: Romeo (ITER)

Task 1.5.1: Slope Stability of Soil Liquefaction (Subtask 1.3.4 of 1DM*)

Work Group WG 1.6

Leader: Guerrieri (ISPRA) / Co-leader: Spies (BRG)

Task 1.6.1: Environmental Seismic Intensity & Paleo Seismology (Task 1.5 of 1DM*)

General Work Group 1.1b WG 1.4

Leader: Wu (JNES)

Task 1.4.1: Deep Borehole Seismic Observation

General Work Group 1.2 (GWG 1.2)

Leader: Kameda

General Work Group 1.2

Documentation

Work Group WG 1.1

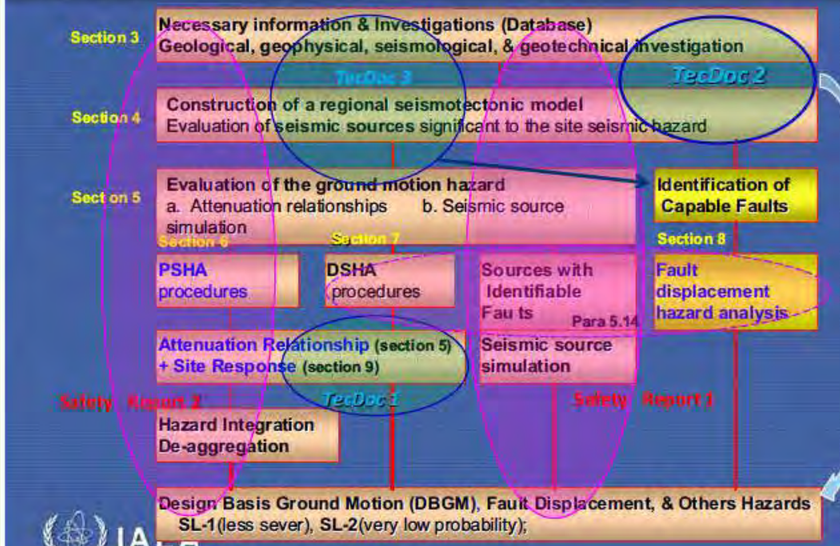
Leader: WU (JNES) / Co-leader: (NRC)

Task 1.1.1: Development of Supporting Documents (Subtask 1.3.5 of 1DM*)

*1DM: 1st Donors' Meeting in Jan 2011

Relationship with SSG-9

IAEA Safety Standards Series No. SSG 9
Seismic Hazards in Site Evaluation for Nuclear Installations



Section 3 — Necessary information & Investigations (Database)
Geological, geophysical, seismological, & geotechnical investigation

TecDoc 3

TecDoc 2

Section 4 — Construction of a regional seismotectonic model
Evaluation of seismic sources significant to the site seismic hazard

Section 5 — Evaluation of the ground motion hazard
a. Attenuation relationships b. Seismic source simulation

Identification of Capable Faults

Section 6

Section 7

Section 8

PSHA procedures

DSHA procedures

Sources with Identifiable Faults

Para 5.14

Fault displacement hazard analysis

Attenuation Relationship (section 5) + Site Response (section 9)

Seismic source simulation

Safety Report 2

TecDoc 1

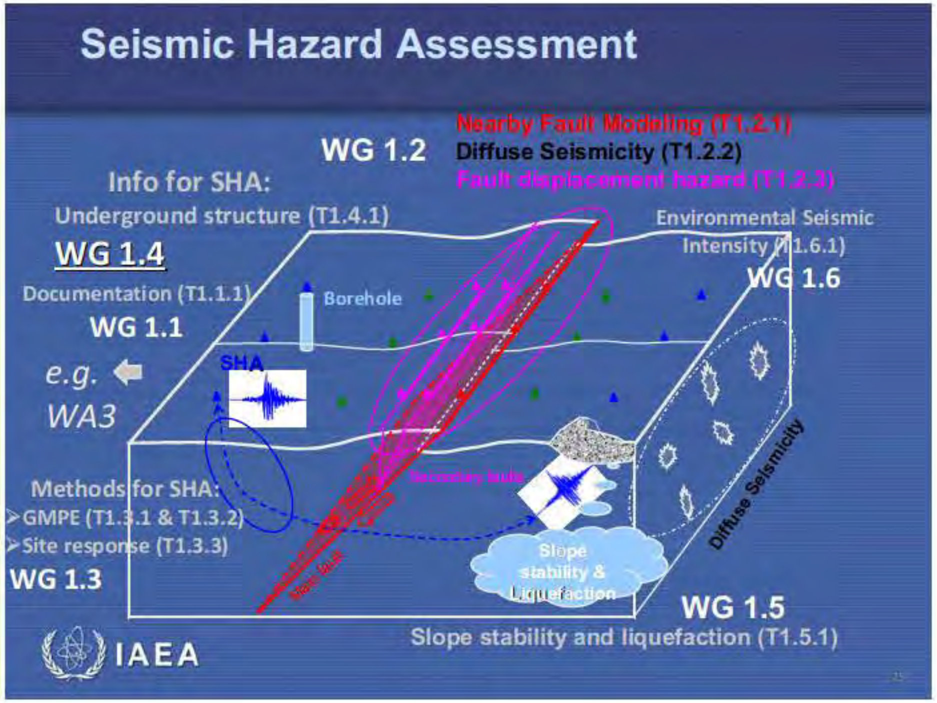
Safety Report 1

Hazard Integration
De-aggregation

Design Basis Ground Motion (DBGM), Fault Displacement, & Others Hazards
SL-1(less sever), SL-2(very low probability);

IAEA

2nd SODB WS Op-01-6



Seismic Hazard Assessment

WG 1.2
Nearby Fault Modeling (T1.2.1)
Diffuse Seismicity (T1.2.2)
Fault displacement hazard (T1.2.3)

Info for SHA:
Underground structure (T1.4.1)
WG 1.4

Documentation (T1.1.1)
WG 1.1

e.g. ⇦
WA3

Methods for SHA:
- GMPE (T1.3.1 & T1.3.2)
- Site response (T1.3.3)

WG 1.3

Environmental Seismic Intensity (T1.6.1)
WG 1.6

WG 1.5
Slope stability and liquefaction (T1.5.1)

…Thank you for your attention

The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications

JNES's Activities in the Extra-budgetary Programme of the International Seismic Safety Centre: WA1 Seismic Hazard

Changjiang WU

Japan Nuclear Energy Safety Organization (JNES)

---

1. The 2010 Kashiwazaki International Symposium & WA1

JNES **Nov. 24 26, 2010** IAEA


First Kashiwazaki International Symposium on Seismic Safety of Nuclear Installations

– Mission for Technology Innovation toward Next Generation –

25 November (Thu)

Joint session on WS1 & Session A (8 30 12 00)

Session A: *(JNES / IAEA)* **Earthquake and ground motions** (11/24, 13 00 11/25, 15 00)

WS1: *(JNES / OECD NEA)* **Deep borehole seismic observation** (11/24, 13 00 11/25, 14 30)

WS2: *(JNES / EDF)* **Seismic isolation** (11/24, 8 30 11/25, 14 30)

Session C: *(JNES / IAEA)* **Seismic margin and risk assessment** (11/24, 8 30 11/25, 14 30)

Session D: *(JNES / IAEA)* **Information dissemination system for seismic safety** (8 30 17 30)

26 November (Fri)

Session B: *(JNES / IAEA)* **Tsunami** (8 30 15 00)

Concluding Plenary Session (15 30 17 30)
Panel discussion based on each session reports
Reports of the each session and workshop
Outcomes of the Symposium and perspectives to the next round

Ⅱ. Keynote speech *Chair: K. Koketsu (Univ. Tokyo), A. Gürpinar (IAEA)*

2) Expectation for deep boreholes seismic observation and geophysical exploration from viewpoint of ground motion evaluation *K. Irikura (Univ. Aichi Inst. Tech.)*

3) Passive downhole seismic observations: Lessons learnt and future challenges *M. Bohnhoff (GFZ)*

4) Future IAEA action plan for evaluation of ground motion *A. Gürpinar (IAEA)*

Tasks in WA1 Seismic Hazards

(2011 Jan. Donor Meeting)

Task 1.1: CAV and JMA intensity
Task 1.2: Site response & GMPE
Task 1.3: Development of detailed guidance on seismic hazard assessment methods in relation to:
  Subtask 1.3.1: Nearby fault modelling
  Subtask 1.3.2: Diffuse seismicity
  Subtask 1.3.3: Fault displacement assessment
  Subtask 1.3.4: Slope stability and liquefaction
  Subtask 1.3.5: Supporting document
Task 1.4: Deep borehole seismic observation
Task 1.5: Environmental Seismic Intensity Scale


"IAEA Action Plan for the Evaluation of Ground Motion"

A. Gürpinar
INTERNATIONAL SEISMIC SAFETY CENTRE, ISSC/NSNI/IAEA

Follow up from the 2010 Steering Committee Meeting in Vienna – Needs in New Build Countries

- Continue work on CAV and JMA intensity
- Integrate 'nearby fault movement models' within SHA
- Develop Case Studies for PFDA
- Develop Case Studies for PSHA
- Address Specific Issues in SHA such as
  - Site response
  - Design Earthquakes
  - Project Management Systems

Comparison of the SA resolutions with WA1

Resolutions of Session A (Earthquake & Ground Motion Session)

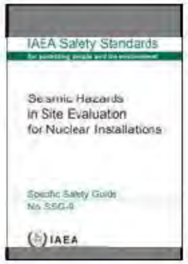
(1)**DSHA/PSHA** should be established by taking sufficient account of **regional seismotectonics**. In particular, hazard evaluations for regions with diffuse seismicity may show differences from those areas where seismicity is well associated with seismogenic structures. In addition, individual countries have established their own regulations, which may be more deterministic or risk informed leading to the use of DSHA or PSHA. It was observed during the Symposium that some countries with deterministically oriented regulatory framework are starting to use PSHA as a confirmatory tool.

(2) **Near-source ground motions** may be evaluated based on continuous accumulation of near-source records. In addition, detailed technical assessments on the source simulation method are needed e.g. to develop attenuation relationships applicable to nearby faults. Knowledge related to these assessments should be shared.

(3)**Diffuse seismicity** should be characterized adequately because even using state-of-the-art field surveys, it may not always be possible to identify the seismogenic structures. It is proposed to develop detailed technical assessments with case studies as examples on treatment of ground motion for those near-site earthquakes with sources difficult to be specified in advance.

(4)**Quantification and Reduction of uncertainties in SHA** should be implemented through
(a) identification of key factors of uncertainties in SHA (e.g., aleatory uncertainty)
(b) analysis of effectiveness of associated treatments of uncertainties (e.g., logic tree)
(c) state-of-the-arts surveys (e.g., geologic/tectonic, geomorphological & geophysical surveys) and relevant applications (e.g., separating sites effects from other effects);
(d) opinion exchange among experts.
(e) interdisciplinary interface issues and avoidance of double counting

(5)**Damage Indicators** (e.g. CAV and JMA Intensity) relevant to seismic design of critical SSCs have been proposed by the engineering side. Further research is needed on this topic. Moreover, e.g. CAV is useful for SHA as filtering of sources with low-magnitude and/or far-distance. It is proposed to develop detailed technical assessments on easily mastered and practical evaluation methods.


IAEA Safety Standards

Seismic Hazards in Site Evaluation for Nuclear Installations

Specific Safety Guide No. SSG-9

IAEA

Tasks in WA1 Seismic Hazards

2011 Donor Meeting

Task 1.1: CAV and JMA intensity
Task 1.2: Site response & GMPE
Task 1.3: Development of detailed guidance on seismic hazard assessment methods in relation to:
  Subtask 1.3.1: Nearby fault modelling
  Subtask 1.3.2: Diffuse seismicity
  Subtask 1.3.3: Fault displacement assessment
  Subtask 1.3.4: Slope stability and liquefaction
  Subtask 1.3.5: Supporting document
Task 1.4: Deep borehole seismic observation
Task 1.5: Environmental Seismic Intensity Scale

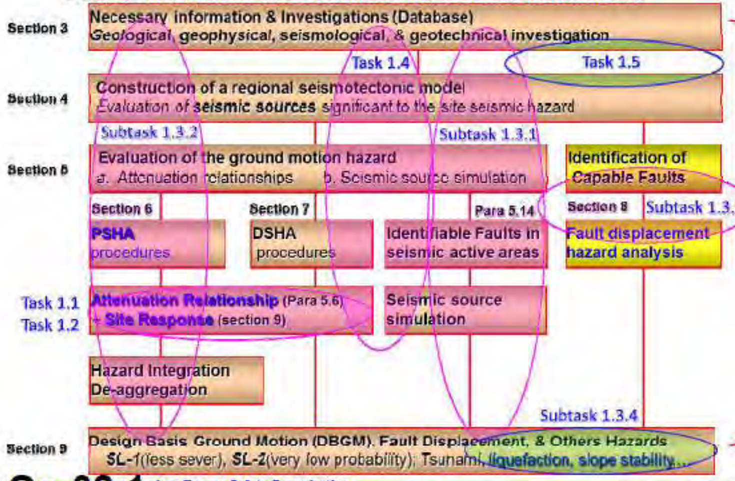
Working Groups in WA1

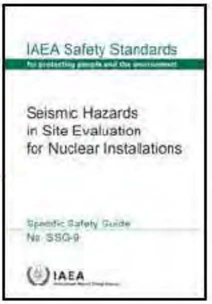
2011 Donor Meeting		Leader
WG1-1: T1.3.5	Documentation	+JNES&NRC
WG1-2: T1.3.1~3	Near Fault + Diffuse seismicity+ FDA	+JNES
WG1-3: T1.1/1.2	GMPE	+JNES
WG1-4: T1.2/1.4	Site Response & Borehole	+JNES
WG1-5: T1.3.4	Geotechnical Phenomena	+NRC
WG1-6: T1.5	INQUA	+ISPRA

Relationship with SSG-9

Task 1.1: CAV and JMA intensity
Task 1.2: Site response & GMPE
Task 1.3: Development of detailed guidance on seismic hazard assessment methods in relation to:
  Subtask 1.3.1: Nearby fault modelling
  Subtask 1.3.2: Diffuse seismicity
  Subtask 1.3.3: Fault displacement assessment
  Subtask 1.3.4: Slope stability and liquefaction
  Subtask 1.3.5: Supporting document
Task 1.4: Deep borehole seismic observation
Task 1.5: Environmental Seismic Intensity Scale

IAEA Safety Standards Series No. SSG 9
Seismic Hazards in Site Evaluation for Nuclear Installations




IAEA Safety Standards

Seismic Hazards in Site Evaluation for Nuclear Installations

Specific Safety Guide No. SSG-9

IAEA

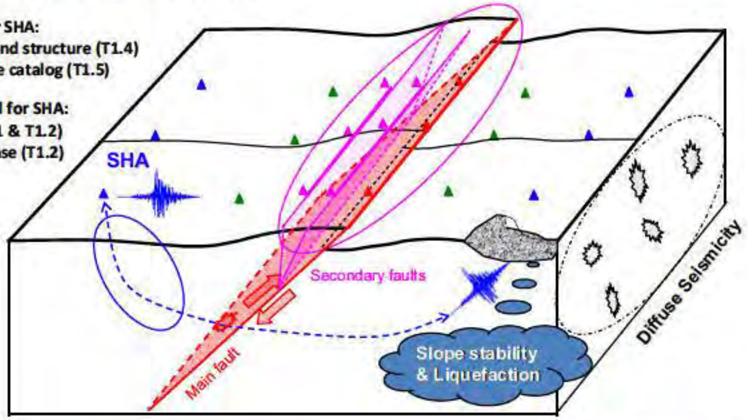
Seismic Hazard Analysis

Task 1.1: CAV and JMA intensity
Task 1.2: Site response & GMPE
Task 1.3: Development of detailed guidance on seismic hazard assessment methods in relation to:
  Subtask 1.3.1: Nearby fault modelling
  Subtask 1.3.2: Diffuse seismicity
  Subtask 1.3.3: Fault displacement assessment
  Subtask 1.3.4: Slope stability and liquefaction
  Subtask 1.3.5: Supporting document
Task 1.4: Deep borehole seismic observation
Task 1.5: Environmental Seismic Intensity Scale

Nearby Fault Modeling (ST1.3.1)
Diffuse Seismicity (ST1.3.2)
Fault displacement hazard (ST1.3.3)
Slope stability and liquefaction (ST1.3.4)

Info for SHA:
- **Underground structure (T1.4)**
- **Earthquake catalog (T1.5)**

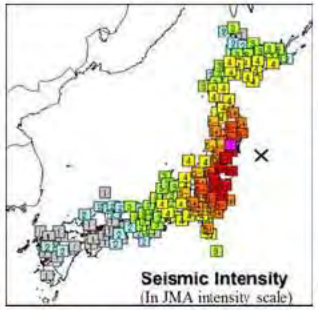
Method for SHA:
- **GMPE (T1.1 & T1.2)**
- **Site response (T1.2)**



---

2. The 2011 Tohoku Earthquake & WA1

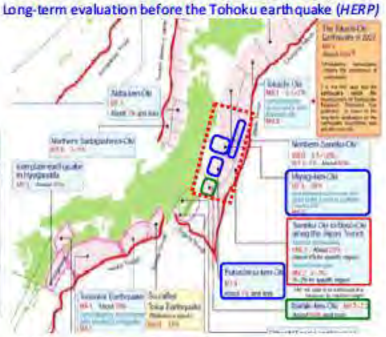
- The hypocenter of the Tohoku earthquake was located in a source area long warned of an M7.5 earthquake (with a occurrence probability of 99% in next 30 years) by *the Headquarters for Earthquake Research Promotion (HERP).*
- Strong shaking distribution and aftershock activities both suggested that the rupture occurred in multiple source areas, which had been individually evaluated by the HERP but without assessment of simultaneous rupturing.



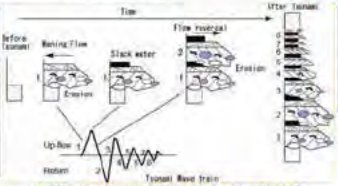
Origin: 2011/3/11 14:46
Epicenter: 38.10N, 142.86E
Depth: 24km
Magnitude: Mw9.0

Photo taken by TEPCO

Long-term evaluation before the Tohoku earthquake (*HERP*)



Miyako *Mainichi Newspaper*



JNES's previous studies on tsunami deposit

Reflection: Why seismologists failed to warn this earthquake
- Bad theory (tectonic model).
- No observation for Japan trench
- Lack of historical/paleo data.

Revision of the tectonic models;
Importance of tsunami deposit survey

SSD/JNES reaction to the Tohoku earthquake: Project Adjustment

New/Emergency Projects Regarding Seismic Safety	Category
➢ Studies on the Tohoku earthquake and tsunami ✓ Studies on the seismic/tsunami source, ground motion and tsunami simulation ✓ Reflection of the findings to the development of DBGM/DBTH ✓ Construction of Tsunami database for NPP safety	SSD 11
➢ Verification of the current seismic/tsunami design measures ✓ Investigation of tsunami damage and design measures ✓ Reflection of the findings to the relevant regulatory guides	SSD 12
➢ Advancement on PTHA ✓ **Literature investigation (Paleo-tsunami)** ✓ **Tsunami database and guideline of tsunami deposit survey** ✓ Code improvement for analyzing tsunami sediment transport ✓ Verification of the analysis code of tsunami sediment transport ✓ Methodological development of tsunami source modeling using tsunami deposit	SSD 13
➢ Seismic assessment of air cooled EDG ✓ Review and assessment of previous experiments ✓ Experiment preparation and preliminary analysis ✓ Evaluation of the damage mode and system capability using shaking table experiments ✓ Construction of capability database and analysis method ✓ Proposal of assessment standards	SSD 14

PTHA: Probabilistic Tsunami Hazard Analysis
EDG: Emergency Diesel Generator

WA1: Reaction to the Tohoku earthquake

JNES's proposal

Task 1.5 Environmental Seismic Intensity
⇩
Task 1.5 Environmental Seismic Intensity & Paleoseismology

Proposal of TECDOC documentation on paleoseismology
- Agreed by WA1 members;
- Led by Dr. Guerrieri (ISPRA) & Spies (BGR), preparation of this TECDOC is undoing .

JNES's active participation in Task1.5
- Propose to include tsunami deposit survey; expert nomination;
- Propose to add a chapter on NPP seismic hazard assessment; expert nomination
- Drafting (part); Organize/support the Japan-side experts

⇩

The consultancy meeting for drafting the paleoseismology TECDOC
(at Modena, Italy, October 2nd 4th)

IAEA TECDOC XXXX

The Contribution of Paleoseismology to Seismic Hazard Assessment

Contents

1. Introduction

2. Paleoseismology: state of the art
  2.1 Paleoseismic characterization of capable faults
  2.2 Paleoseismic characterization of diffuse seismicity areas
  2.3 Surveys of paleotsunami deposits

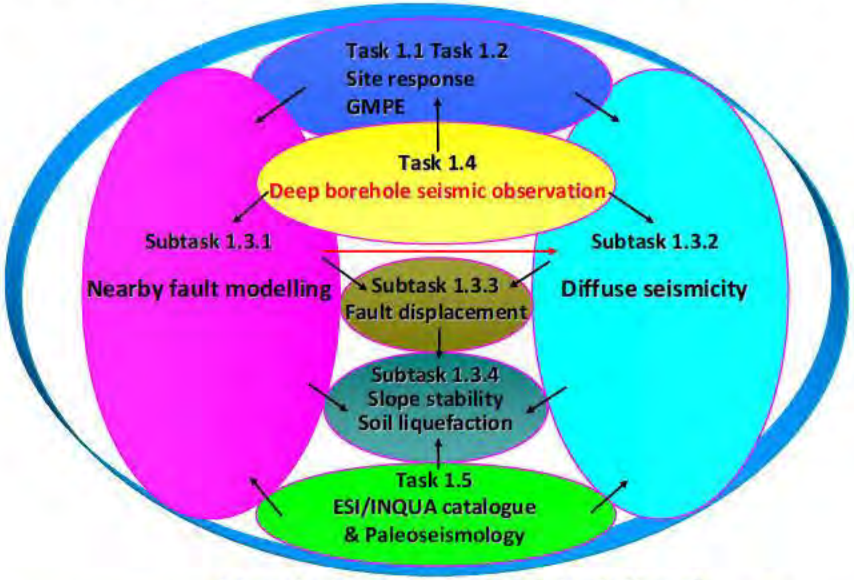
3. The contribute of paleoseismic data to an improved seismic hazard assessment
  3.1 Empirical relationships between surface faulting parameters and magnitude
  3.2 The ESI scale and the EEE global catalogue
  3.3 Regional paleoseismic databases

4. Application of paleoseismology to NPP seismic hazard assessment

5. Conclusions

Consultancy meeting at Modena
(October 2nd 4th)

3. Re-arrangement of the Implementation Framework



Task 1.1 Task 1.2
Site response
GMPE

Task 1.4
Deep borehole seismic observation

Subtask 1.3.1
Nearby fault modelling

Subtask 1.3.2
Diffuse seismicity

Subtask 1.3.3
Fault displacement

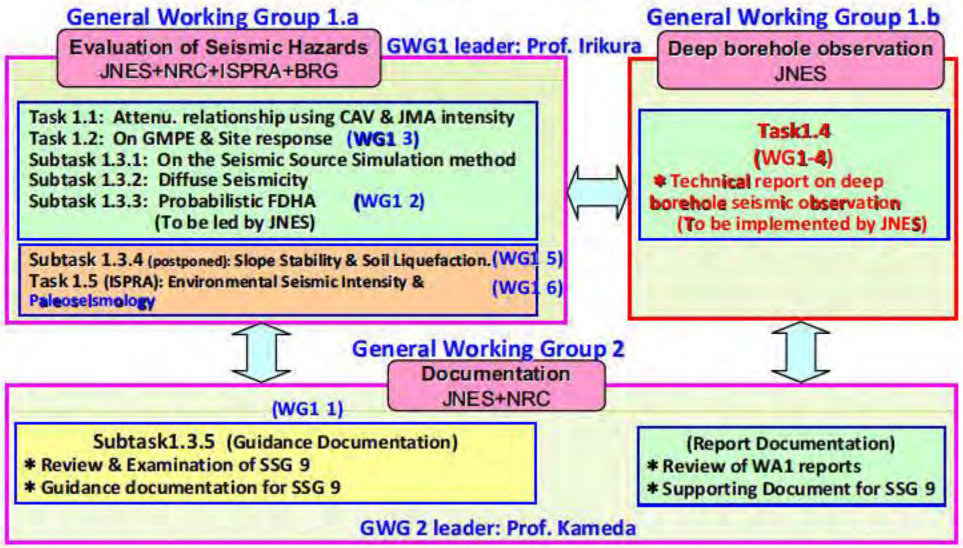
Subtask 1.3.4
Slope stability
Soil liquefaction

Task 1.5
ESI/INQUA catalogue
& Paleoseismology

Internal relationship in WA1 Seismic Hazards

Re-arrangement of the WG framework of the Work Area 1

Technical coordinator: Dr. Fukushima (IAEA)



General Working Group 1.a

Evaluation of Seismic Hazards
JNES+NRC+ISPRA+BRG

GWG1 leader: Prof. Irikura

Task 1.1: Attenu. relationship using CAV & JMA intensity
Task 1.2: On GMPE & Site response (WG1 3)
Subtask 1.3.1: On the Seismic Source Simulation method
Subtask 1.3.2: Diffuse Seismicity
Subtask 1.3.3: Probabilistic FDHA (WG1 2)
(To be led by JNES)

Subtask 1.3.4 (postponed): Slope Stability & Soil Liquefaction. (WG1 5)
Task 1.5 (ISPRA): Environmental Seismic Intensity & Paleoseismology (WG1 6)

General Working Group 1.b

Deep borehole observation
JNES

Task1.4
(WG1-4)
* Technical report on deep borehole seismic observation
(To be implemented by JNES)

General Working Group 2

Documentation
JNES+NRC

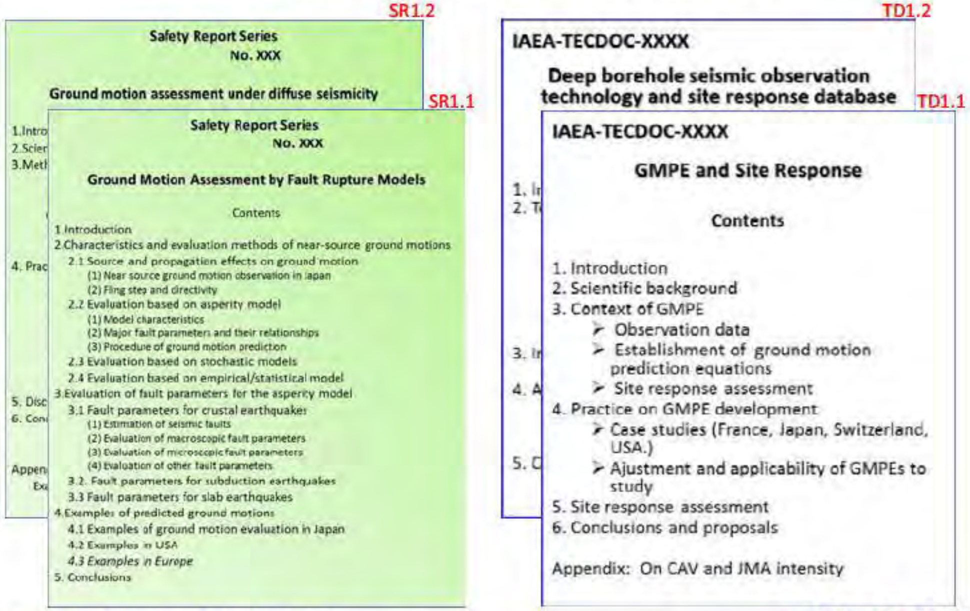
(WG1 1)

Subtask1.3.5 (Guidance Documentation)
* Review & Examination of SSG 9
* Guidance documentation for SSG 9

(Report Documentation)
* Review of WA1 reports
* Supporting Document for SSG 9

GWG 2 leader: Prof. Kameda

Proposal of technical guidance for SSG-9



SR1.2

Safety Report Series
No. XXX

Ground motion assessment under diffuse seismicity

1.Intro
2.Scier
3.Met
4. Prac
5. Disc
6. Con
Appen
Ex

SR1.1

Safety Report Series
No. XXX

Ground Motion Assessment by Fault Rupture Models

Contents

1.Introduction
2.Characteristics and evaluation methods of near-source ground motions
  2.1 Source and propagation effects on ground motion
    (1) Near source ground motion observation in Japan
    (2) Fling step and directivity
  2.2 Evaluation based on asperity model
    (1) Model characteristics
    (2) Major fault parameters and their relationships
    (3) Procedure of ground motion prediction
  2.3 Evaluation based on stochastic models
  2.4 Evaluation based on empirical/statistical model
3.Evaluation of fault parameters for the asperity model
  3.1 Fault parameters for crustal earthquakes
    (1) Estimation of seismic faults
    (2) Evaluation of macroscopic fault parameters
    (3) Evaluation of microscopic fault parameters
    (4) Evaluation of other fault parameters
  3.2. Fault parameters for subduction earthquakes
  3.3 Fault parameters for slab earthquakes
4.Examples of predicted ground motions
  4.1 Examples of ground motion evaluation in Japan
  4.2 Examples in USA
  4.3 Examples in Europe
5. Conclusions

TD1.2

IAEA-TECDOC-XXXX

Deep borehole seismic observation technology and site response database

1. I
2. T
3. I
4. A
5. C

TD1.1

IAEA-TECDOC-XXXX

GMPE and Site Response

Contents

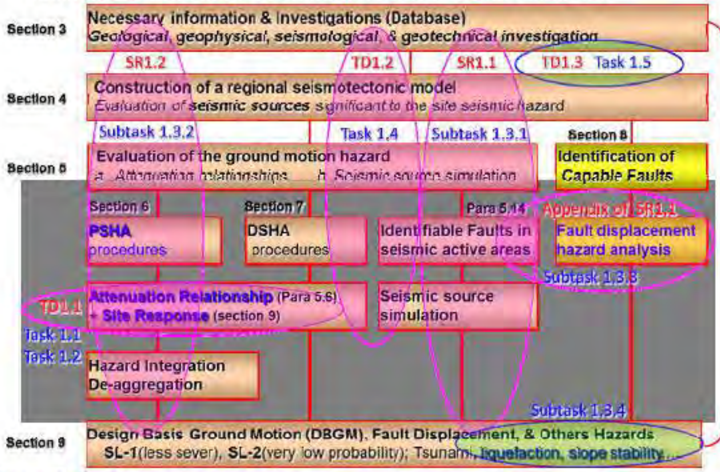
1. Introduction
2. Scientific background
3. Context of GMPE
  ➢ Observation data
  ➢ Establishment of ground motion prediction equations
  ➢ Site response assessment
4. Practice on GMPE development
  ➢ Case studies (France, Japan, Switzerland, USA.)
  ➢ Ajustment and applicability of GMPEs to study
5. Site response assessment
6. Conclusions and proposals

Appendix: On CAV and JMA intensity

Supporting documents for SSG-9

Task 1.1: CAV and JMA intensity
Task 1.2: Site response & GMPE
Task 1.3: Development of detailed guidance on seismic hazard assessment methods in relation to:
  Subtask 1.3.1: Nearby fault modelling
  Subtask 1.3.2: Diffuse seismicity
  Subtask 1.3.3: Fault displacement assessment
  Subtask 1.3.4: Slope stability and liquefaction
  Subtask 1.3.5: Supporting document
Task 1.4: Deep borehole seismic observation
Task 1.5: Environmental Seismic Intensity Scale

IAEA Safety Standards Series No. SSG 9
Seismic Hazards in Site Evaluation for Nuclear Installations



Section 3 Necessary information & Investigations (Database)
Geological, geophysical, seismological, & geotechnical investigation

SR1.2 TD1.2 SR1.1 TD1.3 Task 1.5

Section 4 Construction of a regional seismotectonic model
Evaluation of seismic sources significant to the site seismic hazard

Subtask 1.3.2 Task 1.4 Subtask 1.3.1 **Section 8**

Section 5 Evaluation of the ground motion hazard
a. Attenuation relationships b. Seismic source simulation

Identification of Capable Faults

Section 6 Section 7 Para 5.14 Appendix of SR1.1

PSHA procedures

DSHA procedures

Identifiable Faults in seismic active areas

Fault displacement hazard analysis

Subtask 1.3.3

TD1.1 **Attenuation Relationship** (Para 5.6) + **Site Response** (section 9)

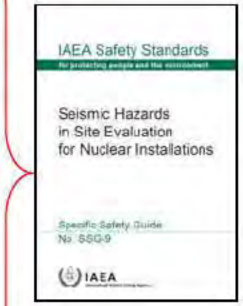
Seismic source simulation

Task 1.1
Task 1.2

Hazard Integration
De-aggregation

Subtask 1.3.4

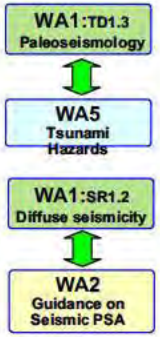
Section 9 Design Basis Ground Motion (DBGM), Fault Displacement, & Others Hazards
SL-1(less sever), **SL-2**(very low probability); Tsunami, liquefaction, slope stability...



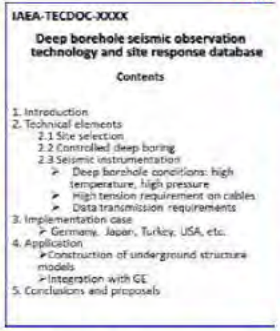
IAEA Safety Standards
Seismic Hazards in Site Evaluation for Nuclear Installations
Specific Safety Guide No. SSG-9
IAEA

Proposal of Documentation Policy

- Supporting documents should be concrete, practical, from the point of view of MS users, and consistent with SSG 9.
- Special attention should be paid to the needs and situations of newcomer MSs in order to ensure the utility of the developed documents.
- Documentation should be open and fair to appropriately reflect contributions from all participants.
- Documentation should be implemented by collaboration with relevant work areas, i.e., WA2, WA4, WA5, WA8 and WA9.



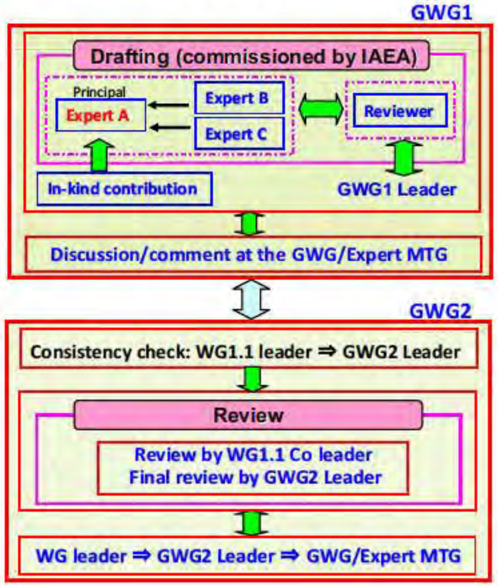
TD1.2


IAEA-TECDOC-XXXX

Deep borehole seismic observation technology and site response database

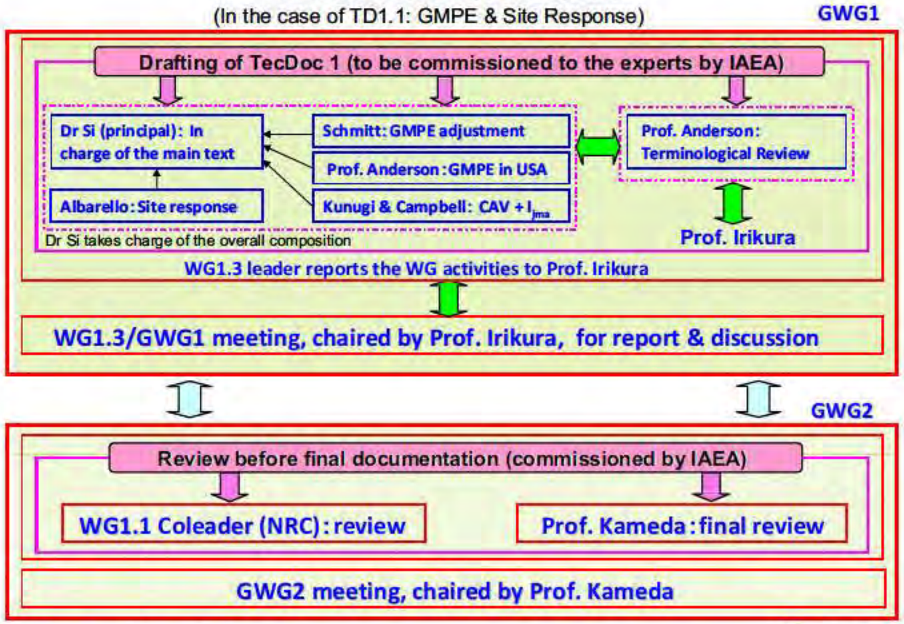
Contents

1. Introduction
2. Technical elements
    - 2.1 Site selection
    - 2.2 Controlled deep boring
    - 2.3 Seismic instrumentation
        - Deep borehole conditions: high temperature, high pressure
        - High tension requirement on cables
        - Data transmission requirements
3. Implementation case
    - Germany, Japan, Turkey, USA, etc.
4. Application
    - Construction of underground structure models
    - Integration with GE
5. Conclusions and proposals



Documentation Procedure

(In the case of TD1.1: GMPE & Site Response)

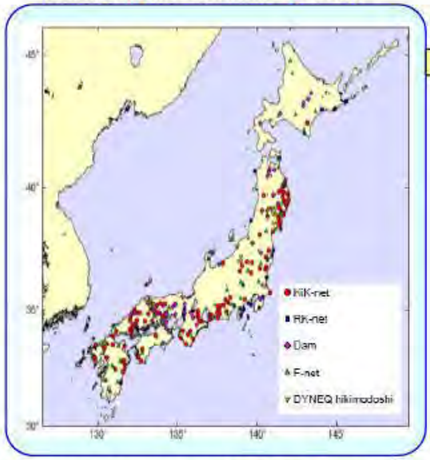


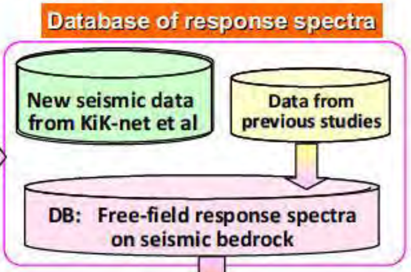
4. JNES's other contribution to WA1:

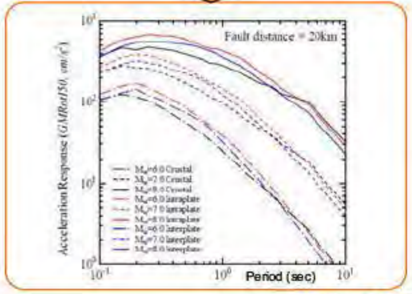
(1) A new attenuation relationship for predicting ground motions on seismic bedrocks

Seismic stations

1. Those deployed on outcrop of Vs > 2km/s
2. KiK net stations of which the borehole meter is on the basement of Vs >2km/s

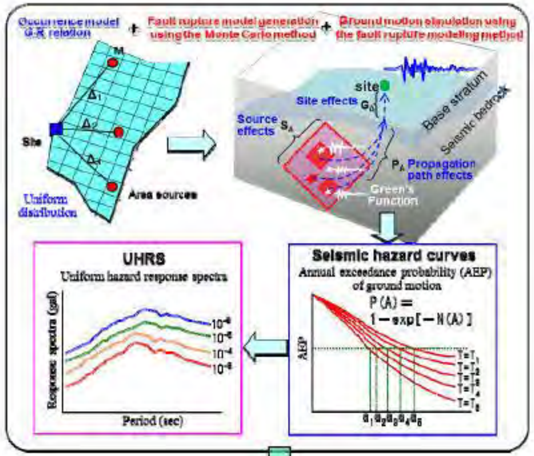


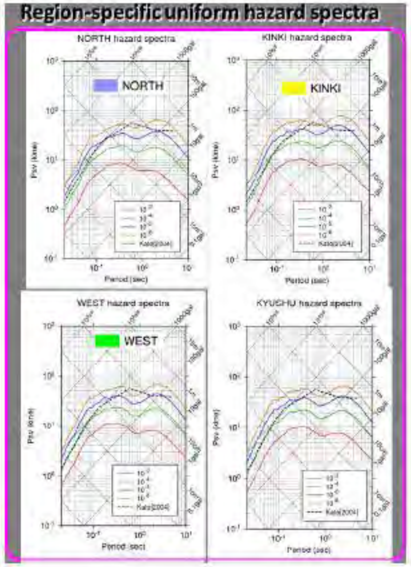




JNES project (implemented from 2008 to 2011)

(2). Probabilistic Seismic Hazard Analysis for Near-site sources





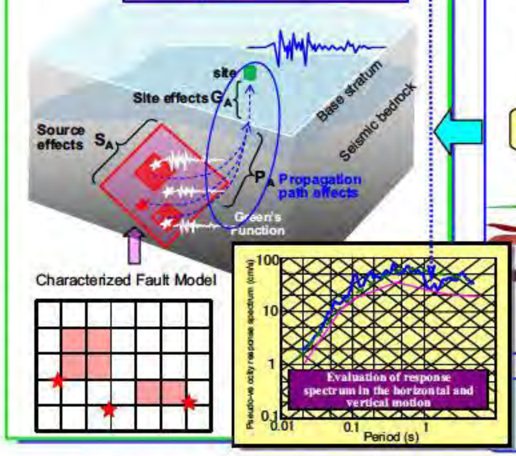
JNES project (2007～2012)
Probabilistic seismic hazard analysis for earthquakes with sources difficult to identify in advance

(3). Development of deep borehole seismic observation system

(1) The Fault Rupture Modeling Method

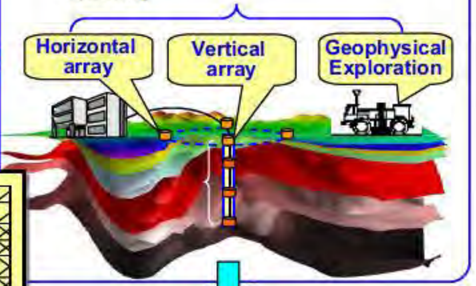
- **Detailed evaluation of ground motion taking into account the extent of a fault and rupture propagation characteristics (especially those near-site faults)**

$$F_A(f) = \sum_i S_A^i(f) P_A^i(f) G_A(f) \Rightarrow S_R(f)$$



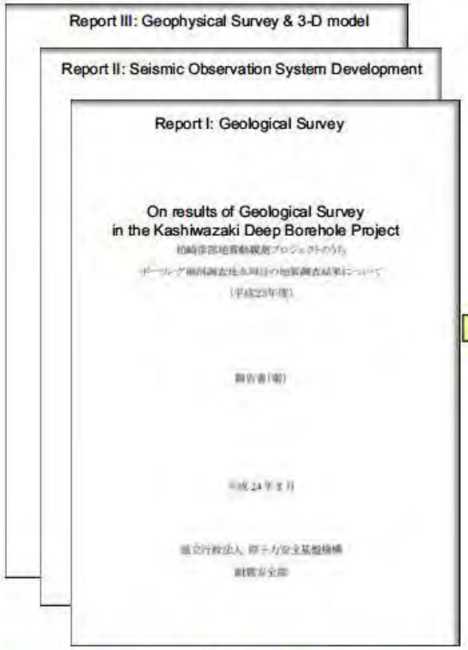
The Kashiwazaki Project

1. Technical development for the Deep borehole observation system;
2. Construction of a 3-D ground structure model & evaluation of 3-D effects;
3. Evaluation of surface layer effects (e.g. Q-value)



ISSC EBP: WA1

Task1.4 Deep Borehole Observations



Report III: Geophysical Survey & 3-D model

Report II: Seismic Observation System Development

Report I: Geological Survey

On results of Geological Survey
in the Kashiwazaki Deep Borehole Project

ISSC-EBP WA1 Seismic Hazards
Task1.4/WG1.4 Deep Borehole Observation

WG1.4 is an important venue for sharing technology/data.

IAEA-TECDOC-XXXX

Deep borehole seismic observation technology and site response database

Contents

1. Introduction
2. Technical elements
   - 2.1 Site selection
   - 2.2 Controlled deep boring
   - 2.3 Seismic instrumentation
     - ➢ Deep borehole conditions: high temperature, high pressure
     - ➢ High tension requirement on cables
     - ➢ Data transmission requirements
3. Implementation case
   - ➢ Germany, Japan, Turkey, USA, etc.
4. Application
   - ➢Construction of underground structure models
   - ➢Integration with GE
5. Conclusions and proposals

Task1.4-related items
(to be discussed in this workshop)

- ➢ Discussion/comments/advice are appreciated to improve the tentative contents of the proposed TECDOC
- ➢ Tentative list of experts for the TECDOC;
- ➢ Contribution to the drafting of the TECDOC
- ➢ Any other in-kind contribution to the TECDOC

Report to
the Joint Consultancy meeting of WA1
(to be held next week at JNES)

TD1.2

IAEA-TECDOC-XXXX

Deep borehole seismic observation technology and site response database

Contents

1. Introduction
2. Technical elements
   - 2.1 Site selection
   - 2.2 Controlled deep boring
   - 2.3 Seismic instrumentation
     - ➢ Deep borehole conditions: high temperature, high pressure
     - ➢ High tension requirement on cables
     - ➢ Data transmission requirements
3. Implementation case
   - ➢ Germany, Japan, Turkey, USA, etc.
4. Application
   - ➢Construction of underground structure models
   - ➢Integration with GE
5. Conclusions and proposals

Candidate experts and in-kind contributions

SR-1.2 Ground motion assessment under diffuse seismicity
(to be conducted in coming two to four years)
Prof. Kagawa (Principal)
Dr. Schmitt on validation of PSHA
Dr. Somerville (Review)
Dr. McDuffie (In-kind) reflecting CEUS
Dr. Senfaute (In-kind) reflecting SIGMA
Dr. Renault (In-kind) reflecting PEGASOS Refinement
Dr. Tran (CS only)
Dr. Wu (In-kind)
Dr. Mark Petersen (???)
Dr. Christophe Martin (???)
XXXX

TD-1.1 Site response and ground motion prediction equations
(to be conducted in coming two to four years)
Dr. Si (Principal)
Dr. Schmitt on selection, application and adjustment of GMPE at site
Dr. Senfaute (In-kind) reflecting SIGMA
Dr. Renault (In-kind) reflecting PEGASOS Refinement
Dr. Kunugi (CS only) on UMA&CAV
Dr. Campbell on UMA&CAV
Prof. Anderson (Review)
Prof. Romeo (In-kind, Principal for site response)
Dr John Douglas (???)
Dr Maria Jose Crespo (In-kind)
Prof. Dario Albarello Drafting of Site response
XXXX

TD-1.3 Seismic source potential from paleoseismology
(implemented in 2012 and documented in 2013)
Dr. Roncoroni (Principal)
Prof. Michetti (Review)
Prof. Nishimura on Paleotsunami survey
Dr. Pervaiz (CS only) Paleoseismology in Pakistan
Prof. Costa (CS only) Paleoseismology in South America
Prof. Serva (CS only) comprehensive review
Prof. Atwater Paleotsunami in Cascadia and others
Dr. Spies (In-kind) Paleoseismology in moderate seismicity
Dr. Cushing (In-kind) Paleoseismology in moderate seismicity
Dr. McDuffie (In-kind) reflecting CEUS
Prof. Romeo (In-kind) regional paleoseismic database
Mr. Chigama (in-kind) Practice of paleoseismology to NPP
Dr. Kevin Berryman (CS only)
Dr. Jose S. Cabenero (In-kind)
Dr. Klaus Reicherter (CS only)

SR-1.1 Ground motion assessment by fault rupture model
(to be implemented in 2012 and documented in 2013)
Dr. Dan (Principal)
Dr. Schmitt on near-field effects
Dr. Somerville (Review)
Dr. Tran (CS only)
Dr. Wu (In-kind)
Prof. Gulen (???)
Dr. Miyakoshi (CS ?)
XXXX

Expert list for TD-1.2

TD-1.2 Deep borehole seismic observation technology and site response database
To be determined at the Kashiwazaki Workshop

5. Joint Consultancy Meeting of WA1

IAEA-TECDOC-XXXX

IAEA-TECDOC-XXXX

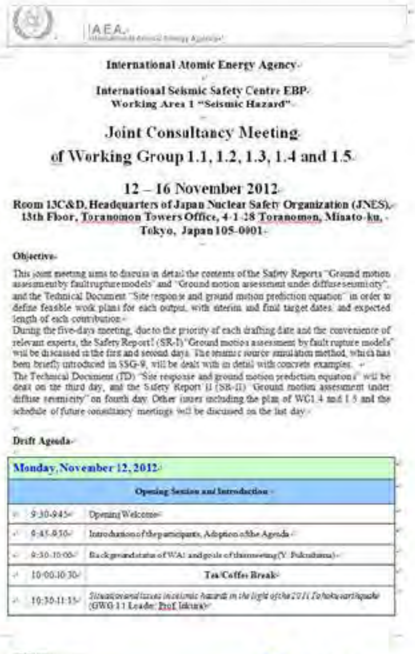
Safety Report Series

Safety Report Series
No. XXX

Ground Motion Assessment by Fault Rupture Models

Contents

1.Introduction
2.Characteristics and evaluation methods of near-source ground motions
  2.1 Source and propagation effects on ground motion
    (1) Near source ground motion observation in Japan
    (2) Fling step and directivity
  2.2 Evaluation based on asperity model
    (1) Model characteristics
    (2) Major fault parameters and their relationships
    (3) Procedure of ground motion prediction
  2.3 Evaluation based on stochastic models
  2.4 Evaluation based on empirical/statistical model
3.Evaluation of fault parameters for the asperity model
  3.1 Fault parameters for crustal earthquakes
    (1) Estimation of seismic faults
    (2) Evaluation of macroscopic fault parameters
    (3) Evaluation of microscopic fault parameters
    (4) Evaluation of other fault parameters
  3.2. Fault parameters for subduction earthquakes
  3.3 Fault parameters for slab earthquakes
4.Examples of predicted ground motions
  4.1 Examples of ground motion evaluation in Japan
  4.2 Examples in USA
  4.3 Examples in Europe
5. Conclusions



IAEA

International Atomic Energy Agency

International Seismic Safety Centre EBP
Working Area 1 "Seismic Hazard"

Joint Consultancy Meeting
of Working Group 1.1, 1.2, 1.3, 1.4 and 1.5

12 – 16 November 2012
Room 13C&D, Headquarters of Japan Nuclear Safety Organization (JNES),
13th Floor, Toranomon Towers Office, 4-1-28 Toranomon, Minato-ku,
Tokyo, Japan 105-0001

Objective

This joint meeting aims to discuss in detail the contents of the Safety Reports "Ground motion assessment by fault rupture models" and "Ground motion assessment under diffuse seismicity", and the Technical Document "Site response and ground motion prediction equation" in order to define feasible work plans for each output, with interim and final target dates and expected length of each contribution.

During the five-days meeting, due to the priority of each drafting date and the convenience of relevant experts, the Safety Report I (SR-I) "Ground motion assessment by fault rupture models" will be discussed at the first and second days. The seismic source simulation method, which has been briefly introduced in SSG-9, will be dealt with in detail with concrete examples.

The Technical Document (TD) "Site response and ground motion prediction equations" will be dealt on the third day, and the Safety Report II (SR-II) "Ground motion assessment under diffuse seismicity" on fourth day. Other issues including the plan of WG1.4 and 1.5 and the schedule of future consultancy meetings will be discussed on the last day.

Drift Agenda

Monday, November 12, 2012		
Opening Session and Introduction		
	9:30-9:45	Opening Welcome
	9:45-9:50	Introduction of the participants, Adoption of the Agenda
	9:50-10:00	Background status of WA1 and goals of this meeting (Y. Fukushima)
	10:00-10:30	**Tea/Coffee Break**
	10:30-11:15	*Situation and issues in seismic hazards in the light of the 2011 Tohoku earthquake* (GWG 1.1 Leader: Prof. Irikura)

Thanks for your attention!

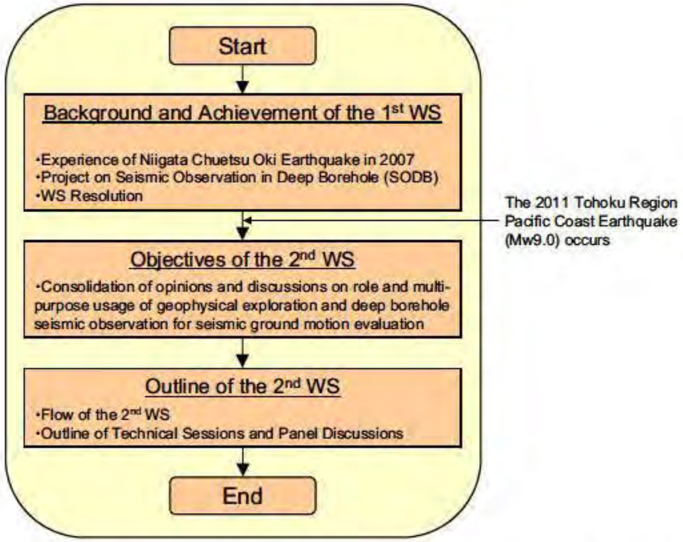
Aim and points of this workshop: The 2nd Workshop on Seismic Observation in Deep Borehole (SODB) and its Applications

Yuichi Sugiyama
Active Fault and Earthquake Research Center (AFERC)
National Institute of Advanced Industrial Science and Technology (AIST)

■Content of Presentation

1. Background of the 1st Workshop
2. Achievement of the 1st Workshop
3. Objectives of the 2nd Workshop
4. Flow of the 2nd Workshop
5. Outline of Technical Sessions and Panel Discussions

■Viewpoint of this presentation



Start

Background and Achievement of the 1st WS

- Experience of Niigata Chuetsu Oki Earthquake in 2007
- Project on Seismic Observation in Deep Borehole (SODB)
- WS Resolution

The 2011 Tohoku Region Pacific Coast Earthquake (Mw9.0) occurs

Objectives of the 2nd WS

- Consolidation of opinions and discussions on role and multi-purpose usage of geophysical exploration and deep borehole seismic observation for seismic ground motion evaluation

Outline of the 2nd WS

- Flow of the 2nd WS
- Outline of Technical Sessions and Panel Discussions

End

■Background of the 1st WS

■Background "Experience of the 2007 Niigata Chuetsu Oki Earthquake"

Seismic ground motion observed at the Kashiwazaki Kariwa Nuclear Power Plant far exceeded the design ground motion assumed under the former Regulatory Guide for Seismic Design of Nuclear Power Plants.

(1) Source Characteristics of Earthquake
(2) Propagation Characteristics affected by 3D irregular structures of deep underground at the site
(3) Amplification Characteristics affected by thick sedimentary layers up to 5-7km at the site

⇒⇒ Analysis of the seismic ground motion has revealed that the structure of deep underground around the nuclear power plant site might cause significant amplification of ground motion.

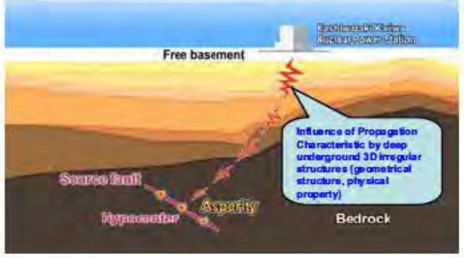
It is important to understand the details of 3D deep underground structure from seismic bedrock to free basement.

⇩

Deep Borehole Seismic Observation, Geophysical Exploration

⇩

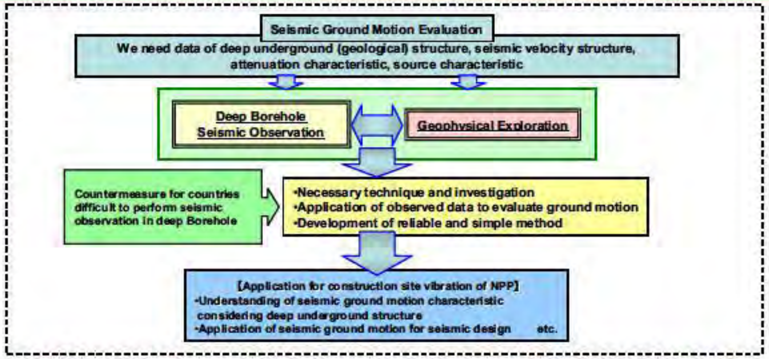
"Project on Seismic Observation in Deep Borehole (SODB)"



⇩

24-26 November 2010, The 1st Kashiwazaki WS on Seismic Observation in Deep Borehole (SODB) and its Applications

■Achievement of the 1st WS



Seismic Ground Motion Evaluation

We need data of deep underground (geological) structure, seismic velocity structure, attenuation characteristic, source characteristic

Deep Borehole Seismic Observation

Geophysical Exploration

Countermeasure for countries difficult to perform seismic observation in deep Borehole

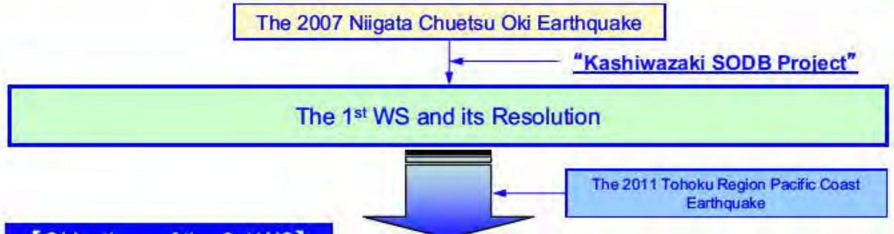
·Necessary technique and investigation
·Application of observed data to evaluate ground motion
·Development of reliable and simple method

【Application for construction site vibration of NPP】
·Understanding of seismic ground motion characteristic considering deep underground structure
·Application of seismic ground motion for seismic design etc.

【The 1st WS Resolution】

①Significance of deep boreholes seismic observation and geophysical exploration in seismic ground motion evaluation
—Understand influence of deep underground structure to seismic ground motion
—Establish evaluate schemes for wave propagation characteristics and for site amplifications
②Development of required method and technology
—Develop economic methods for low cost and efficient underground surveys
—Develop new observation technology (high temperatue and high pressure resistant seismometer, multi-depth seismometer installation method etc.)
③Application of observed data
—Prepare common policy on application and evaluation of observed data for better practice
—Share sets of observed data between countries
④Knowledge sharing
—Observation systems, evaluation methods
—Provide technical supports

■Objectives of the 2nd WS



The 2007 Niigata Chuetsu Oki Earthquake

"Kashiwazaki SODB Project"

The 1st WS and its Resolution

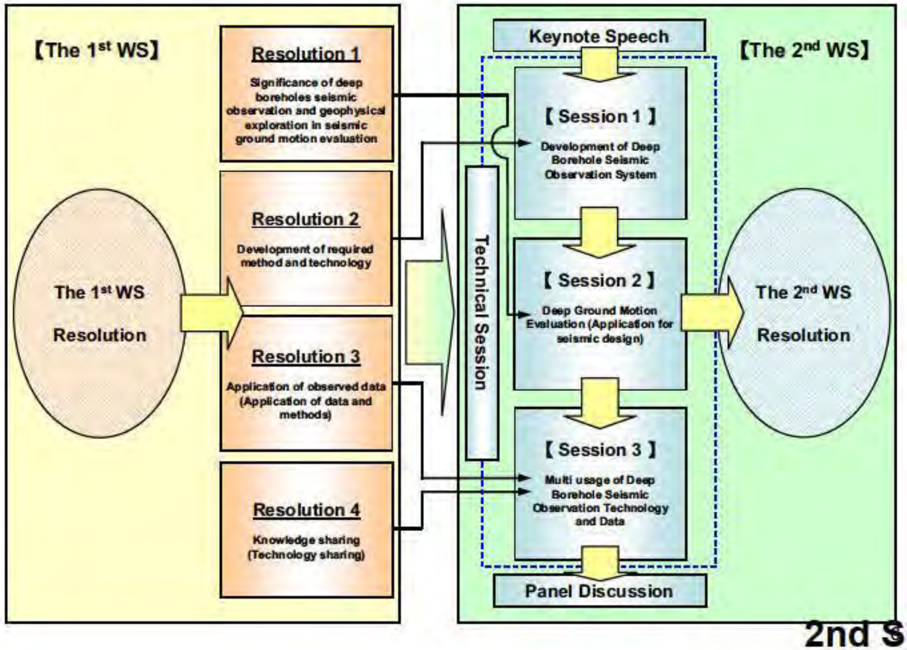
The 2011 Tohoku Region Pacific Coast Earthquake

【Objectives of the 2nd WS】

①Develop and promote the 1st WS resolution regarding SODB, re-recognize significance of seismic ground motion evaluation based on newly added deep boreholes seismic observation in addition to existing borehole investigation, geological survey, geophysical exploration.

②Acknowledge deep boreholes seismic observation and geophysical exploration (hardware), site characteristic evaluation method (software) required for seismic ground motion evaluation. Also consolidate opinions on multi-purpose application of observation technology and data, acknowledge issues to be addressed and technological problems.

■Flow of the 2nd WS



【The 1st WS】

The 1st WS Resolution

Resolution 1
Significance of deep boreholes seismic observation and geophysical exploration in seismic ground motion evaluation

Resolution 2
Development of required method and technology

Resolution 3
Application of observed data (Application of data and methods)

Resolution 4
Knowledge sharing (Technology sharing)

【The 2nd WS】

Keynote Speech

Technical Session

【Session 1】
Development of Deep Borehole Seismic Observation System

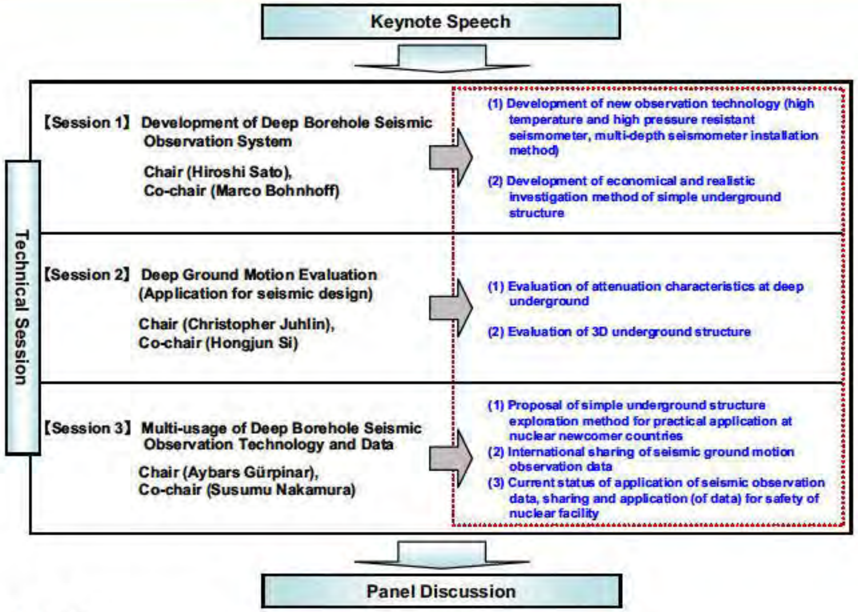
【Session 2】
Deep Ground Motion Evaluation (Application for seismic design)

【Session 3】
Multi usage of Deep Borehole Seismic Observation Technology and Data

Panel Discussion

The 2nd WS Resolution

■Outline of Technical Sessions



Keynote Speech

Technical Session

【Session 1】 Development of Deep Borehole Seismic Observation System
Chair (Hiroshi Sato),
Co-chair (Marco Bohnhoff)

(1) Development of new observation technology (high temperature and high pressure resistant seismometer, multi-depth seismometer installation method)
(2) Development of economical and realistic investigation method of simple underground structure

【Session 2】 Deep Ground Motion Evaluation (Application for seismic design)
Chair (Christopher Juhlin),
Co-chair (Hongjun Si)

(1) Evaluation of attenuation characteristics at deep underground
(2) Evaluation of 3D underground structure

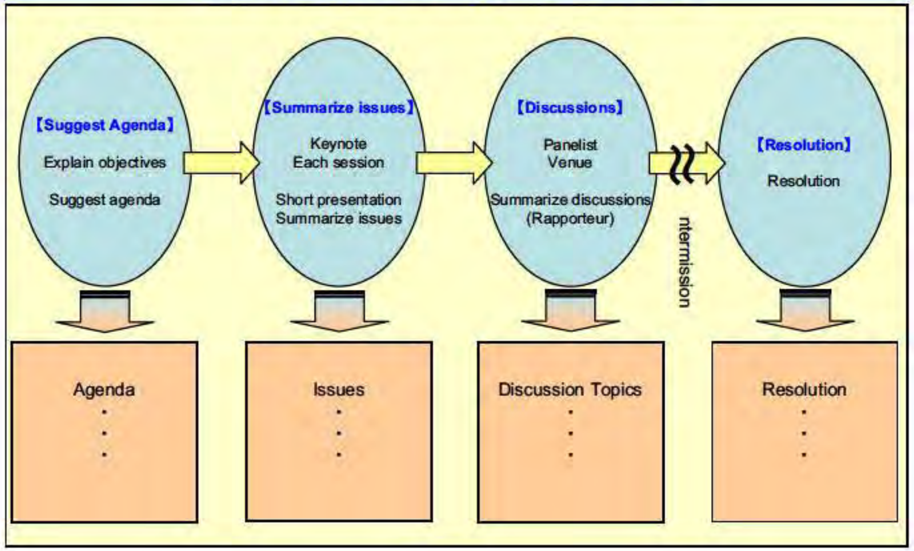
【Session 3】 Multi-usage of Deep Borehole Seismic Observation Technology and Data
Chair (Aybars Gürpinar),
Co-chair (Susumu Nakamura)

(1) Proposal of simple underground structure exploration method for practical application at nuclear newcomer countries
(2) International sharing of seismic ground motion observation data
(3) Current status of application of seismic observation data, sharing and application (of data) for safety of nuclear facility

Panel Discussion

■Outline of Panel Discussion

Discussions on role and multi-usage of SODB in deep underground investigation and geophysical exploration for deep ground motion evaluation



【Suggest Agenda】
Explain objectives
Suggest agenda

【Summarize issues】
Keynote
Each session
Short presentation
Summarize issues

【Discussions】
Panelist
Venue
Summarize discussions
(Rapporteur)

ntermission

【Resolution】
Resolution

Agenda
・
・
・

Issues
・
・
・

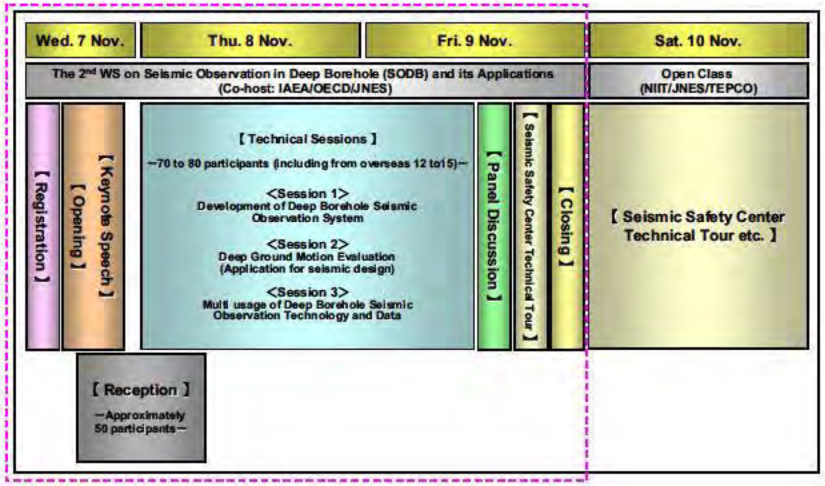
Discussion Topics
・
・
・

Resolution
・
・
・

■Essential Framework of the 2nd WS

The 2nd Workshop on Seismic Observation in Deep Borehole (SODB) and its Applications

Essential Framework



Wed. 7 Nov.
Thu. 8 Nov.
Fri. 9 Nov.
Sat. 10 Nov.

The 2nd WS on Seismic Observation in Deep Borehole (SODB) and its Applications
(Co-host: IAEA/OECD/JNES)

Open Class
(NIIT/JNES/TEPCO)

【Registration】
【Opening】
【Keynote Speech】

【Technical Sessions】
−70 to 80 participants (including from overseas 12 to15)−

<Session 1>
Development of Deep Borehole Seismic Observation System

<Session 2>
Deep Ground Motion Evaluation
(Application for seismic design)

<Session 3>
Multi usage of Deep Borehole Seismic Observation Technology and Data

【Panel Discussion】
【Seismic Safety Center Technical Tour】
【Closing】

【Seismic Safety Center Technical Tour etc.】

【Reception】
−Approximately 50 participants−

Thank you for your attention!!

Memo on Some Target of Previous Meeting in 2004 and Now

Heki Shibata, Prof. Emeritus. University of Tokyo
Member of Science Committee, ISSC,
IAEA

(Step 0)

- This, my talk is not the key note speech like, but the talk on a story some year ago, *based on my memo.*
- *I am a mechanical engineer working for the seismic safety of NPP.*
- Back to 1980's, I visited the area of the propose site of Tianwan **田湾** NPP in China. While walking the area, at Huaguaoshan Mountain or *Stone Head Mtn.*, I found a pile of core debris, granite fragments, from bore hole. One of pieces had a gap of 1.5 to 3mm filled with needle–like crystal. I brought back to my office. I reminded one word "asperity" from this one piece of core.
- This mountain is famous through old Chinese story **of 孫悟空, Sun Wukong.**
- and he was born from the heart of the mountain with stone head, that is, this piece of core might be similar to his brain; I thought.
- The following story came from my experience, that I got the peace of the brain of **孫悟空**.

Tianwan 田湾 NPP and Huaguaoshan Mtn. in China

孫 悟空 Sūn Wùkōng

- Born in the Mtn. near NPP.
- Monkey with the Stone-head.

Starting point of the Series of WSs for Deep Bore Hole in the field of the Seismic Safety of NPP

- In early 2000's, during a talk with Prof. Katayama; Dean of the NIED, he mentioned that researchers in the field of deep bore hole study, they had their interest only details of core specimen, and no further development in the field of engineering. Then I was planning one workshop with the memory of the piece of the core; the brain of the stone head monkey;**孫悟空**, I got in the site area of proposed Tianwan NPP.
- My thought on the sticked gap in its core had been developed into the discussion on the Asperity of the active fault, and my plan had been developed into a small international workshop regarding to the deep bore hole topics, in 2002, then that WS was held in the campus of NIED, Tsukuba.

Step 1: USGS and NIED Workshop in 2002

USGS and NIED Workshop in NIED

in Feb 22~23, 2002

Int. WS on "Physics of Active Fault"

Deep Borehole and Faults

Sanandreas Fault

Nojima Fault

(Nozima)

Purpose and Target of the Workshop in 2002

- Thus this workshop; USGS and NIED Workshop was held in National Research Institute for Earth Science Disaster Prevention, NIED in February 22～23, 2002 under the title "Physics of Active Fault". We discussed about mainly on 「Deep Borehole and Faults, *San Andreas Fault and Nozima (Nojima) Fault*」.
- For us, also to establish the Practical Approach to Design Basis Earthquake for Nuclear Power Plant Design; and developed to the 1 st WS.

And it developed into Step 2 and more; My Plan and Target at the first OECD/NEA WS, 2004

November 15, 2004
Tsukuba, JAPAN

CSNI Workshop on
"Seismic Input Motions,
Incorporating Recent Geological Studies"

Purpose and Target of Special Session

Heki Shibata, Prof.-Dr.
Guest Research Fellow

National Research Institute for
Earth Science and Disaster Prevention, NIED

Title of my presentation was more general; toward the Seismic Safety, but ---

Purpose of the Special Session

to establish the Practical Approach
to Design Basis Earthquake
for Nuclear Power Plant Design

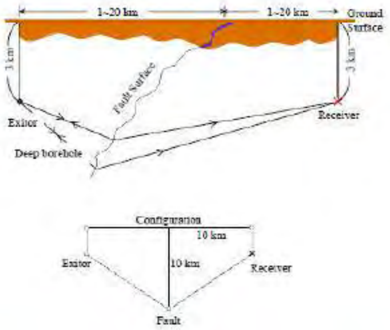
My thought was backed to the WS in 2002,

USGS and NIED Workshop in NIED
in Feb 22~23, 2002
Int. WS on "Physics of Active Fault"
Deep Borehole and Faults

Sanandreas Fault
Nojima Fault
(Nozima)

How to get the information on the Asperity, its Activity and other parameters of a fault up to 10km deep for deciding DBE;
this is the subject in my mind

Use of Deep Borehole



In this workshop, Dr. Bohnhoff is going to talk, but he talked in another International Meeting here in Kashiwazaki some years ago on the role of deep bore hole study.

- Delete the Figure by Dr. Bhnhoff

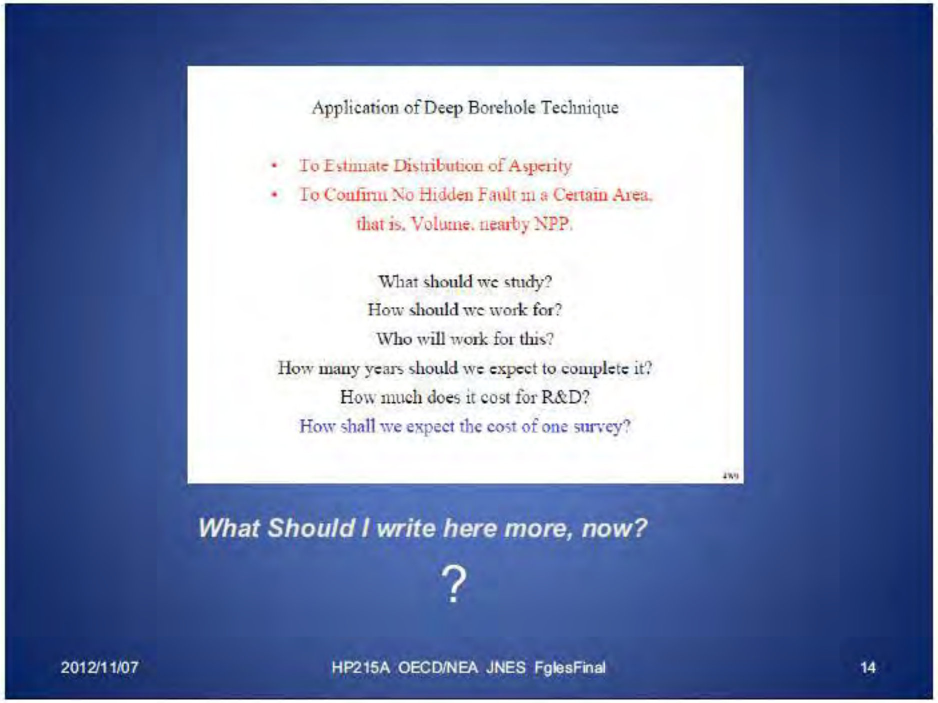
Role of Active Fault is significant to decide the DBE in Japan, *as well as in all over the world.*

The 98 Faults.

Fault in Ocean Trench,
Ambiguous Fault,
undetermined.

Hidden Fault.

Active Faults in Japan, by *HERP*



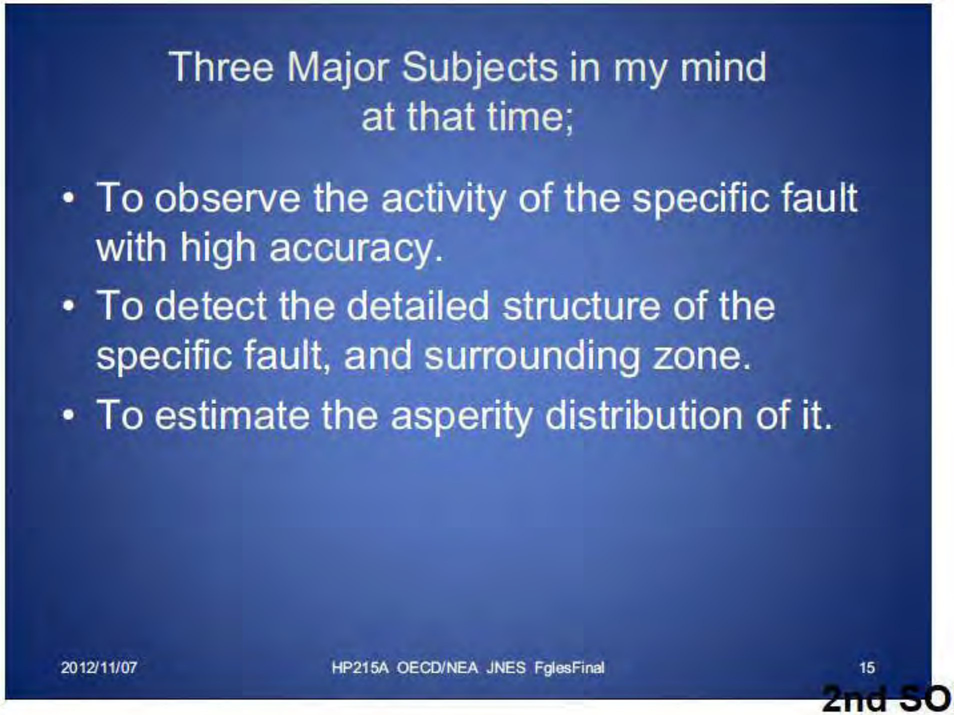
Application of Deep Borehole Technique

- To Estimate Distribution of Asperity
- To Confirm No Hidden Fault in a Certain Area,
that is, Volume, nearby NPP.

What should we study?
How should we work for?
Who will work for this?
How many years should we expect to complete it?
How much does it cost for R&D?
How shall we expect the cost of one survey?

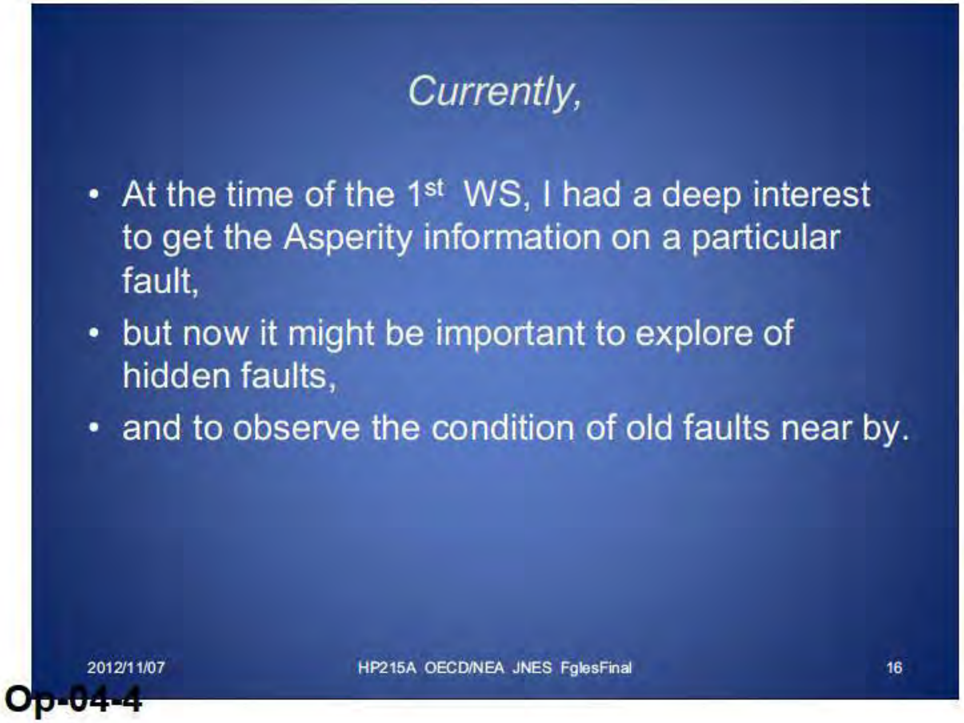
What Should I write here more, now?

?



Three Major Subjects in my mind at that time;

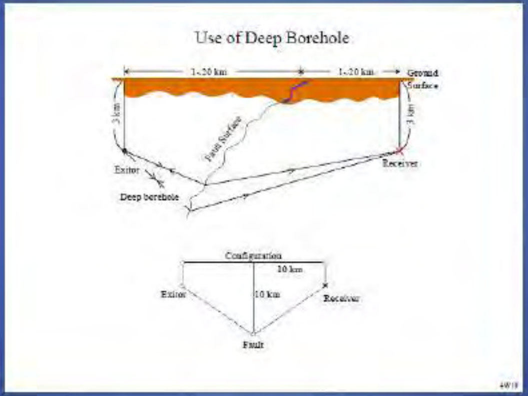
- To observe the activity of the specific fault with high accuracy.
- To detect the detailed structure of the specific fault, and surrounding zone.
- To estimate the asperity distribution of it.



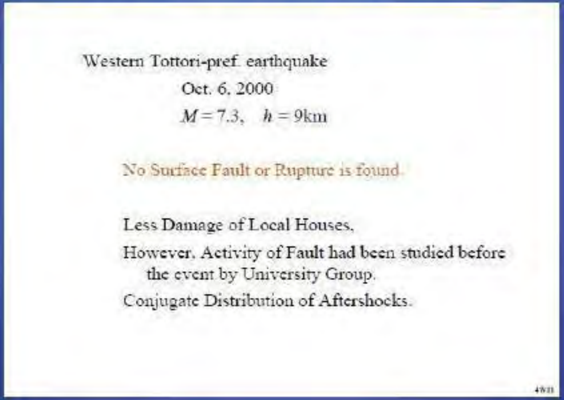
Currently,

- At the time of the 1st WS, I had a deep interest to get the Asperity information on a particular fault,
- but now it might be important to explore of hidden faults,
- and to observe the condition of old faults near by.

Two, or more bore holes to explore the structure; as the Hydrogen industry is working;


Use of Deep Borehole

One of the current subject at that time, the Behavior of *M* 7.7 earthquake near to Shimane NPP, and the engineer wanted to know the structure including the conjugate faults in the area. In such a case, several deep bore holes in the area might be useful to clarify it.


Western Tottori-pref. earthquake
Oct. 6, 2000
$M = 7.3$, $h = 9$km

No Surface Fault or Rupture is found.

Less Damage of Local Houses.

However, Activity of Fault had been studied before the event by University Group.

Conjugate Distribution of Aftershocks.

The First Paper on the use of the Deep Bore Hole was published in 1987.


1987年 地殻傾斜観測資料集
[関東・東海地域地殻活動観測網]

Data Report of Crustal Tilt Observation for 1987

Back to the Short History of Bore-hole Study on Earthquake Motion in Japan

- The Research group had been working for them rather long years mainly for defense of Metropolitan Tokyo, and they got some holes near to 3000m deep in Chofu and Iwatsuki and also Shimohusa near to Tokyo. These Bore holes were planned for detecting the potential earthquakes which might be destructive one to Metropolitan Area in early phase. That was one of defending device of the Area.
- And their interest developed into study of core itself as geology and petrology. The dean, Prof. Katayama wanted to developed their study into more practical area for the disaster prevention.
- The Purpose of the WS in 2002 was focused on the structure of active faults themselves, San Andreas Fault in California and Nozima fault, which induced Hyogoken-nanbu earthquake, *so-called Kobe Eq.* in 1995 by excavating deep bore holes across these faults.

Short History of Bore-hole Study on Earthquake Motion in Japan (2)

- Such an effort of NIED developed into the recent net works of various seismic networks like Kik-net and so on through the country and more geological study.
- And also, developed into other areas for the disaster prevention.
- Such an activity was started for the prediction of Tokai Earthquake in late 1980's.
- Another activity is related to Nuclear Waste Disposal; JAEA and ADEP.

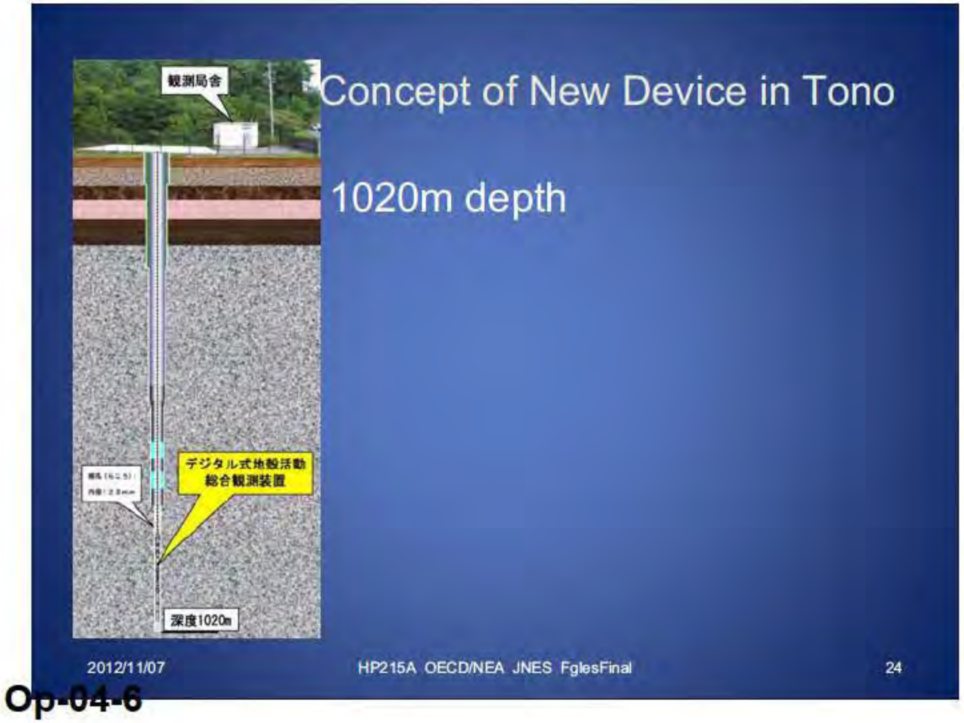
ADEP: Tono Project

- Tono Research Institute of Earthquake Science, *Tries* ; operated by ADEP.
- Deep Bore holes and Laboratory
- Digital multi-purpose Cluster Activity Measuring System in the depth of 1020m.
- Final Target of this Project is opening the Laboratory for the geological study in the depth of 1000m.
- The detail of Tono Project will be presented in this WS by Dr. Ishii.

- ADEP: Assoc. for the Development of Earthquake Prediction
- Tono;東濃, Area near to Nagoya & Gifu; Central Hinshu-island

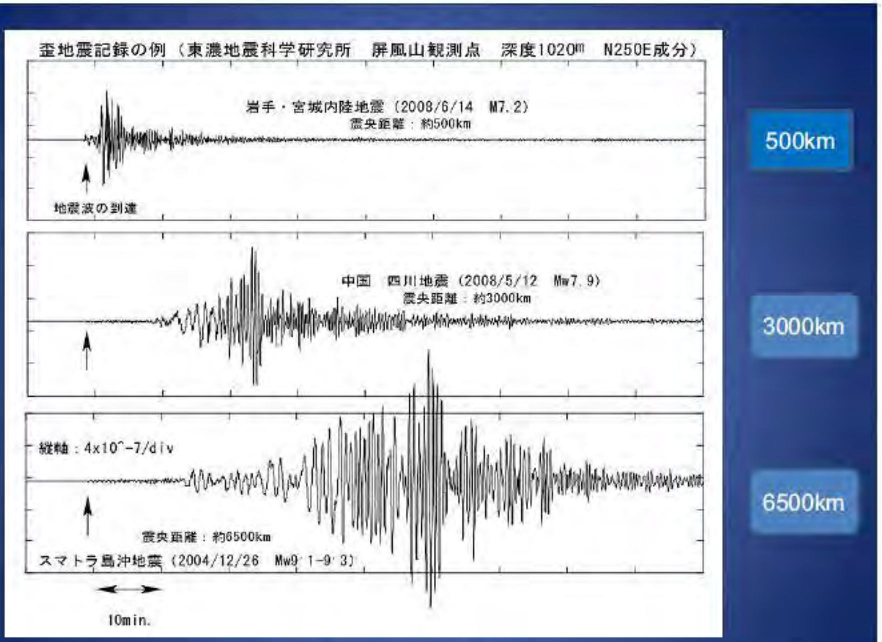
Deep Observatory and Laboratory for the New Sensing Device and other engneering problems in the Depth.

- Digital Observatory of Geological State and Crust's Condition; earthquake motions, strain & stress, dip, temperature and terrestrial magnetism, and Laboratory for other testing is planned in the depth of 511m.
- Digital multi-purpose Cluster Activity Measuring System is setting in the depth of 1020m as mentioned above.



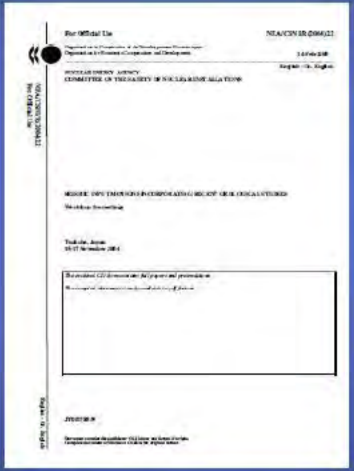
Concept of New Device in Tono

1020m depth

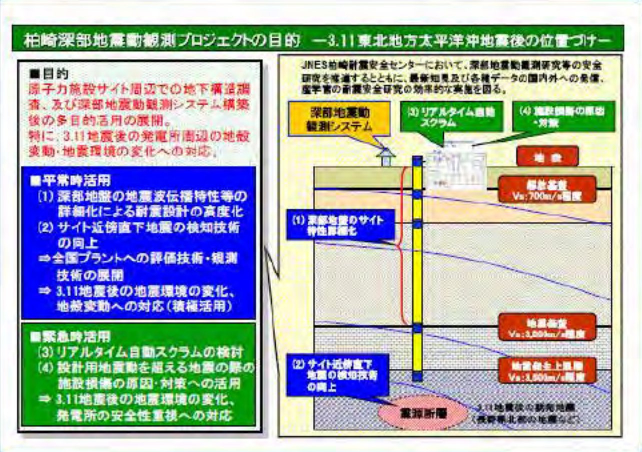


- Then, back to the 2004 meeting on November 15～17, the first OECD/NEA meeting.
- The Purpose of my Presentation was focused on those of previous meeting in 2002 with USGS. But tried to develop to more practical way in the meeting in 2004;

The 1st Meeting in 2004,



The previous WS induced the new Project of JNES Bore Hole.

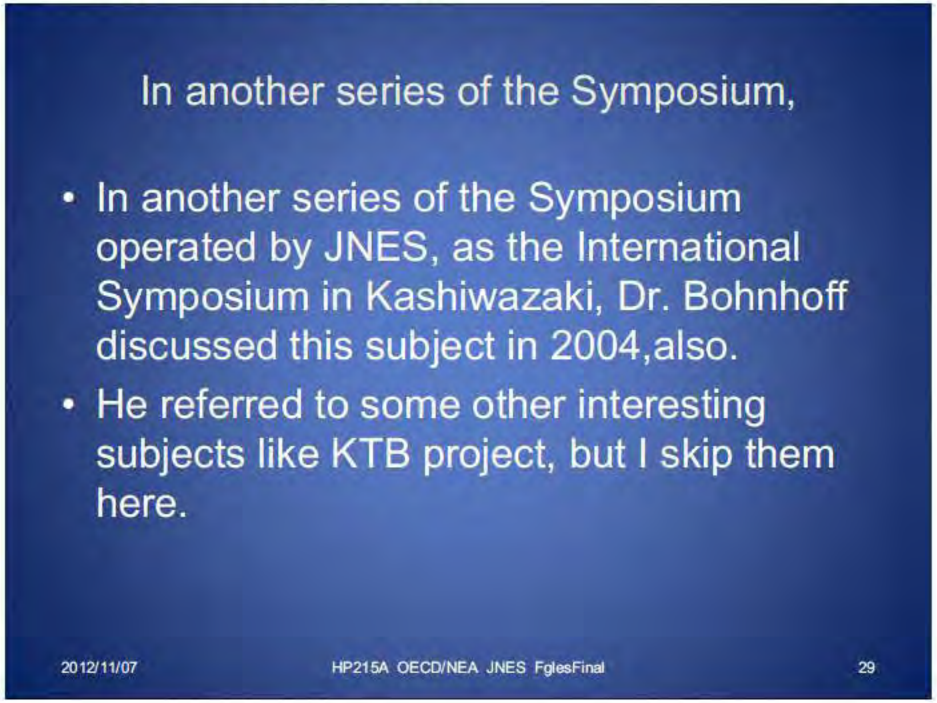

柏崎深部地震動観測プロジェクトの目的　―3.11東北地方太平洋沖地震後の位置づけ―

■目的
原子力施設サイト周辺での地下構造調査、及び深部地震動観測システム構築後の多目的活用の展開。
特に、3.11地震後の発電所周辺の地殻変動・地震環境の変化への対応。

■平常時活用
(1) 深部地盤の地震波伝播特性等の詳細化による耐震設計の高度化
(2) サイト近傍直下地震の検知技術の向上
⇒全国プラントへの評価技術・観測技術の展開
⇒ 3.11地震後の地震環境の変化、地殻変動への対応（積極活用）

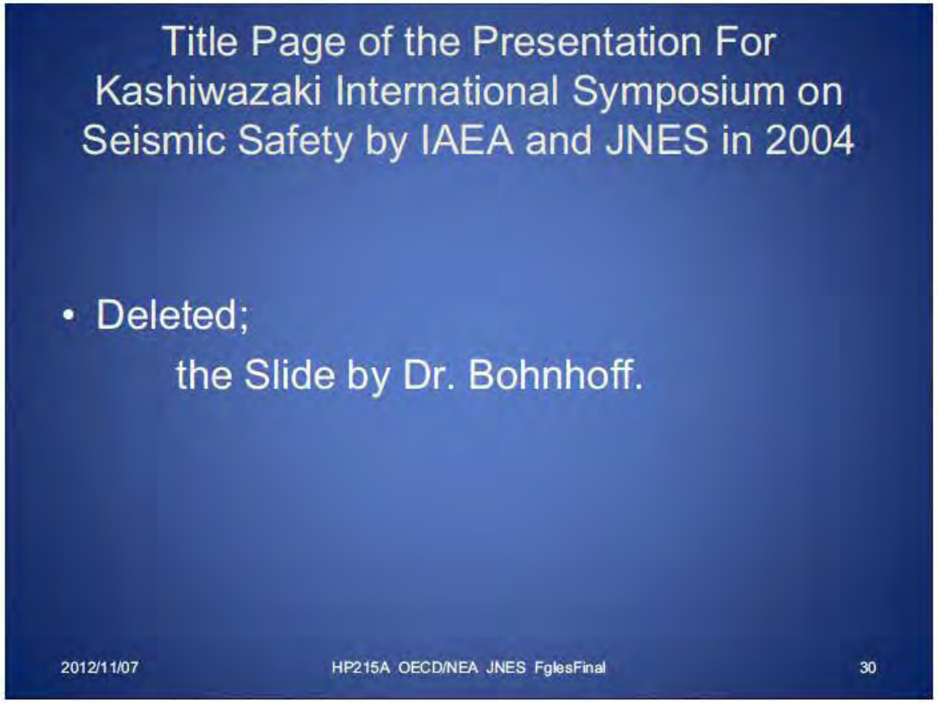
■緊急時活用
(3) リアルタイム自動スクラムの検討
(4) 設計用地震動を超える地震の際の施設損傷の原因・対策への活用
⇒ 3.11地震後の地震環境の変化、発電所の安全性重視への対応

JNES柏崎耐震安全センターにおいて、深部地震動観測研究等の安全研究を推進するとともに、最新知見及び各種データの国内外への発信、産学官の耐震安全研究の効率的な実施を図る。



In another series of the Symposium,

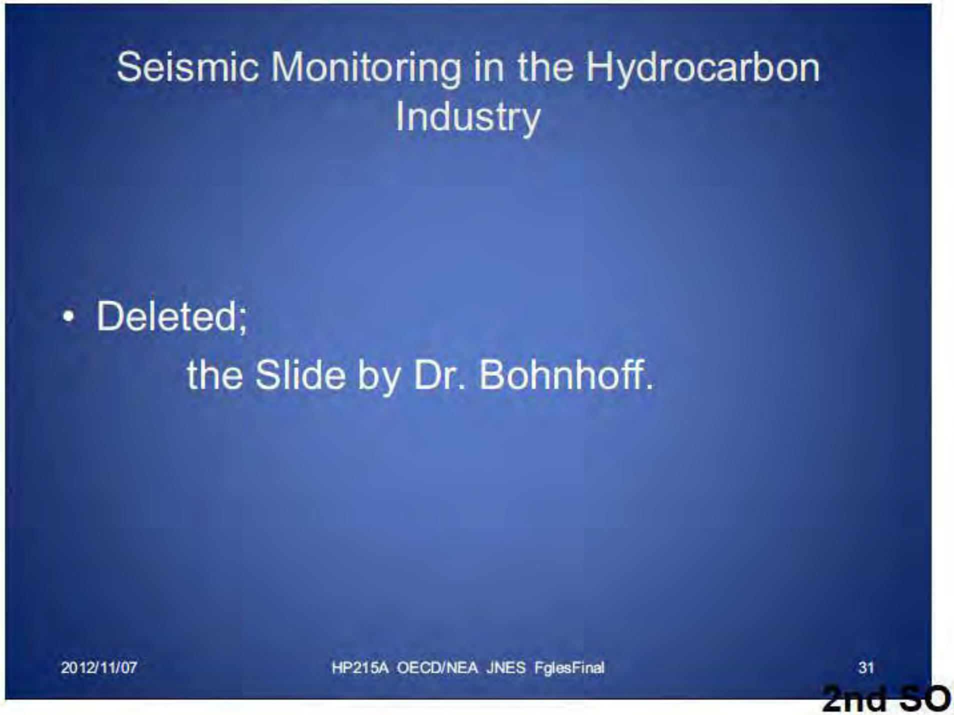
- In another series of the Symposium operated by JNES, as the International Symposium in Kashiwazaki, Dr. Bohnhoff discussed this subject in 2004,also.
- He referred to some other interesting subjects like KTB project, but I skip them here.



Title Page of the Presentation For Kashiwazaki International Symposium on Seismic Safety by IAEA and JNES in 2004

- Deleted;

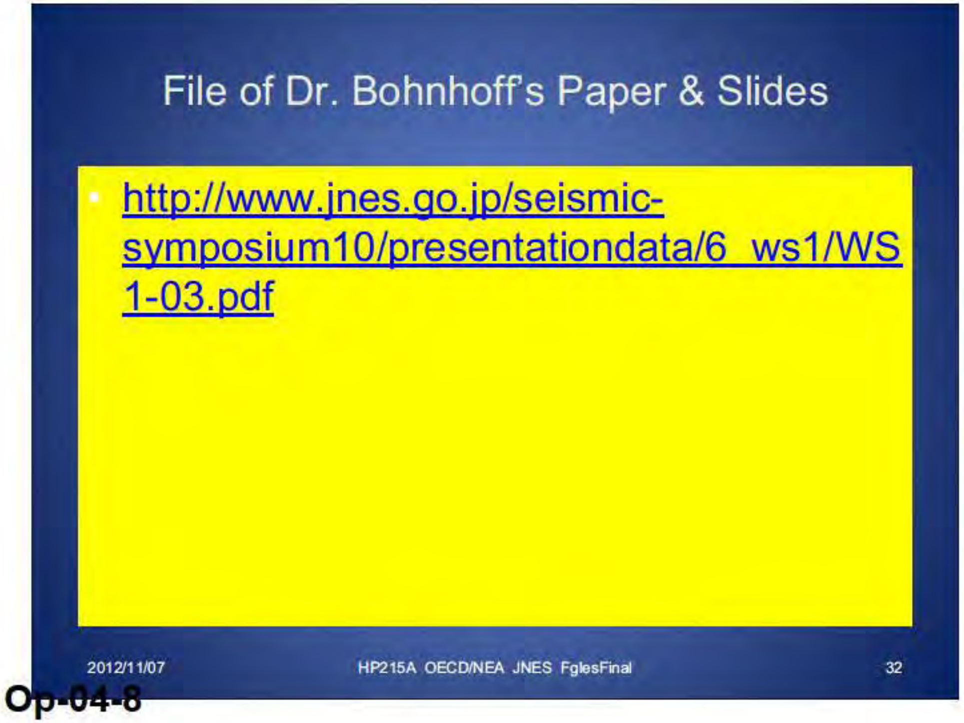
  the Slide by Dr. Bohnhoff.



Seismic Monitoring in the Hydrocarbon Industry

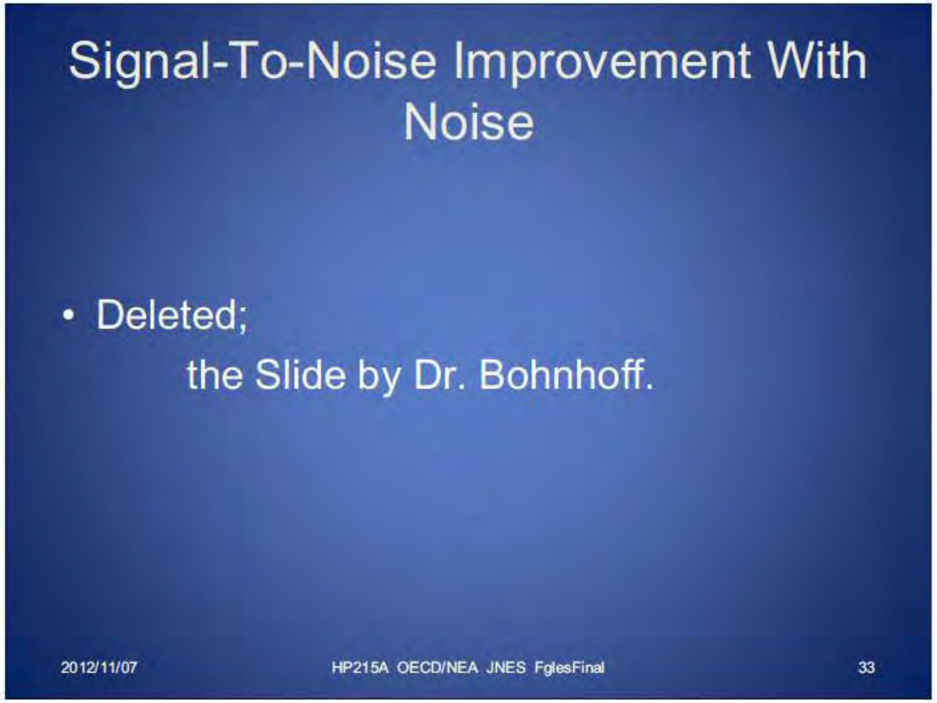
- Deleted;

  the Slide by Dr. Bohnhoff.



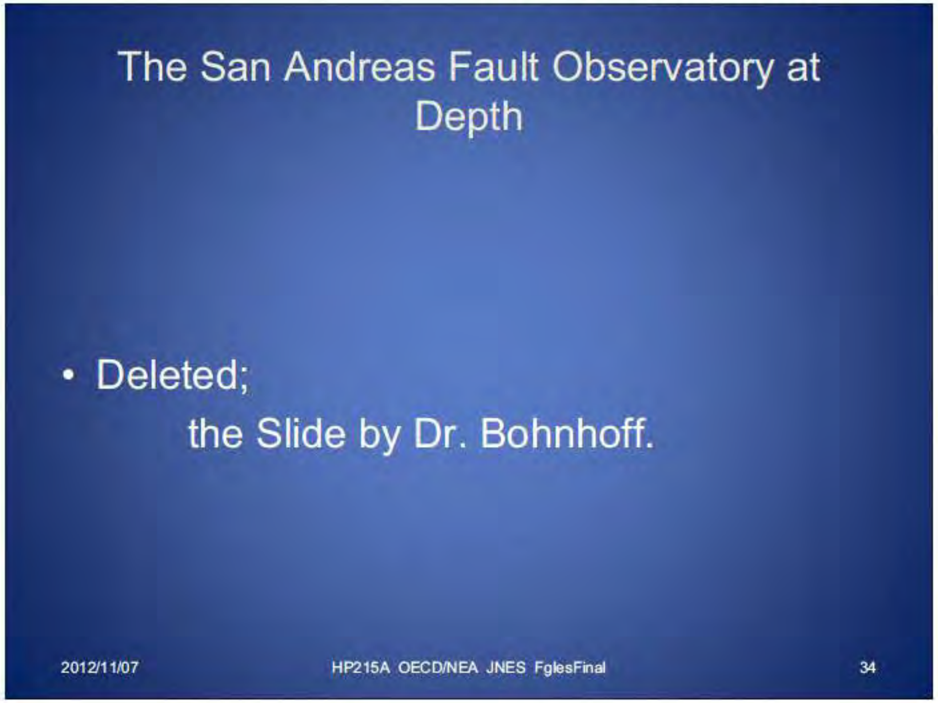
File of Dr. Bohnhoff's Paper & Slides

- http://www.jnes.go.jp/seismic-symposium10/presentationdata/6_ws1/WS1-03.pdf



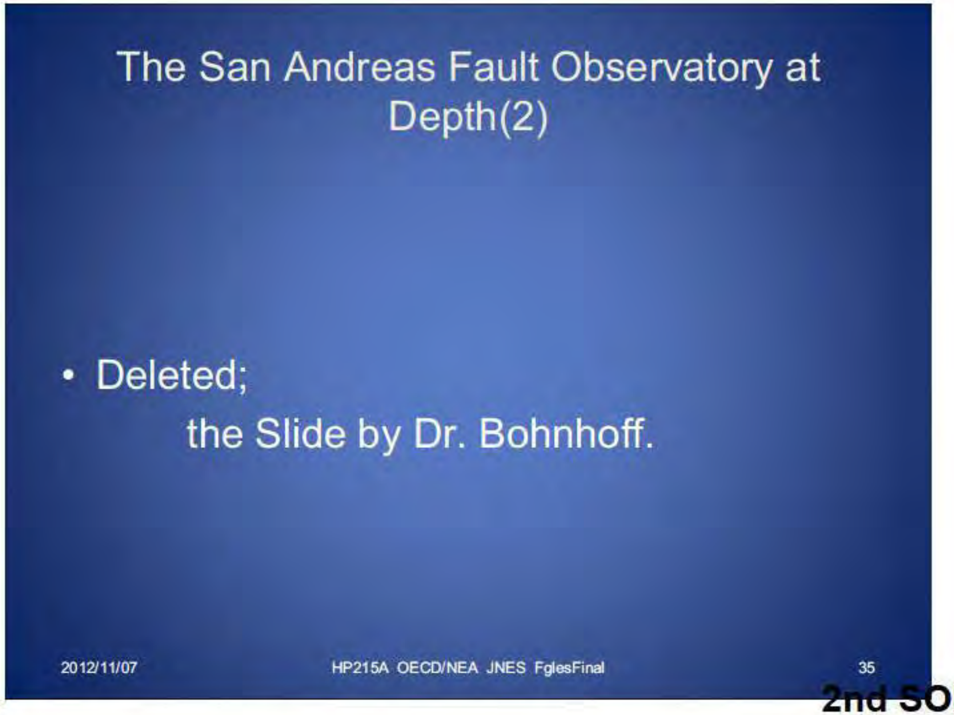
Signal-To-Noise Improvement With Noise

- Deleted;
  the Slide by Dr. Bohnhoff.



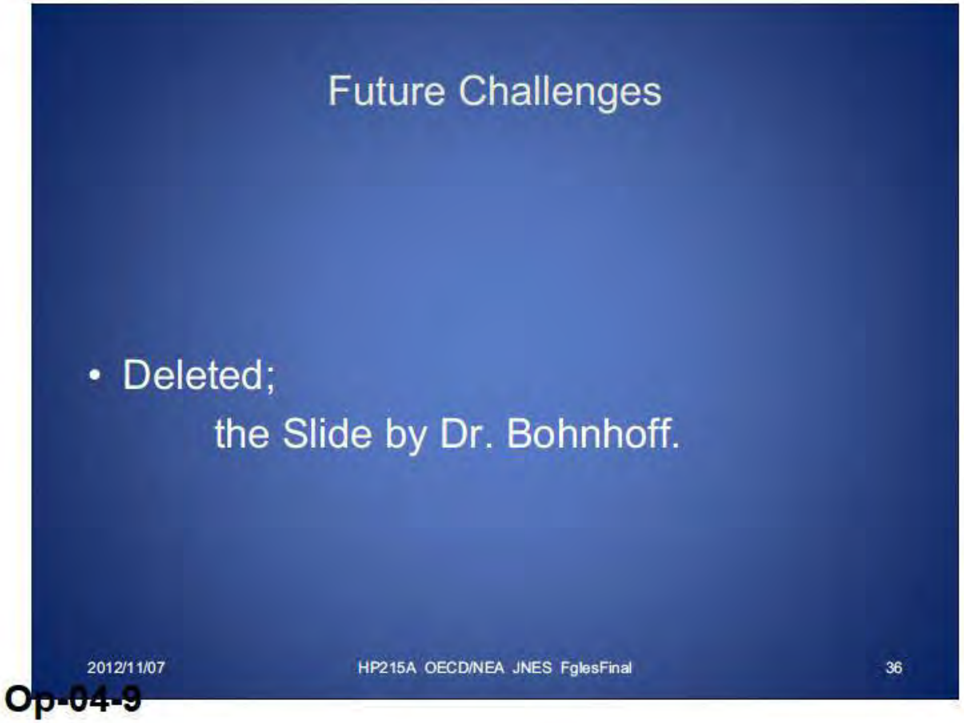
The San Andreas Fault Observatory at Depth

- Deleted;
  the Slide by Dr. Bohnhoff.



The San Andreas Fault Observatory at Depth(2)

- Deleted;
  the Slide by Dr. Bohnhoff.



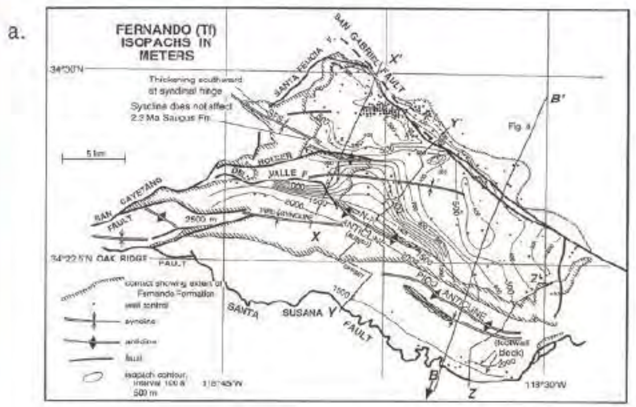
Future Challenges

- Deleted;
  the Slide by Dr. Bohnhoff.

Oil wells and Fault; in relation to Kashiwazaki Bore Hole by JNES.

- Seismic Monitoring in the Hydrocarbon Industry, *by the slide of Dr. Bohnhoff's* .
- There are many wells in the area of Northridge Earthquake; 1994 near to the Fault.
- JNES bore hole is located in the region of oil wells.
-

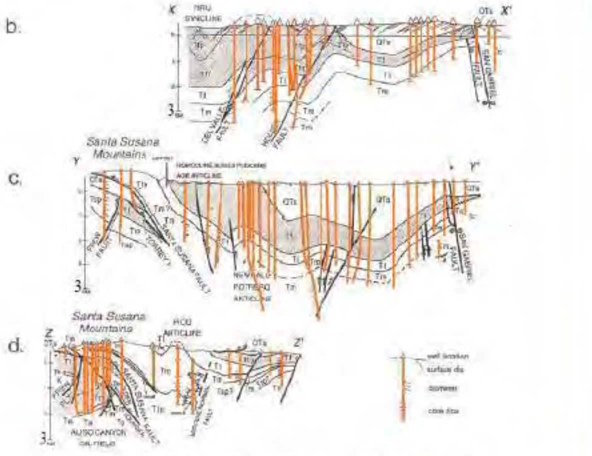
Northridge Eq., the Area and Fault



Map of Northridge Eq.-1994, Source Area and Faults [Ref. (4), BSSA]

4W17

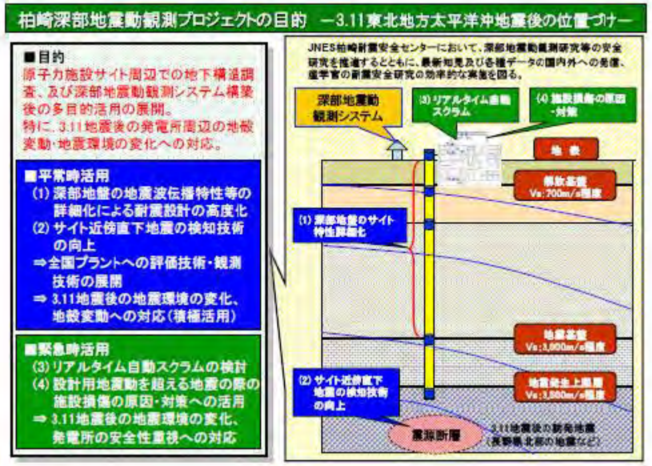
Fault and Wells



Bore Holes for Oil-wells and Structures [Ref. (4), BSSA]

4W16

Plan and Concept of Kashiwazaki Bore Hole by JNES



柏崎深部地震動観測プロジェクトの目的 －3.11東北地方太平洋沖地震後の位置づけ－

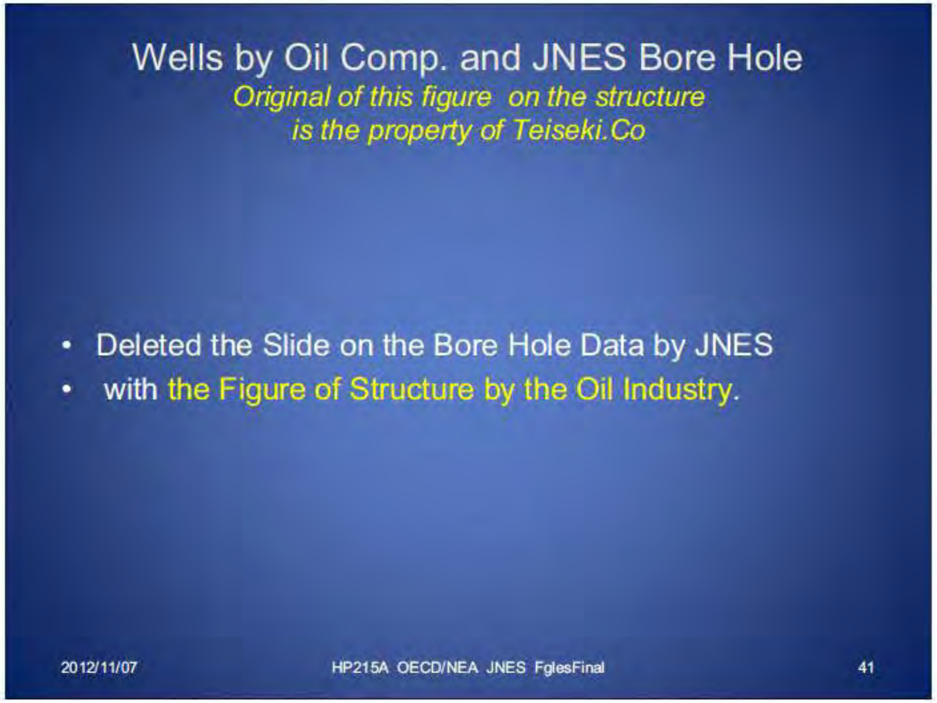
■目的

原子力施設サイト周辺での地下構造調査、及び深部地震動観測システム構築後の多目的活用の展開。
特に、3.11地震後の発電所周辺の地殻変動・地震環境の変化への対応。

■平常時活用
- (1) 深部地盤の地震波伝播特性等の詳細化による耐震設計の高度化
- (2) サイト近傍直下地震の検知技術の向上
- ⇒全国プラントへの評価技術・観測技術の展開
- ⇒ 3.11地震後の地震環境の変化、地殻変動への対応（積極活用）

■緊急時活用
- (3) リアルタイム自動スクラムの検討
- (4) 設計用地震動を超える地震の際の施設損傷の原因・対策への活用
- ⇒ 3.11地震後の地震環境の変化、発電所の安全性重視への対応

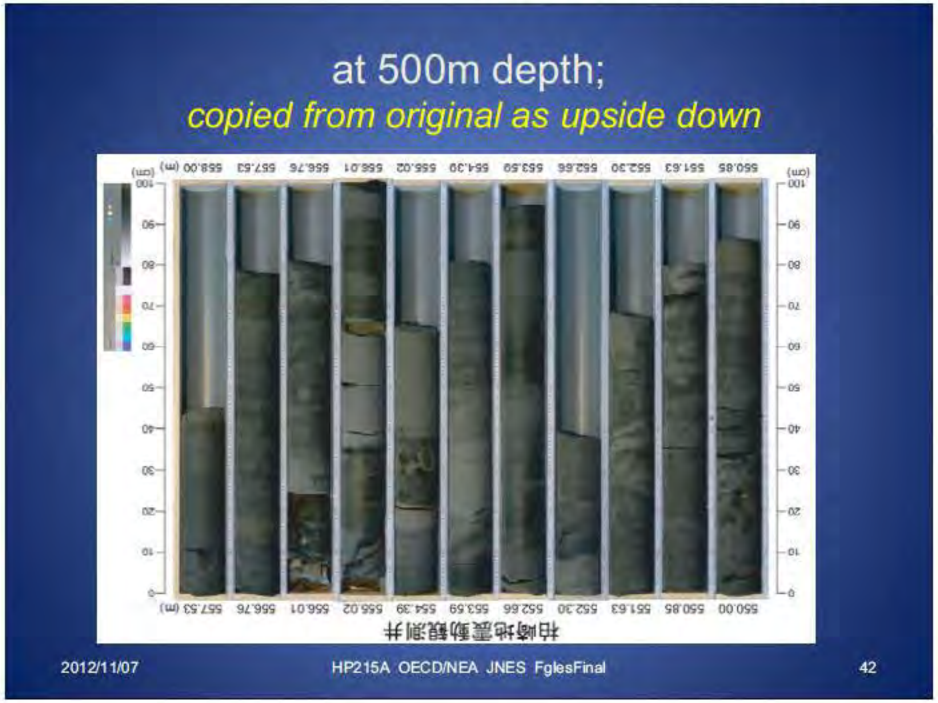
JNES柏崎耐震安全センターにおいて、深部地震動観測研究等の安全研究を推進するとともに、最新知見及び各種データの国内外への発信、産学官の耐震安全研究の効率的な実施を図る。



Wells by Oil Comp. and JNES Bore Hole

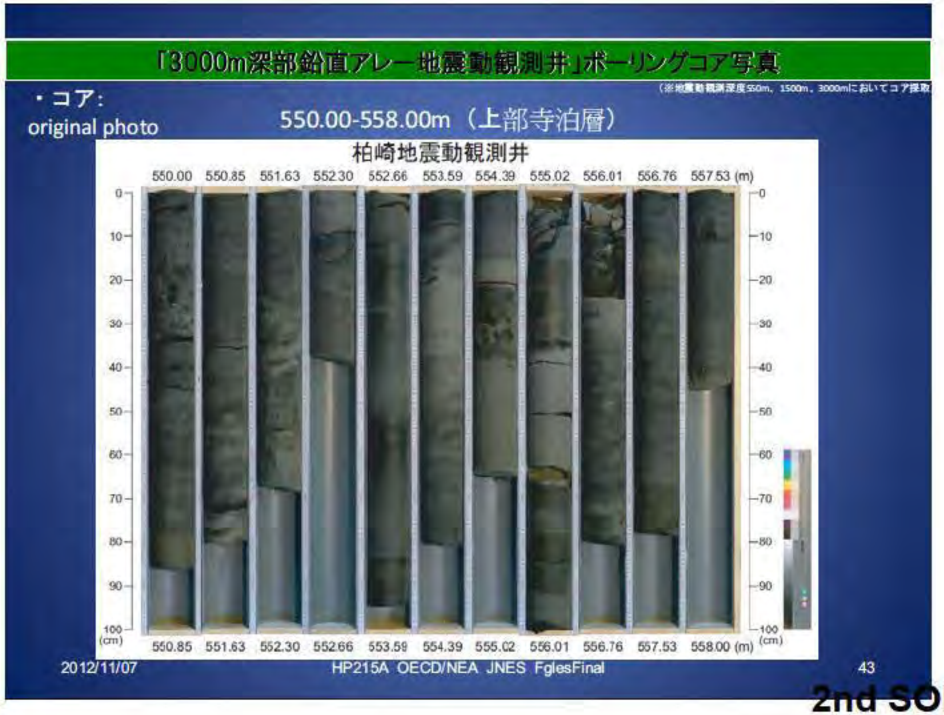
Original of this figure on the structure is the property of Teiseki.Co

- Deleted the Slide on the Bore Hole Data by JNES
- with the Figure of Structure by the Oil Industry.



at 500m depth;

copied from original as upside down



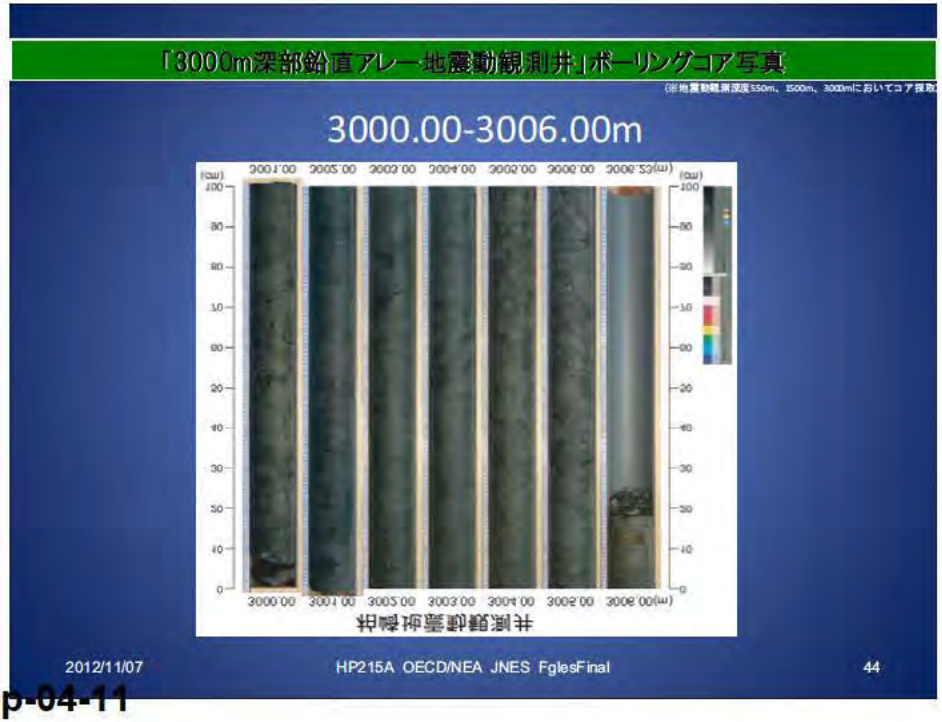
「3000m深部鉛直アレー地震動観測井」ボーリングコア写真

（※地震動観測深度550m、1500m、3000mにおいてコア採取

・コア:
original photo

550.00-558.00m（上部寺泊層）

柏崎地震動観測井



「3000m深部鉛直アレー地震動観測井」ボーリングコア写真

（※地震動観測深度550m、1500m、3000mにおいてコア採取

3000.00-3006.00m

I expect the further development JNES' project, and the suggestion from Dr. Bohnhoff in this WS.

Toward to the new subject; in relation to some recent topics in Japan as *tin the next several figures*.

In relation to coming of some new regulatory matter,

- After 3.11, various regulatory requirement has been added in the field of seismology; most serious one is about the activity of tertiary fault and small local fracture zone in or near to the site.
- Several days ago, Dairy News Paper reported such a news almost every days,
- The seismologists are checking and discussing about their activity and their effect to the structures.

On Expanding the Definition of Active Fault, 130,000y→400,000y, and so on;

第49162号

新聞

10月24日（水）

活断層定義拡大を検討

全原発 再点検の可能

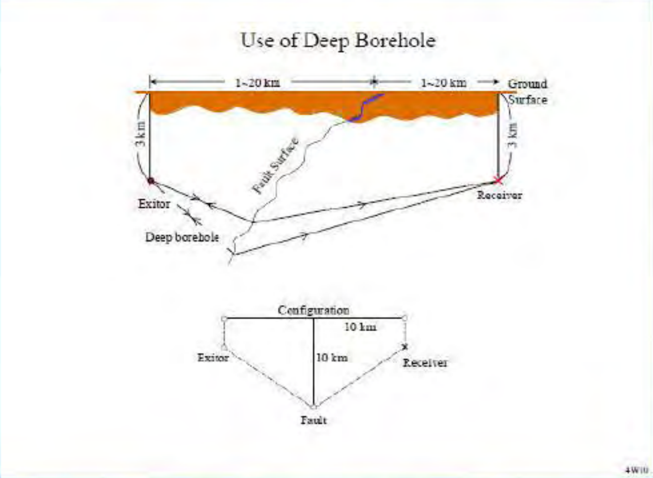
規制委

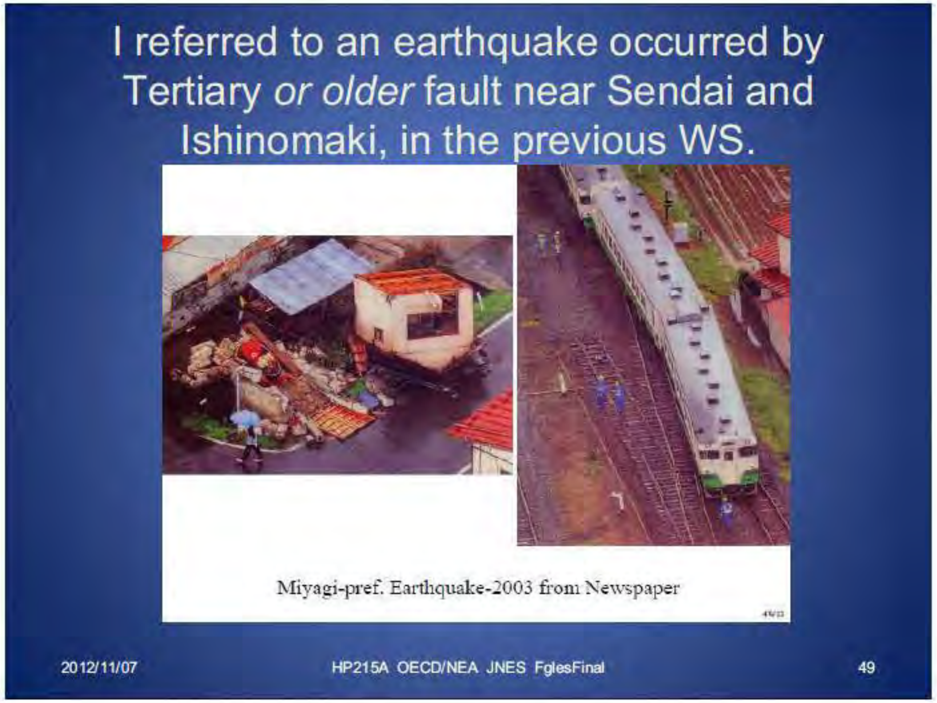
愛されて60年
日本製です

HARUTA

NEWS

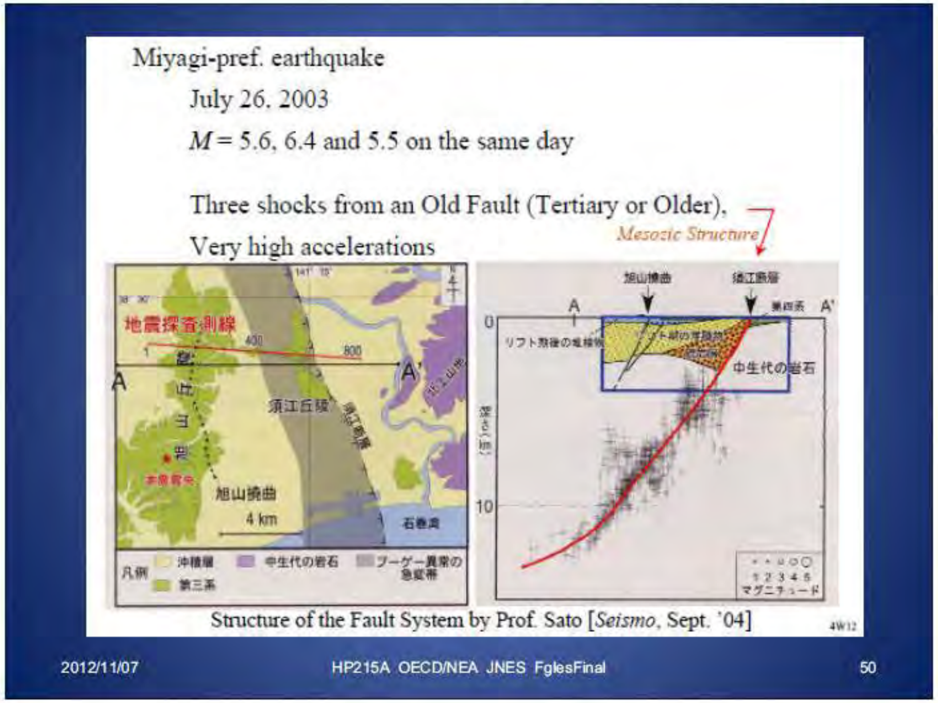
Is this technique is applicable to detect its micro-activity?





I referred to an earthquake occurred by Tertiary *or older* fault near Sendai and Ishinomaki, in the previous WS.

Miyagi-pref. Earthquake-2003 from Newspaper



Miyagi-pref. earthquake

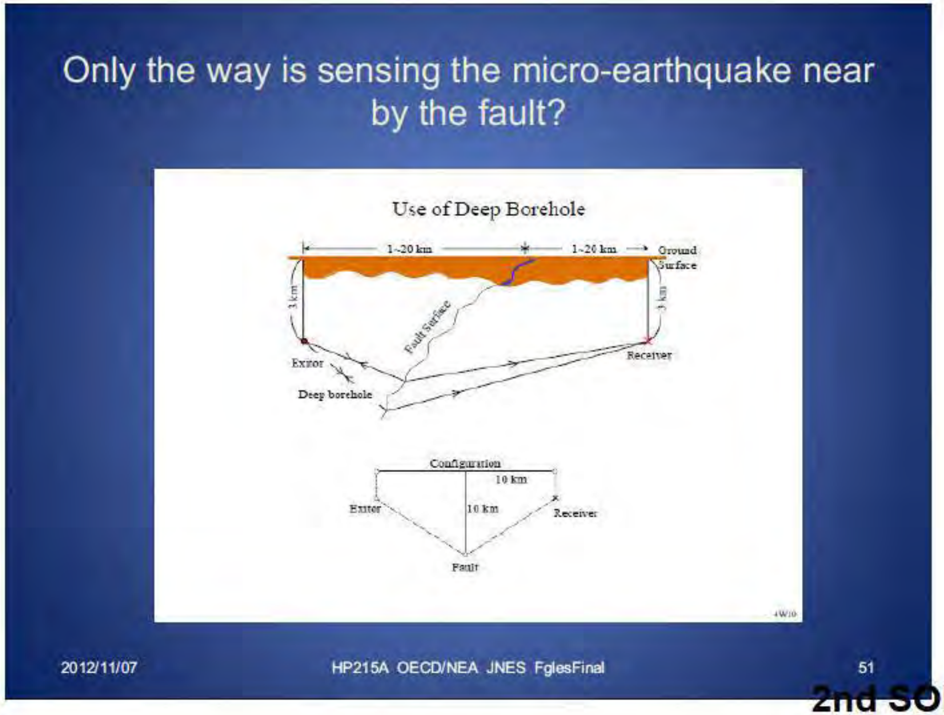
July 26, 2003

M = 5.6, 6.4 and 5.5 on the same day

Three shocks from an Old Fault (Tertiary or Older),

Very high accelerations

Structure of the Fault System by Prof. Sato [*Seismo*, Sept. '04]

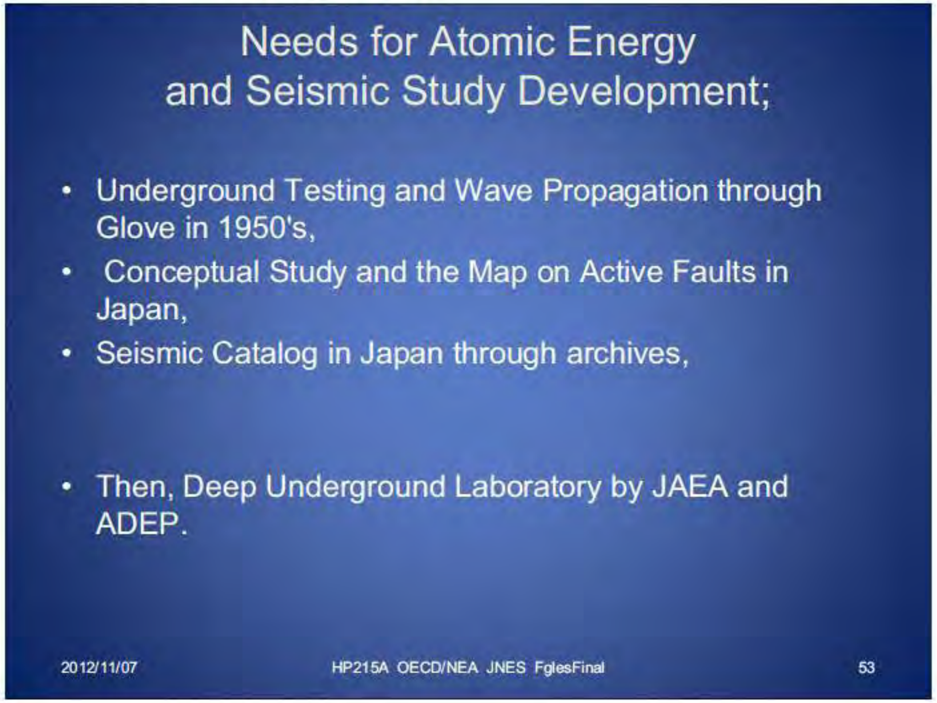


Only the way is sensing the micro-earthquake near by the fault?

Use of Deep Borehole

Discussion on the Possibility of the Re-activation of the Tertiary Fault

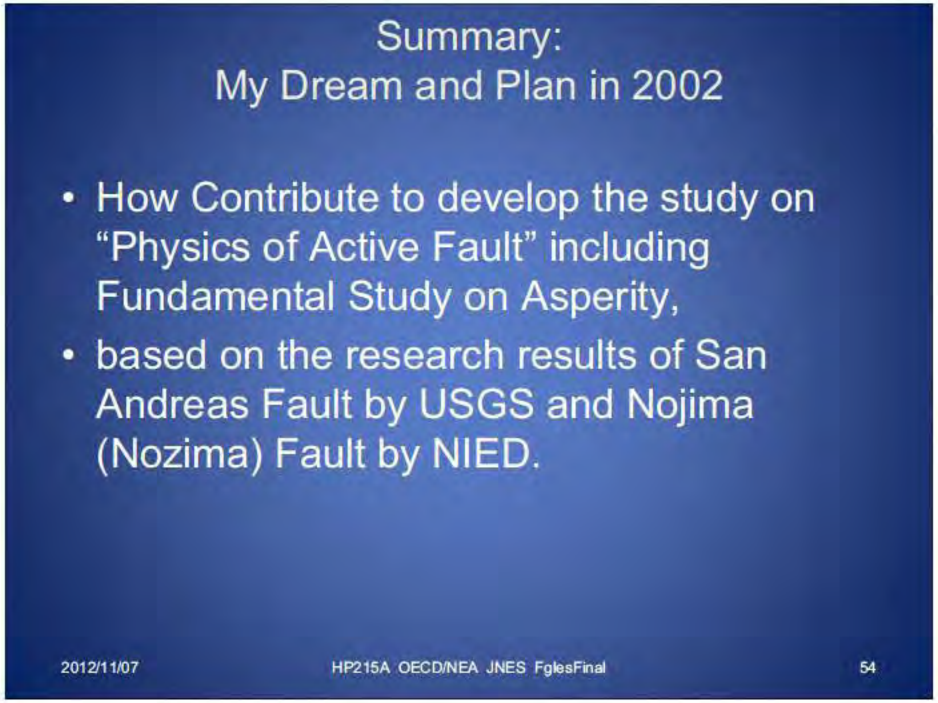
- Professor Sato referred to this event as the re-movement of a Tertiary Fault in Sendai-Ishinomaki Area under the reverse strain field in the old time.
- The measurement near to the fault in 3000m deep might be effective to know its behavior
- I feel the necessity of much help from Seismologist as well as Geologist for our engineer's seismic safety on design and judgment regarding to such a subject by various engineering approaches including new techniques as deep bore hole observatory



Needs for Atomic Energy and Seismic Study Development;

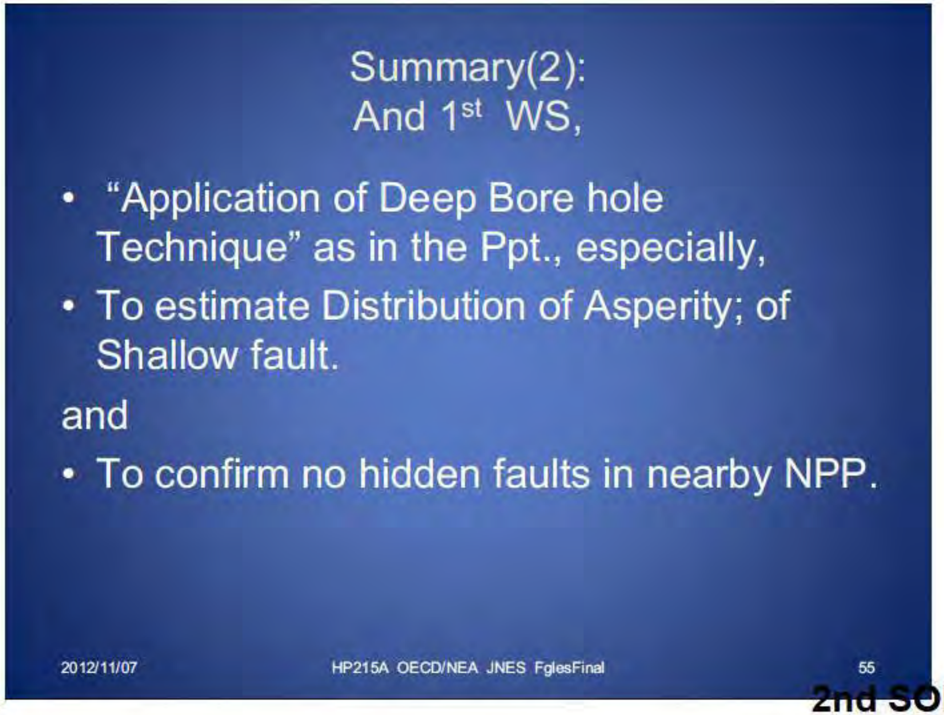
- Underground Testing and Wave Propagation through Glove in 1950's,
- Conceptual Study and the Map on Active Faults in Japan,
- Seismic Catalog in Japan through archives,

- Then, Deep Underground Laboratory by JAEA and ADEP.



Summary: My Dream and Plan in 2002

- How Contribute to develop the study on “Physics of Active Fault” including Fundamental Study on Asperity,
- based on the research results of San Andreas Fault by USGS and Nojima (Nozima) Fault by NIED.

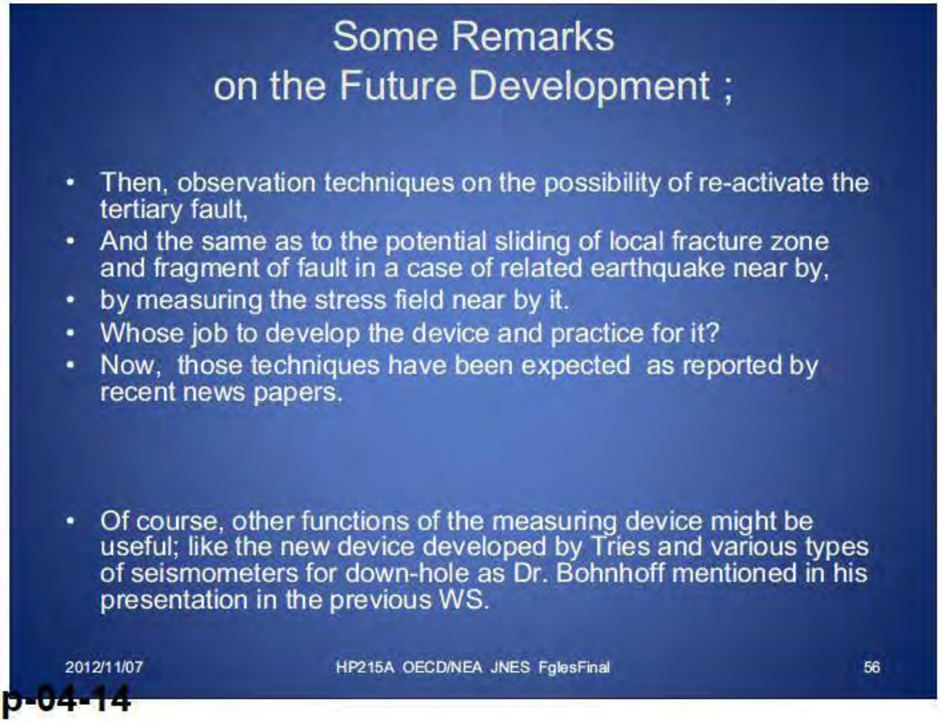


Summary(2): And 1st WS,

- “Application of Deep Bore hole Technique” as in the Ppt., especially,
- To estimate Distribution of Asperity; of Shallow fault.

and

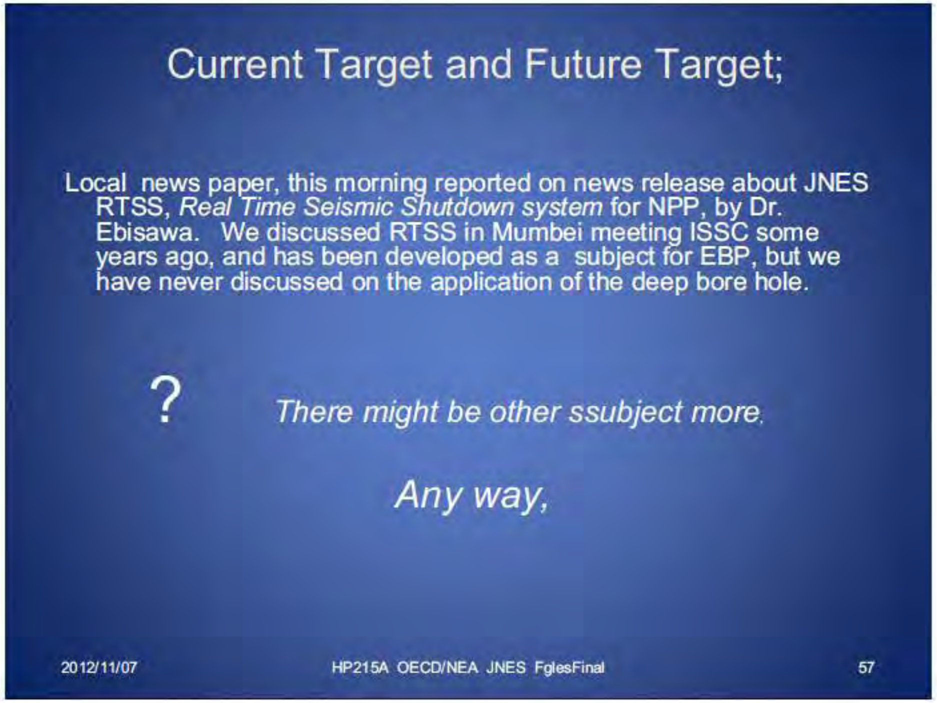
- To confirm no hidden faults in nearby NPP.



Some Remarks on the Future Development ;

- Then, observation techniques on the possibility of re-activate the tertiary fault,
- And the same as to the potential sliding of local fracture zone and fragment of fault in a case of related earthquake near by,
- by measuring the stress field near by it.
- Whose job to develop the device and practice for it?
- Now, those techniques have been expected as reported by recent news papers.

- Of course, other functions of the measuring device might be useful; like the new device developed by Tries and various types of seismometers for down-hole as Dr. Bohnhoff mentioned in his presentation in the previous WS.

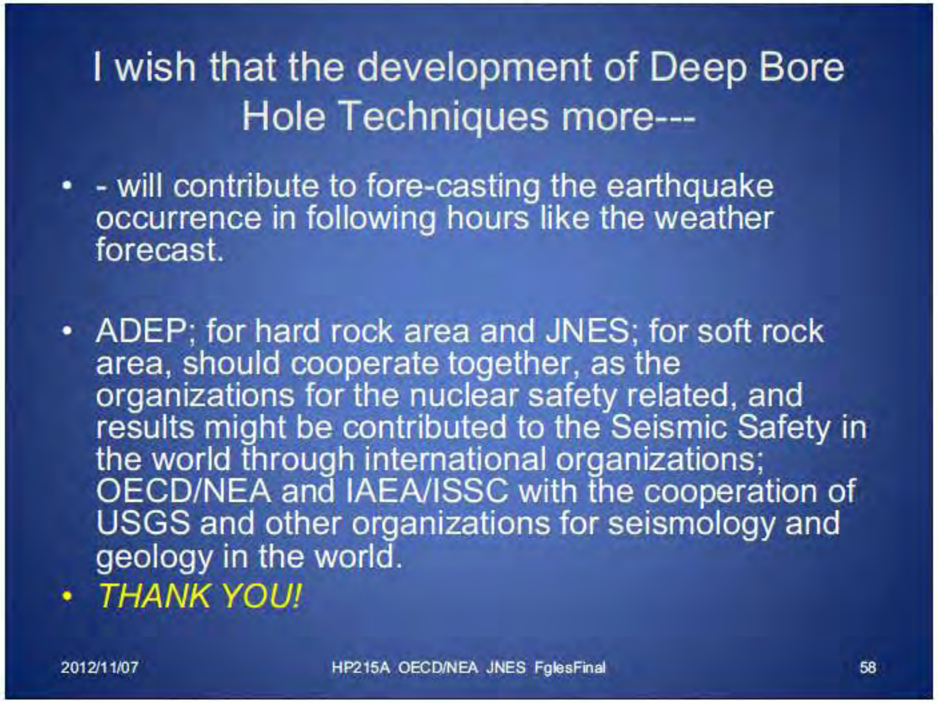


Current Target and Future Target;

Local news paper, this morning reported on news release about JNES RTSS, *Real Time Seismic Shutdown system* for NPP, by Dr. Ebisawa. We discussed RTSS in Mumbei meeting ISSC some years ago, and has been developed as a subject for EBP, but we have never discussed on the application of the deep bore hole.

? *There might be other ssubject more.*

Any way,

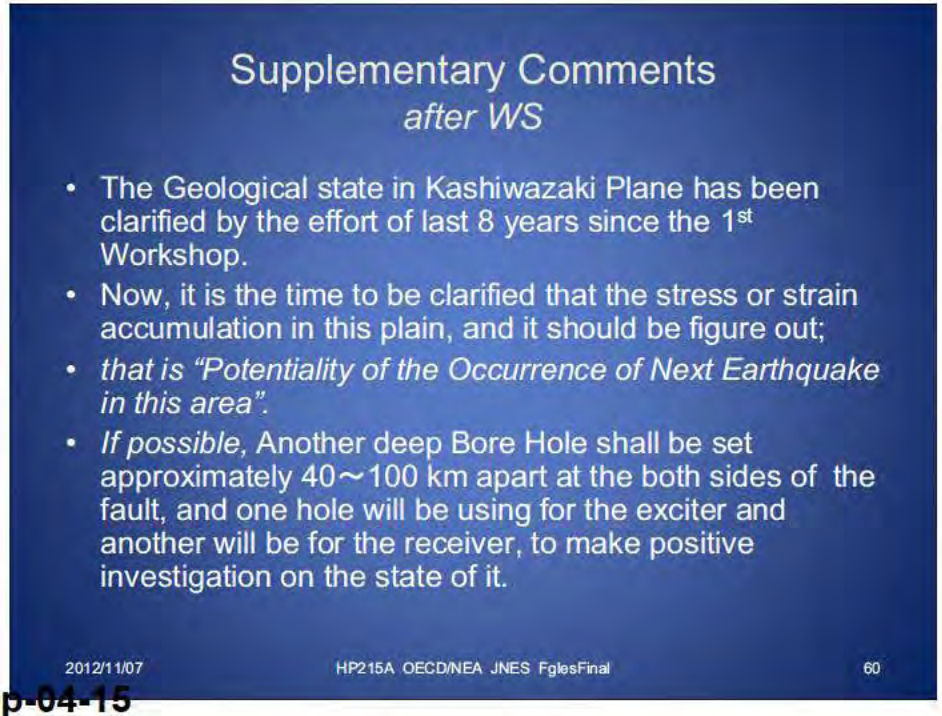


I wish that the development of Deep Bore Hole Techniques more---

- - will contribute to fore-casting the earthquake occurrence in following hours like the weather forecast.
- ADEP; for hard rock area and JNES; for soft rock area, should cooperate together, as the organizations for the nuclear safety related, and results might be contributed to the Seismic Safety in the world through international organizations; OECD/NEA and IAEA/ISSC with the cooperation of USGS and other organizations for seismology and geology in the world.
- *THANK YOU!*

About Discussion; If you would have any question, Please send your mail to me.

- *Because of degrading of my hearing ability;*
- To me, please send your Question to the following address:
- hshibata@iis.u-tokyo.ac.jp
  hshibata@syskon.jp
  or
- hshibata@sj9.so-net.ne.jp



Supplementary Comments

after WS

- The Geological state in Kashiwazaki Plane has been clarified by the effort of last 8 years since the 1st Workshop.
- Now, it is the time to be clarified that the stress or strain accumulation in this plain, and it should be figure out;
- *that is "Potentiality of the Occurrence of Next Earthquake in this area".*
- *If possible,* Another deep Bore Hole shall be set approximately 40～100 km apart at the both sides of the fault, and one hole will be using for the exciter and another will be for the receiver, to make positive investigation on the state of it.

End

Borehole Seismology: Fundamentals and Applications

Prof. Dr. Marco Bohnhoff
Helmholtz Centre Potsdam GFZ and Free University Berlin
Contact: bohnhoff@gfz potsdam.de

Presentation Outline

Introduction to Borehole Seismology

- → Why downhole?
- → Challenges and State of the Art

Case Studies of Downhole Passive Seismic Monitoring

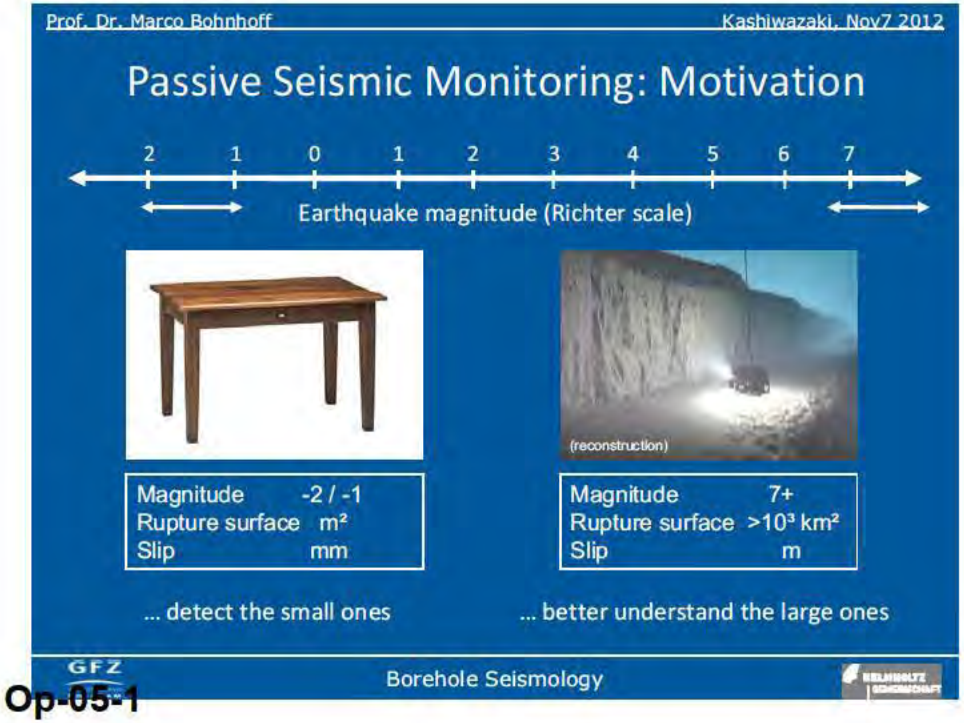
- → Induced seismicity at the Berlin geothermal field in El Salvador
- → Seismic monitoring of CO_2 storage and leakage at the Penn West EOR pilot (CA)

Concluding Remarks

…with contributions from:

(in alphabetical order, co authors of referred own paper)

Bulut, Fatih (GFZ Potsdam)
Chalaturnyk, Rick (U Alberta, CA)
Dresen, Georg (GFZ Potsdam)
Ellsworth, Bill (USGS Menlo Park)
Ito, Hisao (JAMSTEC Tokyo)
Kwiatek, Grzegorz (GFZ Potsdam)
Martinez, Patricia (GFZ Potsdam)
Zoback, Mark (Stanford U)



Passive Seismic Monitoring: Motivation

Magnitude	-2 / -1
Rupture surface	m²
Slip	mm

Magnitude	7+
Rupture surface	>10³ km²
Slip	m

… detect the small ones

… better understand the large ones

Earthquake Magnitude Ranges

Magnitude range	Class	Length Scale	Displacement Scale	Frequency Scale	Seismic Moment*
8 – 10	Great	100-1000km	4-40m	0.001-0.1 Hz	1KAk-1MAk
6 – 8	Large	10-100km	0.4-4m	0.01-1 Hz	1Ak-1KAk
4 – 6	Moderate	1-10km	4-40cm	0.1-10Hz	1mAk-1Ak
2 – 4	Small	0.1-1km	4-40mm	1-100 Hz	1μAk-1mAk
0 – 2	Micro**	10-100m	0.4-4mm	10-1000 Hz	1nAk-1μAk
-2 – 0	Nano	1-10m	40-400μm	0.1-10 kHz	1pAk-1nAk
-4 – -2	Pico	0.1-1m	4-40μm	1-100 kHz	1fAk-1pAk
-6 – -4	Femto	1-10cm	0.4-4μm	10-1000 kHz	1aAk-1fAk
-8 – -6	Atto	1-10mm	0.04-0.4μm	1-100MHz	1tAk-1aAk

(Bohnhoff et al., ILP, 2010)

Length and displacement approx. and appropriate for stress drops of 3 MPa

* 1 Aki is defined as 10^{18} Nm and named after Keiiti Aki who pioneered the use of seismic moment in theory and practice

** the term 'microearthquake' traditionally refers to M<3

Why Going Downhole?

→ Drilling is expensive (in oil/gas industry drilling costs are >10 times the costs for pre-site surveys...).

→ Drilling is risky and logistically extremely difficult. Downhole instruments need to operate at elevated pressure and temperature conditions.

BUT: Downhole seismic monitoring...

... allows to monitor at substantially reduced noise conditions thereby improving signal-to-noise ratio, magnitude detection threshold and precision of hypocenter determination.

... allows to broaden the frequency band of the recorded wavefield through recording also higher frequency contents.

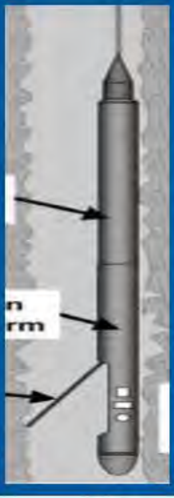
HOWEVER, challenges in borehole seismology are a secure deployment of sensors (ensuring good coupling to the formation), safe data transmission to the surface, formation pressure/temperature/fluids.

Coupling of Borehole Seismometers

A good coupling of the sensors to the casing/formation is essential to generate reasonably good data quality.

This can be achieved through:

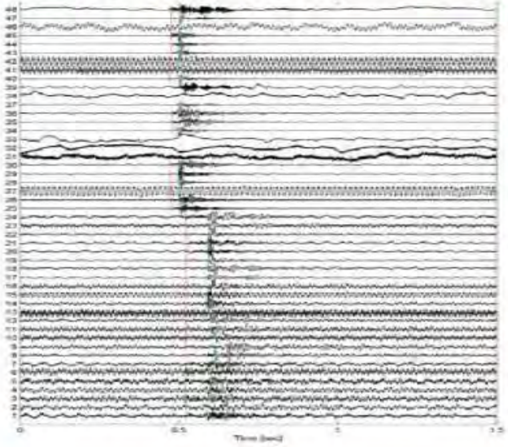
- Sand back-filling sensors at the base of the borehole (temporary or permanent)
- Cementing sensors in borehole or behind casing (permanent)
- Mechanical coupling of the sensor to the borehole wall or casing (mostly temporary)



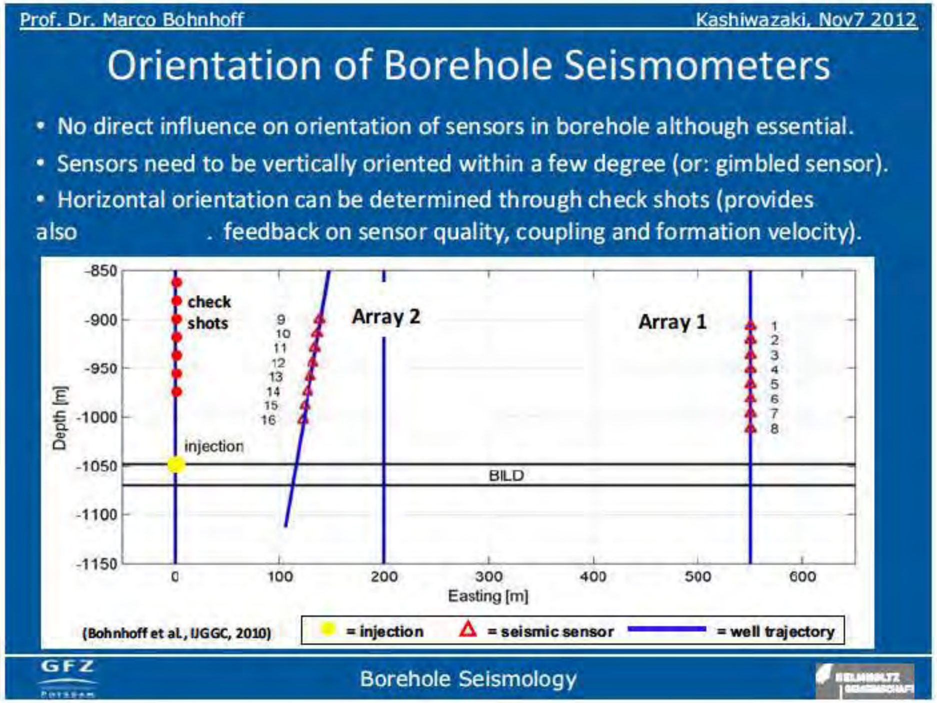
Temporary deployment in an open-hole setting

Coupling of Borehole Seismometers

Example from a 2 x 8 3C borehole geophone array



Deployment of a borehole geophone (ESG Ltd.)



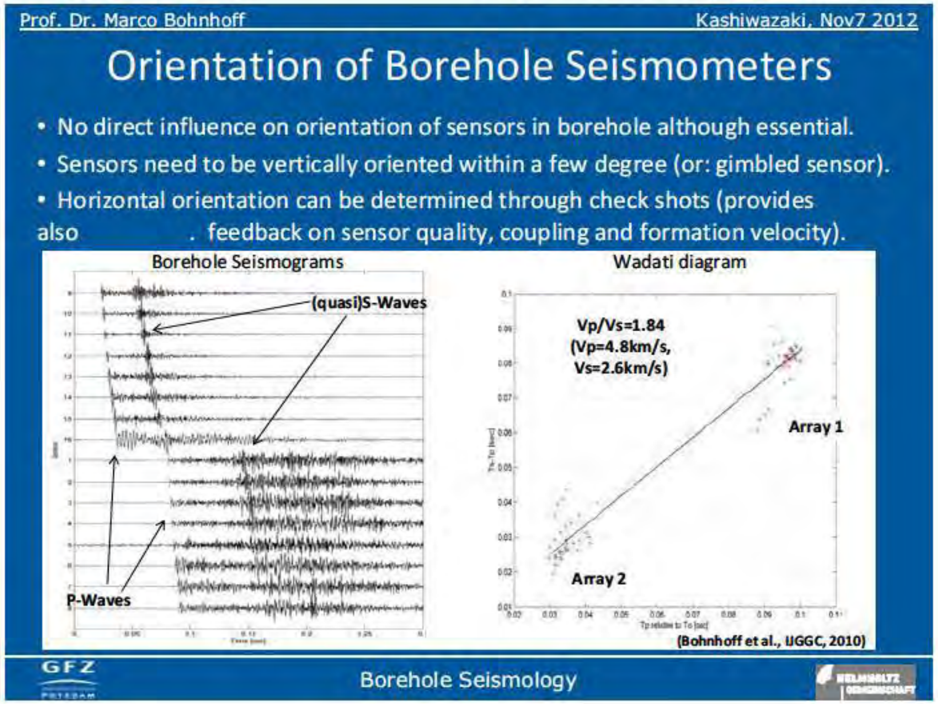
Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

Orientation of Borehole Seismometers

- No direct influence on orientation of sensors in borehole although essential.
- Sensors need to be vertically oriented within a few degree (or: gimbled sensor).
- Horizontal orientation can be determined through check shots (provides also . feedback on sensor quality, coupling and formation velocity).

(Bohnhoff et al., IJGGC, 2010)

GFZ Borehole Seismology



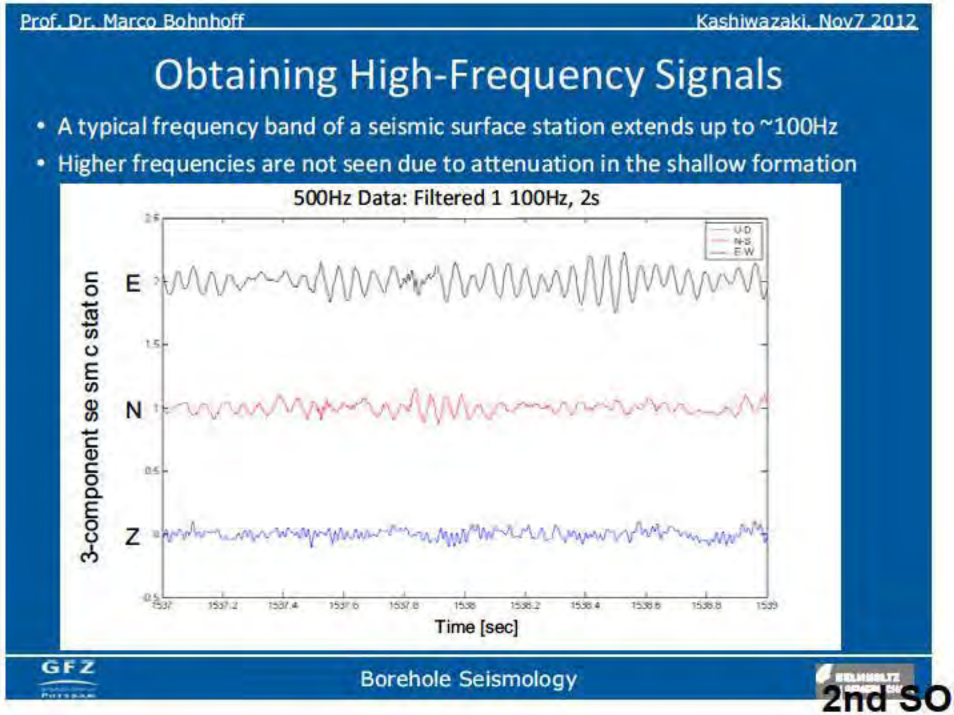
Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

Orientation of Borehole Seismometers

- No direct influence on orientation of sensors in borehole although essential.
- Sensors need to be vertically oriented within a few degree (or: gimbled sensor).
- Horizontal orientation can be determined through check shots (provides also . feedback on sensor quality, coupling and formation velocity).

(Bohnhoff et al., IJGGC, 2010)

GFZ Borehole Seismology

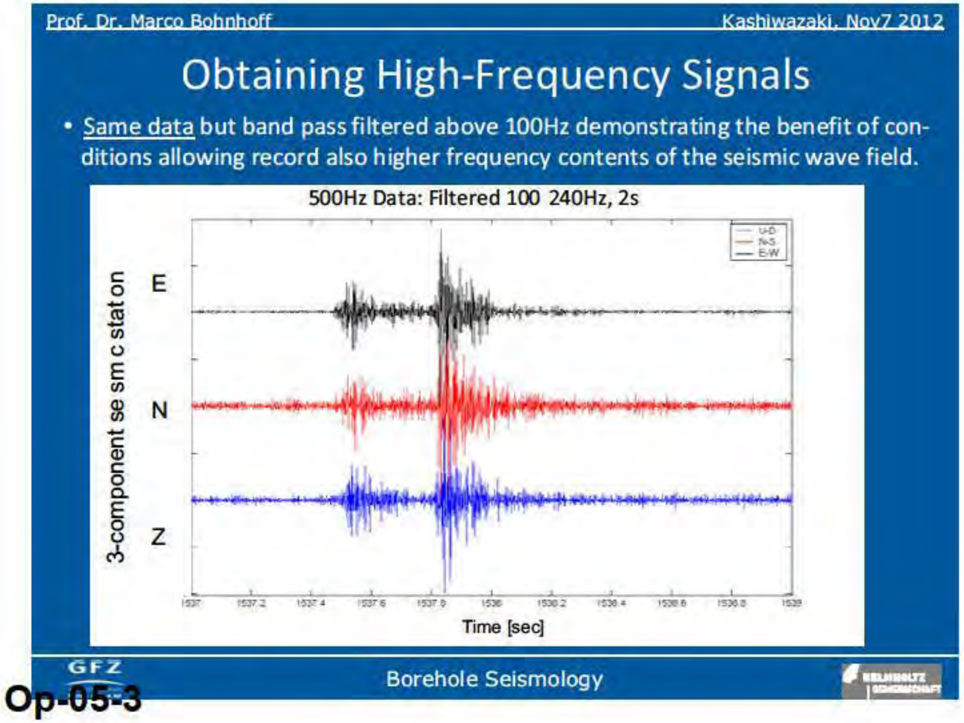


Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

Obtaining High-Frequency Signals

- A typical frequency band of a seismic surface station extends up to ~100Hz
- Higher frequencies are not seen due to attenuation in the shallow formation

GFZ Borehole Seismology

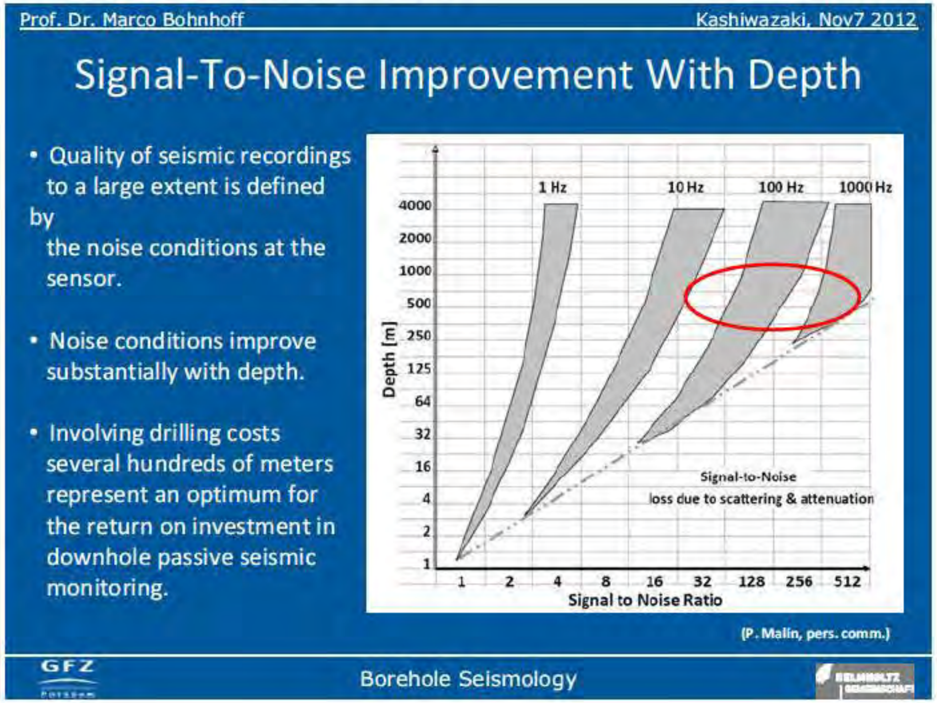


Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

Obtaining High-Frequency Signals

- Same data but band pass filtered above 100Hz demonstrating the benefit of conditions allowing record also higher frequency contents of the seismic wave field.

GFZ Borehole Seismology



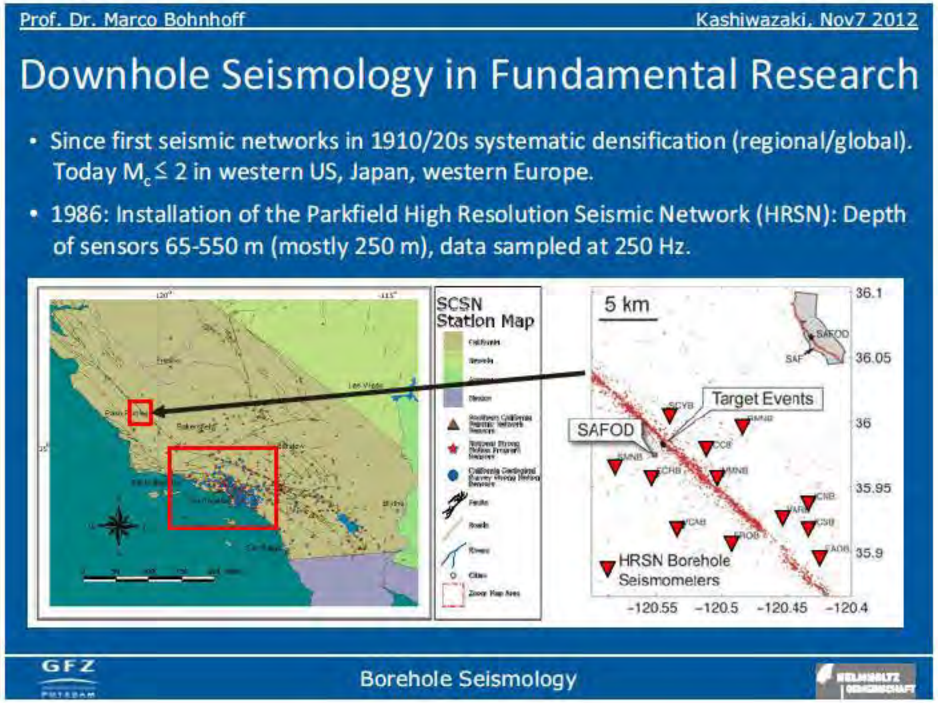
Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

Signal-To-Noise Improvement With Depth

- Quality of seismic recordings to a large extent is defined by the noise conditions at the sensor.
- Noise conditions improve substantially with depth.
- Involving drilling costs several hundreds of meters represent an optimum for the return on investment in downhole passive seismic monitoring.

(P. Malin, pers. comm.)

GFZ Borehole Seismology

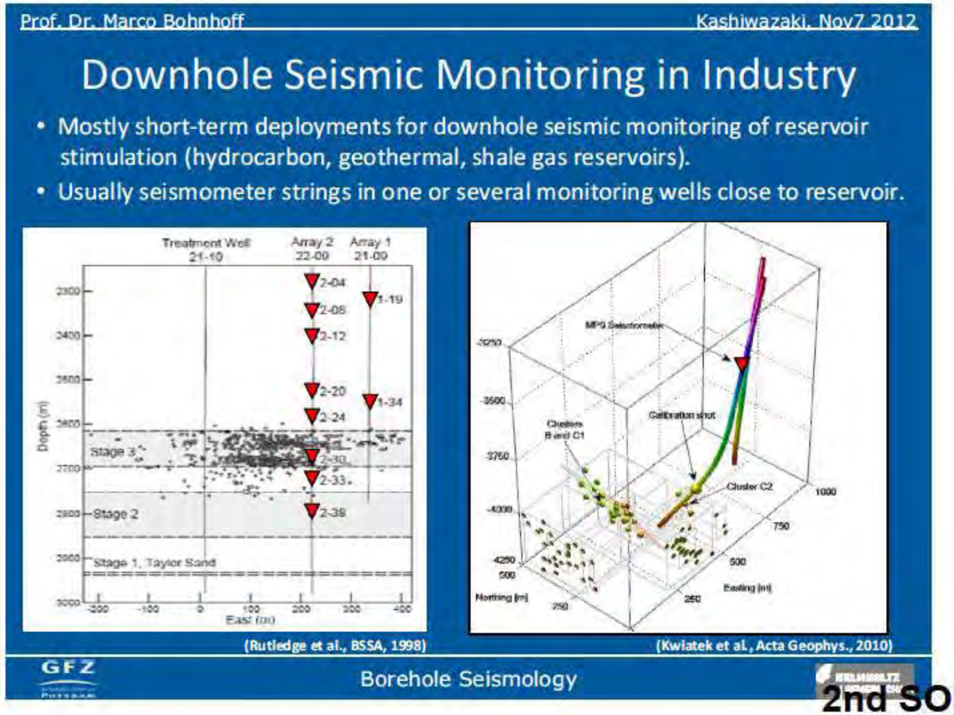


Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

Downhole Seismology in Fundamental Research

- Since first seismic networks in 1910/20s systematic densification (regional/global). Today $M_c \leq 2$ in western US, Japan, western Europe.
- 1986: Installation of the Parkfield High Resolution Seismic Network (HRSN): Depth of sensors 65-550 m (mostly 250 m), data sampled at 250 Hz.

GFZ Borehole Seismology



Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

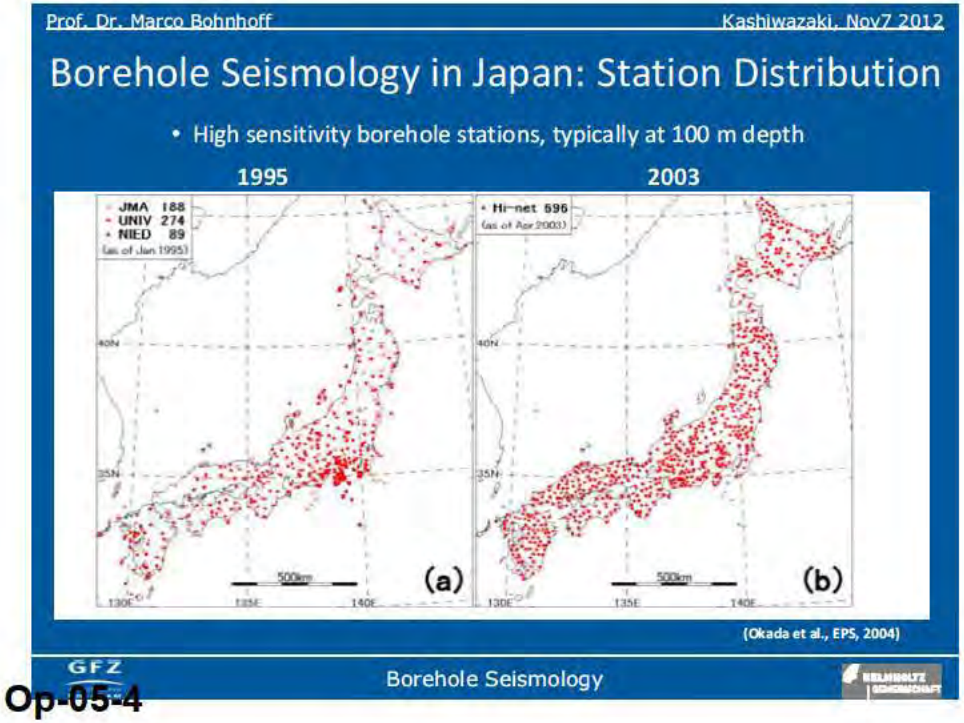
Downhole Seismic Monitoring in Industry

- Mostly short-term deployments for downhole seismic monitoring of reservoir stimulation (hydrocarbon, geothermal, shale gas reservoirs).
- Usually seismometer strings in one or several monitoring wells close to reservoir.

(Rutledge et al., BSSA, 1998)

(Kwiatek et al., Acta Geophys., 2010)

GFZ Borehole Seismology



Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

Borehole Seismology in Japan: Station Distribution

- High sensitivity borehole stations, typically at 100 m depth

(Okada et al., EPS, 2004)

GFZ Borehole Seismology

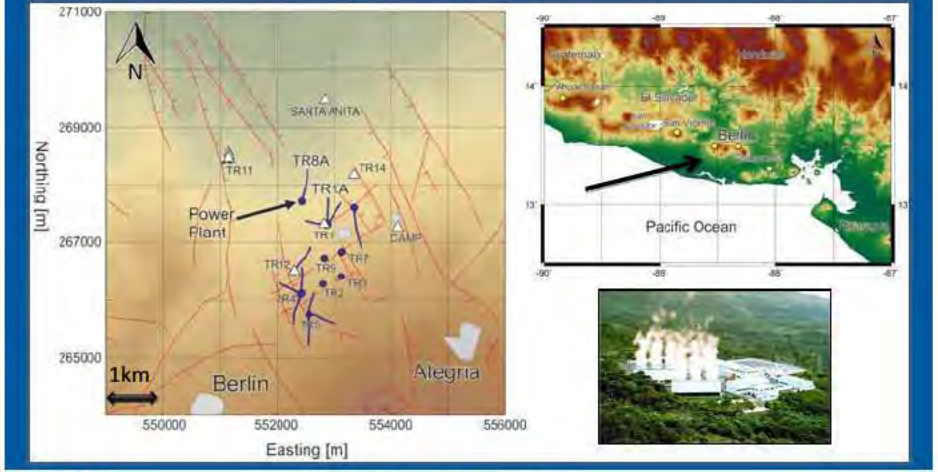
Case study 1:

Monitoring Induced Seismicity in the Berlin Geothermal Field, El Salvador

---

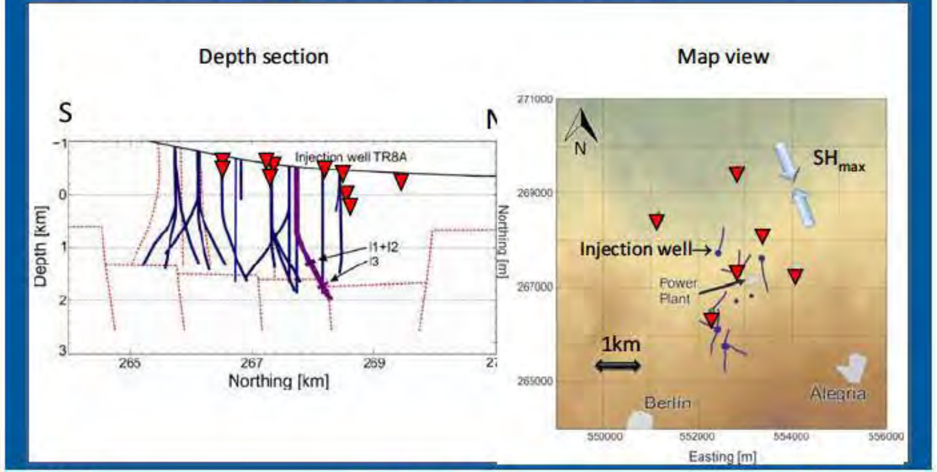
Berlin Geothermal Field: Location

- Located on the flancs of dormant volcano Cerro Tecapa.
- 8 production wells and 10 injection wells (closed fluid circulation).

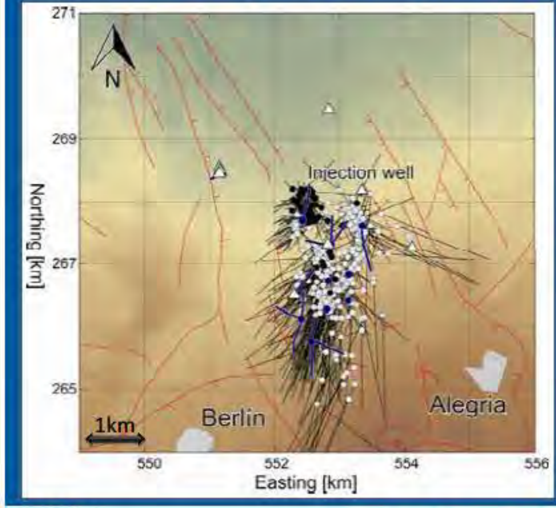


Borehole Seismometer Network

- 12 borehole sensors (nat. frequencies 1/4,5/5,5/30 Hz) sampled 24-3000 Hz.
- 3 stimulation campaigns of 3 weeks each at 2 different depth intervals.



Relevance of Applying state-of-the-art Processing Techniques: Relative Relocation



- Application of hypoDD technique (Waldhauser/Ellsworth, 2001) to traveltime picks.
- Systematic shift of hypocenter locations towards the geothermal field (wrt initial absolute locations).
- Strong clustering of events around injection wells.
- Clear relation between seismic events and stimulation.

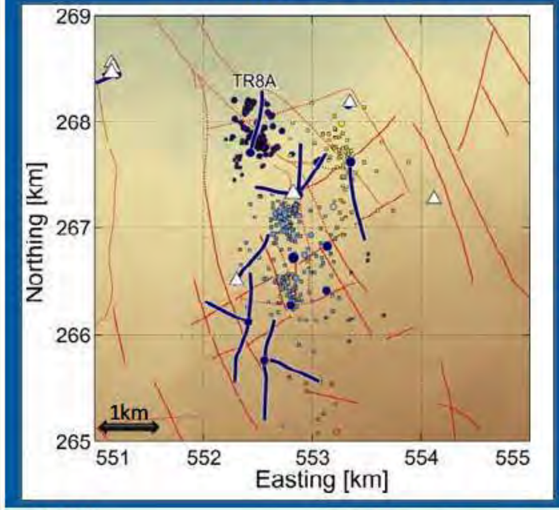
○ Whole dataset

● During injection into TR8A

(Kwiatek et al., subm.)

Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

Relevance of Applying state-of-the-art Processing Techniques: Cluster Analysis



- Application of waveform cross-correlation technique to determine signal similarity at individual borehole sensors.
- Identification of 9 event families displaying similar rupture processes.
- Focus on seismicity at well TR8A in the following (deep blue family).

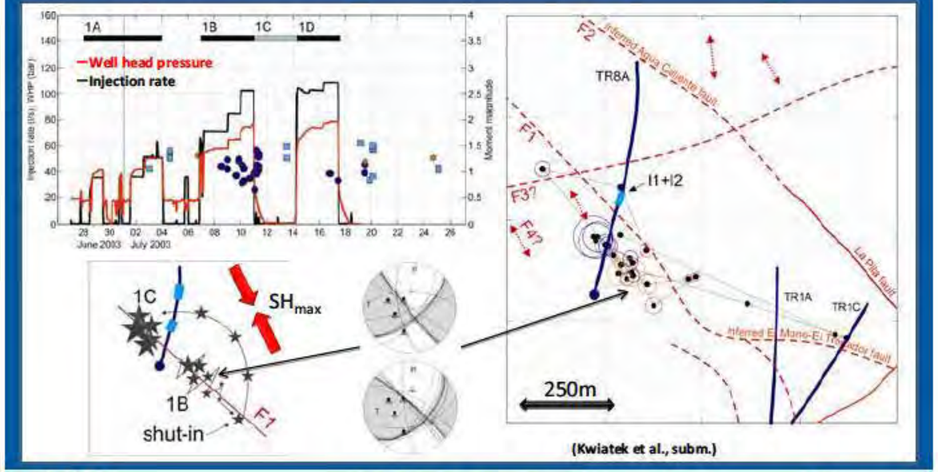
(Kwiatek et al., subm.)

GFZ Borehole Seismology

Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

Spatiotemporal occurrence of seismicity

- Temporal migration of seismicity away from the reservoir towards a fault plane.
- Abrupt increase of event magnitudes and change of migration during shut-in.



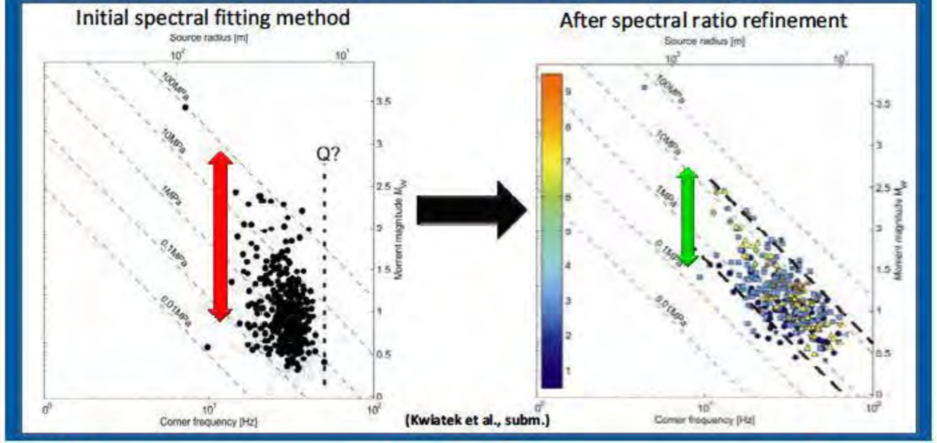
(Kwiatek et al., subm.)

GFZ Borehole Seismology

Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

Relevance of Applying state-of-the-art Processing Techniques: Source Parameters

- Determination of source parameters using a refined spectral ratio technique
- Strong improvements on the quality of source parameters (M_0, r_0, $\Delta\sigma$)



(Kwiatek et al., subm.)

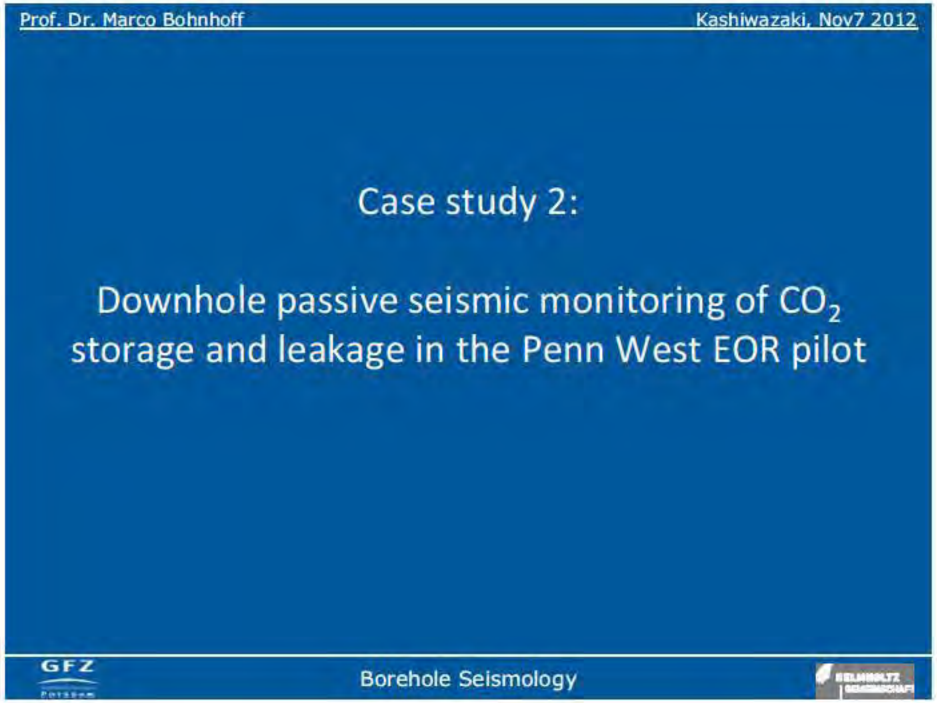
GFZ Borehole Seismology

Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

Berlin Geothermal Field: Lessons Learnt…

- While good quality data is a pre-requisite for any study, state of the art evaluation methods are essential to obtain optimum and reliable results.
- Relative relocation of hypocenters allows to identify a systematic migration of events towards and along mapped fault planes, probably initiated by the elevated downhole pressure during injection.
- Larger magnitude events and seismicity clusters are observed during shut-in phases.
- Seismicity occurs in previously active areas only once the earlier maximum downhole pressure is exceeded (Kaiser effect).

GFZ Borehole Seismology

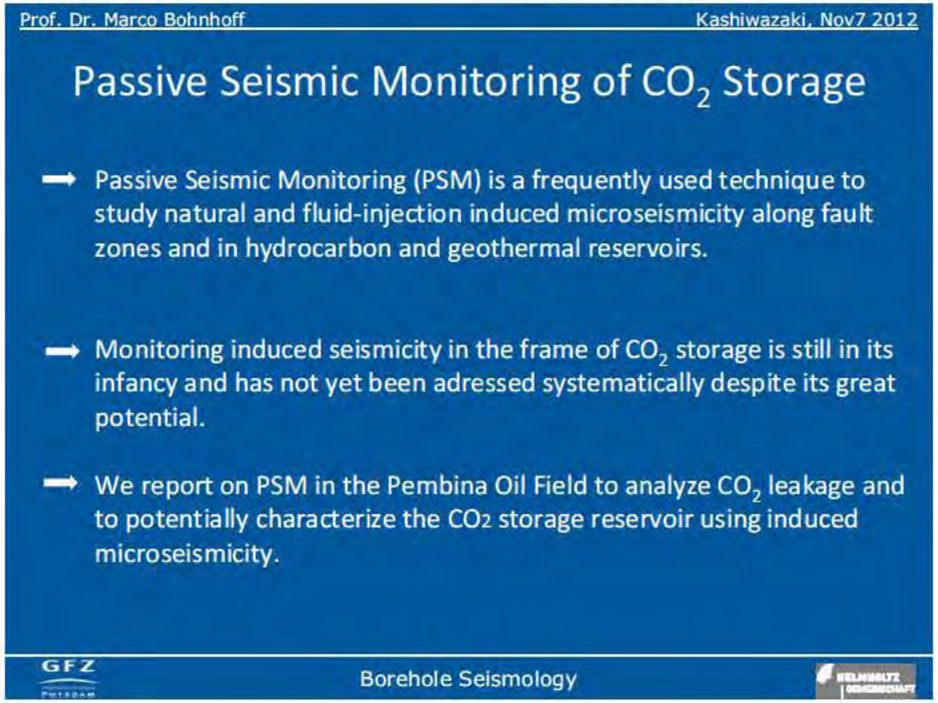


Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

Case study 2:

Downhole passive seismic monitoring of CO_2 storage and leakage in the Penn West EOR pilot

GFZ Borehole Seismology



Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

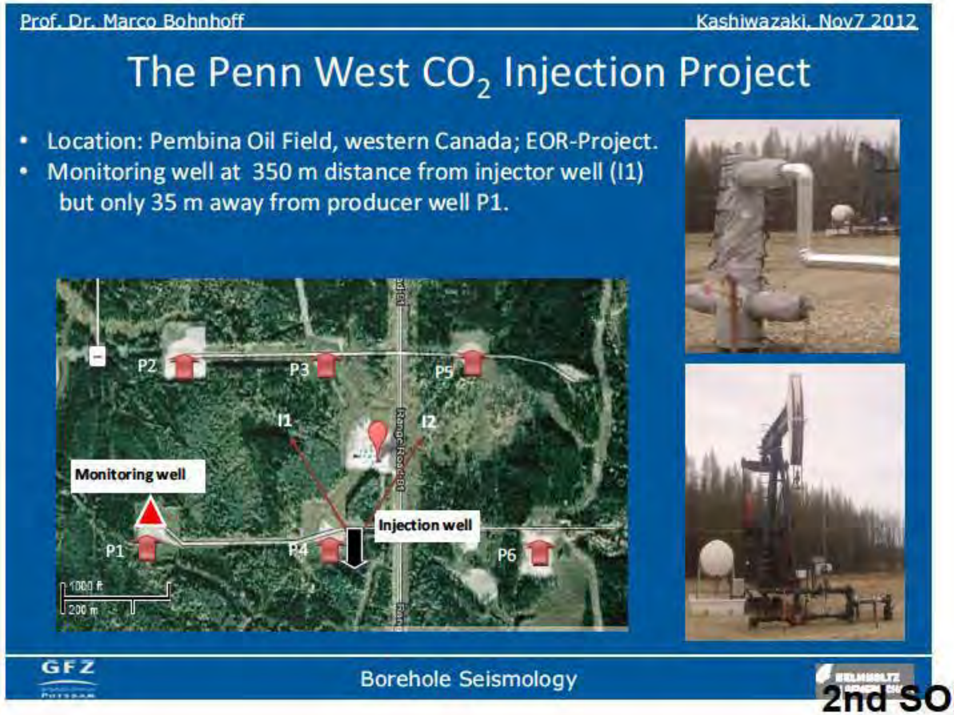
Passive Seismic Monitoring of CO_2 Storage

➡ Passive Seismic Monitoring (PSM) is a frequently used technique to study natural and fluid-injection induced microseismicity along fault zones and in hydrocarbon and geothermal reservoirs.

➡ Monitoring induced seismicity in the frame of CO_2 storage is still in its infancy and has not yet been adressed systematically despite its great potential.

➡ We report on PSM in the Pembina Oil Field to analyze CO_2 leakage and to potentially characterize the CO_2 storage reservoir using induced microseismicity.

GFZ Borehole Seismology

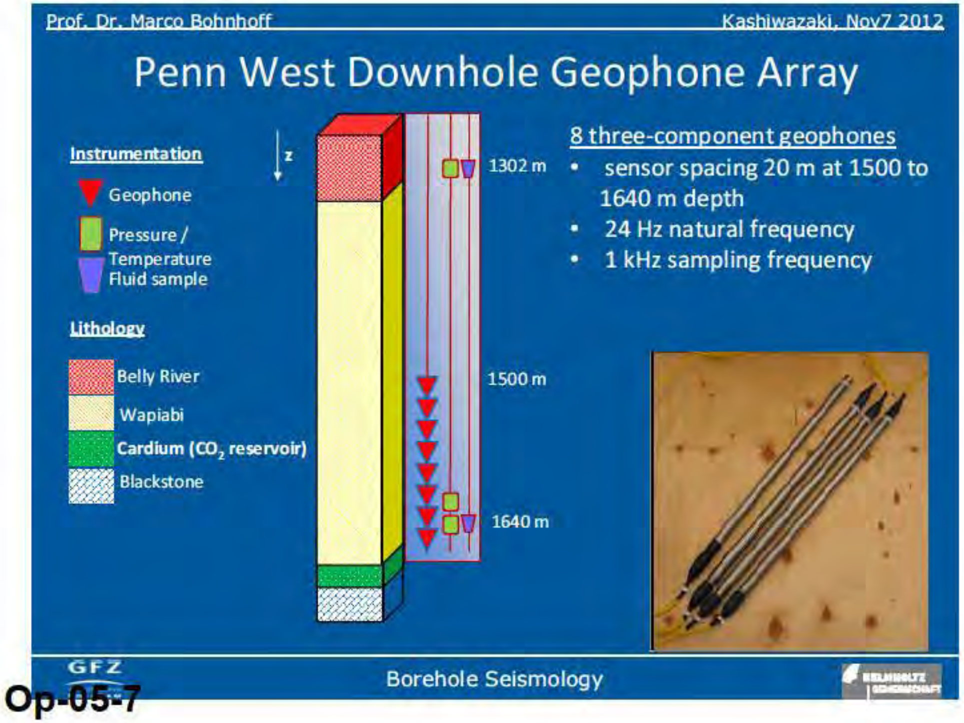


Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

The Penn West CO_2 Injection Project

- Location: Pembina Oil Field, western Canada; EOR-Project.
- Monitoring well at 350 m distance from injector well (I1) but only 35 m away from producer well P1.

GFZ Borehole Seismology



Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

Penn West Downhole Geophone Array

Instrumentation

- 🔻 Geophone
- 🟩 Pressure / Temperature
- 🔻 Fluid sample

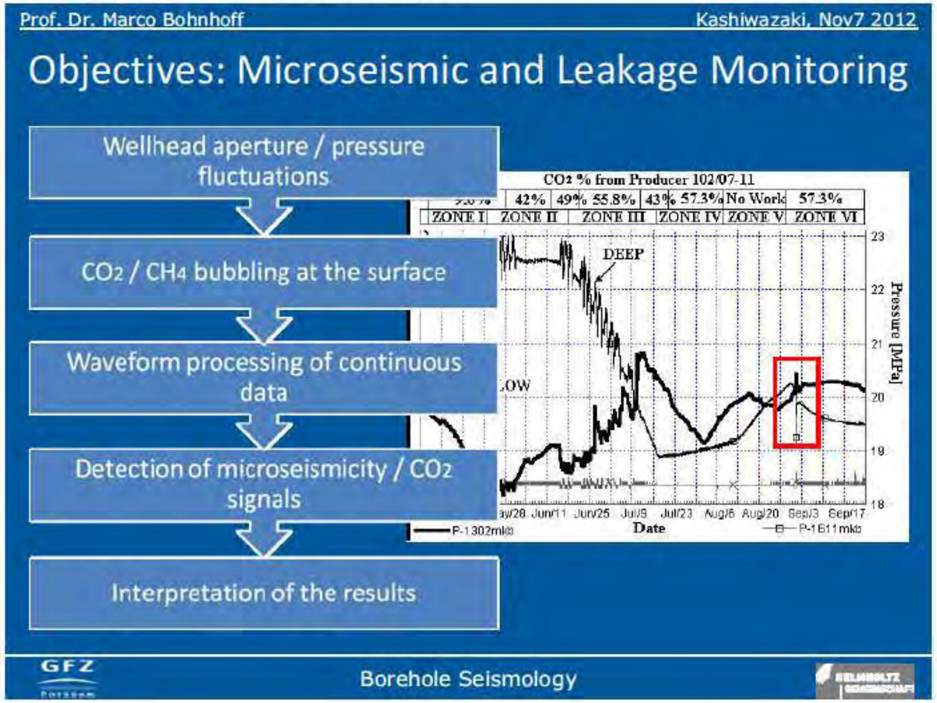
Lithology

- ▨ Belly River
- ▨ Wapiabi
- ▨ Cardium (CO_2 reservoir)
- ▨ Blackstone

8 three-component geophones

- sensor spacing 20 m at 1500 to 1640 m depth
- 24 Hz natural frequency
- 1 kHz sampling frequency

GFZ Borehole Seismology



Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

Objectives: Microseismic and Leakage Monitoring

Wellhead aperture / pressure fluctuations

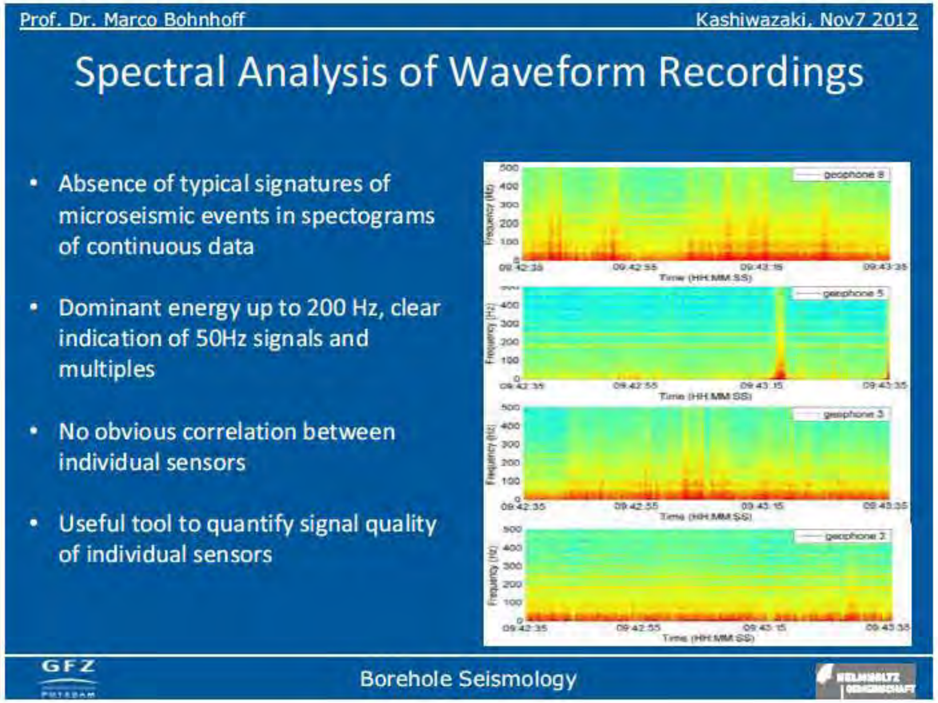
CO_2 / CH_4 bubbling at the surface

Waveform processing of continuous data

Detection of microseismicity / CO_2 signals

Interpretation of the results

GFZ Borehole Seismology

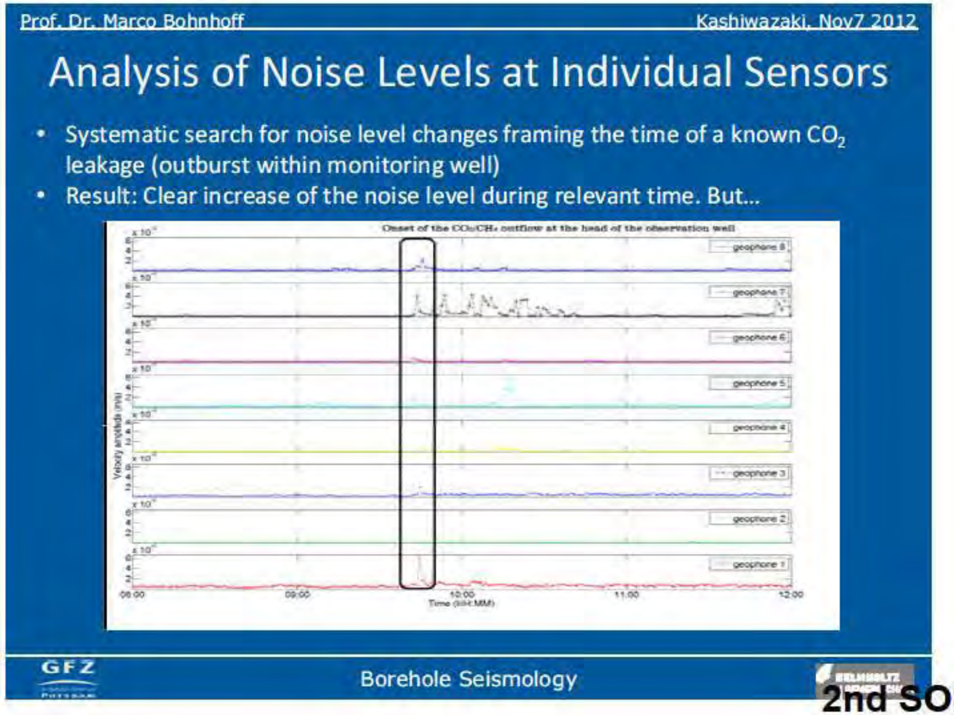


Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

Spectral Analysis of Waveform Recordings

- Absence of typical signatures of microseismic events in spectograms of continuous data
- Dominant energy up to 200 Hz, clear indication of 50Hz signals and multiples
- No obvious correlation between individual sensors
- Useful tool to quantify signal quality of individual sensors

GFZ Borehole Seismology

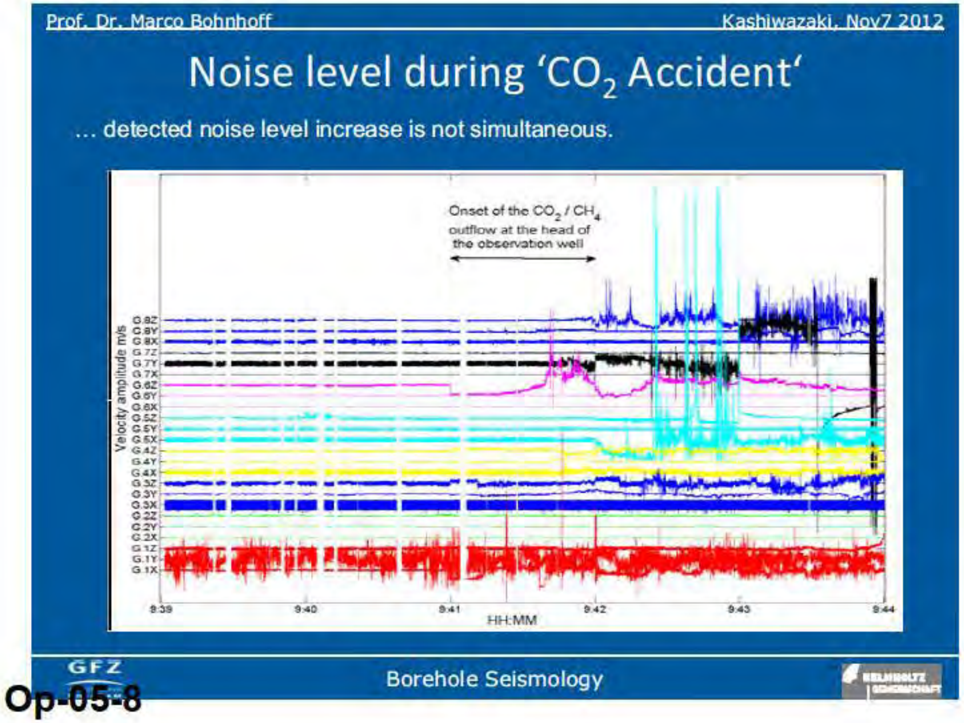


Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

Analysis of Noise Levels at Individual Sensors

- Systematic search for noise level changes framing the time of a known CO_2 leakage (outburst within monitoring well)
- Result: Clear increase of the noise level during relevant time. But…

GFZ Borehole Seismology

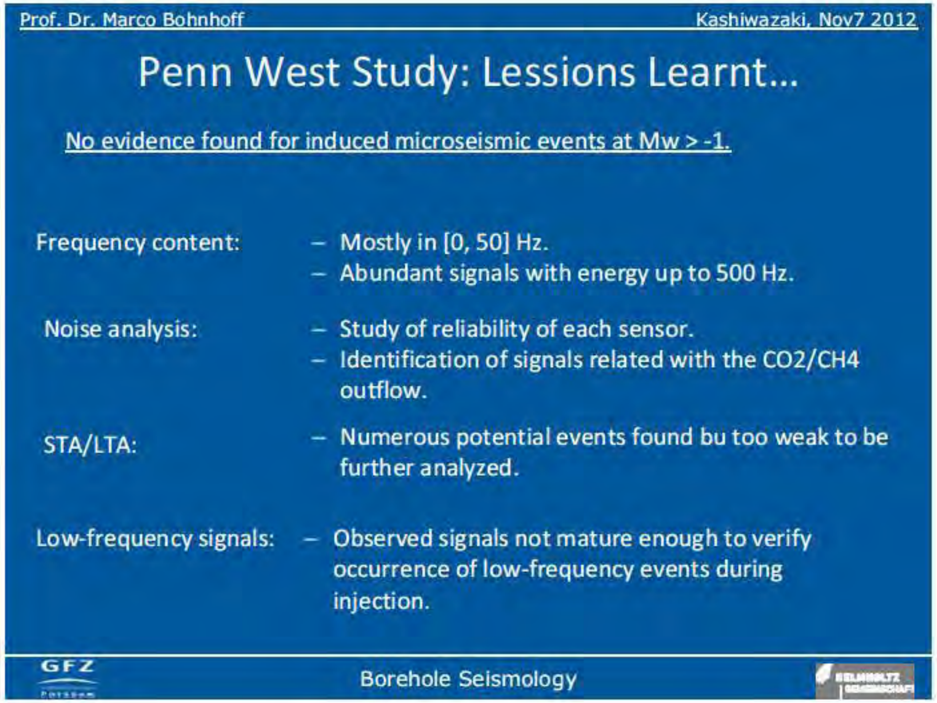


Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

Noise level during 'CO_2 Accident'

… detected noise level increase is not simultaneous.

GFZ Borehole Seismology



Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

Penn West Study: Lessions Learnt…

No evidence found for induced microseismic events at Mw > -1.

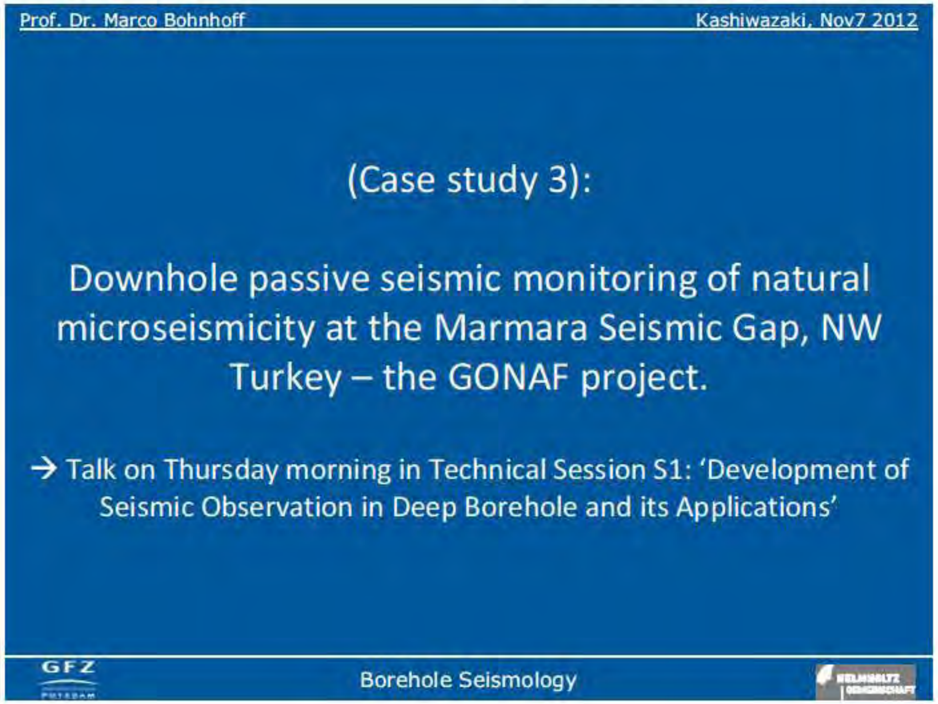
Frequency content:
- Mostly in [0, 50] Hz.
- Abundant signals with energy up to 500 Hz.

Noise analysis:
- Study of reliability of each sensor.
- Identification of signals related with the CO2/CH4 outflow.

STA/LTA:
- Numerous potential events found bu too weak to be further analyzed.

Low-frequency signals:
- Observed signals not mature enough to verify occurrence of low-frequency events during injection.

GFZ Borehole Seismology



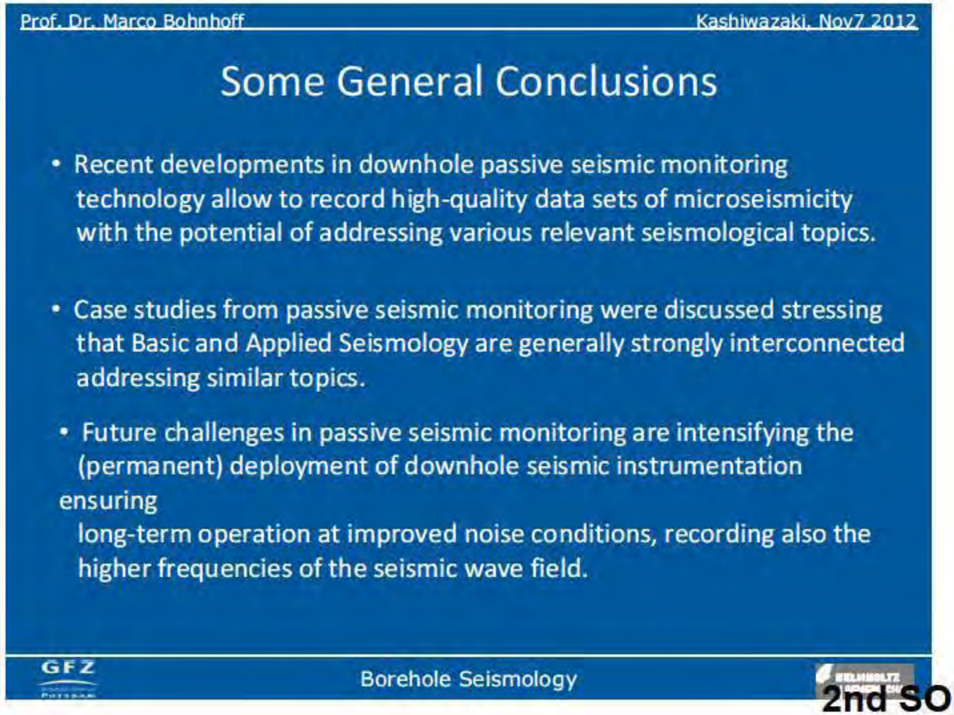
Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

(Case study 3):

Downhole passive seismic monitoring of natural microseismicity at the Marmara Seismic Gap, NW Turkey – the GONAF project.

→ Talk on Thursday morning in Technical Session S1: 'Development of Seismic Observation in Deep Borehole and its Applications'

GFZ Borehole Seismology



Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

Some General Conclusions

- Recent developments in downhole passive seismic monitoring technology allow to record high-quality data sets of microseismicity with the potential of addressing various relevant seismological topics.
- Case studies from passive seismic monitoring were discussed stressing that Basic and Applied Seismology are generally strongly interconnected addressing similar topics.
- Future challenges in passive seismic monitoring are intensifying the (permanent) deployment of downhole seismic instrumentation ensuring long-term operation at improved noise conditions, recording also the higher frequencies of the seismic wave field.

GFZ Borehole Seismology

Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov7 2012

Thank you for your attention!

GFZ Borehole Seismology

International Seismic Safety Centre, International Atomic Energy Agency

The Second Workshop on Seismic Observation in Deep Borehole and Its Application
7-9 November 2012, JNES Kashiwazaki Seismic Safety Center

Seismic Safety of Nuclear Power Plants Based on the Lessons learned from the 2012 Tohoku Earthquake

Kojiro Irikura (Aichi Institute of Technology, Japan)

Today's Topics

1. Outline of National Hazard Map in Japan
   a: Probabilistic seismic hazard map
   b: Scenario earthquake shaking map
2. Evaluation of design basis ground motions for the back-check of nuclear power plants
3. Short-period source models of the 11 March 2011 Mw 9.0 Tohoku earthquake
4. Period-dependence of rupture processes for megathrust earthquakes
5. Recipe of predicting strong ground motions from megathrust earthquakes
6. Summary

1. Outline of National Hazard Map in Japan before the 11 March 2011 Mw 9.0 Tohoku earthquake

a. Probabilistic seismic hazard map

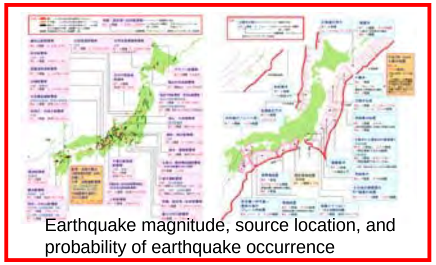
Long-term evaluation of earthquake occurrence
+
Attenuation-distance relationship of PGV

b. Scenario earthquake shaking map

Source characterization based on fault model
+
Ground motion simulation using hybrid method

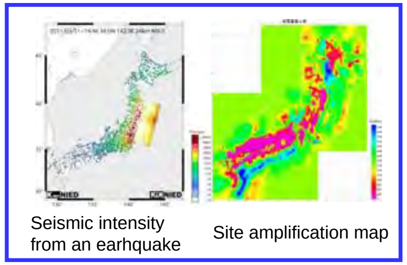
National Seismic Hazard Map in Japan

Long-term evaluation of seismic activity



Earthquake magnitude, source location, and probability of earthquake occurrence

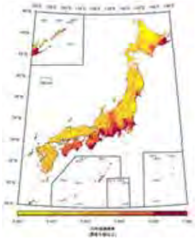
Strong motion evaluation



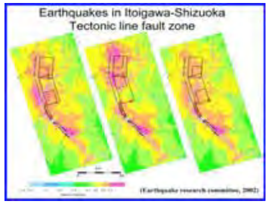
Seismic intensity from an earhquake

Site amplification map

Probabilistic seismic hazard map



Scenario earthquake shaking map



Fujiwara (2011)

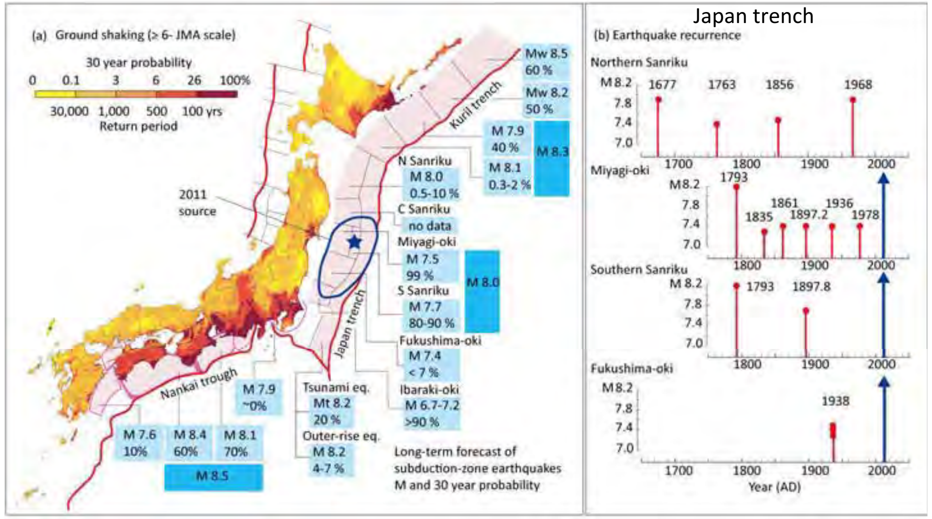
a. Probabilistic seismic hazard map

- ■ Long-term evaluation of subduction-zone earthquakes, in-slab earthquakes, crustal earthquakes, and diffusive earthquakes

  +
- ■ Attenuation-distance relationships of PGV

Probabilistic Seismic Hazard Map for Japan
and Long-term Forecast along Subduction Zone

Recurrence of large earthquakes along
Japan trench



NIED (2011)

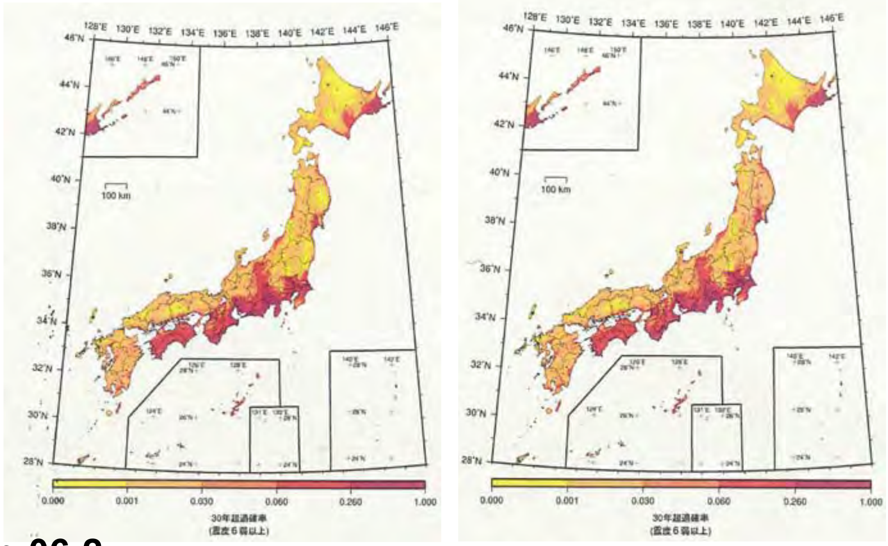
Revision of long-term evaluation of seismic activity for the region from the off Sanriku to the off Boso ,

(Earthquake Research Committee , 25 Nov. , 2011)

Earthquakes with the same type as **the 2011 off the Pacific coast of Tohoku Earthquake**

- ■Past Activity
  - 5 times for past 2,500 years
    - 2011 M 9.0 earthquake
    - 15 century from Tsunami deposits
    - 869 (the Jogan earthquake) from a history book
    - 4 to 5 centuries from Tsunami deposits
    - 3 to 4 centuries B.C. from Tsunami deposits
- ■ Return periods
  - 400 – 800 years
  - average period 600 years
- ■ Probability of earthquake occurrence before the 2011 earthquake
  - 10 – 20 years in 30 years

Probabilistic Seismic Hazard Map in 2011


Without Mw 9 earthquake

With Mw 9.0

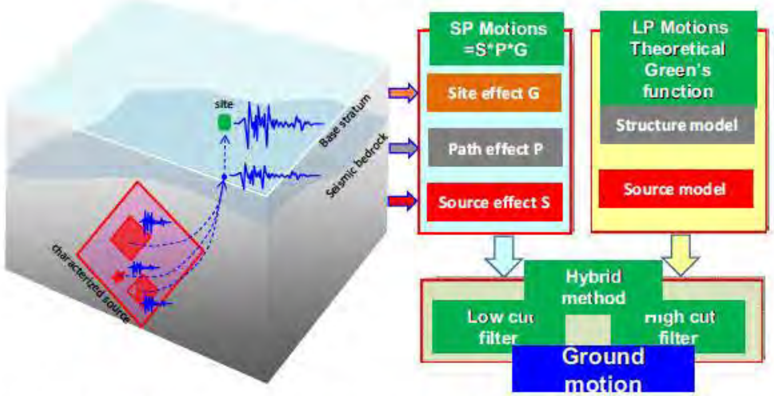
b. Scenario earthquake shaking map

- Source modeling using a recipe of predicting strong ground motions

+

- Ground motion simulation using hybrid method, theoretical simulation for long-period motions and stochastic simulation for short-period motions

Estimation of strong motion for national seismic hazard map with specified source model



The 2006 NSC/JPN regulatory guide for seismic design explicitly requires to establish DBGM using fault rupture models (i.e., the seismic source simulation method).

Illustration of Characterized Source Model

1. Outer Fault Parameters-

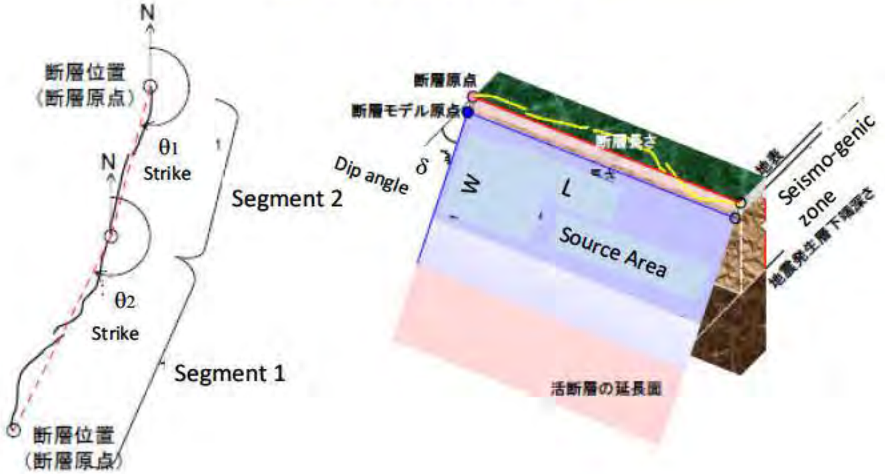
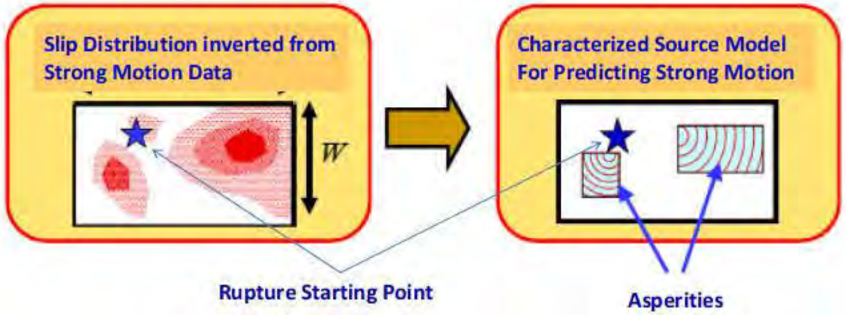
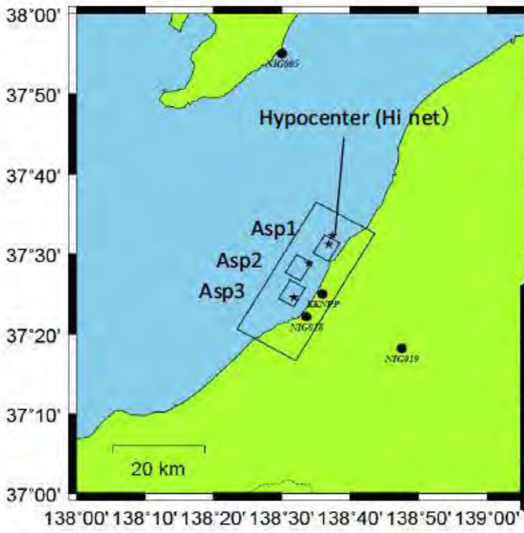


Illustration of Characterized Source Model



SOURCE MODEL OF THE 2007 CHUETSU-OKI E



Best-fit source model with three asperities (ASP1, ASP2 AND ASP3) is estimated from comparison between observed and simulated motions using the Empirical Green's Function Method.

	L (km) × W (km)	⊿σ (MPa)	Mo (Nm)
ASP 1	5.5 × 5.5	23.7	1.69×10^{18}
ASP 2	5.5 × 5.5	23.7	1.69×10^{18}
ASP 3	5.04 × 5.04	19.8	1.02×10^{18}

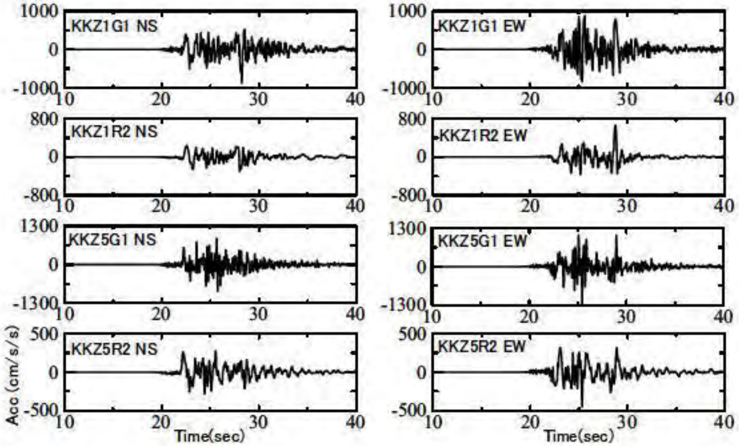
- Strike：30° , Dip Angle：40°

Star mark on each asperity shows rupture starting point in the asperity.

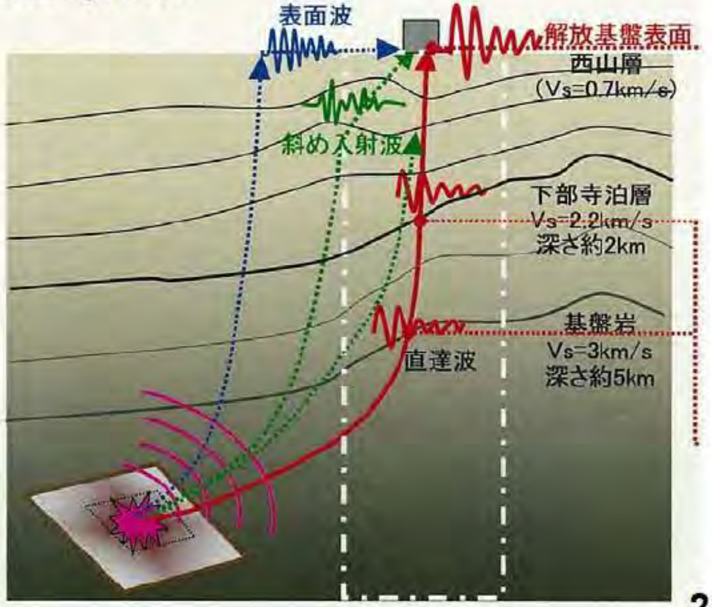
Acceleration Ground Motions recorded at the Kashiwazaki-Kariwa Nuclear Power Station from the 2007 Chuetsu-oki Earthquake

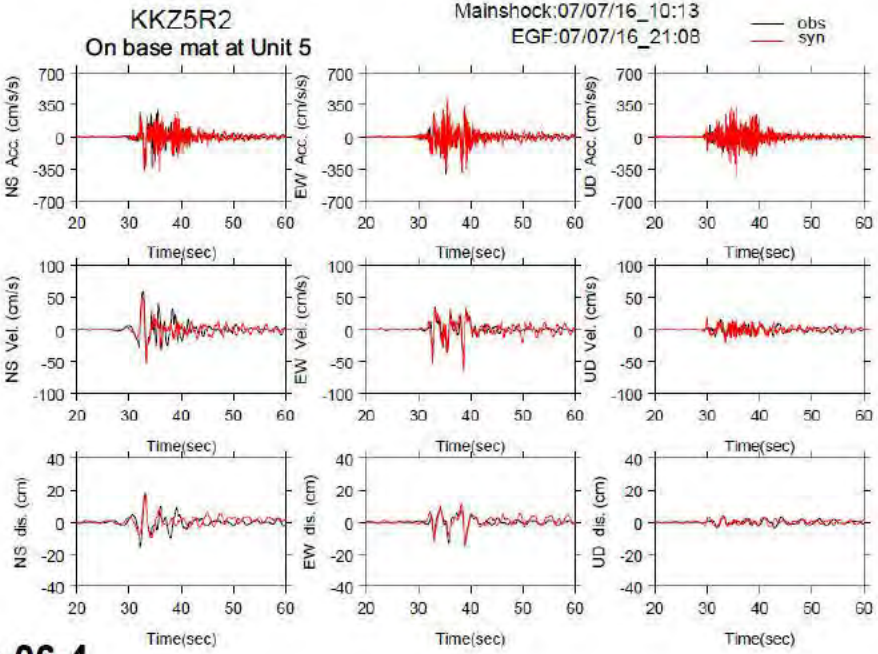
KKZ1G1 : Surface Obs. P. of Unit 1 KKZ1R2 : Base Mat Obs. P. of Unit 1

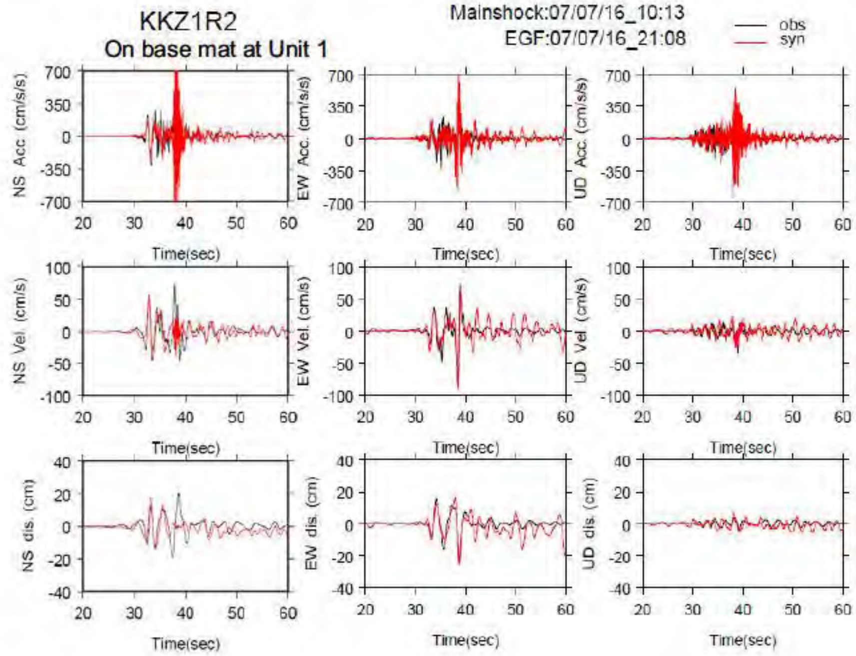
KKZ5G1 : Surface Obs. P. of Unit 5 KKZ5R2 : : Base Mat Obs. P. of Unit 5



Amplification of ground motions near Kashiwazaki-Kariwa NPP due to focusing effects





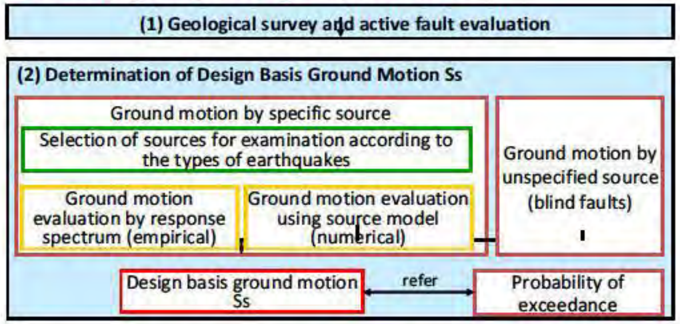


2. Evaluation of design basis ground motions for the back-check of nuclear power plants

- Evaluation of design basis ground motion in the 2006 regulatory guide by the Nuclear Safety Commision, Japan
- Estimation of strong ground motions for the back-check of nuclear power plants based on the strong motion prediction recipe

Seismic Safety Assessments based on the new Regulatory Guide (2006)

- Determination of design basis ground motion Ss for NPP defined based on the new Regulatory Guide (2006).
- Policy on determining design basis ground motion Ss



(1) Geological survey and active fault evaluation

(2) Determination of Design Basis Ground Motion Ss

Ground motion by specific source

Selection of sources for examination according to the types of earthquakes

Ground motion evaluation by response spectrum (empirical)

Ground motion evaluation using source model (numerical)

Ground motion by unspecified source (blind faults)

Design basis ground motion Ss

refer

Probability of exceedance

- Design basis ground motion Ss for the existing NPPs in Japan were determined and the facilities' seismic safety were reevaluated. The facilities' seismic safety was upgrading to improve their margin.

Example of Seismic Reevaluation

-The Kashiwazaki-Kariwa Nuclear Power Plant-

Selected Active Faults and Folds Inland and Offshore

Active Faults selected for D.B.S.M.

	Faults	Fault Length	Length of Source Fault.
n and	①Kakuta-Yahiko	54km	Nagaoka-Heiya Sei-en Fault: Total length of 91 km
	②Kihinomiya	22km	
	③ Katagai	16km	
Offshore	④F－B	36km	36km

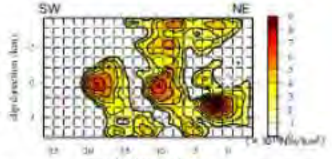
Evaluated Desin Basis Ground Motions for the Nagaoka Heiya Seien Danso評価

(Unit:gal)

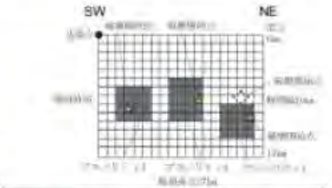
Maximum Acceleration	Unit:1～4	Unit:5～7
Design Basis G.M. Ss	2300	1209
Old Regulatory Guide S2	450	

Source Model of F-B Fault

1. Asperity model was formulated based on the recipe for strong motion prediction by Headquarters for Earthquake Research Promotion (2008)
(Fault length: 27km x width: 20km)

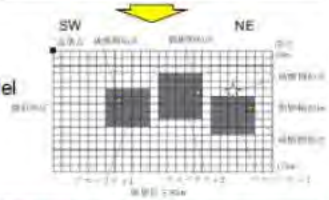


Seismic inversion of NCO EQ (M6.8)



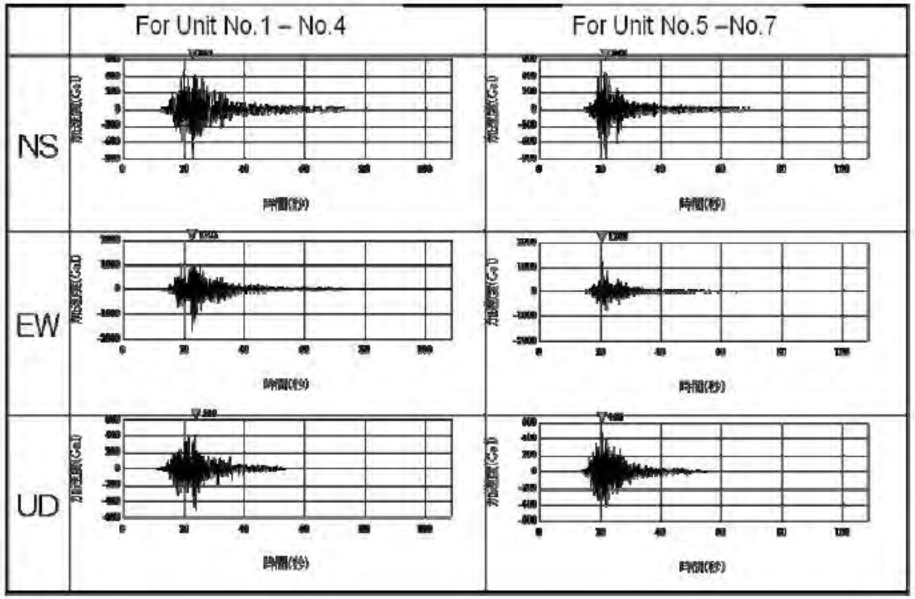
1. Asperity model for NCO EQ (M6.8)

2. Source fault model was formulated by extending fault length of the asperity model formulated at 1., into 36km (M7.0) which is based on the geological survey result



2. Source fault model of F-B fault (M7.0)

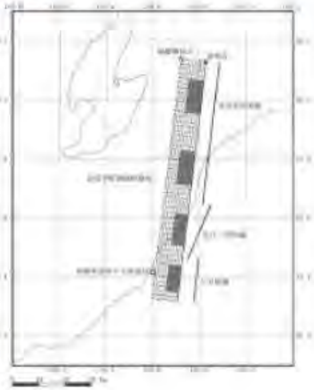
Acceleration Time Histories from the F-B Fault Earthquake



Source Model of Naoka Heiya Sei-en Fault

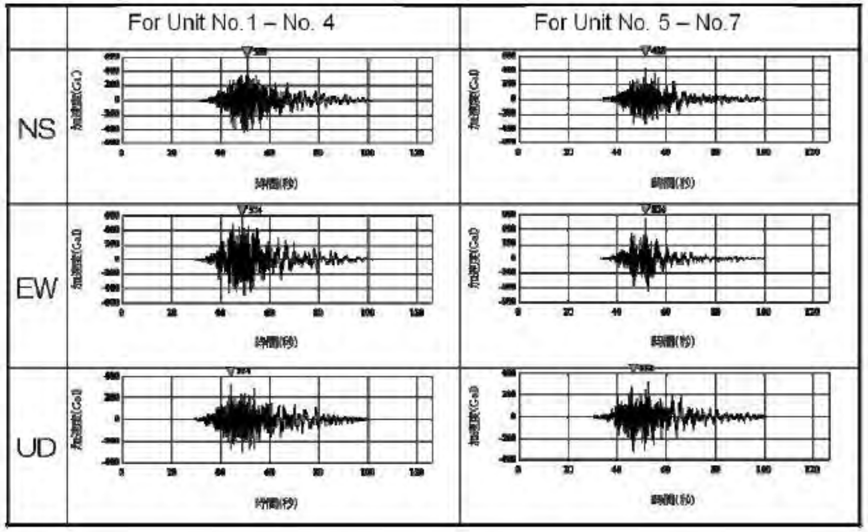
Three Faults (Katagai, Kihinomiya, and Kakuta Yahiko) are connected.

Parameters to be considered with uncertainty



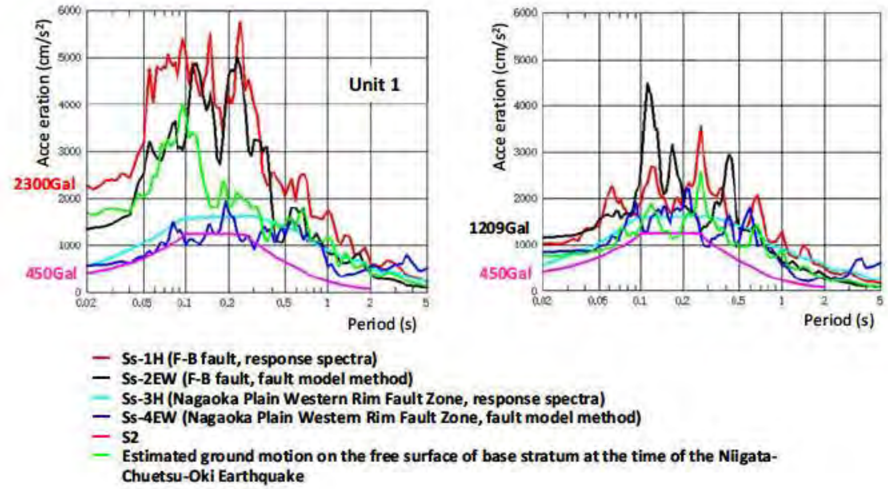
- **Fault length**
  Activity of Katakai fault is standard case, and consider fault interlocking with its surrounding faults (Kihinomiya fault, Kakuda-Yahiko fault)
- **Fault dipping angle**
  50 deg. Is the standard case according to the evaluation of HERP, and 35 deg. is also taken into account as an uncertainty.
- **The number & location of asperity**
  Upper-center position of the fault plain is the standard case, and lower-center is also considered.
- **The amount of stress drop & avg. slip**
  1.5 times larger than recipe is considered.
- **Rupture starting point**
  Place which rupture proceed toward the site is the standard case, and boundary of asperity is also considered as an uncertainty

Acceleration Time Histories from the Nagaoka-Heiya Sei-en Fault



Response Spectra for the Design-basis Ground Motion

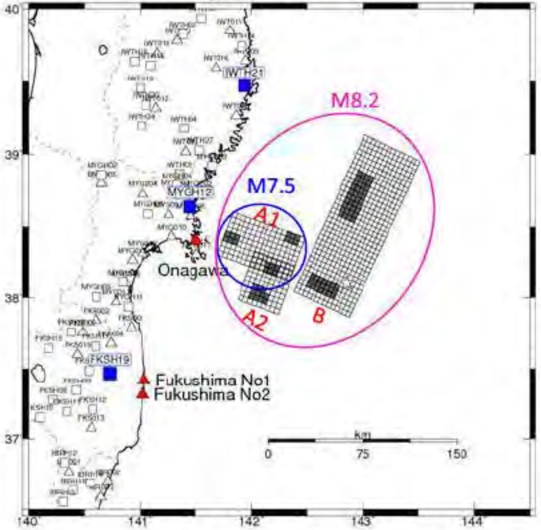
(Free surface of base stratum)



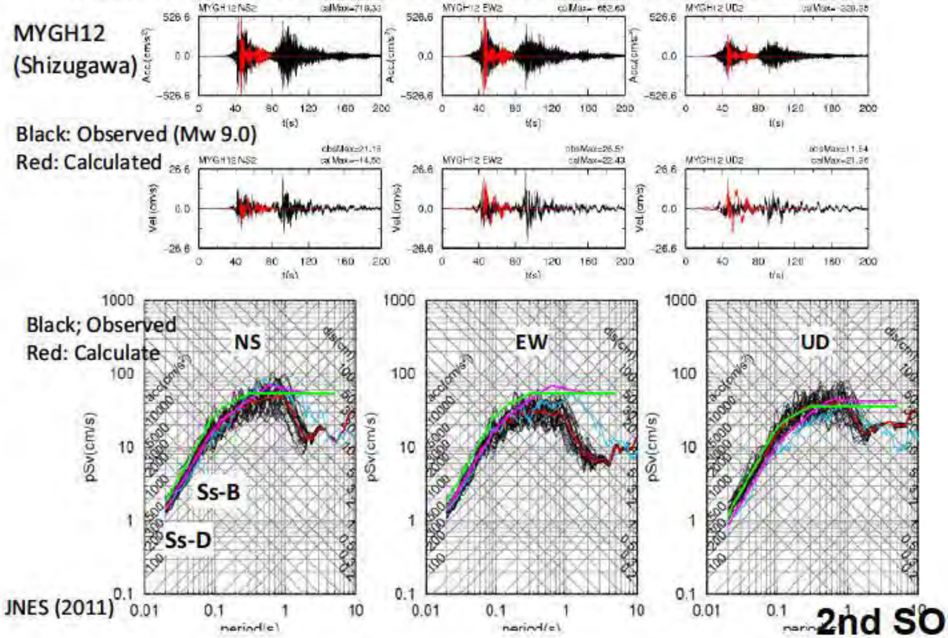
Scenario Earthquake Model for Design Basis Ground Motions

- Hypothetical Source Model of 1793 Miyagi-oki Earthquake (M 8.2) -

Onagawa NPP



Comparison between Observed Records from the Tohoku earthquake and Calculated Motions from Scenario earthquake (Miyagi-ken Oki earthquake)



JNES (2011)

What happened at Onagawa NPS due to strong ground motions

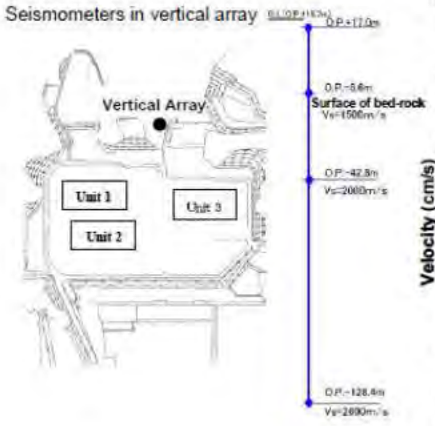
Comparison between recorded acceleration and design acceleration to the DBGM Ss on Base Mats at Units 1 – 3.

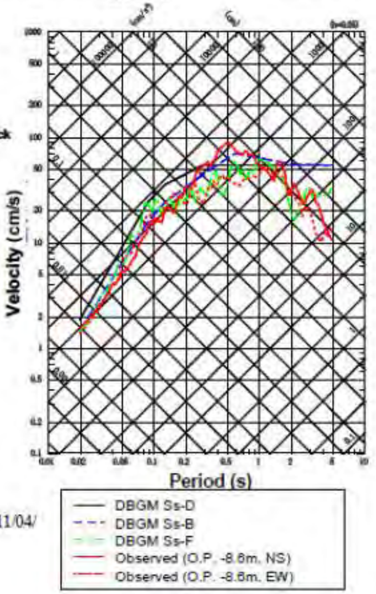
Loc. Of Seismometer (bottom floor of reactpr bld.)		Record Max. acc. (Gal)			Max. response acceleration to the DBGM Ss (Gal)		
		NS	EW	UD	NS	EW	UD
Onagawa	Unit 1	540	587	439	532	529	451
	Unit 2	607	461	389	594	572	490
	Unit 3	573	458	321	512	497	476

◯ Observed records were larger than design levels marked be ◯.

Comparison between Observed Response Spectra and the DBGM

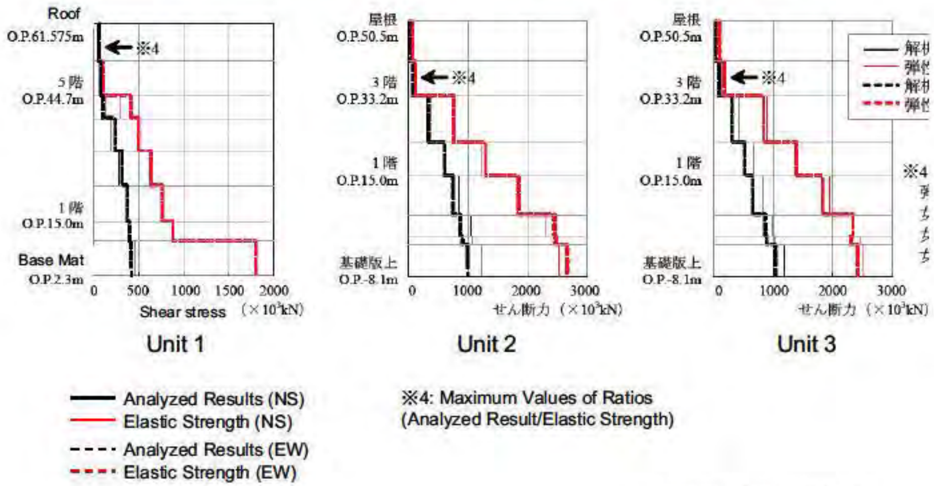
Partially modified by JNES.





Reference: Tohoku Electric Power Co., Inc
[Online] http://www.tohoku-epco.co.jp/ICSFiles/afieldfile/2011/04/25/110425np_s.pdf
Partially modified by JNES.

Limit of shear stress acting on earthquake-resistant wall at each floor of the reactor building of the Onagawa NPP



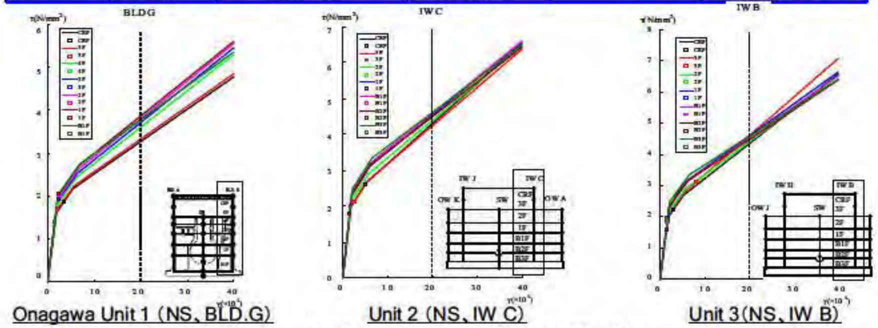
※4: Maximum Values of Ratios (Analyzed Result/Elastic Strength)

Report of NISA (2011)

Seismic Safety Evaluation of Reactor Buildings

Max. Shear Strains on Earthquake-Resisting Walls for the Tohoku Earthquake

		Analyzed Results		Evaluation Criteria	（参考） 基準地震動Ss
		Max. Shear Strain	Element		
Onagawa Unit 1	NS	0.36×10^{3}	BLD.G CRF	2.0×10^{3}	0.65×10^{3}
	EW	0.35×10^{3}	BLD.7 5F		0.56×10^{3}
Unit 2	NS	0.49×10^{3}	IW-C CRF		1.15×10^{3}
	EW	0.28×10^{3}	IW-4 3F		0.55×10^{3}
Unit 3	NS	0.81×10^{3}	IW-B 3F		0.99×10^{3}
	EW	0.18×10^{3}	IW-2、4 3F		0.41×10^{3}



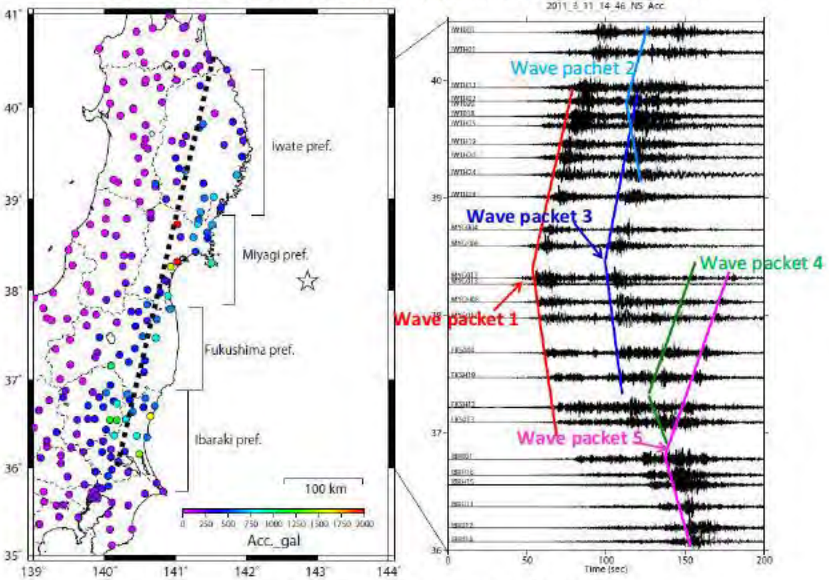
Onagawa Unit 1 (NS、BLD.G)　Unit 2 (NS、IW C)　Unit 3 (NS、IW B)

Maximum Response on Shear Skelton

3. Short-period source model of the 2011 Tohoku earthquake (Mw 9.0) estimated from strong motion data

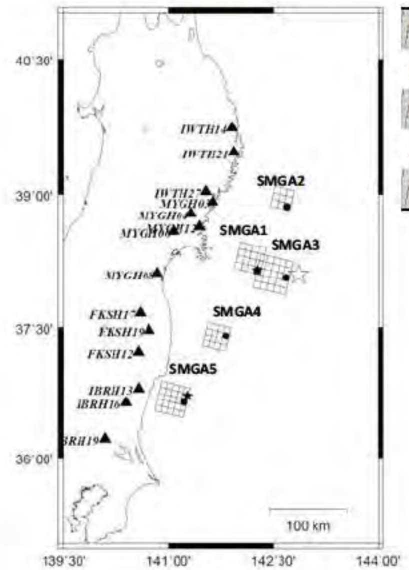
- ■ Five distinctive wavapackets were detected on strong motion sesimograms at stations near the source fault.
- ■ The arrival azimuths of those wavepackets were estimated using the semblance analysis in several small arrays.
- ■The locations of strong motion generation areas (SMGAs) are coincident with the origins of those wavepackets.

Re-estimation of Locations of SMGAs from Semblance Analysis of Wave-Packets seen in Short-Period Seismograms



After Irikura and Kurahashi (2011)

Revised Model



	L,W	Mo	Stress drop
SMGA1	34 × 34	2.68E+20	16
SMGA2	23.1 × 23.1	1.41E+20	20
SMGA3	42.5 × 42.5	6.54E+20	20
SMGA4	25.5 × 25.5	1.24E+20	25.2
SMGA5	38.5 × 38.5	5.75E+20	25.2

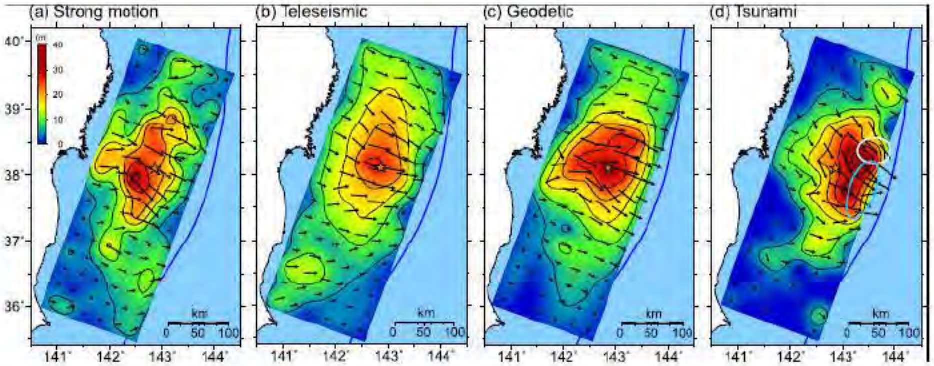
4. Period-dependence of rupture processes – comparison of short-period source model and long-period source models inverted long-period strong motion data, tsunami waveforms, geodetic data -

- Long-period source models inverted from tsunami data (Fujii et al., 2012) , geodetic data (Iinuma et al., 2012) and joint data (Yokota et al.)

- Short-period source models using backprojection of teleseismic short-period P-waves

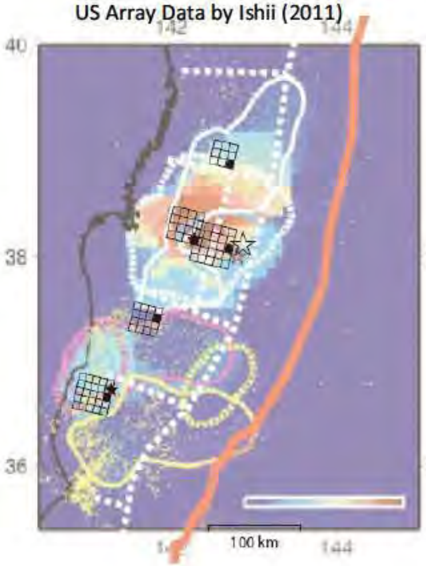
Source Model of the 11 March 2011 off Tohoku, Japan Earthquake

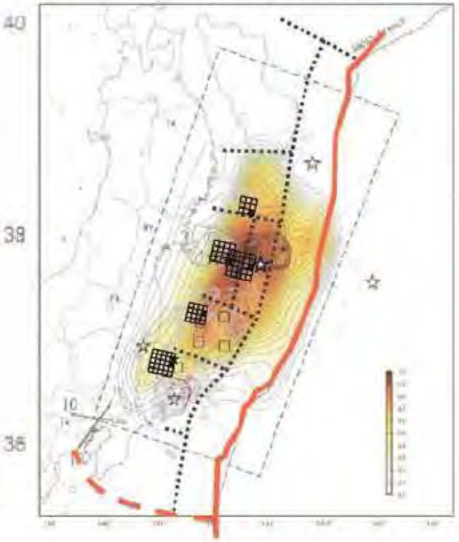
Slip Distributions by the separate inversions of (a) strong motion, (b) teleseismic, (c) geodetic, (d) tsunami datasets.



Yokota et al. (GRL 2011)

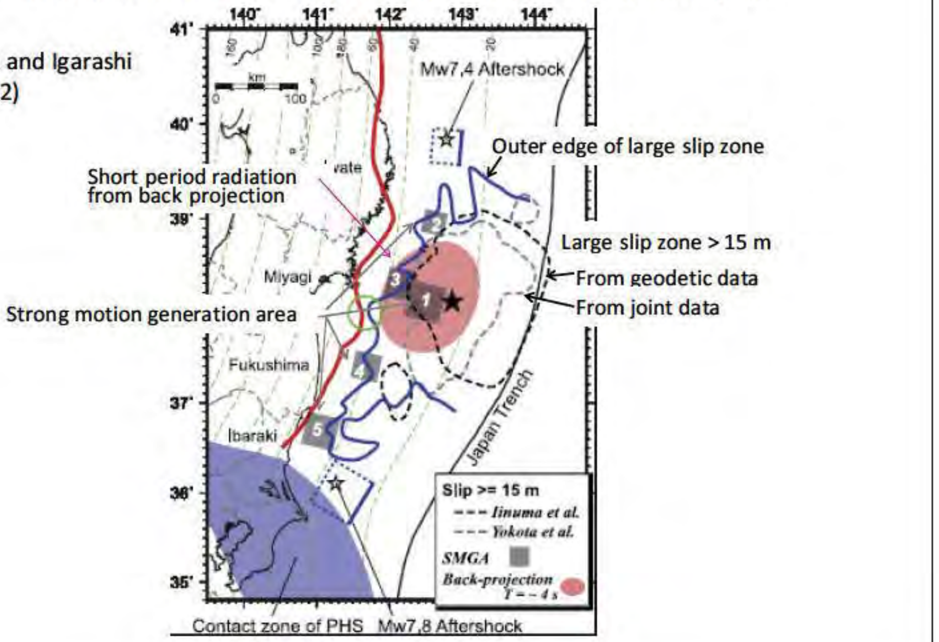
Comparison of Short Period Source Model in This Study with Short Period Released Energy by the back projevtion method


US Array Data by Ishii (2011)


Kanto Array Data by Hoda et al, (2011)

Period-Dependent Source Model of the 2011 Tohoku Earthquake

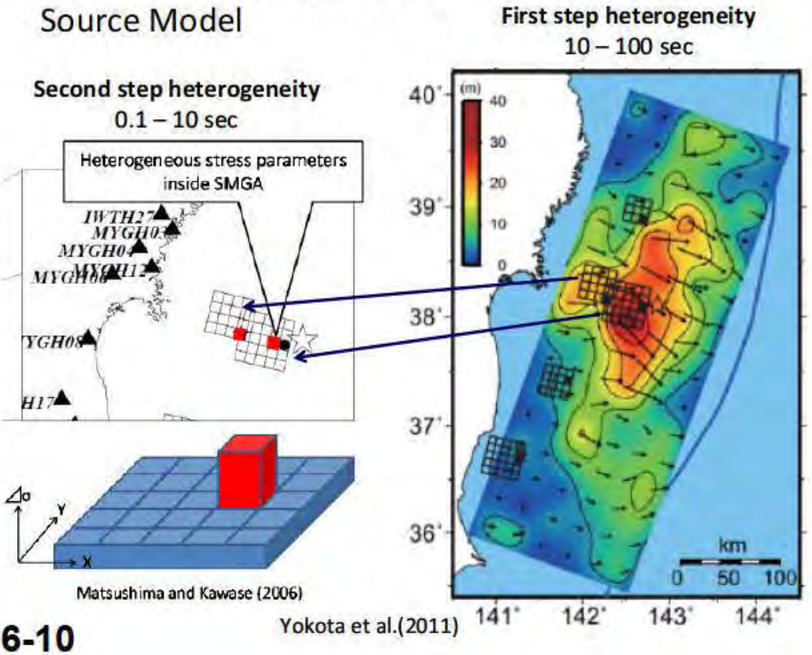
Kato and Igarashi (2012)



5. Recipe of predicting strong ground motions for subduction-zone megathrust earthquakes

- ■ Rupture process of subduction-zone megathrust earthquakes show period-dependence.
- ■ New source image for period-dependent source process is expressed as multi-step heterogeneous-source-model.
- ■ Strong ground motions of engineering interest in the period-range from 0.1 to 10 sec are estimated using the characteristic source model with outer-fault parameters and inner fault parameters. It is just one step heterogeneity.

Multi-Step Heterogeneous Source Model


Second step heterogeneity
0.1 – 10 sec

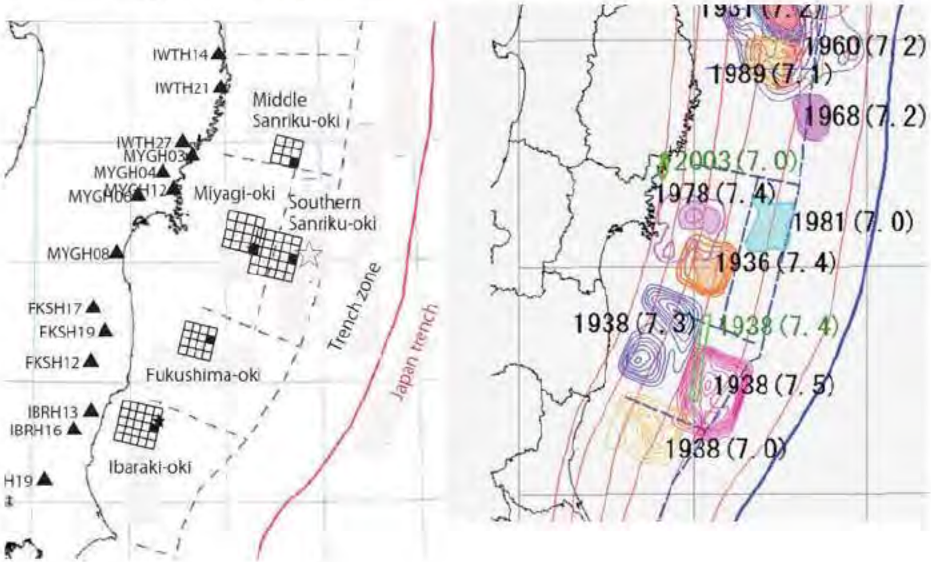
Heterogeneous stress parameters inside SMGA

Matsushima and Kawase (2006)

First step heterogeneity
10 – 100 sec

Yokota et al.(2011)

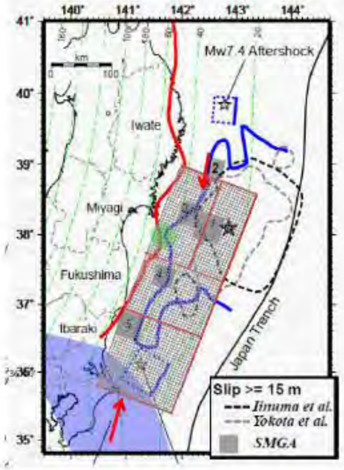
Comparison between SMGAs in this study and source locations of past earthquakes off the Pacific coast of Tohoku



Outer fault parameters

- Fault segments are estimated from seimic activity in target region.
- Deep and shallow limits are given from the characteristics of the past seismic activities following Kato and Igarashi (2012).

Deep limit ~ 50 km



Shallow limit ~ 20 km

Outer fault parameters

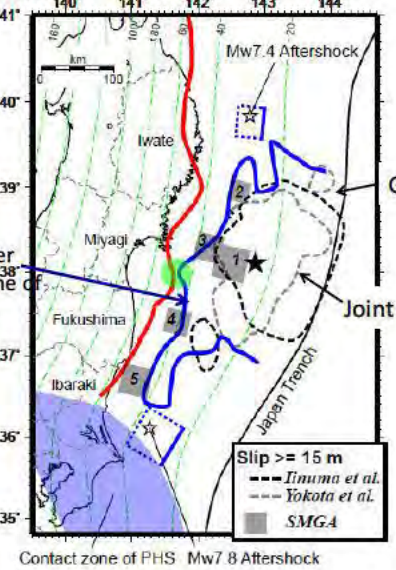
- Five segments in the region off the Pacific coast of Tohoku are given as middle Sanriku-oki, Southern Sanriku-oki, Miyagi-oki, Fukushima-oki and Ibaragi-oki, which were segmente for long-term forecast by the Headquarters of Earthquake Research Promotion.
- As a result, moment magnitude is estimated as Mw 8.5 from the empirical relation $S=5.88\times10^{-7}\times Mo^{1/2}$, L=380km and W=120km.

	Area S (km²)	Mo※ (N m)
Sanriku oki	9000	4.74E+20
Miyagi oki	10500	5.98E+20
Fukushima oki	12350	7.62E+20
Ibaragi oki	17550	1.29E+21
Total	49400	

※1 S (km²) $1.48\times10^{10}\times Mo^{2/3}$ (Nm)
（Murotani et al.、2008）

Inner fault parameters

- Strong motion generation areas are located along the down-dip edge (~35 km deep) of subducting plate.



Geodetic data

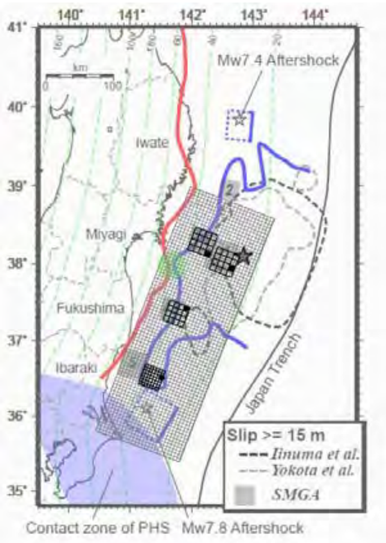
Joint data

Brue solid line is the outer edge of the large slip zone of the mainshock, ~35 km.

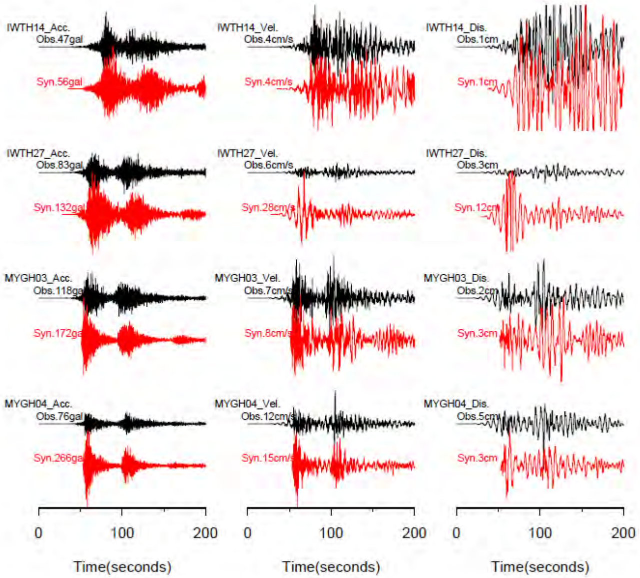
After Kato and Igarashi (2012)

Inner fault parameters

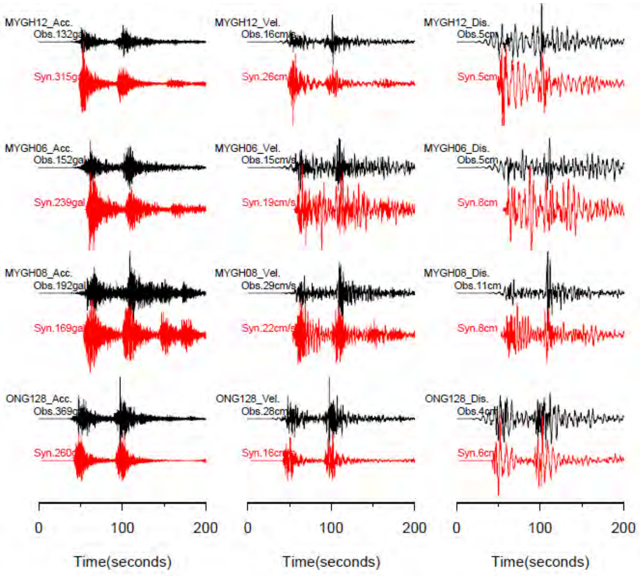
- Stress parameter (σ_a) on strong motion generation areas is given as ~ 26 MPa from the empirical relations for mega-thrust earthquakes.
- Area of SMGAs is given as ~ 1024 km^2 from the high-frequency flat level of acceleration source spectra (A0). A0 is taken from the short-period source model by Kurahashi and Irikura (2012).
- Ground motions are calculated using the empirical Green's function method.
- As a result, average stress drop ($\Delta\sigma$) is estimated at1.8MPa and S/Sa, about 14 %.



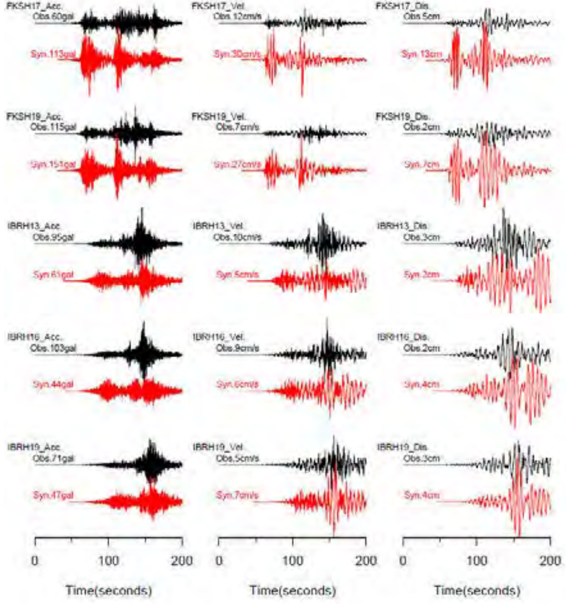
Comparison between observed and synthetic waveforms in northern region (Iwate and Miyagi)



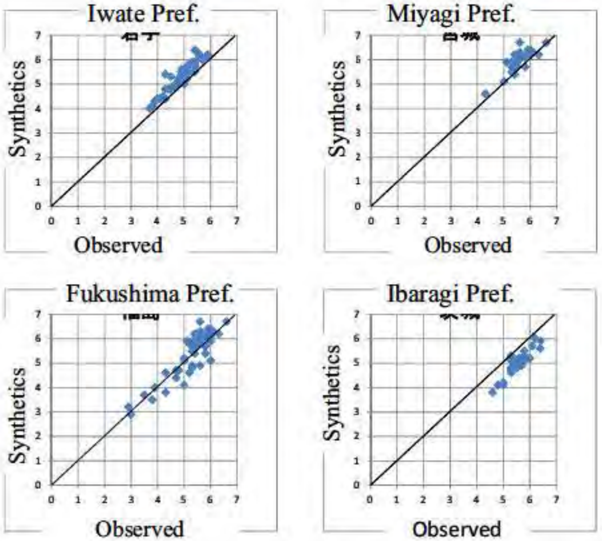
Comparison between observed and synthetic waveforms in the region near the source fault (Miyagi and Onagawa)



Comparison between observed and synthetic waveforms in the southern region (Fukui and Ibaragi)



Comparison of Seismic Intensity between Observed and Synthetics



5. Summary

1. The 11 March 2011 giant earthquake with Mw 9.0 occurred off the Pacific coast of Tohoku, and is the largest historical earthquake to strike in or near Japan. Probabilistic seismic hazard maps so far published in Japan have never considered such big earthquakes as Mw 9.0 , then ground motions for a 3% exceedance probability occurring within 30 years have been underestimated in some areas near the source area of this earthquake.

2. From the forward modeling of the source model for simulating short-period ground motions such as acceleration and velocity seismograms, there are five SMGAs over the source fault located west of the hypocenter and along the down-dip edge of the source fault.

3. Period-dependence of rupture process was found, that is large slips in shallow zones of the source fault near the trench west of the hypocenter and short-period generation in deeper zones west of the hypocenter.

4. Strong ground motions of engineering interest in the period-range from 0.1 to 10 sec are estimated using the characteristic source model with outer-fault parameters and inner fault parameters.

Second Workshop on Seismic Observations in Deep Borehole and Its Applications

7 – 9 November 2012

JNES Kashiwazaki Seismic Safety Center

Effective Use of Deep Underground Observation for NPP Seismic Hazard Analysis

Aybars Gürpınar, Independent Consultant
Nuclear and Risk Consultancy

Contents of the Presentation

- IAEA Safety Guide SSG-9 Site Vicinity and Site Area Scale Investigations
- Ground Motion Prediction Equations and their Limitations
- Site Response Models and their Limitations
- Need to Consider the Two Phenomena (GMPE and SR) Together
- (P)SHA and (P)FDA
- Two case histories: K-K and F1 F2 challenges

IAEA Safety Guide SSG-9 Site Vicinity and Site Area Scale Investigations

- Site vicinity studies should cover a geographical area typically not less than 5 km in radius. In addition to providing a yet more detailed database for this smaller area, the objective of these investigations is to define in greater detail the neotectonic history of faults, especially for determining the potential for and rate of fault displacement at the site (fault capability), and to identify conditions of potential geological instability of the site area. (Para. 3.16)

IAEA Safety Guide SSG-9 Site Vicinity and Site Area Scale Investigations

- Site area studies should include the entire area covered by the NPP, which is typically one square km. The primary objective of these investigations is to obtain detailed knowledge of the potential for permanent ground displacement phenomena associated with earthquakes and to provide information on the static and dynamic properties of foundation materials to be used in site response analysis. (Para. 3.19)

Ground Motion Prediction Equations and their Limitations

- According to para 5.6 of SSG-9, GMPEs need to include the following parameters:
  - Earthquake magnitude
  - Seismic source to site distance (e.g. distance to fault rupture)
  - Style of faulting
  - Hanging wall effects
  - Local site conditions (V_{s30})
  - Aleatory variability

Ground Motion Prediction Equations and their Limitations (Cont'd)

- However data obtained in recent earthquakes in Japan have shown that GMPEs may not be able to account for local differences effectively.

Site Response Models and their Limitations

- For sites with V_{s30} > 1100 m/s, IAEA Safety Standards do not necessarily recommend a site response analysis. This is done through the GMPEs which already include V_{s30}.
- For sites with V_{s30} < 1100 m/s, a separate site response analysis is needed. Generally, this analysis has limitations due to the area/depth of collected data and the analytical model. V_s is measured under the reactor and to a depth of maximum 100 meters. Analytical models assume vertically propagating S waves through horizontal layers.

Soil Amplification ?

- Uniform amplification of ground motion is not possible in geological layers. That is amplitudes corresponding to each frequency cannot be amplified individually.
- "Soil amplification" occurs as a result of:
  - Frequency shifts – high to low
  - Focusing due to topography, inhomogenieties and non-horizontal layering
  - Ground motion directivity
  - Change in boundary conditions
  - Co-seismic movement of secondary tectonic features
- It is therefore needed to consider GMPE and SR together!

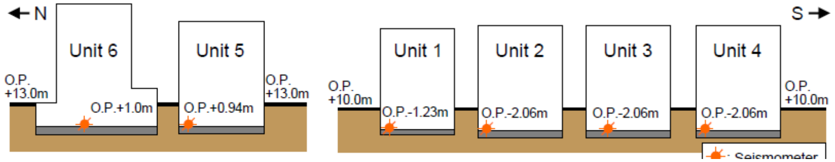
(P)SHA and (P)FDA

- Site response may include co-seismic movement of secondary tectonic structures in the site vicinity and site area and therefore a more holistic view needs to be considered.
- Deep underground observations and investigations are promising methods to bridge the gap that we have between ‘site vicinity’ and ‘site area’ scales.

Records of Observations at Base-mat Slab of Reactor Building at Fukushima Daiichi NPS

	Maximum acceleration value from observation records (Gal)			Maximum response acceleration value (Gal)					Static horizontal acceleration (Gal)
				New design-basis seismic ground motion Ss			Original design-basis seismic ground motion		
	NS	EW	UD	NS	EW	UD	NS	EW	
Unit 1	460	447	258	487	489	412	245		470
Unit 2	348	550	302	441	438	420	250		
Unit 3	322	507	231	449	441	429	291	275	
Unit 4	281	319	200	447	445	422	291	283	
Unit 5	311	548	256	452	452	427	294	255	
Unit 6	298	444	244	445	448	415	495	500	

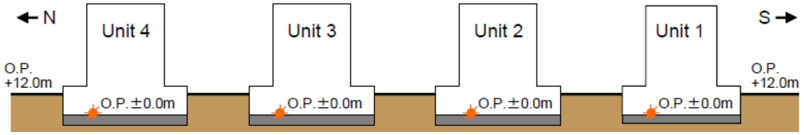
* □ indicates the observed value was beyond the response of Ss, the others were under the response of Ss.



Records of Observations at Base-mat Slab of Reactor Building at Fukushima Daini NPS

	Maximum acceleration value from observation records (Gal)			Maximum response acceleration value (Gal)					Static horizontal acceleration (Gal)
				New design-basis seismic ground motion Ss			Original design-basis seismic ground motion		
	NS	EW	UD	NS	EW	UD	NS	EW	
Unit 1	254	230	305	434	434	512	372	372	470
Unit 2	243	196	232	428	429	504	317	309	
Unit 3	277	216	208	428	430	504	196	192	
Unit 4	210	205	288	415	415	504	199	196	

* All observed maximum acceleration values were under the response of Ss.



Base mat motions at Daiichi and Daini

For approximately the same epicentral distance and distance from fault rupture (about 200 kms) the base mat motions at the two plants (only 10 kms apart) are significantly different.

The soil properties are similar (~50 meters to Vs = 700 km/s layer).

Plant structures are also similar and the embedment depth ~ 10 – 12 m for all units.

Curious statistics

Dai-ichi (average for 6 units):	Daini (average for 4 units):
NS: 367	NS: 246
EW: 469	EW: 212
UD: 249	UD: 258
NS/EW: 0.78	NS/EW: 1.16
UD: lowest component	UD: highest component

Curious statistics

Daiichi Averages / Daini Averages

NS: 1.49
EW: 2.21
UD: 0.97

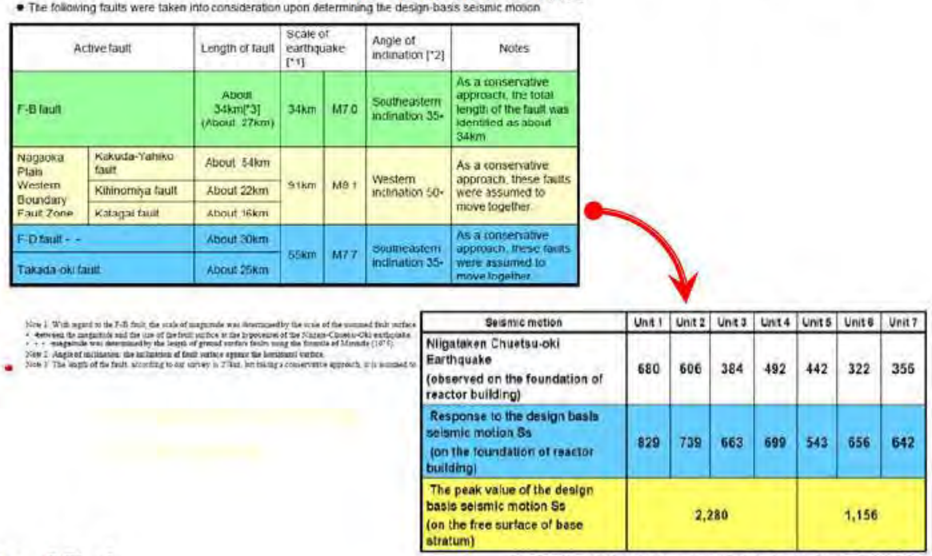
11. Maximum acceleration value of standard ground motion Ss

(Unit: Gal)

Standard ground motion	unit 1	unit 2	unit 3	unit 4	unit 5	unit 6	unit 7
Ss 1 (F-B fault / JEA spectrum)	Horizontal: 2280 Vertical: 1010				Horizontal: 1040 Vertical: 630		
Ss 2 (F-B fault / Empirical Green's function)	Horizontal: 1354 Vertical: 402				Horizontal: 1156 Vertical: 501		
Ss 3 (Nagaoka plain western boundary fault zone / JEA spectrum)	Horizontal: 600 Vertical: 400				Horizontal: 600 Vertical: 400		
Ss 4 (Nagaoka plain western boundary fault zone / Empirical Green's function)	Horizontal: 589 Vertical: 314				Horizontal: 826 Vertical: 332		

(The "horizontal" figures represent the greater of the figures for the NS and EW components.)

Revised New Seismic Hazard at the K-K NPP Site



- The following faults were taken into consideration upon determining the design-basis seismic motion

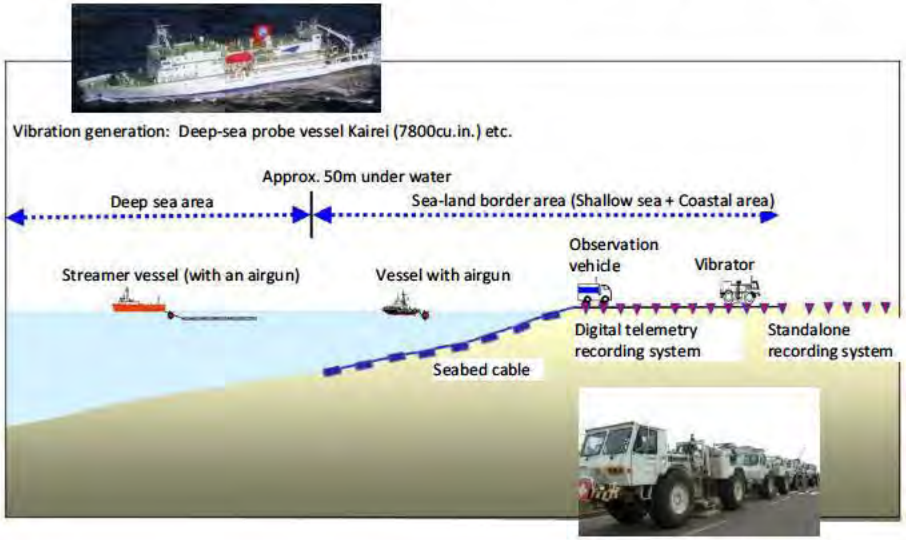
Active fault		Length of fault	Scale of earthquake [*1]		Angle of inclination [*2]	Notes
F-B fault		About 34km[*3] (About 27km)	34km	M7.0	Southeastern inclination 35•	As a conservative approach, the total length of the fault was identified as about 34km
Nagaoka Plain Western Boundary Fault Zone	Kakuda-Yahiko fault	About 54km	91km	M8.1	Western inclination 50•	As a conservative approach, these faults were assumed to move together.
	Kihinomiya fault	About 22km				
	Katagai fault	About 16km				
F-D fault - -		About 30km	55km	M7.7	Southeastern inclination 35•	As a conservative approach, these faults were assumed to move together
Takada-oki fault		About 25km				

Seismic motion	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
Niigataken Chuetsu-oki Earthquake (observed on the foundation of reactor building)	680	606	384	492	442	322	356
Response to the design basis seismic motion Ss (on the foundation of reactor building)	829	739	663	699	543	656	642
The peak value of the design basis seismic motion Ss (on the free surface of base stratum)	2,280				1,156		

The value represents the larger value among horizontal ones (south-north and east-west) (Unit: Gal)

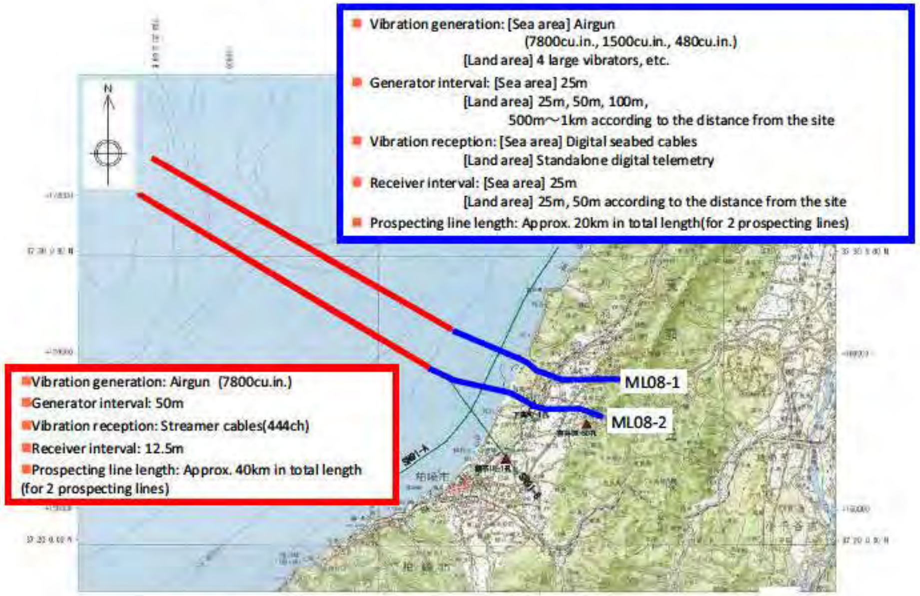
2nd SODB WS Op-07-4

Schematic diagram of offshore and onshore seismic prospecting



Vibration generation: 4 large vibrators

Offshore and onshore prospecting line



- Vibration generation: [Sea area] Airgun
  (7800cu.in., 1500cu.in., 480cu.in.)
  [Land area] 4 large vibrators, etc.
- Generator interval: [Sea area] 25m
  [Land area] 25m, 50m, 100m,
  500m～1km according to the distance from the site
- Vibration reception: [Sea area] Digital seabed cables
  [Land area] Standalone digital telemetry
- Receiver interval: [Sea area] 25m
  [Land area] 25m, 50m according to the distance from the site
- Prospecting line length: Approx. 20km in total length(for 2 prospecting lines)

- Vibration generation: Airgun (7800cu.in.)
- Generator interval: 50m
- Vibration reception: Streamer cables(444ch)
- Receiver interval: 12.5m
- Prospecting line length: Approx. 40km in total length (for 2 prospecting lines)

Conclusions

- Recent data from Kashiwazaki-Kariwa, Fukushima Daiichi and Fukushima Daini NPPs could not have been predicted by the conventional use of GMPEs and site response analyses.
- There is a need for looking at site vicinity and site area scales holistically.
- Deep borehole observation is a promising method to address this issue.

The 2nd International Workshop on Seismic Observation in Deep Borehole and Its Applications

Construction of System for Seismic Observation in Deep Borehole (SODB)

- Overview and Achievement Status of the Project

8 November, 2012
At Niigata Institute of Technology

Genyu Kobayashi
Japan Nuclear Energy Safety Organization (JNES)

Contents of Presentation

1. Background and Objectives of the Project
2. Basic Policy of the Project
3. Overview of the Project and Evaluation of its Achievement
4. Overview of the Results
5. Achievement Status of Important Items
6. Future Issues and Handlings

---

1. Background and Objectives of the Project (1/2)

■Background "Experience of the 2007 Niigata Chuetsu Oki Earthquake"

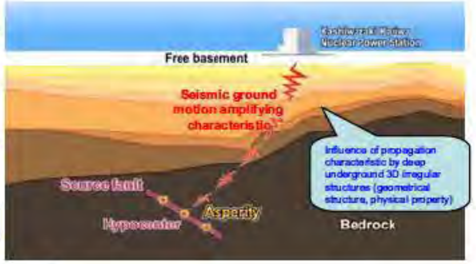
○Seismic ground motion observed at the Kashiwazaki Kariwa Nuclear Power Plant exceeded more than twice the design response in 2007 Niigata Chuetsu Oki Earthquake.

○JNES investigated the cause of exceeding design response and elucidated that main causes are 3D irregularity of deep underground structure and rapid change of S-wave velocity structure around the power plant.

It is necessary to understand the details of 3D deep underground structure from seismic bedrock to free basement around nuclear power plant site.

Deep Borehole Seismic Observation,
Geophysical Exploration

"Project on Seismic Observation in Deep Borehole (SODB)"



Propose common evaluation method, investigation/observation technology to understand seismic ground motion propagation characteristics corresponding to the domestic and overseas needs.

---

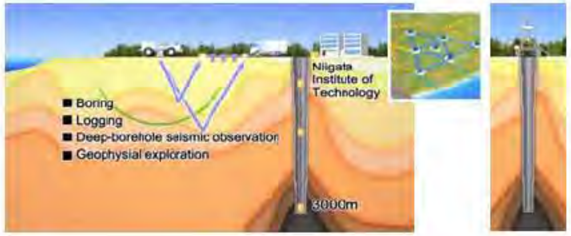
1. Background and Objectives of the Project (2/2)

■Objectives

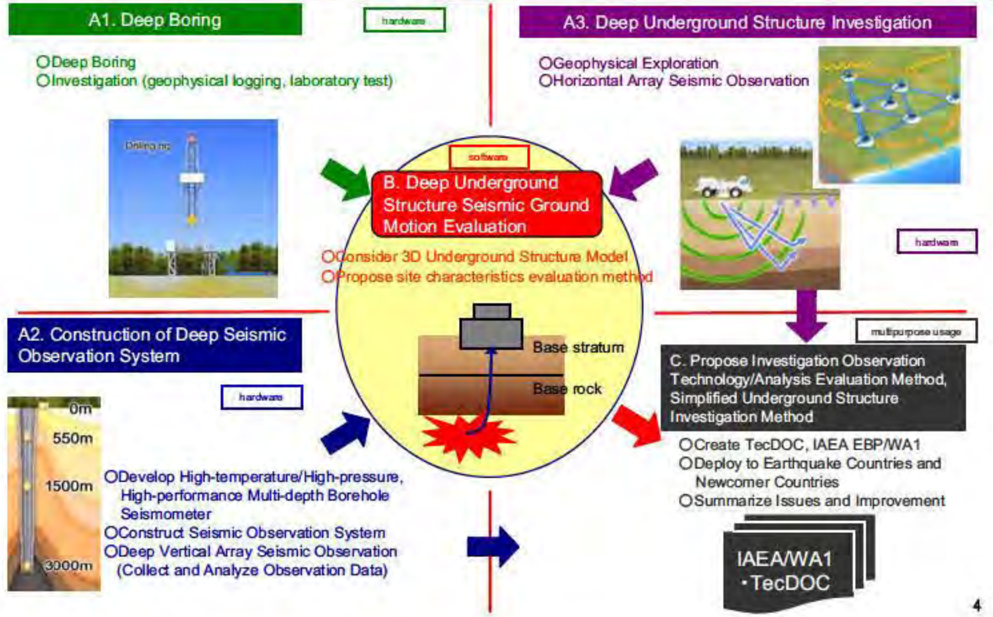
1) In order to confirm in details investigation results of seismic ground motion amplification at 2007 Niigata Chuetsu Oki Earthquake, JNES will develop deep vertical array seismic observation system and understand 3D irregular structure of deep underground and their physical properties using deep boring data, and also understand seismic ground motion using observation seismic ground motion data.

2) And construct wide area horizontal array seismic observation system, in addition to existing geophysical exploration, perform multi-purpose research development such as deep underground structure evaluation method by using horizontal/vertical array system, ground amplification characteristics evaluation method, improvement of real-time automatic scram technology etc..

3) Aim to aggregate these various technologies and methods for nuclear newcomer countries.



2. Basic Policy of the Project



A1. Deep Boring

- ○Deep Boring
- ○Investigation (geophysical logging, laboratory test)

A3. Deep Underground Structure Investigation

- ○Geophysical Exploration
- ○Horizontal Array Seismic Observation

B. Deep Underground Structure Seismic Ground Motion Evaluation

- ○Consider 3D Underground Structure Model
- ○Propose site characteristics evaluation method

A2. Construction of Deep Seismic Observation System

- ○Develop High-temperature/High-pressure, High-performance Multi-depth Borehole Seismometer
- ○Construct Seismic Observation System
- ○Deep Vertical Array Seismic Observation (Collect and Analyze Observation Data)

C. Propose Investigation Observation Technology/Analysis Evaluation Method, Simplified Underground Structure Investigation Method

- ○Create TecDOC, IAEA EBP/WA1
- ○Deploy to Earthquake Countries and Newcomer Countries
- ○Summarize Issues and Improvement

---

3. Overview of the Project and Evaluation of its Achievement (1/3)

■Point of view from hardware

<A1>Deep Boring

A1-1 Choice of seismic observation point

- ○Determine location with similar characteristic of deep underground structure (velocity structure, geological structure, seismic bedrock depth, etc.) of Kashiwazaki Kariwa Nuclear Power Plant.
- ○Location with possibility of reaching seismic bedrock at maximum temperature (below 150 degrees) where high precision seismometer production is possible at current technology from the view point of strong motion observation.
- ○Location large enough for deep boring, site or surrounding possible for oil-well drilling.
  - ⇒Selected Niigata Institute of Technology campus, Kashiwazaki, Niigata
  - ⇒Possibility of reaching seismic bedrock at drilling depth of 3000m

A1-2 Deep boring digging/investigation (technical requirement)

- ○Possibility of constructing deep and high precision digging observation well.
  - ⇒Application of oil-well digging technology
- ○Obtain physical property value (geophysical exploration etc.) regarding underground structure.

<A2>Construction of Deep Seismic Observation System

- ○Design temperature 150 degrees, high precision, broad band strong motion seismometer (Goal: 1000Gal).
- ○Design and production of multi-depth seismic observation system using single borehole. ⇒Development of new technology

---

3. Overview of the Project and Evaluation of its Achievement (2/3)

<A3>Deep Underground Structure Investigation

- ○Implementation of deep underground structure investigation of surroundings (geophysical exploration, horizontal array seismic observation), establishment of deep underground structure/seismic ground motion evaluation method.

■Point of view from software

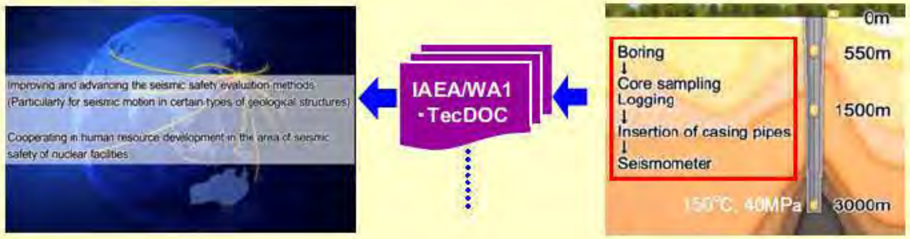
<B>Deep Underground Structure Seismic Ground Motion Evaluation

- ○Investigation of 3D underground structure modeling, proposal of observation technology and analysis method.

■Point of view from multipurpose usage

<C>Propose Investigation Observation Technology/Analysis Evaluation Method, Simplified Underground Structure Investigation Method

- ○Save the technology and know-how of evaluation of deep boring digging/investigation, deep borehole seismic observation, simple underground structure investigation method, seismic ground motion propagation characteristics to document (IAEA WA1・TecDOC etc.), and release domestically and internationally to be able to use as common technology.



---

3. Overview of the Project and Evaluation of its Achievement (3/3)

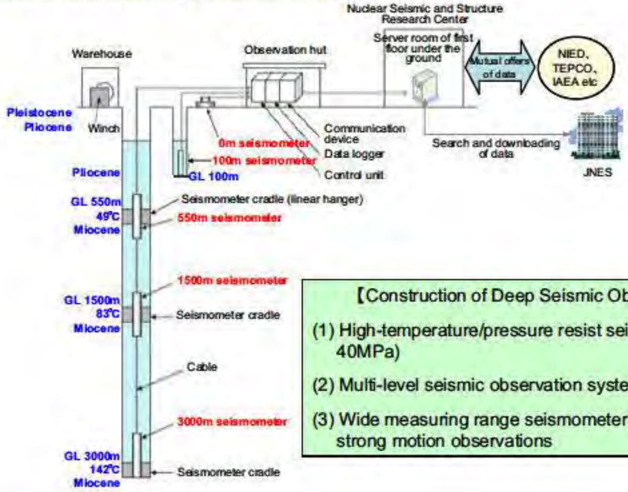
Status of achievement (FY2009 to FY2016)

Sign	Large item	Small item	Status of achievement
A1	Deep Boring	Deep Boring	
		Investigation	
A2	Construction of Deep Seismic Observation System	Develop High-temperature/High-pressure, High-performance Multi-depth Borehole Seismometer	
		Construct Seismic Observation System	
		Deep Vertical Array Seismic Observation	
A3	Deep Underground Structure Investigation	Geophysical Exploration	
		Horizontal Array Seismic Observation	
B	Deep Underground Structure Seismic Ground Motion Evaluation	Consider 3D Underground Structure Model	
		Propose Site Characteristics Evaluation Method	
C	Propose Investigation Observation Technology/Analysis Evaluation Method, Simplified Underground Structure Investigation Method	Deploy to Earthquake Countries and Newcomer Countries	
		Summarize Issues and Improvement	

【Status of achievement】○ : Good, △ : Slightly good, × : Not good

4. Overview of the Results (1/3)

A2. Construction of Deep Seismic Observation System



【Construction of Deep Seismic Observation System】

(1) High-temperature/pressure resist seismometer (150 degrees, 40MPa)

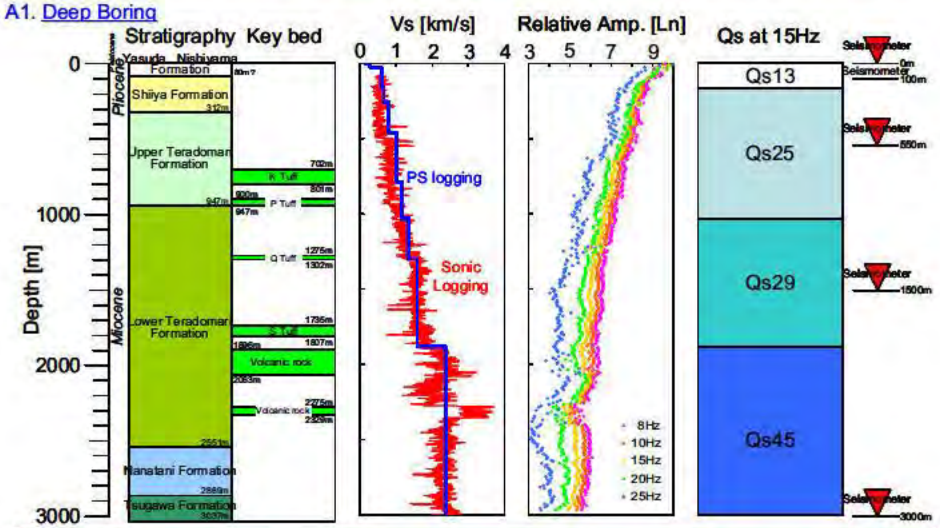
(2) Multi-level seismic observation system using single borehole

(3) Wide measuring range seismometer for Microtremor to strong motion observations

【Achievement】 1 June, 2012: Deep Seismic Observation System was put into use.

4. Overview of the Results (2/3)

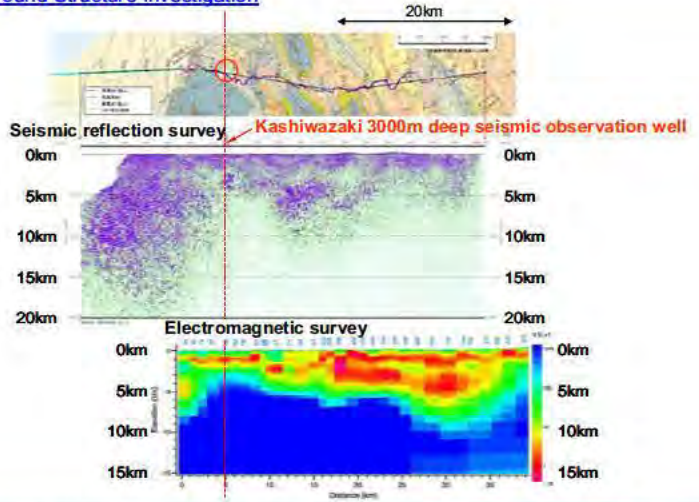
A1. Deep Boring



【Achievement】 We carried out 3000m deep boring reaching to bedrock equivalent to seismic bedrock, geological investigation, various logging (PS logging, density logging etc.), and obtained verified data to construct site characteristics evaluation method at deep underground.

4. Overview of the Results (3/3)

A3. Deep Underground Structure Investigation



【Achievement】 Implemented seismic reflection survey, electromagnetic survey (MT/AMT method), gravity survey, microtremor array survey etc. with an aim to understand in details deep underground structure at Kashiwazaki deep seismic observation well surroundings. Obtained supporting data, worth considering set up method of rational underground structure model.

5. Achievement Status of Important Items

Status of achievement (FY2012, JNES self-evaluation)

Sign	Large item	Small item	Status of achievement
A1	Deep Boring	Deep Boring	○
		Investigation	○
A2	Construction of Deep Seismic Observation System	Develop High-temperature/High-pressure, High-performance Multi-depth Borehole Seismometer	○
		Construct Seismic Observation System	○
		Deep Vertical Array Seismic Observation	△
A3	Deep Underground Structure Investigation	Geophysical Exploration	○
		Horizontal Array Seismic Observation	△
B	Deep Underground Structure Seismic Ground Motion Evaluation	Consider 3D Underground Structure Model	△
		Propose Site Characteristics Evaluation Method	△
C	Propose Investigation Observation Technology/Analysis Evaluation Method, Simplified Underground Structure Investigation Method	Deploy to Earthquake Countries and Newcomer Countries	△
		Summarize Issues and Improvement	×

【Status of achievement】○ : Good, △ : Slightly good, × : Not good

6. Future Issues and Handlings

■Issues and measures

<1>Improvement plan for certainty of construction of seismic observation in deep borehole and accuracy improvement of observation data

⇒Issues and lessons obtained from the project

･･･What we learned through construction of this system, and what we will learn in the future.

･･･Consideration of improvement from the cost-performance view point.

<2>Reflected issues and improvement plans for deep underground structure model

⇒Understand influence to accuracy of 3D deep underground structure model and seismic ground motion evaluation

･･･Verify past 3D deep underground structure model.

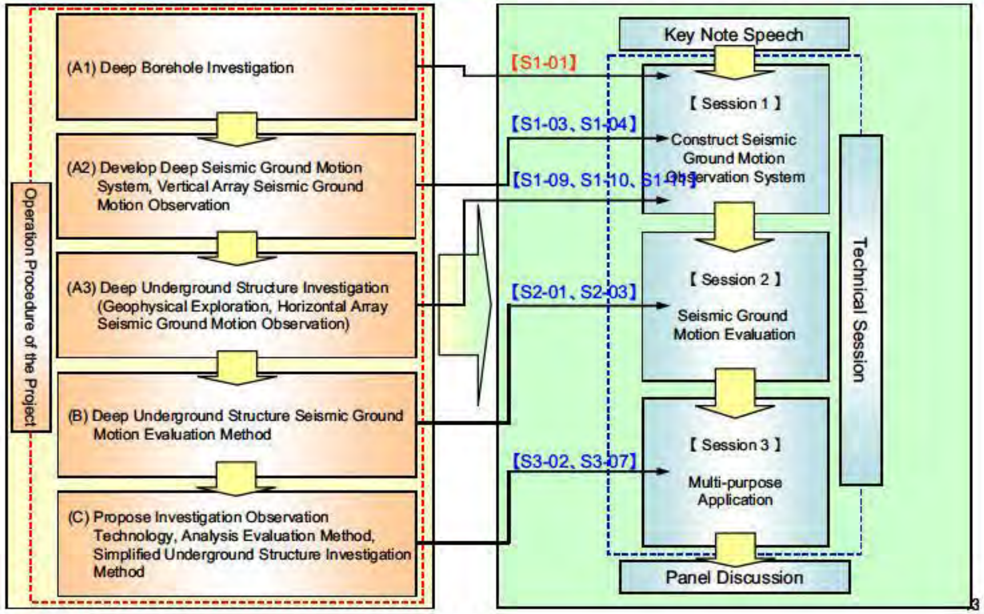
･･･Consider investigation method and data for construction of 3D underground structure model.

<3>Discussions on direction of seismic ground motion observation technology/underground structure investigation technology

⇒Economical and simple seismic observation technology/exploration technology and minimum required observation precision at earthquake country

･･･Discussions on international sharing of seismic ground motion observation data and desirable application.

Relationships between Results of the Support Organization in the Project and Sessions of this Workshop



Operation Procedure of the Project

(A1) Deep Borehole Investigation

(A2) Develop Deep Seismic Ground Motion System, Vertical Array Seismic Ground Motion Observation

(A3) Deep Underground Structure Investigation (Geophysical Exploration, Horizontal Array Seismic Ground Motion Observation)

(B) Deep Underground Structure Seismic Ground Motion Evaluation Method

(C) Propose Investigation Observation Technology, Analysis Evaluation Method, Simplified Underground Structure Investigation Method

【S1-01】

【S1-03、S1-04】

【S1-09、S1-10、S1-11】

【S2-01、S2-03】

【S3-02、S3-07】

Key Note Speech

【Session 1】

Construct Seismic Ground Motion Observation System

【Session 2】

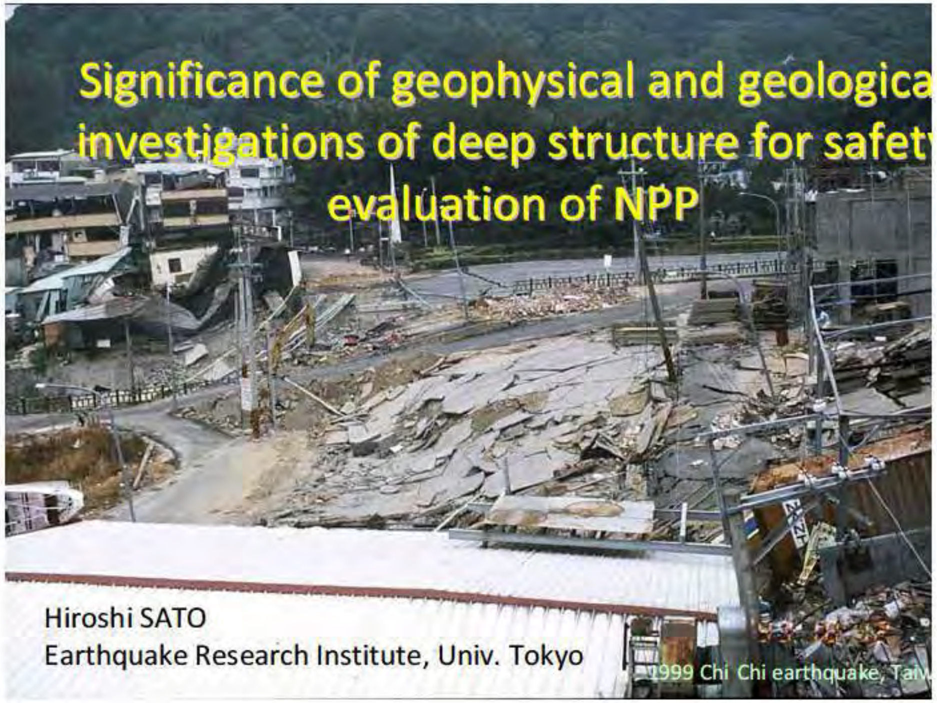
Seismic Ground Motion Evaluation

【Session 3】

Multi-purpose Application

Technical Session

Panel Discussion

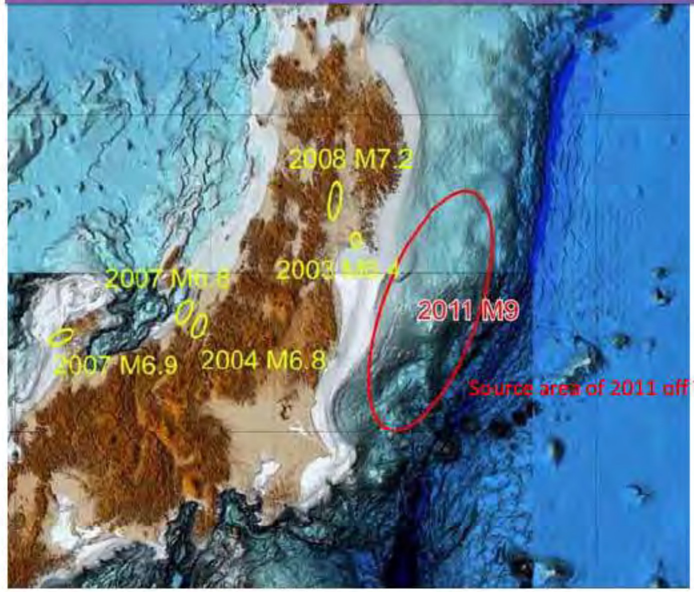


Significance of geophysical and geologica investigations of deep structure for safet evaluation of NPP

Hiroshi SATO
Earthquake Research Institute, Univ. Tokyo

1999 Chi Chi earthquake, Taiw

Damaging earthquakes since 2000 prior to the M9 Tohoku EQ



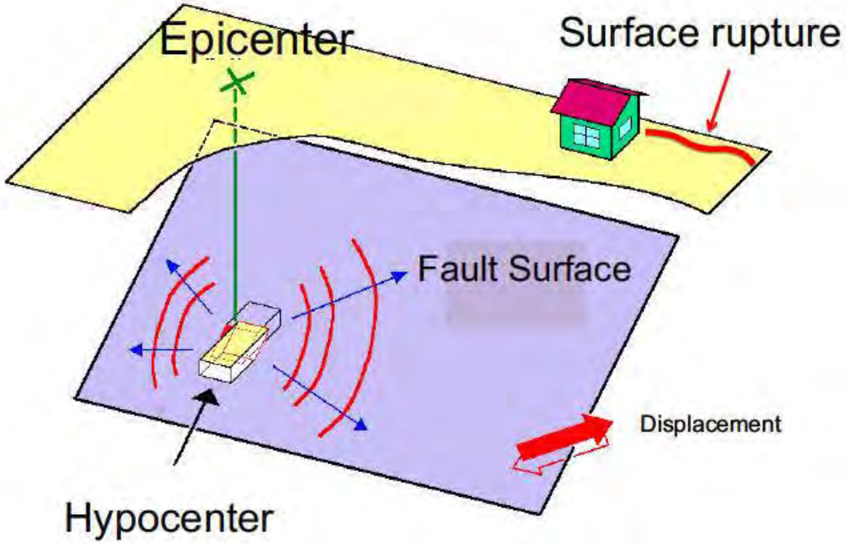
Major inland damaging earthquake in Japanese islands last 20 years

- 2011 Fukushima Hamadori M7.0 surface rupture ☆
- 2008 Iwate-Miyagi Nairiku M7.2 part ×
- 2007 Noto-Hanto M6.9 submarine part ☆
- 2007 Chuetsu-oki M6.8 submarine ? ☆
- 2004 Chuetsu M6.8 part ☆
- 2000 Tottoriken Seibu M7.2 part ×
- 1995 Kobe M7.2 part ☆

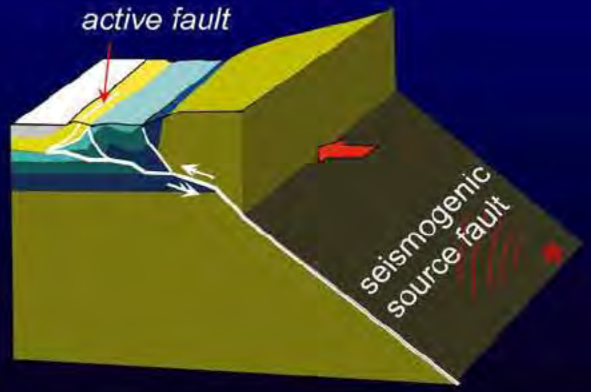
☆ Recognized as active faults before the earthquake
× Not recognized as active faults

Surface rupture associated with the 2011 Hamadori earthquake (M7.0).4.11

2nd SODB WS S1-02-1

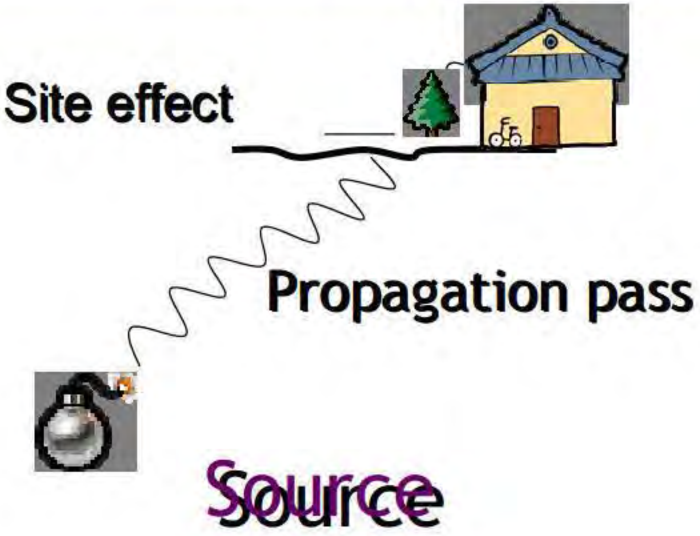


Active – Seismogenic source fault system

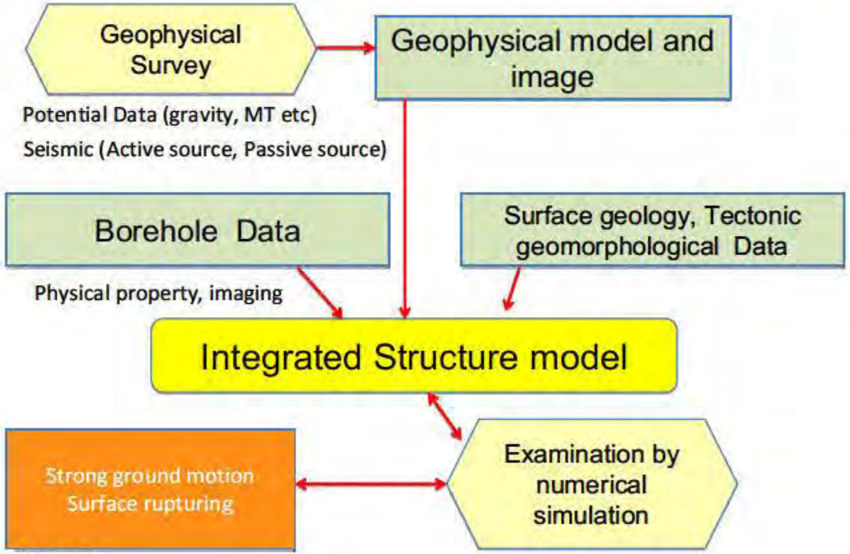


Understanding of the whole system at depth is important.

Evaluation of strong ground motions



Multidisciplinary approach for safety evaluation of NPP



Geophysical Survey

Geophysical model and image

Potential Data (gravity, MT etc)

Seismic (Active source, Passive source)

Borehole Data

Physical property, imaging

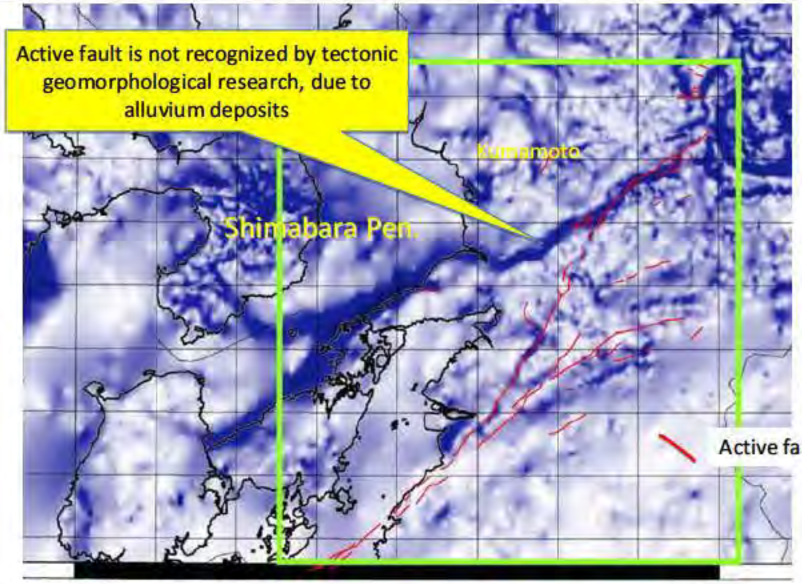
Surface geology, Tectonic geomorphological Data

Integrated Structure model

Examination by numerical simulation

Strong ground motion
Surface rupturing

Bouger Anomaly Map of western Kyushu



Active fault is not recognized by tectonic geomorphological research, due to alluvium deposits

Gravity gradient is after Kudo, K., Chubu Univ..

Map of geomagnetic anomaly of Western Australia

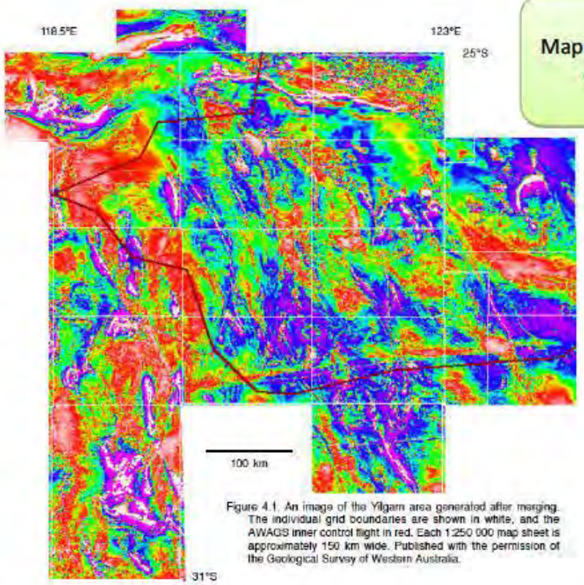
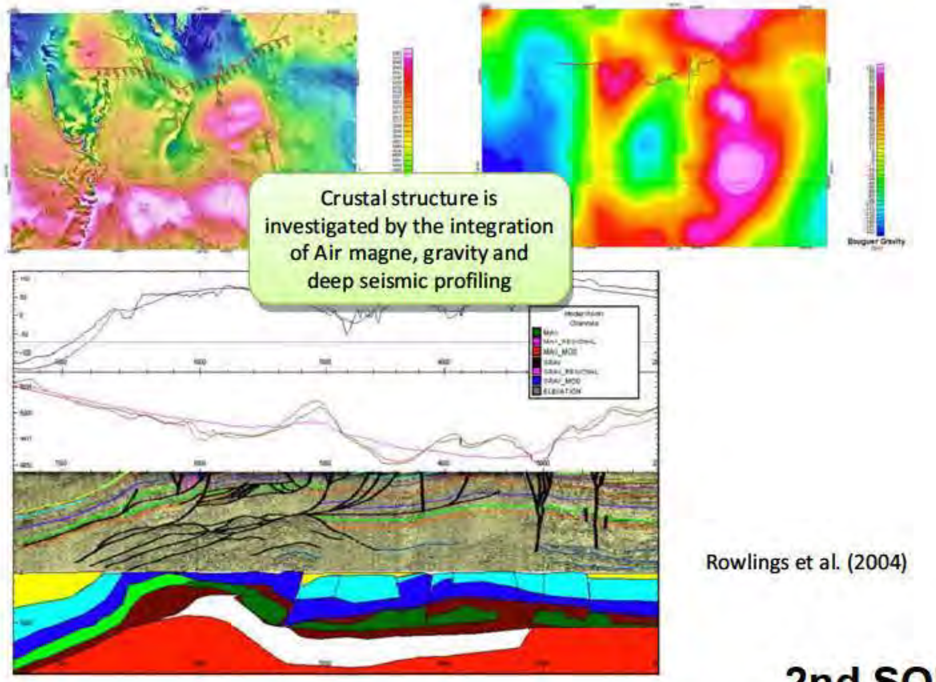


Figure 4.1. An image of the Yilgarn area generated after merging. The individual grid boundaries are shown in white, and the AWAGS inner control flight in red. Each 1:250 000 map sheet is approximately 150 km wide. Published with the permission of the Geological Survey of Western Australia.

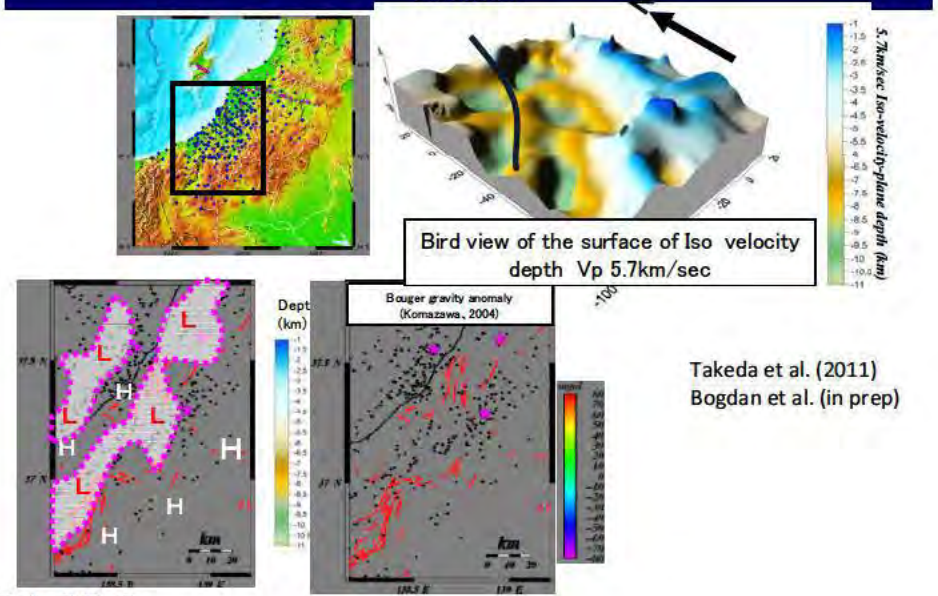
Milligan et al. (2001)



Crustal structure is investigated by the integration of Air magne, gravity and deep seismic profiling

Rowlings et al. (2004)

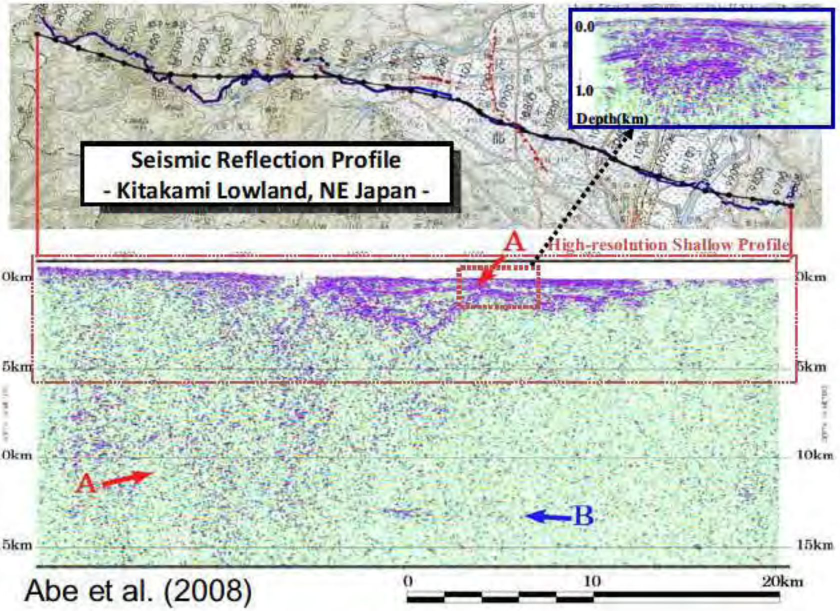
Seismic Tomographic image by dense earthquake observation network



Bird view of the surface of Iso velocity depth Vp 5.7km/sec

Takeda et al. (2011)
Bogdan et al. (in prep)

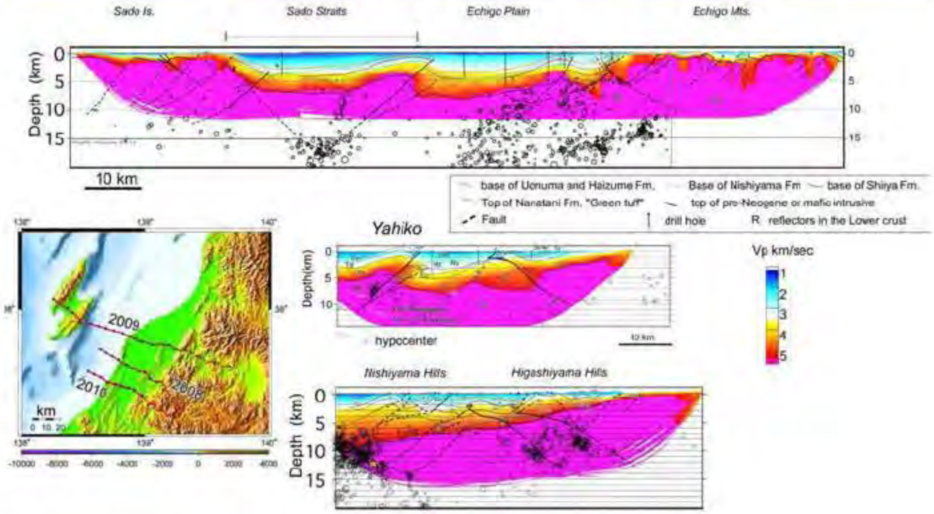
Example of deep seismic profile across active fault



Seismic Reflection Profile
- Kitakami Lowland, NE Japan -

Abe et al. (2008)

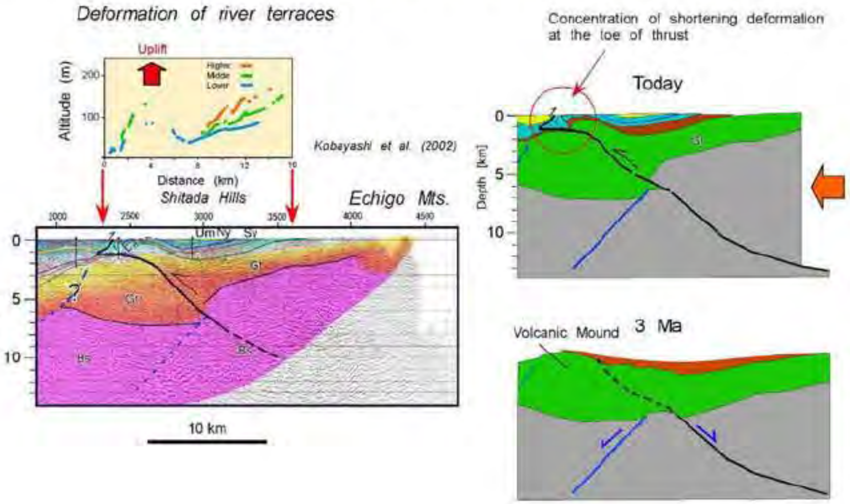
Velocity profiles across the Niigata sedimentary basin



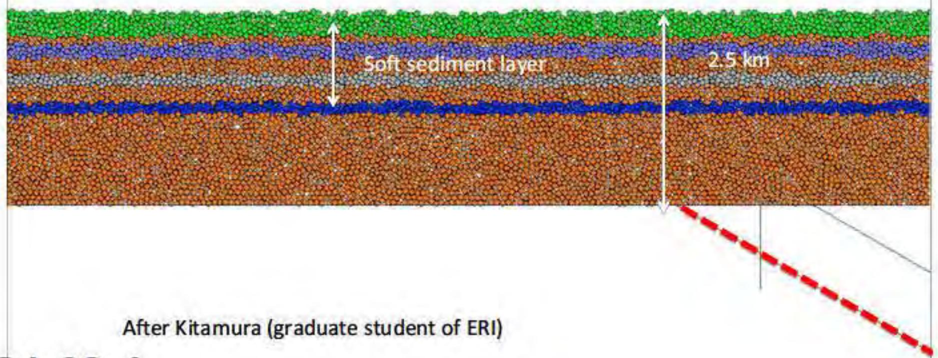
O Hypocentral distribution after Takeda et al (2012)

Sato et al.（2009, 2010,2011）

Fault evolution of the eastern part of the seismic section

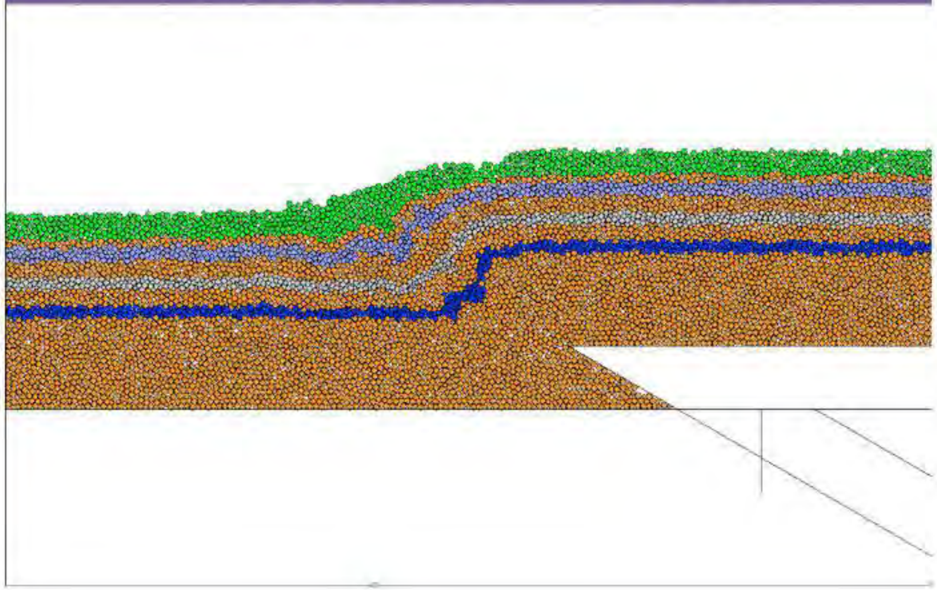


Numerical model showing the deformation of the thrus front by discrete element method

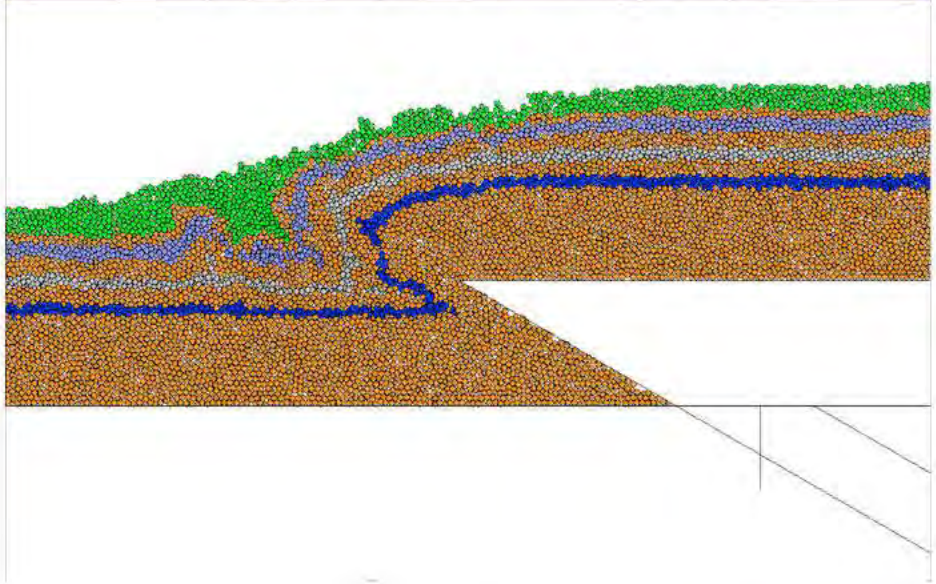


After Kitamura (graduate student of ERI)

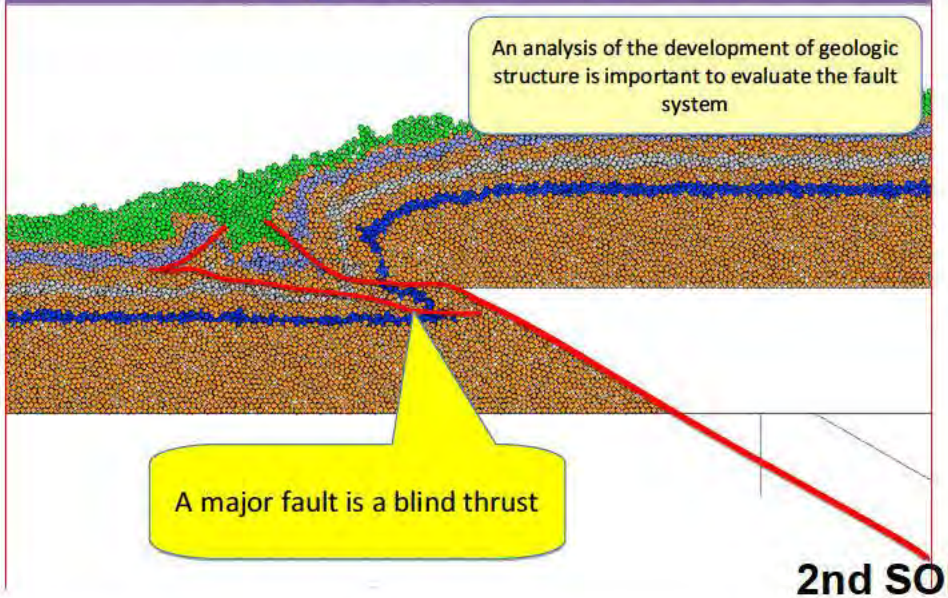
Numerical model showing the deformation of the thrus front by discrete element method



Numerical model showing the deformation of the thrus front by discrete element method



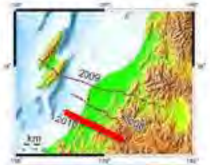
Numerical model showing the deformation of the thrus front by discrete element method

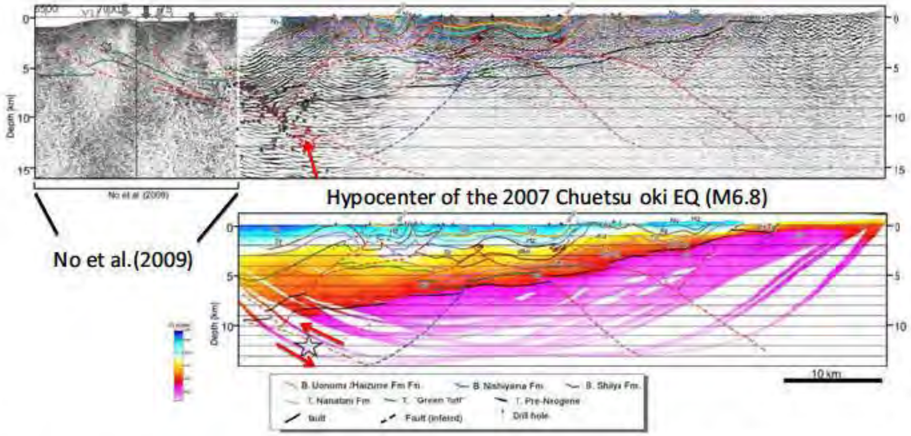


An analysis of the development of geologic structure is important to evaluate the fault system

A major fault is a blind thrust

2010 Higashiyam-Mishima seismic section Northern part of the focal area of 2007 Chuestu-oki EQ (M6.8)

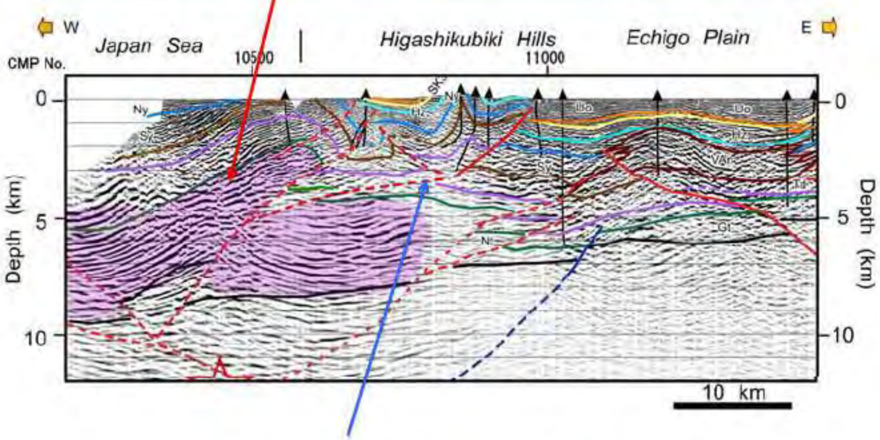




Hypocenter of the 2007 Chuetsu oki EQ (M6.8)

No et al.(2009)

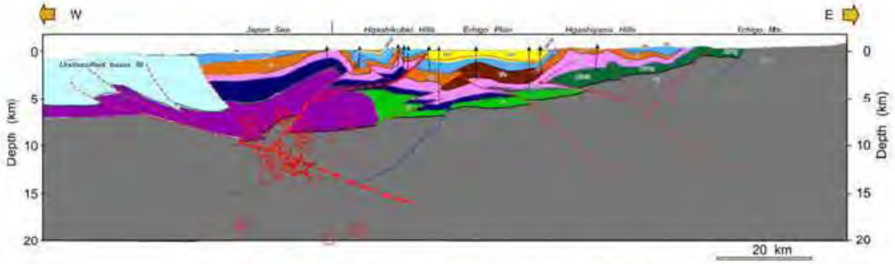
Sato et al. (2010)



Reflective Miocene volcanics: probable dolerite sheets

Shallow detachment is developed in over pressured mudstone

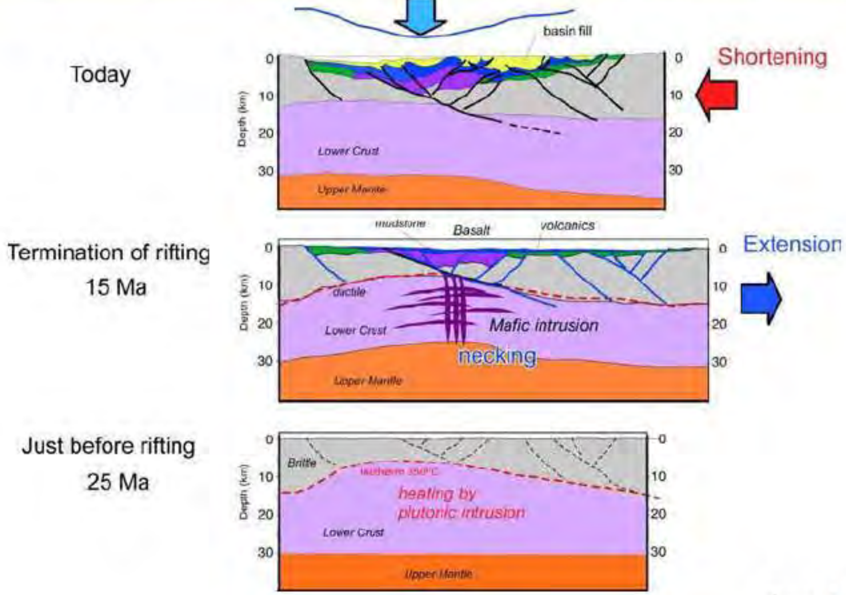
Geologic cross section across the northern part of the epicentral area of 2007 Chuetsu-oki earthquake



○ Aftershocks associated with the 2007 Chuetsu oki earthquake

☆ Main shock after Shinohara et al. (2009, EPS)

Basin development along the 2010 seismic line

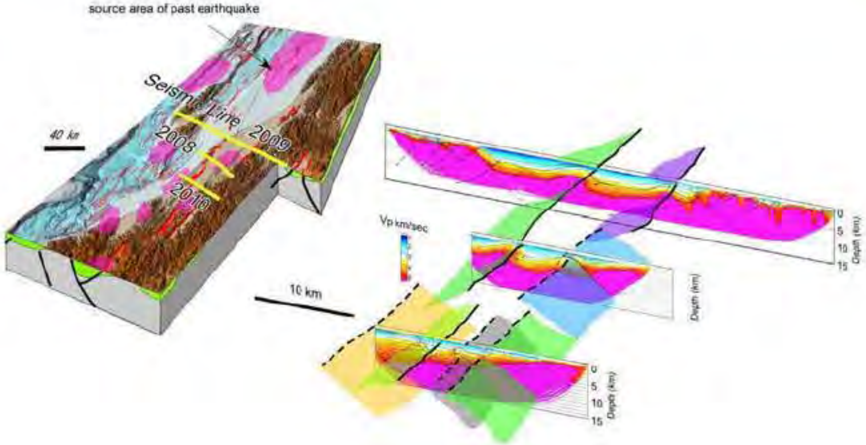


Today

Termination of rifting
15 Ma

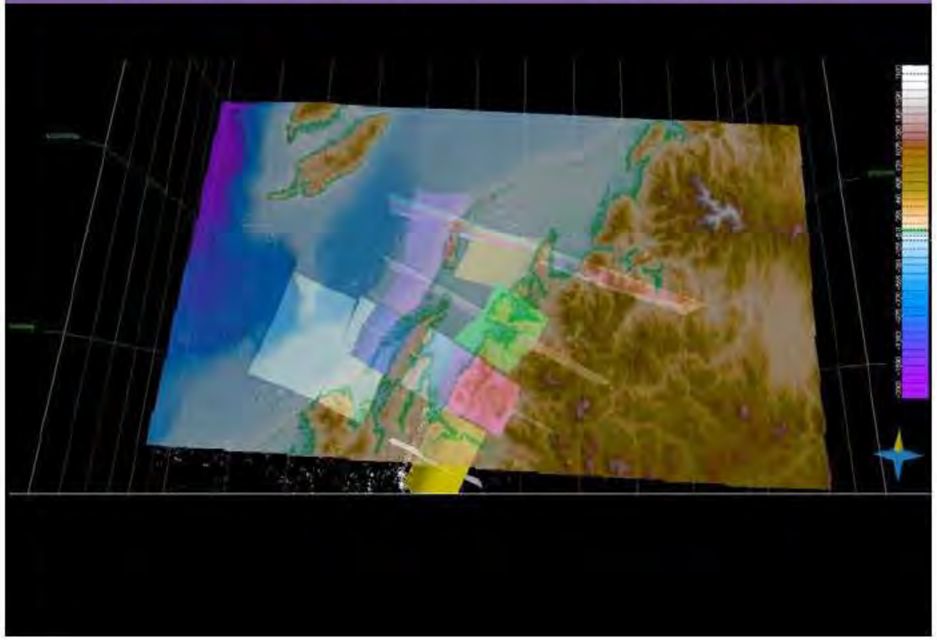
Just before rifting
25 Ma

Geometry of source faults beneath the Niigata Basin

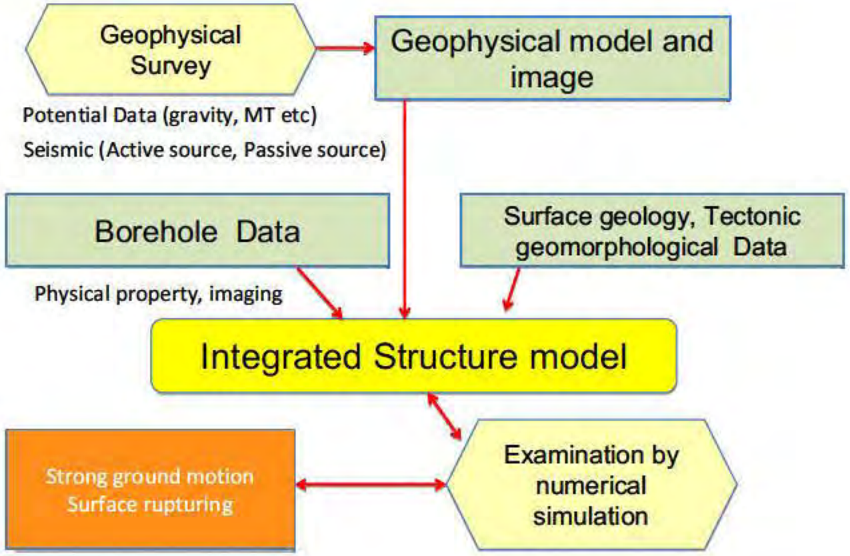


2nd SODB WS S1-02-6

3D model of source faults in Chuetsu district



Multidisciplinary approach for safety evaluation of NPP



Geophysical Survey

Potential Data (gravity, MT etc)

Seismic (Active source, Passive source)

Geophysical model and image

Borehole Data

Physical property, imaging

Surface geology, Tectonic geomorphological Data

Integrated Structure model

Strong ground motion
Surface rupturing

Examination by numerical simulation

The 2nd International Workshop on Seismic Observation in Deep Borehole and Its Applications

Construction of System for Seismic Observation in Deep Borehole (SODB)

- Development of Multi-depth, High-temperature/pressure resistance seismometer

8 November, 2012
At Niigata Institute of Technology

Yutaka Mamada
Japan Nuclear Energy Safety Organization (JNES)

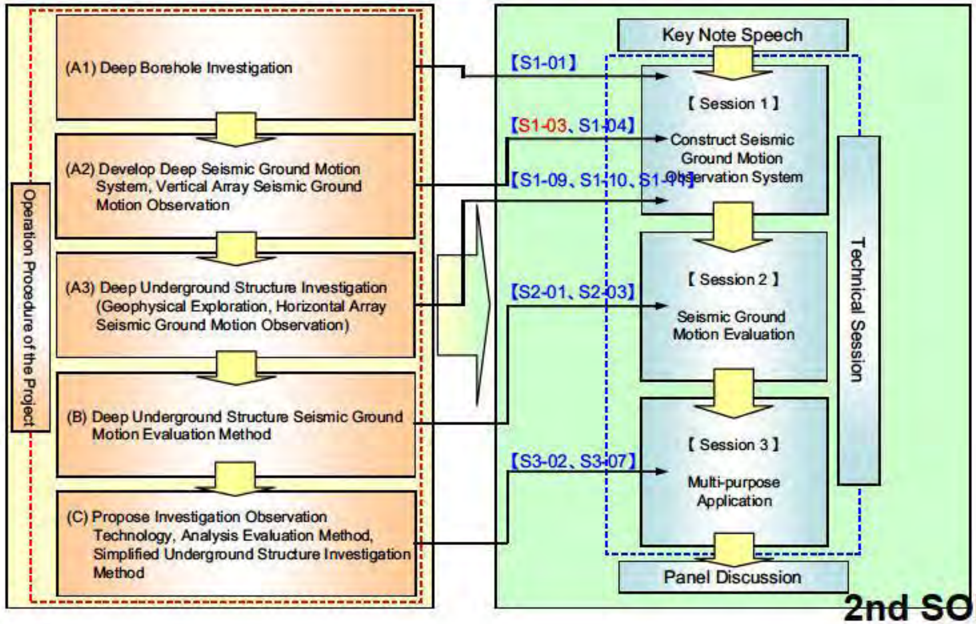
Contents

1. Objective of this project
2. Overview of technology for SODB
3. Key points for development of observation tools
   - 3.1 seismometer
     - ・high-temp. and -pressure resistance
     - ・broadband frequency resp., high sensitive and also available for strong motion
     - design, manufacture and test
   - 3.2 Installation method of multi- depth seismometer
4. Examples of collection data
5. Summary and future problems

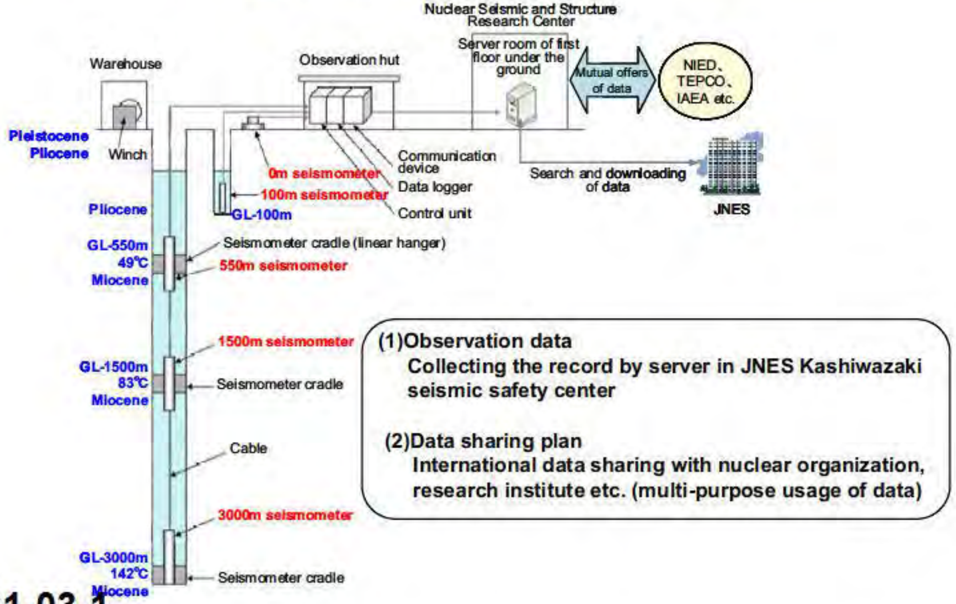
・instrument design and confirmation test

・overview of tests required for development
・short summary of tests

Relationships between Results of the Support Organization in the Project and Sessions of this Workshop



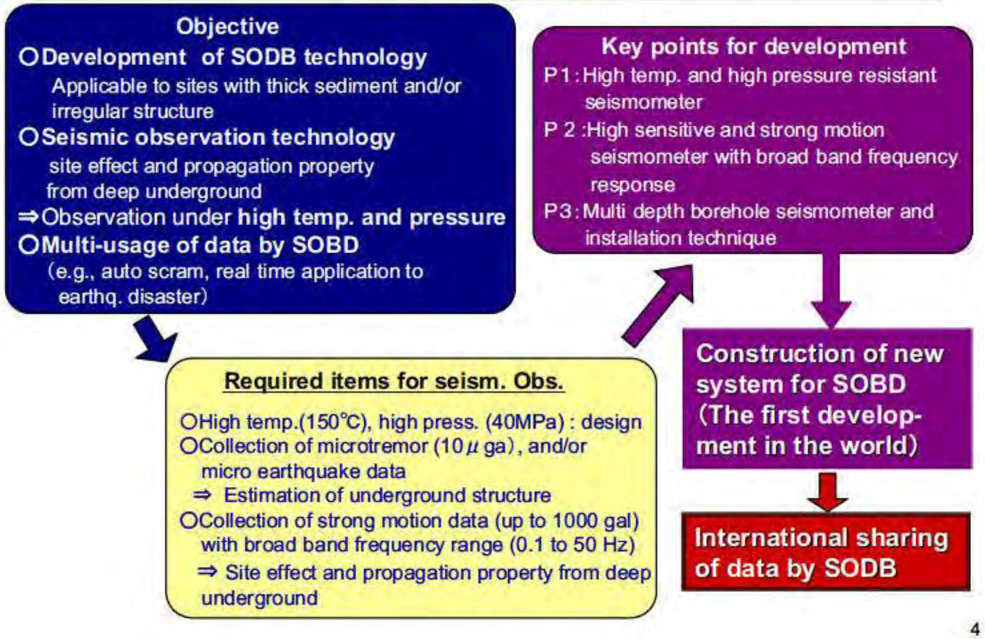
Overview of system of SODB



(1)Observation data
Collecting the record by server in JNES Kashiwazaki seismic safety center

(2)Data sharing plan
International data sharing with nuclear organization, research institute etc. (multi-purpose usage of data)

1. Objective of this project



Objective

- ○**Development of SODB technology**
  Applicable to sites with thick sediment and/or irregular structure
- ○**Seismic observation technology**
  site effect and propagation property from deep underground
- ⇒Observation under **high temp. and pressure**
- ○**Multi-usage of data by SOBD**
  (e.g., auto scram, real time application to earthq. disaster)

Key points for development

- P1 : High temp. and high pressure resistant seismometer
- P 2 : High sensitive and strong motion seismometer with broad band frequency response
- P3 : Multi depth borehole seismometer and installation technique

Required items for seism. Obs.

- ○High temp.(150℃), high press. (40MPa) : design
- ○Collection of microtremor (10 μ ga), and/or micro earthquake data
  - ⇒ Estimation of underground structure
- ○Collection of strong motion data (up to 1000 gal) with broad band frequency range (0.1 to 50 Hz)
  - ⇒ Site effect and propagation property from deep underground

Construction of new system for SOBD (The first development in the world)

International sharing of data by SODB

2. Over view of technology for seismic observation in deep borehole

Specification of observation system

(I)Specification of seismometer

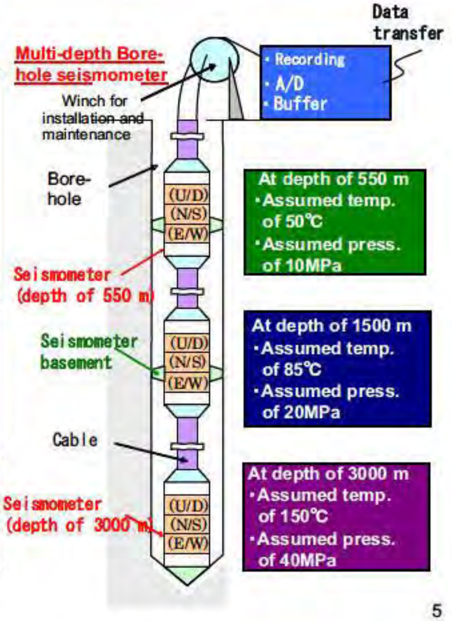
I 1 High temp. and press. : 150℃ and 40MPa
I 2 1 3 components (vertical and horizontal 2 comp.)
I 2 2 Freq. response : constant at 1to 50 Hz
resolution:10 ^{5}gal（at 1Hz）, S/N :100dB以上、
Max accerelation: ±1 000gal
I 3 Specification of cable
temp.:150℃、pressure:40MPa
tensile load:up to 3tf（multi channel:at least 18 chs.)

(II)Specification of seismometer basement

Applicable to contacting to borehole at any depths
Stability of contact（stable up to 20 Hz ）
Applicable to seismometer maintenance
（designed but practically confirmed when maintenance)

(III) Specification of recorder

Sampling rate: higher than 200 Hz and continuous recording with UPS
Online real time data transfer system



At depth of 550 m
・Assumed temp. of 50℃
・Assumed press. of 10MPa

At depth of 1500 m
・Assumed temp. of 85℃
・Assumed press. of 20MPa

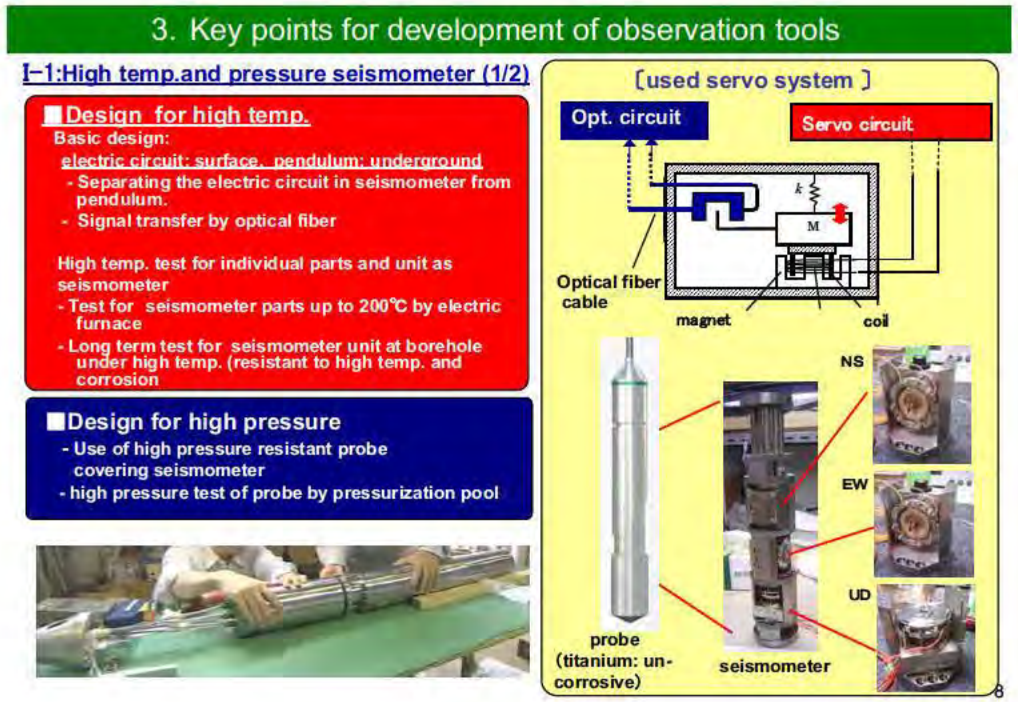
At depth of 3000 m
・Assumed temp. of 150℃
・Assumed press. of 40MPa

■Instrument design and confirmation test ①

Tools	Required design	Tests to confirm required design	Remarks
Seismo-meter (I-1)High temp.& pressure	Temperature:150℃	Heating test up to 200 ℃ by electric furnace	32 days
	Pressure: 30MPa	Pressurization test up to 50 MPa	Seismometer probe (case)
	Acceleration test for high temperature	Periodic temperature changing test between -10 and 120 ℃	Periodic:½day during10 days
	Test against high temp. and pressure	Long term field test in borehole under high temp. (120 ℃,10Mpa)	3 months
Seismo-meter (I-2) Frequency resp.	Freq. Res. :0.1 to 50 Hz	Confirmation by electrical signal (Comparison of in and out put signals)	Freq.Res. :0.1 to 50 Hz
	Resolution:10^{-5} gal (at 1 Hz)	Field experiments under low noise area. Comparing microtremor recorded by seismometer (VSE15D) and developed seismometer	Resolution:10^{-5} gal (at 1 Hz)
	Max. Acc. : greater than 2000 gal	In-house test by shaker	Max. Acc. : greater than 2000 gal

■Instrument design and confirmation test ②

Tools	Required design	Tests to confirm required design	Remarks
(I-3) Cable	Designed tensile strength: 3tf	Tensile loading test up to 3tf of cable unit (cable with cable head)	
	Cross talk test for multi-channel cable	Checking of signal interaction for any pairs of channels	
(II) Seismo-meter basement	Stable contact to bore-hole Freq. range: 0.1 to 50 Hz	Comparison of records: Bottom seismometer and seismometer on basement in middle part in borehole	



3. Key points for development of observation tools

I-1:High temp.and pressure seismometer (1/2)

■Design for high temp.

Basic design:

electric circuit: surface, pendulum: underground

- Separating the electric circuit in seismometer from pendulum.
- Signal transfer by optical fiber

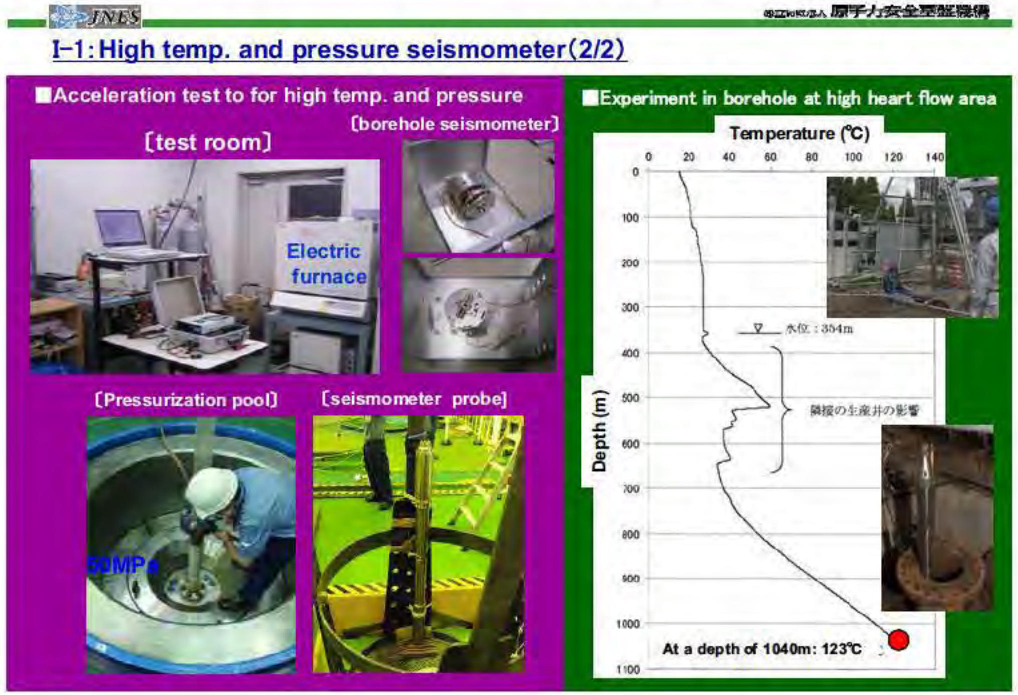
High temp. test for individual parts and unit as seismometer

- Test for seismometer parts up to 200℃ by electric furnace
- Long term test for seismometer unit at borehole under high temp. (resistant to high temp. and corrosion

■Design for high pressure

- Use of high pressure resistant probe covering seismometer
- high pressure test of probe by pressurization pool

〔used servo system 〕



I-1: High temp. and pressure seismometer(2/2)

■Acceleration test to for high temp. and pressure

〔borehole seismometer〕

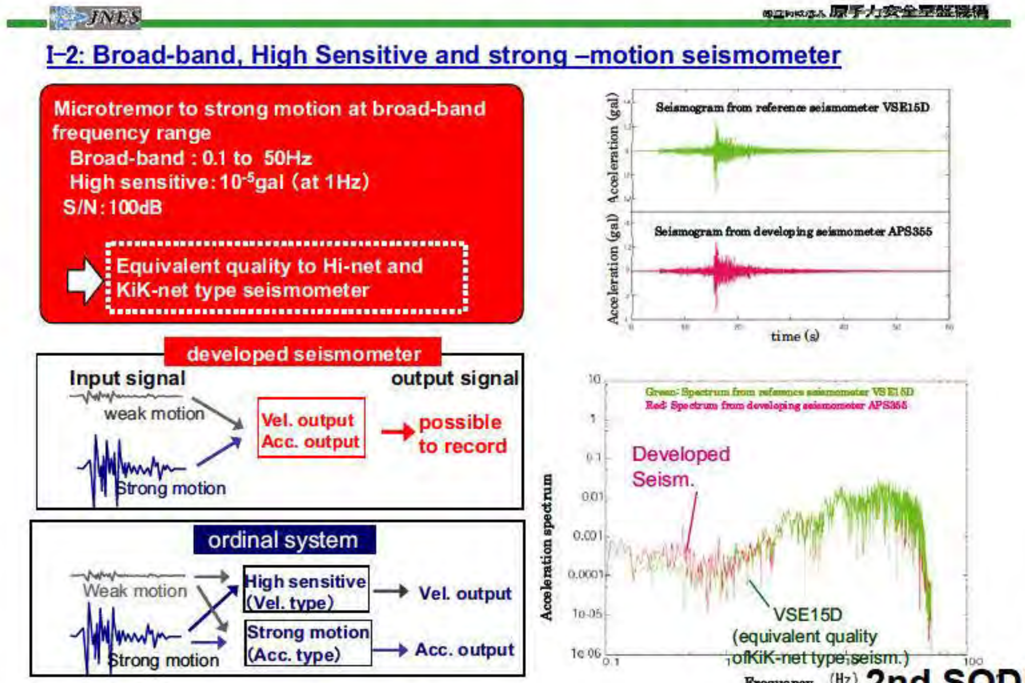
〔test room〕

〔Pressurization pool〕

〔seismometer probe〕

■Experiment in borehole at high heart flow area

At a depth of 1040m: 123℃



I-2: Broad-band, High Sensitive and strong –motion seismometer

Microtremor to strong motion at broad-band frequency range

Broad-band : 0.1 to 50Hz

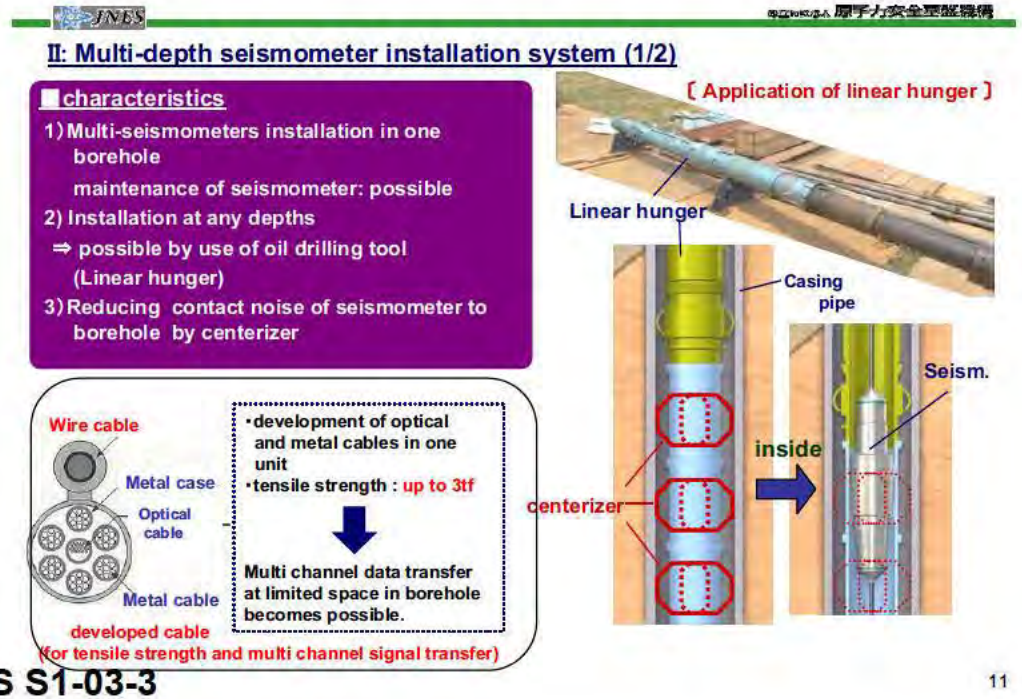
High sensitive: 10^{-5}gal (at 1Hz)

S/N: 100dB

⇨ Equivalent quality to Hi-net and KiK-net type seismometer

developed seismometer

ordinal system



II: Multi-depth seismometer installation system (1/2)

■characteristics

1) Multi-seismometers installation in one borehole

maintenance of seismometer: possible

2) Installation at any depths

⇒ possible by use of oil drilling tool (Linear hunger)

3) Reducing contact noise of seismometer to borehole by centerizer

- development of optical and metal cables in one unit
- tensile strength : up to 3tf

Multi channel data transfer at limited space in borehole becomes possible.

developed cable (for tensile strength and multi channel signal transfer)

〔Application of linear hunger〕

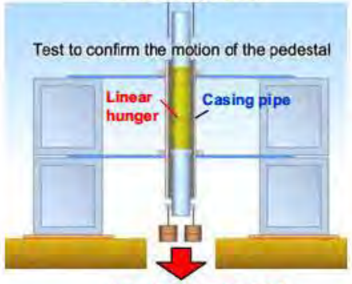
II: Multi-depth seismometer installation system (2/2)

■Field experiment for checking stability of seismometer contact

(1) Loading test of linear hunger
- Confirming the stability of contact to borehole

(2) Effect of seismometer basement on records
- Confirming equivalence of event records independent of seismometer basement

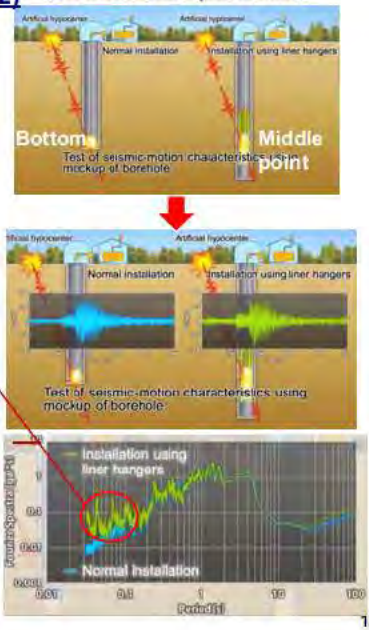
〔Loading test〕



Loading up to 10tf

Similar spectra between 0.1 to 20 Hz

〔Method of experiment〕



Summary of instrument design and confirmation tests ①

Tools	Required design	Tests to confirm required design	Practical design after tests
Seismo-meter (I-1)High temp.& pressure	Temperature:150℃	○	
	Pressure:30MPa	○	
	Acceleration test for high temperature	○	
	Test against high temp. and pressure	○	
Seismo-meter (I-2) Frequency resp.	Freq. Res.:0.1-50 Hz	○	
	Resolution:10^{-5} gal (at 1 Hz)	○	
	Max. Acc. : greater than 2000 gal	Difficult satisfying with resolution	Design change Max. Acc. :up to 1000 gal

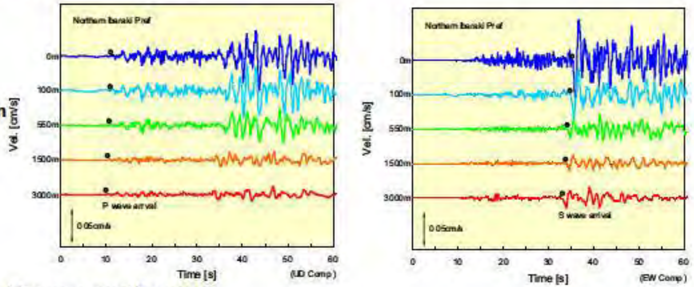
Summary of instrument design and confirmation tests ②

(I-3) Cable	Designed tensile strength: 3tf	○	
	Cross talk test for multi-channel cable	Cross talk is negligible	
(II) Seismo-meter basement	Stable contact to bore-hole Freq. range: 0.1 to 50 Hz	Stable up to 20Hz	Correction necessary above 20 Hz ranges.

4. Examples of collection data

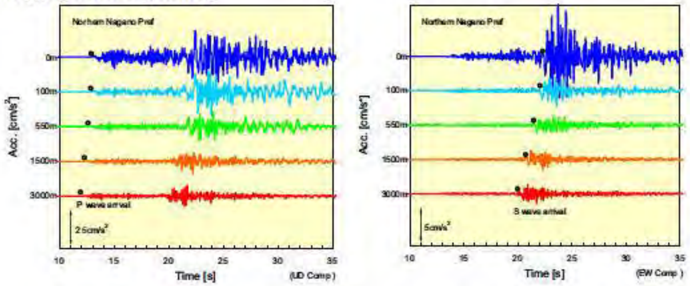
Event 1 (Northern Ibaraki earthquake)

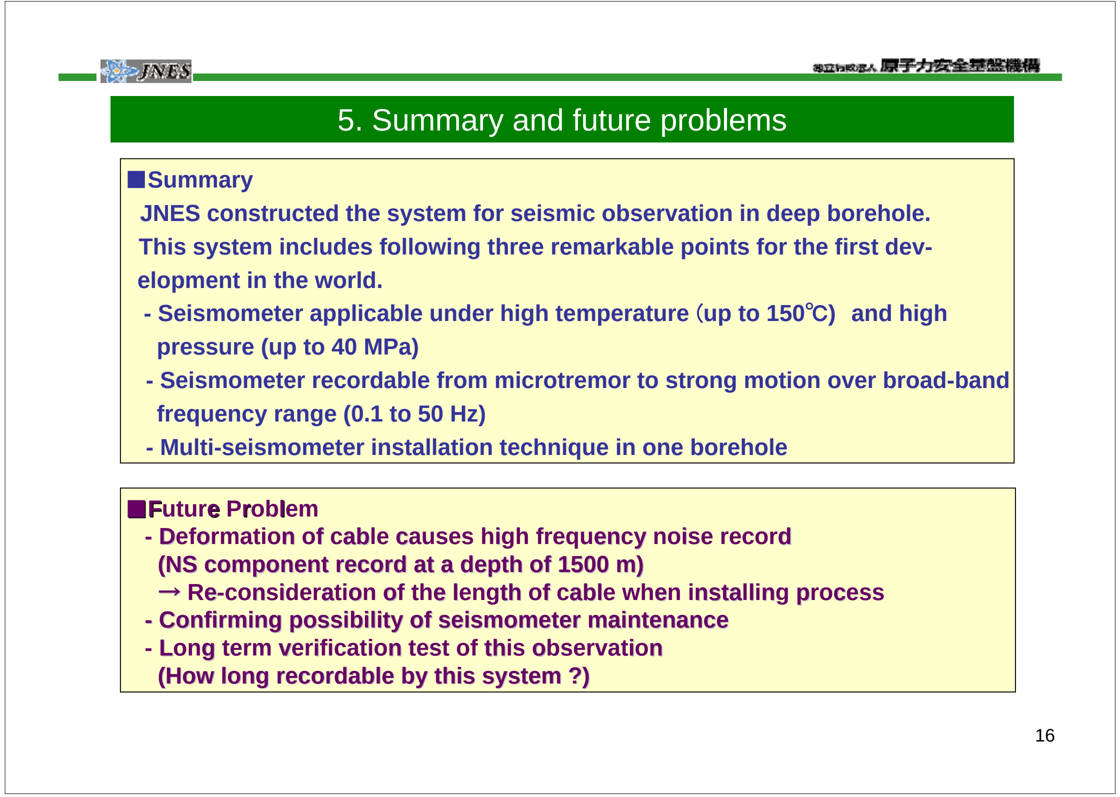
Mj=5.2
Epi. Dist.= 233.2 km
Hypo. Dist.=233.3 km
depth=7.2 km



Event 2 (Northern Nagano earthquake)

Mj=5.2
Epi. Dist.= 60.0 km
Hypo. Dist.=60.6 km
depth=8.5km





5. Summary and future problems

■Summary

JNES constructed the system for seismic observation in deep borehole. This system includes following three remarkable points for the first development in the world.

- **Seismometer applicable under high temperature (up to 150℃) and high pressure (up to 40 MPa)**
- **Seismometer recordable from microtremor to strong motion over broad-band frequency range (0.1 to 50 Hz)**
- **Multi-seismometer installation technique in one borehole**

■Future Problem

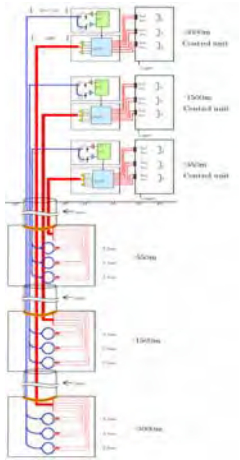
- **Deformation of cable causes high frequency noise record (NS component record at a depth of 1500 m)**
  → Re-consideration of the length of cable when installing process
- **Confirming possibility of seismometer maintenance**
- **Long term verification test of this observation (How long recordable by this system ?)**

Tokyo Sokushin
Design, manufacture, sale and maintenance of the earthquake and vibration measuring equipments

Development of Deep Borehole Seismometer

TOKYO SOKUSHIN .,CO LTD.
KURAHASHI INDUSTRIES CO.,LTD.
SEISMIC INSTRUMENTS GROUP
Satoru Wada

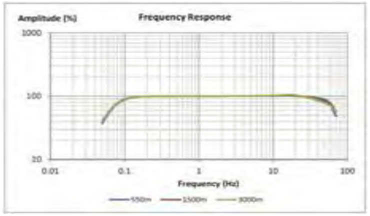
Measurement System (APS-355)



- Servo Velocity meter.
  It consists of spring-mass system and control part (servo circuit).
- Control part (servo circuit) on the ground.
- Only spring-mass system is installed in underground.
- Optical detection of mass movement (volume of light).
- 3 cascade sensors (multi-depth).

Specification of Seismometer (ASP-355)

- Frequency response
  : 0.1Hz～50Hz (-3dB)
- Sensitivity : [Velocity] 250V/m/s (2.5V/cm/s)
  [Acceleration] 10mV/Gal
- Measurement Range (Maximum)
  : 0.2m/s (20cm/s) , 1000Gal
- Resolution : Less than 10 μ Gal (at 1Hz)
- Temperature range
  : -10 to 150 deg C
- Maximum Pressure
  : 40MPa



Prerequisites

I. Seismometer using under high temperature (150 deg C) and high pressure (30MPa) at a depth of 3000m.

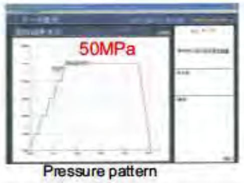
II. Measurement covering from strong motion to weak motion.

III. 3 cascade sensors (multi-depth).

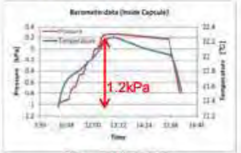
High Pressure and High Temperature Test (1)
High Pressure Test

- High pressure test of borehole capsule.
  50MPa・4hours
  Measurement using barometer in capsule.

Capsule

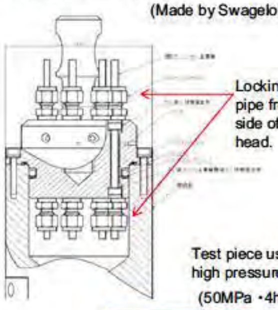


Pressure pattern



Barometer data

- Mold system of capsule head.
  Using tube fitting system.
  (Made by Swagelok Company)



Locking metal pipe from both side of capsule head.

Test piece used in high pressure test.
(50MPa・4hours)

Water leak is not found.

High Pressure and High Temperature Test (2)
High Temperature Test

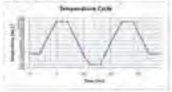
・High temperature test of spring-mass system.

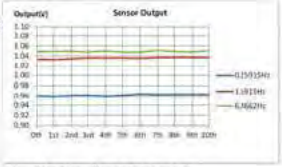
Loose screw occurred at first test.
It was due to the temperature cycle.

Reinforcement of the screw fitting.

・Temperature cycle test

Temperature range
-10 to 120 deg C
10cycle Test
(1cycle/24hours)





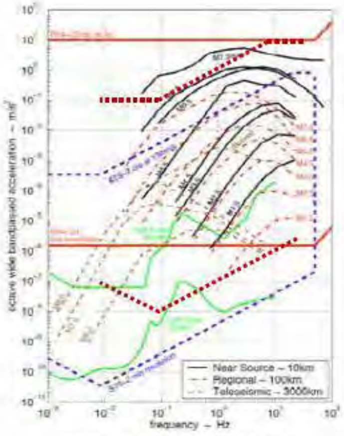
We confirmed the invariance of performance.

・High temperature resistance test

Temperature : 200 deg c
Duration : 1 month

We confirmed invariance of senor response.

Measurement Range (1)

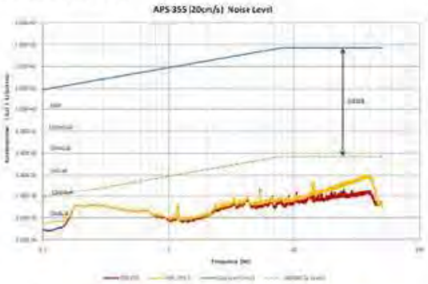


(Modified Clinton, J. F., (2004),)

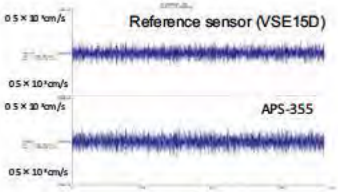
- Strong motion velocity meter.
  Measureable from strong motion (M7) to micro tremor.
- Accelerometer measurement range.
  (Area between 2 red lines.)
- STS-2(Broadband velocity meter) measurement range.
  (Area between 2 blue dash lines.)
- Deep borehole seismometer (APS-355) measurement range.
  (Area between 2 brown dash lines.)

Measurement Range (2)

・Noise level

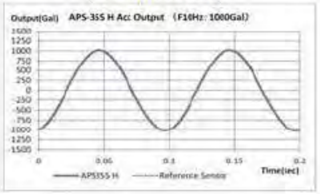


Yasato test site



1 hour

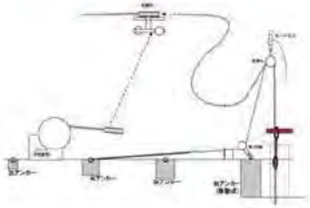
・Shaking table test
(10Hz , 1000Gal)



Cascade Connection (1)

- Connection of borehole capsule and cable

3 sensors are supported by each winch.



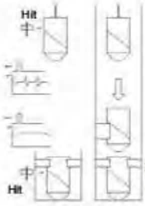
Hatch constructed at the top and bottom of capsule for the cable connection.

Connecting optical fibers

Connecting signal lines

Cascade Connection (2)

- Confirmation of normal setup

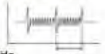


・Hammering test (FFT)

Before grounding
Instability

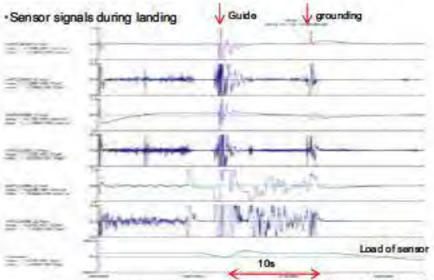
After grounding
Sensor response

・Landing Vibration



Landing distance
landing velocity × laps

・Sensor signals during landing



Hammering test machine

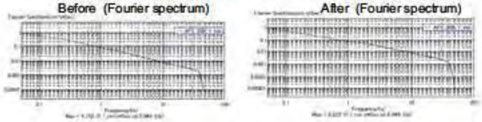
Using solenoid valve
Hit Y axis of senor

We confirmed normal setup
(Normal Setup : 210mm / Landing distance :220mm)

・Hammering test

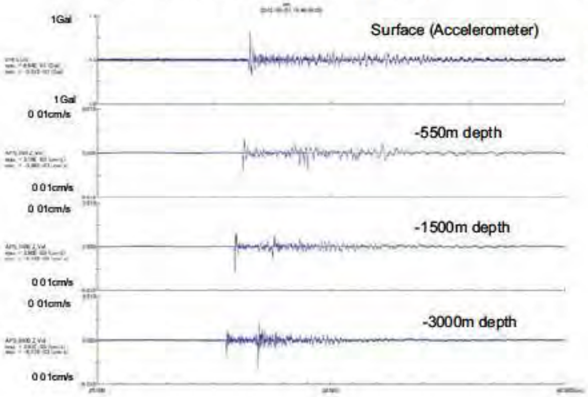
We could not find clear evidence of normal setup

Before (Fourier spectrum) After (Fourier spectrum)



Seismograms

Recorded seismograms (Up-Down component)



May 7,2012 15:40 23.9
(JST)
37° 15.0' N ,138° 37.6'E
Depth 19km , M 1.8
Chuetsu district. (JMA)

10km distance from NIIT.

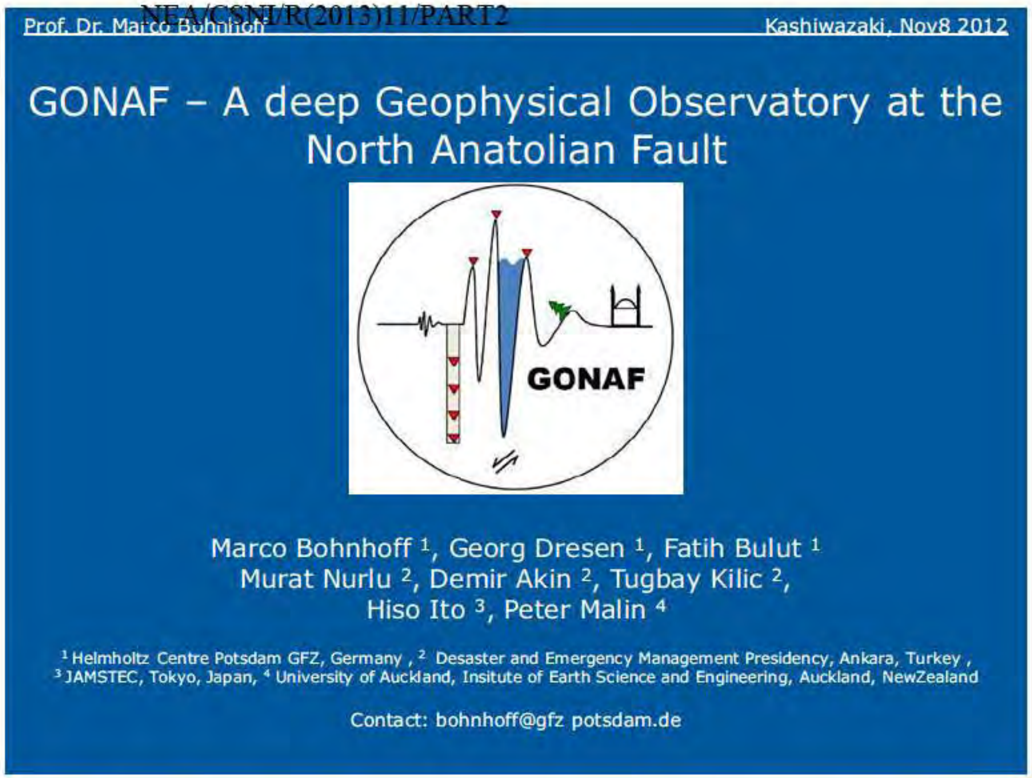
Conclusions

1. Successful seismic observation under high temperature of 150 deg C and high pressure of 30MPa.
2. Successful remote control of the seismometer response characteristics (3000m).

Future issues

1. Reduction of high frequency noise (higher than 10Hz).
2. Long-term test of optical fiber and light source.

THANK YOU.



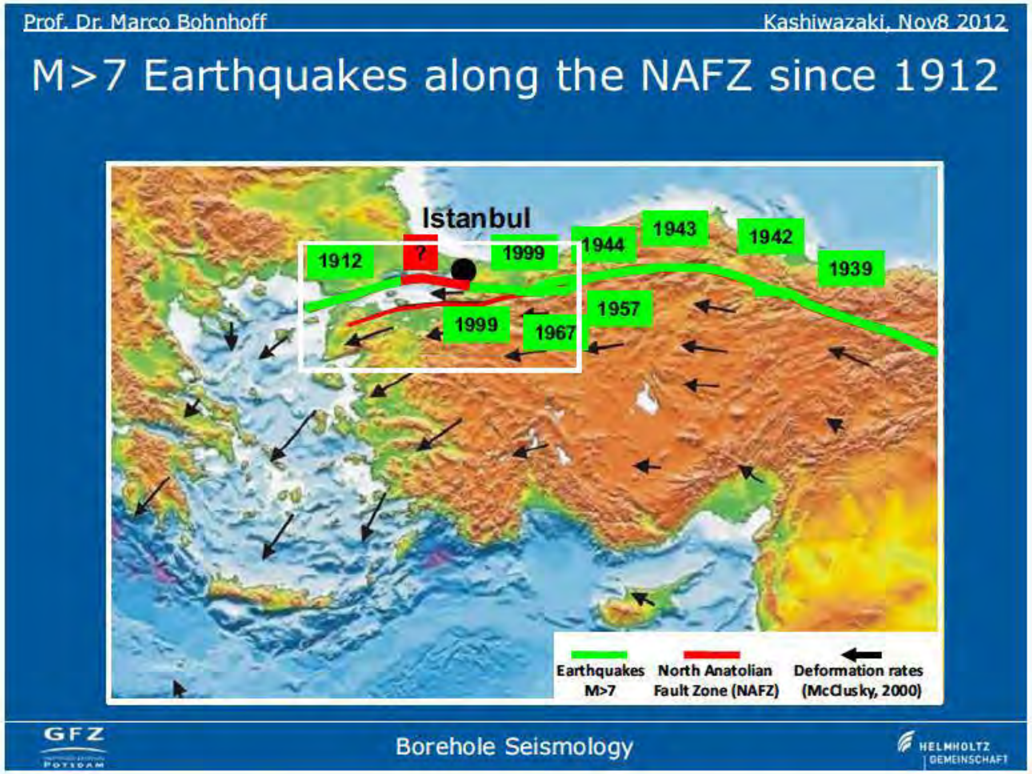
Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov8 2012

GONAF – A deep Geophysical Observatory at the North Anatolian Fault

Marco Bohnhoff [1], Georg Dresen [1], Fatih Bulut [1]
Murat Nurlu [2], Demir Akin [2], Tugbay Kilic [2],
Hiso Ito [3], Peter Malin [4]

[1] Helmholtz Centre Potsdam GFZ, Germany , [2] Desaster and Emergency Management Presidency, Ankara, Turkey ,
[3] JAMSTEC, Tokyo, Japan, [4] University of Auckland, Insitute of Earth Science and Engineering, Auckland, NewZealand

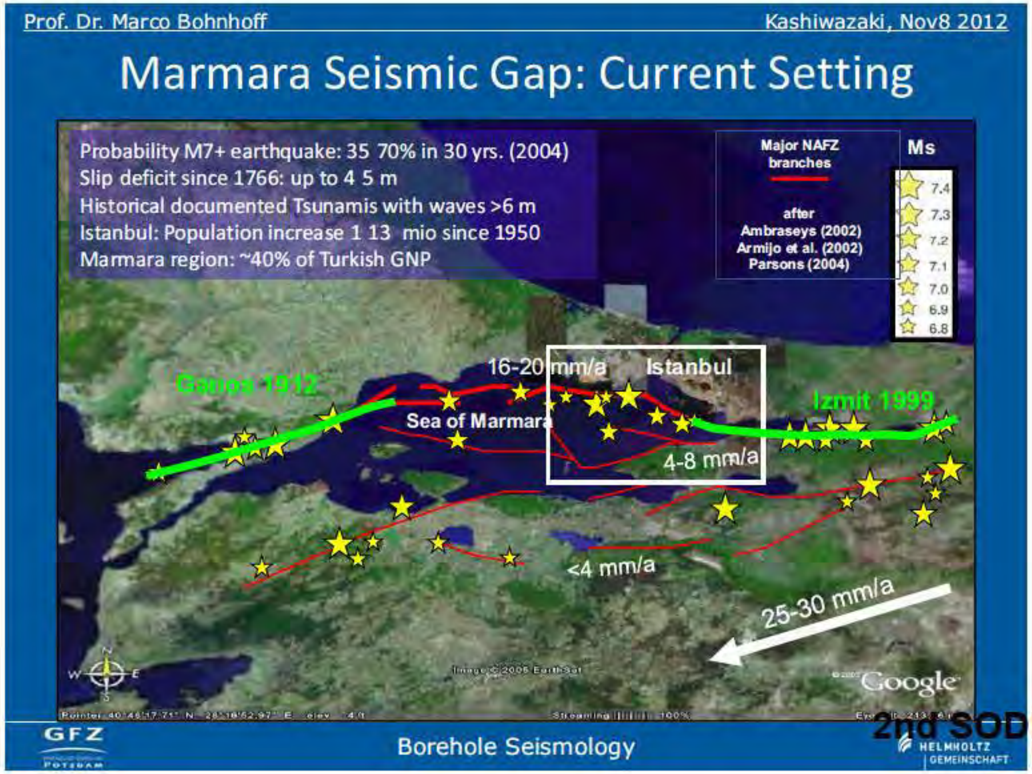
Contact: bohnhoff@gfz potsdam.de



Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov8 2012

M>7 Earthquakes along the NAFZ since 1912

GFZ Borehole Seismology HELMHOLTZ GEMEINSCHAFT

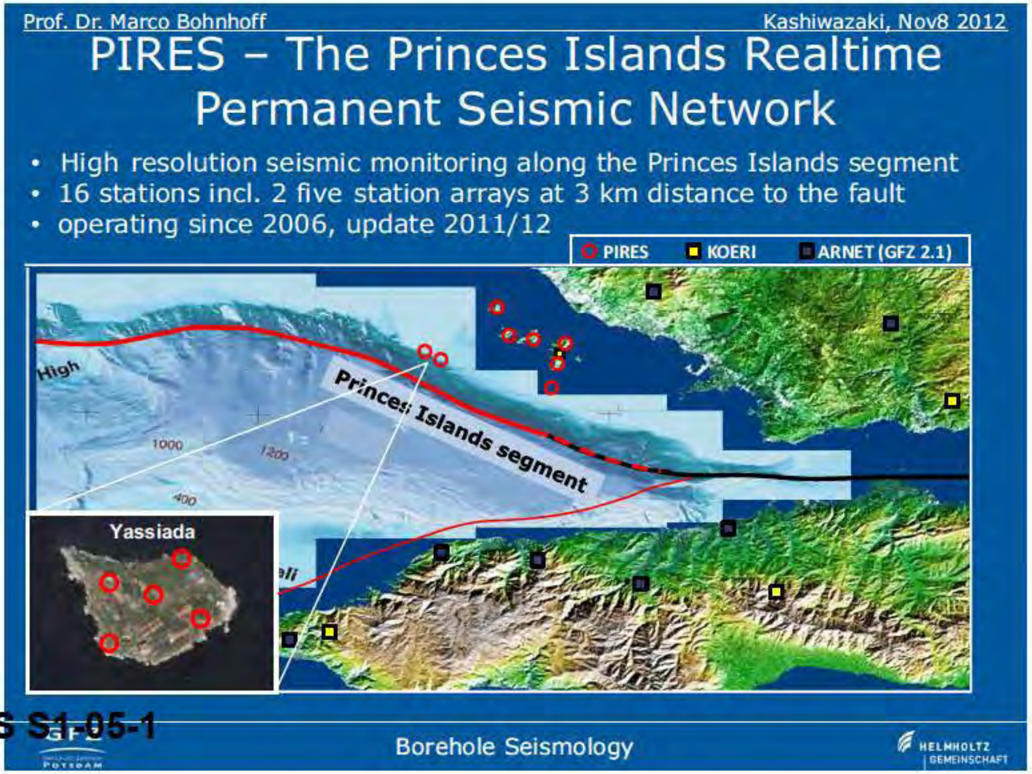


Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov8 2012

Marmara Seismic Gap: Current Setting

Probability M7+ earthquake: 35 70% in 30 yrs. (2004)
Slip deficit since 1766: up to 4 5 m
Historical documented Tsunamis with waves >6 m
Istanbul: Population increase 1 13 mio since 1950
Marmara region: ~40% of Turkish GNP

GFZ Borehole Seismology HELMHOLTZ GEMEINSCHAFT

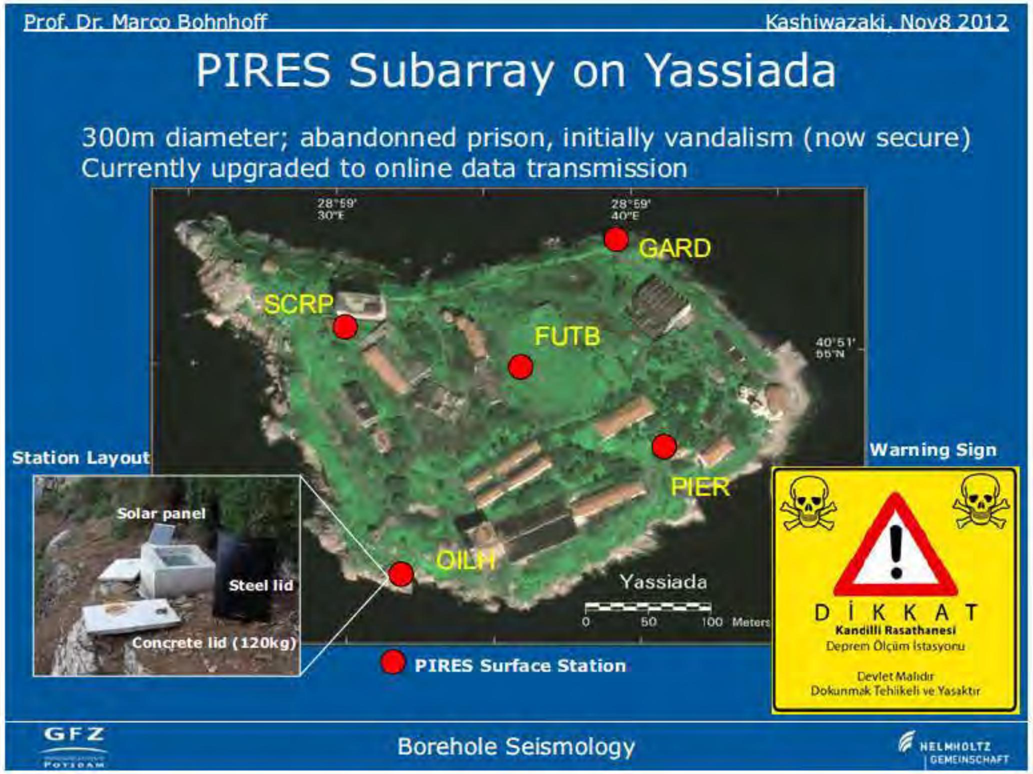


Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov8 2012

PIRES – The Princes Islands Realtime Permanent Seismic Network

- High resolution seismic monitoring along the Princes Islands segment
- 16 stations incl. 2 five station arrays at 3 km distance to the fault
- operating since 2006, update 2011/12

GFZ Borehole Seismology HELMHOLTZ GEMEINSCHAFT

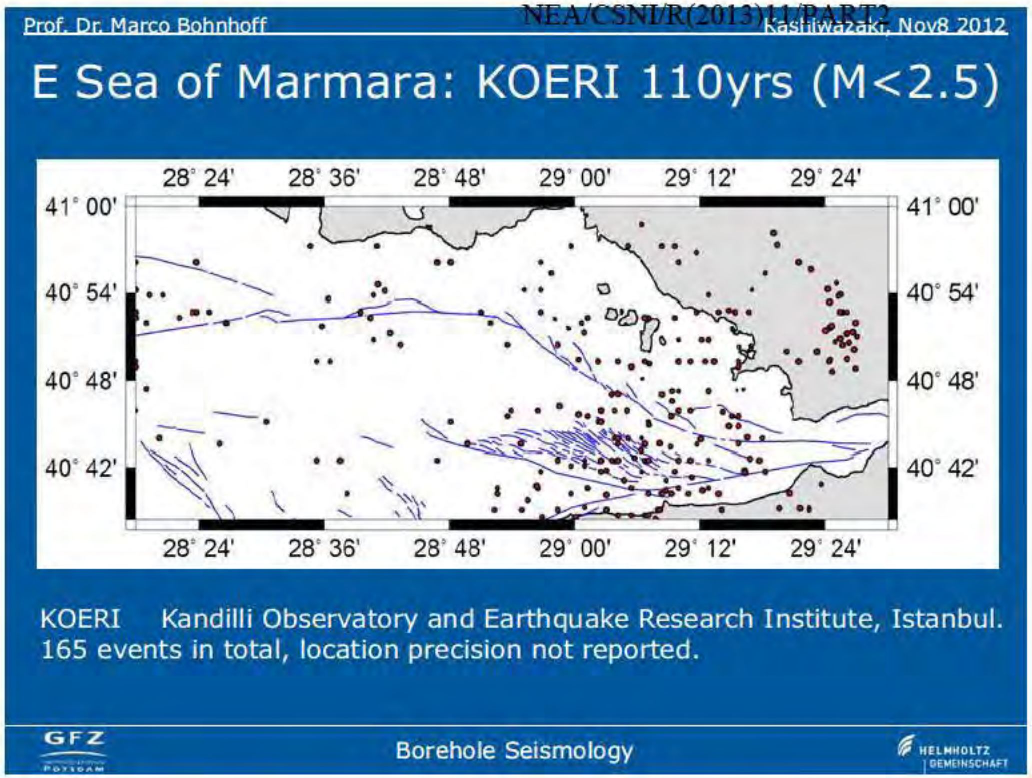


Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov8 2012

PIRES Subarray on Yassiada

300m diameter; abandonned prison, initially vandalism (now secure)
Currently upgraded to online data transmission

Borehole Seismology

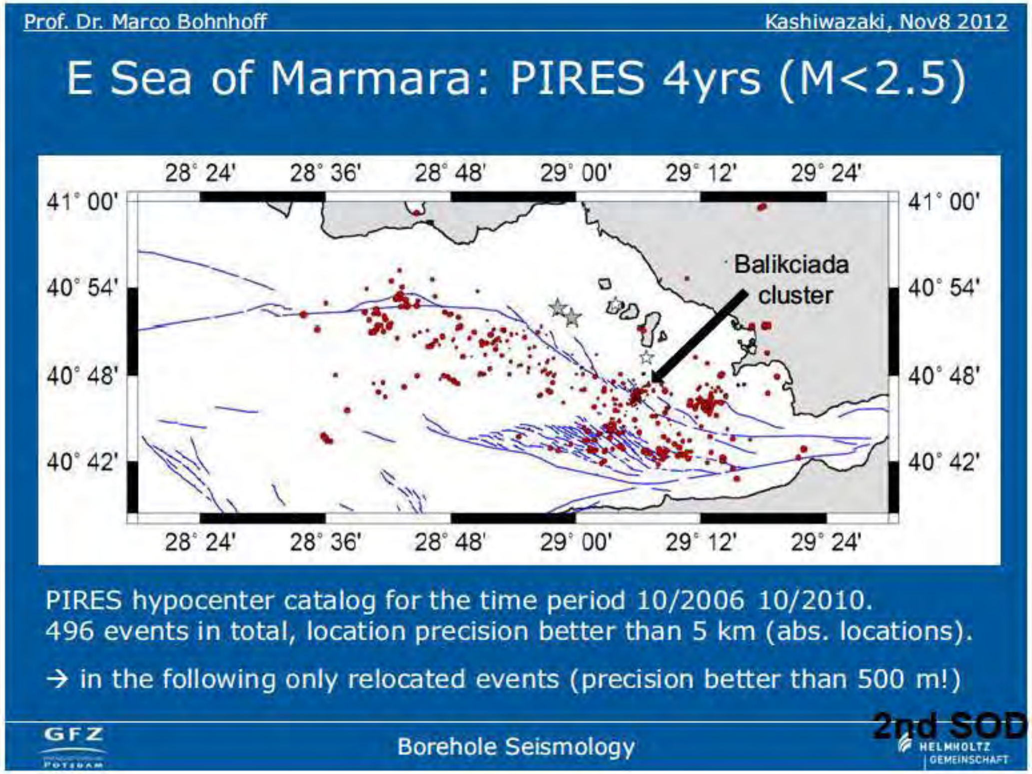


Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov8 2012

E Sea of Marmara: KOERI 110yrs (M<2.5)

KOERI Kandilli Observatory and Earthquake Research Institute, Istanbul.
165 events in total, location precision not reported.

Borehole Seismology



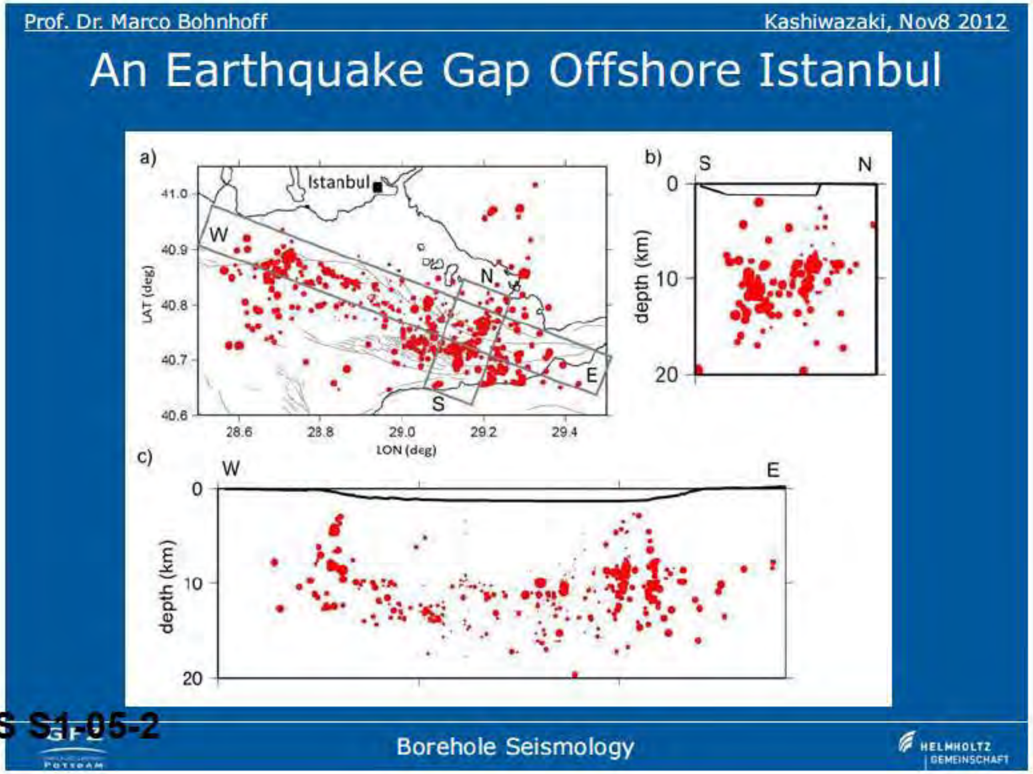
Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov8 2012

E Sea of Marmara: PIRES 4yrs (M<2.5)

PIRES hypocenter catalog for the time period 10/2006 10/2010.
496 events in total, location precision better than 5 km (abs. locations).

→ in the following only relocated events (precision better than 500 m!)

Borehole Seismology



Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov8 2012

An Earthquake Gap Offshore Istanbul

Borehole Seismology

GONAF: A Deep Geophysical Observatory at the North Anatolian Fault Zone

Principal Investigators:
Bohnhoff, Dresen, Bulut (GFZ)
Nurlu, Akin, Kilic (AFAD*)

Partners/Contractors:
Malin (IESE, NZ)
Aktar (KOERI-BU, TR)
Ito (JAMSTEC, JP)
Prevedel (ICDP-OSG, GFZ)
Reilinger (MIT, US)
Mencin (UNAVCO, US)

GONAF is co-funded by
ICDP, GFZ and AFAD

Primary Objectives of GONAF:

- Further decrease the magnitude-detection threshold to below zero throughout eastern Sea of Marmara using downhole seismic observations over the entire frequency band.
- Gain new insights into the physical state of a critically stressed fault segment of a major transform fault prior, and potentially also during and after a large earthquake.
- Monitoring progressive damage evolution at a fault asperity; obtaining unique seismological data on dynamic rupture propagation and for source parameter studies.

* AFAD = Desaster and Emergency Management Presidency, Ankara

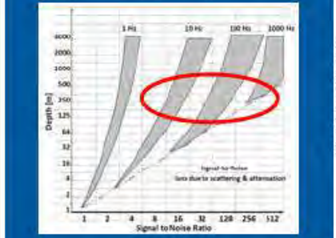
---

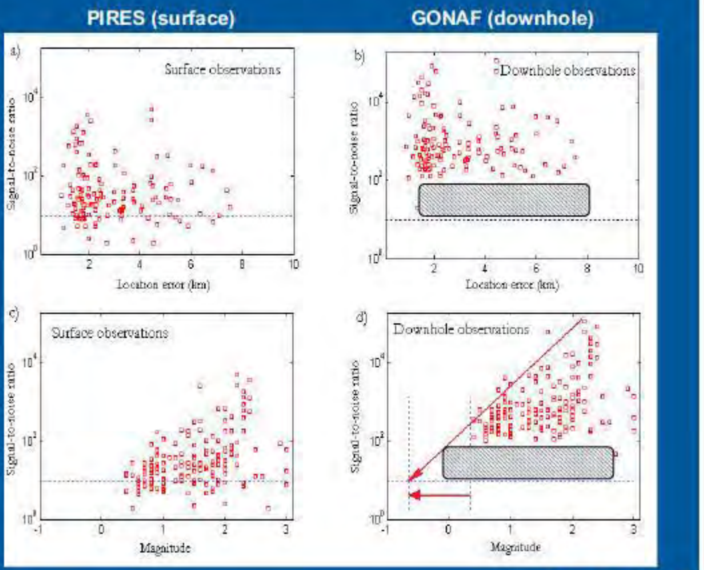
GONAF: A Deep Geophysical Observatory at the North Anatolian Fault Zone

● surveyed GONAF borehole locations

Downhole vs. Surface Seismic Monitoring

- noise conditions will improve >25 times
- M_{det} will improve to - 0.7
- no. of events will increase 10 times



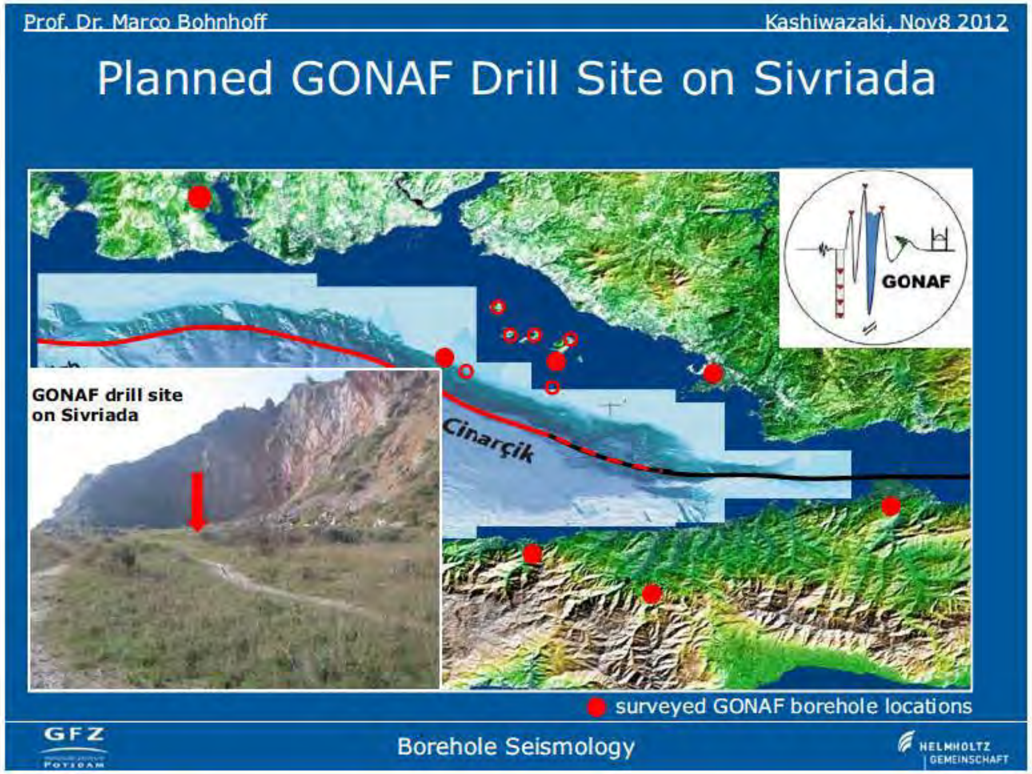


GONAF: Downhole Seismic Instrumentation

Planned instrumentation of GONAF boreholes

0m	1Hz
100m	1Hz
200m	1Hz
300m	2+15Hz

● surveyed GONAF borehole locations



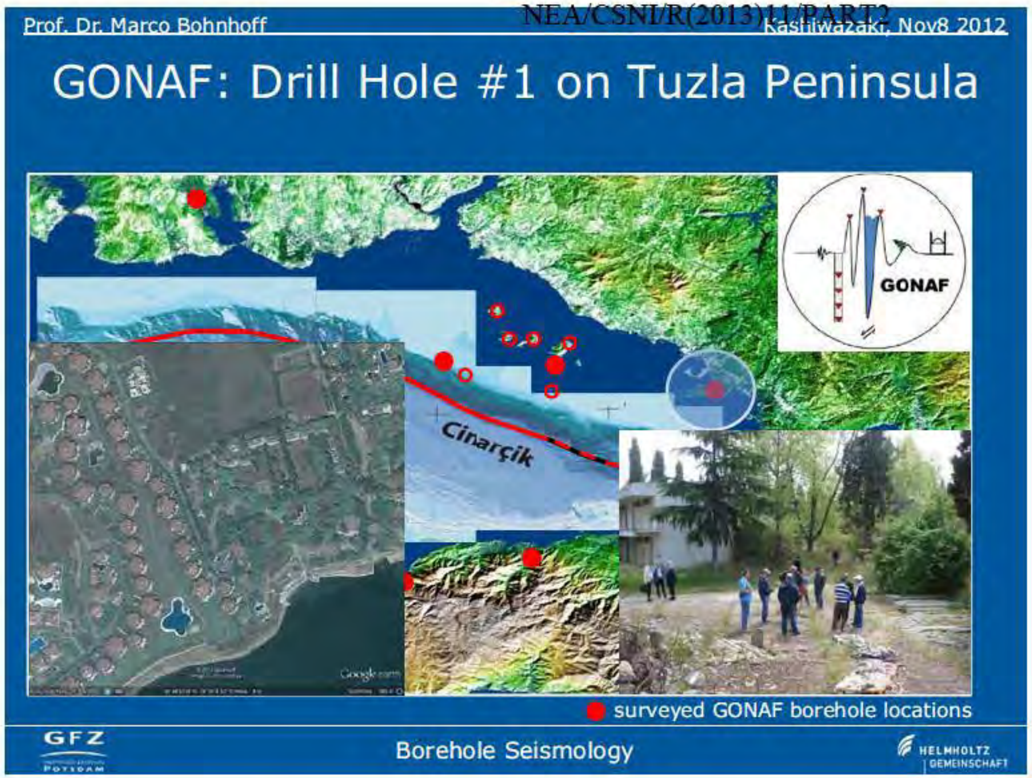
Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov8 2012

Planned GONAF Drill Site on Sivriada

GONAF drill site on Sivriada

● surveyed GONAF borehole locations

Borehole Seismology

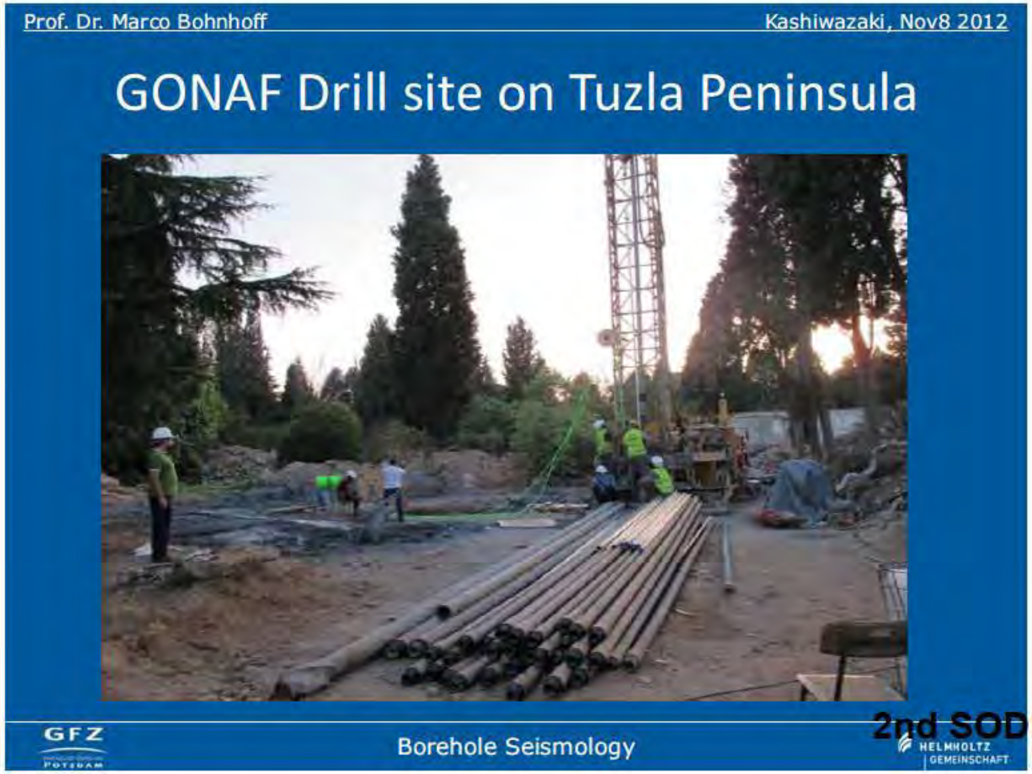


Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov8 2012

GONAF: Drill Hole #1 on Tuzla Peninsula

● surveyed GONAF borehole locations

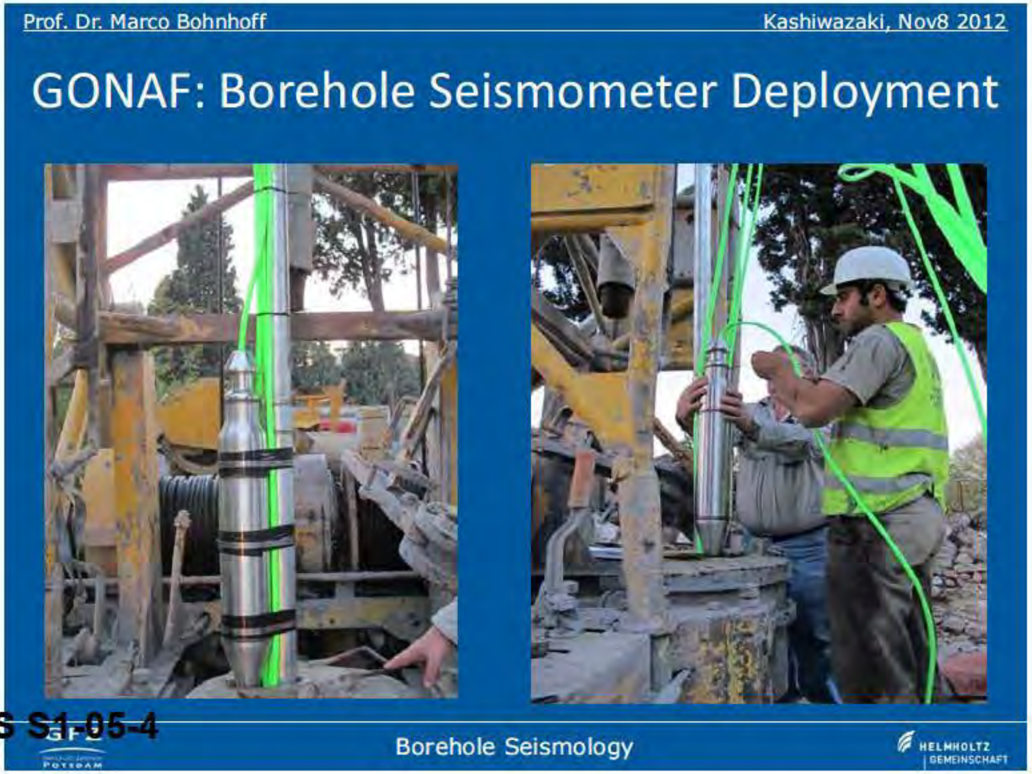
Borehole Seismology



Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov8 2012

GONAF Drill site on Tuzla Peninsula

Borehole Seismology



Prof. Dr. Marco Bohnhoff Kashiwazaki, Nov8 2012

GONAF: Borehole Seismometer Deployment

Borehole Seismology

GONAF$_{plus}$: Permanent Ocean Bottom Seismometer (2014)

● surveyed GONAF borehole locations

Summary and Conclusions

- Near-fault microseismic recordings from the PIRES network allow to define the microseismic activity along the Princes Islands segment of the NAFZ for the first time.
- Relocated microseismicity indicates a single master fault below the seismogenic layer. The Princes Islands segment currently reflects strike-slip faulting, locally incl. thrust (but no normal) faulting components.
- Distinct microseismicity clusters at the transition from the 1999 Izmit rupture to the Marmara seismic gap are interpreted to represent potential nucleation points of the expected Maramara earthquake. A large portion of the Princes Islands segment is currently seismically inactive.
- Recently started activities foresee implementing GONAF, a network of eight borehole seismometer arrays. GONAF will provide substantially improved microseismic monitoring conditions in terms of SNR, magnitude-detection threshold and hypocenter location precision.

Thank you for your attention!

Thank you for your attention!

The Deep Fault Drilling Project, Alpine Fault, New Zealand

Preliminary results, future plans, and affiliated seismological research

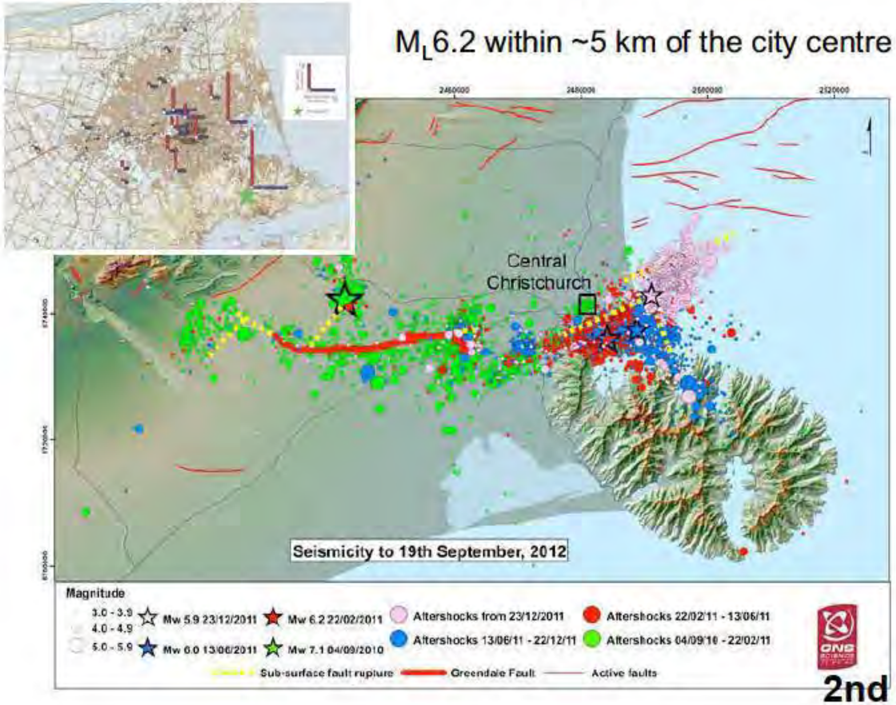
John Townend, EQC Fellow in Seismic Studies
Victoria University of Wellington

Talk outline

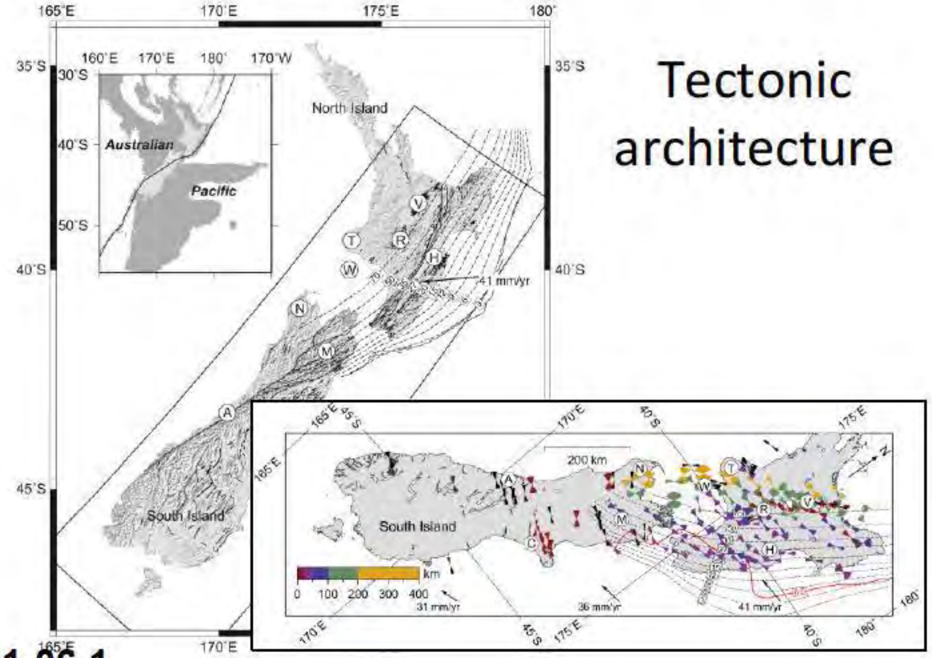
- Introduction
  - New Zealand tectonics and the Alpine Fault
  - GeoNet
- The Deep Fault Drilling Project (DFDP*)
  - DFDP-1— successfully completed in 2011
  - DFDP-2 — now funded and planned for 2014
- Allied seismological research
  - Tremor, triggered seismicity, deep earthquakes
- Summary

*Townend et al., 2009, *Scientific Drilling*, doi:10.2204/iodp.sd.8.12.2009

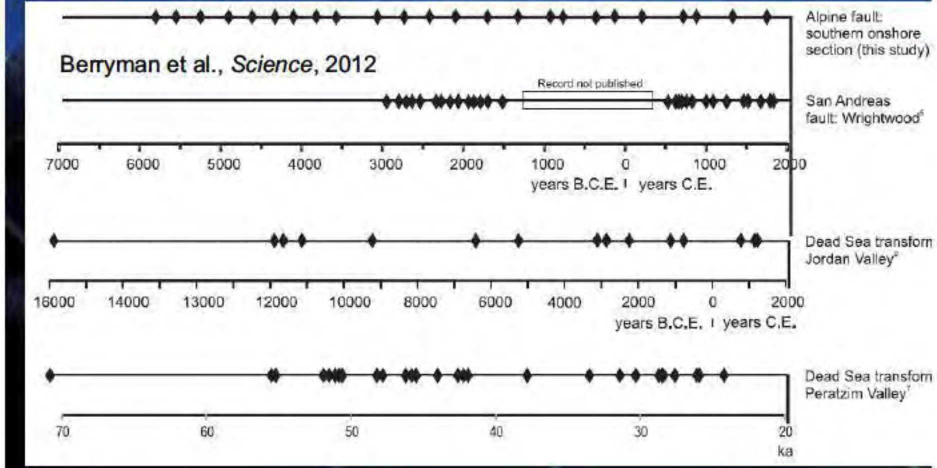
M_L6.2 within ~5 km of the city centre



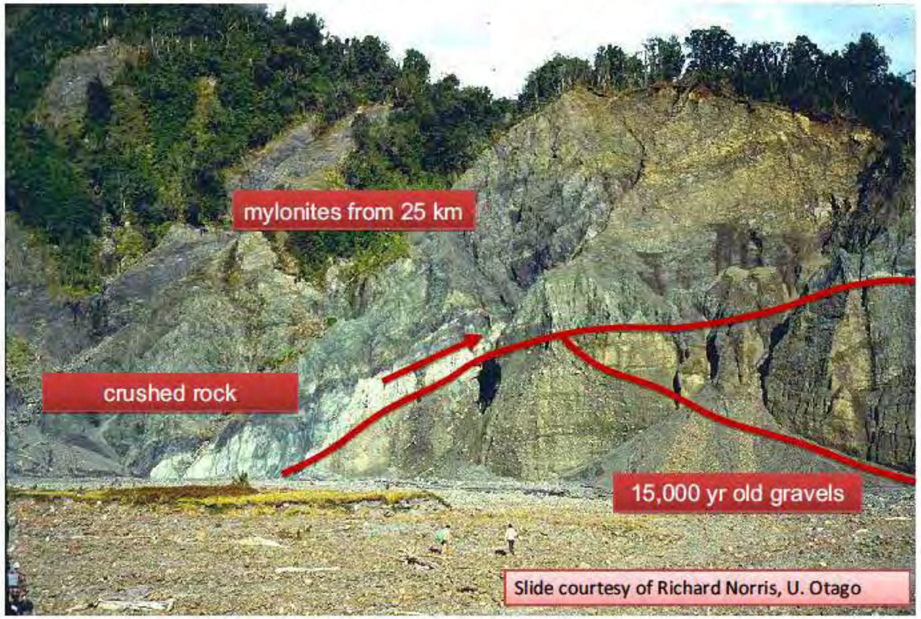
Tectonic architecture



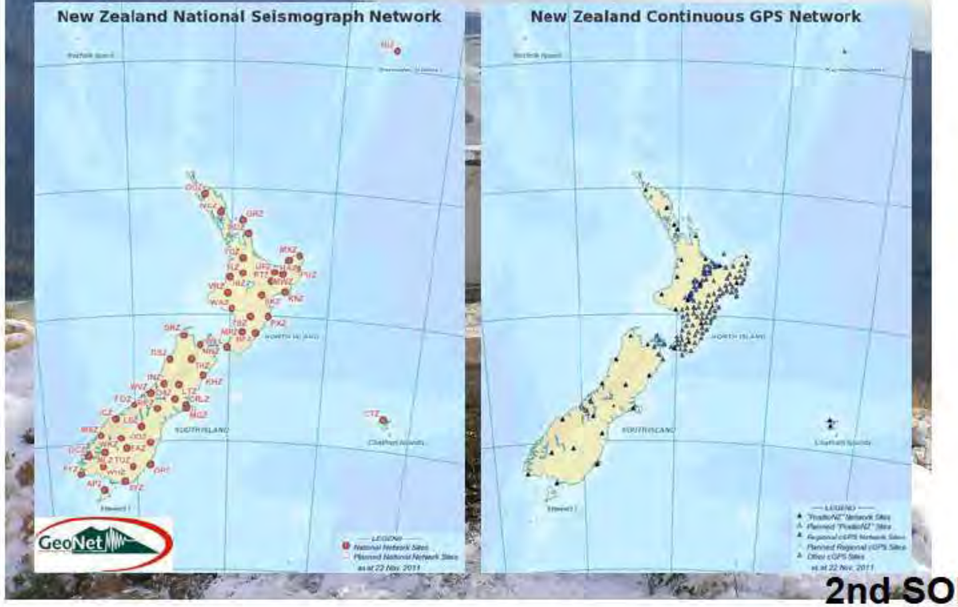
Orogenesis and seismogenesis



Alpine Fault at Gaunt Creek, Westland



Slide courtesy of Richard Norris, U. Otago



GeoNet's current scale and coverage

- Five principal data streams
  - 52 broadband and 126 regional seismograph stations
  - 180 CGPS deformation stations
  - >240 strong ground motion stations and 15 strong motion building and borehole arrays
  - 17 tsunami (sea level) gauges
  - Medium- to low-rate chemistry, landslide observations
- >20 Tb of data (all freely available), 7 Gb/day

Deep Fault Drilling Project

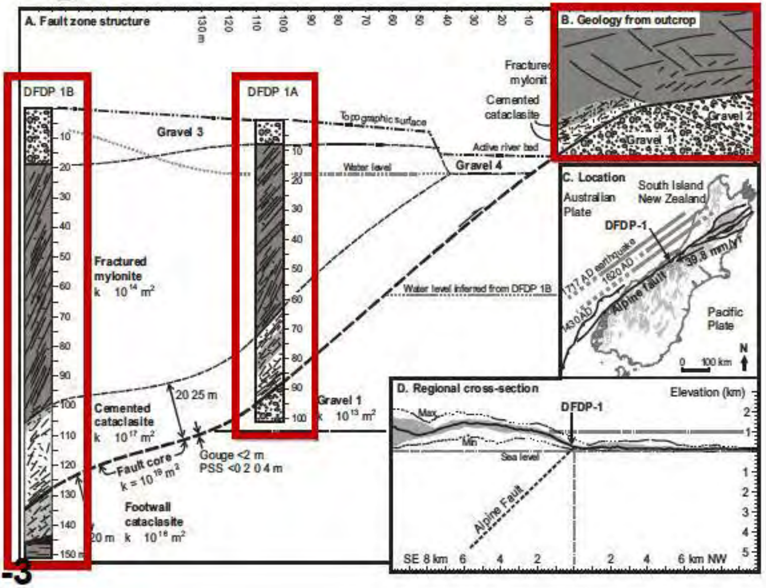
- DFDP addresses fundamental geological-rheological processes
  - Brittle/ductile, stable/unstable friction transitions
  - Earthquake nucleation and predominant slip
  - Fluid over-pressuring and shear zone evolution
- This is an important site for studying active faulting
  - High slip rates (>20 mm/yr), oblique kinematics (2/3 dextral, 1/3 reverse), along-strike homogeneity
  - The opportunity to study a large fault inferred to produce big earthquakes but locked for ~300 years

DFDP-1 technical goals

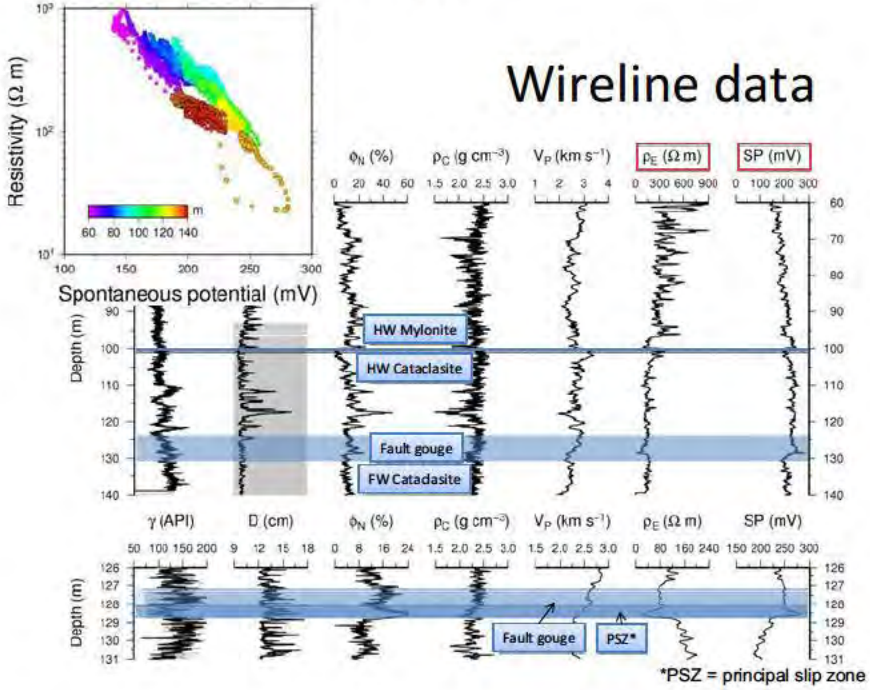
- Drill two boreholes to intersect the fault
- Retrieve core samples for detailed analysis
- Conduct geophysical logging of both holes
- Install permanent monitoring equipment

DFDP-1 Gaunt Ck

Integrated Gaunt Creek cross-section



Wireline data

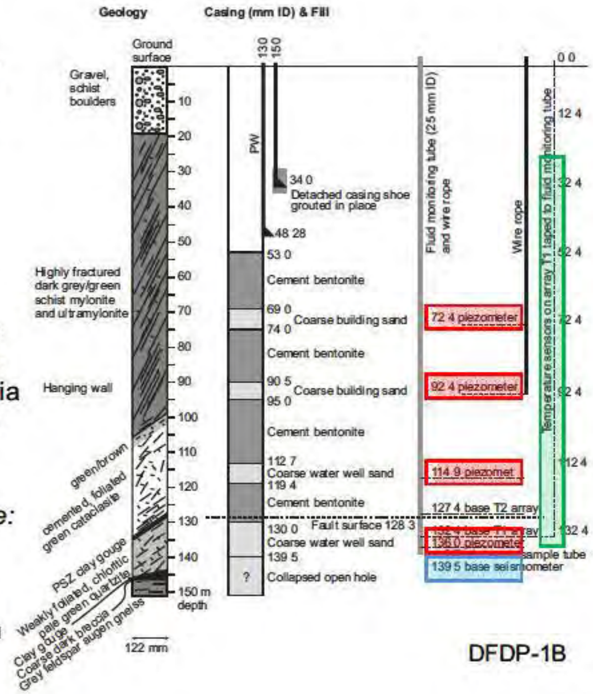


*PSZ = principal slip zone

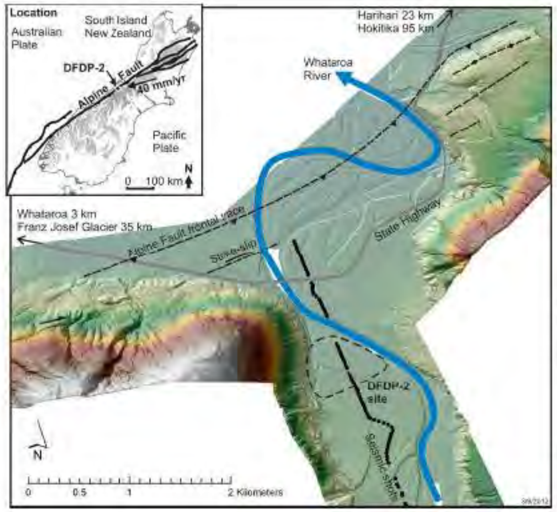
Observatory installation

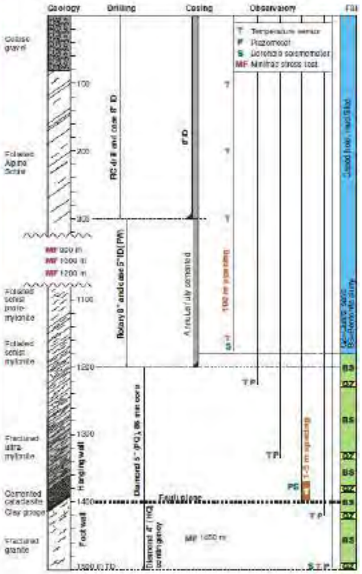
Data from temperature-, pressure-, and seismic-recording instruments are recorded at the DFDP-1B wellhead and telemetered via GeoNet for real-time web access

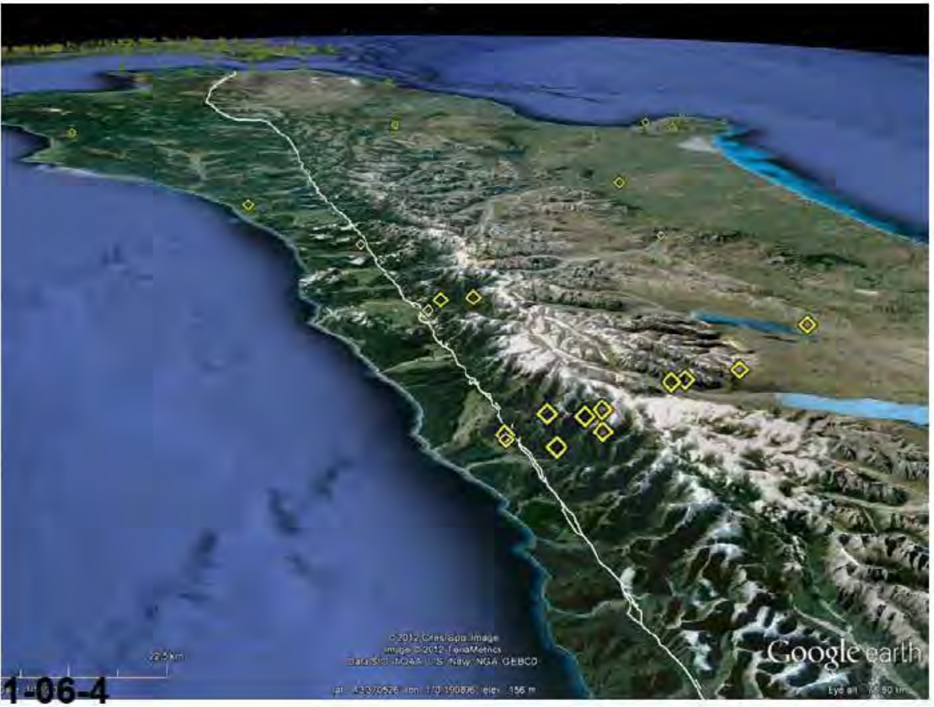
Among other results to date: multiple permeability estimates from pressure decay and a geothermal gradient of 63±2° C km^{-1}

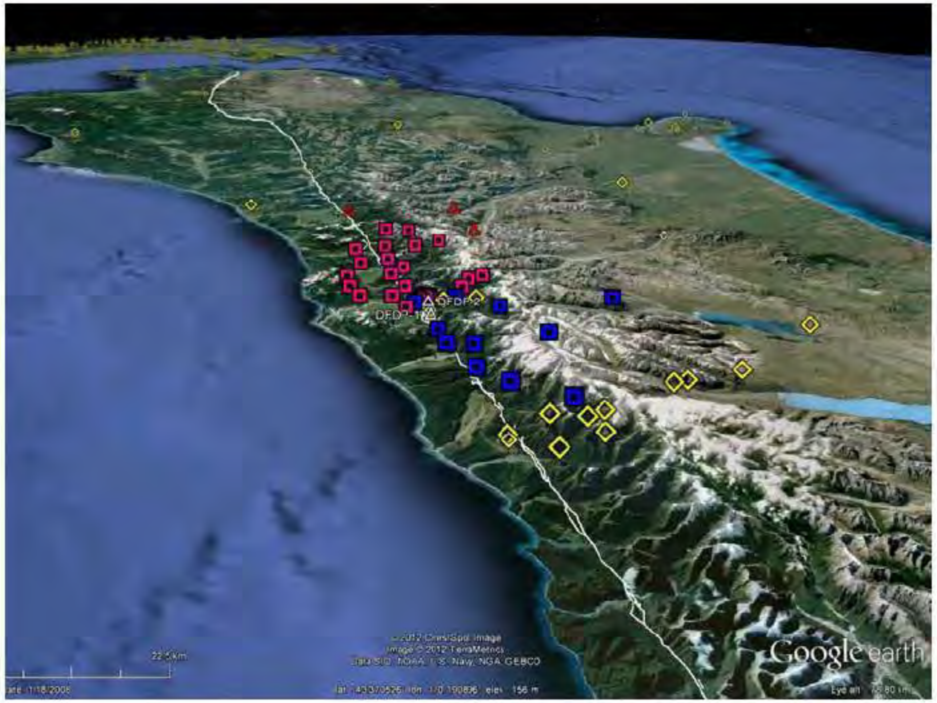


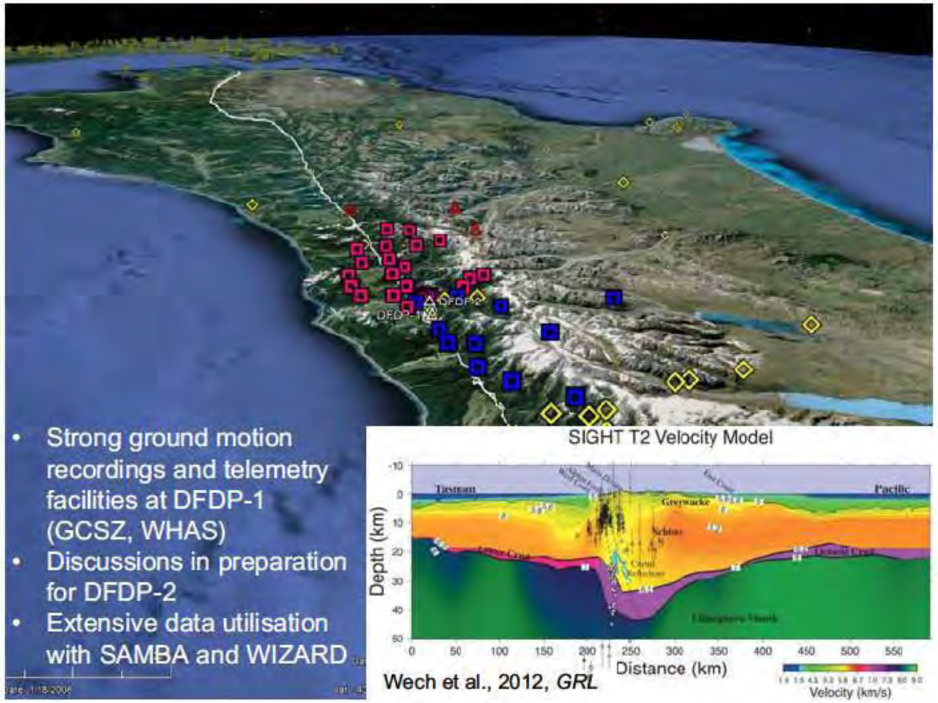
Preliminary operations for DFDP-2







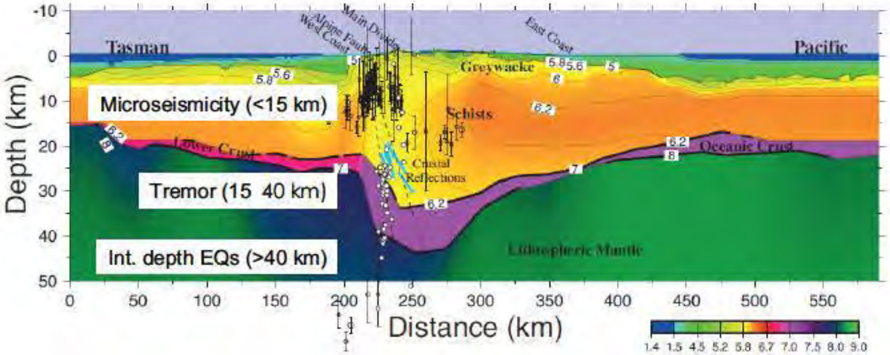




- Strong ground motion recordings and telemetry facilities at DFDP-1 (GCSZ, WHAS)
- Discussions in preparation for DFDP-2
- Extensive data utilisation with SAMBA and WIZARD

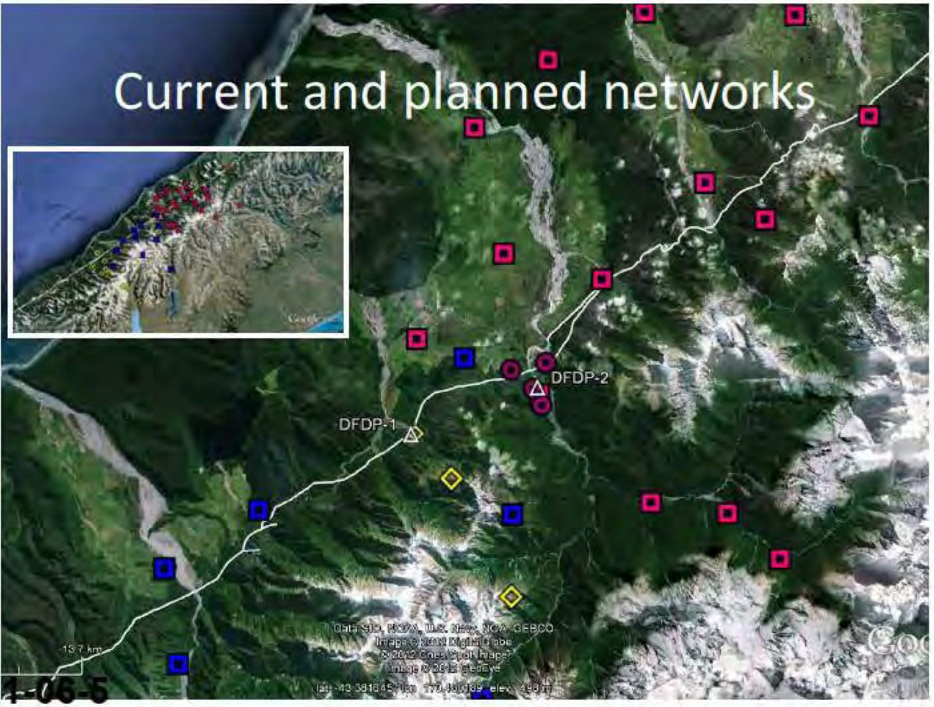
Wech et al., 2012, *GRL*

Recent seismological observations



Using data from the short-period SAMBA network (10 shallow boreholes), augmented by GeoNet, we have successfully located upper crustal microearthquakes (M_L0 4, M_c~1.5), lower crustal seismic tremor, and sub-crustal earthquakes (M_L1 4)

Current and planned networks



Summary (1)

- The Alpine Fault is an important global target for understanding continental faulting
- DFDP-1 has permitted novel observations of ambient conditions and fault zone architecture

Summary (2)

- These observations have been made late in the inferred 2–400 yr cycle of strain accumulation
- DFDP and the allied geoscientific research projects involve vital international collaboration

Summary (3)

- Planning is now underway for the second stage of DFDP, with funding from the Royal Society of New Zealand (RSNZ) and the International Continental Scientific Drilling Program (ICDP)

IESE Institute of Earth Science and Engineering Aotearoa

JNES WS2 08 11 12

San Andreas Fault Observatory at Depth

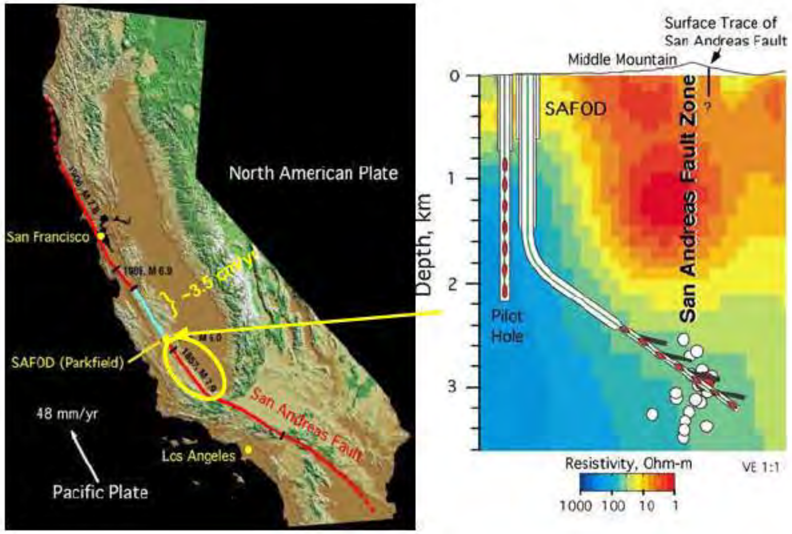
Outline and Prospects of SAFOD Project

Peter Malin and Bill Ellsworth
Staff of IESE, USGS, and many others

Presentation Summary

- The Parkfield Earthquake Prediction Experiment: 1988 was not too late
- SAFOD The San Andreas Fault Observatory at Depth: 2002 was too late
- Hope for both the current and future generation

Institute of Earth Science and Engineering

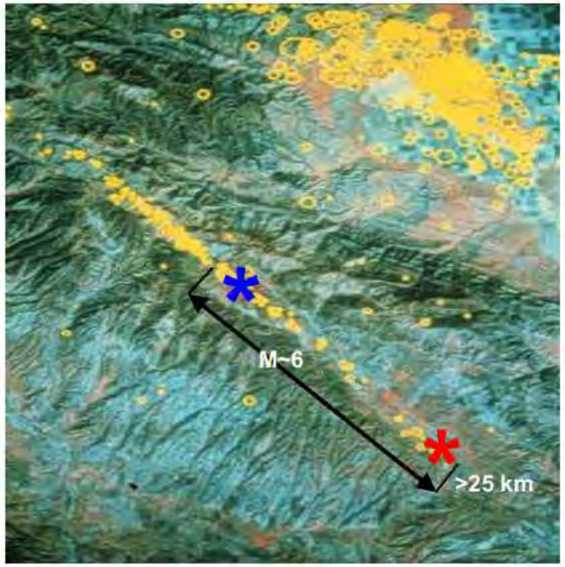


Parkfield

M~6

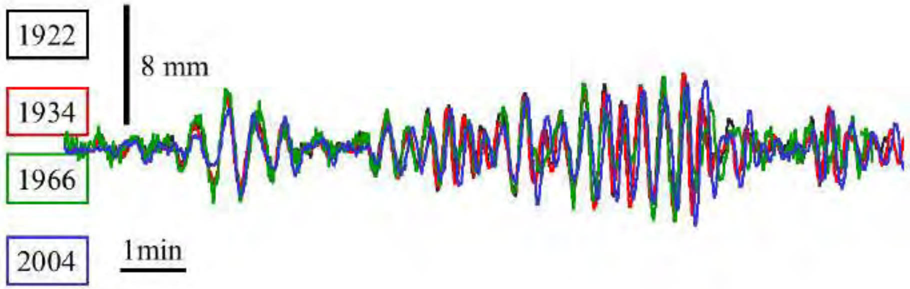
Rupture Zone & Hypocenters

1857	?
1881	?
1901	?
1922	*
1934	*
1966	*
88-92	
2004	*



M 6.0 Parkfield Earthquake
September 28, 2004

Waveform comparisons: 1922, 1934, 1966, 2004



USGS

Japanese James Dean Society

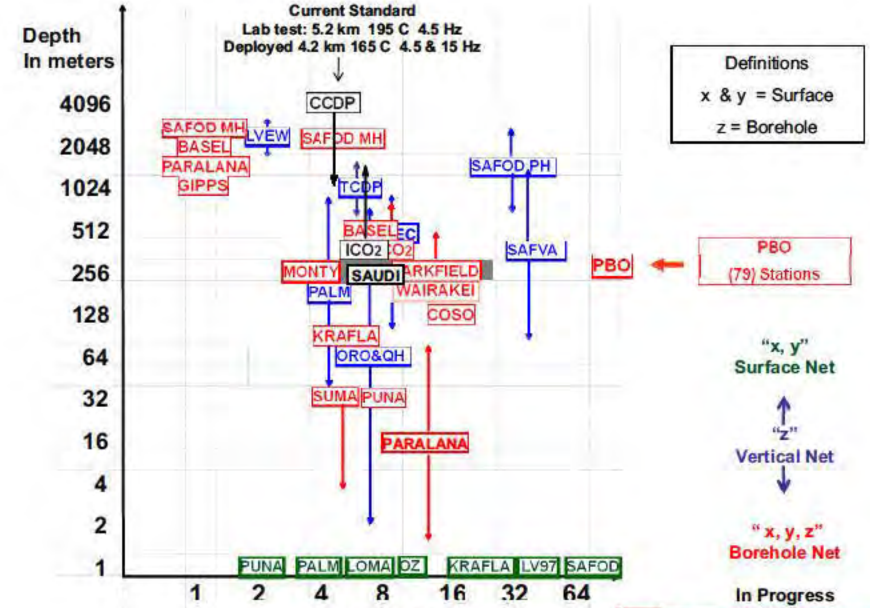
Memorial sculpture near his crash site

Memorial reads:

"That which remains hidden
is of the essence…"

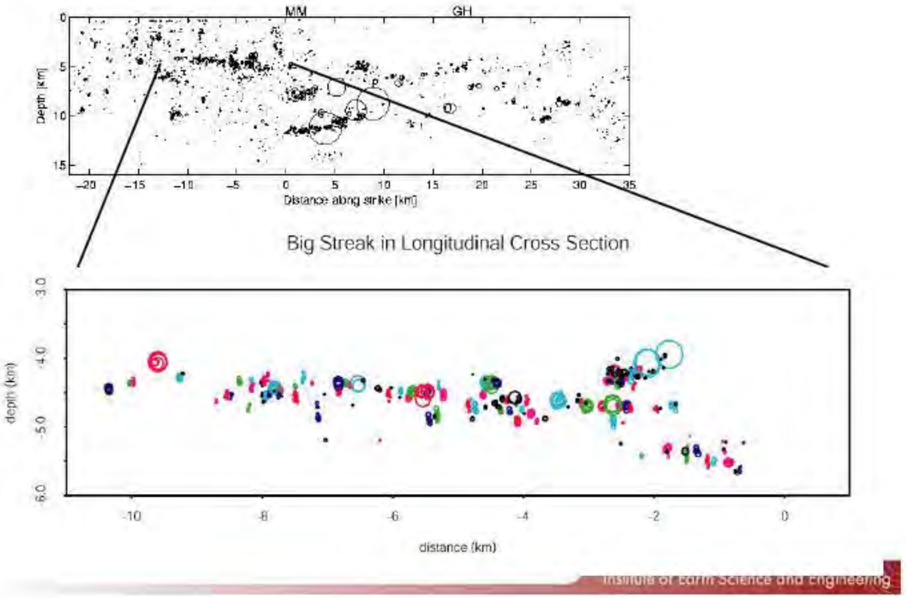
(Russ Evan of the BGS for scale)

Observatory versus depth chart



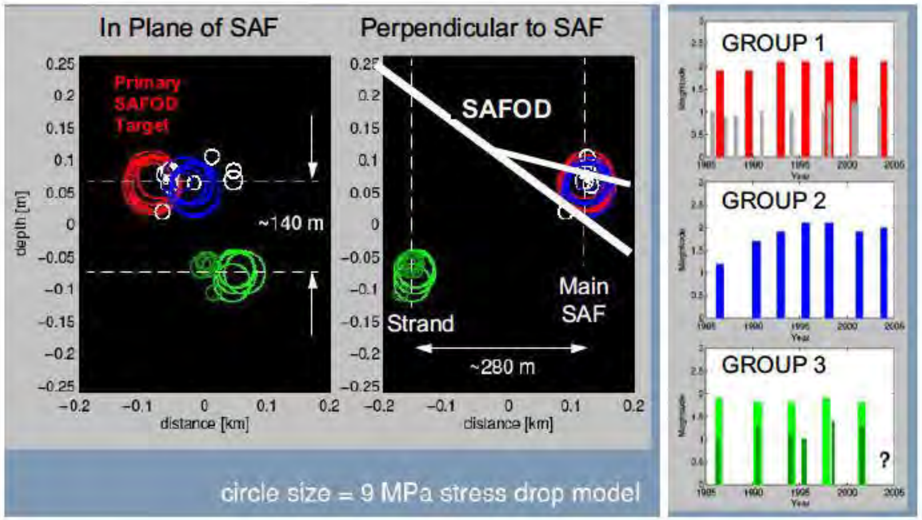
…and don't forget the *SAKE* test…

More Examples of Repeating Earthquakes



Big Streak in Longitudinal Cross Section

Relative Locations of SAFOD Target Earthquakes (Repeaters)



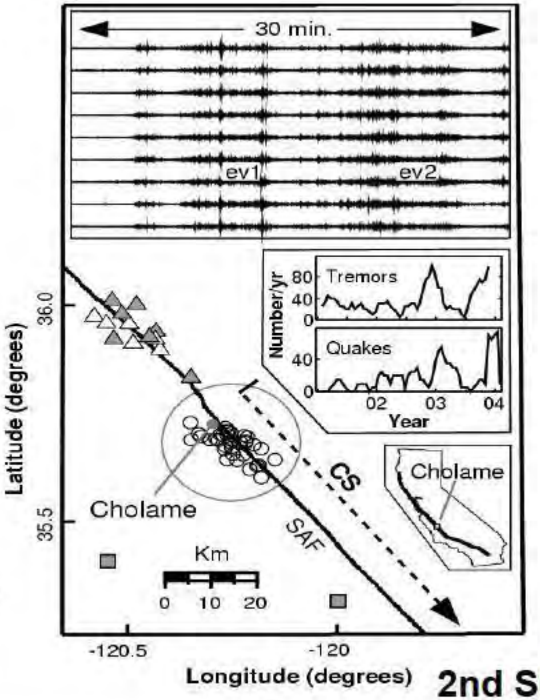
circle size = 9 MPa stress drop model

Felix Waldhauser 2004, and Nadeau et al. 2004

Non-volcanic seismic tremor

Results from

borehole seismic network

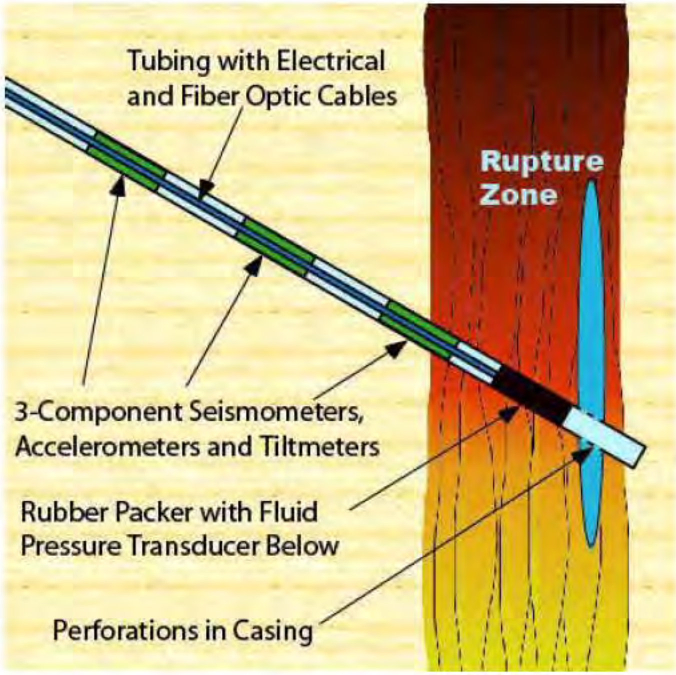


(Figure from R. Nadeu, personal com.)

San Andreas Fault Observatory at Depth: Science Goals

Testing fundamental theories of earthquake mechanics:

- Determine structure and composition of the fault zone.
- Measure stress, permeability and pore pressure in situ.
- Determine physical and chemical processes controlling faulting.
- Characterize 3 D volume of crust containing the fault.
- Monitor strain, pressure and temperature during seismic cycle.
- Observe near field earthquake nucleation and rupture processes.



SAFOD

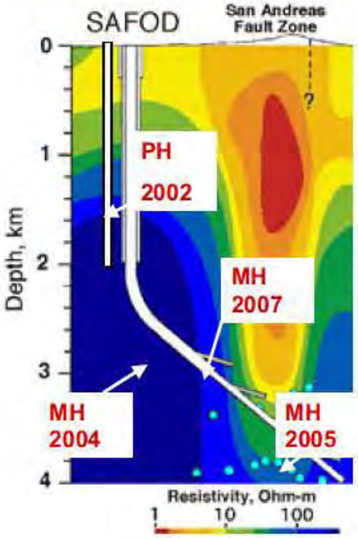
Pilot Hole

and

Main Hole

Drilling:

- Pilot Hole 2002
- Main Hole 2004 - 2007
  - Phase 1 fault approach
  - Phase 2 fault crossing
  - Phase 3 lateral cores



SAFOD

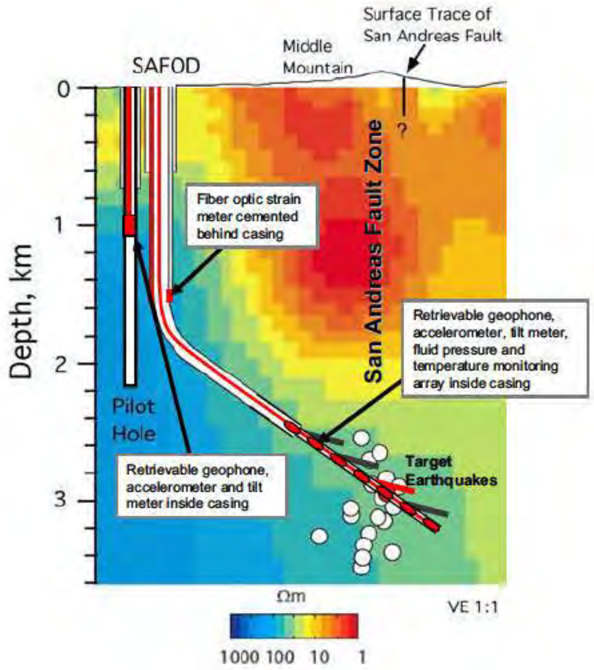
Pilot Hole

and

Main Hole

Instrumentation

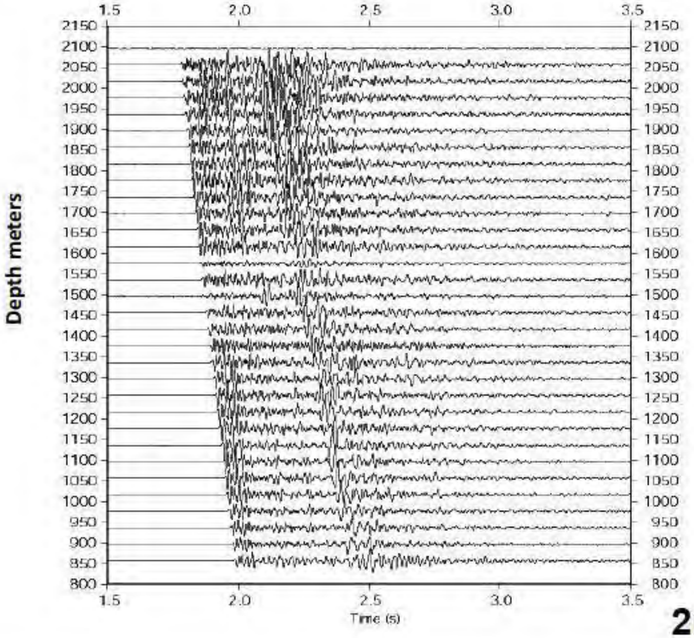
- Stage 1 – Pilot Hole
- Stage 2 – Main Hole
- Stage 3 - Long-Term



Pilot Hole VSP Array 32 Level 3-Component 15 Hz install between 800 to 2,100 m

Pilot Hole VSP Array – Installed on 2 3/8" Production Tubing

PH MEQ VSP



"SEISMIC WHILE DRILLING" REFLECTION IMAGING PROJECT

SURPRIZE NO. 1

"THE CATASTORPHY AT SAP"

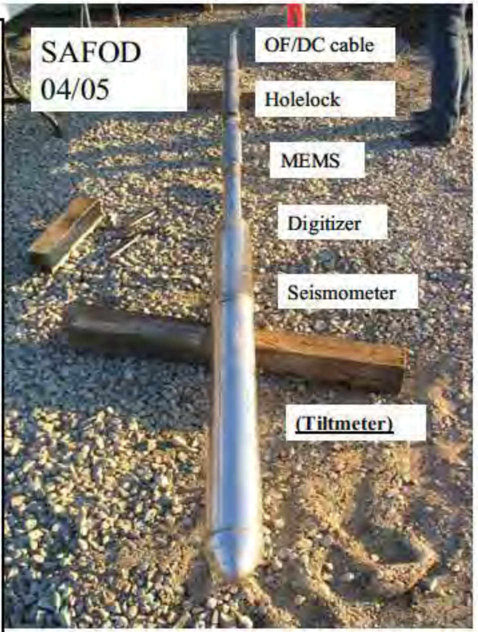
or

HOW AND WHY THE EARTHQUAKE (ALMOST) ESCAPED

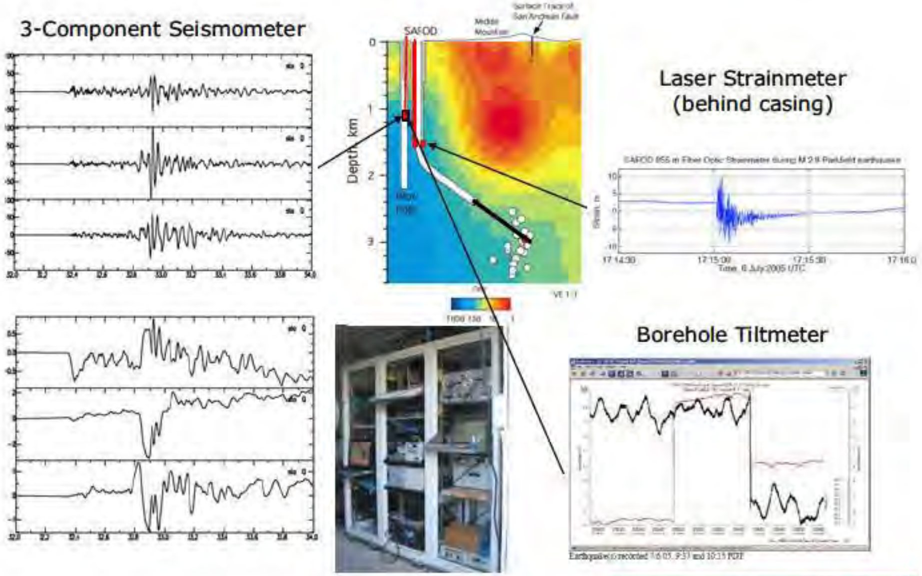
35 years in development:

1978	Mojave	0.8 km 4Hz V
1980	Mojave	0.8 km 4Hz V
1981	Oroville	Hydro locks
1983/5	PKF	0.3 km 2Hz 3D
1987	PKF	1.7 km 42 4Hz V
1990/93	Coso	0.2 km 4Hz 3D
1994/98-Electronic enhancement		
1999	LVEW	3km 2Hz 3D
2001	Monty	0.2km 2Hz 3D
2002	SAFOD	2km 32 15Hz 3D
2004	SAFOD	3km 4Hz 3D
	SAFOD	3km 3D MEMS

....then back to 1987



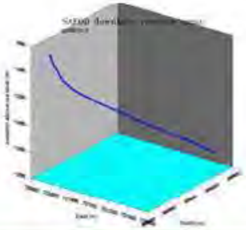
Joint Observations of July 6, 2005 M 2.8 Earthquake at Distance of 4 km


3-Component Seismometer

Laser Strainmeter (behind casing)

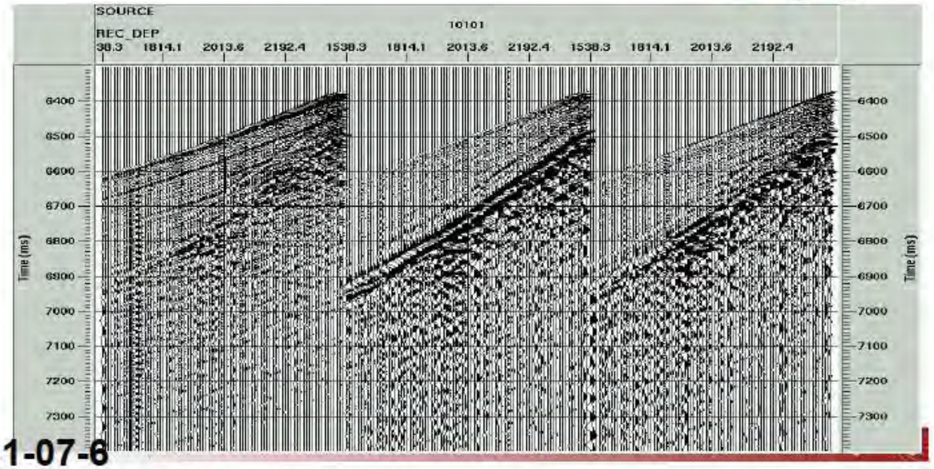
Borehole Tiltmeter

Paulsson Geophysical Services, 80 Level 3C Seismic Array

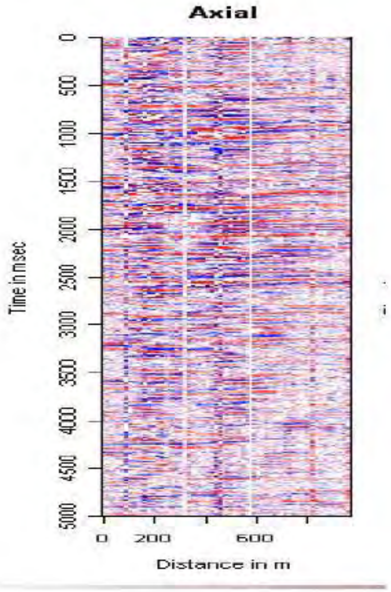


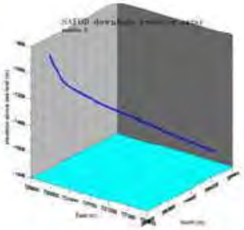
Microearthquake M0.0 May 5, 2005

Event locates at 3415 m (m.d.) along MH



Non Volcanic Tremor Wave Field





Creeping fault intersections

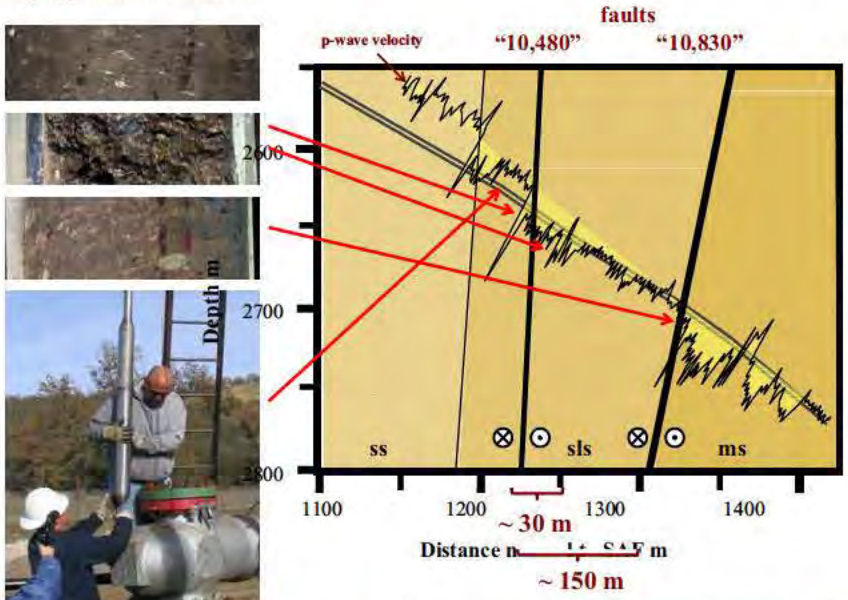
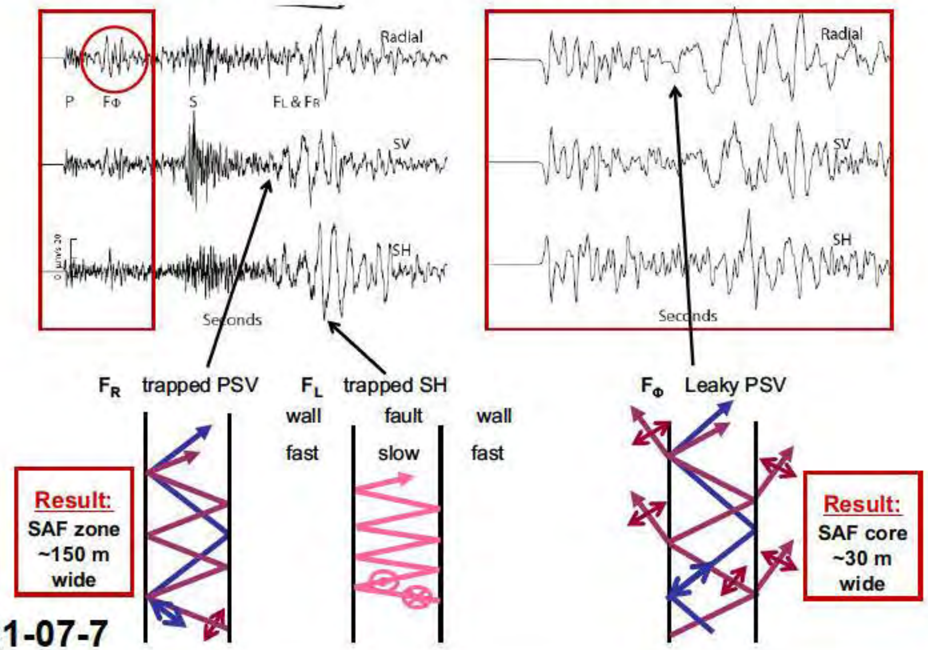


Fig. modified from S.D. Springer et al., Lithosphere 2009

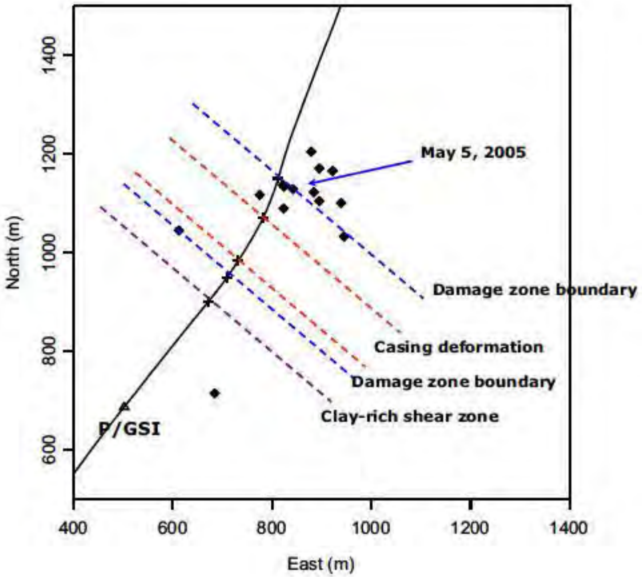
Fault zone guided wave types – Old and New at 10,480 fault



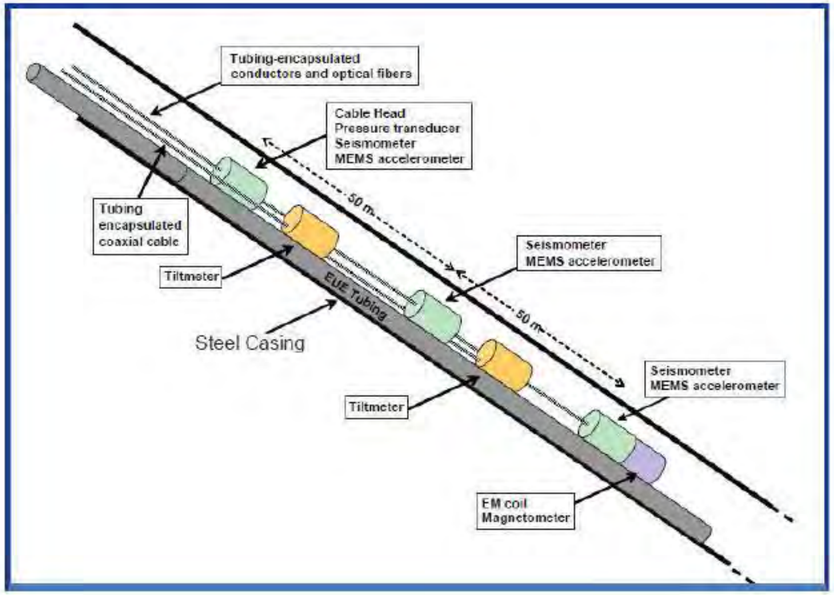
Result:
SAF zone
~150 m
wide

Result:
SAF core
~30 m
wide

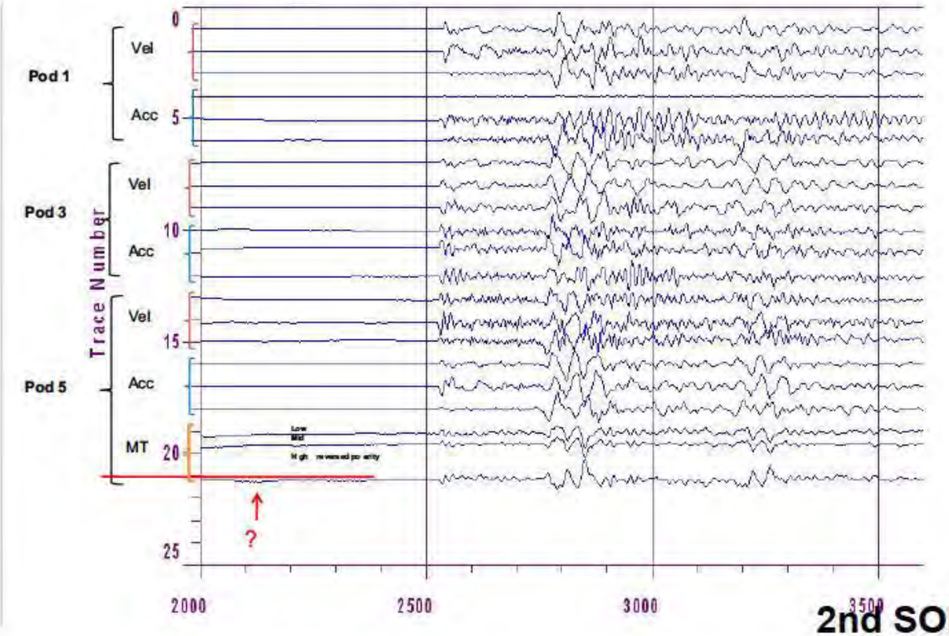
The long term monitoring problem



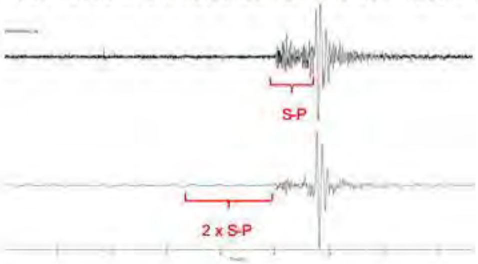
The compromise



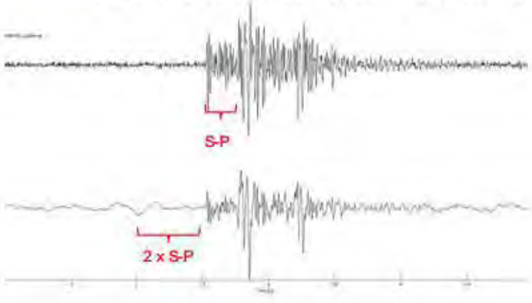
Oct 1 2008 Event : Vel, Acc, MT



Oct 1 2008 Event : Stacked Raw and Low Pass MT

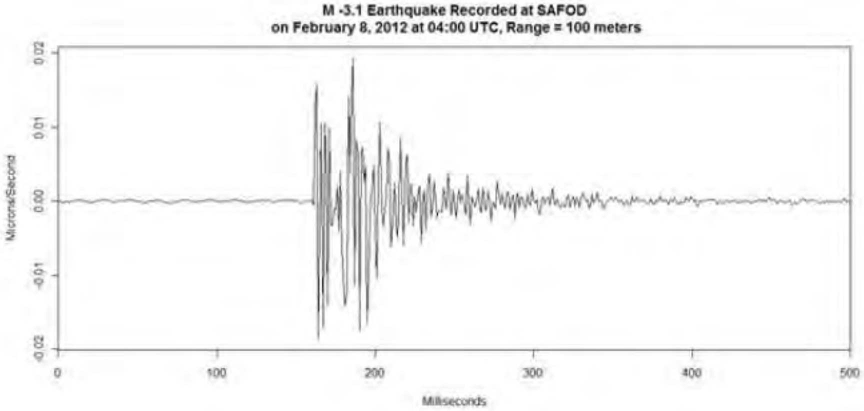


Sept 30 2008 Event : Stacked Raw and Low Pass MT

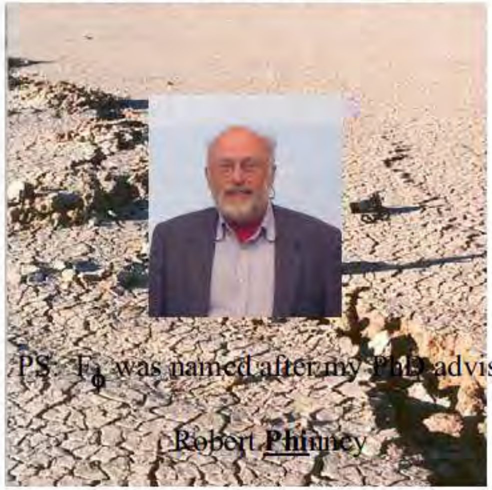


Analog high temperature (200 C) 15 Hz geophones

(IESE, University of Auckland, New Zealand)



THANKS FOR YOUR ATTENTION!



PS: F_ϕ was named after my PhD advisor

Robert **Phi**nney

Engineering Analysis of the Recovered SAFOD Borehole Instrumentation.

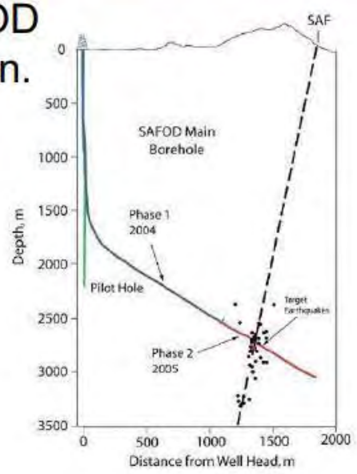
Wade Johnson
UNAVCO, INC

The 2nd International Workshop on Seismic Observation in Deep Boreholes and Its Applications. Nov 7-10th, 2012

UNAVCO

Outline of Talk

- Short history of the SAFOD down hole instrumentation.
- Description of the POD system
- Installation and failure
- Engineering analysis
- Findings
- Conclusions and recommendations



THE SAFOD ENGINEERING SUBCOMMITTEE OF THE ADVISORY COMMITTEE FOR GEOSCIENCES

- Subcommittee Members:
  - Tom Henyey, Professor Emeritus, Earth Sciences, USC (Chair)
  - Joe Henfling , HT Electronics Lead, Geothermal Dept., Sandia National Laboratories
  - Alan Linde, Senior Staff Member, DTM, Carnegie Institution of Washington
  - Jamison Steidl , Research Seismologist, Earth Research Inst., UC Santa Barbara
  - Don DePaolo, Professor, Earth and Planetary Science, UC Berkeley
- UNAVCO Management team:
  - David Mencin
  - Wade Johnson

History of SAFOD Main Hole Deployments.

- Between November 2004 and January 2007 there were 18 temporary instrument deployments in SAFOD
- Most of these deployments used standard wireline.
- Average failure time of two weeks.
- SAFOD borehole is not sealed at bottom and has gas and well fluids infiltrating it. There has not been any success in shutting off this gas.

History of SAFOD Main Hole Deployments.

- Majority of failures of temporary installation were caused by gas and borehole fluids infiltrating cable head.
- Attempts to use better O-rings, Krytox oil and epoxy in the cable heads all failed.
- Needed to design a robust downhole instrument package (DIP) that could operate continuously at temperatures of ~120 degrees C and fluid pressures of 30 MPa for two years.


Viton O-ring in the cable head interconnect MH10


Gas leaking out of wireline.

Description of SAFOD Downhole Instrument Package

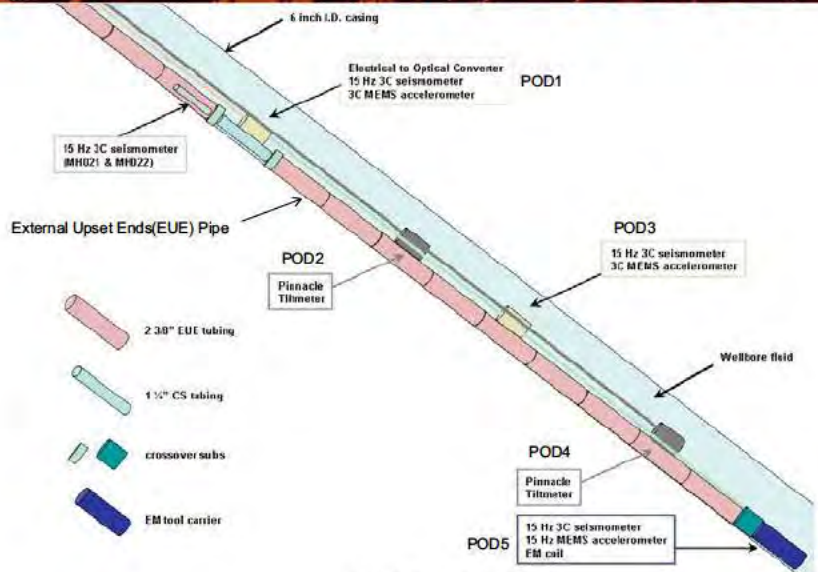
DIP was designed to isolate sensors from borehole fluids and gas using pressure vessels (PODS)

All signal and power lines were encapsulated in ¼ inch stainless steel tubing.

All external seals were meant to be metal on metal gas tight seals


Tiltmeter POD before installation

Description of SAFOD Downhole Instrument Package



Layout of instrument PODs

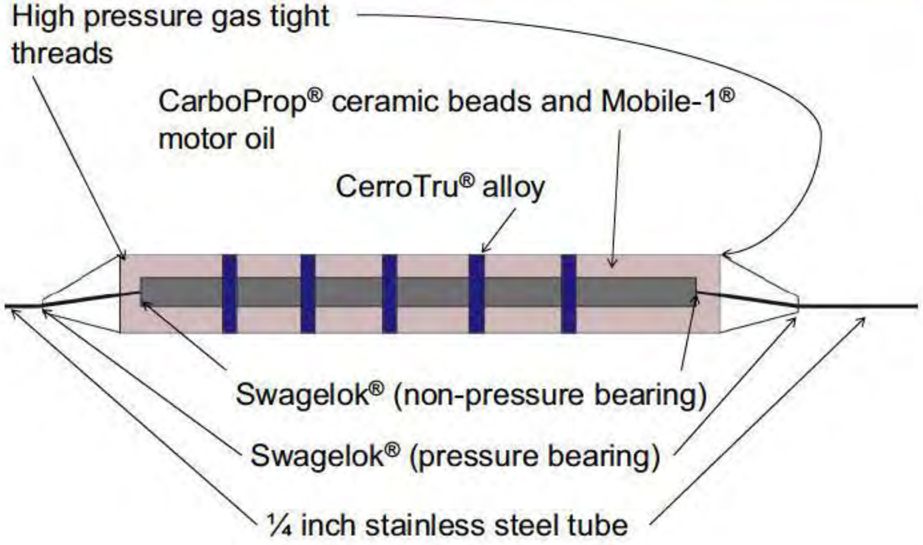
Description of SAFOD Downhole Instrument Package

- PODs used a combination of a low melting temperature metal, ceramic beads and Mobile-1® synthetic motor oil to couple DS150s and tilmeters to POD and to take up airspace.
- PODs were sealed using gas tight threaded ends and Swageloks®


POD filler test using CerroTru®, CarboProp® beads and oil


Threaded end cap.

Description of SAFOD Downhole Instrument Package



High pressure gas tight threads

CarboProp® ceramic beads and Mobile-1® motor oil

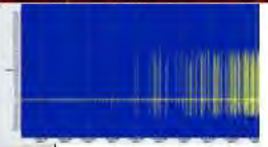
CerroTru® alloy

Swagelok® (non-pressure bearing)

Swagelok® (pressure bearing)

¼ inch stainless steel tube

Installation and Failure of SAFOD Downhole Instrument Package



2008/09/24: Begin of installation
2008/09/26: Bottom tiltmeter fails
2008/09/29: Installation is complete
2008/10/03: Seismic data starts to show data spikes
2008/10/09: Now running only one seismic instrument
2008/10/09: Top tiltmeter tool runs on uncontrolled power for several hours. Y accelerometer fails.
2008/10/13: last running seismic tool fails.
2008/10/18: Communication problems to top tiltmeter begin
2008/10/24: Last communication to top tiltmeter.

All instruments were offline in less than one month.

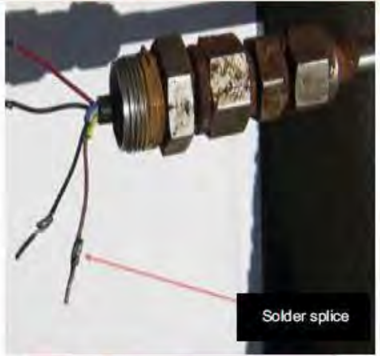
SAFOD Downhole Instrument Package Analysis Plan

1. Analysis of data to understand timeline of failure
2. Remove instrument safely, maintaining integrity of spliced section and documenting any external clues. Test instrument at surface
3. Open PODs in a way that allows for sampling and avoids damaging instruments.
4. Chemical analysis of fluids recovered from splices and PODs
5. Instrument analysis by instrument manufacturers.

Removal of the SAFOD instrumentation

Signal Line Splices

- Splices between PODs were insufficient for this application.
- Splices were not staggered.
- Insulation around splices not oil and temperature resistant.
- Multiple points of failure with the number of Swagelok® connectors



Findings from External Examination of PODs

- PODs appeared intact when on surface. Fluids were leaking from cut ¼ inch stainless steel tubing.

Findings From External Examination of PODs

- EUE crossover connection to top of POD5 was not welded.
- When crossover was removed pressurized gas and fluid escaped. Crossover used a non-gas tight thread.

Chemical Analysis of Collected Fluids.

- All oil samples were consistent with Mobile-1®, 10W-40 synthetic motor oil.
- No evidence of hydrocarbons from any source other than Mobile-1® oil.
- The oil from the PODs demonstrated evidence of thermal degradation and the presence of volatile hydrocarbon oxidation products.
- Water samples consistent with corrosive waters from the geologic formation.

Sample collection from base of POD5

Analysis of Instruments Inside PODs

Cutting into POD

DS150 coated with CerroTru® and ceramic beads.

Cleaned DS150 stack

Analysis of DS150s

- Signs of corrosion, and occasionally minor traces of oil on most instrument circuit boards.
- Examination of DS150s revealed many failed electronic components.
- Most likely caused long term exposure to elevated temperatures.

DS150: Seismometers on left with electronics in center and cable head connector on right.

Analysis of Tiltmeters

- Examination of the electronics boards in the tiltmeters indicated wide spread failure of components.
- As with the DS150s, the failure of the electronic components and motors were likely caused by long term exposure to elevated temperatures.
- No indication of leakage of PODs to outside environment.

Top of Tiltmeter 1 after recovery from POD2

Failure Scenario of Seismic PODs

- Fluid infiltrated through un-welded pipe thread at top of POD5. POD5 failed shortly afterwards.
- Well fluids and oil from the PODs migrated from POD 5 to POD 3 and POD 1 causing their failure in that order.

5. POD 1 pressurized with fluids from PODs3 and 5. Aqueous phase of well bore fluids not detected.

4. As Fluid moved through tubing splices were flooded

3. Fluids and gas from POD5 infiltrated POD3

2. As Fluid moved through tubing splices were flooded

1. Fluid and gas entered at EUE crossover, Breached internal seals and flooded ¼" ss tube

UNAVCO

Failure Scenario of Seismic PODs

- Fluid infiltrated through un-welded pipe thread at top of POD5. POD5 failed shortly afterwards.
- Well fluids and oil from the PODs migrated from POD 5 to POD 3 and POD 1 causing their failure in that order.

5. POD 1 pressurized with fluids from PODs3 and 5. Aqueous phase of well bore fluids not detected.

4. As Fluid moved through tubing splices were flooded

3. Fluids and gas from POD5 infiltrated POD3

2. As Fluid moved through tubing splices were flooded

1. Fluid and gas entered at EUE crossover, Breached internal seals and flooded ¼" ss tube

---

UNAVCO

Failure Scenario of Seismic PODs

- Fluid infiltrated through un-welded pipe thread at top of POD5. POD5 failed shortly afterwards.
- Well fluids and oil from the PODs migrated from POD 5 to POD 3 and POD 1 causing their failure in that order.

5. POD 1 pressurized with fluids from PODs3 and 5. Aqueous phase of well bore fluids not detected.

4. As Fluid moved through tubing splices were flooded

3. Fluids and gas from POD5 infiltrated POD3

2. As Fluid moved through tubing splices were flooded

1. Fluid and gas entered at EUE crossover, Breached internal seals and flooded ¼" ss tube

---

UNAVCO

Failure Scenario of Seismic PODs

- Fluid infiltrated through un-welded pipe thread at top of POD5. POD5 failed shortly afterwards.
- Well fluids and oil from the PODs migrated from POD 5 to POD 3 and POD 1 causing their failure in that order.

5. POD 1 pressurized with fluids from PODs3 and 5. Aqueous phase of well bore fluids not detected.

4. As Fluid moved through tubing splices were flooded

3. Fluids and gas from POD5 infiltrated POD3

2. As Fluid moved through tubing splices were flooded

1. Fluid and gas entered at EUE crossover, Breached internal seals and flooded ¼" ss tube

---

UNAVCO

Failure Scenario of Seismic PODs

- Fluid infiltrated through un-welded pipe thread at top of POD5. POD5 failed shortly afterwards.
- Well fluids and oil from the PODs migrated from POD 5 to POD 3 and POD 1 causing their failure in that order.

5. POD 1 pressurized with fluids from PODs3 and 5. Aqueous phase of well bore fluids not detected.

4. As Fluid moved through tubing splices were flooded

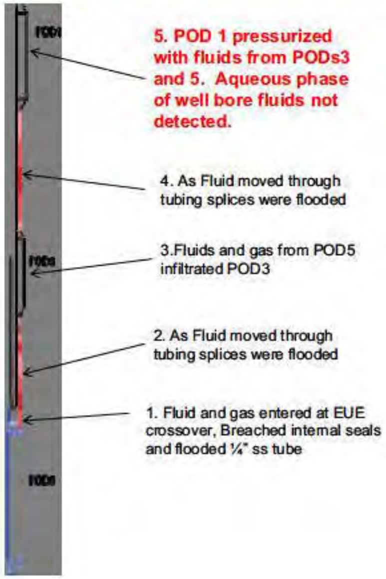
3. Fluids and gas from POD5 infiltrated POD3

2. As Fluid moved through tubing splices were flooded

1. Fluid and gas entered at EUE crossover, Breached internal seals and flooded ¼" ss tube

Failure Scenario of Seismic PODs

- Fluid infiltrated through un-welded pipe thread at top of POD5. POD5 failed shortly afterwards.
- Well fluids and oil from the PODs migrated from POD 5 to POD 3 and POD 1 causing their failure in that order.



5. POD 1 pressurized with fluids from PODs3 and 5. Aqueous phase of well bore fluids not detected.

4. As Fluid moved through tubing splices were flooded

3.Fluids and gas from POD5 infiltrated POD3

2. As Fluid moved through tubing splices were flooded

1. Fluid and gas entered at EUE crossover, Breached internal seals and flooded ¼" ss tube

Findings of SAFOD Analysis Committee

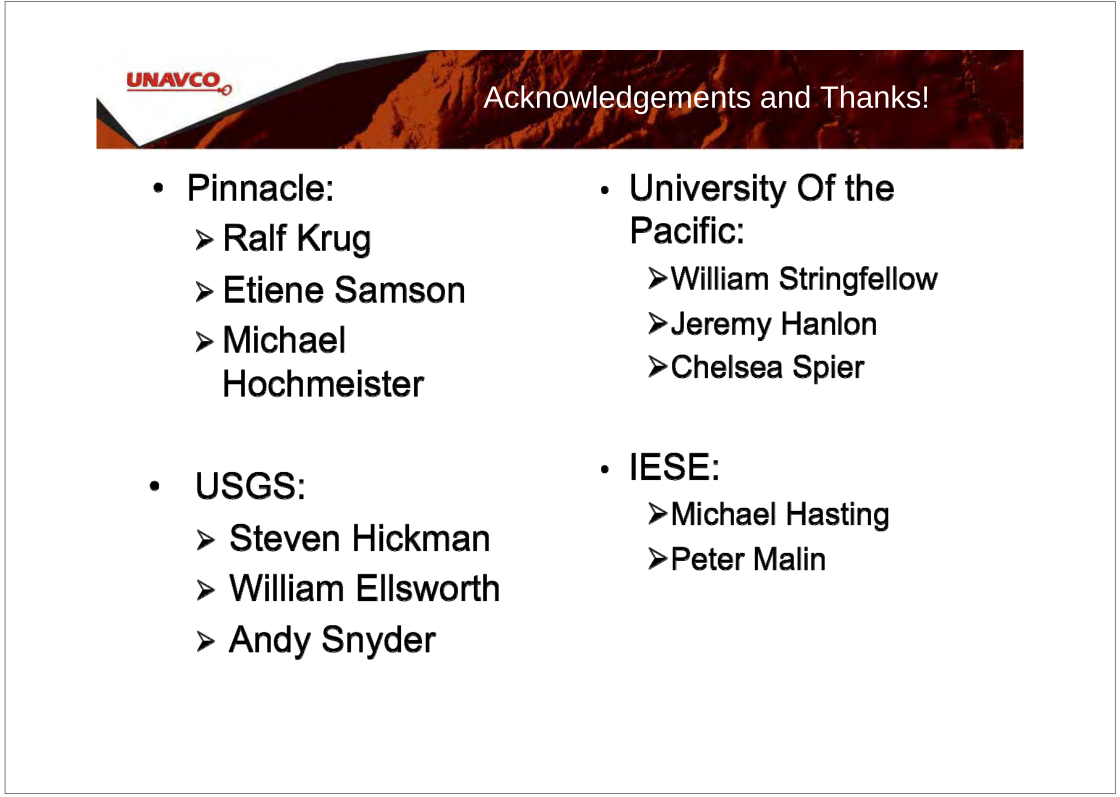
- The EUE crossover on top of POD5 not gas tight!
- Insufficient internal barriers to fluid and gas flow between the PODs. Multiple single points of failure. Any of these points of failure would take down all PODs
- There was a lack of documentation from the manufacturer regarding the manufacturing process and procedures.

Findings of SAFOD Analysis Committee

- Presence of volatile compounds consistent with the thermal degradation of motor oil
- DS150s employed in the DIP were not designed for long-term deployment in an 120C environment.
- Splices between PODs were inadequate.
- Lack of oversight and management in the construction of the downhole instrument package.

Conclusions and Recommendations

- Need strict oversight of sub contractors
- Need robust risk analysis and risk mitigation plan.
- Multiple checks by different people on points of failure.
- If possible avoid use of active electronics in environments like SAFOD.
- Components must be rated for the temperature of the environment.
- If failure occurs, remove instrumentation in a timely manor.
- SAFOD POD design not inherently flawed but poorly implemented.



Acknowledgements and Thanks!

- Pinnacle:
  - Ralf Krug
  - Etiene Samson
  - Michael Hochmeister

- USGS:
  - Steven Hickman
  - William Ellsworth
  - Andy Snyder

- University Of the Pacific:
  - William Stringfellow
  - Jeremy Hanlon
  - Chelsea Spier

- IESE:
  - Michael Hasting
  - Peter Malin

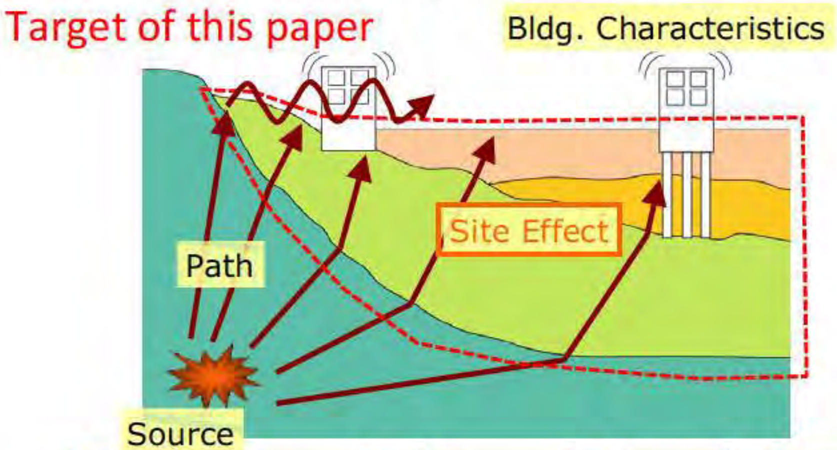
Estimation of S-wave velocity structure of deep sedimentary layers using geophysical data and earthquake ground motion records.

Haruhiko Suzuki・Hiroto Nakagawa
（OYO）
Genyu Kobayashi（JNES）

Outline

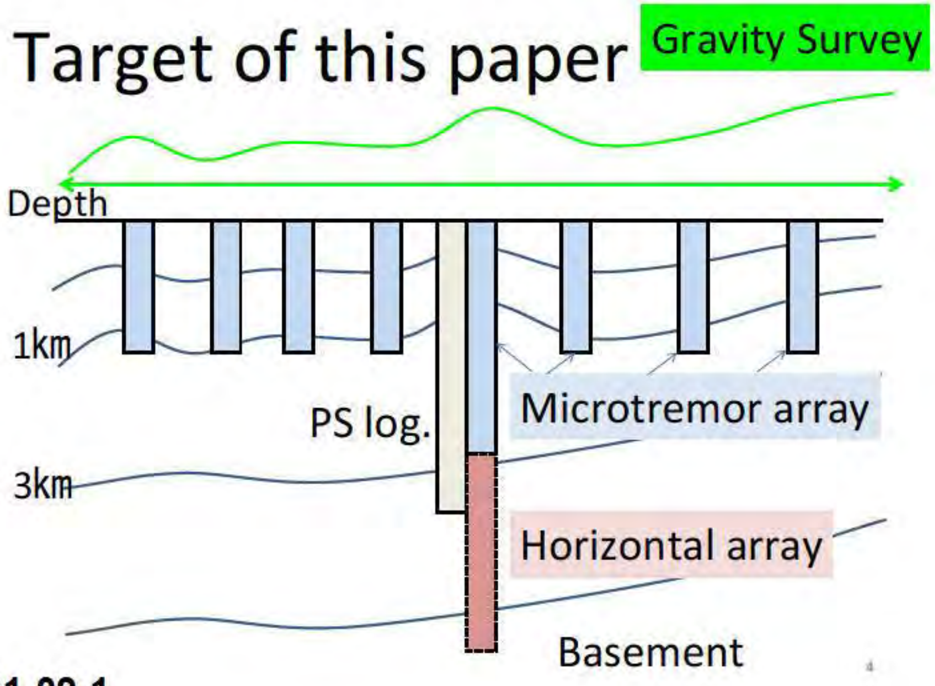
- Background
- Target of this paper
- Microtremor Survey
- Horizontal array of strong motion observation points
- Gravity Survey
- Conclusions

Background



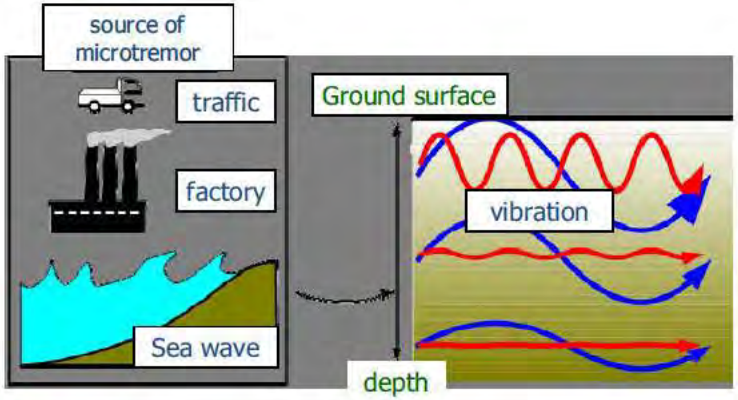
Ground Motion = Source × Path × Site

Target of this paper



Microtremor Survey

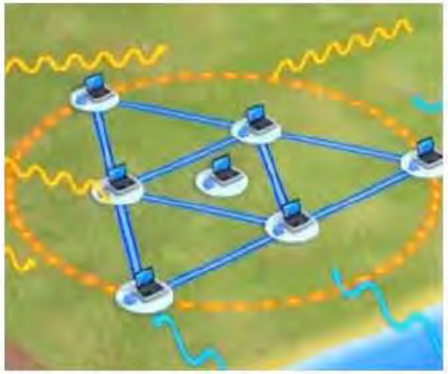
- Low Cost
- Surface Waves
  (e.g., Tokimatsu et al.(1992); Bonnefoy-Claudet et al.(2008))
- Survey depth is influenced by the power of microtremor.



Horizontal array of strong motion observation points

Deep borehole array

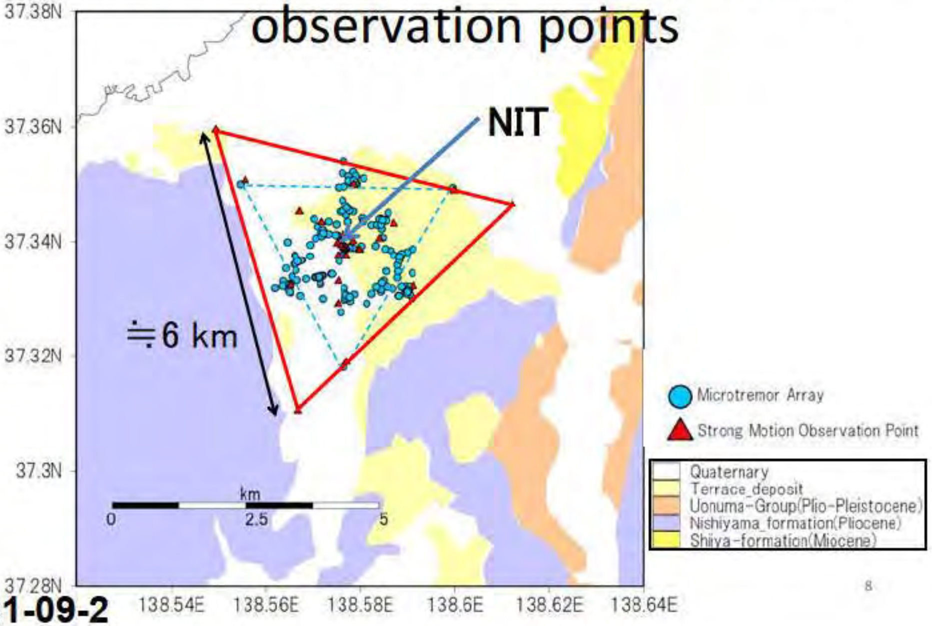
Horizontal array



The long period earthquake records more than 5sec.

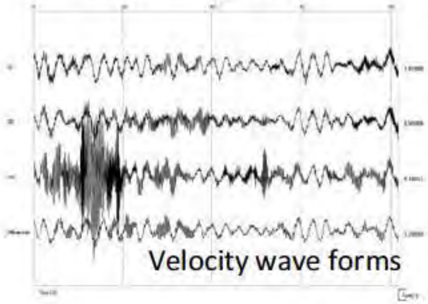
Microtremor Survey(Array Design)

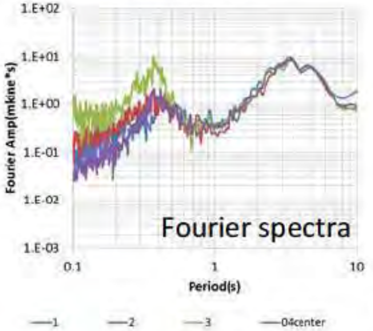
Horizontal array of strong motion observation points



Microtremor Exploration(Array Design)

- The array consists of 7 vertical seismometers with the length of triangle from 4km to 125m
- We carried out the 11 array which the length of triangle is 1km.
- Three component of Microtremor at the center of array.


Velocity wave forms



Fourier spectra

Definition of Misfit for Joint Inversion

- More than 2 observation data are used (e.g., Dispersion curve (phase vel.) H/V Spectrum)

$$misfit = \frac{w_V}{N_V}\sum_{i=1}^{N_V}\left(\frac{c_{obs\,i}-c_{cal\,i}}{c_{obs\,i}}\right)^2 + \frac{w_{(H/V)}}{N_{(H/V)}}\sum_{i=1}^{N_{(H/V)}}\left(\frac{(H/V)_{obs\,i}-(H/V)_{cal\,i}}{(H/V)_{obs\,i}}\right)^2$$

w : Weighting factor

N : Number of data

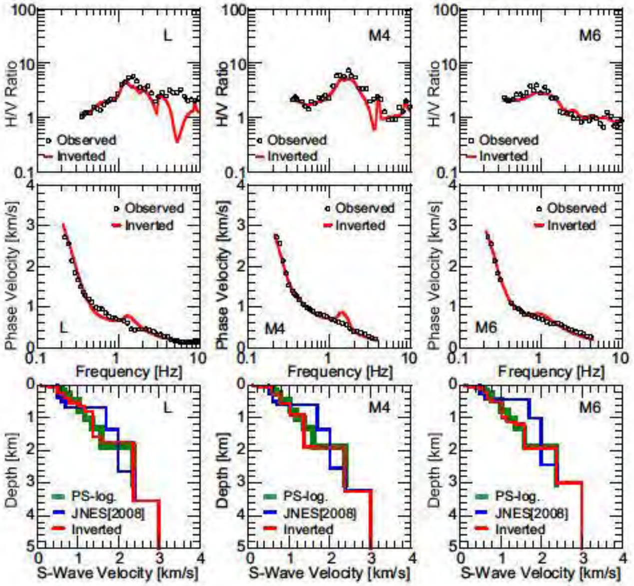
c_{obs} : Phase velocity (obs.)

c_{cal} : Phase velocity (cal.)

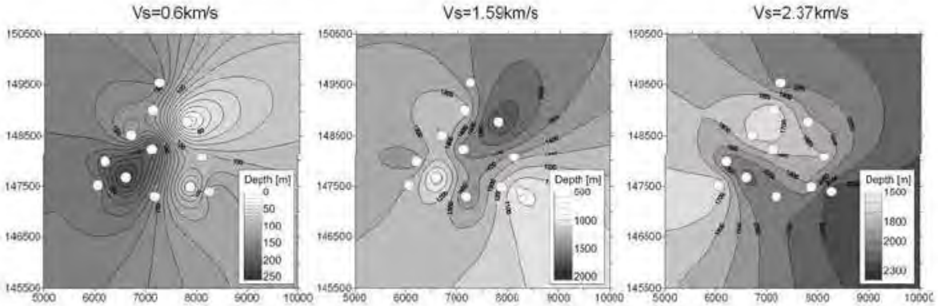
$(H/V)_{obs}$: H/V ratio (obs.)

$(H/V)_{cal}$: H/V ratio (cal.)

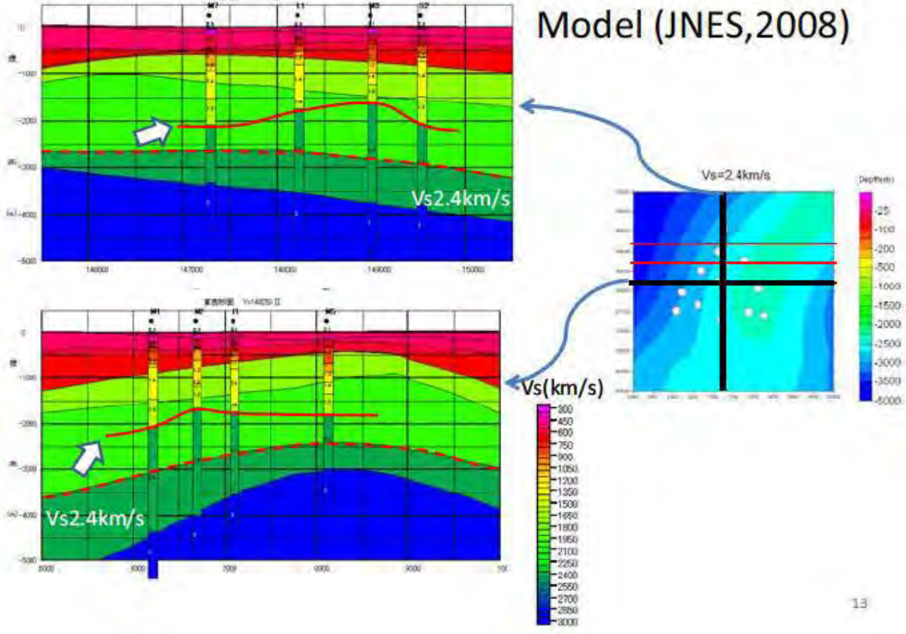
Joint Inversion Result



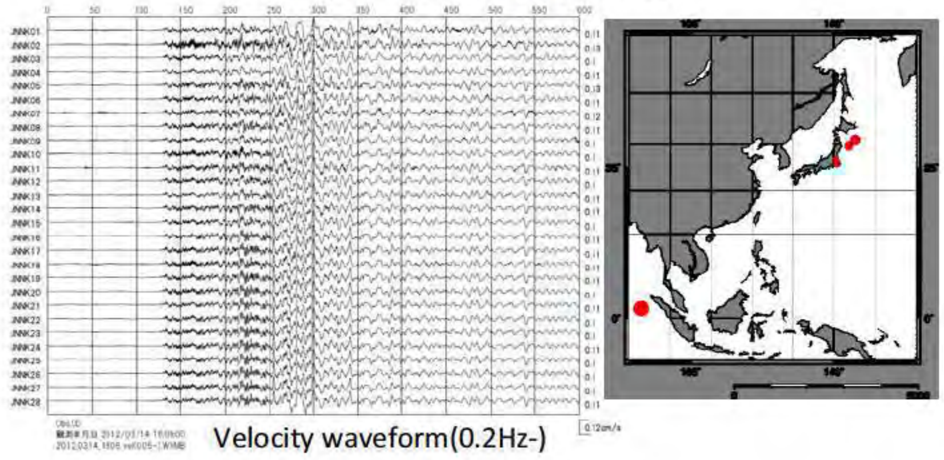
Depth of Each Layers



Comparison with 3D Model (JNES,2008)



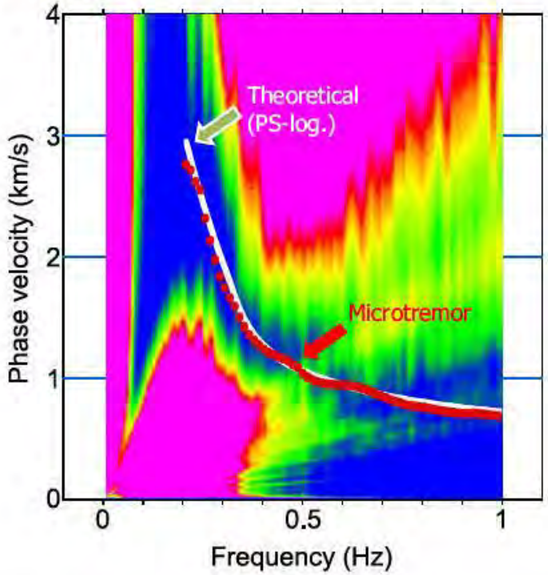
The strong motion records observed by the Horizontal array data.



Velocity waveform(0.2Hz-)

2012/3/14 FAR SE OFF HOKKAIDO
Mj 6.9 Dep64km

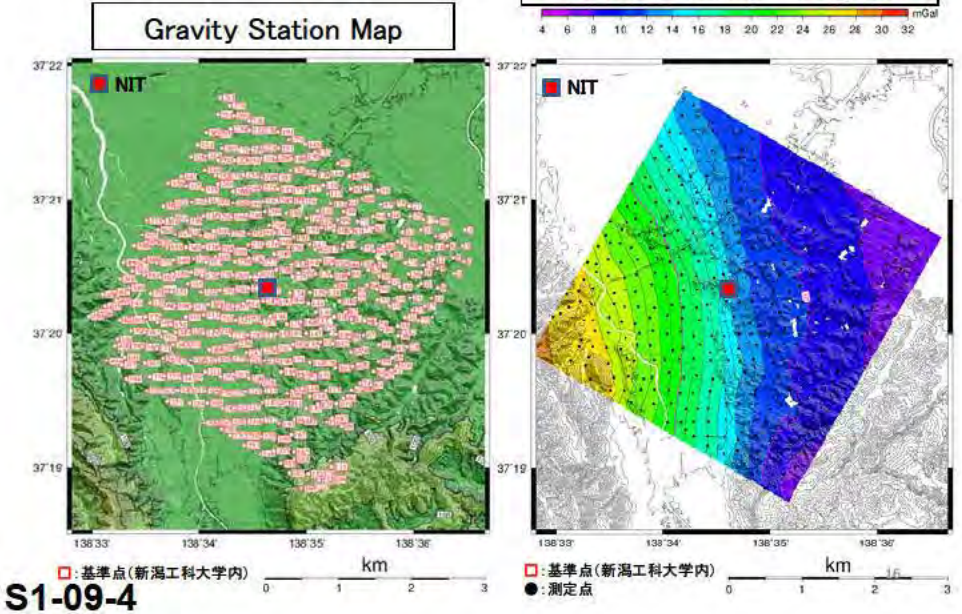
The image of surface wave dispersion curve using earthquake ground motion records.



Gravity map

Bouguer Anomaly
Asuumed density 2.52g/cm^3

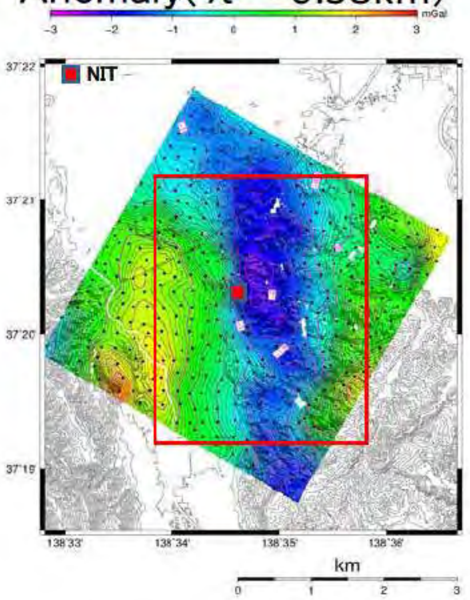
Gravity Station Map



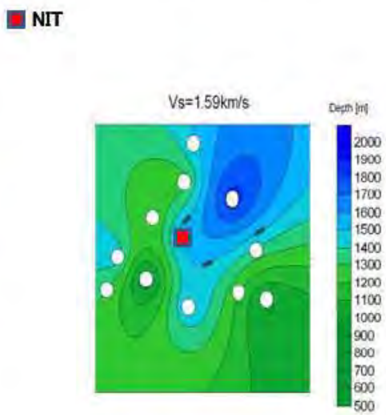
□:基準点(新潟工科大学内)

□:基準点(新潟工科大学内)
●:測定点

Residual Bouguer Anomaly(λ～0.38km)



Comparison with Residual Bouguer Anomaly



Conclusions

- We conduct microtremor exploration at 12 sites in and around NIT.
- By the use of joint inversion, S-wave velocity profiles can be obtained.
- Phase velocity estimated form horizontal array of strong motion observation agree with that from microtremor survey.
- Estimation result is harmonious with other literature such as PS-logging data and gravity map.
- We will improve the 3D model using microtremor survey and horizontal array survey results.

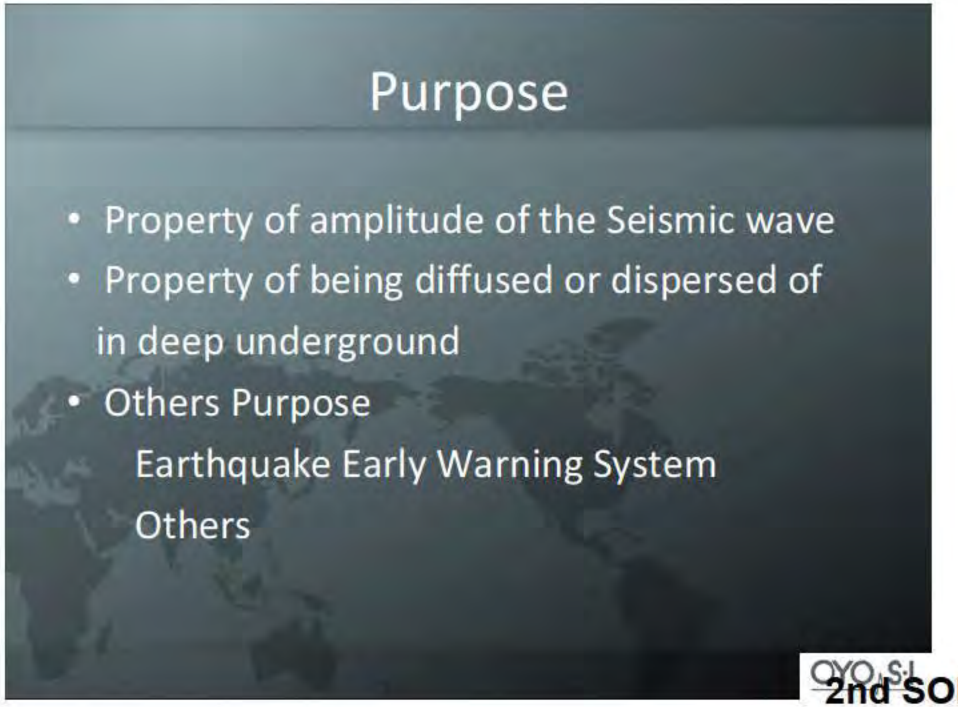
Development of Simple Borehole-Seismometer

The 2nd International Workshop pn Seismic Observation in
Deep Borehole and It's Applications
Nov. 8 2012

Toru Kajiwara
OYO Seismic Instrumentation Corp.

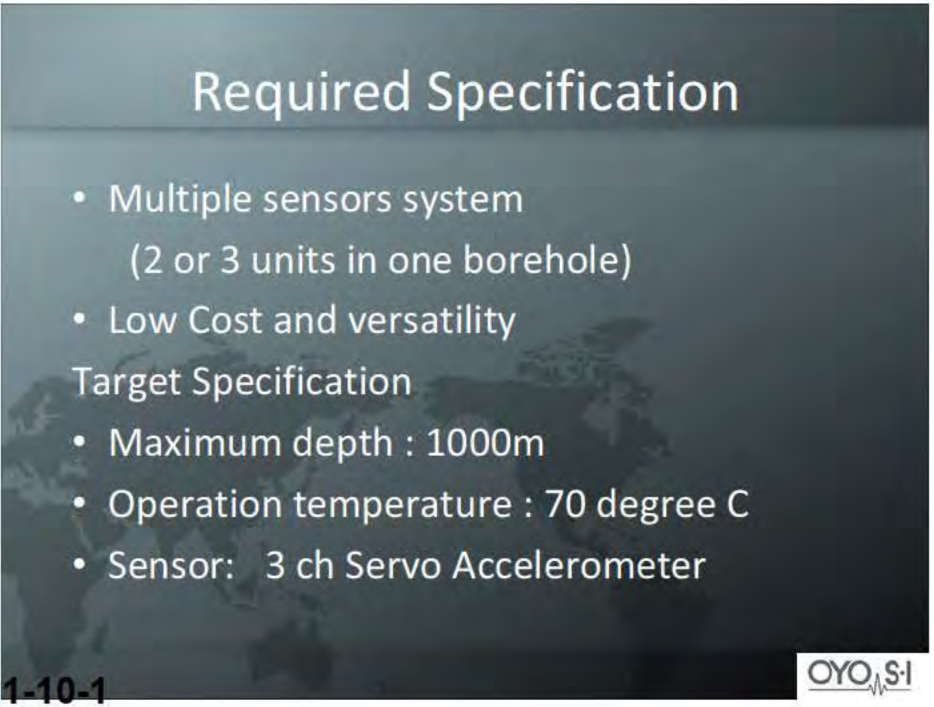
Menu

- Purpose of Development and Circumstance
- Outline of the New Borehole Seismometer
- Features
- Installation
- Results



Purpose

- Property of amplitude of the Seismic wave
- Property of being diffused or dispersed of in deep underground
- Others Purpose
  Earthquake Early Warning System
  Others



Required Specification

- Multiple sensors system
  (2 or 3 units in one borehole)
- Low Cost and versatility

Target Specification

- Maximum depth : 1000m
- Operation temperature : 70 degree C
- Sensor: 3 ch Servo Accelerometer

Features of developing system

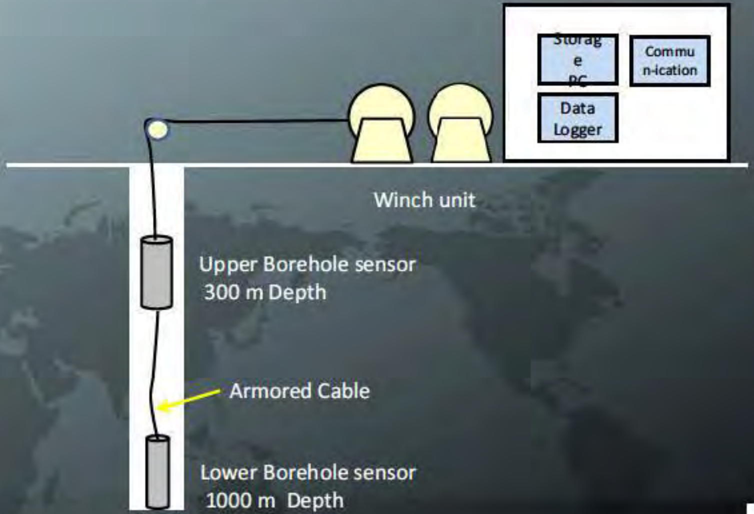
- Armored Cable System
  Metal multiple cables (24 and 48 wire)
  with Armored
- High performance Servo accelerometer
  Full Scale : +/- 4G , Resolution : 1micro G
- Locking Mechanism
- Detect Bottom Sensor (Fixed)
- Leak Sensor
- High Dynamic range Data Logger (128dB@100Hz)

Application

Middle depth earthquake monitoring

- Low Cost system
  - Slim and light weight borehole unit
  - Using 5 inch casing
  - Multiple sensors in one borehole.
- Easy Installation
  - Armored cable system
  - Remote Locking/ Unlocking

System Configuration



Borehole Seismometer

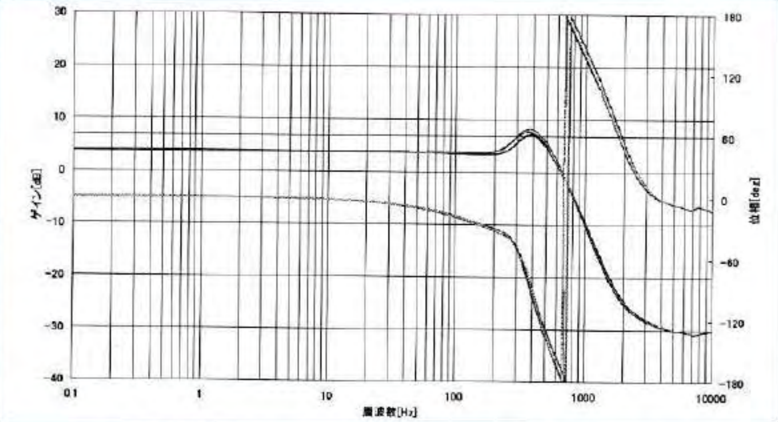
Upper Borehole Seismometer

Lower Borehole Seismometer

Accelerometer Sensor

- Type: Force balance Servo Accelerometer
- Full Scale: +/- 4 G
- Resolution: 1 micro G
- Output : 2 V/G
- Frequency: DC to 200 Hz
- Operation temperature :
  -20 to 70 degree C

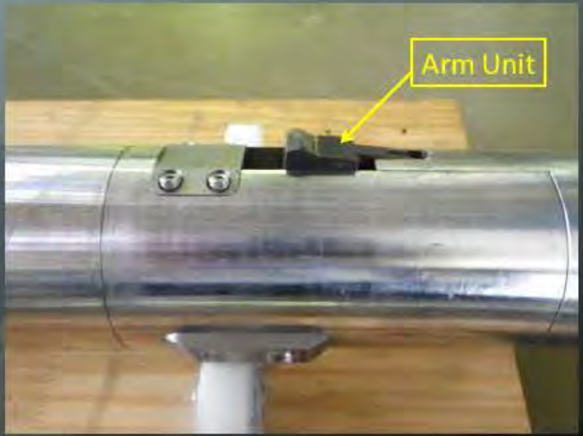
Frequency and Fhase



Frequency Response and Phase Response

Locking Mechanism

Lock mechanism: Spread Arm by Motor



Detect Sensor for Fixing

Mechanism of Detect Sensor

Winch unit

[Upper Winch]
Reel: 400m
Motor: Electric P.
Power: 2 .2 ton

[Lower Winch]
Reel: 800m
Motor: Electric P.
Power: 1 .8 ton

Winch Unit

Winch (for 1000m)

Tension meter & Sheave

Armored Cable

Data Logger

High Dynamic Range Multi-channel Recorder

■ Feature ■

- ◆ Up to 36 channels at ~130dB dynamic range
- ◆ Record and communicate multiple sample rates
- ◆ Multiple data formats and telemetry protocols
- ◆ Power Management for ultra-low power operation
- ◆ Extensive state-of-health monitoring, including input and system voltages, internal temperature, humidity, communication link diagnostics

OYO S·I

Lower Borehole Seismometer

Borehole Sensor
(for 1000m depth)

OYO S·I

Upper Borehole Seismometer

Borehole Sensor (for 300m depth)

OYO S·I

Field Installation

Tottori Site

OYO S·I

Field Installation

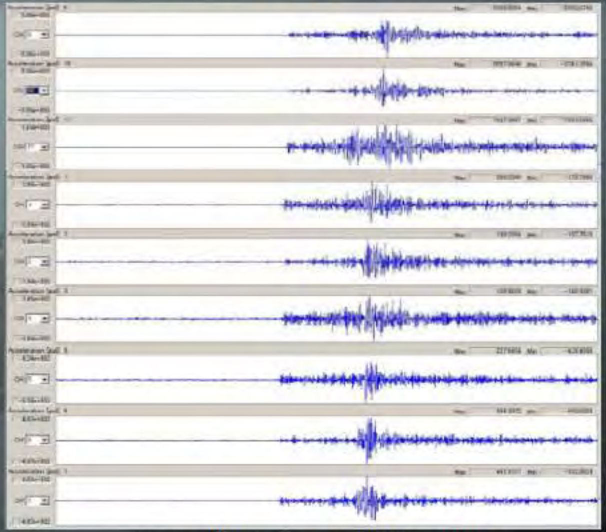
Tottori Site

Field Installation

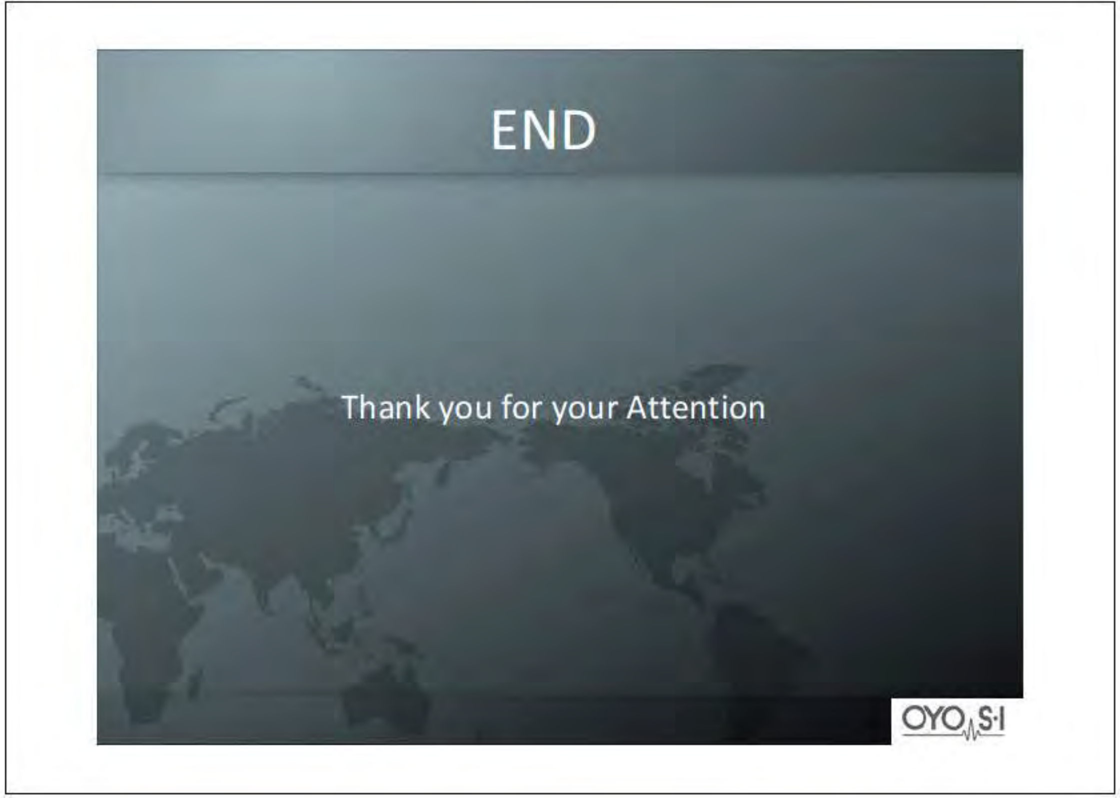
Field Installation

Surface Accelerometer

Data Collection

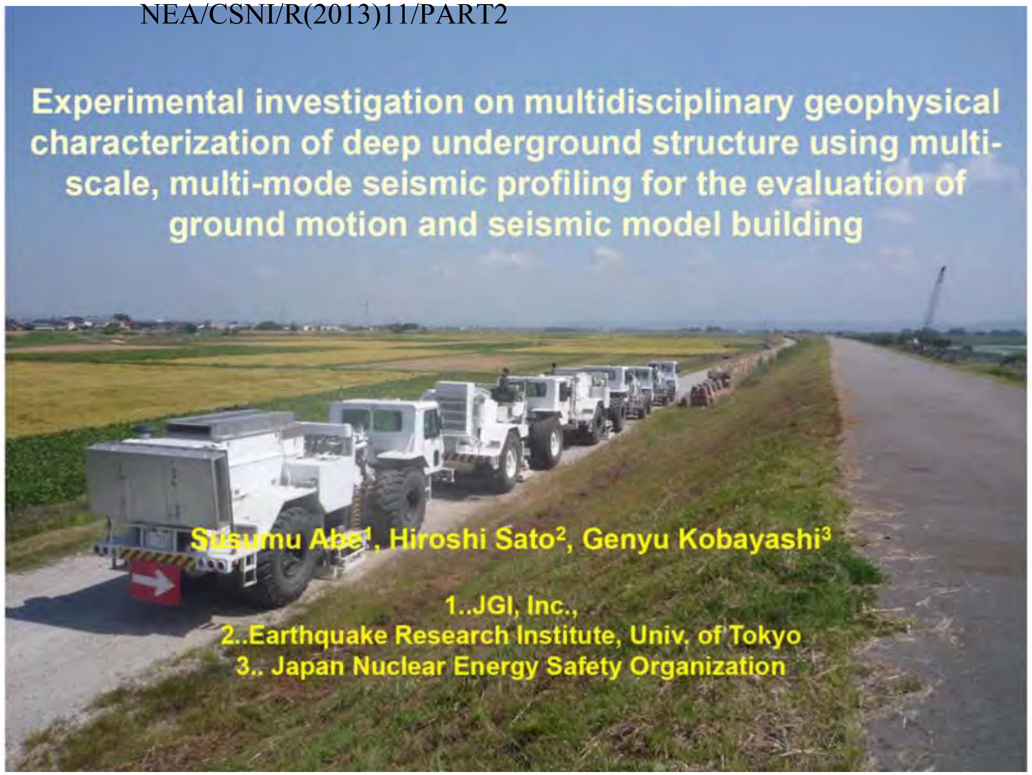


Earthquake Nov.05 , 2012



END

Thank you for your Attention



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

Susumu Abe[1], Hiroshi Sato[2], Genyu Kobayashi[3]

1..JGI, Inc.,
2..Earthquake Research Institute, Univ. of Tokyo
3.. Japan Nuclear Energy Safety Organization

Outline

1. Recent advances in data acquisition and velocity estimation for multi-mode, multi-scale seismic exploration
2. Basic concept of strategic geophysical survey for an assessment of NPP siting
3. Case study - Multidisciplinary geophysical characterization of deep underground structure beneath JNES Kashiwazaki Seismic Safety Center
4. Conclusion and future work

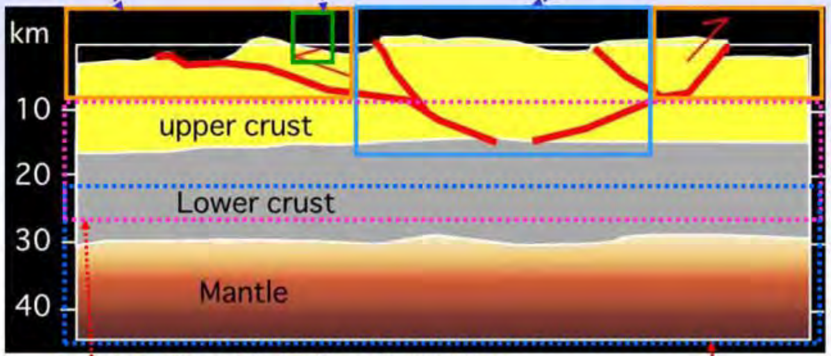
Multi-scale Data Acquisition ➡ **Different Spatial Sampling**
Multi-mode Data Acquisition ➡ **Combination of Reflection, Wide-angle Reflection, Refraction and 3C Data**

JGI(2011)

Shallow Seismic Profiling
High-resolution Reflection Survey

Basin-scale Seismic Profiling
Reflection and Refraction Survey

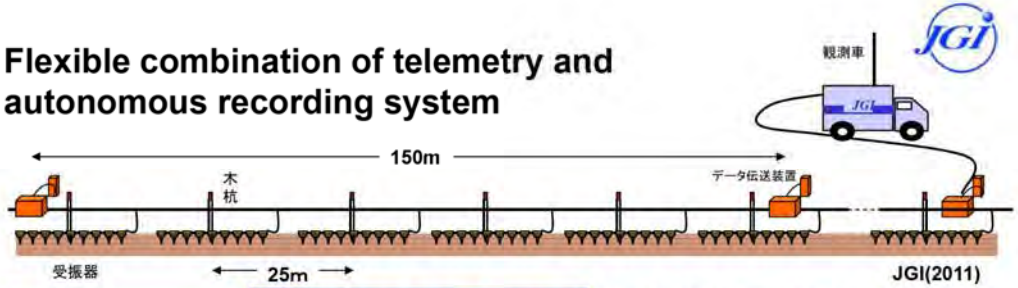
Crustal-scale Seismic Profiling
Wide-angle Reflection and Refraction Survey with High-energy Source



Seismic Profiling of the Middle and Lower Crust
Seismic Imaging by RVSP and SI using Local Earthquake

Seismic Profiling of the Lower Crust and Moho
Seismic Imaging by RCM and SI using Teleseismic Wave

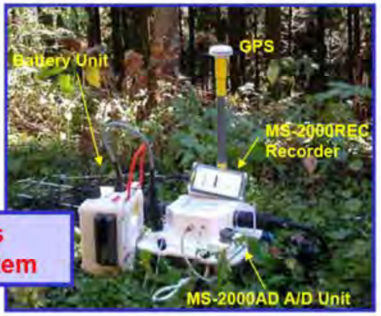
Flexible combination of telemetry and autonomous recording system

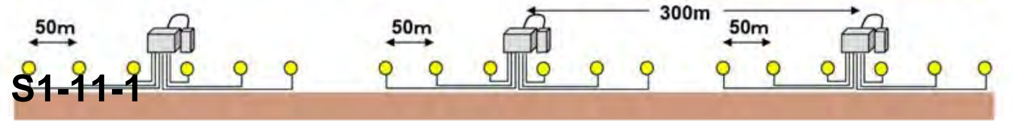


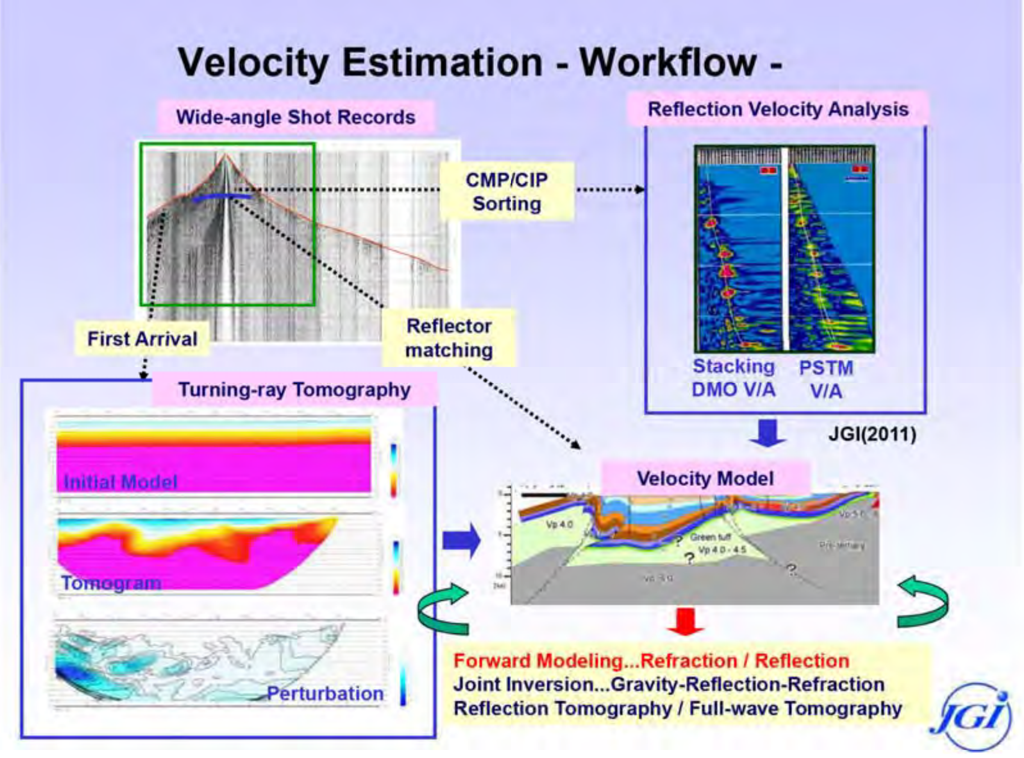
JGI(2011)

Telemetry Cable System
512-4096CHs

Autonomous Recording System

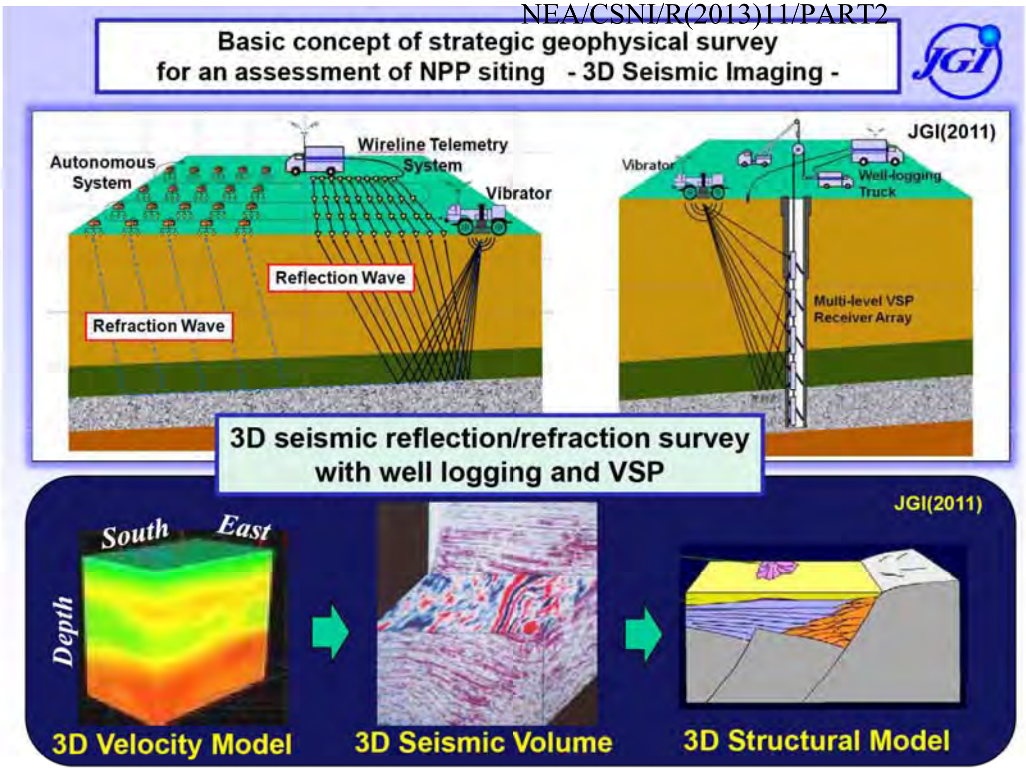






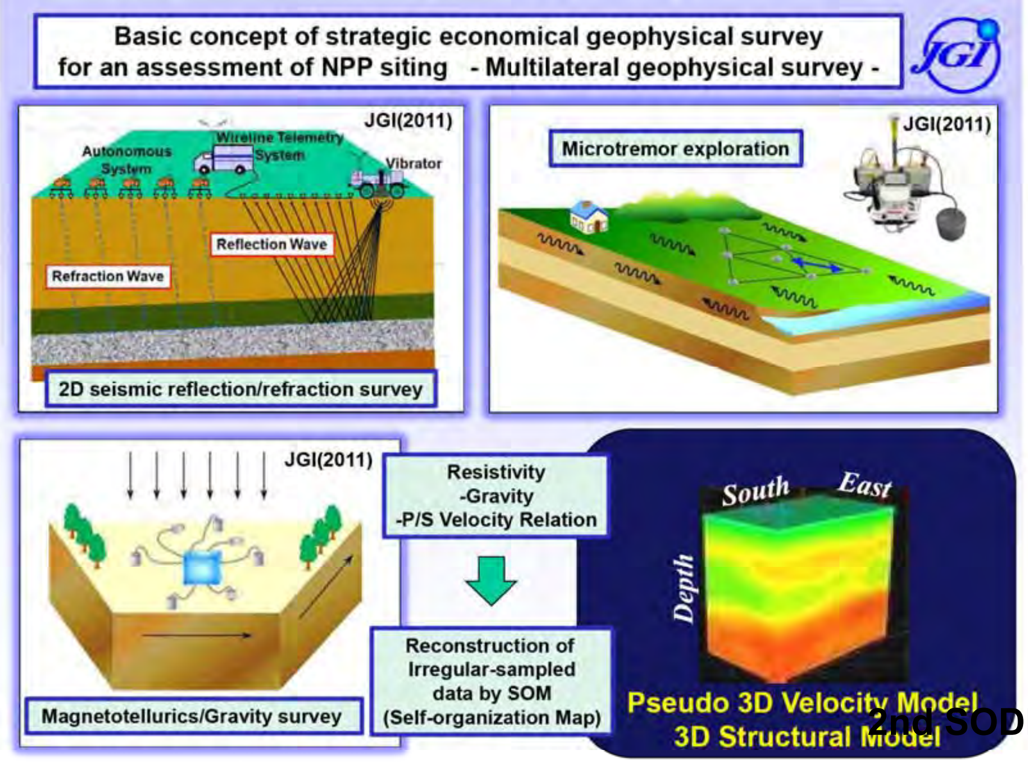
Velocity Estimation - Workflow -

Forward Modeling...Refraction / Reflection
Joint Inversion...Gravity-Reflection-Refraction
Reflection Tomography / Full-wave Tomography

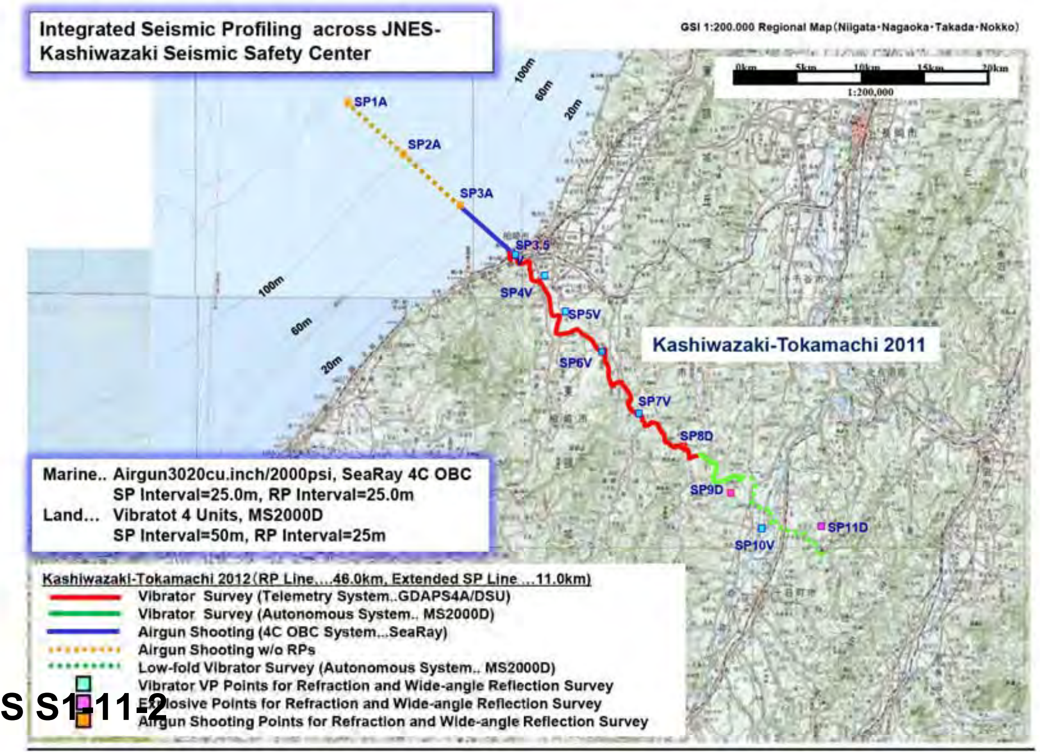


Basic concept of strategic geophysical survey for an assessment of NPP siting - 3D Seismic Imaging -

3D seismic reflection/refraction survey with well logging and VSP



Basic concept of strategic economical geophysical survey for an assessment of NPP siting - Multilateral geophysical survey -



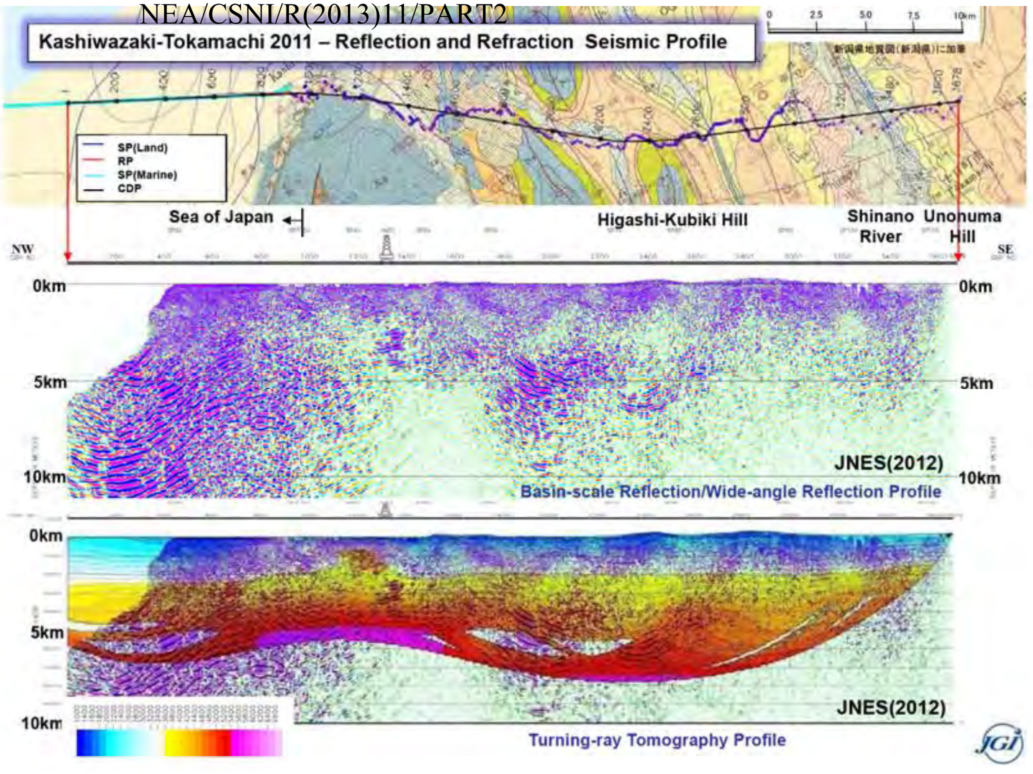
Integrated Seismic Profiling across JNES-Kashiwazaki Seismic Safety Center

Marine.. Airgun3020cu.inch/2000psi, SeaRay 4C OBC
SP Interval=25.0m, RP Interval=25.0m
Land... Vibratot 4 Units, MS2000D
SP Interval=50m, RP Interval=25m

Kashiwazaki-Tokamachi 2012(RP Line....46.0km, Extended SP Line ...11.0km)

- Vibrator Survey (Telemetry System..GDAPS4A/DSU)
- Vibrator Survey (Autonomous System.. MS2000D)
- Airgun Shooting (4C OBC System...SeaRay)
- Airgun Shooting w/o RPs
- Low-fold Vibrator Survey (Autonomous System.. MS2000D)
- ☐ Vibrator VP Points for Refraction and Wide-angle Reflection Survey
- ☐ Explosive Points for Refraction and Wide-angle Reflection Survey
- ☐ Airgun Shooting Points for Refraction and Wide-angle Reflection Survey

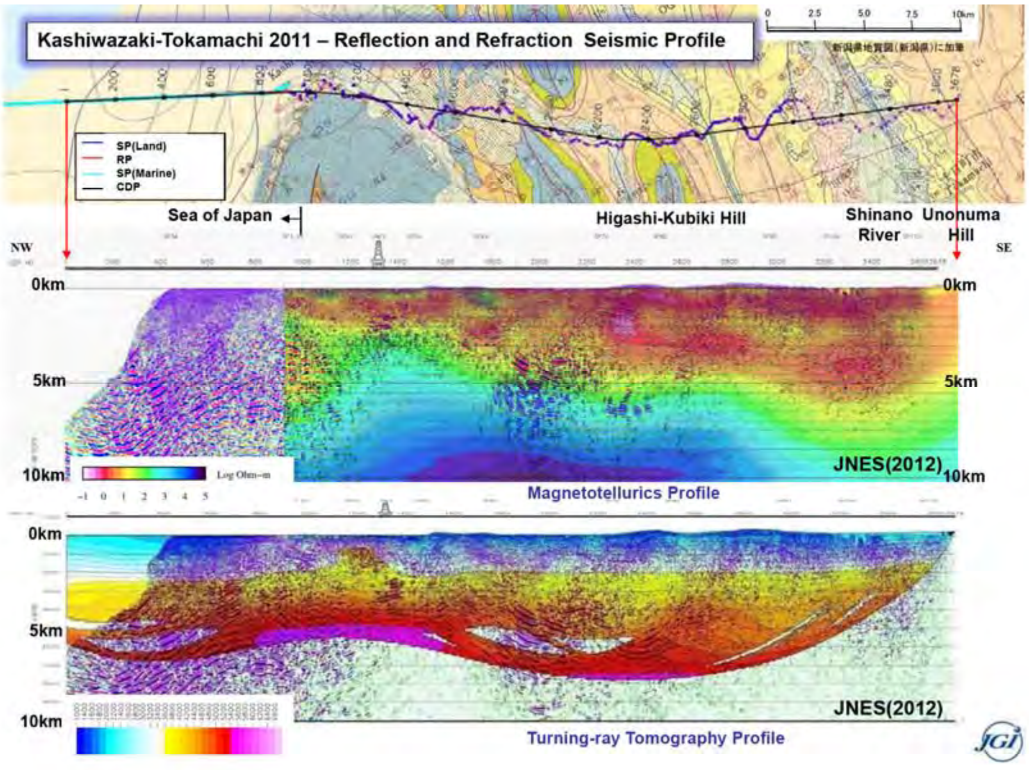
Kashiwazaki-Tokamachi 2011 – Reflection and Refraction Seismic Profile



Basin-scale Reflection/Wide-angle Reflection Profile

Turning-ray Tomography Profile

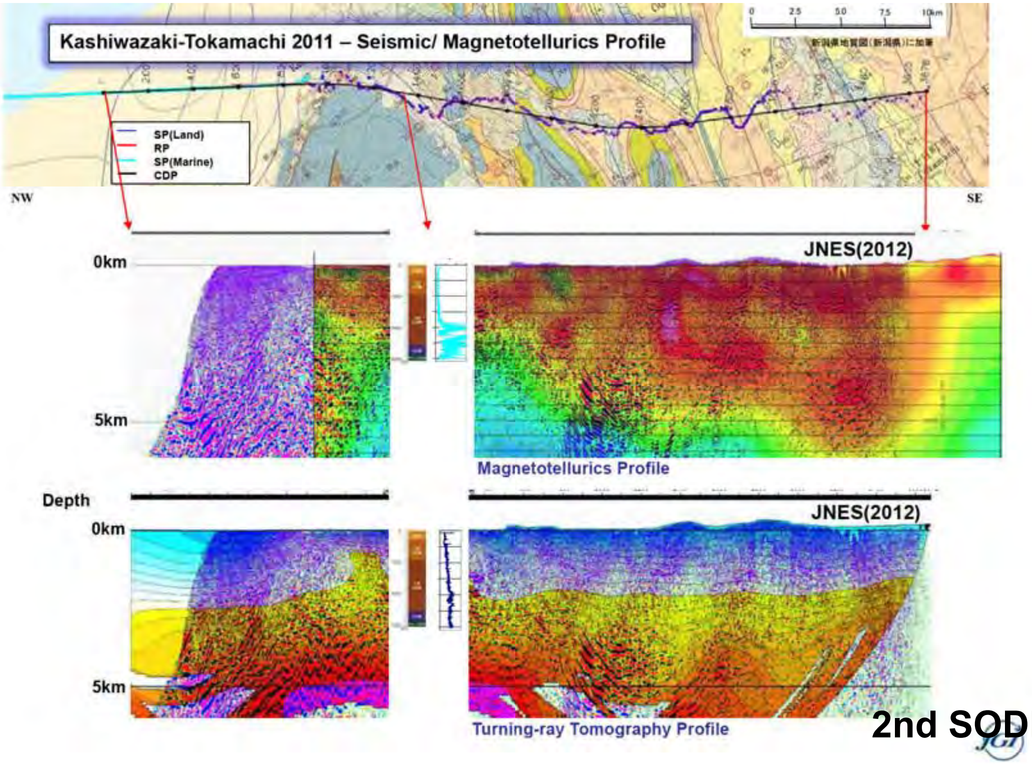
Kashiwazaki-Tokamachi 2011 – Reflection and Refraction Seismic Profile



Magnetotellurics Profile

Turning-ray Tomography Profile

Kashiwazaki-Tokamachi 2011 – Seismic/ Magnetotellurics Profile



Magnetotellurics Profile

Turning-ray Tomography Profile

Estimation of deep underground structure for velocity-model reconstruction and strong-motion prediction

Multi-scale and multi-mode seismic data acquisition

- Combination of telemetry and autonomous recording system provides the deployment of long survey line across the area of land-marine transition zones(TZ) with dense seismic array.
- Combination of different seismic sources types: vibrator, airgun and explosives for higher productivity without compromising data quality

High-resolution Velocity Estimation

- Multilateral velocity estimation using reflection and refraction data
- Refraction traveltime tomography with Monte Carlo uncertainty analysis based on initial-model randomization

The 2nd International Workshop on Seismic Observation in Deep Borehole and Its Applications

Evaluation of near-surface attenuation of S-waves based on PS logging and vertical array seismic observation

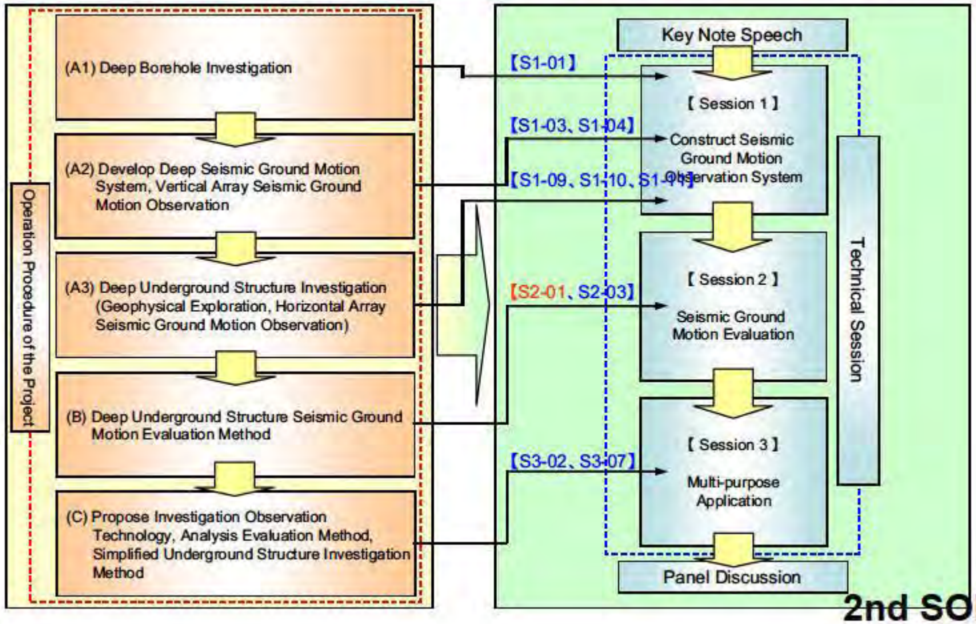
8 November, 2012
At Niigata Institute of Technology

Genyu Kobayashi
Japan Nuclear Energy Safety Organization (JNES)

Contents of Presentation

1. Establishing issues and objectives for consideration
2. Proposal of evaluation method of attenuation characteristics (draft)
3. Evaluation of attenuation characteristics based on various in-situ data
4. Verification test of method for evaluating attenuation characteristics at three representative sites
    - 4.1 Soil ground site
    - 4.2 Sedimentary rock site
    - 4.3 Igneous rock site
5. Discussion: Investigate the cause of high attenuation characteristics of ground
6. Summary and utilization of achievement

Relationships between Results of the Support Organization in the Project and Sessions of this Workshop



---

1. Establishing issues and objectives for consideration

■ It has become clear that urgent establishment is needed to set rational method of near-surface attenuation characteristics covering a depth range from an engineering bedrock to seismic bedrock because of the lessons learned from the experience of Kashiwazaki Kariwa nuclear power plant caused by 2007 Niigata Chuetsu Oki Earthquake (Mj6.8)

※Consideration on rational evaluation method of attenuation characteristics

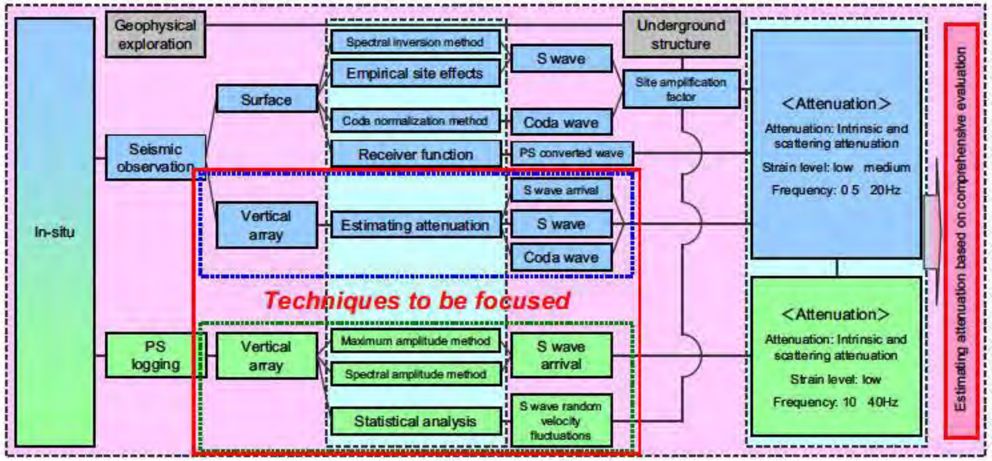
※Investigation of "high" attenuation characteristics of seismic wave obtained by vertical array seismic observation (Why is a damping factor considerably overestimated?)

Common issues for seismic safety review

⇒ Development and proposal of evaluation method of near-surface attenuation based on various in-situ data

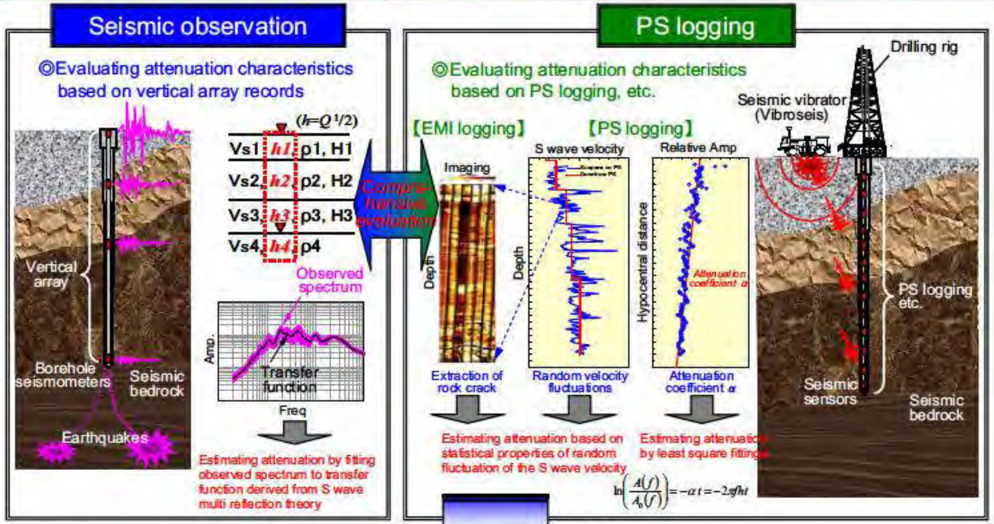
2. Proposal of evaluation method of attenuation characteristics (draft)

【Method for evaluating near-surface attenuation characteristics based on seismic observation and PS logging, etc.】



Verification tests ⇒ Development of methods for estimating attenuation based on comprehensive evaluation

3. Evaluation of attenuation characteristics based on various in-situ data



◎Evaluating attenuation characteristics based on vertical array records

Estimating attenuation by fitting observed spectrum to transfer function derived from S wave multi reflection theory

◎Evaluating attenuation characteristics based on PS logging, etc.

Estimating attenuation based on statistical properties of random fluctuation of the S wave velocity

Estimating attenuation by least square fitting

$$\ln\left(\frac{A(f)}{A_0(f)}\right) = -\alpha t = -2\pi f h t$$

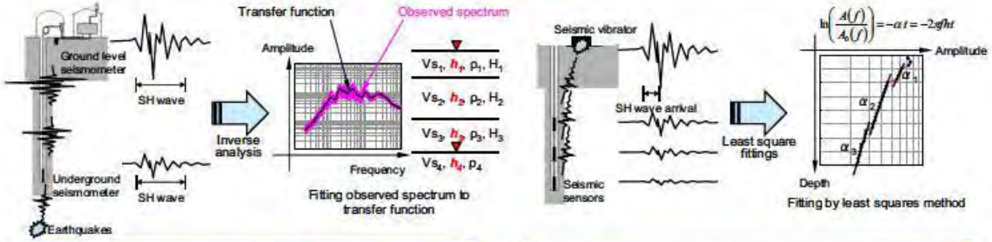
Establishment evaluation method of attenuation characteristics (site amplifications) based on records of seismic observation and PS logging

Issues on evaluation of attenuation characteristics based on in-situ data

Consideration of relation of attenuations evaluated by vertical array seismic observation and PS logging data by means of field and numerical experiments

Evaluating attenuation based on vertical array records

Evaluating attenuation based on PS logging data



Fitting observed spectrum to transfer function

$$\ln\left(\frac{A(f)}{A_0(f)}\right) = -\alpha t = -2\pi f h t$$

Fitting by least squares method

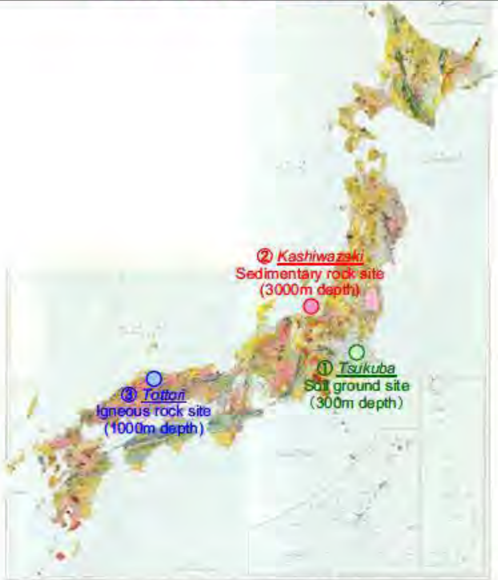
- Evaluation of attenuation based on wide frequency range of seismic waves having complex wave propagation characteristics
- Evaluation accuracy of average attenuation of ground between observation points (vertical arrays) are comparatively high

⇒Identification error of each layer's attenuation is large due to limited number of observation points
⇒Unable to evaluate without observation data

- Detail evaluation of each layer's attenuation is possible
- Attenuation evaluation is easy because of simple measurement waves with seismic vibrator
- Evaluation of attenuation based on high frequency range (more than 10Hz) with a single frequency (or very narrow band)

⇒It is necessary to explain the effectiveness of applying evaluation of attenuation to seismic ground motion evaluation

4. Verification test of method for evaluating attenuation characteristics at three representative sites



1:1,000,000 Japanese geologic map

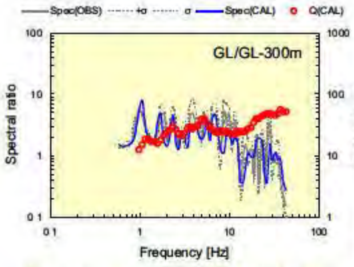
4.1 Soil ground site（300m deep)

■Outline of records and data

Vertical array seismic observation record

- Observation depth GL 0m, GL 40m, GL 300m
- Observation start date 2010/7/22
- Sampling 500Hz fast sampling
- Earthquake subject to analysis 4 earthquakes (Mj3 4 to 4 6)

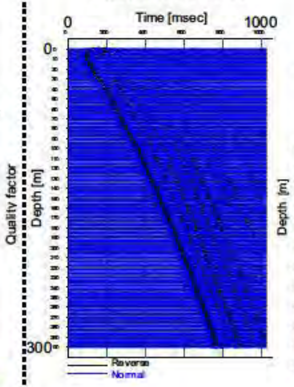
Evaluating attenuation



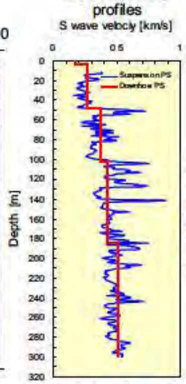
Estimating attenuation (quality factor) by fitting observed spectrum to transfer function derived from S wave multi-reflection theory

PS logging data

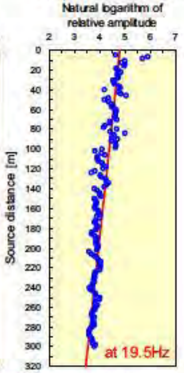
Measurement S waves



S wave velocity profiles



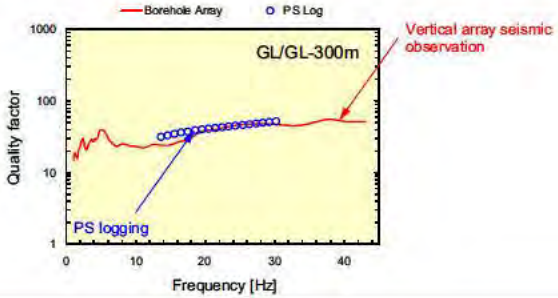
Amplitude distribution



Estimating attenuation (quality factor) by least square fittings

【Achievement】Verification test result at Soil ground site（300m deep)

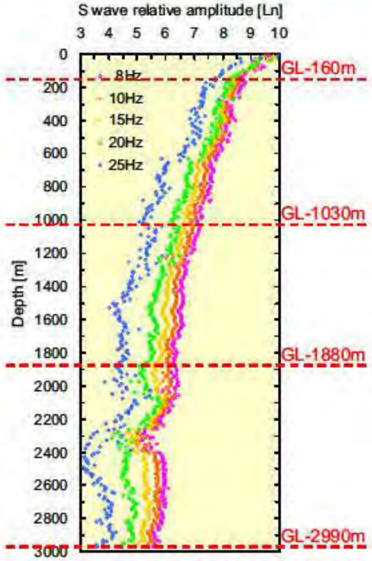
Quality factor based on vertical array seismic observation and PS logging

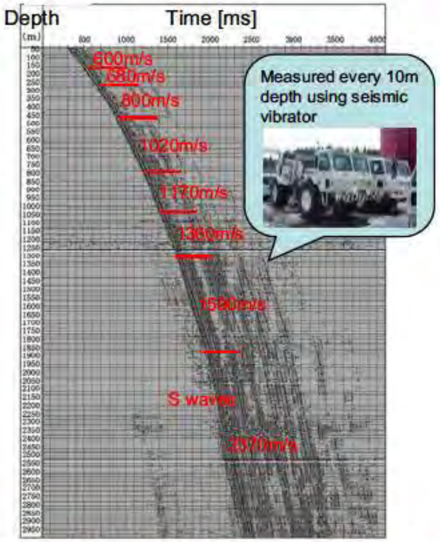


If we look at the S wave in same frequency range, attenuation (quality factor) evaluated from "vertical array seismic observation" and "PS logging" roughly matches each other

⇒ There is no difference in attenuation by different technique (evaluation method)

4.2 Sedimentary rock site (3000m depth)

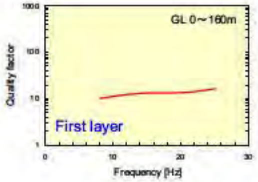


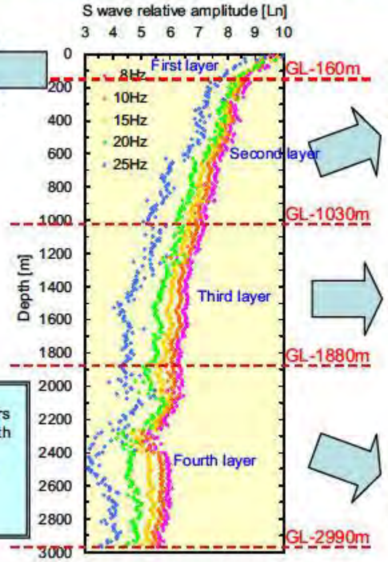


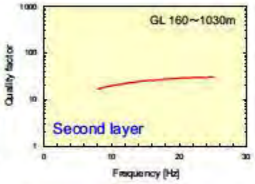
Measured every 10m depth using seismic vibrator

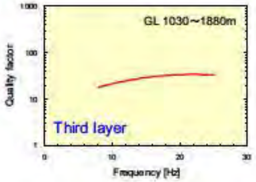
Attenuation structure presents 3 to 4 layers of wider structure by S wave relative amplitude distribution (profile)

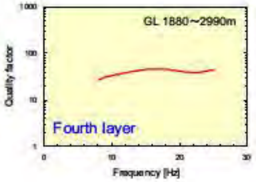
4.2 Sedimentary rock site (3000m depth)







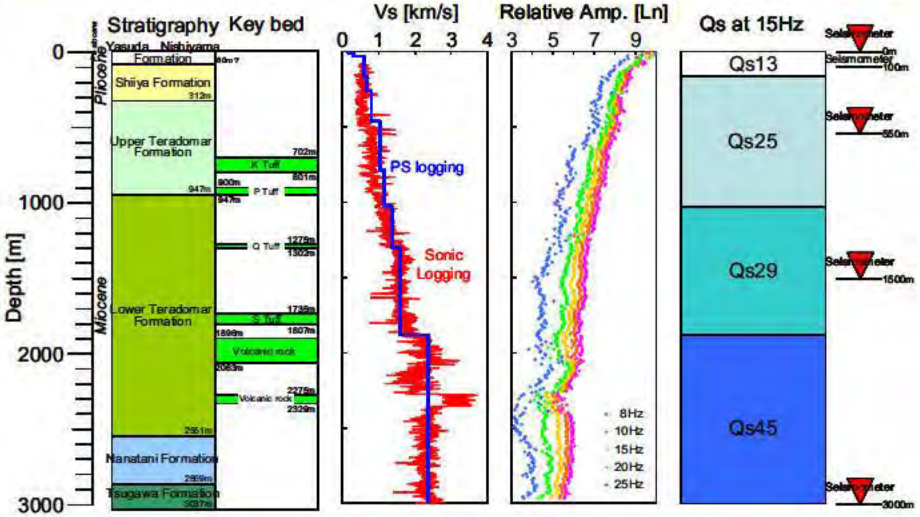




※Attenuation structure presents 3 to 4 layers of wider structure up to about 1000m depth

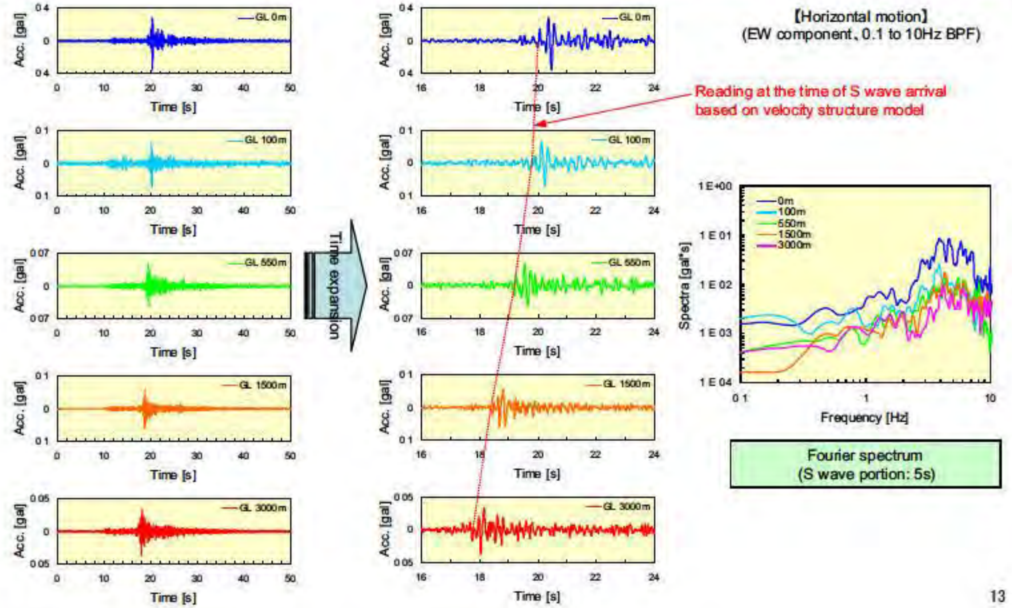
※Quality factor (Qs) of each layer has low frequency dependence and very high attenuations (Qs<50)

【Achievement】 Verification test result at Sedimentary rock site (3000m depth)



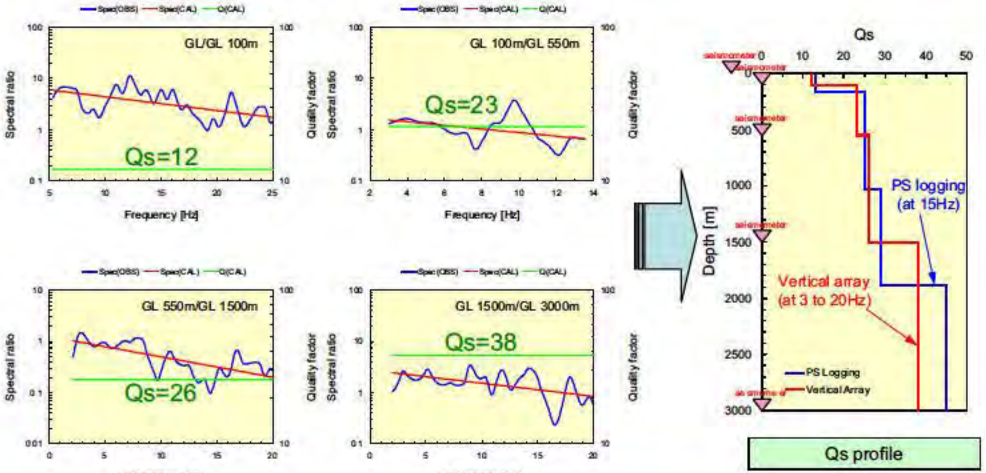
【Achievement】 We carried out 3000m deep boring reaching to bedrock equivalent to seismic bedrock, geological investigation, various logging (PS logging, density logging etc.), and obtained verified data to construct site characteristics evaluation method at deep underground.

Examples of waveform by vertical array seismic observation【Northern Nagano Pref.(3 Apr., Mj3.0)】



Fourier spectrum
(S wave portion: 5s)

Evaluation of attenuation characteristics based on vertical array seismic observation【Prediction result】

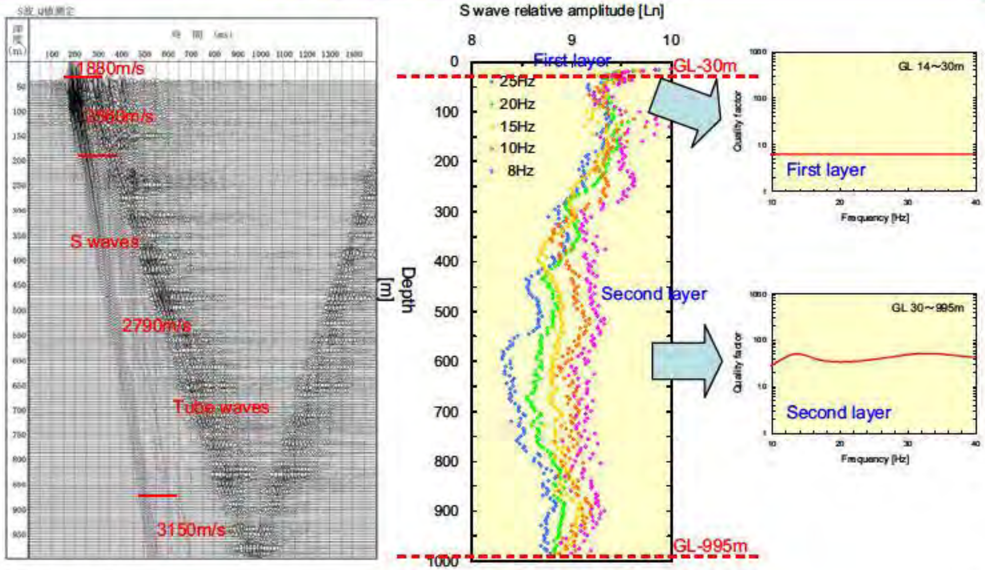


Qs profile

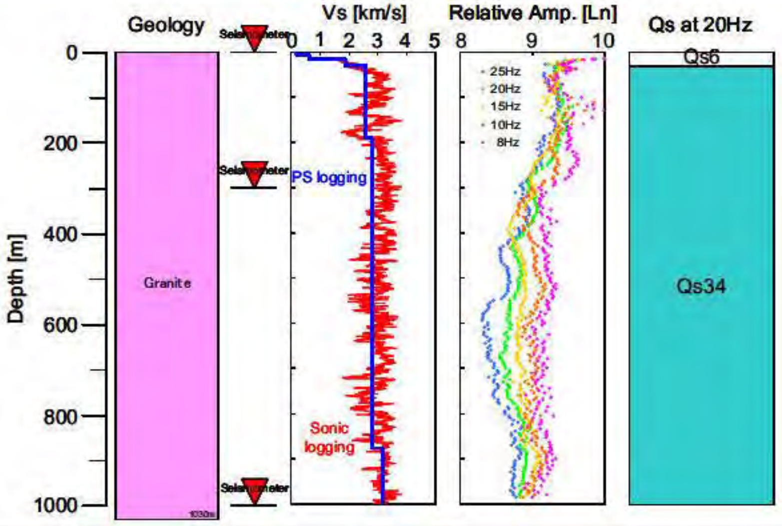
Attenuation (Qs) evaluated by "vertical array seismic observation" and "PS logging" are nearly the same

⇒ We predictively confirm applicability of the method for evaluating attenuation at soft rock site

4.3 Igneous rock site (1000m depth)



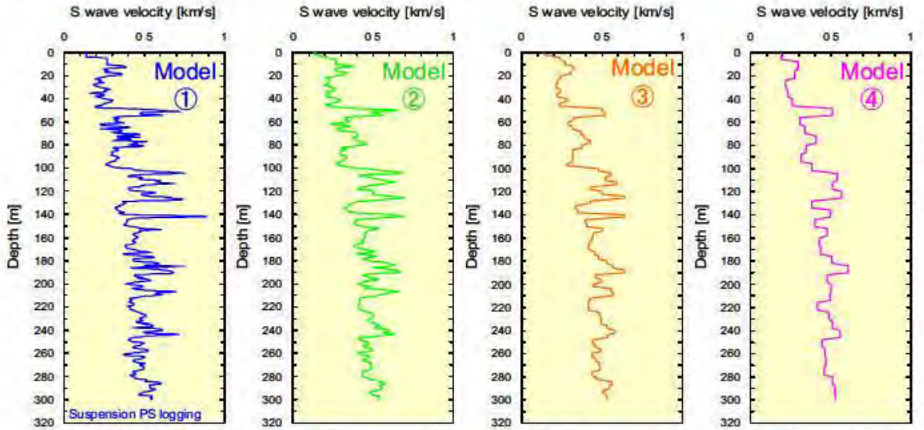
【Achievement】Verification test result at Igneous rock site (1000m depth)



【Achievement】 We carried out 1000m deep boring reaching to seismic bedrock, geological investigation, various logging (PS logging, density logging etc.), and obtained verified data to construct site characteristics evaluation method at deep underground

5. Discussion: Investigate the cause of high attenuation characteristics of ground 【Evaluation of attenuation characteristics considering fluctuation of S wave velocity structure】

■Statistical property of random fluctuation of 4 types of S wave velocity structure (Example of Soil ground site)



【300 layer model】
Min. thickness of layer 1m
a = 2.48m
ε = 0.21
<in-situ data>

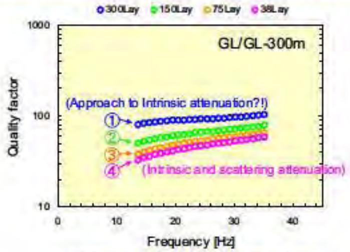
【150 layer model】
Min. thickness of layer 2m
a = 2.97m
ε = 0.19

【75 layer model】
Min. thickness of layer 4m
a = 3.97m
ε = 0.17

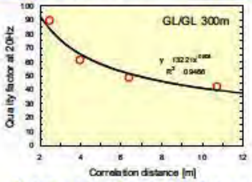
【38 layer model】
Min. thickness of layer 8m
a = 6.40m
ε = 0.13

5. Discussion: Investigate the cause of high attenuation characteristics of ground 【Evaluation of attenuation characteristics considering fluctuation of S wave velocity structure】

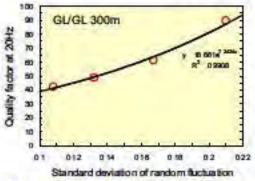
■Difference in consideration of heterogeneity of ground at identification analysis (Difference in velocity structure model)



Difference in Q factor by difference in velocity structure model



Relationship of correlation distance of fluctuation of S wave velocity and Q factor



Relation of heterogeneity strength of S wave velocity fluctuation (standard deviation) and Q factor

In usual identification analysis, heterogeneity of velocity is not considered at velocity structure model, so we can interpret that the attenuation coefficient is visibly evaluated large in the form of adding its effect

Considering heterogeneity of ground at velocity structure model will make identified attenuation to be low
⇒Trade-off will occur between approximate scale of velocity structure and attenuation in identification analysis

6. Summary and utilization of achievement

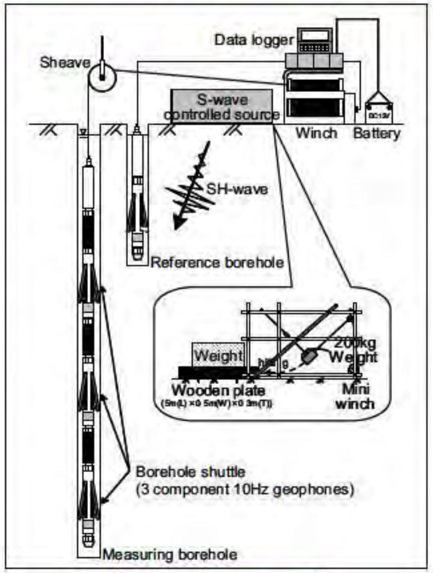
- JNES developed evaluation method of attenuation characteristics based on PS logging and records of seismic ground motion observation, and proposed evaluation system (draft) of attenuation characteristics.
- JNES performed PS logging and vertical array seismic ground motion observation at Soil ground site, Sedimentary rock site and Igneous rock site, and obtained verified data to construct evaluation method of attenuation characteristics (site characteristics) of deep underground.
- Qs frequency dependence is low at each site, they are all low below Qs 50 (Attenuation is high).
- It is indicated by detailed ground model in analysis that considering heterogeneity will make Qs high (attenuation characteristics becomes low).
  ⇒ Trade-off will occur between approximate scale of velocity structure and attenuation in identification analysis
- JNES will continue to perform deep seismic observation (vertical array seismic observation) and establish evaluation method of near-surface attenuation of S-waves based on PS logging and vertical array seismic observation.

Influence on safety review of Japan, Technical document of IAEA etc.

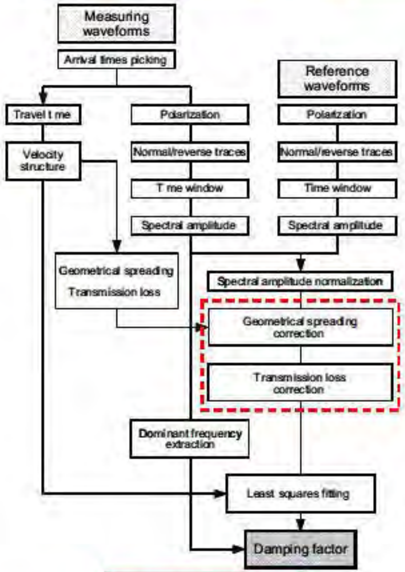
Propose logical setting method of ground attenuation characteristics based on comprehensive evaluation of PS logging, vertical array seismic ground motion observation records, and current location data

Supplementary explanation material

Evaluation of S wave attenuation characteristics based on PS logging



Measurement method



Analysis method

SITE-RESPONSE ESTIMATION BY 1D HETEROGENEOUS VELOCITY MODEL USING BOREHOLE LOG AND ITS RELATIONSHIP TO DAMPING FACTOR

Civil Engineering Research Lab.
Central Research Institute of Electric Power Industry
Ph.D. HIROAKI SATO

The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications
November 8th ,2012

Background

The Niigata area, now we are here, has been often hit by large earthquakes, such as

- The 1964 Niigata earthquake (M_{JMA}7.5)
- The 2004 Niigataken Chuetsu earthquake (M_{JMA}6.8)
- The 2007 Niigataken Chuetsu-oki earthquake (M_{JMA}6.8)

The 1964 Niigata earthquake (M_{JMA}7.5)

A sloshing of liquid of large oil storage tank was excited and caused a tank fire that burned down about 350 nearby houses.

CRIEPI(1964)

In this area, geophysical surveys have been eagerly conducted for estimating deep S wave velocity structure that aim to simulate **long-period ground motion**.

The 2007 Niigataken Chuetsu-oki earthquake (M_{JMA}6.8)

◆ Strong ground motions were recorded at Kashiwazaki-Kariwa Nuclear Power Station in Niigata pref..
Observed PGA is larger than the design level.

[redacted]

Unit: Gal (cm/s/s)

Numbers shown in ( ) are the design value

The estimation of **high-frequency site response is important** to reduce earthquake disaster in this area.

Objectives

- The velocity models in this area have been mainly constructed for the purpose of estimating the long-period ground motion.

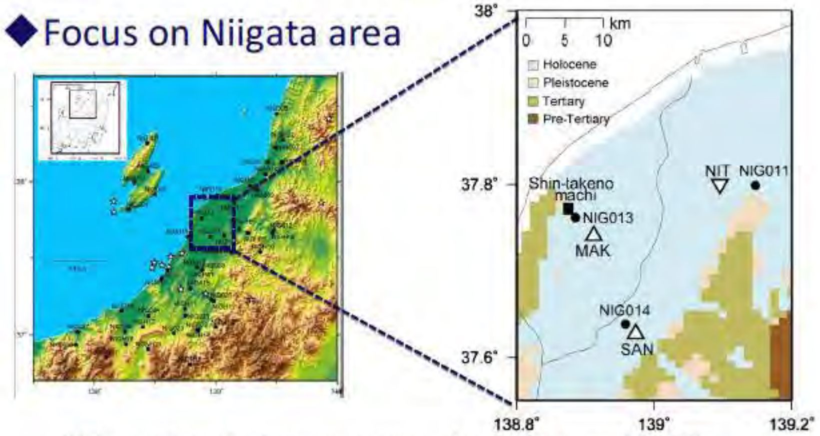
(ex. Phase velocity inversion from microtremor array measures)

Is it possible to use high-frequency site response estimation?

We examine whether the site response transfer functions using 1D layered velocity models (for long-period ground motion) would be possible to explain the observed high-frequency site responses or not.

Sites

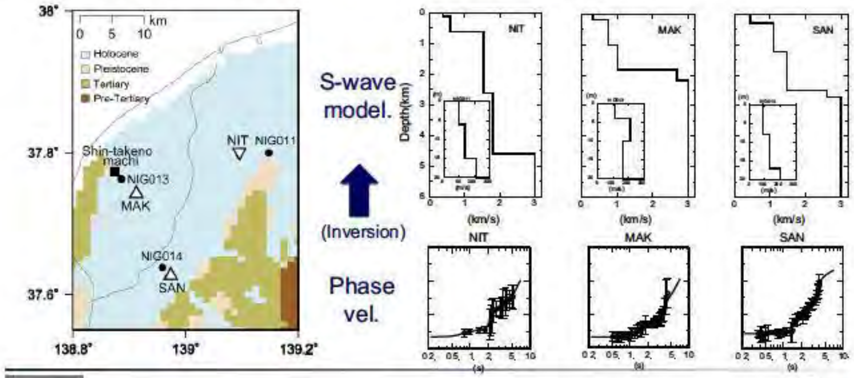
- Focus on Niigata area



△▽ : Locations of microtremor array exploration [Sato et al. (2009)]
(⇒1D velocity model for long period ground motion simulation)
● : NIED/K NET Earthquake observations (⇒ site response estimation)
■ : Borehole point (⇒ Precise sonic velocity log.)

1D layered models

- **Microtremor array exploration** : Vertical-component of microtremor array measurements gives us the Rayleigh wave phase velocity, and S-wave velocity models are derived from phase velocity inversions.

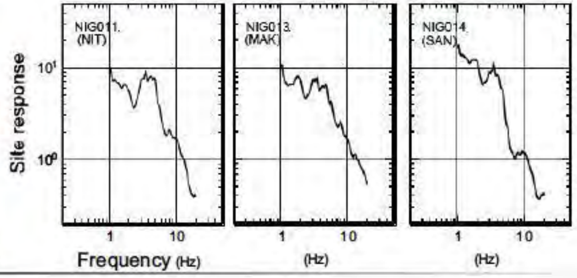


Site responses

- **Site response estimation from observed earthquake data :**

Source, path and site factor are separated from following observation matrix (Iwata and Irikura, 1986) . We used 668 surface S-wave records from 13 earthquakes (i=1-13) and 48 stations (j=1-48) in the inversion.

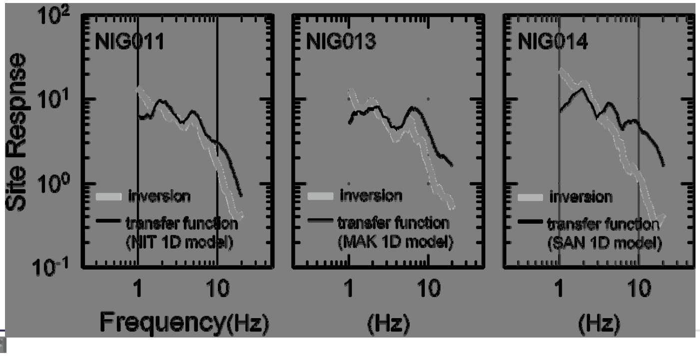
$$\underset{\text{Observed spectrum}}{\log O_{ij}(f)} = \log \underset{\text{Source spectrum}}{\underline{S_i(f)}} + \log \underset{\text{Qs(Path)}}{\underline{P(f)}} + \log \underset{\text{Site response}}{\underline{G_j(f)}}$$



Comparisons of site responses

- ◆Transfer functions of 1D layered velocity models based on microtremor array exploration are relatively larger in the frequency over about 3 or 6 Hz than the observed site responses.

1D model transfer functions > observed site responses



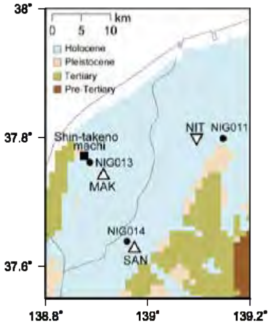
Is it possible to use high-frequency site response estimation?

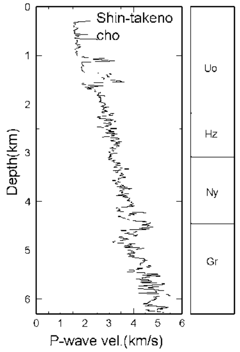
- ◆1D layered velocity models based on microtremor array exploration are not appropriate enough for the simulation of <u>high-frequency</u> site responses.
- ◆Because these models are <u>only calibrated for the use of long-period ground motion</u> simulation.

What is short for existing 1D layered model
in the high-frequency site response estimation ?

Actual characteristics of velocity structure from precise velocity log.

- ◆The precise velocity structure in this area is strongly characterized by two factors of <u>depth-dependence</u> and <u>random fluctuation</u>.





Borehole logging (Sonic-log). was conducted by JNOC[1994] (Japan National Oil Corporation; the predecessor of JOGMEC)

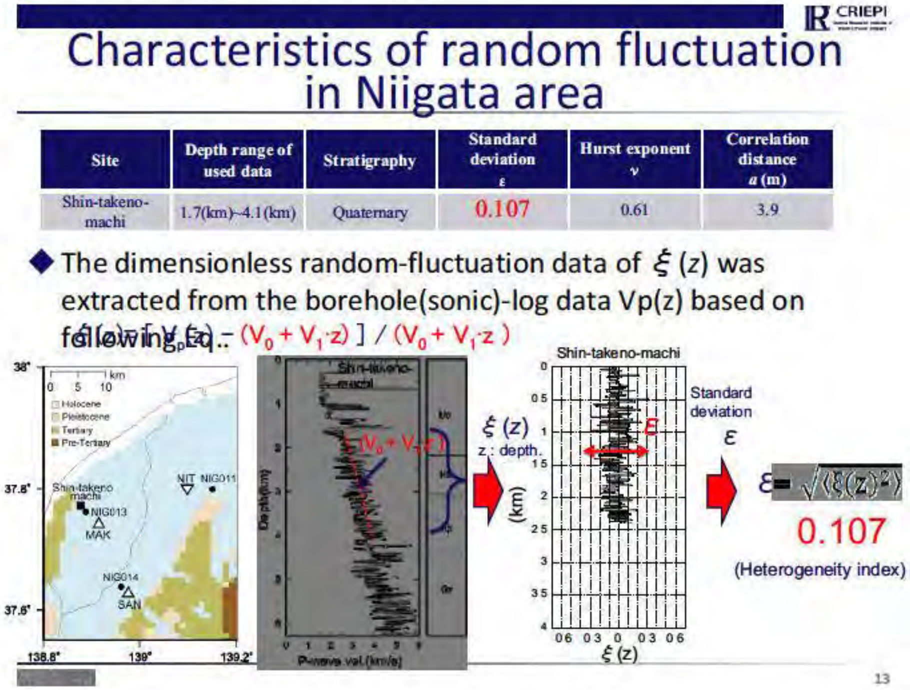
Toward the improvement of 1D layered velocity model

- ◆**From precise velocity structure :**

It might be suggested that the two factors (Depth-dependence & Random fluctuation) should be considered in a velocity model, for the better estimation of high-frequency site responses in the Niigata area.

In existing 1D layered velocity model…

- ◆**Depth-dependence:** Roughly considered.
- ◆**Random fluctuation:** Not considered.



Characteristics of random fluctuation in Niigata area

Site	Depth range of used data	Stratigraphy	Standard deviation ε	Hurst exponent ν	Correlation distance a (m)
Shin-takeno-machi	1.7(km)~4.1(km)	Quaternary	0.107	0.61	3.9

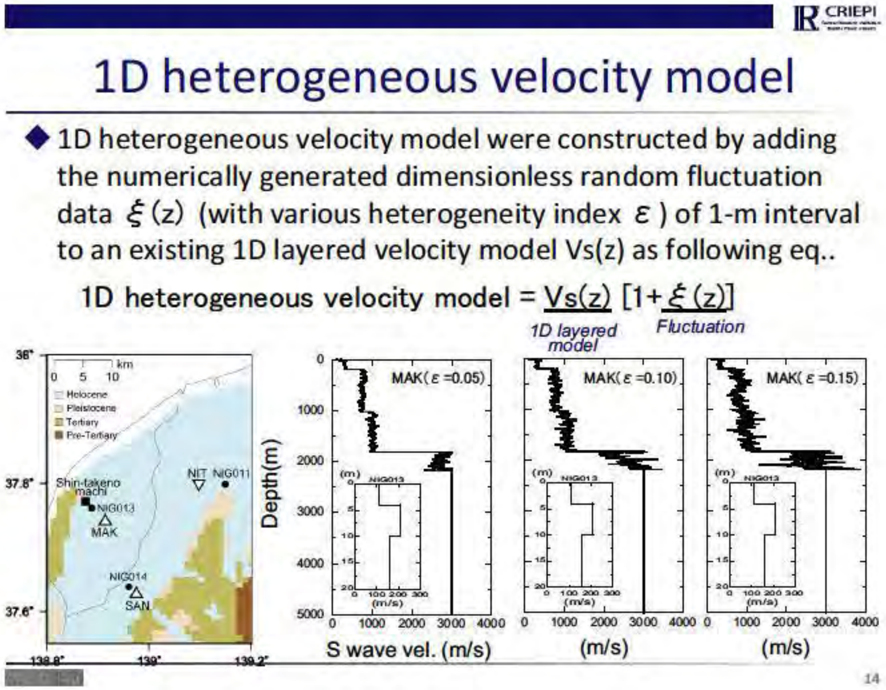
- The dimensionless random-fluctuation data of $\xi(z)$ was extracted from the borehole(sonic)-log data Vp(z) based on following Eq..

$$\xi(z) = [\, V_p(z) - (V_0 + V_1 \cdot z)\,] \,/\, (V_0 + V_1 \cdot z)$$

$\varepsilon = \sqrt{\langle \xi(z)^2 \rangle}$

0.107

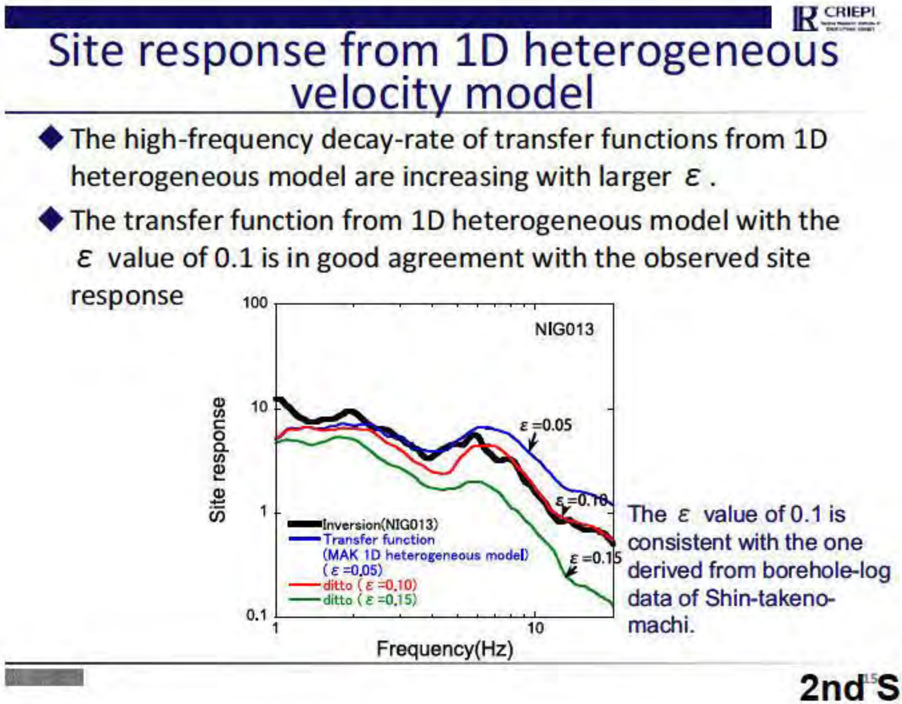
(Heterogeneity index)



1D heterogeneous velocity model

- 1D heterogeneous velocity model were constructed by adding the numerically generated dimensionless random fluctuation data ξ(z) (with various heterogeneity index ε) of 1-m interval to an existing 1D layered velocity model Vs(z) as following eq..

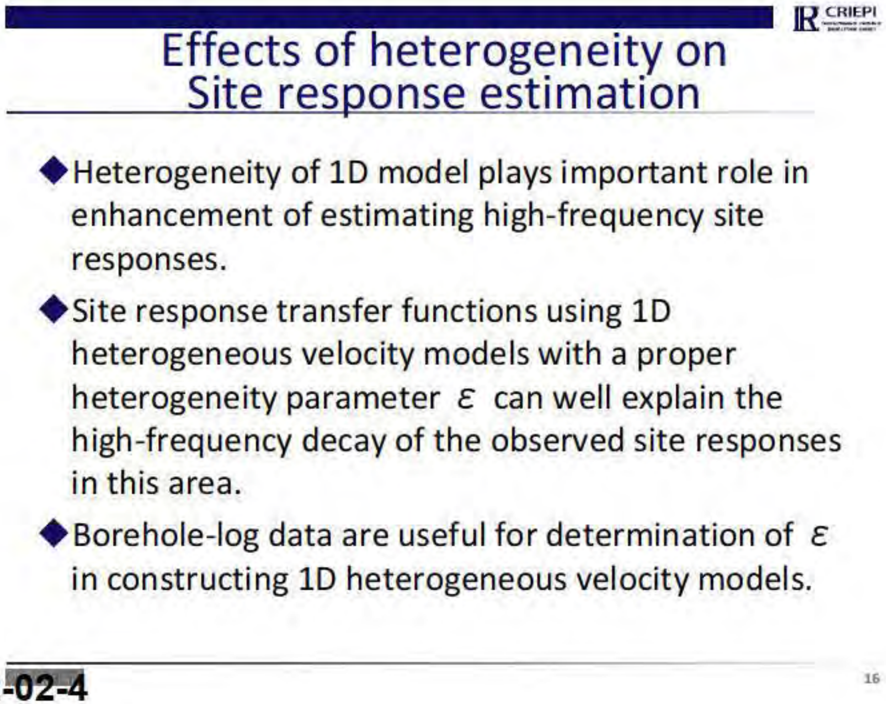
1D heterogeneous velocity model = $\underbrace{Vs(z)}_{\text{1D layered model}}\,[1+\underbrace{\xi(z)}_{\text{Fluctuation}}]$



Site response from 1D heterogeneous velocity model

- The high-frequency decay-rate of transfer functions from 1D heterogeneous model are increasing with larger ε .
- The transfer function from 1D heterogeneous model with the ε value of 0.1 is in good agreement with the observed site response

The ε value of 0.1 is consistent with the one derived from borehole-log data of Shin-takeno-machi.



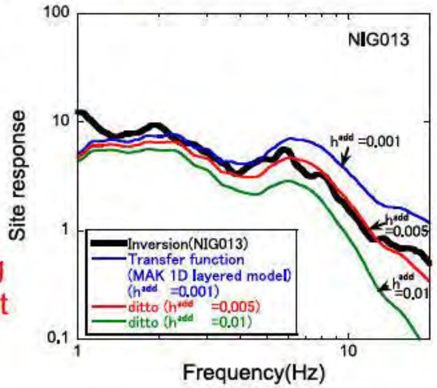
Effects of heterogeneity on Site response estimation

- Heterogeneity of 1D model plays important role in enhancement of estimating high-frequency site responses.
- Site response transfer functions using 1D heterogeneous velocity models with a proper heterogeneity parameter ε can well explain the high-frequency decay of the observed site responses in this area.
- Borehole-log data are useful for determination of ε in constructing 1D heterogeneous velocity models.

Effect of additional damping factor(1/(2Qs)) on site response estimation

- ◆The effects of various additional damping factors h^{add} (h^{add}=0.001, 0.005, 0.01) on high-frequency transfer function were examined by using the <u>1D layered velocity model</u>.
- ◆The high-frequency decay-rates of transfer functions are increasing with larger h^{add}.

The effect of additional damping factor is very similar to the effect of heterogeneity.



Concluding remarks

- ◆1D layered velocity models based on microtremor array exploration are not appropriate enough for the simulation of high-frequency site responses.
- ◆Heterogeneity of 1D model plays important role in enhancement of estimating high-frequency site responses.
- ◆The heterogeneity was strongly related to the damping factor of 1D layered velocity model.
- ◆The high-frequency site responses might be controlled by the strength of heterogeneity of underground structure.

- ◆ Thank you for your attention!

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－

Yoshihiro Sugimoto（DIA consultants Co.,Ltd）

Hideaki Tsutsumi and Genyuu Kobayashi (JNES）

.

Background

- Hyougoken-Nanbu earthquake in 1995 (M7.2):

Serious strong motions are observed in a restricted stripe-like zone, so-called "Earthquake disaster belt" .

→ Focusing effect due to the basement structure.

Basin-edge effect.

- Niigataken Chuetsu-oki earthquake in 2007 (M6.8)：

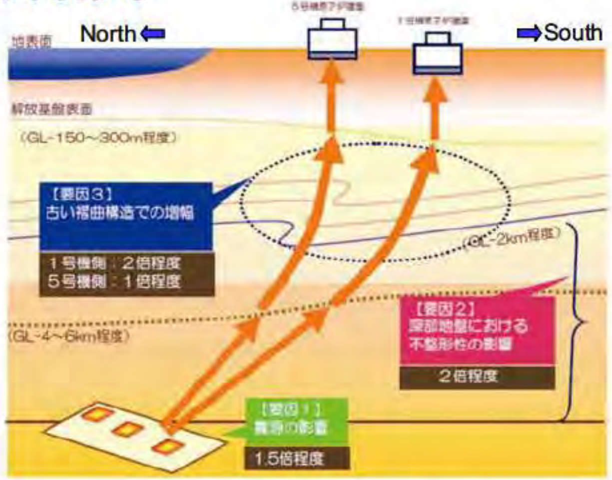
Depending on the local position at Kashiwazaki-Kariha NPP, different ground motion levels were observed.

The south side of the site showed significantly lager ground motion level than the northern side.

→ Focusing effect due to the fold structure.

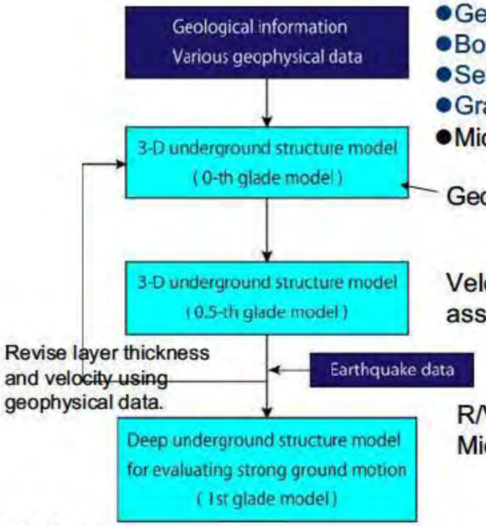
→ High accuracy S-wave velocity model is important for precise strong motion prediction and seismic hazard evaluation.

Large amplification caused by the old fold structure



（Tokyo Electric Power Company, 2008)

Representative conventional flow to construct underground S-wave velocity model



Geological information
Various geophysical data

- ●Geological data
- ●Borehole data
- ●Seismic data (reflection & refraction)
- ●Gravity data
- ●Micro-tremor array data ・・・・・

3-D underground structure model
(0-th glade model)

Geological structure model

3-D underground structure model
(0.5-th glade model)

Velocity in each layer is usually assumed to be constant.

Revise layer thickness and velocity using geophysical data.

Earthquake data

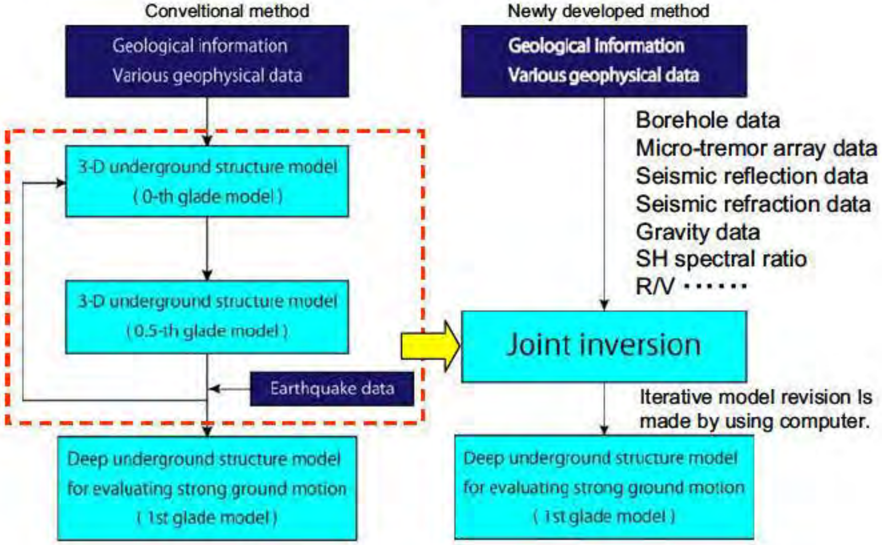
R/V, Receiver function, Spectral ratio
Micro-tremor array data.

Deep underground structure model
for evaluating strong ground motion
(1st glade model)

Problems of Conventional Method for building S-wave Velocity Structure Model

- Many cases of trial and error for adjusting inconsistency of each data are needed (take much time).
- In some cases, calculated data from the created model does not consistent with the observed data.
- Process of trial and error is depended on the skills and techniques of analyst（Black box）.
- Same result is not obtained again (Lack of traceability）.
- Model construction using objective method is needed.
  →Development of computer program for model creation using joint inversion.

Construction of 3-D underground S-wave velocity model using joint inversion



Conveltional method

Geological information
Various geophysical data

3-D underground structure model
(0-th glade model)

3-D underground structure model
(0.5-th glade model)

Earthquake data

Deep underground structure model
for evaluating strong ground motion
(1st glade model)

Newly developed method

Geological information
Various geophysical data

Borehole data
Micro-tremor array data
Seismic reflection data
Seismic refraction data
Gravity data
SH spectral ratio
R/V ・・・・・・

Joint inversion

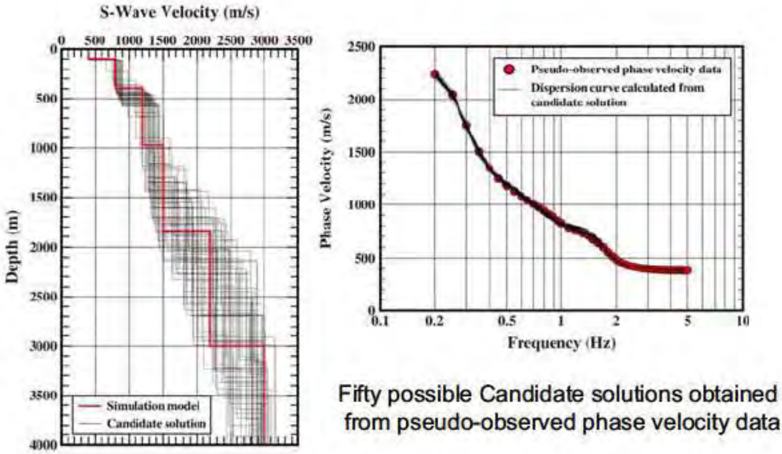
Iterative model revision Is
made by using computer.

Deep underground structure model
for evaluating strong ground motion
(1st glade model)

The feature of Joint inversion

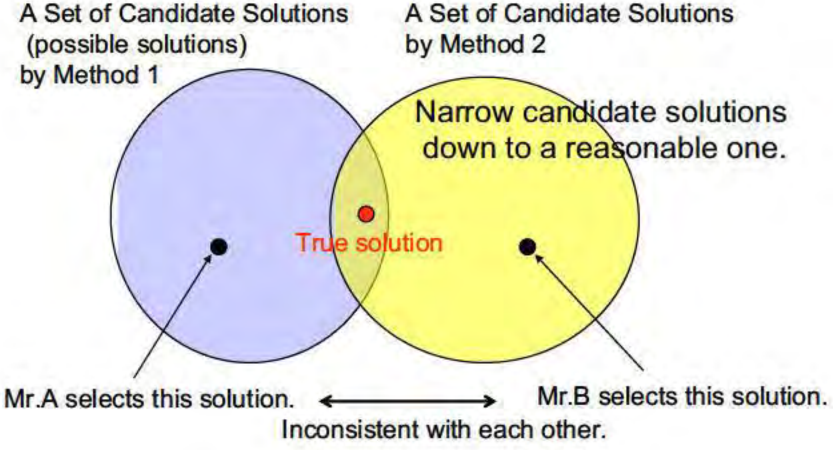
- All of the data is analyzed simultaneously.
  - → Multi data compensate each other.
  - → High accuracy.
- Trial and error calculation by Computer.
  - → Work saving of analysis.
  - → High consistency analysis results.
- Priority of data is quantified as weight coefficient.
  → Advancement of traceability.

Deviation of Candidate solutions in Micro-tremor Array Inversion



Fifty possible Candidate solutions obtained from pseudo-observed phase velocity data.

How to obtain reasonable solution



A Set of Candidate Solutions
(possible solutions)
by Method 1

A Set of Candidate Solutions
by Method 2

Narrow candidate solutions down to a reasonable one.

True solution

Mr.A selects this solution. ←→ Mr.B selects this solution.

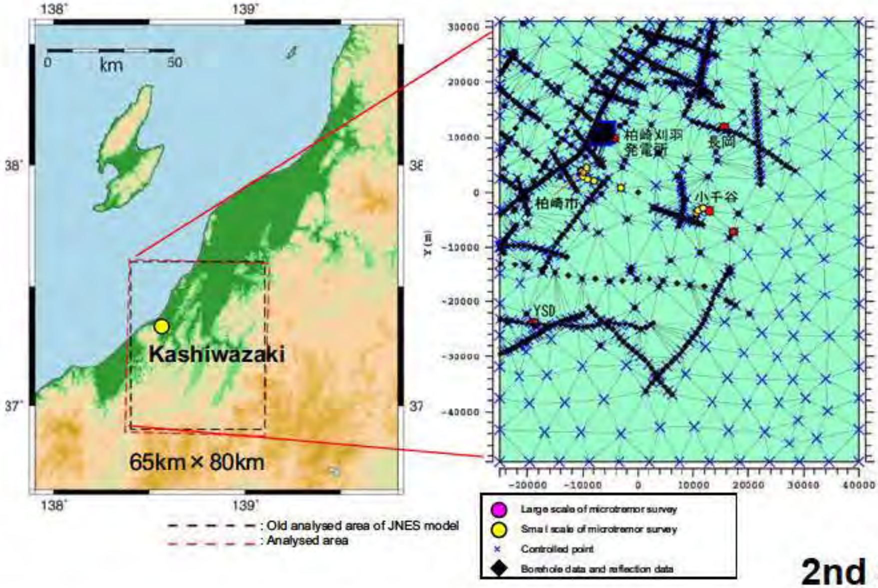
Inconsistent with each other.

The feature of Joint inversion

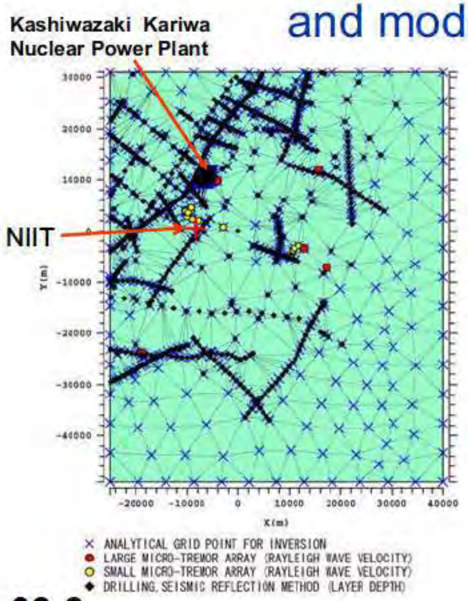
- All of the data is calculate Simultaneously.
  - → Multi data compensates each other.
  - → High accuracy.
- Trial and error calculation by Computer.
  - → Work saving of analysis.
  - → High consistency analysis results.
- Priority of data is quantified as weight coefficient.
  → Advancement of traceability.

CASE HISTORY

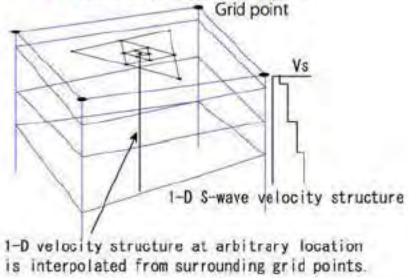
Creation of 3-D Structure Model around Kashiwazaki Area



Data set used for joint inversion and model structure



- Depth data of stratum boundary
  - Borehole: 161
  - Reflection survey, etc.: 25 sections
  - Gravity data
  - Micro tremor array : 8 large arrays
    12 small arrays
- Analysis model
  - Grid point: 825 points
  - Number of layer: 10 layers



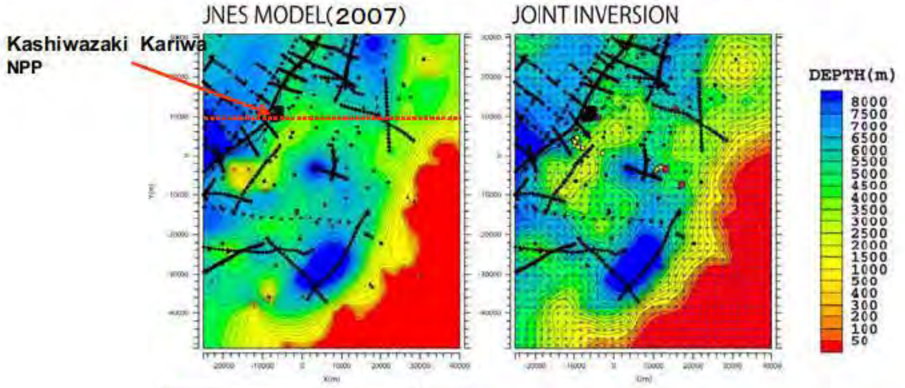
1-D velocity structure at arbitrary location is interpolated from surrounding grid points.

Stratum Classification of Model（JNES Model,2004）

	P wave velocity (m/ s)	S wave velocity (m/ s)	Density (g/ cm^2)
Uonuma Group	1799	600	1.90
	2212	800	2.05
	2606	1000	2.15
Nishiyama Formation	2796	1100	2.20
Shiiya Formation	3336	1400	2.30
Upper Teradomari Formation	3336	1400	2.40
Lower Teradomari Formation	3990	1800	2.50
Nanatani Formation	4567	2200	2.50
Green Tuff Formation	4567	2200	2.50
Basement	5490	3000	2.65

The model structure used as the initial model for joint inversion.

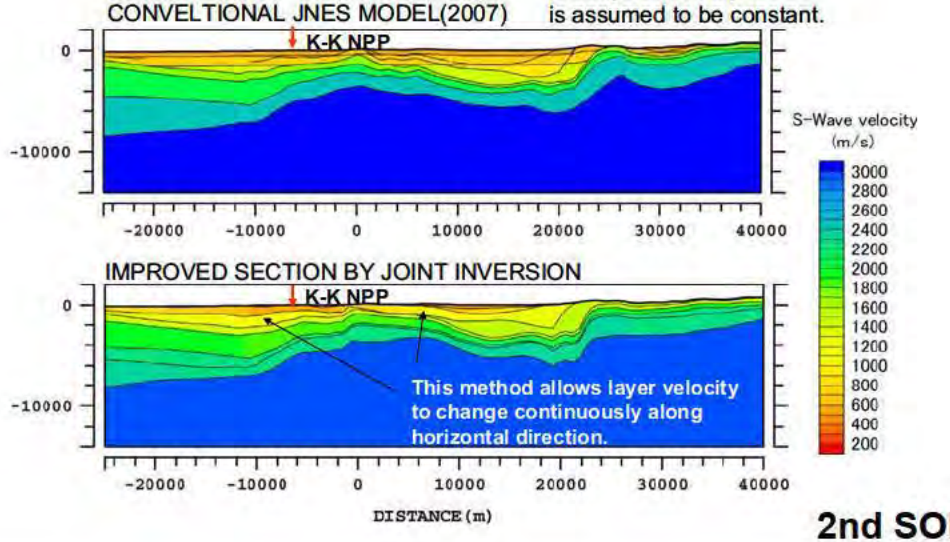
Comparison between JNES model and re-analyzed model using joint inversion



● : Large scale of microtremor survey
○ : Small scale of microtremor survey
+ : Gravity data
◆ : Borehole data
◆ : Additional shackled provision

Depth of seismic basement

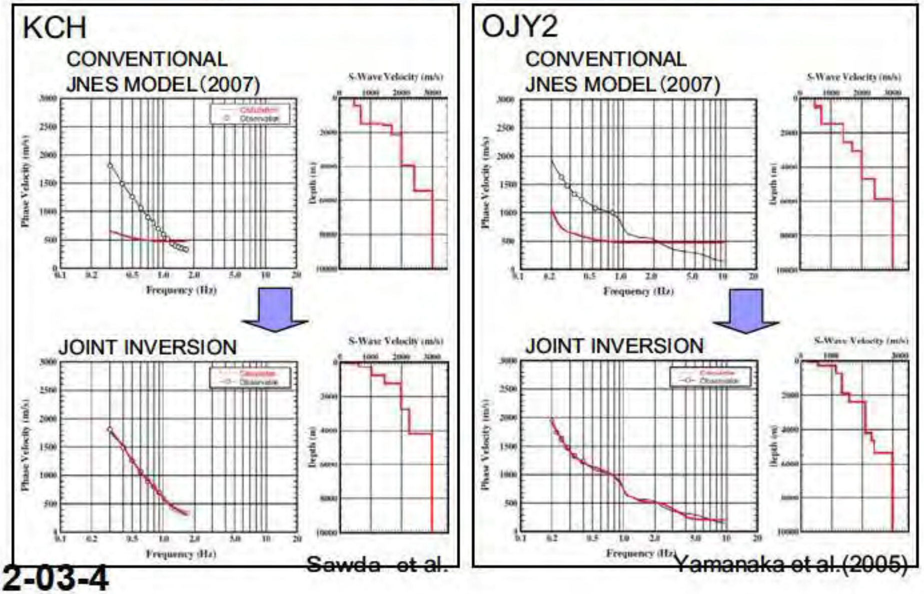
Cross-section across Kashiwazaki Area



Velocity in each layer is assumed to be constant.

This method allows layer velocity to change continuously along horizontal direction.

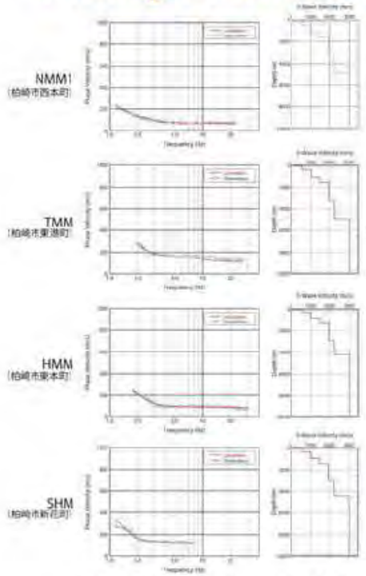
Fitting of Micro-tremor Survey Data



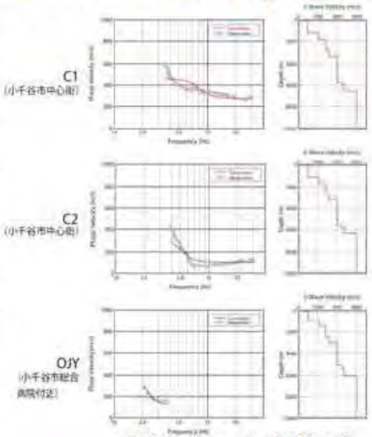
Sawda et al.

Yamanaka et al.(2005)

Fitting of Micro-tremor Survey Data



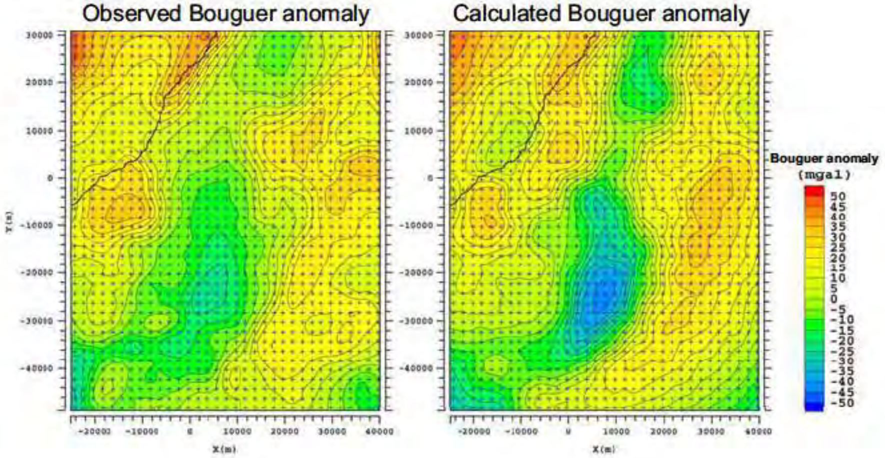
Motoki and Yamanaka(2010)



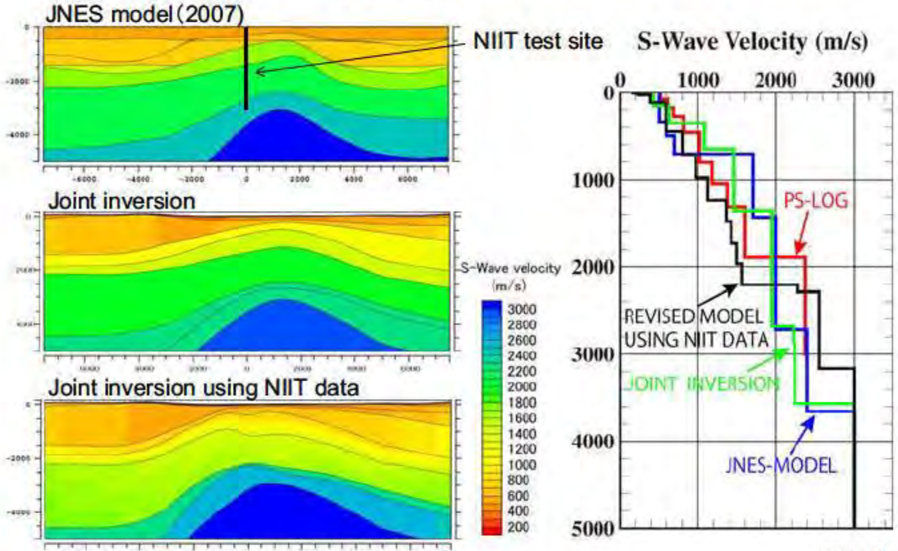
Tokimatsu et al.(2007)

- There is a very good agreement between the observed and calculated phase velocity in the frequency range from 1Hz to 30Hz.
- This method is available for creation of integrated model from very shallow area to deep area

Comparison between observed and calculated gravity anomaly



Comparison of joint inversion results with JNES model (2007) at NIIT site



Conclusion

- We have developed a computer program for constructing S-wave velocity structure model using joint inversion method.
- This method enable us
  … to integrate various geophysical and geological data.
  … to create high accuracy underground model for strong motion prediction.
  (High accuracy, good consistency, low cost)
  … to build integrated model from very shallow to deep structure (3km/s).

Future Suggestion

- Joint analysis of NIIT test field data including seismic reflection and refraction, micro-tremor array, gravity, and spectral ratio data.
- Conducting strong motion simulation and comparing accuracy between observed and calculated wave form.

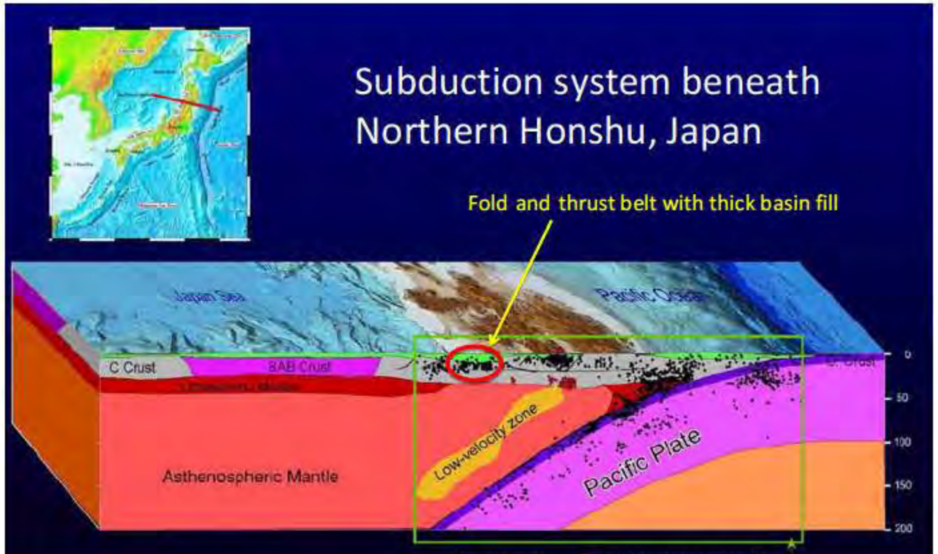
ご静聴ありがとうございました
Thank you for your attention!

2nd International Symposium on **Seismic Observation in Deep Borehole and Its Applications**
7 9 November , 2012

Estimation of seismogenic source faults by seismic reflection profiling: case study of the Niigata Basin

Hiroshi Sato, Susumu Abe, Naoko Kato
ERI, Univ. Tokyo JGI. Inc.

Subduction system beneath Northern Honshu, Japan



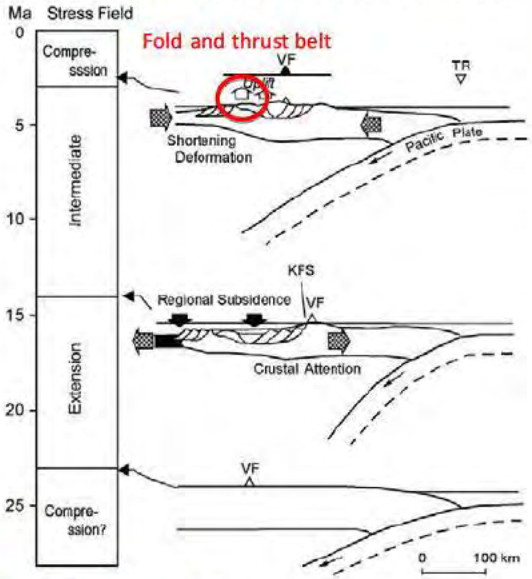
Fold and thrust belt with thick basin fill

○ hypocenter
● Low-frequency earthquake

Area of seismic constraints

ERI. Univ. Tokyo

Tectonic evolution of Northern Honshu



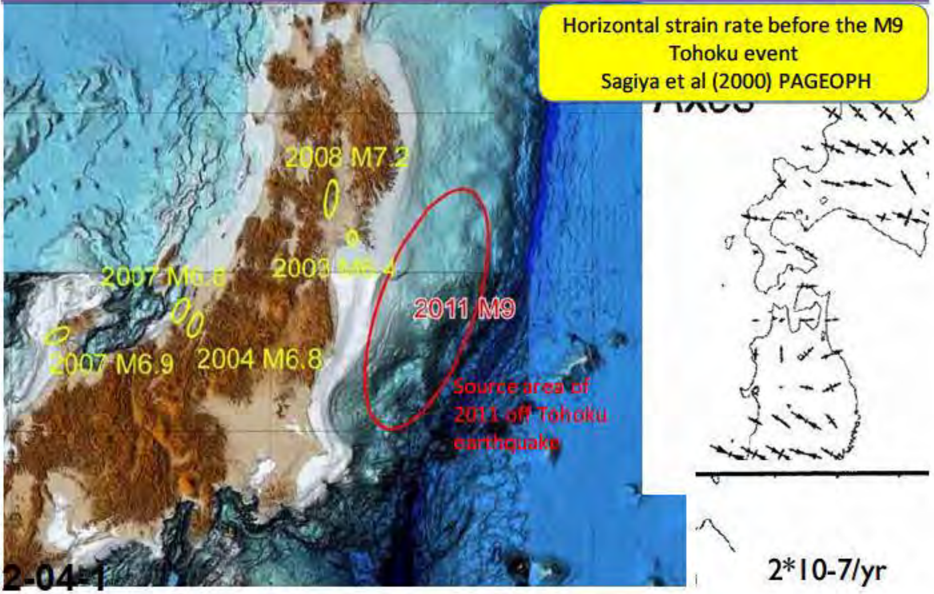
Fold and thrust belt

Rifting

Sato and Amano (1991)

ERI. Univ. Tokyo

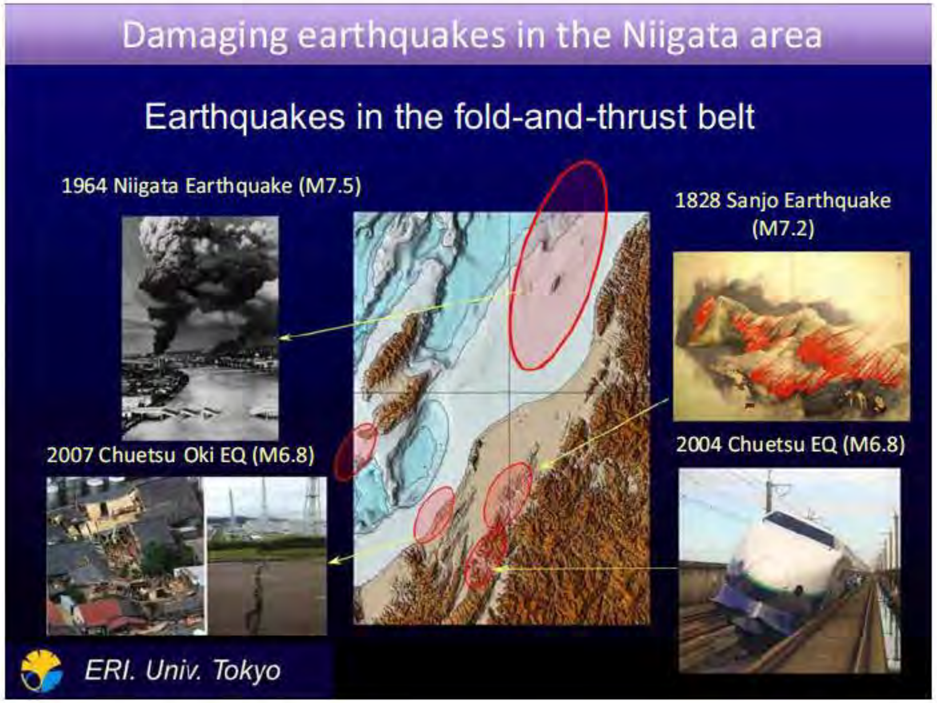
Damaging earthquakes since 2000 prior to the M9 Tohoku EQ



Horizontal strain rate before the M9 Tohoku event
Sagiya et al (2000) PAGEOPH

Source area of 2011 off Tohoku earthquake

2*10-7/yr

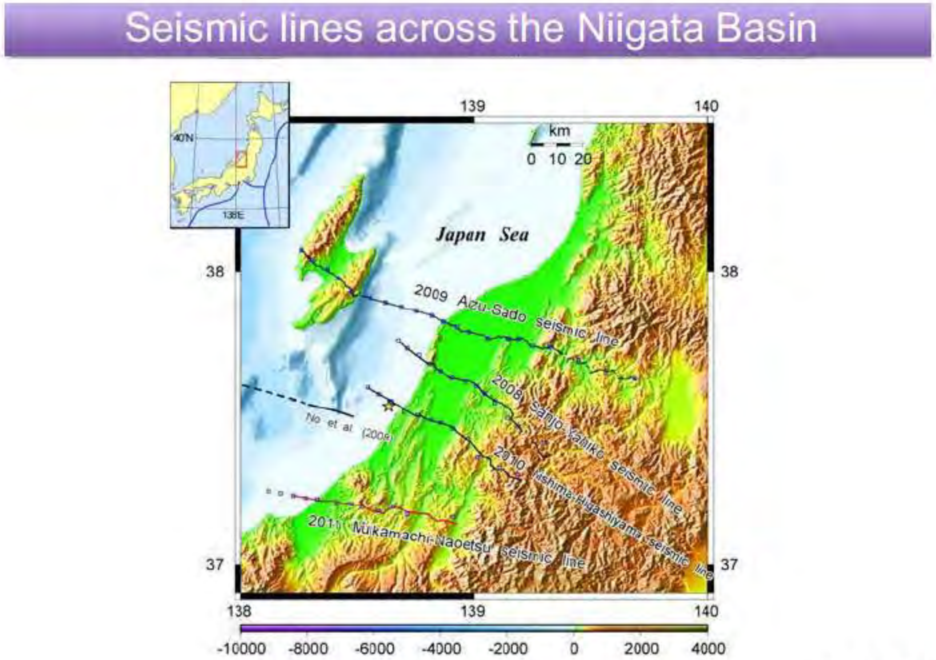


Damaging earthquakes in the Niigata area

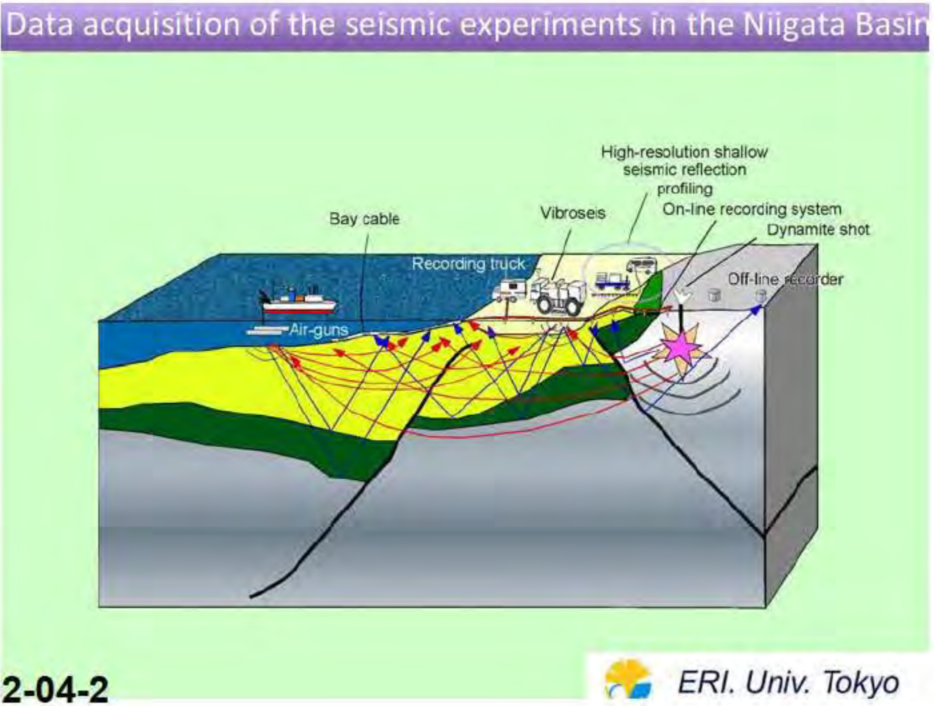
Earthquakes in the fold-and-thrust belt

Contents

- Seismogenic source faults beneath thick-sediment cover.
- Fault reactivation of the Miocene syn-rift normal faults as reverse faults.
- Basin development of inverted back-arc failed rift.

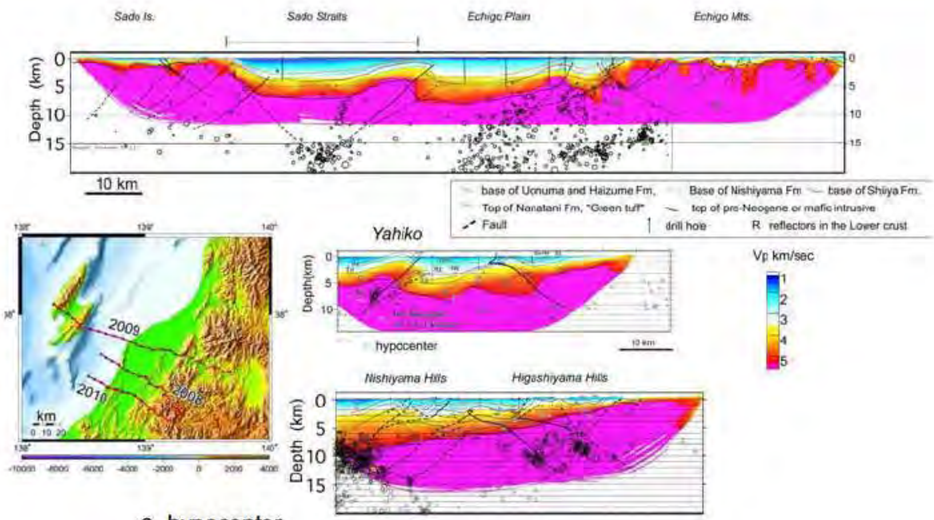


Seismic lines across the Niigata Basin



Data acquisition of the seismic experiments in the Niigata Basin

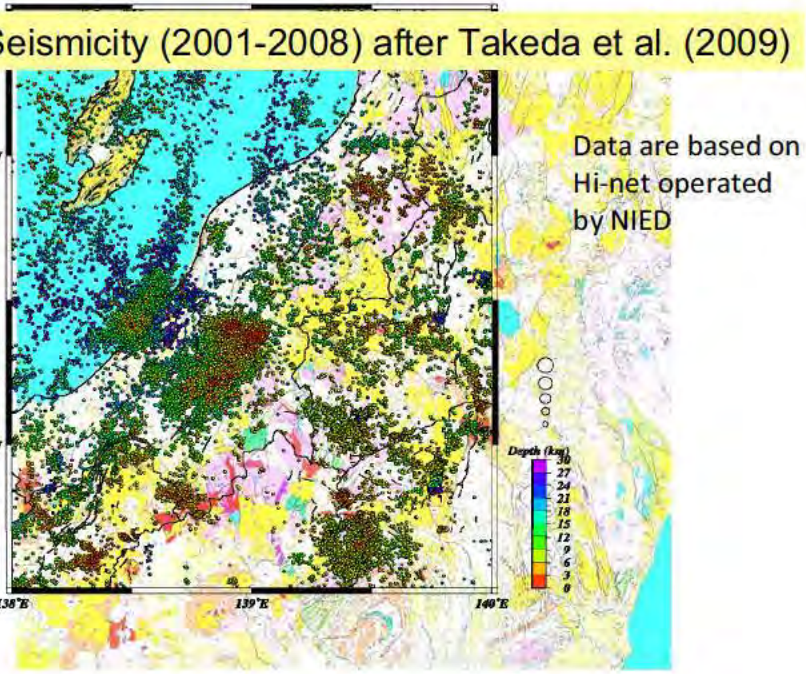
P-wave velocity profiles across the Niigata Basin



○ hypocenter

Hypocenter is after National Institute for Earth Science and Disaster Prevention.

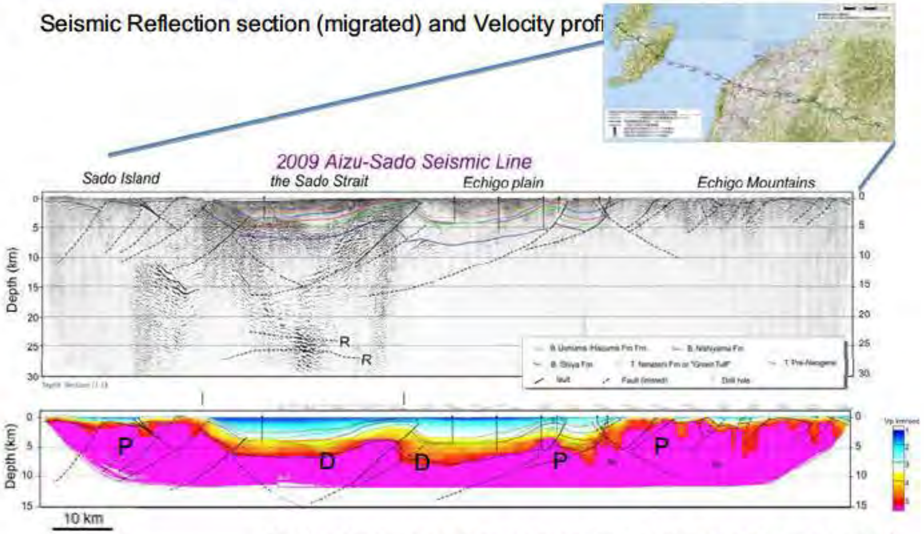
Seismicity (2001-2008) after Takeda et al. (2009)



Data are based on Hi-net operated by NIED

Velocity Profile across the Niigata Sedimentary basin

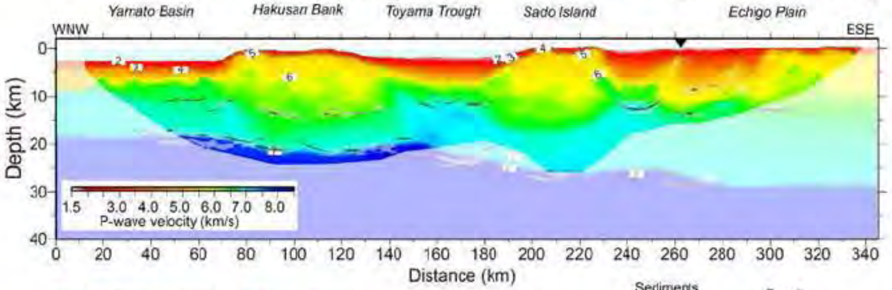
Seismic Reflection section (migrated) and Velocity profi

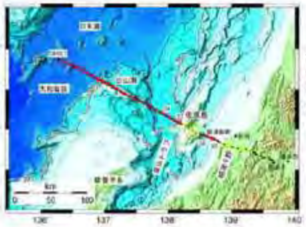


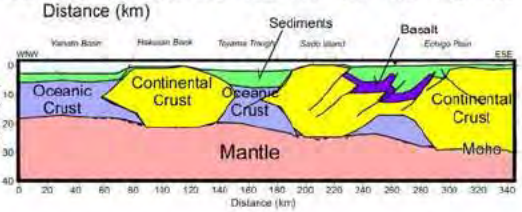
P: Pre-Neogene (Meta-sedimentary rocks and granitic rocks)
D: Pre-Neogene with Neogene dolerite

Velocity Profile by refraction tomography

Sato Takeshi et al. (2011) : JAMSTEC and ERI joint seismic survey

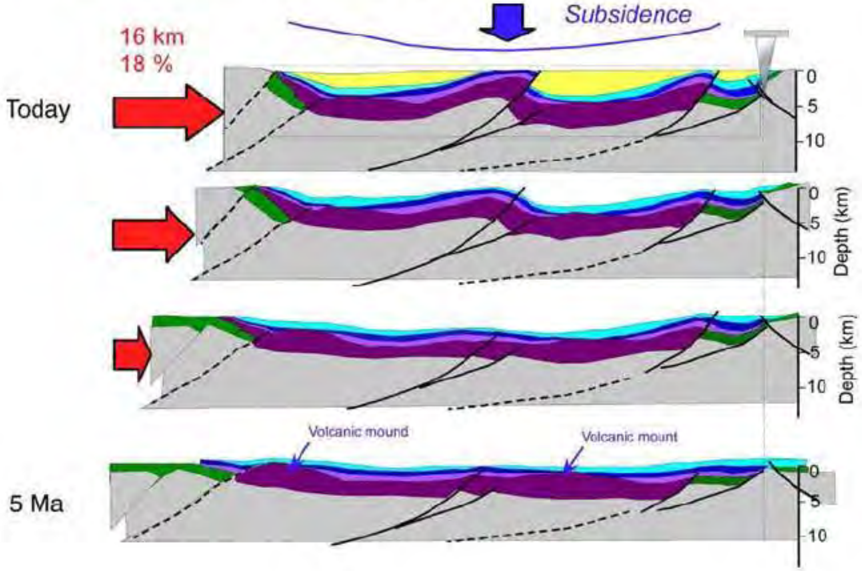




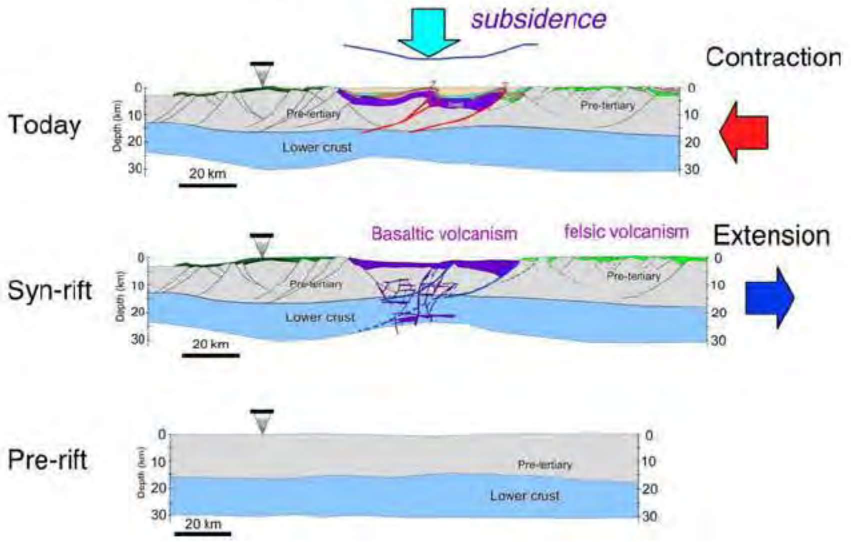


Possible interpretation of the velocity profile

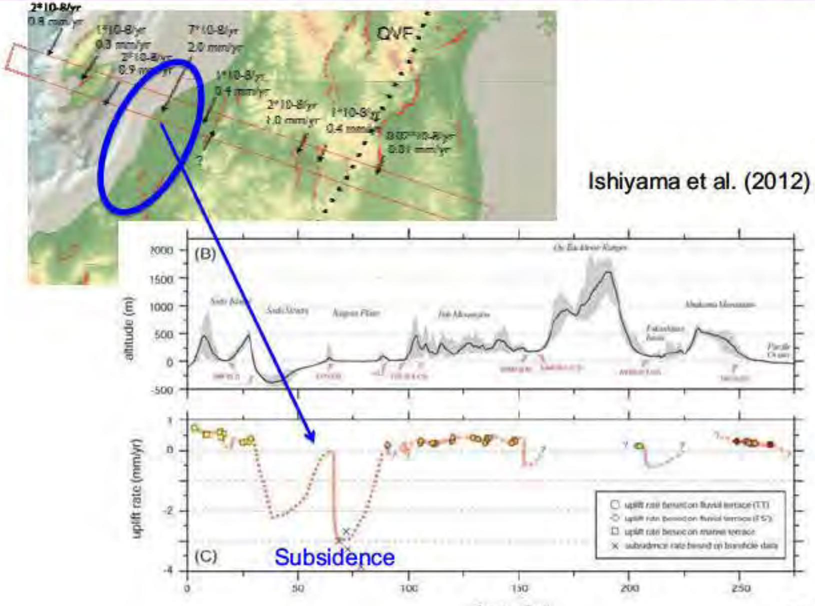
Shortening and subsidence of the Niigata Basin



Basin development

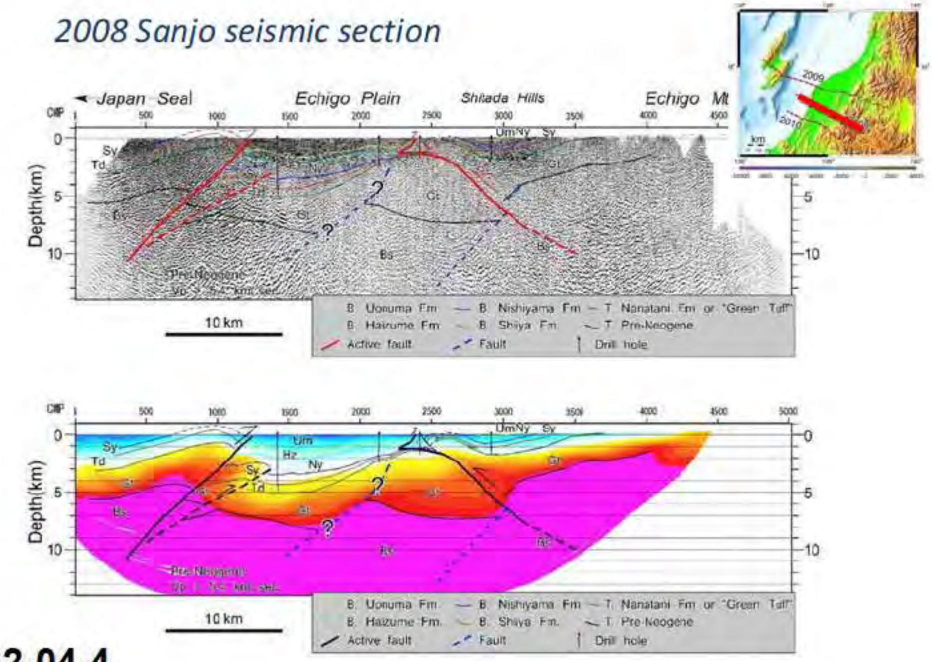


Across arc late Quaternary subsidence rate

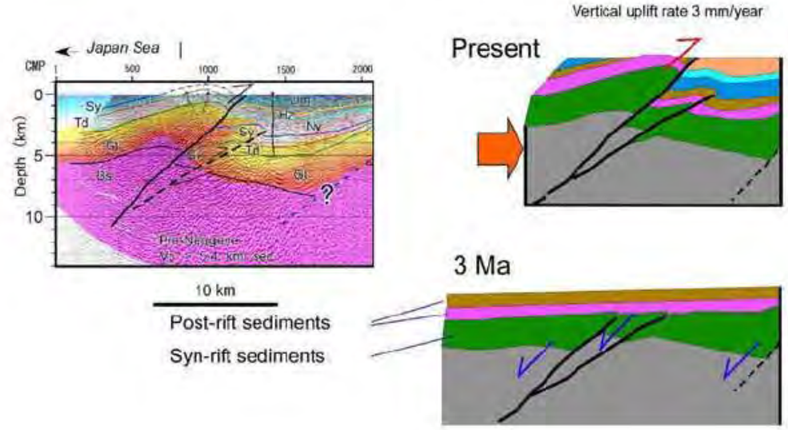


Ishiyama et al. (2012) JpGU

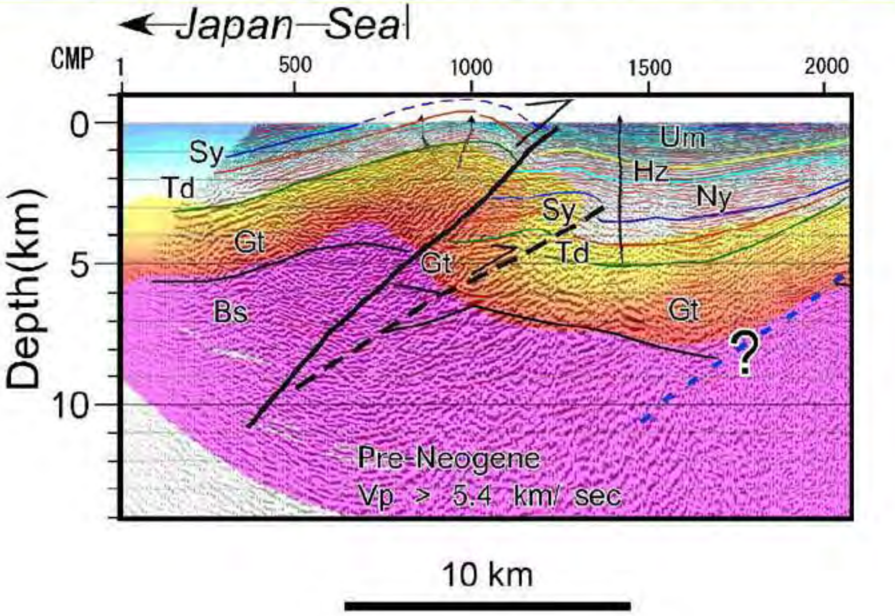
2008 Sanjo seismic section



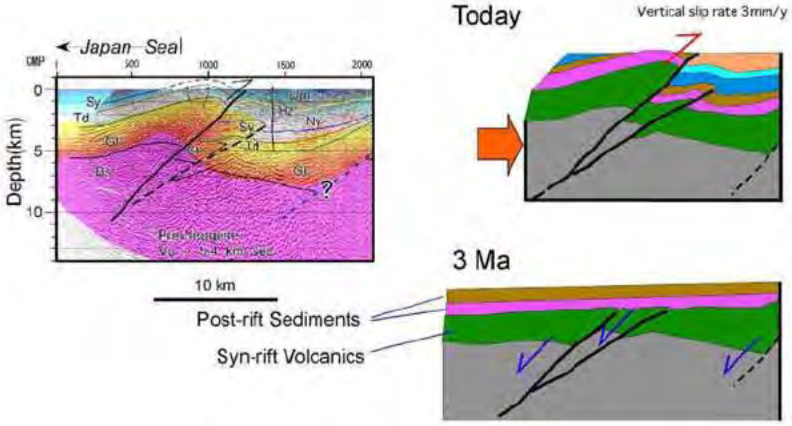
Thrusting of Miocene syn-rift normal faults



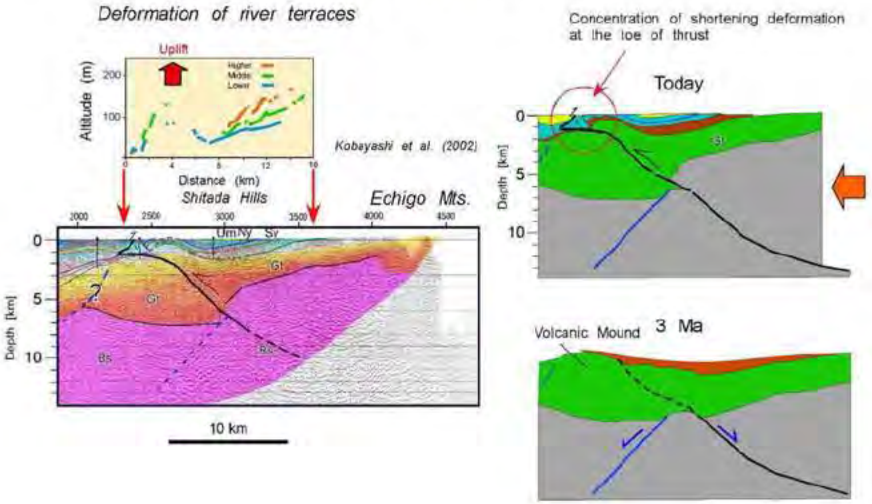
Western part of Sanjo-Yahiko seismic section

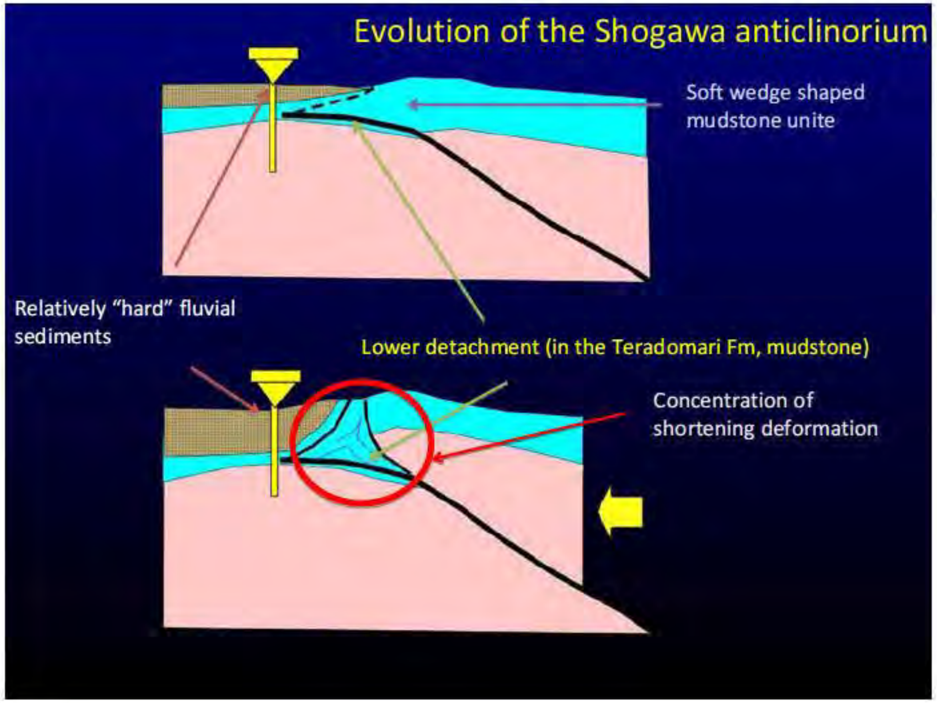


Fault evolution of the western part of the seismic section



Fault evolution of the eastern part of the seismic section





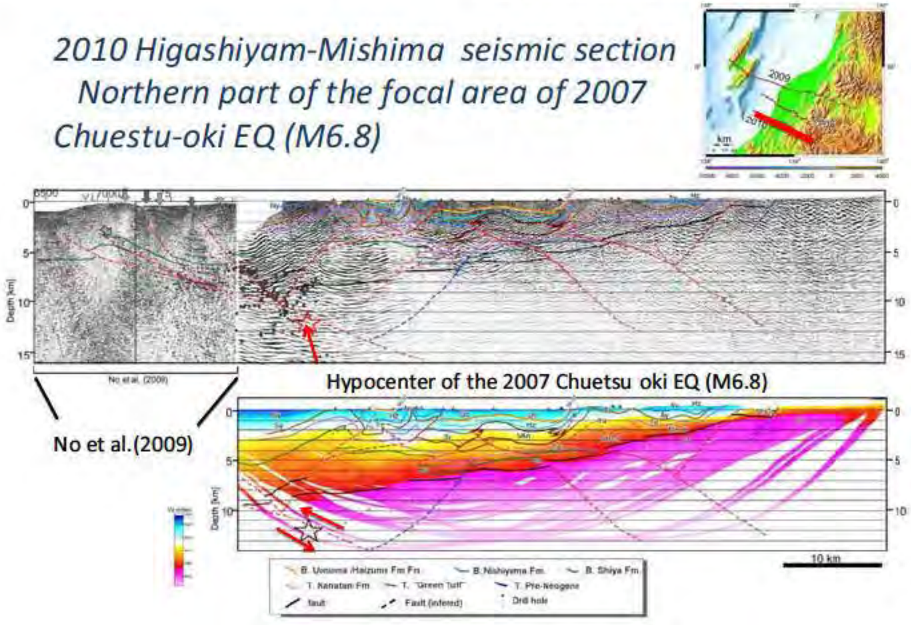
Evolution of the Shogawa anticlinorium

Soft wedge shaped mudstone unite

Relatively "hard" fluvial sediments

Lower detachment (in the Teradomari Fm, mudstone)

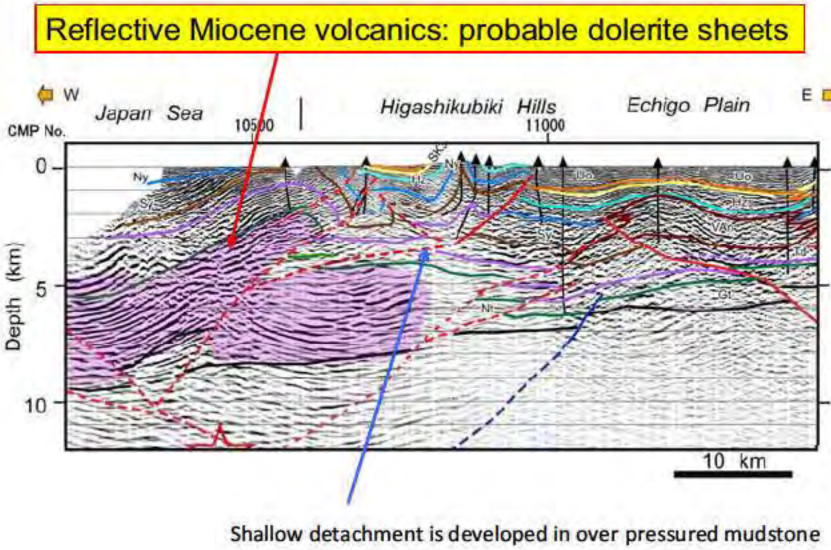
Concentration of shortening deformation



2010 Higashiyam-Mishima seismic section Northern part of the focal area of 2007 Chuestu-oki EQ (M6.8)

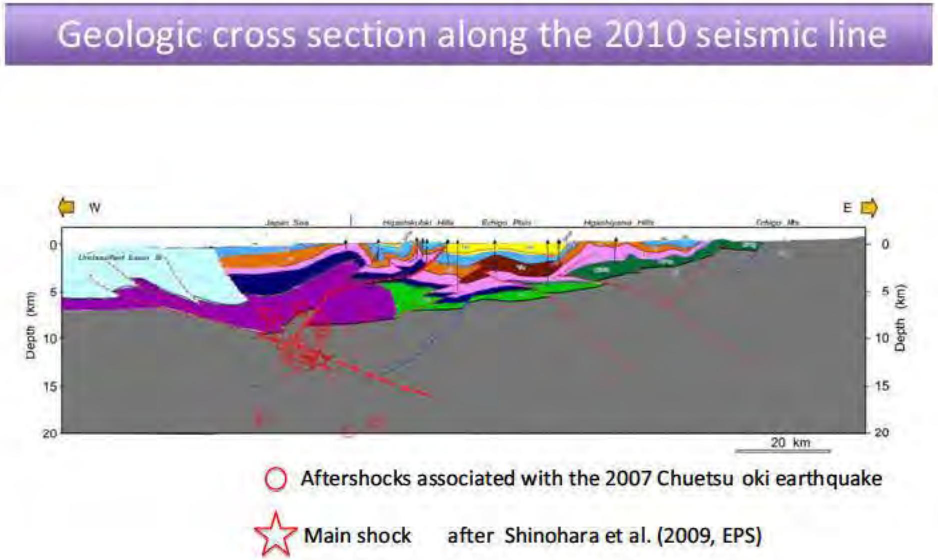
Hypocenter of the 2007 Chuetsu oki EQ (M6.8)

No et al.(2009)



Reflective Miocene volcanics: probable dolerite sheets

Shallow detachment is developed in over pressured mudstone

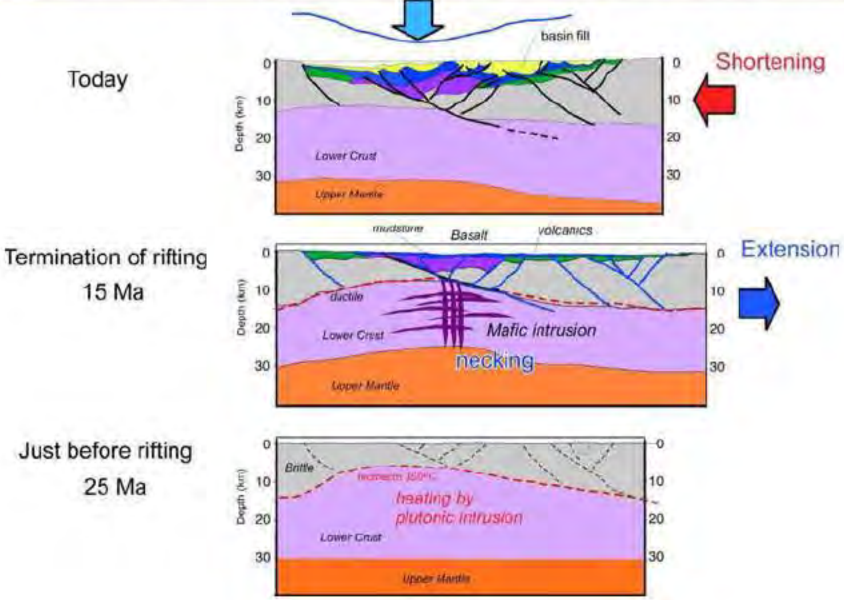


Geologic cross section along the 2010 seismic line

○ Aftershocks associated with the 2007 Chuetsu oki earthquake

☆ Main shock after Shinohara et al. (2009, EPS)

Basin development along the 2010 seismic line



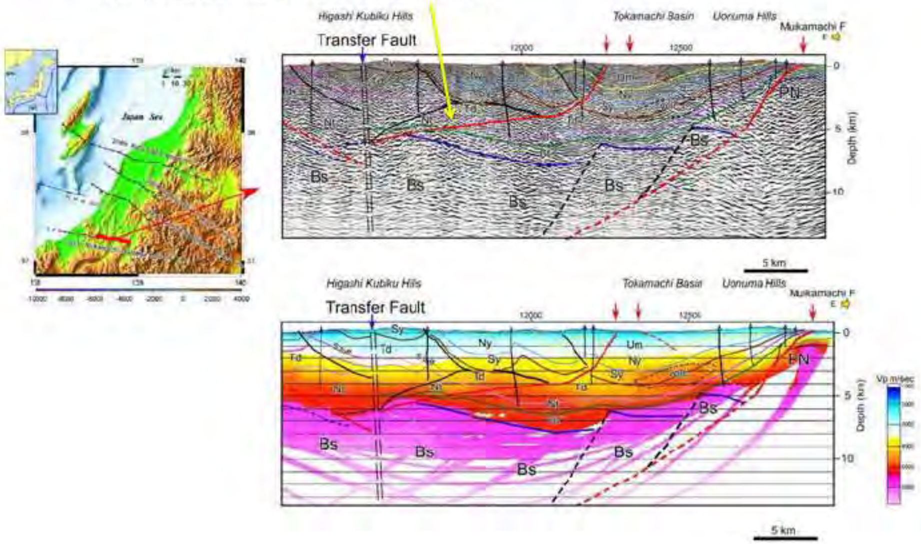
Today

Termination of rifting
15 Ma

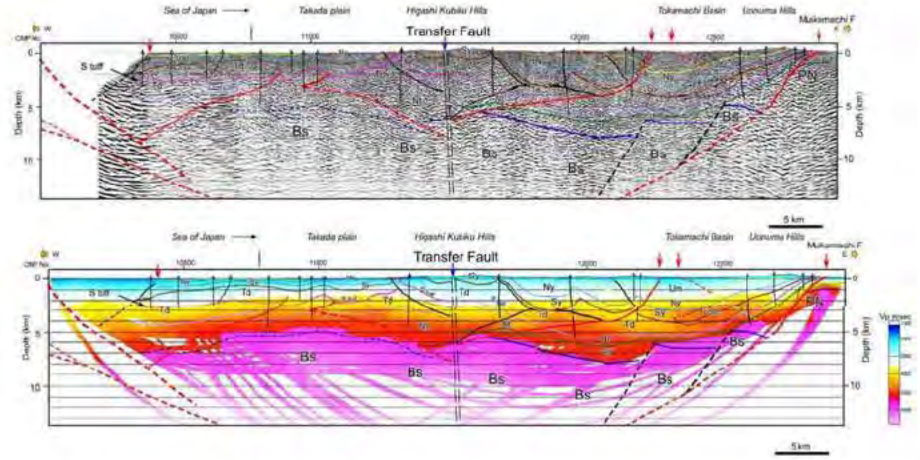
Just before rifting
25 Ma

Eastern part of the Muikamachi-Naoetsu Seismic line

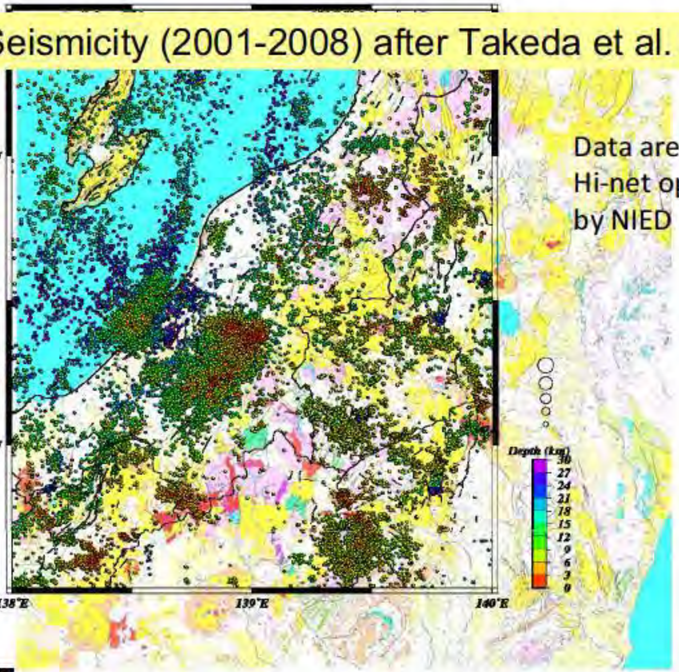
Shallow detachment in the Teradomari Fm



Geologic interpretation of the 2011 Muikamachi-Naoetsu seismic section

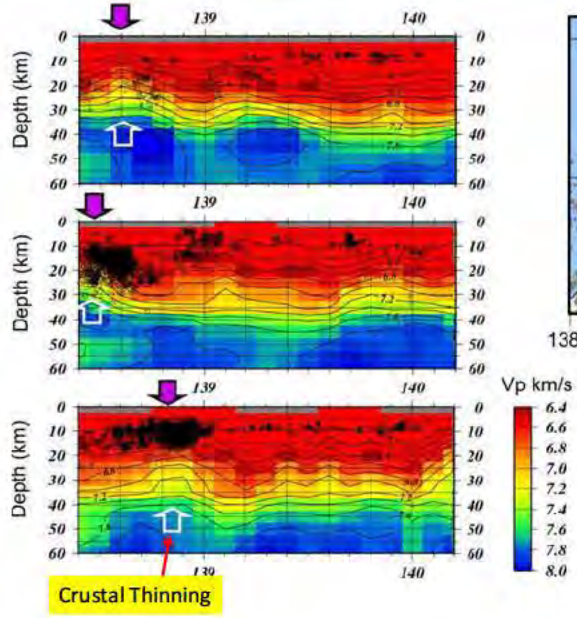


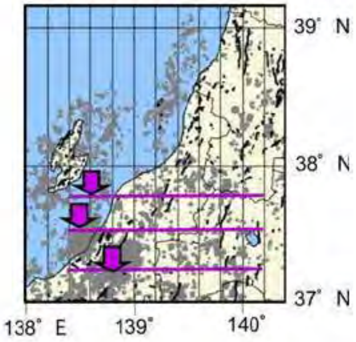
Seismicity (2001-2008) after Takeda et al. (2009)



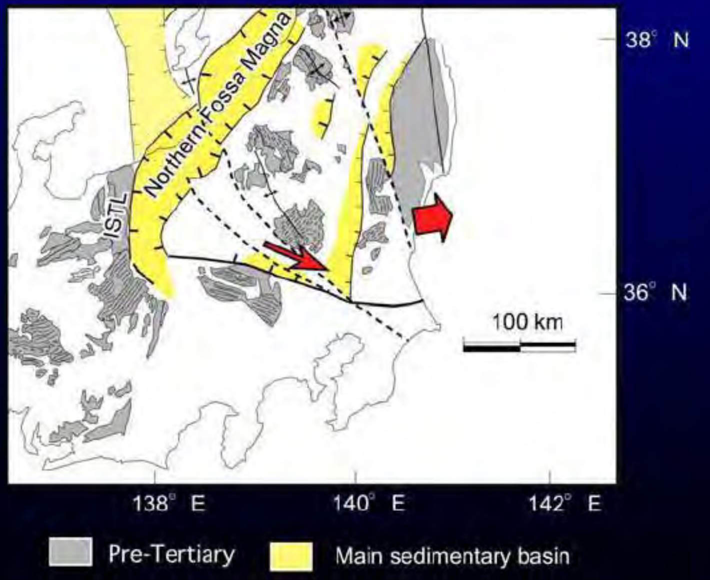
Data are based on Hi-net operated by NIED

P-wave velocity structure by earthquake tomography

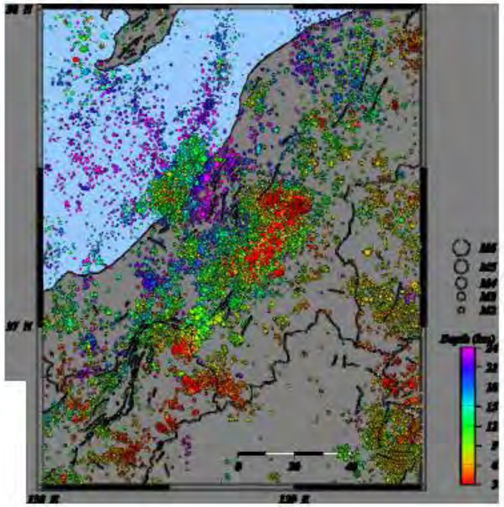


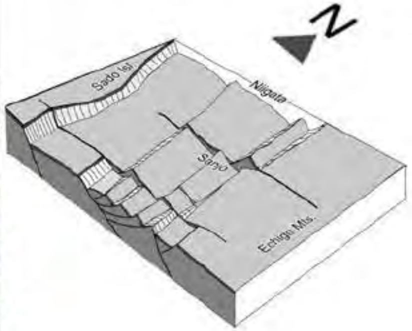


Matsubara and Obara (2011) EPS



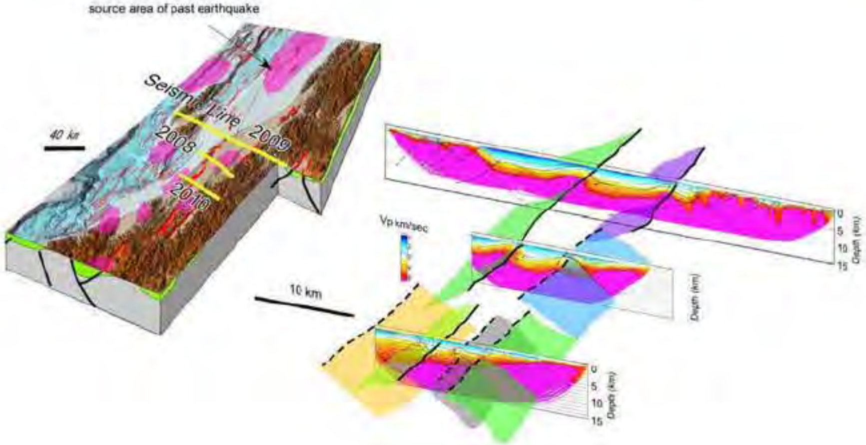
Seismicity (2001-2011)





After Takeda et al. (2012)

Geometry of source faults beneath the Niigata Basin



Conclusion

-Inverted, failed rift structure and deep geometry of active fault are well demonstrated by CMP seismic reflection profiling and refraction tomography.

-The Miocene rift structure strongly controls the geometry of seismogenic source faults.

- Detachments, commonly developed in the Miocene mudstone, controls the style of deformation.

3D seismic imaging of the subsurface for underground construction and drilling

Christopher Juhlin
Dept. of Earth Sciences
Uppsala University

Outline

- Motivation
- Methods
- Examples
  - CO2 storage at Ketzin, Germany
  - Millennium uranium deposit, Canada
  - Forsmark spent nuclear fuel repository, Sweden
  - COSC drilling project, Sweden
- Summary

Motivation

- Planning of drilling and deep construction projects require a good understanding of the sub-surface structure
- Seismic methods provide the highest resolution images (5-10 m) of the deeper (1-5 km) sub-surface
- Development is still necessary for improving methods for seismic applications in the crystalline rock environment

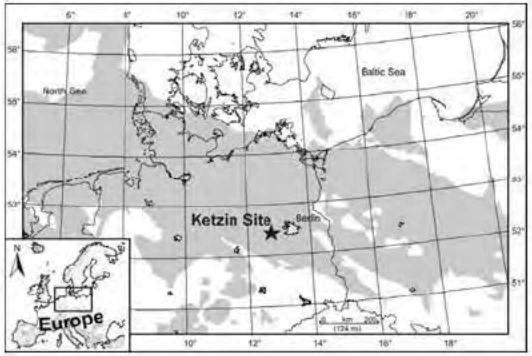
---

Methods

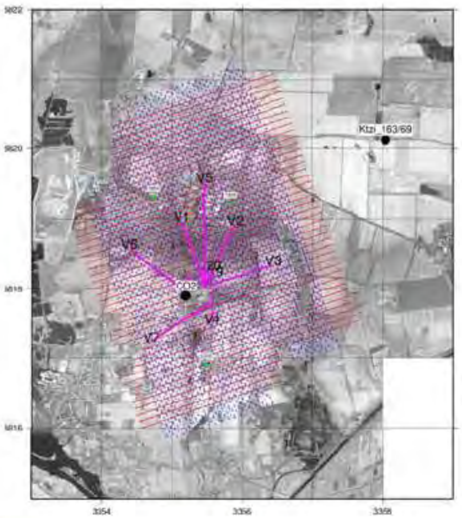
- Active source
  - Reflection seismic imaging (CDP)
  - Traveltime tomography
    - Requires downhole sources/receivers
    - Resolution is less then CDP imaging
  - Seismic waveform tomography
- Passive source
  - Lower resolution
  - Cannot necessarily focus on objectives

The Ketzin project

- CO2 is injected at about 650 m depth into a saline aquifer at a rate of up to 80 t/day
- Field experience in small scale storage in a saline aquifer
- Injection started in summer 2008 and about 62,000 tons have been injected to date.
- Strong monitoring component

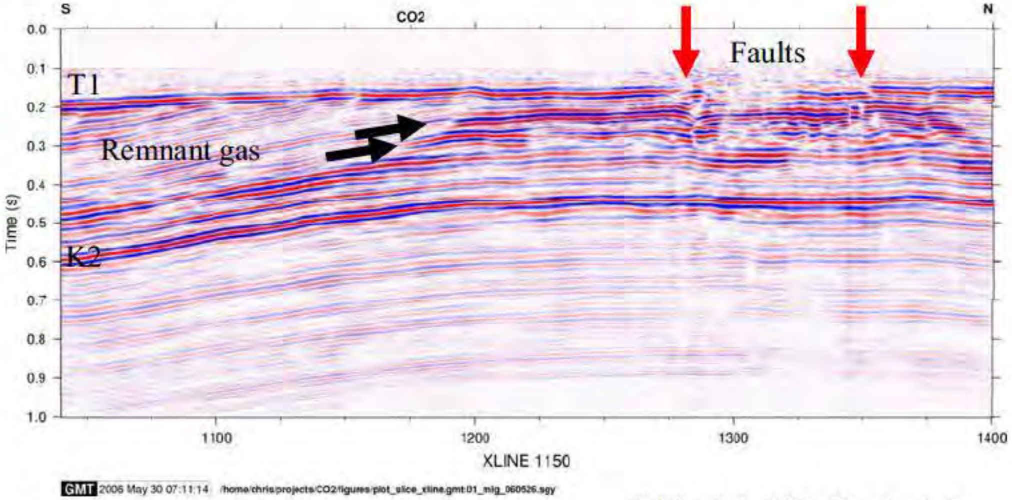


Ketzin: 3D baseline and repeat surveys



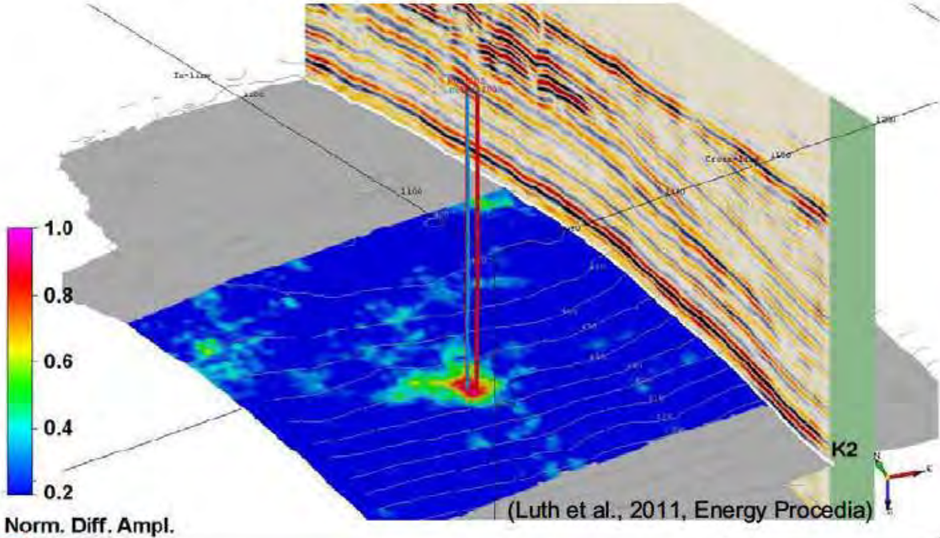
9 drops/SP: ca. 120 SPs / day
Photo by R. Giese

Ketzin: Cross-line 1150



(Juhlin et al., 2007, Geophysics)

Amplitude map of the 3D distribution of injected CO2 at Ketzin, Germany

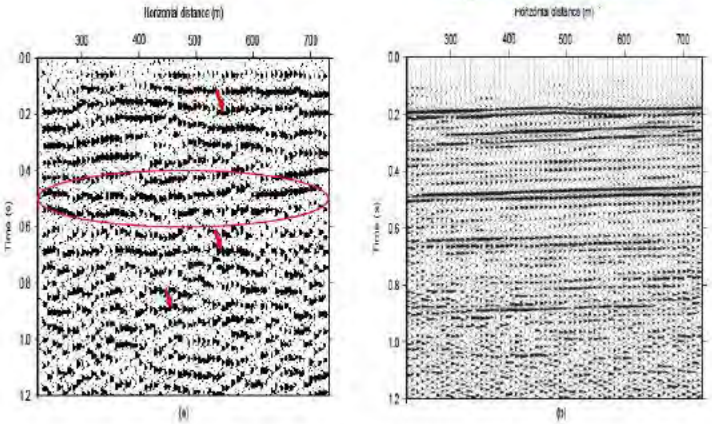


(Luth et al., 2011, Energy Procedia)

Ketzin: Passive source test

- Passive seismic: Line 1

- Active seismic: Line 1
- Exploration frequencies

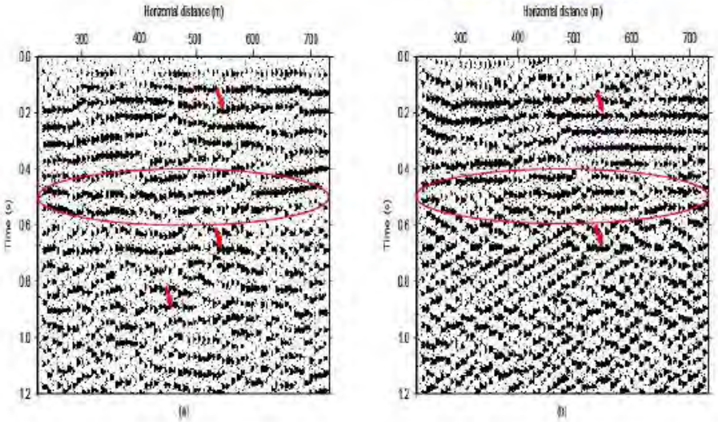


(Xu et al., 2011, GJI)

Ketzin: Passive source test

- Passive seismic: Line 1

- Active seismic: Line 1
- Passive frequencies



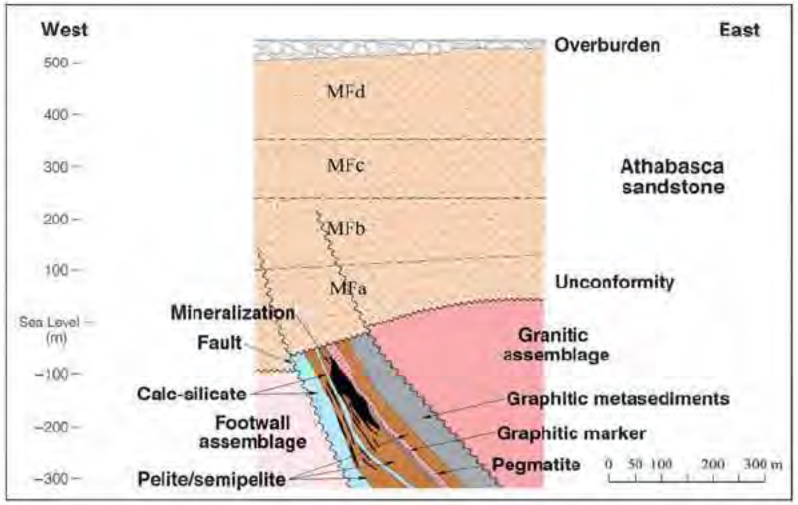
(Xu et al., 2011, GJI)

Mine planning at the Millennium deposit, Saskatchewan, Canada

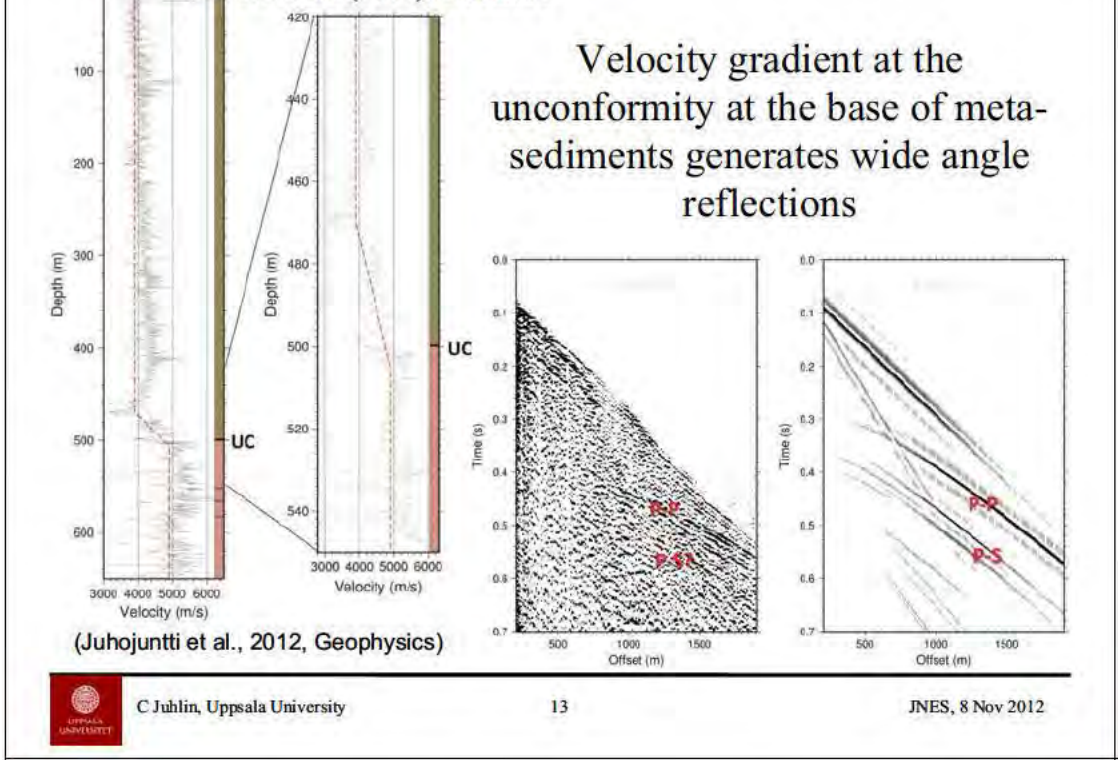
(Juhojuntti et al., 2012, Geophysics)

Uranium ore located at about 600 m depth, below Precambrian meta-sediments

Want to locate the mine shaft where the meta-sediments are thinnest



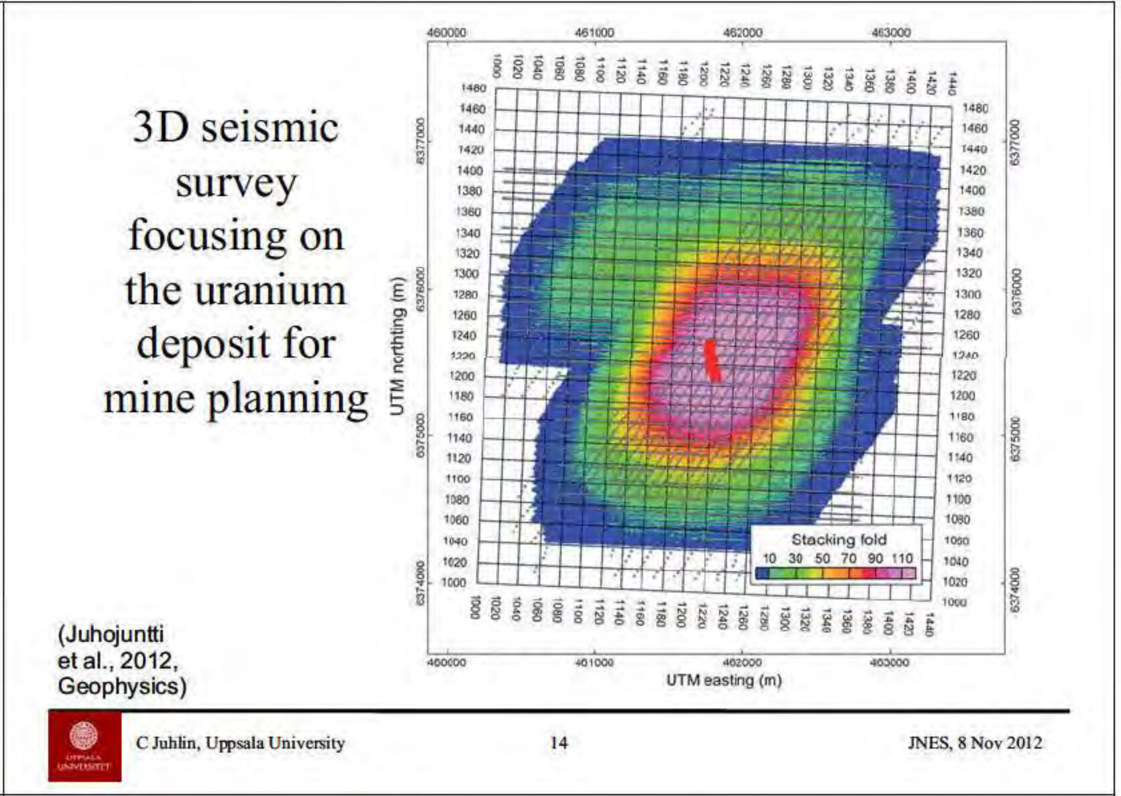
(Juhojuntti et al., 2012, Geophysics)



Velocity gradient at the unconformity at the base of meta-sediments generates wide angle reflections

(Juhojuntti et al., 2012, Geophysics)

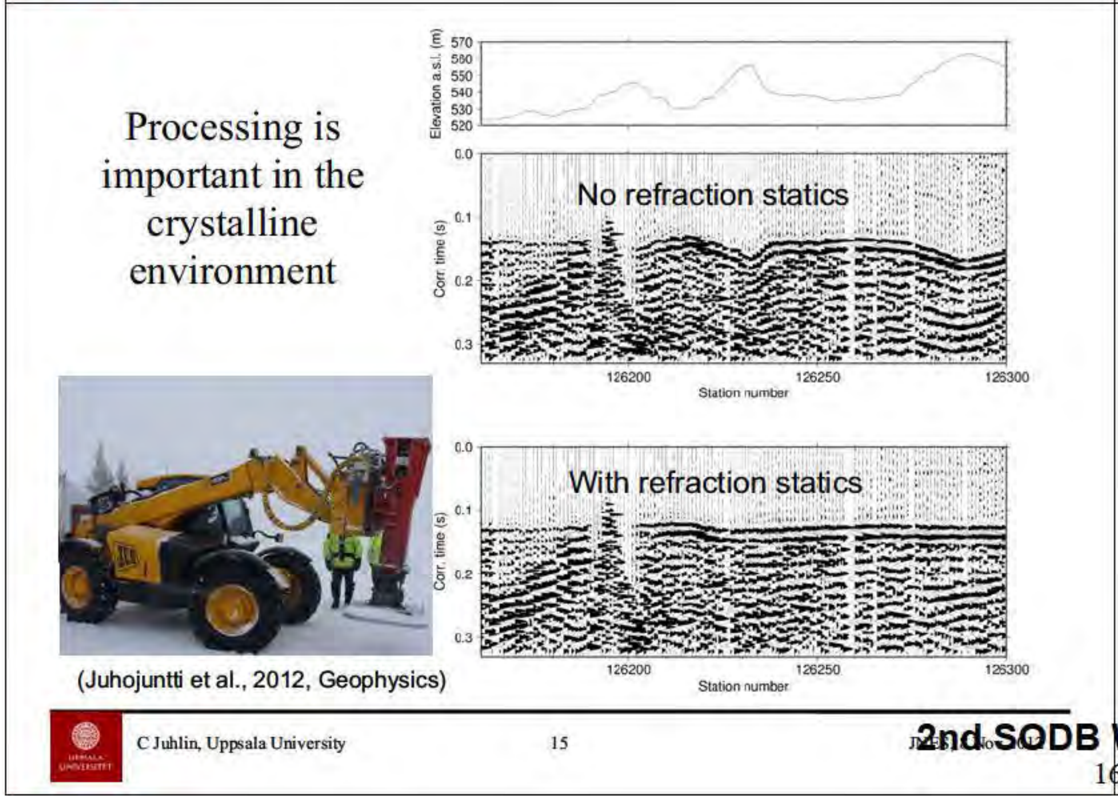
C Juhlin, Uppsala University 13 JNES, 8 Nov 2012



3D seismic survey focusing on the uranium deposit for mine planning

(Juhojuntti et al., 2012, Geophysics)

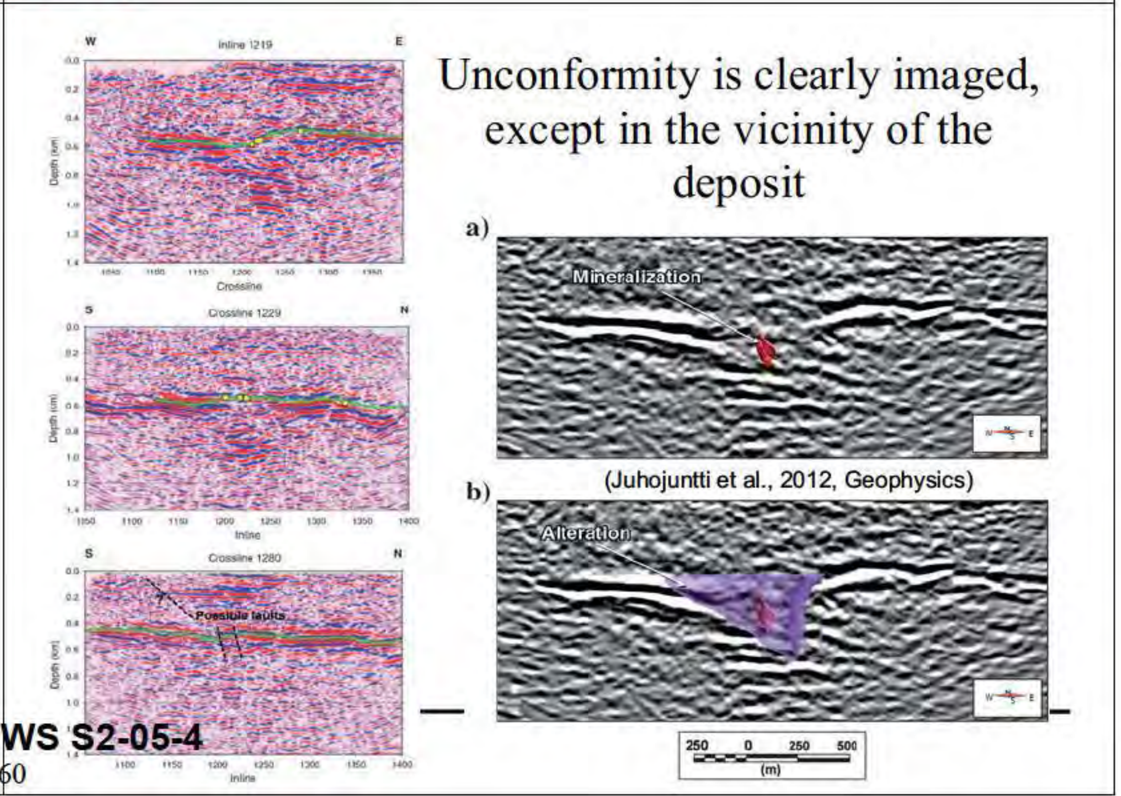
C Juhlin, Uppsala University 14 JNES, 8 Nov 2012



Processing is important in the crystalline environment

(Juhojuntti et al., 2012, Geophysics)

C Juhlin, Uppsala University 15



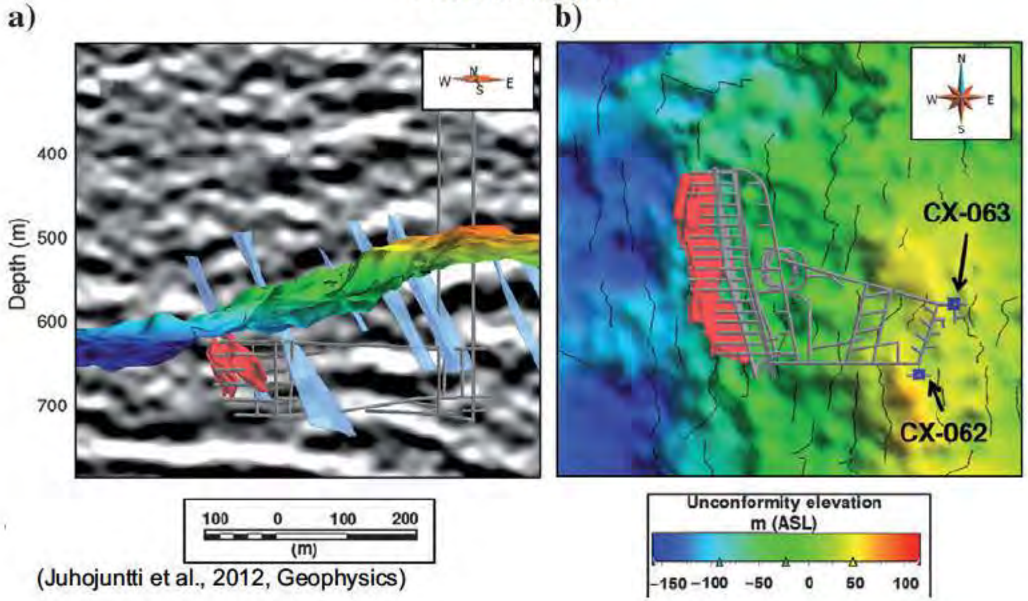
Unconformity is clearly imaged, except in the vicinity of the deposit

a)

(Juhojuntti et al., 2012, Geophysics)

b)

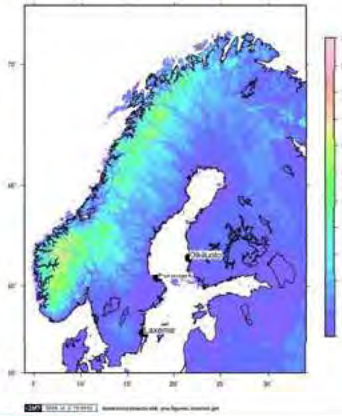
3D seismic allow the mine shaft to be placed on an unconformity high → reduced costs for the mine construction

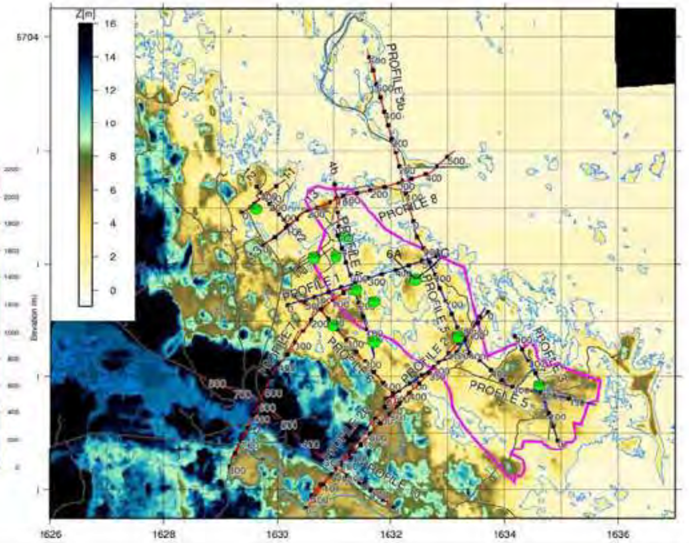


(Juhojuntti et al., 2012, Geophysics)

Forsmark: Planned site for storing Sweden's spent nuclear fuel

About 40 km of high resolution seismic profiling



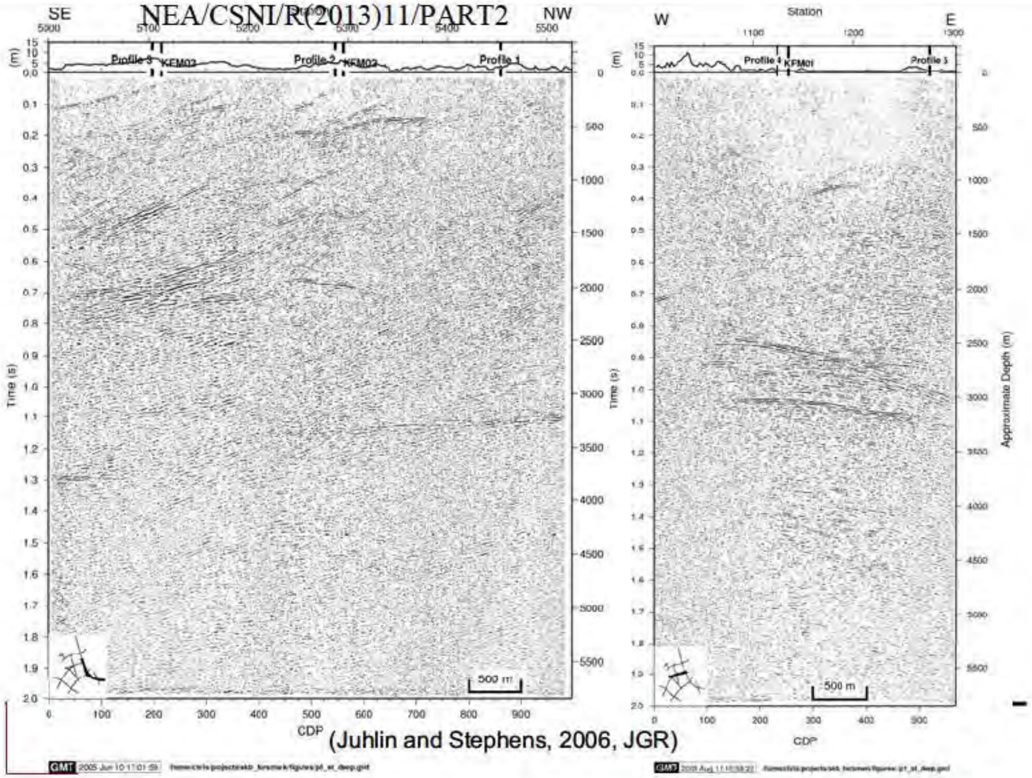


Planned repository at Forsmark

(www.skb.se)

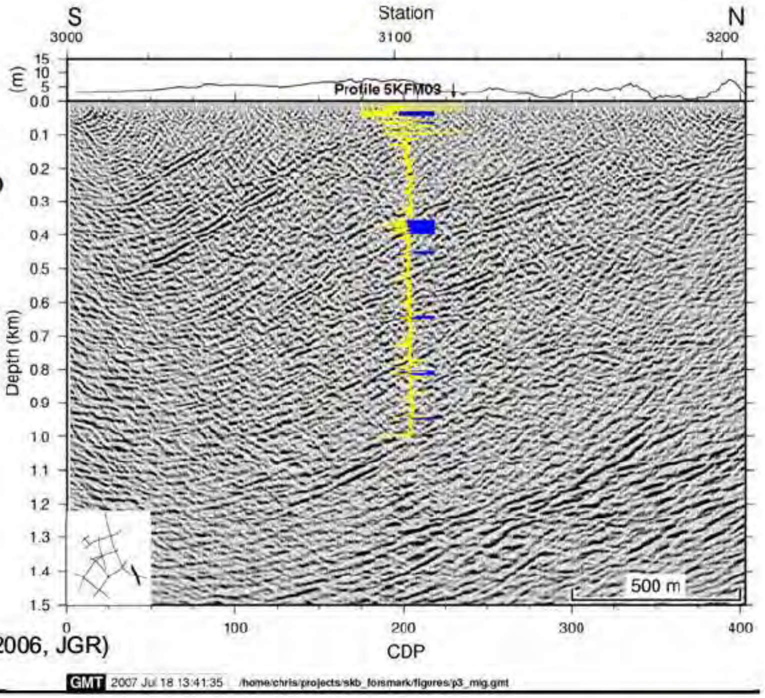
Explosive source: 15-75g dynamite

Mechanical hammer source also used on some profiles



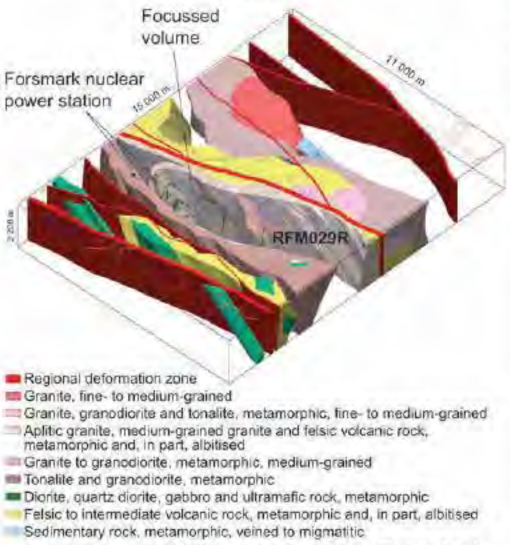
(Juhlin and Stephens, 2006, JGR)

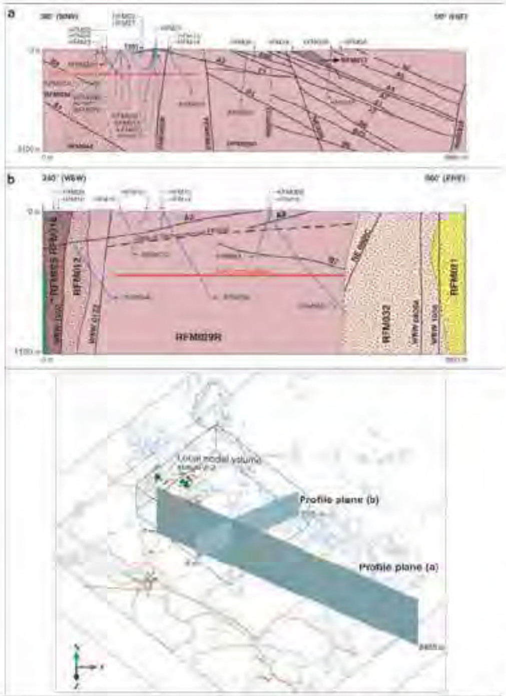
Sub-horizontal to gently dipping seismic reflections from hydraulically conductive fracture zones



(Juhlin and Stephens, 2006, JGR)

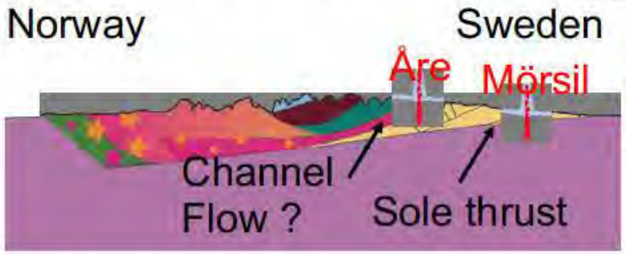
Geological modeling of sub-horizontal zones largely based on reflection seismics

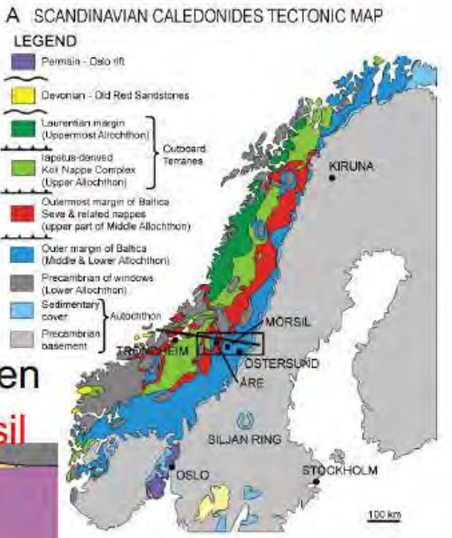




(Milnes et. al., 2008, Episodes)

Exploring the Scandinavian Mountain Belt by Deep Drilling (COSC)

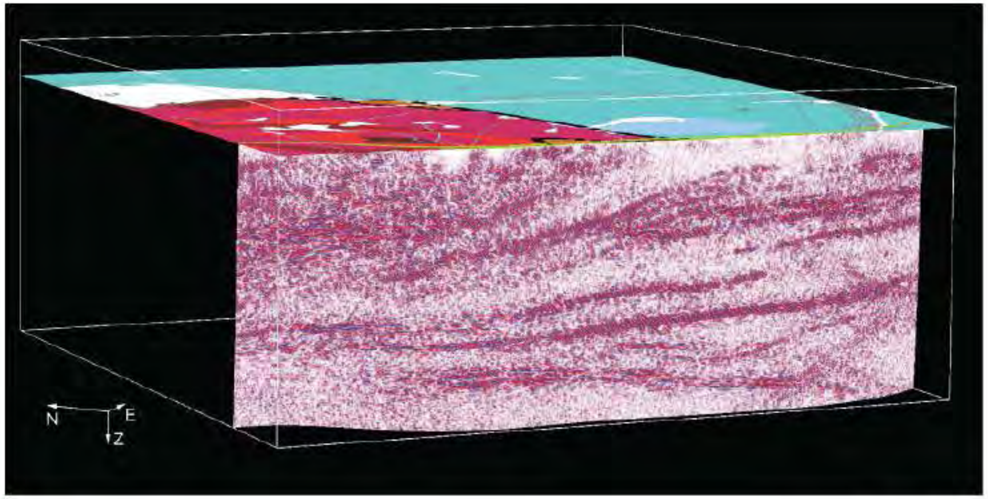




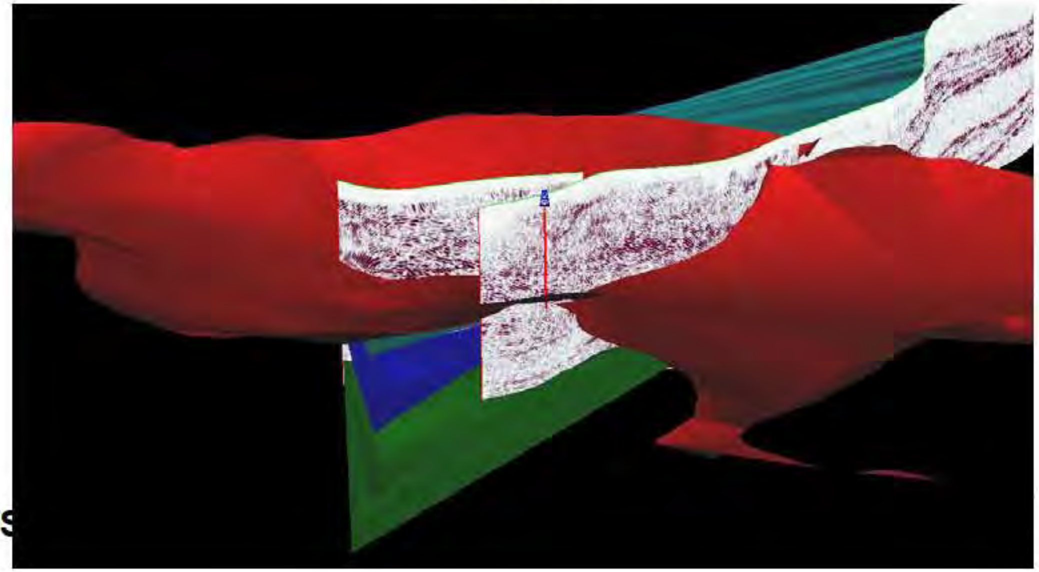
Why drill in the Caledonides?

- Tectonic evolution
  - Channel flow
  - Basement involved thrusting
- Comparison with the Himalayas
- Present day and past deep fluid circulation patterns
- Current heat flow and climate modeling
- Deep biosphere
- Calibration of high quality surface geophysics

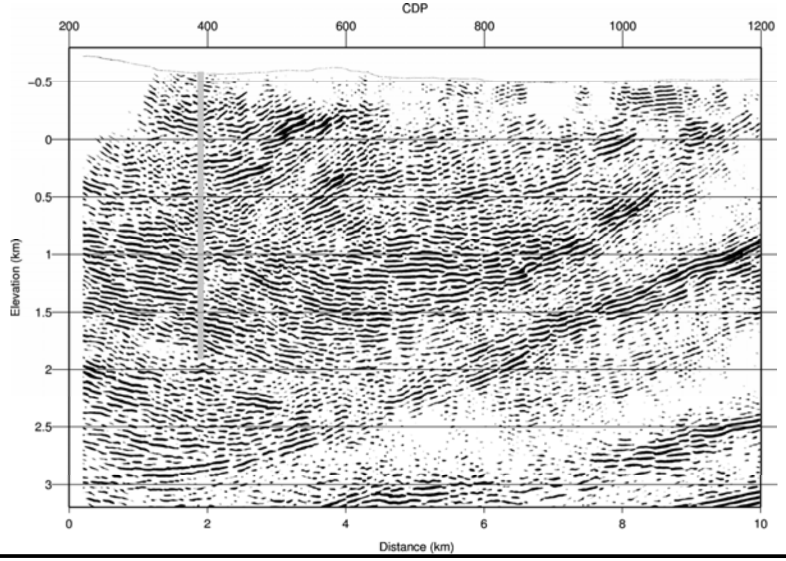
High grade Seve Nappe is highly reflective



Reflection seismic data ad surface geology used to build a 3D geological model



COSC 1 (2.5 km): Drilling planned for 2013 ← dependent upon funding



Summary

- 3D seismic methods are proven in the sedimentary environment
- Development is necessary in the crystalline environment, but numerous successful case histories exist
- Integration of geology, geophysics and drilling provides the optimum interpretations

IESE Institute of Earth Science and Engineering Aotearoa

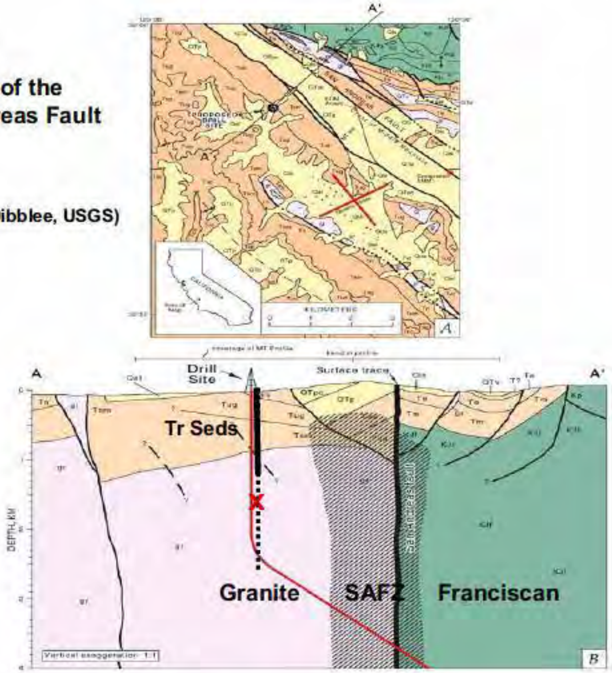
JNES W2 08 11 2012

Evaluation of Three Dimensional Underground Structure at SAFOD Project

Peter Malin and IESE Staff

"Known" Geology of the Parkfield San Andreas Fault in ~2002

(after M. Rymer & T.W. Dibblee, USGS)



Earthquakes location: a lesson from SAFOD

The problem:

Define drilling target using best 3 D method

Mag 2 repeating event ~ **10x10 m**.

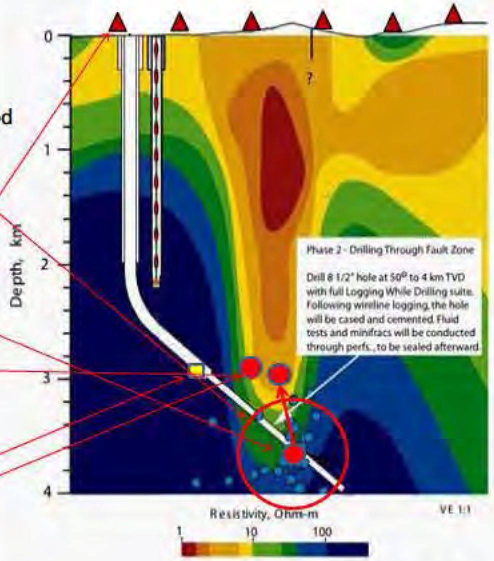
Phase 1: 60 surface stations, 2 years, located within "**100 m errors**"

Phase 2: add 32 levels borehole, 1 year, located within "**50 m errors**"

moved 800 m

Phase 3: add sensor 400 m from target, located within "**20 m errors**"

moved 200 m



Phase 2 - Drilling Through Fault Zone

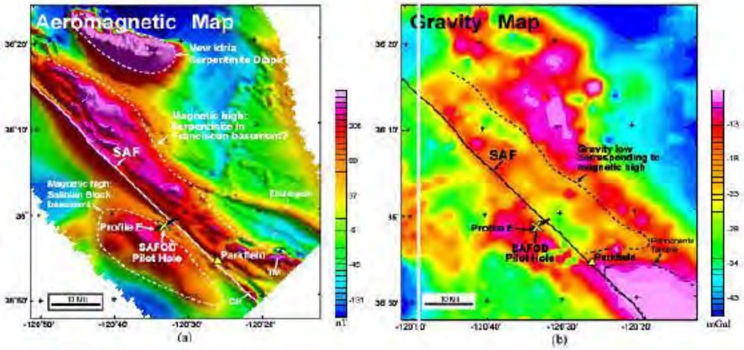
Drill 8 1/2" hole at 50° to 4 km TVD with full Logging While Drilling suite. Following wireline logging, the hole will be cased and cemented. Fluid tests and minifracs will be conducted through perfs., to be sealed afterward

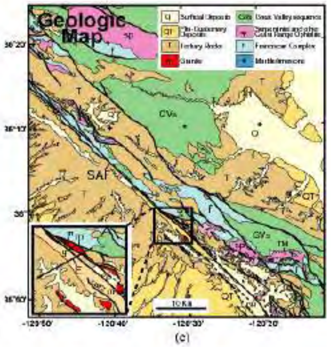
---

Potential Field Data

Good for regional Picture

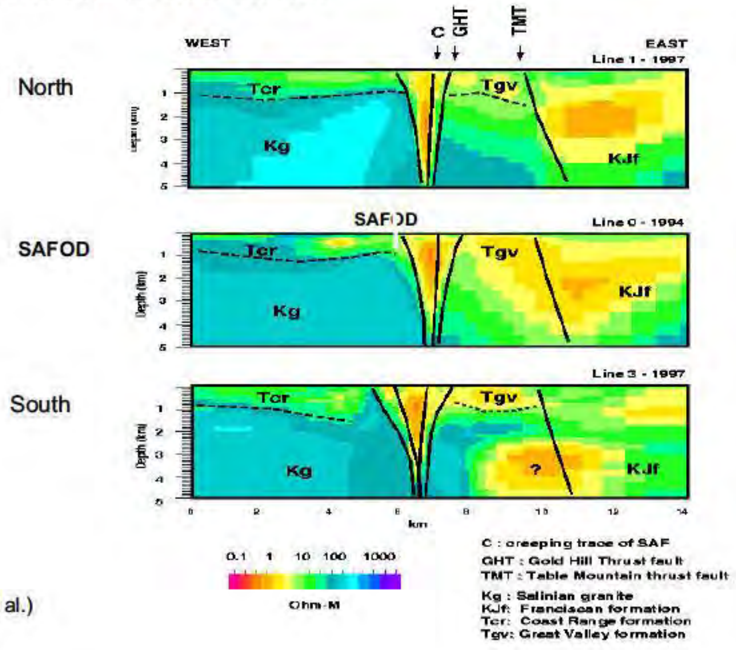
- not drilling



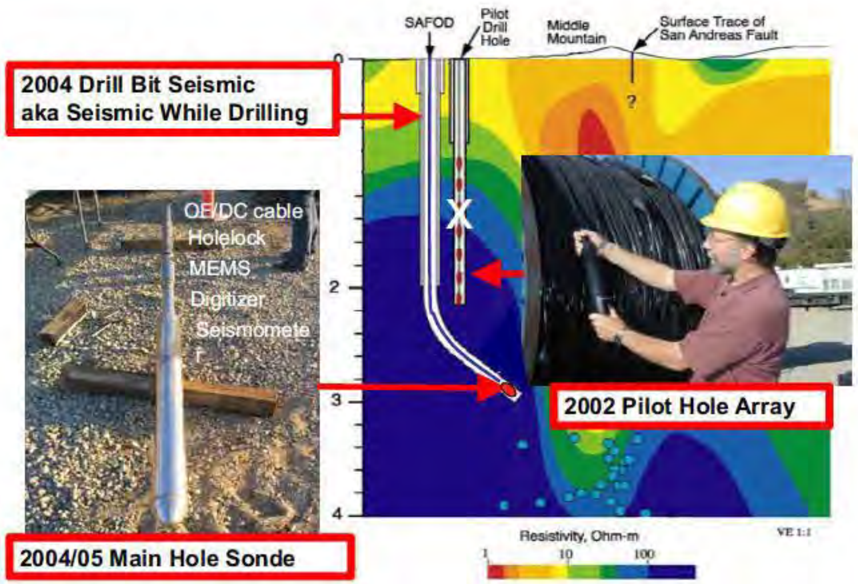


SAF at surface

MT Electrical Resistance Cross Sections



(Unsworth et al.)

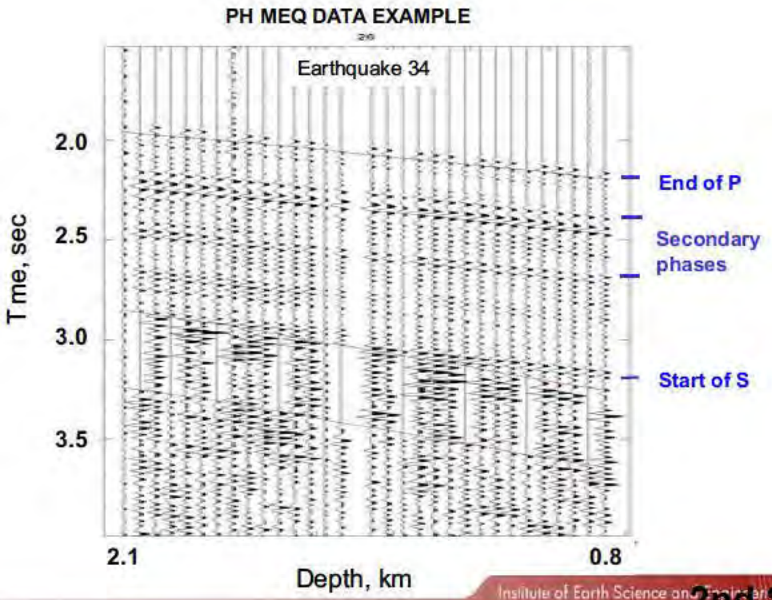


2004 Drill Bit Seismic aka Seismic While Drilling

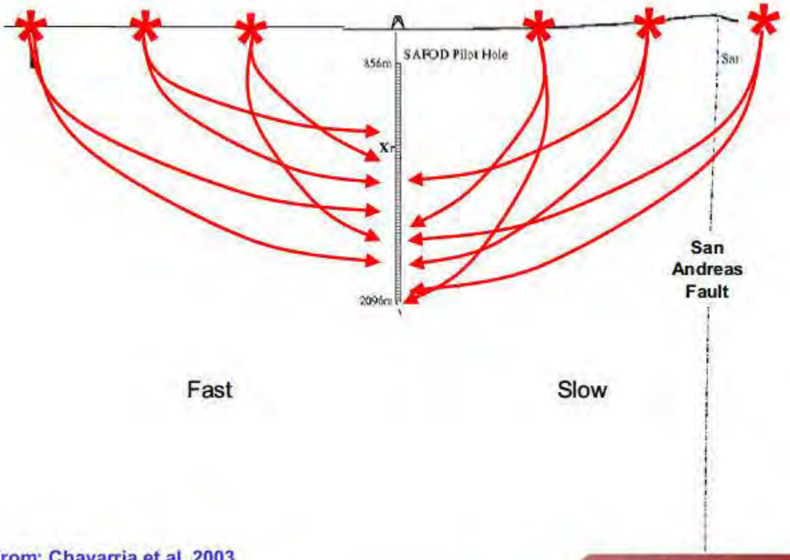
2002 Pilot Hole Array

2004/05 Main Hole Sonde

Pilot Hole Array Imaging Using Tomography, Scattered Wave Migration & Vp/Vs

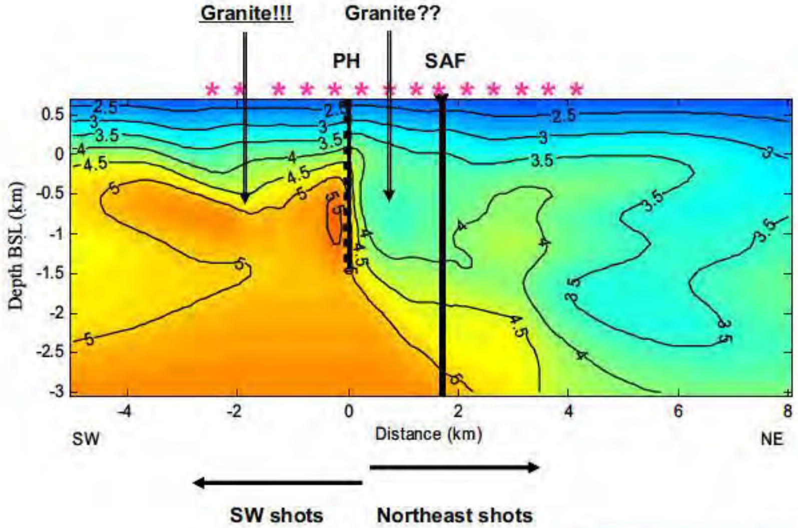


Pilot Hole Array Imaging Using explosion Tomography



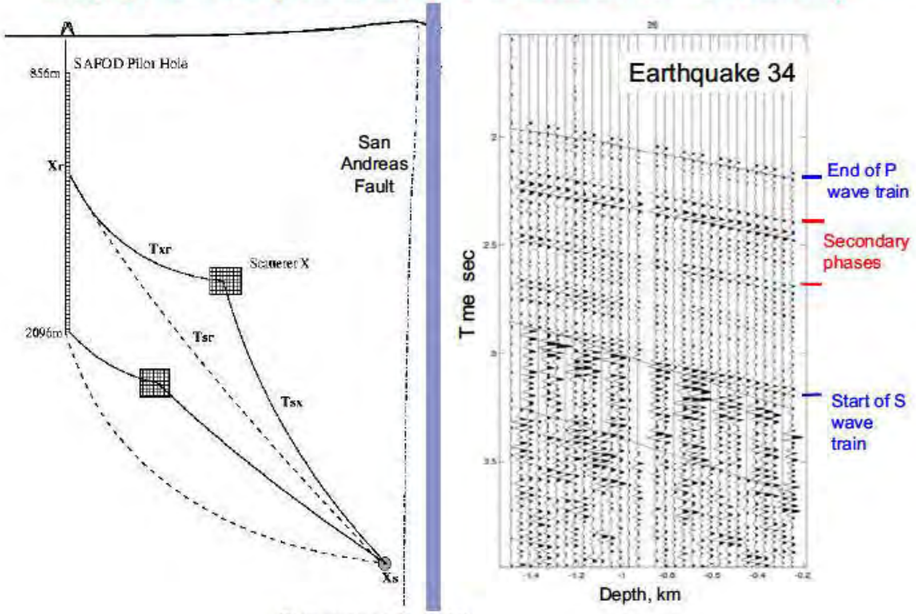
From: Chavarria et al. 2003

Surface shot & PH array P-wave velocity tomography - Pre Main Hole Drill



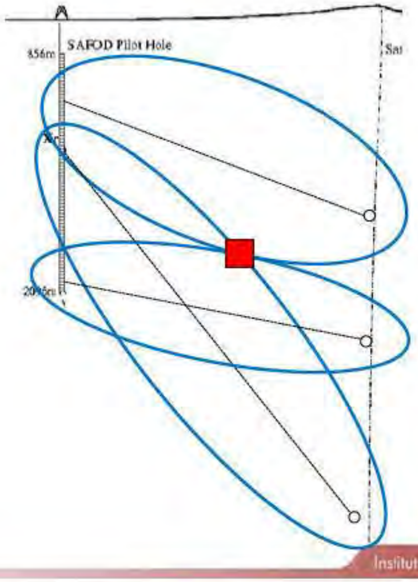
Institute of Earth Science and Engineering

Imaging Faults Using Scattered P and S Waves on the Pilot Hole Array



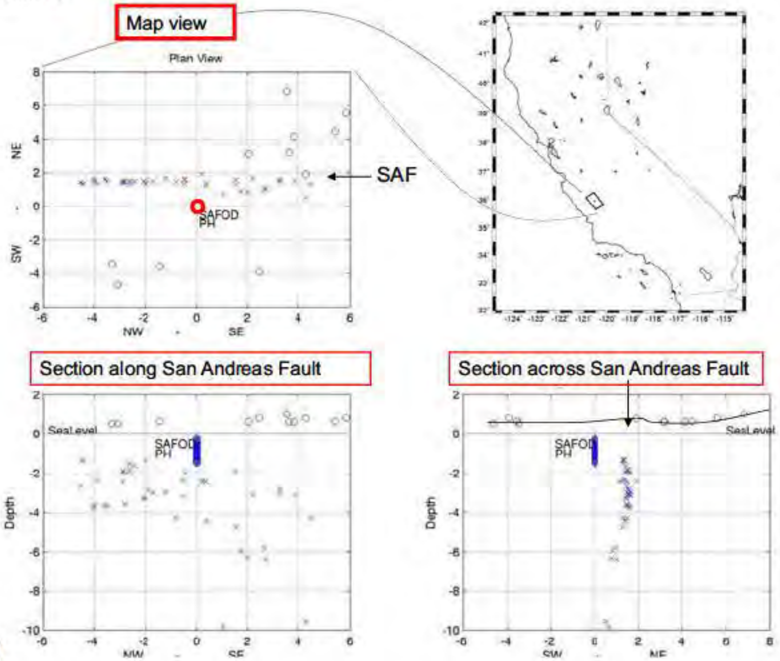
Chavarria et al. 2003

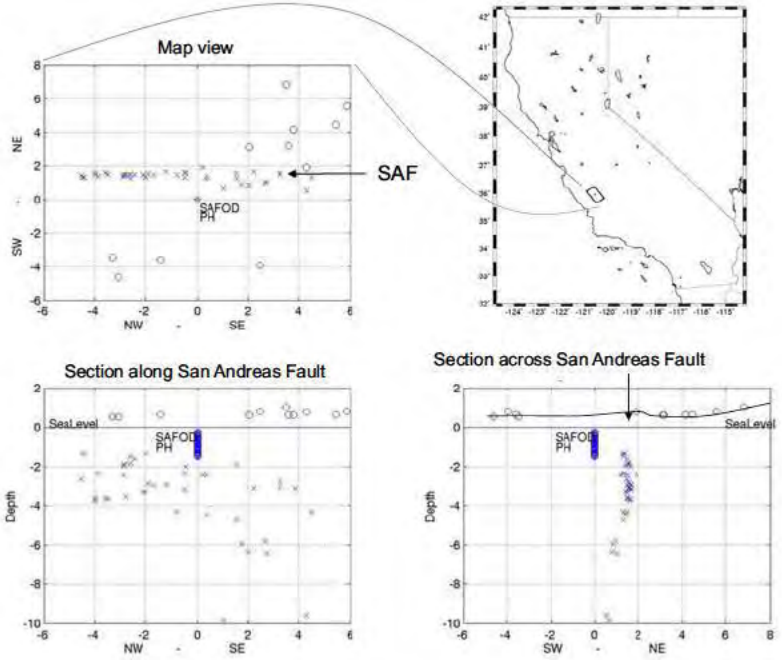
Migration Ellipses



Institute of Earth Science and Engineering

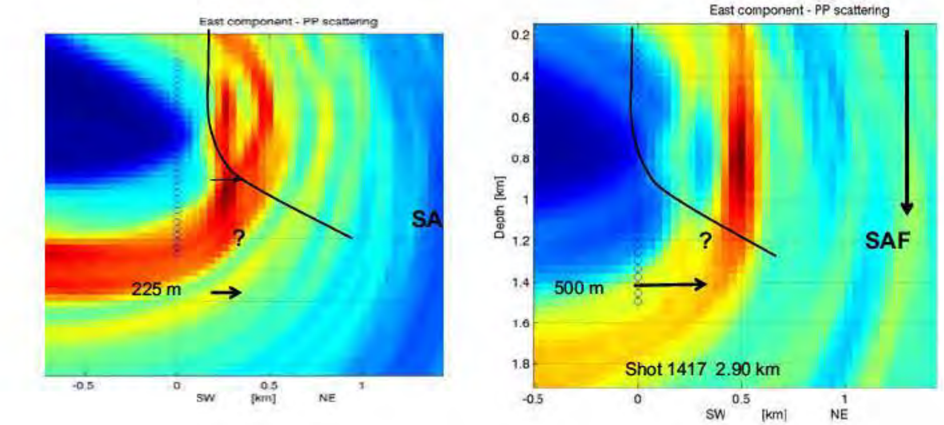
Source Locations



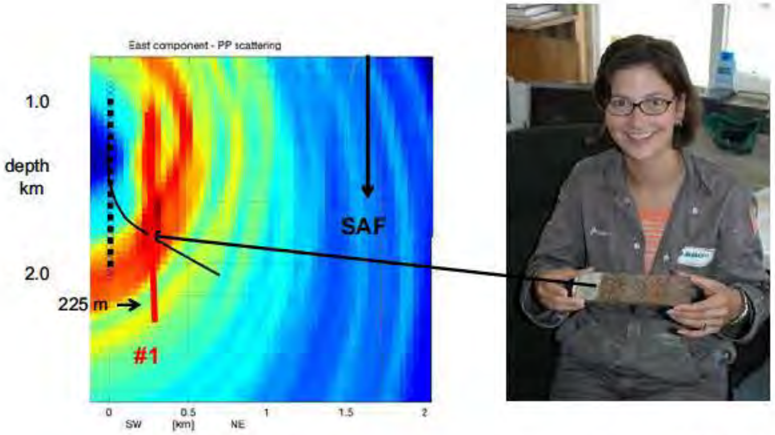


Migration of 2 shots southeast of PH

show 2 reflectors to its northeast.



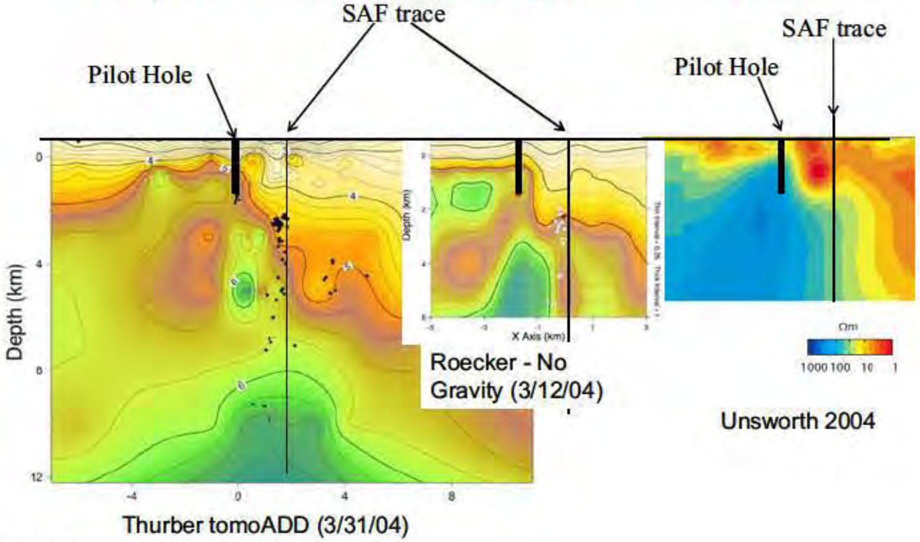
Ground truth of pre MH Drilling migration of shots to southwest of PH



Shot 1402 2.30 km

From: Chavarria et al. 2003

Comparison of Seismic and Magnetotelluric Models



Roecker - No Gravity (3/12/04)

Unsworth 2004

Thurber tomoADD (3/31/04)

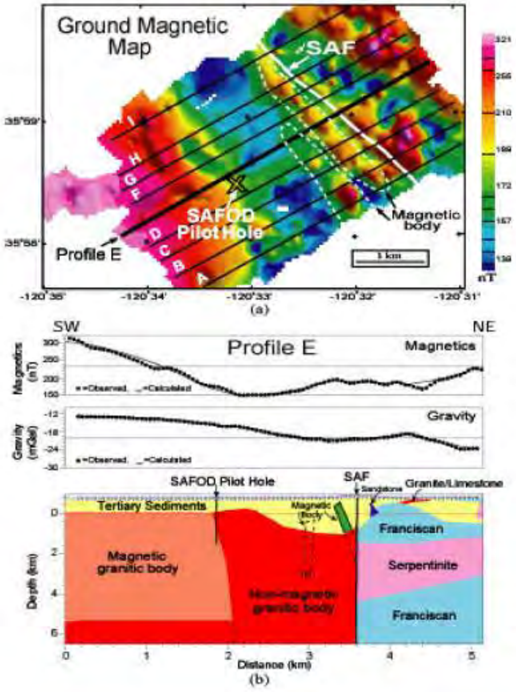
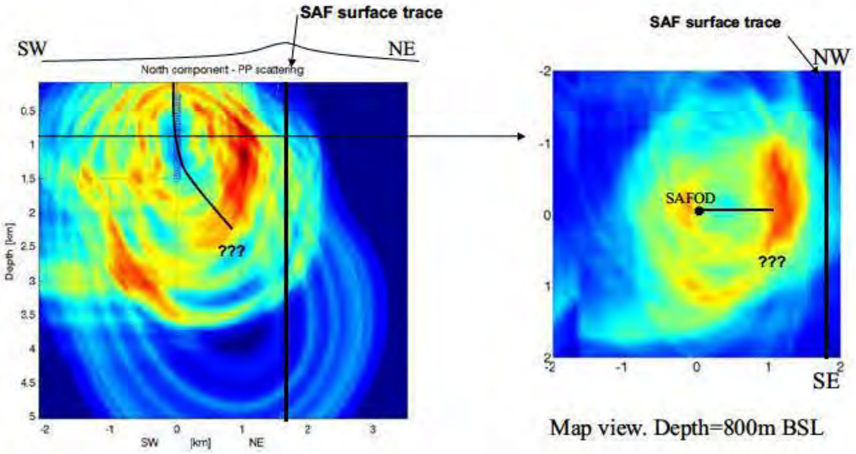


Figure 2. (a) Ground magnetic map in the vicinity of the SAFOD pilot hole. White line – SAF; dashed white lines outline magnetic anomalies. 2-D magnetic modeling was performed along Profiles A through I shown in solid black lines. (b) 2-D geologic model along Profile E and corresponding fit to ground magnetic and gravity data. Dashed body shows the projection of the magnetic body modeled along profiles A through D onto Profile E. (From *McPhee et al., GRL, 2004*)

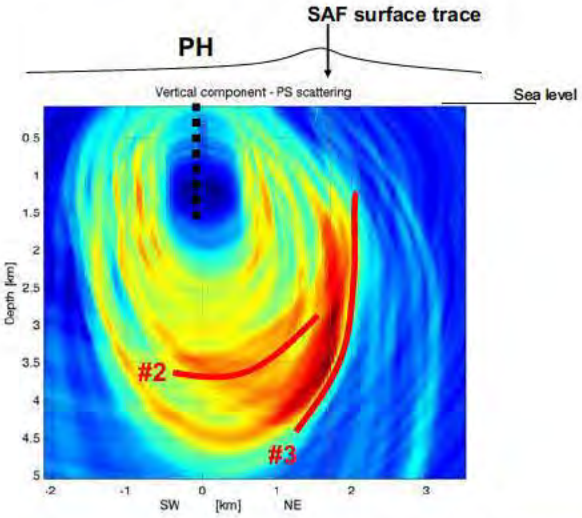
Structure near the end of 2004 drilling

(Are we there yet ???)



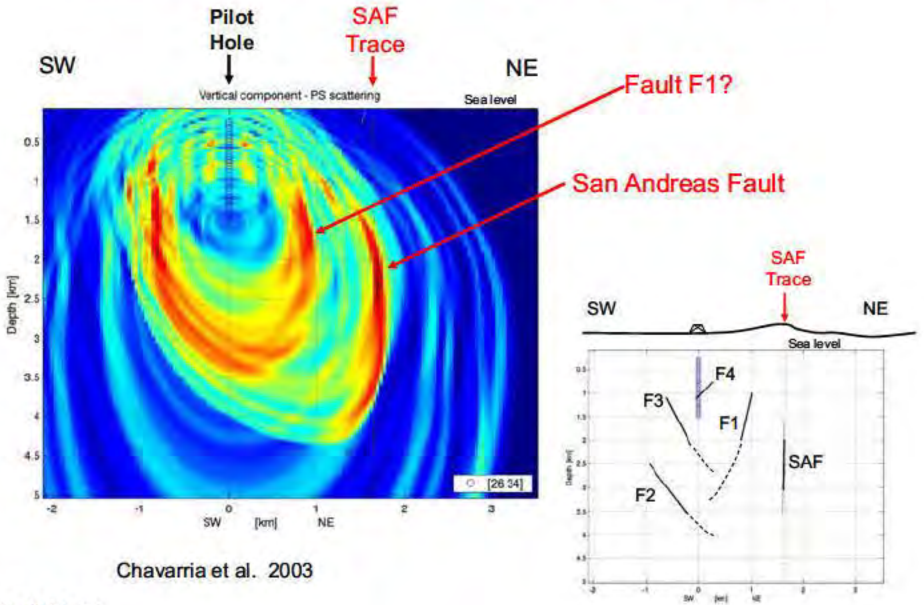
Map view. Depth=800m BSL

Kirkchoff migration of scattered waves

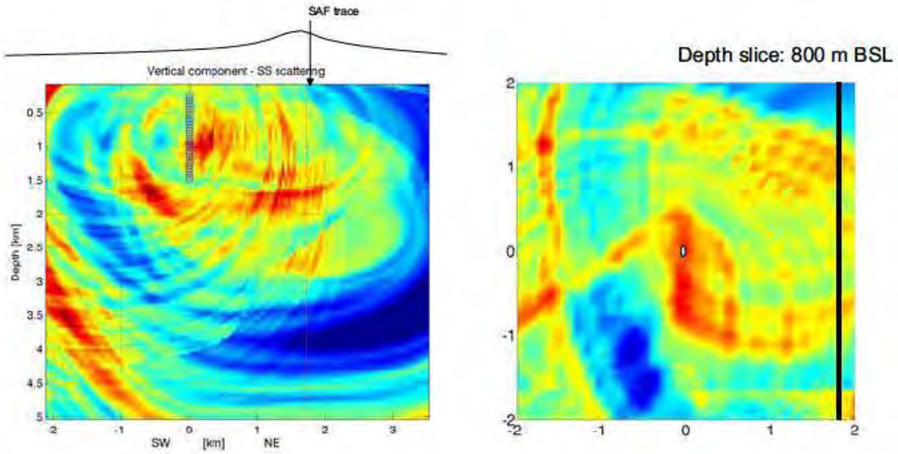


From: Chavarria et al. 2003

Migrated Section Perpendicular to SAF (EQs 26 and 34)

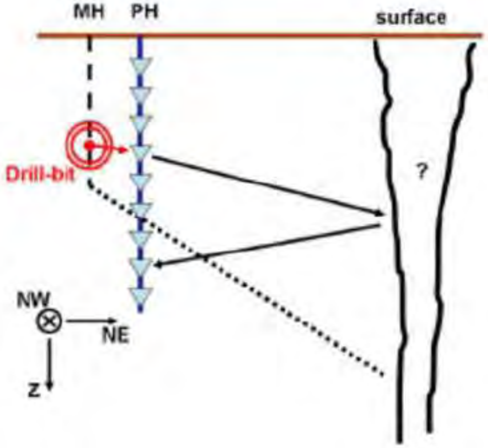


Chavarria et al. 2003



DBS – Drill Bit Seismic

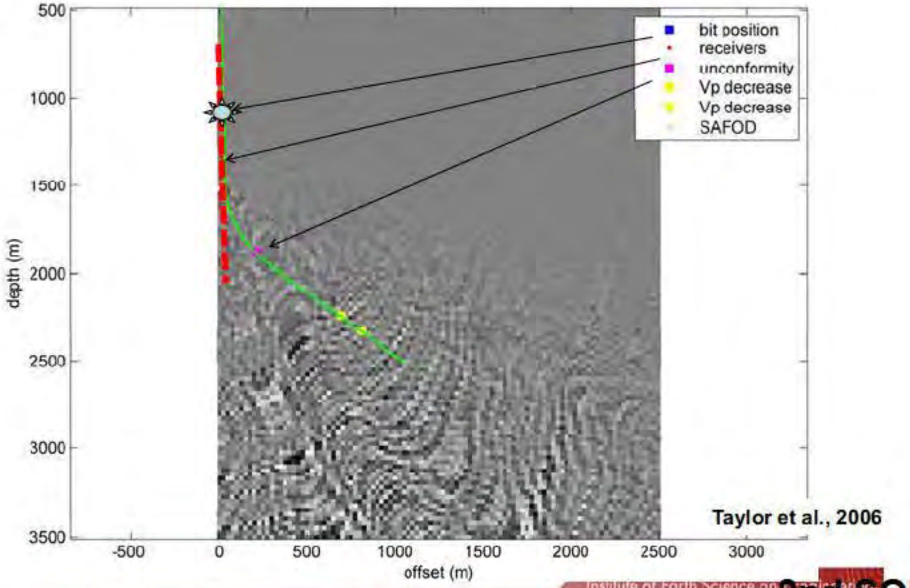
(Taylor et al., 2006)



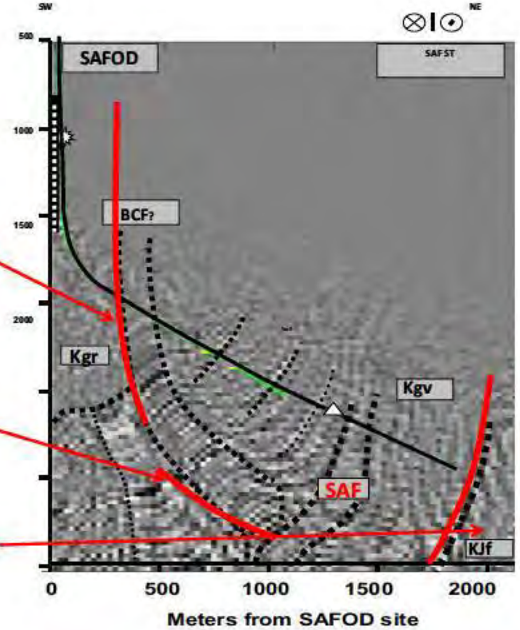
Duke University and Schlumberger collaboration

Institute of Earth Science and Engineering

Migrated DBS Image – 65 s source at Level 7 into 32 Level Pilot Hole Array



Taylor et al., 2006

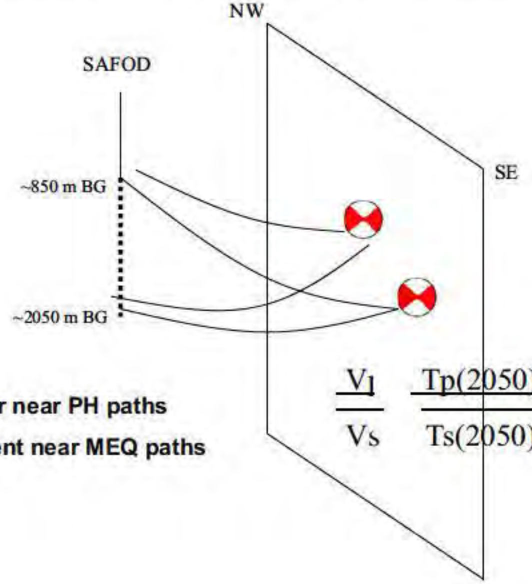


Near fault - xtaline-seds
#1

Bottom of the low velocity seds
#2

Franciscan?
#3

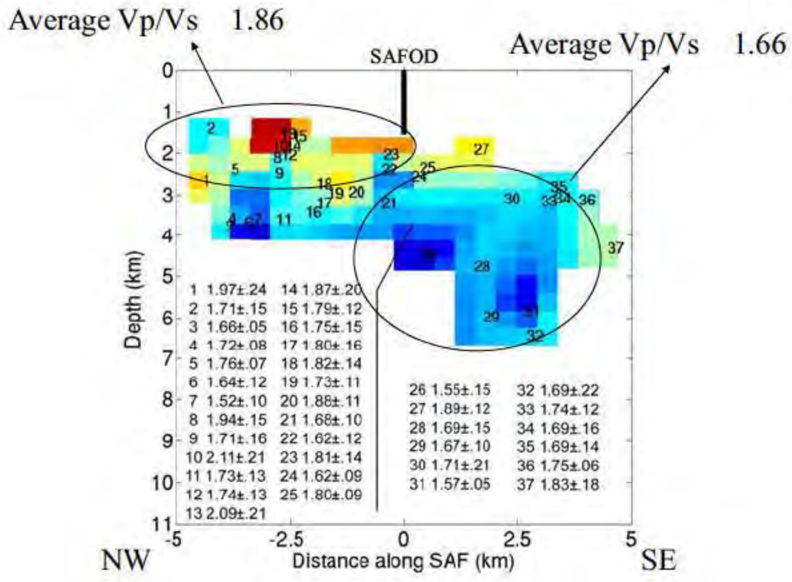
Vp/Vs further from the Pilot Hole can be estimated as follows:



$$\frac{V_I}{Vs} \quad \frac{Tp(2050) \quad Tp(850)}{Ts(2050) \quad Ts(850)}$$

Similar near PH paths

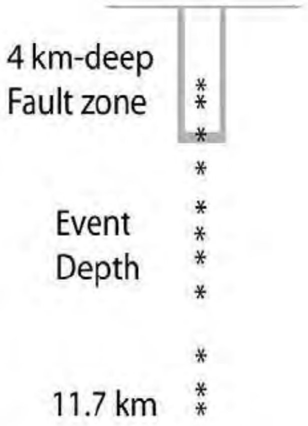
Different near MEQ paths



1	1.97±.24	14	1.87±.20
2	1.71±.15	15	1.79±.12
3	1.66±.05	16	1.75±.15
4	1.72±.08	17	1.80±.16
5	1.76±.07	18	1.82±.14
6	1.64±.12	19	1.73±.11
7	1.52±.10	20	1.88±.11
8	1.94±.15	21	1.68±.10
9	1.71±.16	22	1.62±.12
10	2.11±.21	23	1.81±.14
11	1.73±.13	24	1.62±.09
12	1.74±.13	25	1.80±.09
13	2.09±.21		

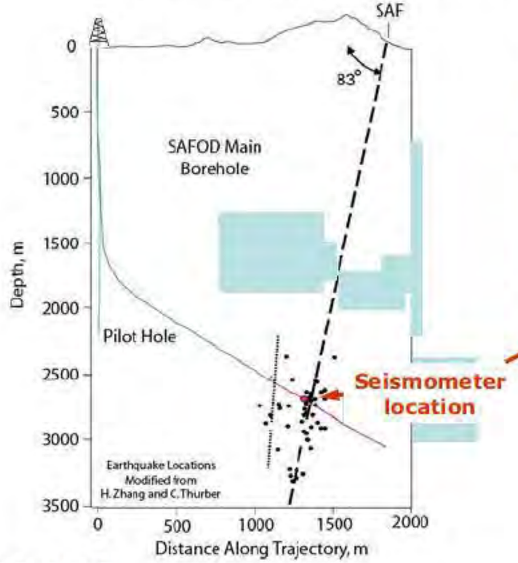
26	1.55±.15	32	1.69±.22
27	1.89±.12	33	1.74±.12
28	1.69±.15	34	1.69±.16
29	1.67±.10	35	1.69±.14
30	1.71±.21	36	1.75±.06
31	1.57±.05	37	1.83±.18

Shallow versus deep fault model

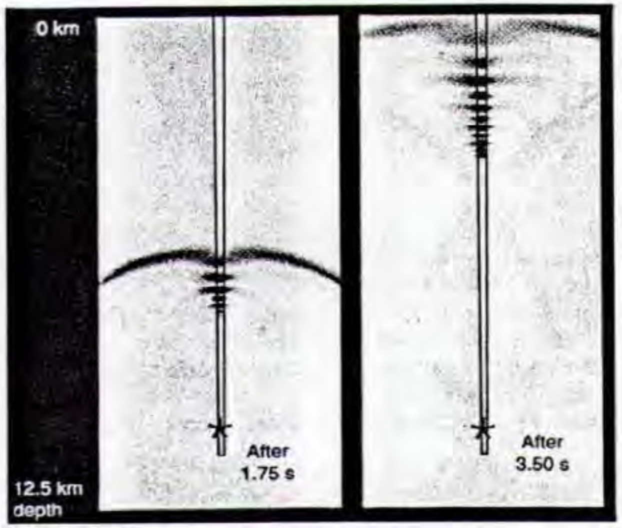


WHAT CAN BE SAID ABOUT THE DEPTH OF THE DAMAGE ZONE?

Location of the borehole seismometer observing Fault Guided Waves

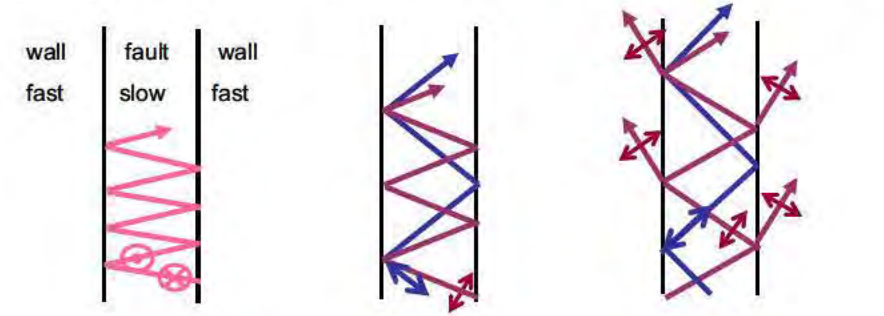


WHAT IS A FAULT GUIDED WAVE? A model of an "F_L" wave



Li et al. 1995

Fault zone guided wave types – Old and New



Previously Studied

NEW

F_L – Fully trapped SH

F_R – Fully trapped PSV

F_Φ – Leaky mode trapped P

slowest

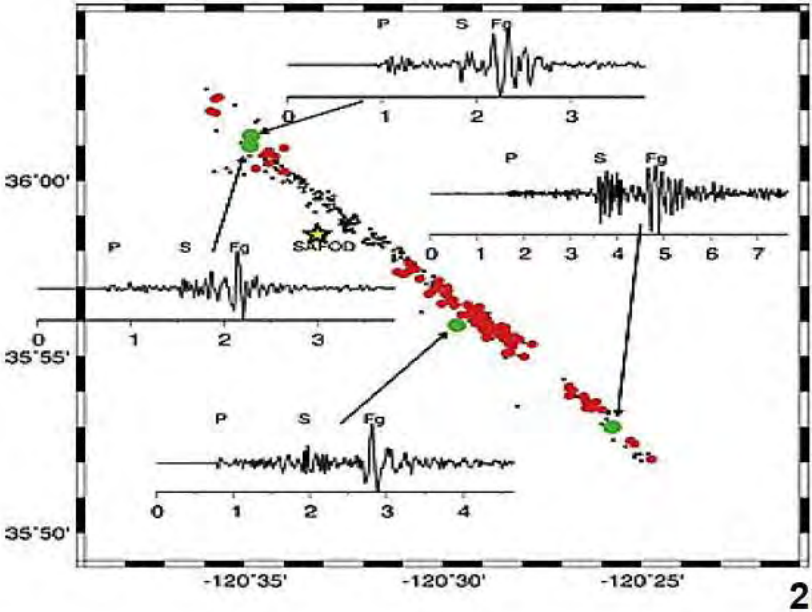
faster

fastest

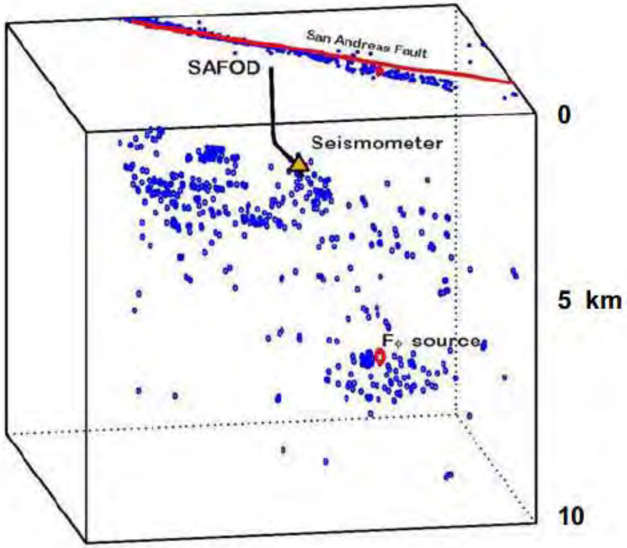
GROUP VELOCITIES

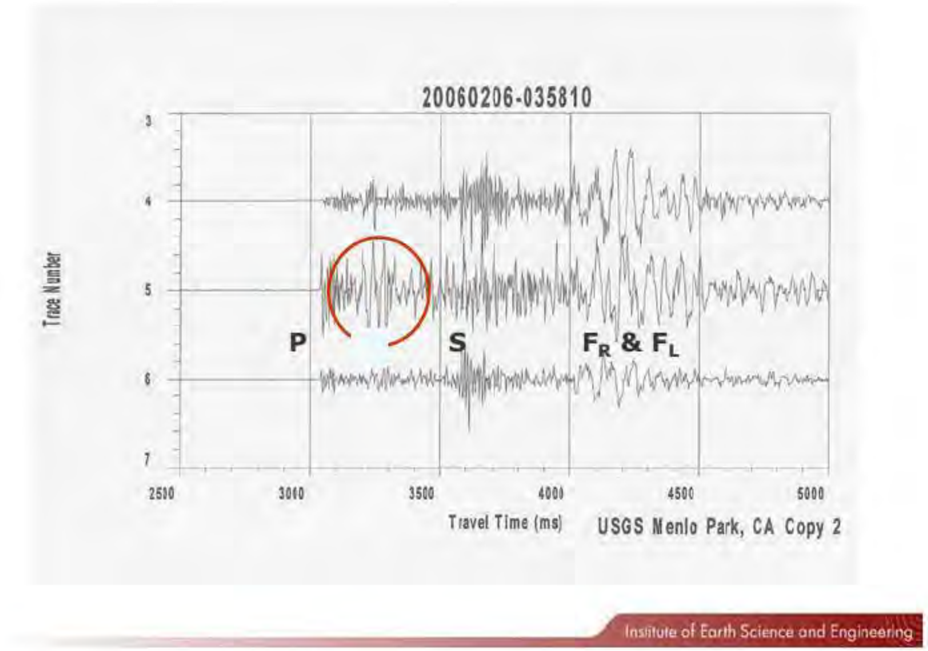
Institute of Earth Science and Engineering

Some Shallow Earthquakes Recorded in MH

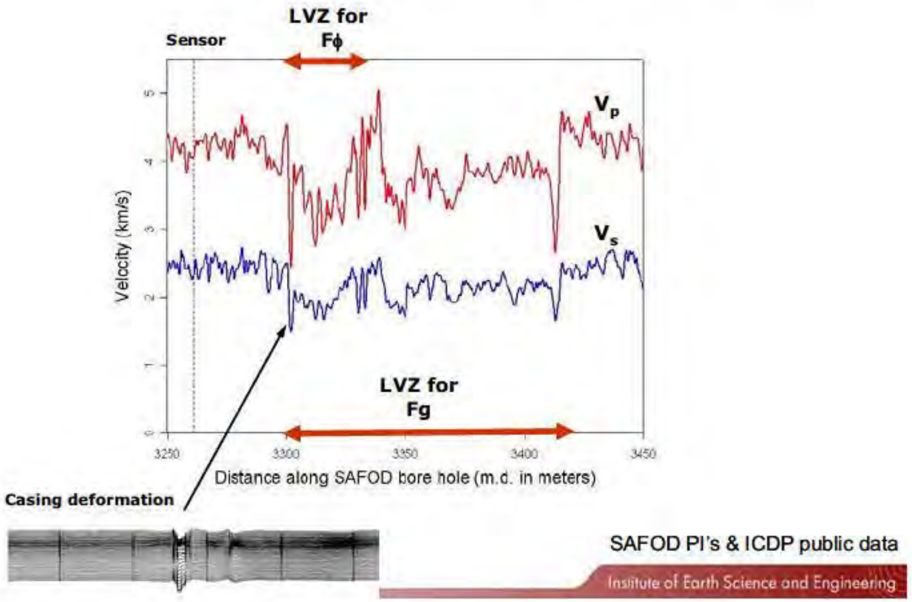


Deeper Fault Guided Wave Sources



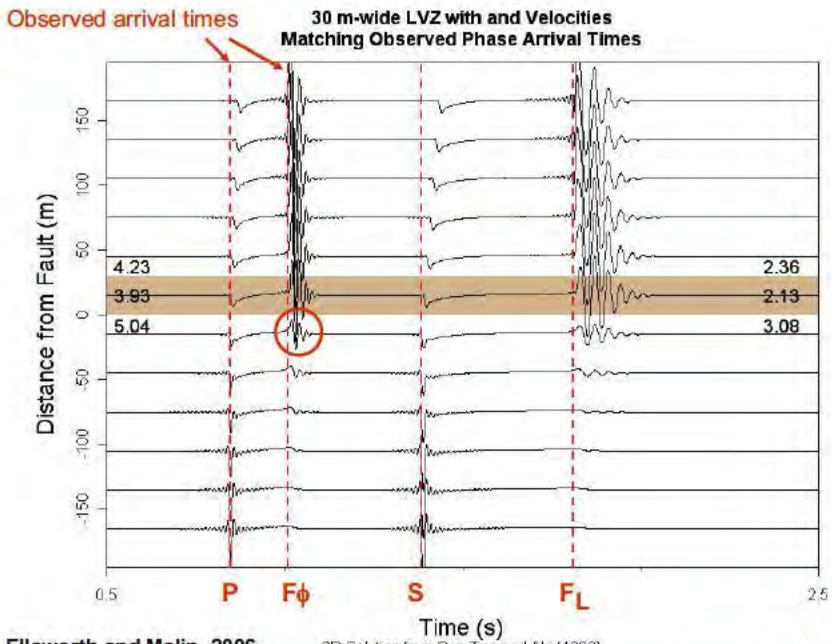


NEW WAVE TYPES ASSOCITED WITH LOW VELOCITY FAULTS



SAFOD PI's & ICDP public data

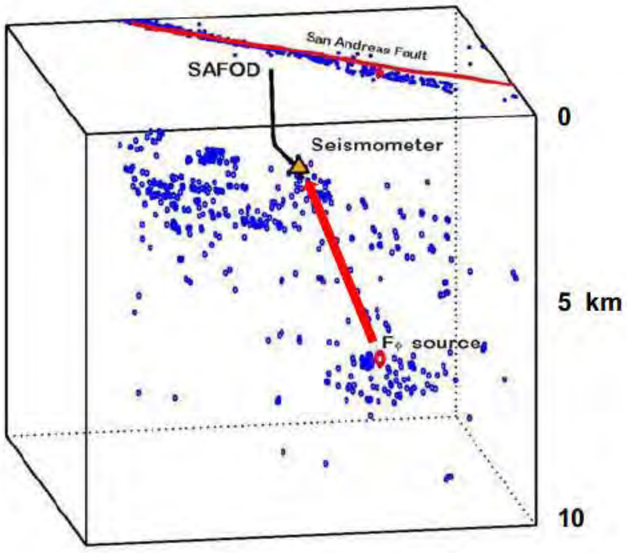
30 m-wide LVZ with and Velocities Matching Observed Phase Arrival Times



Ellsworth and Malin, 2006

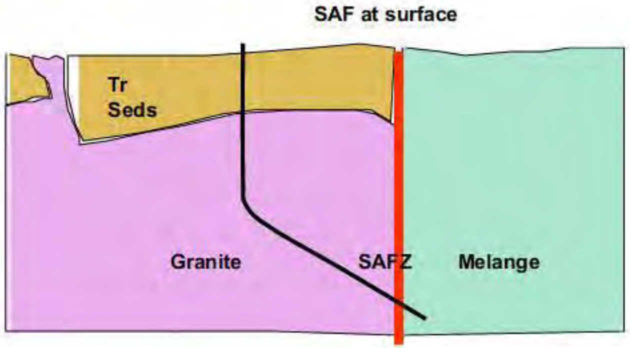
2D Solution from Ben Zion and Aki (1990)

Deeper Fault Guided Wave Sources



New Cross Section through the Parkfield San Andreas

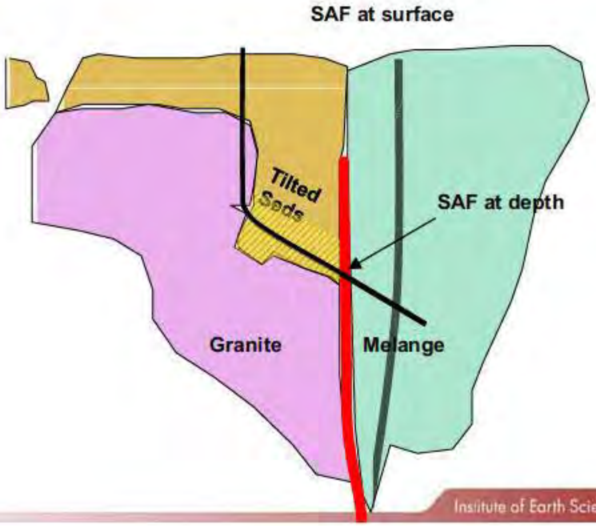
THE OLD PICTURE:



Institute of Earth Science and Engineering

New Cross Section through the Parkfield San Andreas

THE NEW PICTURE:

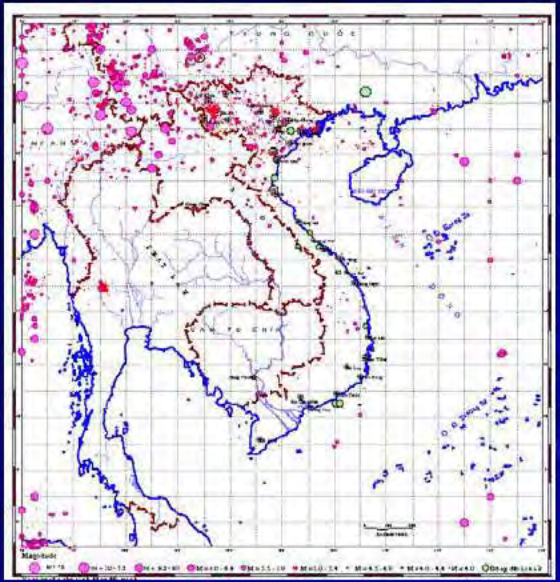


Institute of Earth Science and Engineering

On Ground Motion Evaluation and Geophysical Surveys in Vietnam

Dr. Tran Thi My Thanh

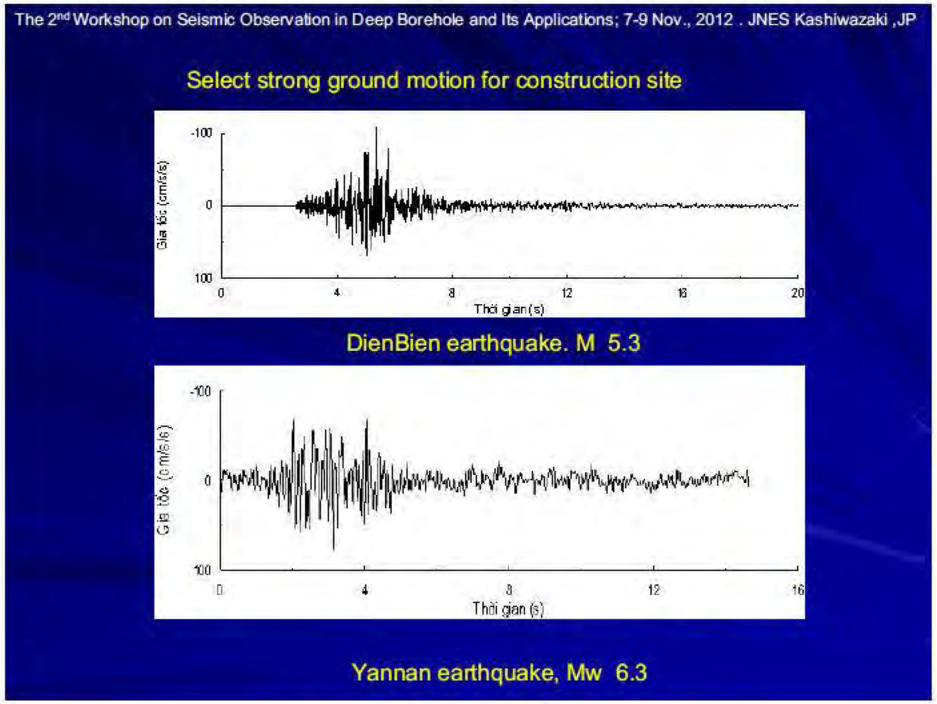
Seismology Department; Institute of Geophysics
VietNam Academy of Science and Technology



Historical seismicity (1900-2002)

(2010)

Dien Bien earthquake of M5.3 , 2001.



The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications; 7-9 Nov., 2012 . JNES Kashiwazaki ,JP

Select strong ground motion for construction site

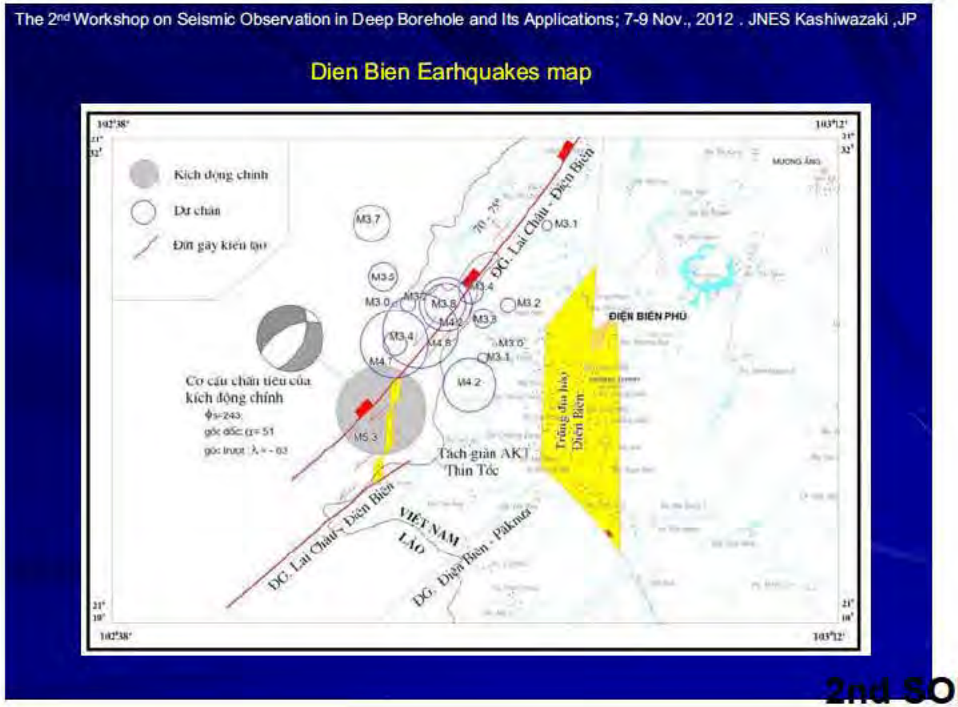
DienBien earthquake. M 5.3

Yannan earthquake, Mw 6.3

The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications; 7-9 Nov., 2012 . JNES Kashiwazaki ,JP

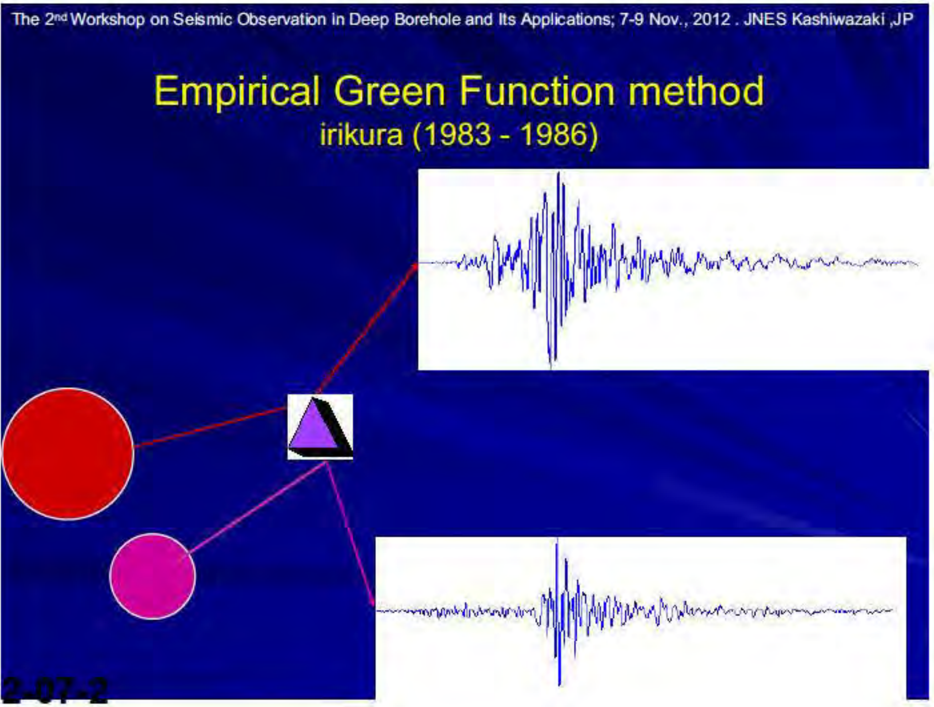
Empirical Green Function method

irikura (1983 ;1986)



The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications; 7-9 Nov., 2012 . JNES Kashiwazaki ,JP

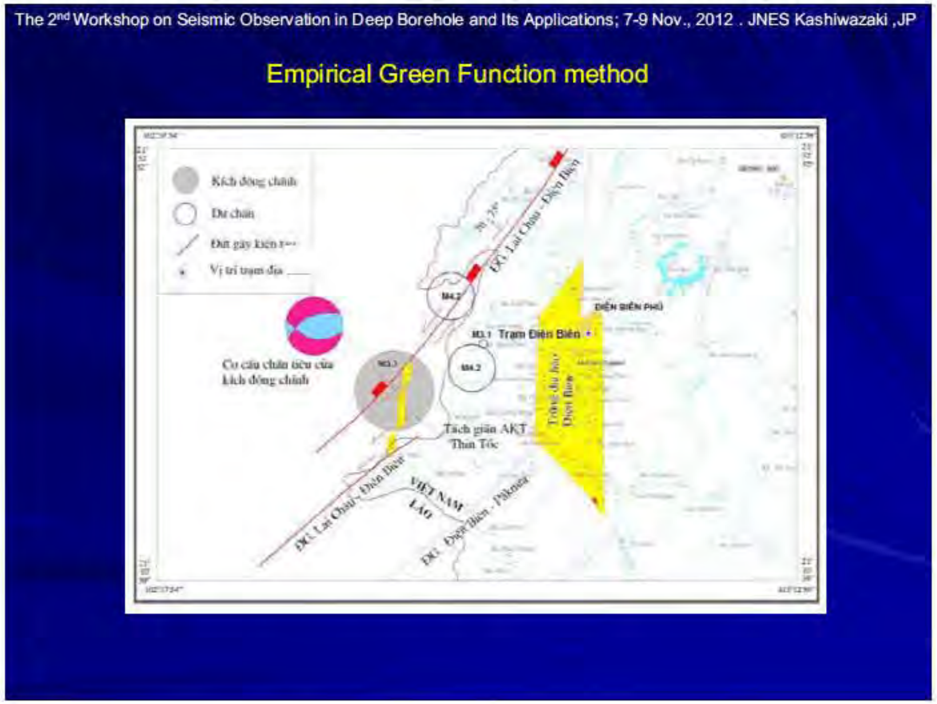
Dien Bien Earhquakes map



The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications; 7-9 Nov., 2012 . JNES Kashiwazaki ,JP

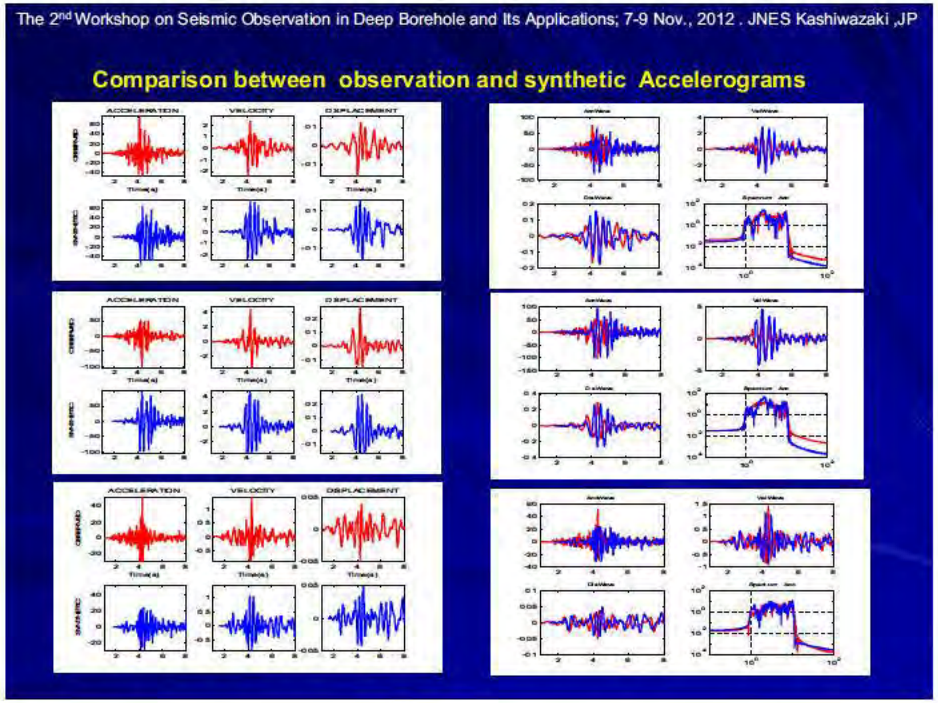
Empirical Green Function method

irikura (1983 - 1986)



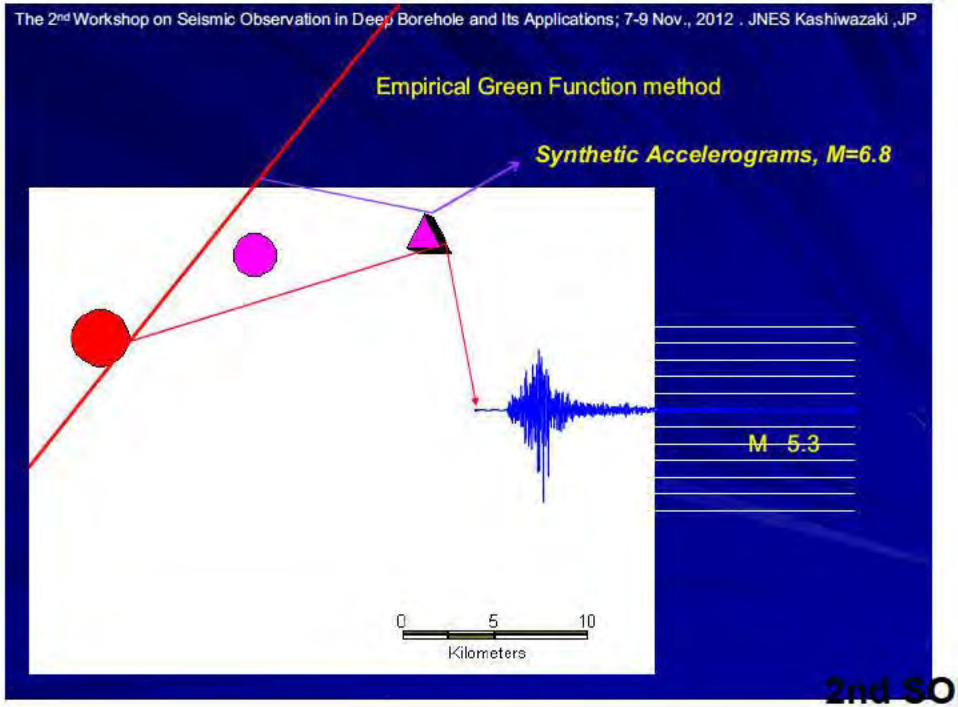
The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications; 7-9 Nov., 2012 . JNES Kashiwazaki ,JP

Empirical Green Function method



The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications; 7-9 Nov., 2012 . JNES Kashiwazaki ,JP

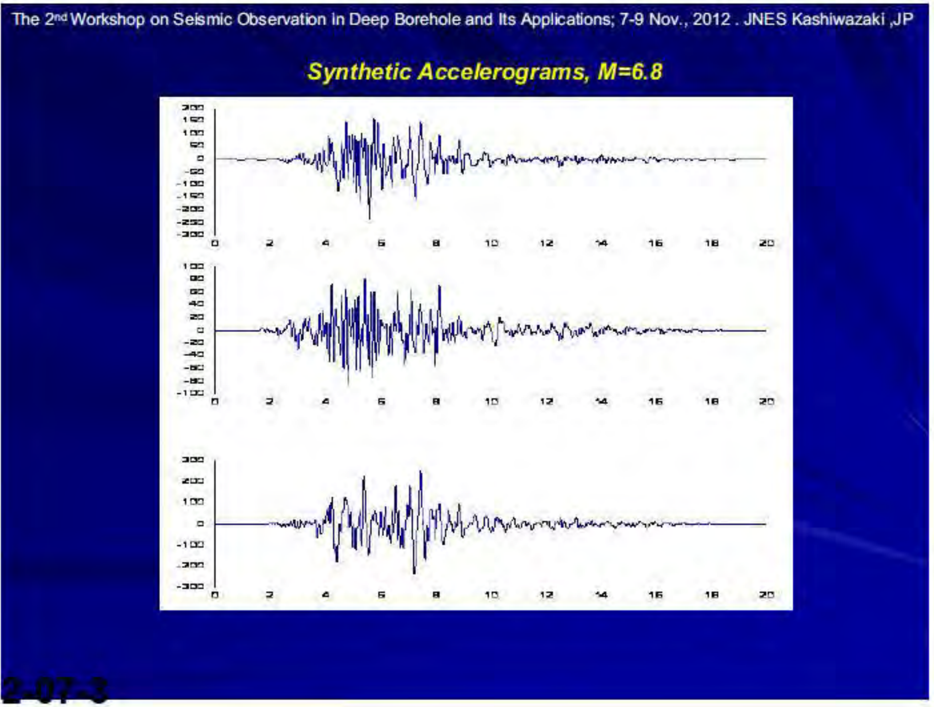
Comparison between observation and synthetic Accelerograms



The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications; 7-9 Nov., 2012 . JNES Kashiwazaki ,JP

Empirical Green Function method

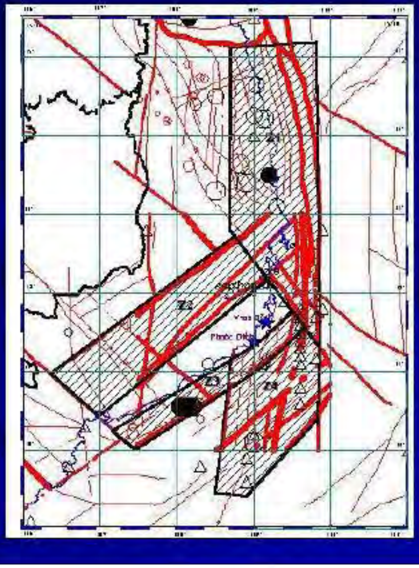
Synthetic Accelerograms, M=6.8



The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications; 7-9 Nov., 2012 . JNES Kashiwazaki ,JP

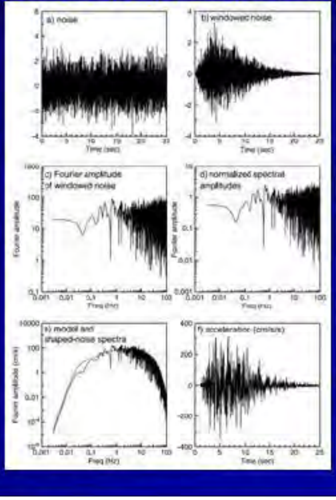
Synthetic Accelerograms, M=6.8

Seismogenic zone at Ninh Thuan NPP (2003)



However, if there were not ground motion records from previous events, the empirical Green's function method can not be applied. This is a common problem for regions with low seismicity like Vietnam.

Alternatively, we consider the Stochastic Green's function method for known active faults.



(Boore, 2003)

But, a lot of information necessary for the Stochastic Green's function method remains unknown in Vietnam…

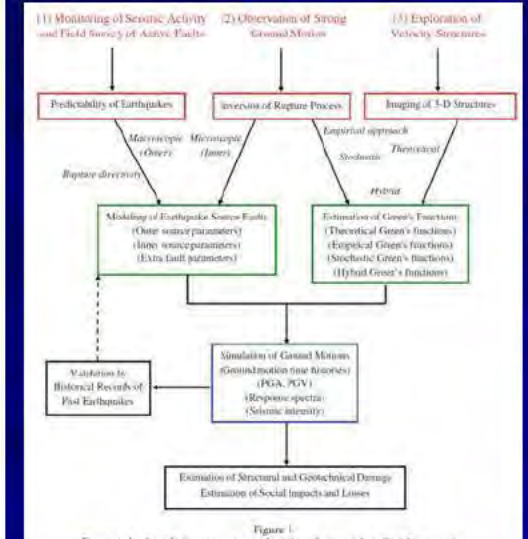


Figure 1
Framework of predicting strong ground motions for crustal earthquake scenarios

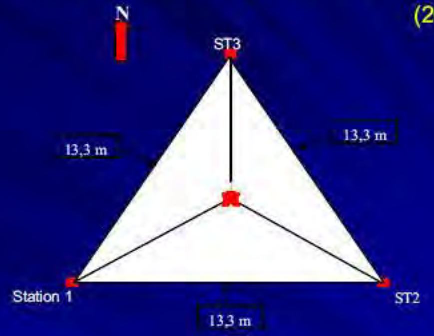
1. How to define the fault length?
2. More difficultly, how to define the fault width? Not sufficient earthquake events to constrain the depths to the top /bottom of the seismogenic zone.
3. Do inner source parameters of earthquakes in Vietnam follow the same relationships with those in Japan?
4. A reliable structure model?
5. How to evaluate the site effects in lack of data?

(Irikura & Miyake, 2010)

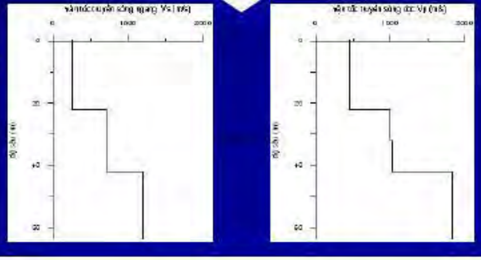
Application of the SPAC method in Vietnam

(2005-2006)

Observation Array



Structure Models Estimated



The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications; 7-9 Nov., 2012 . JNES Kashiwazaki ,JP

Plan outline for geophysical/seismic/geological surveys

To determine reliable values for Vs & Vp;

- Deep structure : crust & mantle
- Surface layers: site effects

To estimate the attenuation Quality: Q-vaule;

The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications; 7-9 Nov., 2012 . JNES Kashiwazaki ,JP

THANK YOU !

The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications; 7-9 Nov., 2012 . JNES Kashiwazaki ,JP

DEEP BOREHOLE SEISMOLOGY IN VIETNAM: NEEDS AND CHALLENGES

Nguyen Hong Phuong
Earthquake Information and Tsunami Warning Center
Institute of Geophysics, VAST

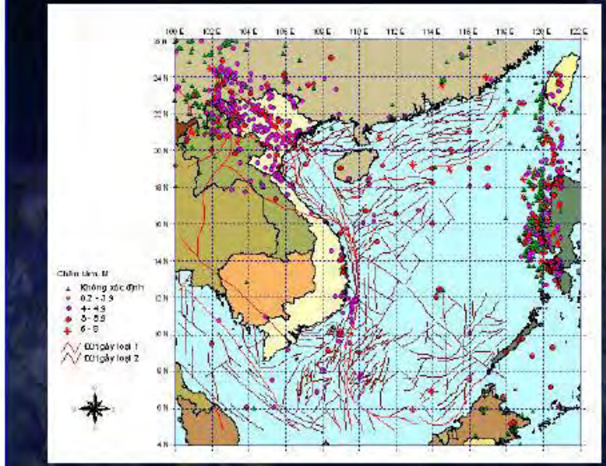
OUTLINE

- **Motivation**
- **Seismic Hazard in Vietnam**
- **Urban seismic risk assessment: Hanoi case**
- **Discussion**

MOTIVATION

- To date, the deep borehole seismology technique has never been used in Vietnam. The only deep borehole application is in the field of oil and gas exploration.
- Through an example of urban seismic risk assessment for Hanoi city, we would like to share some thoughts about the possibility of the application of Deep Borehole Seismology in Vietnam.

SEISMIC HAZARD IN VIETNAM



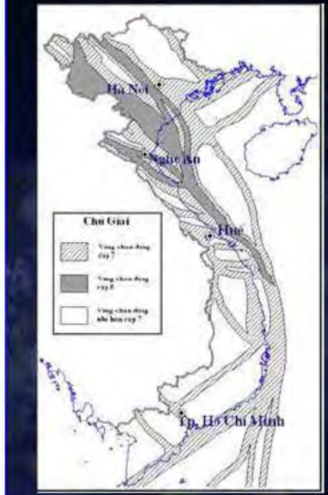
Seismotectonic map of Vietnam and adjacent sea areas

- The largest earthquakes in country: 3
  - -1 historical (in the 14th century)
  - - 2 recorded:
  - -Dien Bien 1935 (M 6.7) and Tuan Giao 1983 (M 6.8)
- Offshore volcanic earthquake 1923 (M 6.1).

SEISMIC HAZARD IN VIETNAM

The Tuan Giao earthquake,1983 (M 6.8)

URBAN SEISMIC RISK ASSESSMENT

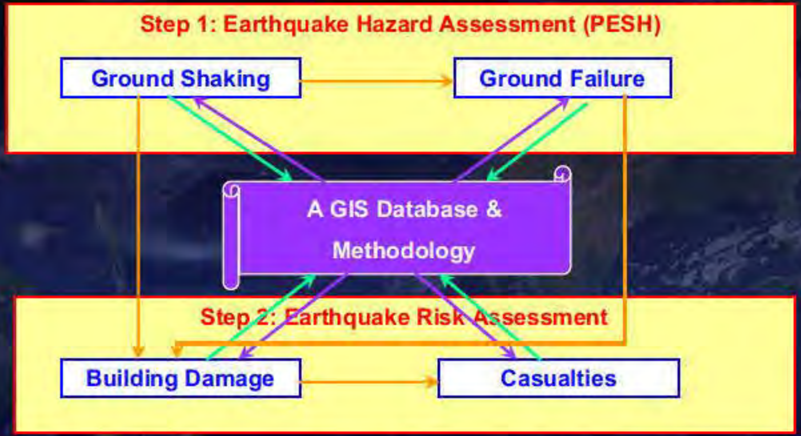


- Hanoi, the capital of Vietnam, with population over 3 million people, and an area 920.97 km² is laying in the zone of Intensity 8 (MSK-64) in the seismic zoning map of Vietnam.
- Since 2001, several projects on urban seismic risk have been carried out for megacities of Vietnam, including Hanoi, using scenario-based approach.

Nguyễn Hồng Phương
Institute of Geophysics,

URBAN SEISMIC RISK ASSESSMENT

PROCEDURE



Step 1: Earthquake Hazard Assessment (PESH)

Ground Shaking

Ground Failure

A GIS Database & Methodology

Step 2: Earthquake Risk Assessment

Building Damage

Casualties

Nguyễn Hồng Phương
Institute of Geophysics,

URBAN SEISMIC RISK ASSESSMENT

GIS TOOL: A Decision Support System

1. Define the study region

2. Define an earthquake scenario

3. Ground motion assessment

4. Ground failure assessment

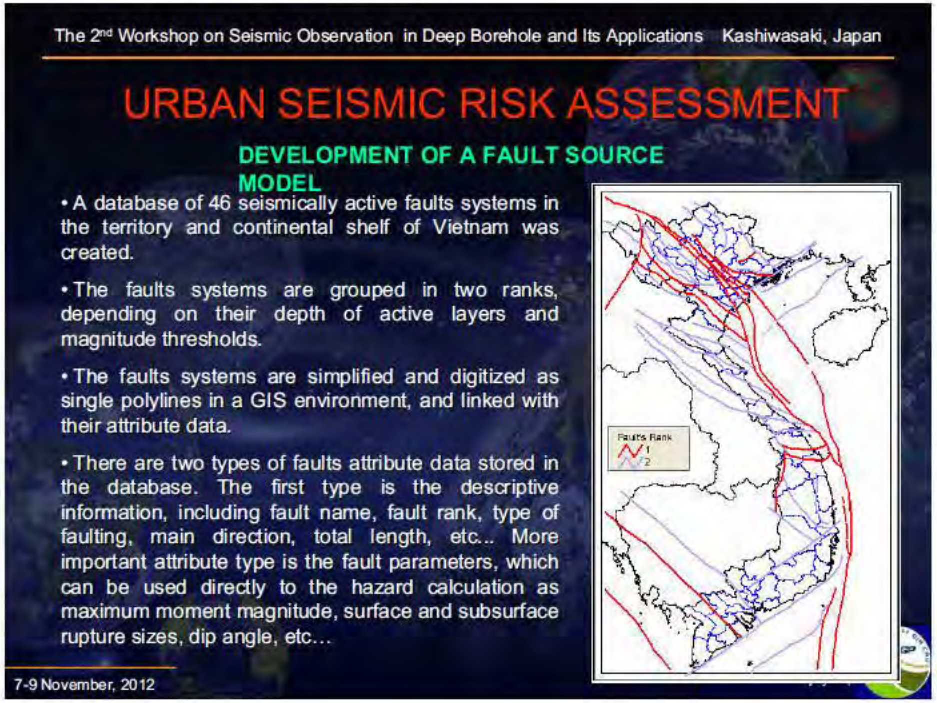
5. Damage and loss estimation

Demographic data inventory and vulnerability

Decision making: *Earthquake disaster reduction planning*

- Preparedness
- Emergency response
- Recovery

Nguyễn Hồng Phương
Institute of Geophysics,



The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications Kashiwasaki, Japan

URBAN SEISMIC RISK ASSESSMENT

DEVELOPMENT OF A FAULT SOURCE MODEL

- A database of 46 seismically active faults systems in the territory and continental shelf of Vietnam was created.
- The faults systems are grouped in two ranks, depending on their depth of active layers and magnitude thresholds.
- The faults systems are simplified and digitized as single polylines in a GIS environment, and linked with their attribute data.
- There are two types of faults attribute data stored in the database. The first type is the descriptive information, including fault name, fault rank, type of faulting, main direction, total length, etc... More important attribute type is the fault parameters, which can be used directly to the hazard calculation as maximum moment magnitude, surface and subsurface rupture sizes, dip angle, etc…

7-9 November, 2012

The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications Kashiwasaki, Japan

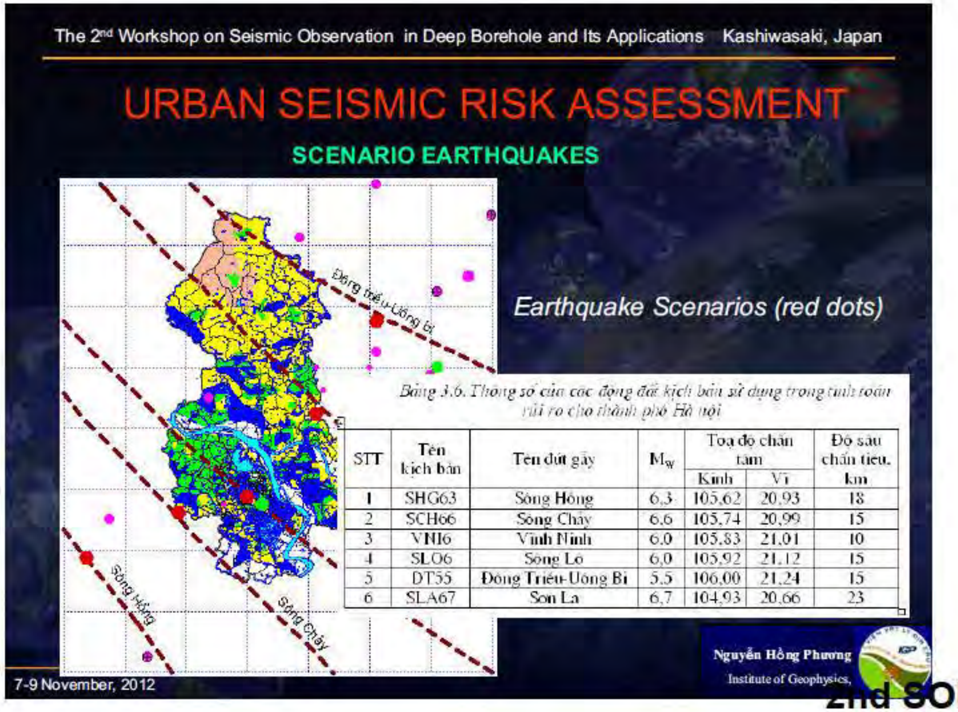
URBAN SEISMIC RISK ASSESSMENT

SCENARIO EARTHQUAKES

Fault-source model was applied to define scenario earthquakes to be used in seismic risk assessment.

Nguyễn Hồng Phương
Institute of Geophysics,

7-9 November, 2012



The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications Kashiwasaki, Japan

URBAN SEISMIC RISK ASSESSMENT

SCENARIO EARTHQUAKES

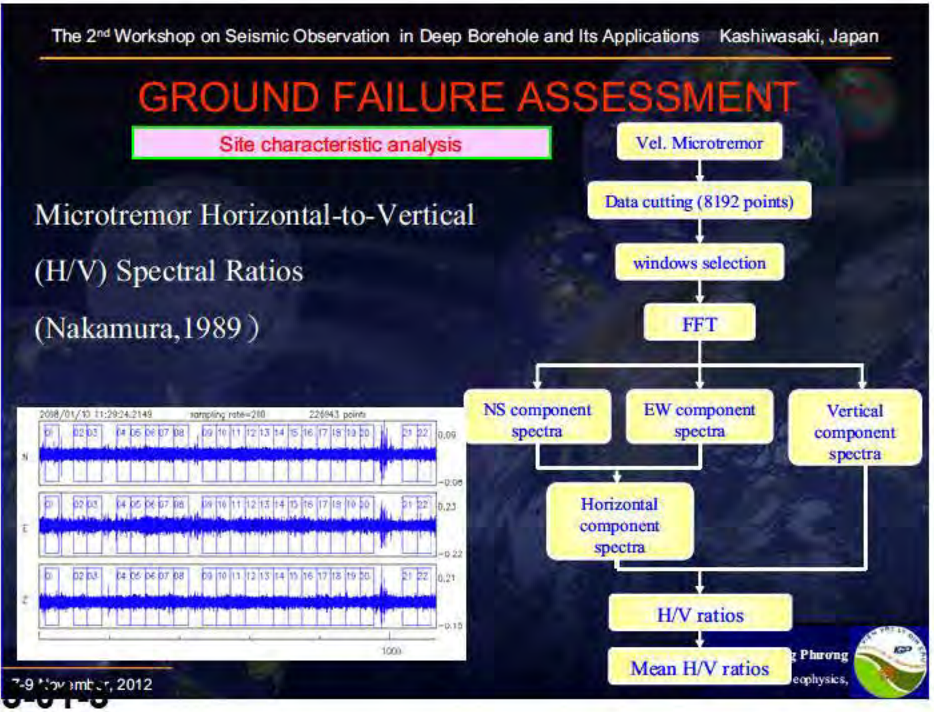
Earthquake Scenarios (red dots)

Bảng 3.6. Thông số của các động đất kịch bản sử dụng trong tính toán rủi ro cho thành phố Hà nội

STT	Tên kịch bản	Tên đứt gãy	M_W	Toạ độ chấn tâm		Độ sâu chấn tiêu, km
				Kinh	Vĩ	
1	SHG63	Sông Hồng	6,3	105,62	20,93	18
2	SCH66	Sông Chảy	6,6	105,74	20,99	15
3	VNI6	Vĩnh Ninh	6,0	105,83	21,01	10
4	SLO6	Sông Lô	6,0	105,92	21,12	15
5	DT55	Đông Triều-Uông Bí	5,5	106,00	21,24	15
6	SLA67	Sơn La	6,7	104,93	20,66	23

Nguyễn Hồng Phương
Institute of Geophysics,

7-9 November, 2012



The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications Kashiwasaki, Japan

GROUND FAILURE ASSESSMENT

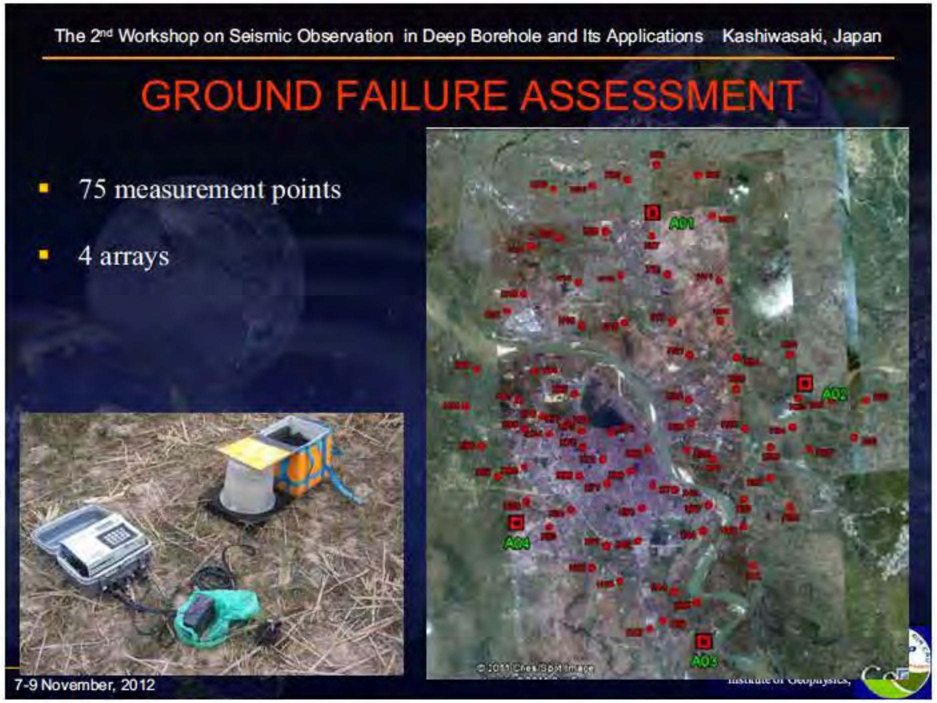
Site characteristic analysis

Microtremor Horizontal-to-Vertical (H/V) Spectral Ratios (Nakamura,1989)

Vel. Microtremor
Data cutting (8192 points)
windows selection
FFT
NS component spectra
EW component spectra
Vertical component spectra
Horizontal component spectra
H/V ratios
Mean H/V ratios

Phương
eophysics,

7-9 November, 2012



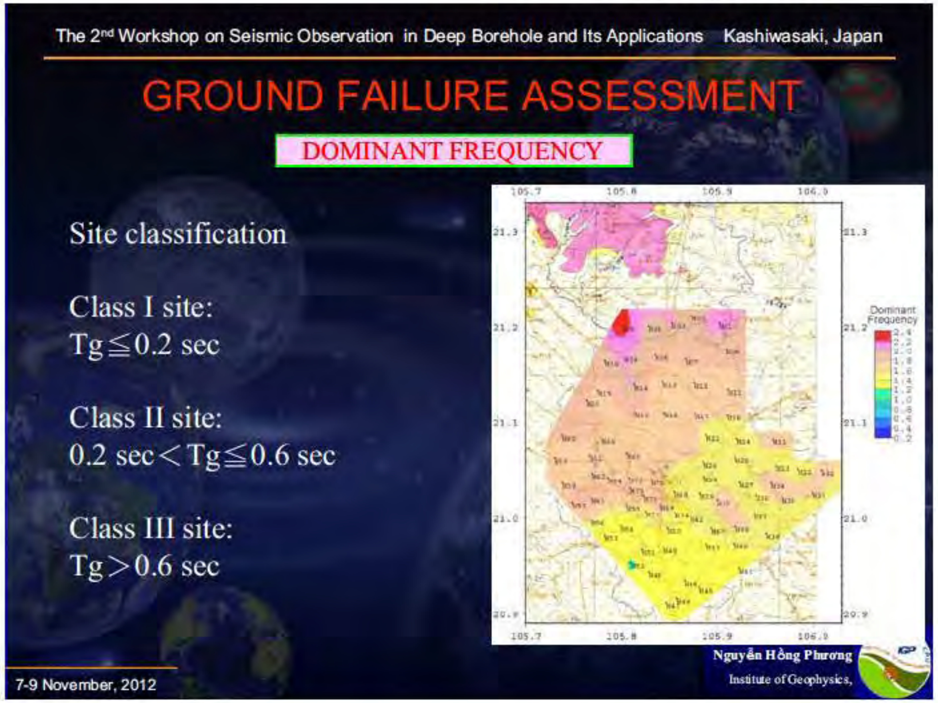
The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications Kashiwasaki, Japan

GROUND FAILURE ASSESSMENT

- 75 measurement points
- 4 arrays

Institute of Geophysics,

7-9 November, 2012



The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications Kashiwasaki, Japan

GROUND FAILURE ASSESSMENT

DOMINANT FREQUENCY

Site classification

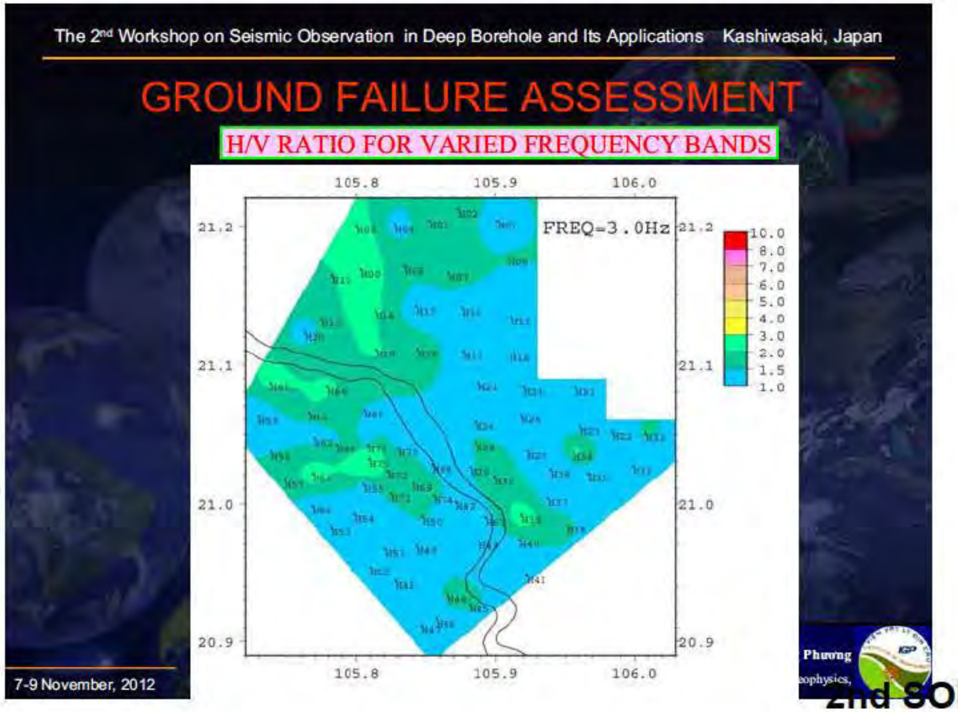
Class I site:
Tg≦0.2 sec

Class II site:
0.2 sec＜Tg≦0.6 sec

Class III site:
Tg＞0.6 sec

Nguyễn Hồng Phương
Institute of Geophysics,

7-9 November, 2012



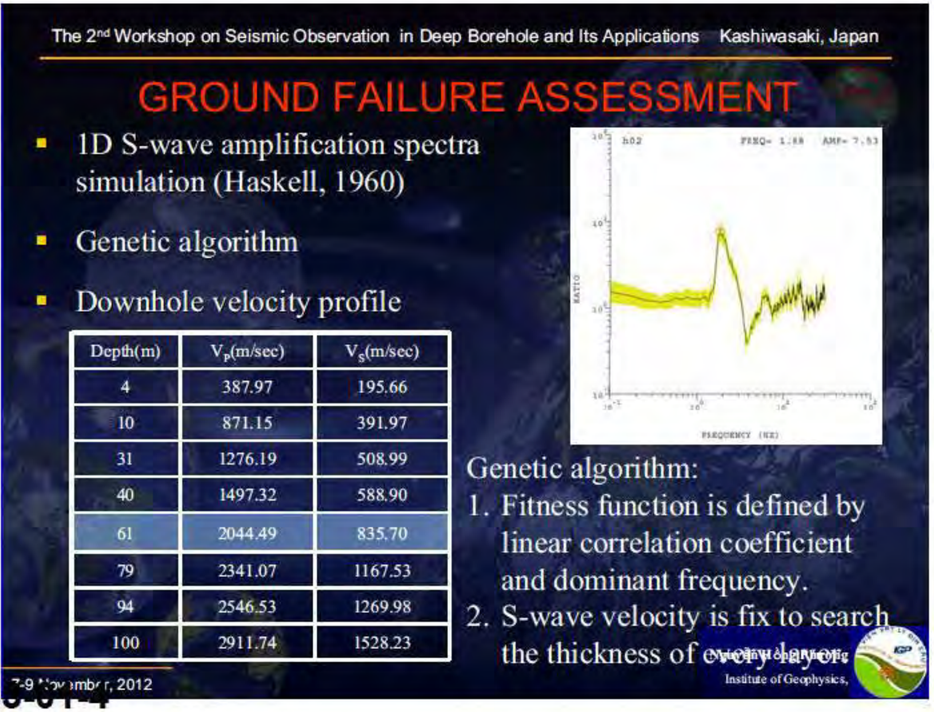
The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications Kashiwasaki, Japan

GROUND FAILURE ASSESSMENT

H/V RATIO FOR VARIED FREQUENCY BANDS

Phuong
ophysics,

7-9 November, 2012



The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications Kashiwasaki, Japan

GROUND FAILURE ASSESSMENT

- 1D S-wave amplification spectra simulation (Haskell, 1960)
- Genetic algorithm
- Downhole velocity profile

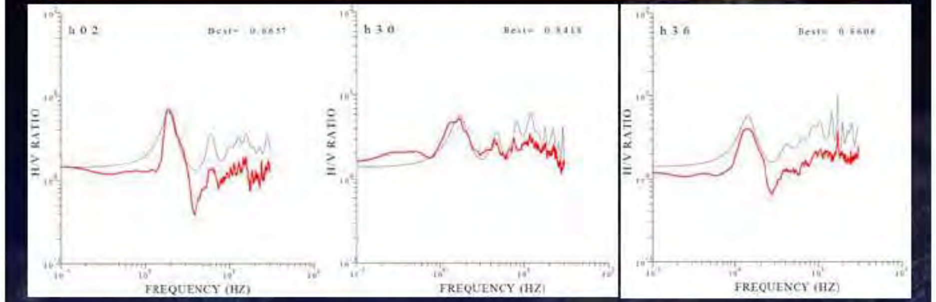
Depth(m)	V_p(m/sec)	V_s(m/sec)
4	387.97	195.66
10	871.15	391.97
31	1276.19	508.99
40	1497.32	588.90
61	2044.49	835.70
79	2341.07	1167.53
94	2546.53	1269.98
100	2911.74	1528.23

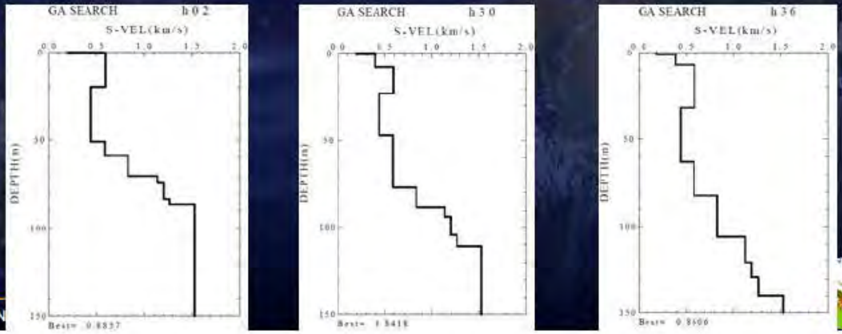
Genetic algorithm:
1. Fitness function is defined by linear correlation coefficient and dominant frequency.
2. S-wave velocity is fix to search the thickness of every layer.

Institute of Geophysics,

7-9 November, 2012

The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications Kashiwasaki, Japan



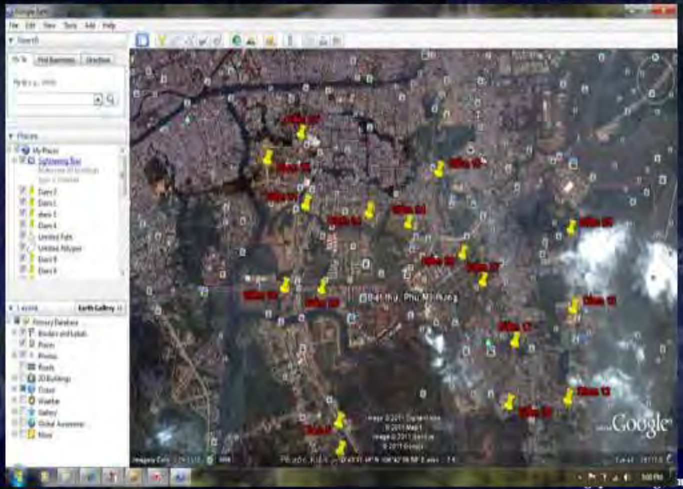


7-9 N

The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications Kashiwasaki, Japan

GROUND FAILURE ASSESSMENT

SEISMIC REFRACTION MEASUREMENTS



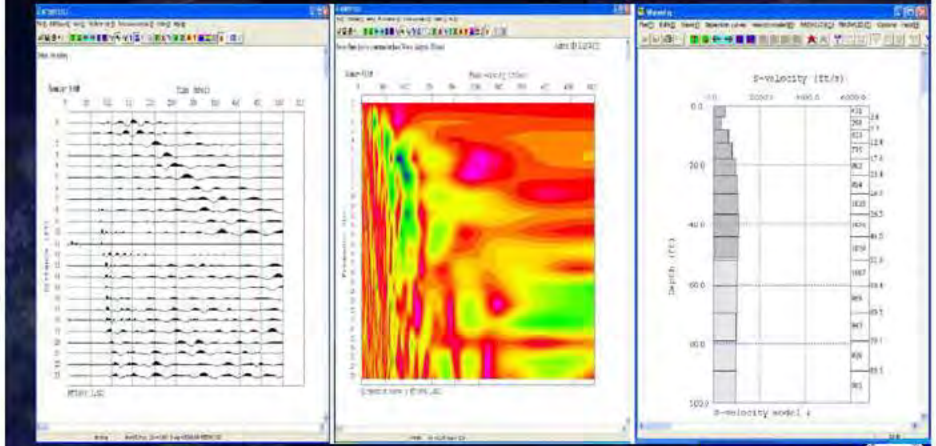
7-9 November, 2012

ương
Institute of Geophysics,

The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications Kashiwasaki, Japan

GROUND FAILURE ASSESSMENT

SEISMIC REFRACTION MEASUREMENTS



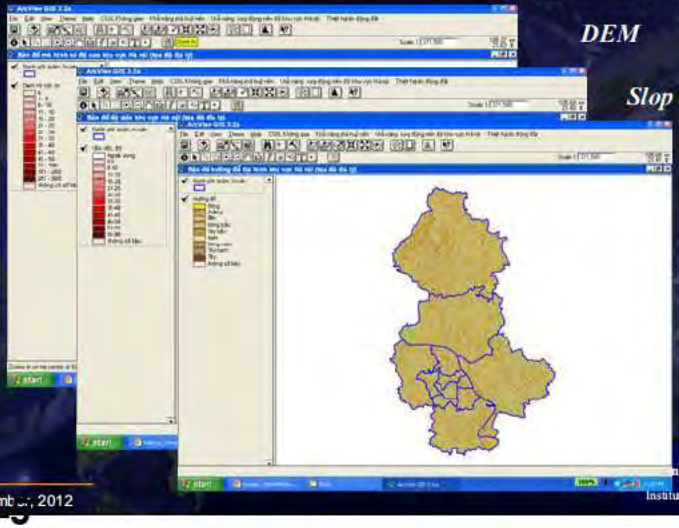
Nguyễn Hồng Phương
Institute of Geophysics,

7-9 November, 2012

The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications Kashiwasaki, Japan

GROUND FAILURE ASSESSMENT

INPUT LAYERS



DEM

Slop map

Aspect map

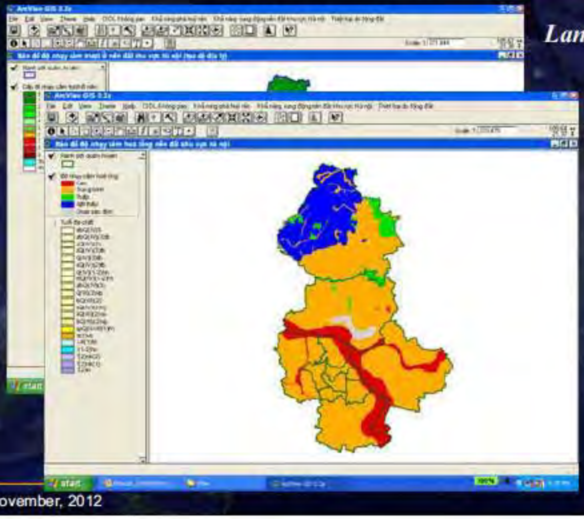
n Hồng Phương
Institute of Geophysics,

7-9 November, 2012

The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications Kashiwasaki, Japan

GROUND FAILURE ASSESSMENT

RESULTS: THEMATIC MAPS



Landslide susceptibility

Liquefaction susceptibility

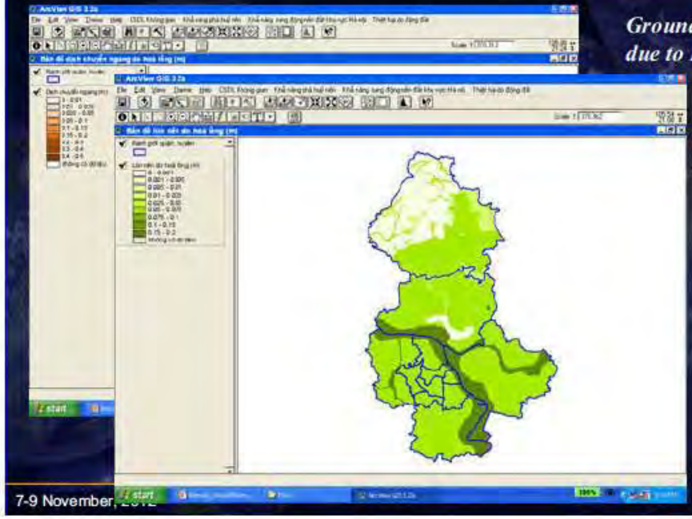
Nguyễn Hồng Phương
Institute of Geophysics,

7-9 November, 2012

The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications Kashiwasaki, Japan

GROUND FAILURE ASSESSMENT

RESULTS: THEMATIC MAPS



Ground lateral spreading due to Liquefaction

Ground settlement due to Liquefaction

Nguyễn Hồng Phương
Institute of Geophysics,

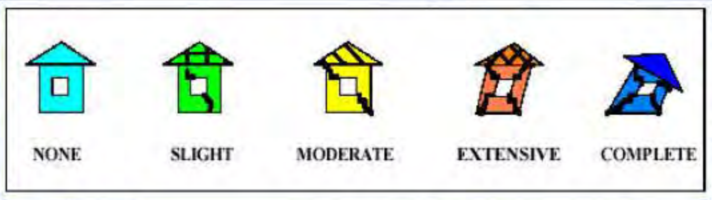
7-9 November, 2012

The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications Kashiwasaki, Japan

LOSS ESTIMATION

BUILDING DAMAGE

- Elements at Risk : 1) Buildings
- Building damage: 5 states (None, Slight, Moderate, Extensive and Complete)



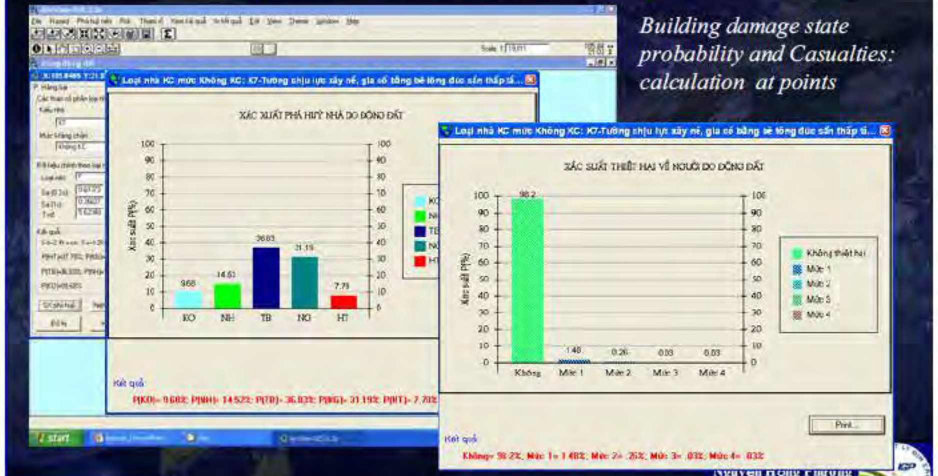
Nguyễn Hồng Phương
Institute of Geophysics,

7-9 November, 2012

The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications Kashiwasaki, Japan

LOSS ESTIMATION

BUILDING DAMAGE



Kết quả
P(KO)= 9.68%; P(NH)= 14.52%; P(TB)= 36.83%; P(NG)= 31.19%; P(HT)= 7.70%

Kết quả
Không= 98.2%; Mức 1= 1.48%; Mức 2= .26%; Mức 3= .03%; Mức 4= .03%

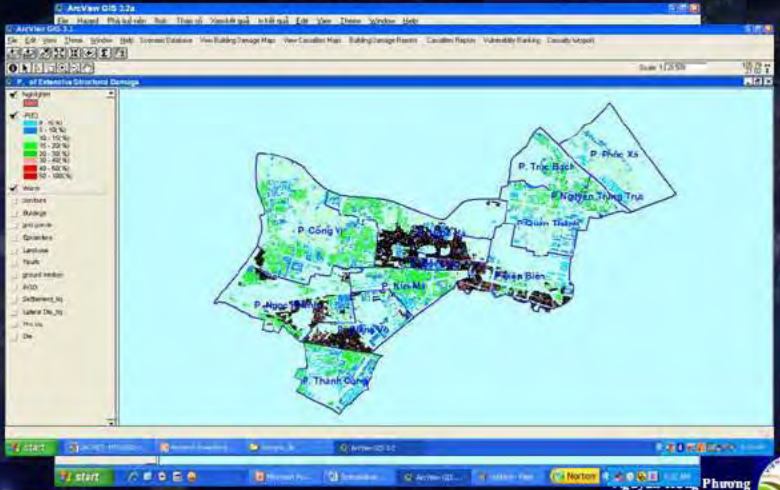
Building damage state probability and Casualties: calculation at points

Nguyễn Hồng Phương
Institute of Geophysics,

7-9 November, 2012

LOSS ESTIMATION

BUILDING DAMAGE



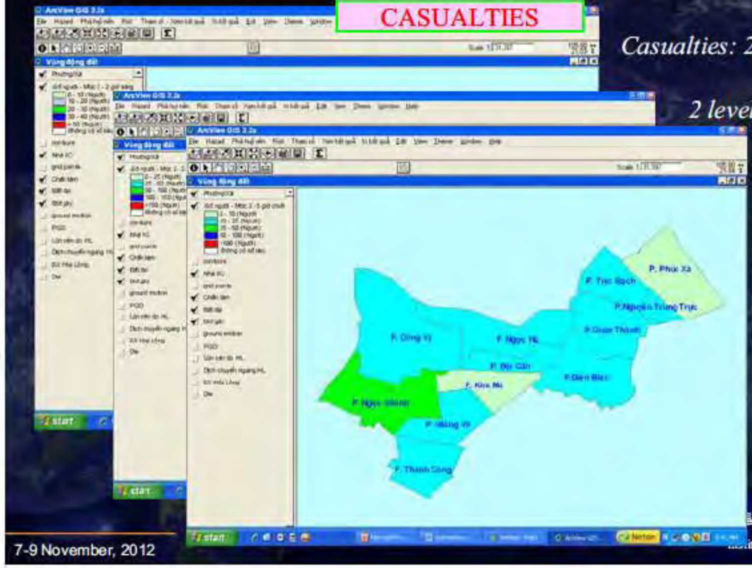
LOSS ESTIMATION

CASUALTIES

- Elements at Risk: 2) People
- Casualties: 4 severity levels, at 2 am, 2 pm and 5 pm

LOSS ESTIMATION

CASUALTIES



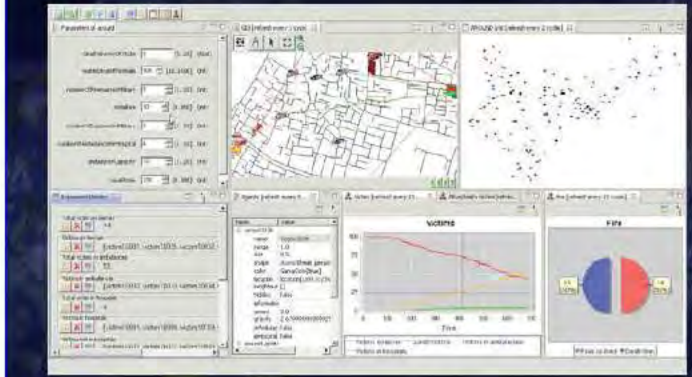
Casualties: 2 level, at 2 am

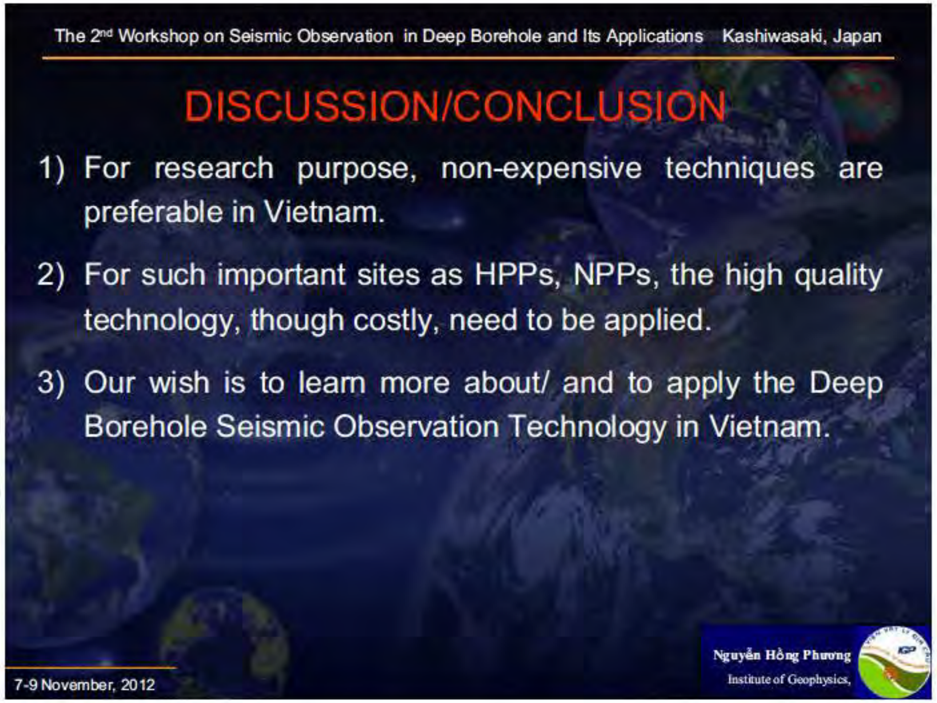
2 level, at 2 pm

2 level, at 5 pm

EMERGENCY RESPONSE

- Coupling GIS and simulation: ArcRisk and GAMA (Gis & Agent-based Modeling Architecture)
- Search and Rescue Tools in a DSS





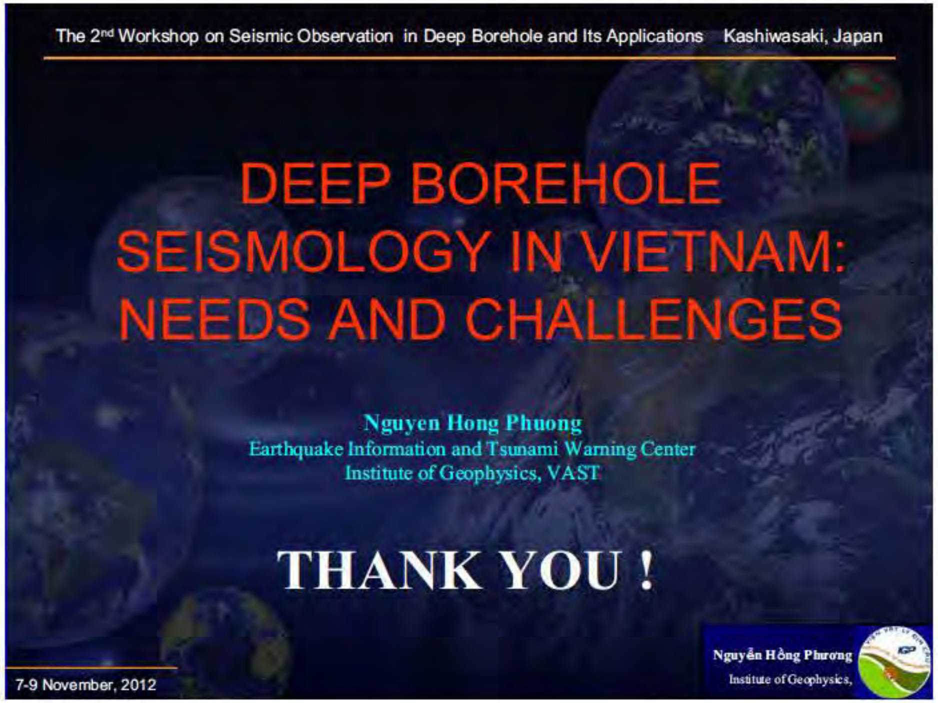
The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications Kashiwasaki, Japan

DISCUSSION/CONCLUSION

1) For research purpose, non-expensive techniques are preferable in Vietnam.
2) For such important sites as HPPs, NPPs, the high quality technology, though costly, need to be applied.
3) Our wish is to learn more about/ and to apply the Deep Borehole Seismic Observation Technology in Vietnam.

7-9 November, 2012

Nguyễn Hồng Phương
Institute of Geophysics,



The 2nd Workshop on Seismic Observation in Deep Borehole and Its Applications Kashiwasaki, Japan

DEEP BOREHOLE SEISMOLOGY IN VIETNAM: NEEDS AND CHALLENGES

Nguyen Hong Phuong
Earthquake Information and Tsunami Warning Center
Institute of Geophysics, VAST

THANK YOU !

7-9 November, 2012

Nguyễn Hồng Phương
Institute of Geophysics,

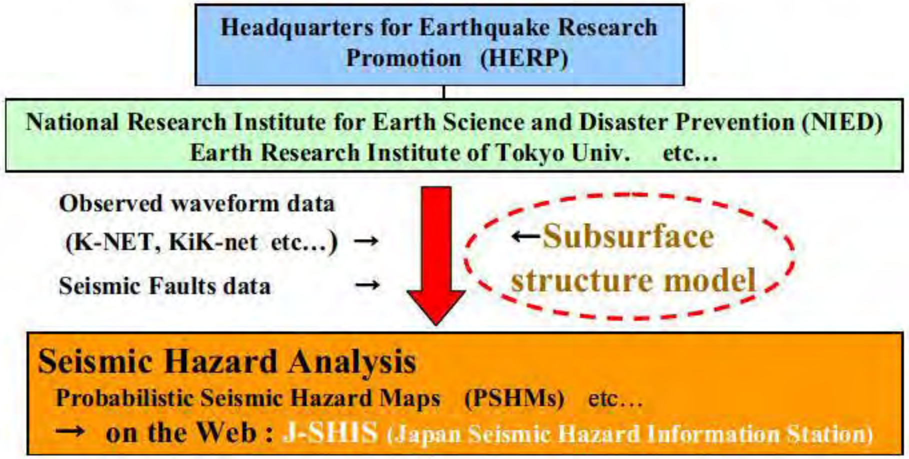
Construction method and application of 3D velocity model for evaluation of strong seismic motion and its cost performance

Hisanori MATSUYAMA (OYO Corporation)
Hiroyuki FUJIWARA(NIED)

Contents of presentation

1. about 3-D Subsurface Models for seismic hazard analysis.
   objectives and characters of the subsurface model
2. about modeling method and used data.
   properties and comparisons of each other.
3. conclusions

Objective of the subsurface structure Model



Headquarters for Earthquake Research Promotion (HERP)

National Research Institute for Earth Science and Disaster Prevention (NIED)
Earth Research Institute of Tokyo Univ. etc…

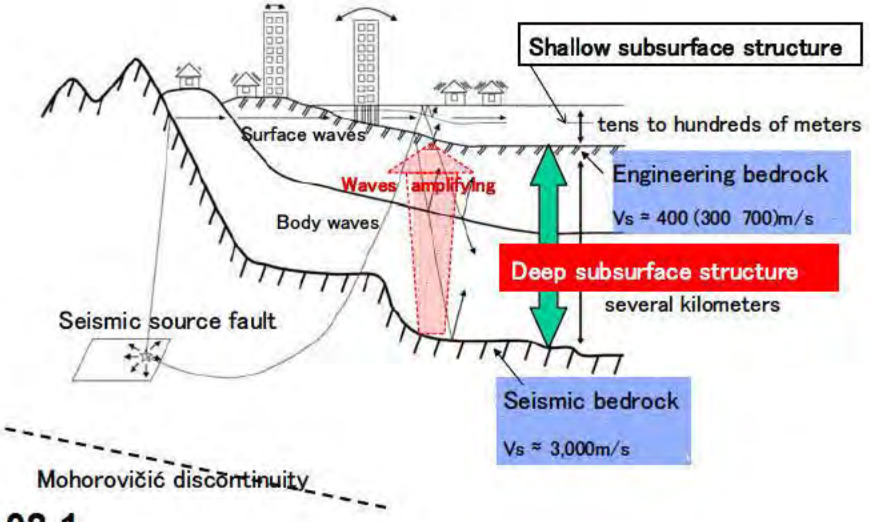
Observed waveform data (K-NET, KiK-net etc…) →
Seismic Faults data →

←Subsurface structure model

Seismic Hazard Analysis
Probabilistic Seismic Hazard Maps (PSHMs) etc…
→ on the Web : J-SHIS (Japan Seismic Hazard Information Station)

"strengthening disaster prevention measures, particularly for the reduction of damage and casualties from earthquakes "

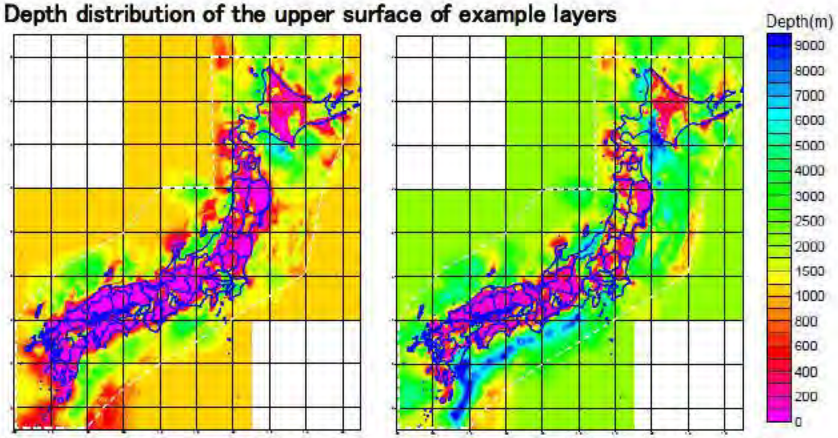
Schematic overview of the subsurface structure models



2nd SODB WS S3-02-1

Deep subsurface structure model

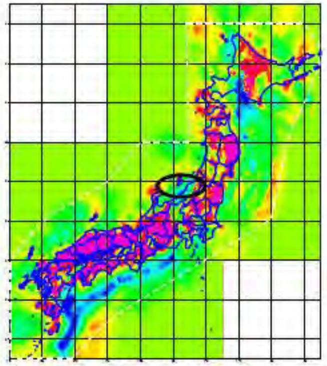
Depth distribution of the upper surface of example layers



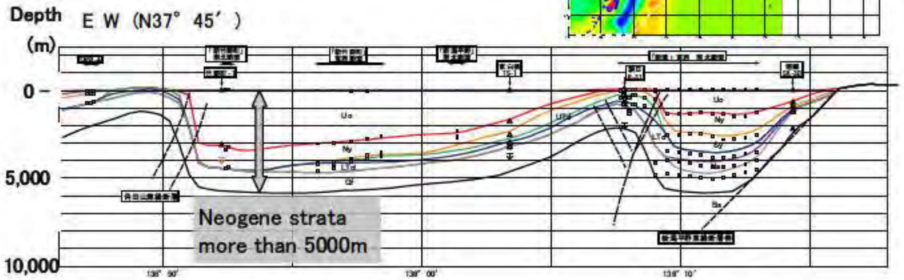
Upper surface of layer of Vs 2.1km/s

Upper surface of the seismic bedrock

Deep subsurface structure model



Profile in Niigata area

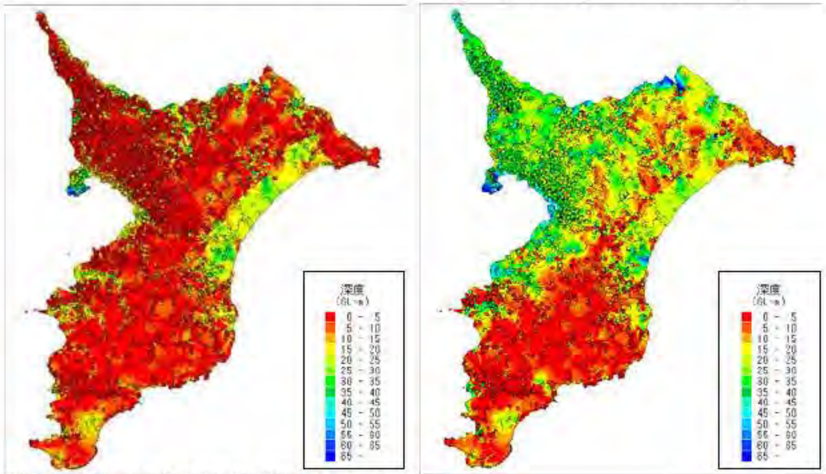


Neogene strata more than 5000m

Shallow subsurface sturcture models: Depth contours of upper surfaces of layers

Holocene marine clay

Engineering bedrocks (almostly N-values >50)



※In areas of absence of marine clay, data of "0m" are shown as dummies.

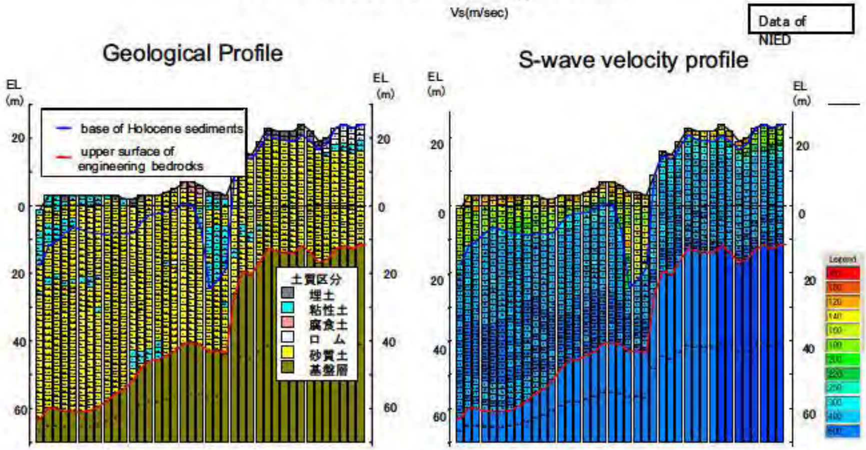
Data of NIED

Shallow subsurface sturcture models : Profiles of the ground

Data of NIED

Geological Profile

S-wave velocity profile



With Deep subsurface structure model , these Shallow ones are used for Strong-motion Evaluation **(1st-order model)**

Data for making of 3D subsurface structure model

○ Geological data : maps, profiles, deep borehole

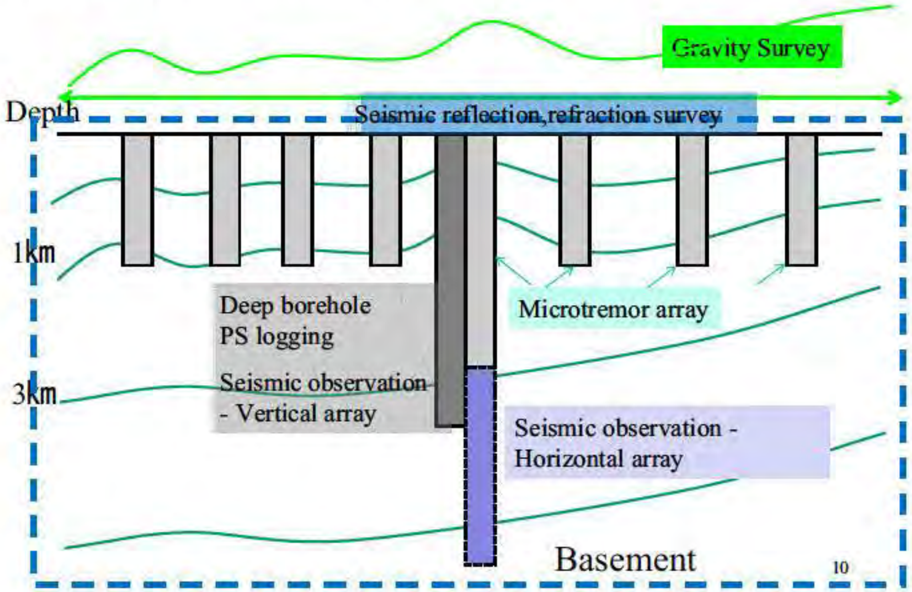
○ Geophysical exploration data

- ･contorolled source
  PS-logging, seismic reflection survey,
  seismic refraction survey
- ･gravity survey
- ･micro-tremor survey

○ Observed seismic data

seismometer ground surface, in-borehole,
K-NET, KiK-net, F-net (NIED) : all over Japan

Target of each survey : deep subsurface structure



Gravity Survey

Seismic reflection,refraction survey

Depth

1km

3km

Deep borehole
PS logging

Seismic observation
- Vertical array

Microtremor array

Seismic observation -
Horizontal array

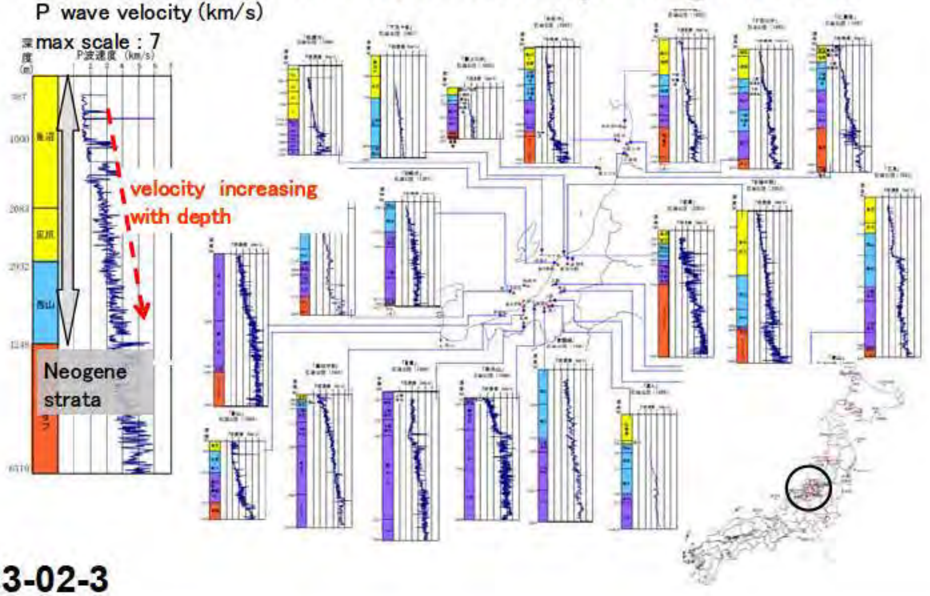
Basement

Points of Deep ,shallow Boring

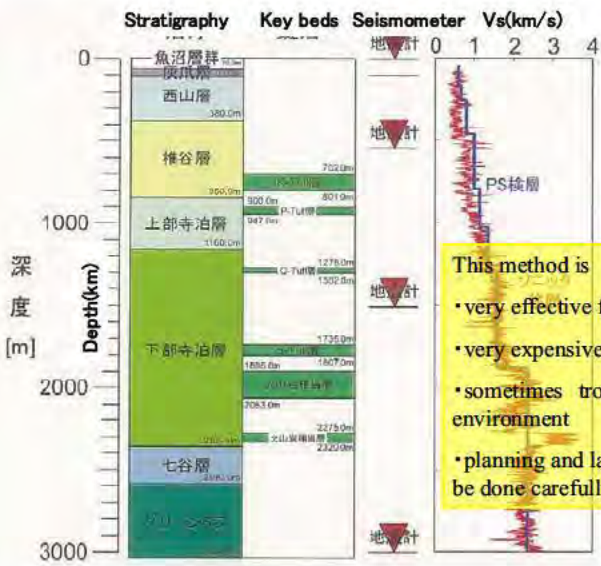
H. Fujiwara et al(2009): A Study on Subsurface Structure Model for Deep Sedimentary layers of Japan for Strong motion Evaluation

---

Deep borehole and seismic logging data <Borehole and P-wave velocity : Niigata area>



Deep borehole at NIU by JNES

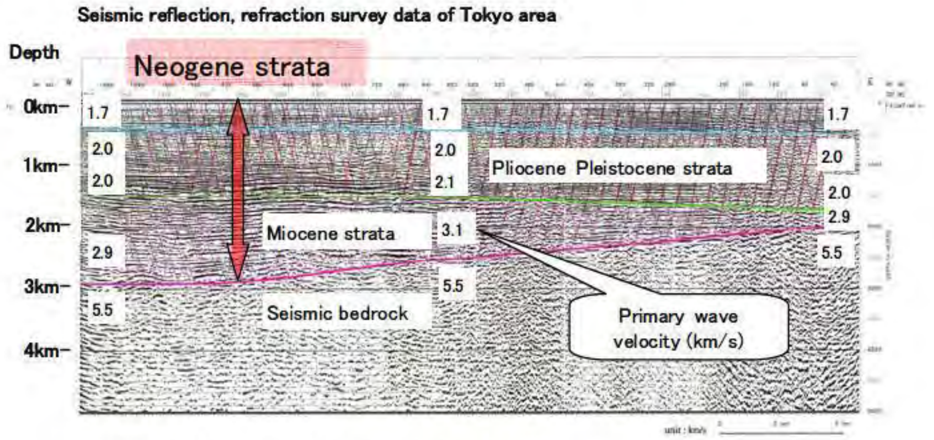


This method is

- very effective for model making.
- very expensive
- sometimes troublesome in dwelling environment
- planning and land negotiation must be done carefully.

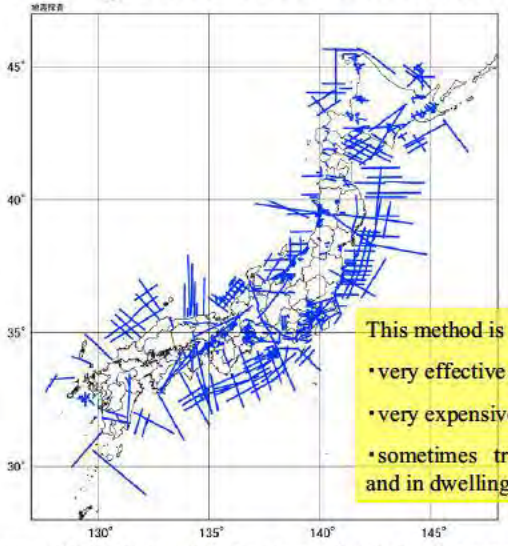
Seismic survey data

Seismic reflection, refraction survey data of Tokyo area



Data of the Deep subsurface survey project by HERP

Survey lines of seismic survey



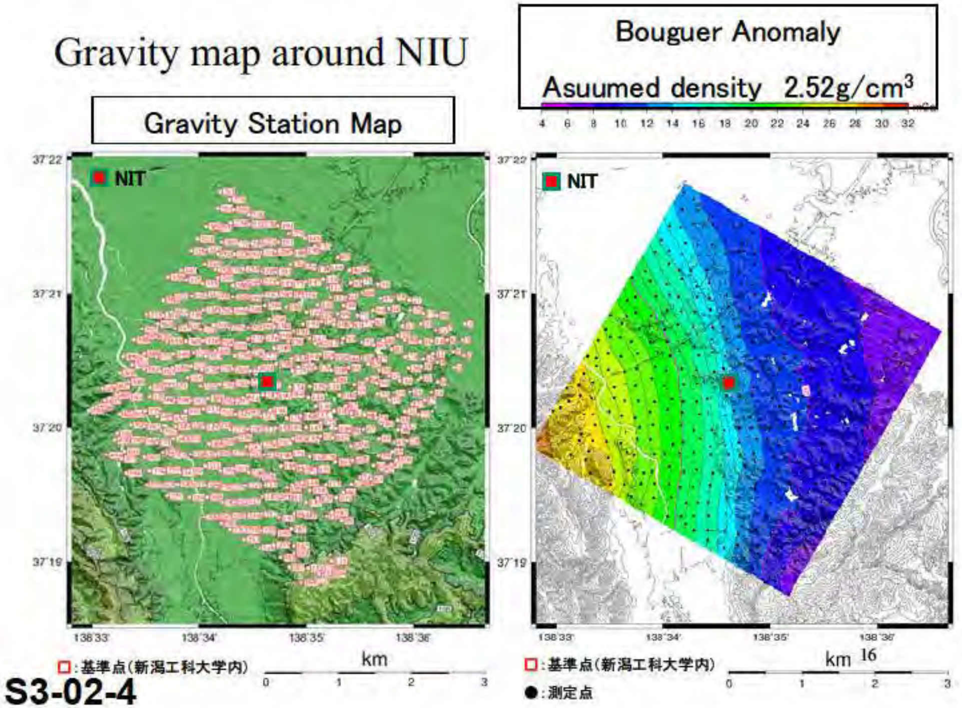
This method is

- very effective for model making.
- very expensive
- sometimes troublesome in road using and in dwelling environment

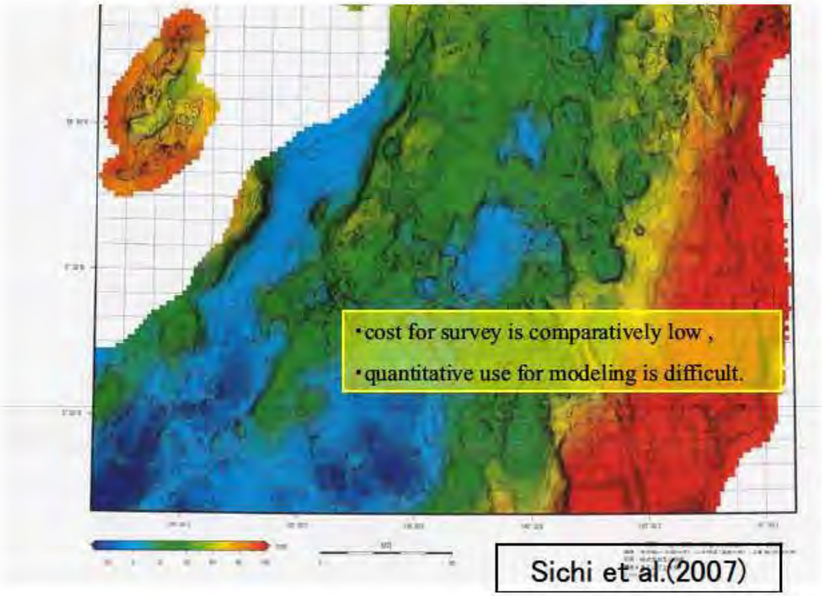
H. Fujiwara et al(2009): A Study on Subsurface Structure Model for Deep Sedimentary layers of Japan for Strong motion Evaluation

---

Gravity map around NIU



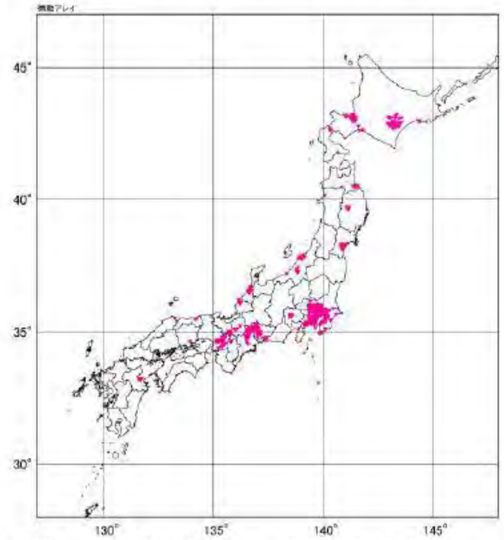
Gravity map :Bouguer Anomaly in Niigata area



- cost for survey is comparatively low ,
- quantitative use for modeling is difficult.

Sichi et al.(2007)

Survey points of microtremor survey



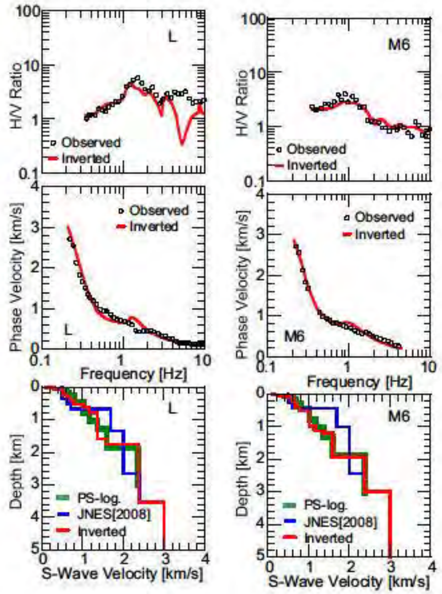
H. Fujiwara et al(2009): A Study on Subsurface Structure Model for Deep Sedimentary layers of Japan for Strong motion Evaluation

Microtremor data : Results of joint Inversion analysis around NIU .

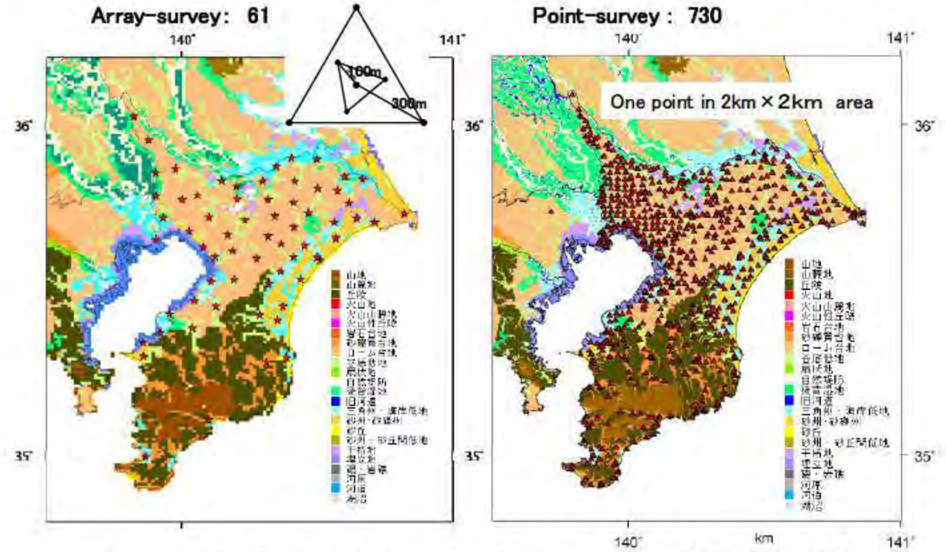
(Suzuki,2012)

This method is

- very effective for model tuning.
- very convienenct and low in budget.
- Environmentally friendly.

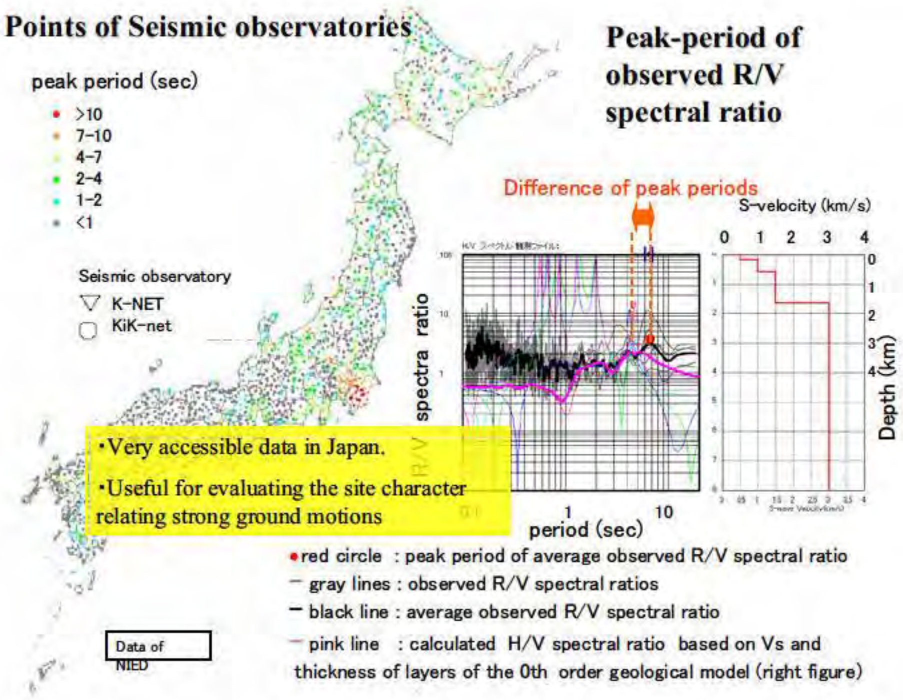


Micro tremor data for shallow subsurface modeling



S.Senna et al(2009):Spectral amplification of ground motion estimated from microtremor observation in Chiba Prefecture.

Peak-period of observed R/V spectral ratio



- Very accessible data in Japan.
- Useful for evaluating the site character relating strong ground motions

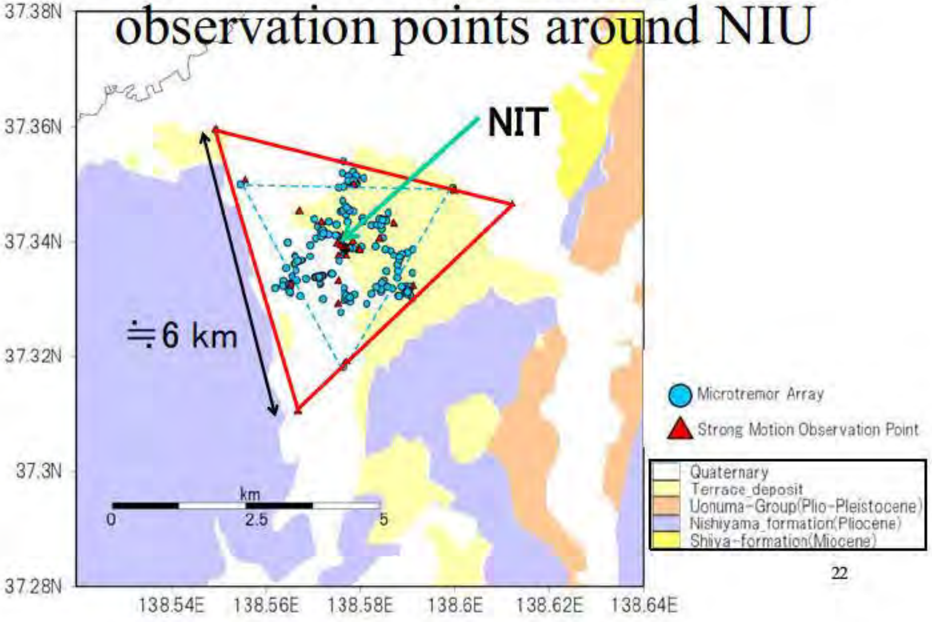
● red circle : peak period of average observed R/V spectral ratio

— gray lines : observed R/V spectral ratios

— black line : average observed R/V spectral ratio

— pink line : calculated H/V spectral ratio based on Vs and thickness of layers of the 0th order geological model (right figure)

Horizontal array of strong motion observation points around NIU



Comparison of modeling method

Method		Obtainable data		Applicability for subsurface structure analysis		Convenience	Cost
Source of tremor	Survey method	Ground structure	Physical property	Area	Depth		
controlled	Deep boring PS-logging	Stratigraphy	Velocity distribution of layers	In one place	Dozens m～ Several km	not so convenient	High ～ Very high
	Seismic reflection	Structure layer boundary		Line		troublesome in land-use, road-use	High
	Seismic refraction	Velocity structure					High
–	Gravity	Gravity basement	Density	One place ～ Area		Very convenient	Low
Natural tremor	Microtremor	Velocity structure	Spectral ratios Phase velocity			Convenient	Low ～a little high
earthquakes	Earthquake observation (vertical array)	-	Spectral ratios Q-value	In one place	Several km	not so convenient	Very high
	Earthquake observation (horizontal array)	-	Spectral ratios Surface wave dispersion	Area		troublesome in land-use, road-use	High
Earthquake observatory network data		-	Spectral ratios	Broad area	-	Very convenient	(for use, free)

Conclusions :

- In making subsurface structure models for seismic strong motion evaluation, several methods have been used.
- These method have several advantages and shortcomings respectively
- In all of them, gravity survey or microtremor survey , particularly, the latter is very valid in convenience and in cost.
- But for making accurate 3-D subsurface structure models, we must establish standards data of stratigraphy and seismic velocity structure. Without the standards, gravity data or microtremor data would not be very useful.
- In fixing standards, the methods of direct examinations of subsurface ground or of using controlled tremor source are needed though at a high cost.
- So in modeling subsurface structure, some sort of plans including both two types methods are desirable and several methods must be combined to your purposes and budgets.

That’s all.

Thank you for your attention .

The 2nd International Workshop on Seismic Observation in Deep Borehole and Its Applications

ISSC Information & Notification System

Nebi Bekiri
Technical Coordinator

9 November 2012

IAEA
International Atomic Energy Agency

ISSC Extrabudgetary Program

- WA1 – Seismic Hazards
- WA2 – Seismic Design, Qualification and Re-evaluation
- WA3 – Seismic Experience & Real Time Safety Assessment
- WA4 – External Events Preparedness and Response
- WA5 – Tsunami Hazards
- WA6 – Volcano Hazards
- WA7 – Engineering Aspects of Protection Against Sabotage
- WA8 – External Events Safety Assessment of Multi-Unit Sites
- WA9 – Information & Notification System
- WA10 – Public Communication, Dissemination of Lessons & Capacity Building

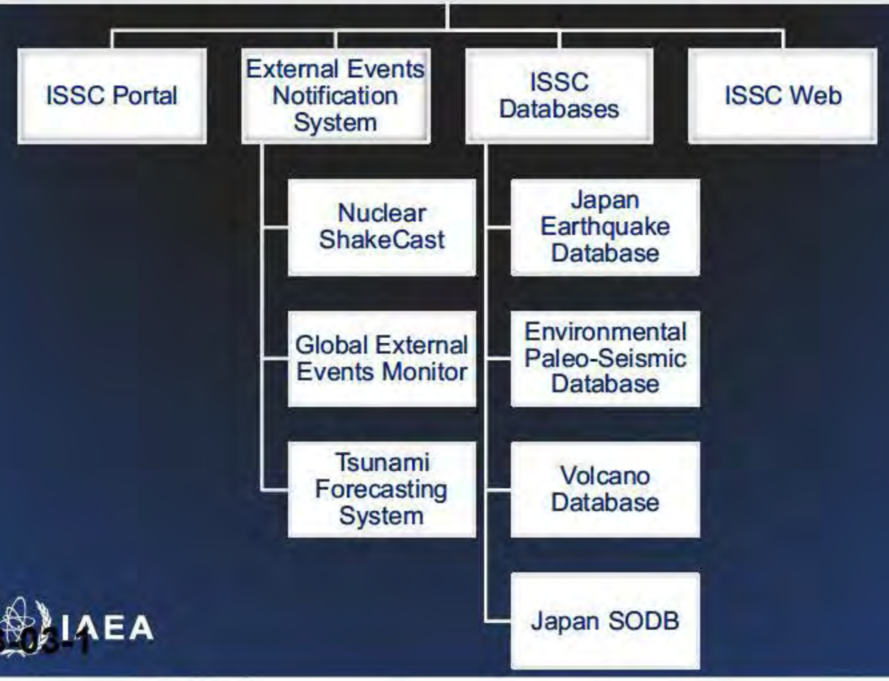
---

ISSC EBP – WA9 Tasks

- ISSC Portal
- Earthquake Experience at Nuclear Installation Sites
- Tsunami Database
- Volcano Database
- Japan Earthquake Database
- ISSC Web Site
- Earthquake Notification System
- Tsunami Notification System
- Volcanic Eruption Notification System

IAEA

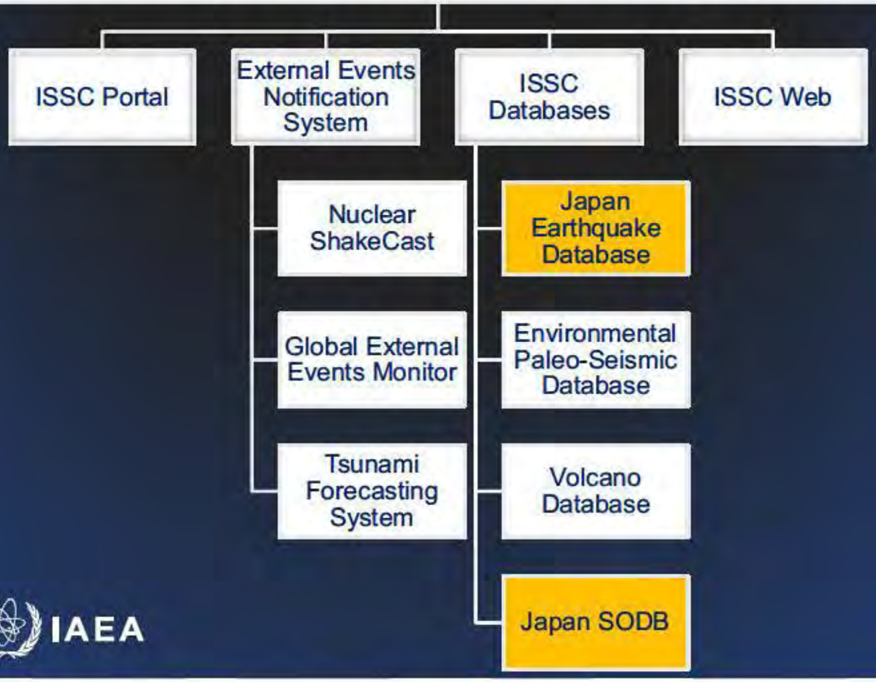
ISSC Information & Notification System



- ISSC Portal
- External Events Notification System
  - Nuclear ShakeCast
  - Global External Events Monitor
  - Tsunami Forecasting System
- ISSC Databases
  - Japan Earthquake Database
  - Environmental Paleo-Seismic Database
  - Volcano Database
  - Japan SODB
- ISSC Web

IAEA

ISSC Information & Notification System



Collaboration

USGS science for a changing world

JNES

NOAA

United States Nuclear Regulatory Commission

ISPRA Istituto Superiore per la Protezione e la Ricerca Ambientale

Smithsonian Institution

Collaboration – Projects

- IAEA – JNES
- IAEA – NIIT
- IAEA – US NRC – USGS
- IAEA – US NRC – NOAA
- IAEA – CNSC
- IAEA – ISPRA
- IAEA – SI

ISSC Portal

Task 1 - https://issc.iaea.org/login.php

ISSC Portal

- Home
- Events
- ISSC EBP
- Nuclear Installation Sites
- Earthquakes
- Documents
- Missions
- Workshops
- Services
- Technical Meetings
- EBP 2007-2010
- Users

Ongoing Events

- 4th Consultancy Meeting
  2012-10-29 | ISSC EBP - WA7

Upcoming Events

- The 2nd Workshop on Seismic Observation in Deep Borehole and its Application
  2012-11-07 | ISSC EBP - Secretariat
- Joint CSs of WG 1.1-5
  2012-11-12 | ISSC EBP - WA1
- WG6-1 and SST 6.1.1 meeting
  2012-11-15 | ISSC EBP - WA6

More Events→

News

IAEA Seismic Safety Mission to Visit Onagawa Nuclear Power Station in Japan
An IAEA mission will visit Japan 29 July - 11 August to undertake research and collect data about possible effects... read more

Predicting Tsunami Impact
IAEA International Seismic Safety Centre Implements NOAA Tsunami Forecasting and Notification System
read more

Annual Donors and Participating Institution's Meeting for the International Seismic Safety Centre (ISSC) extrabudgetary projects
6-10 February 2012, IAEA Headquarters, Vienna, Austria

Site & External Events Design (SEED) Review Services

IAEA Expert Mission to Onagawa NPP

An IAEA team of international experts today delivered its initial report at the end of a two-week mission to gather information about the effects of the Great East Japan Earthquake on the Onagawa Nuclear Power Station (NPS), saying the plant was "remarkably undamaged." Full story »

<< November 2012 >>

Mo	Tu	We	Th	Fr	Sa	Su
29	30	31	1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	1	2

set5
31 October 2012

Set3
31 October 2012

set1
31 October 2012

Introduction by T.Fukushim
31 October 2012

ISSC Quarterly

Newsletter - October 2012

Newsletter - July 2012

External Publications

Earthquake Data Recorded at Onagawa NPP (AEE)

New Seismic Model in US

Recent Publications

Seismic Hazards in Site Evaluation for Nuclear Installations Specific Safety Guide (SSG-9)

Evaluation of Seismic Safety for Existing Nuclear Installations Safety Guide

IAEA

Earthquake experience around Nuclear Installation Sites

Task 9.2

IAEA

Updates

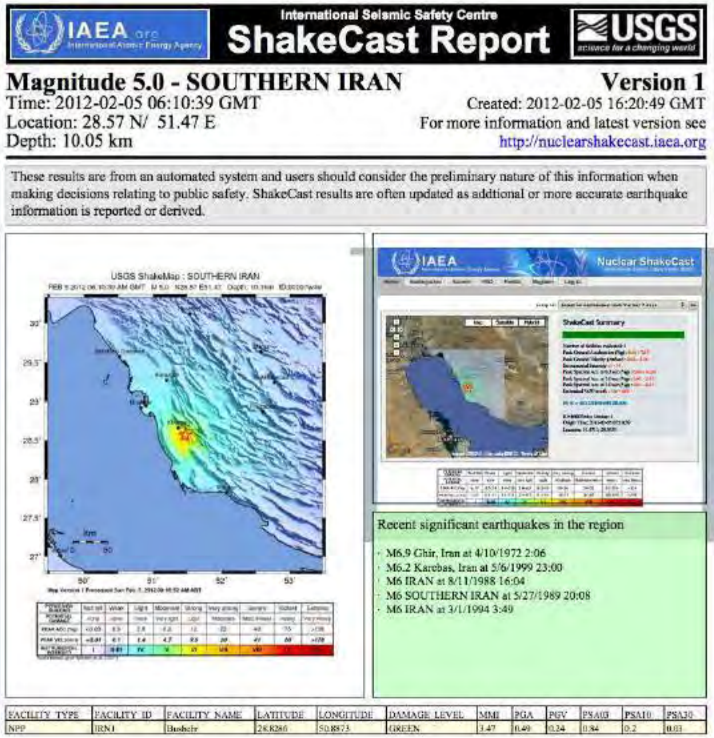
- Regular updates of the ISSC Earthquake Knowledge Database with significant events in the region.
- Earthquakes around NPP Sites (on ISSC Portal)

Earthquakes around NPP Sites

Earthquake	Magnitude	Date
near the east coast of Honshu	4.7	2012-02-05
southern Iran	5	2012-02-05
near the east coast of Honshu	4.7	2012-02-04
Taiwan region	5.1	2012-02-04
Virginia	3.2	2012-01-30
Kyushu	5	2012-01-29
Taiwan region	4.7	2012-01-29
southwestern Ryukyu Islands	5	2012-01-28
near the east coast of Honshu	4.8	2012-01-28 05:21:00

southern Iran
2012-02-05 06:10:39
Magnitude: 5
Depth: 10.1
Distance: 300

IAEA



International Seismic Safety Centre
ShakeCast Report

Magnitude 5.0 - SOUTHERN IRAN
Time: 2012-02-05 06:10:39 GMT
Location: 28.57 N/ 51.47 E
Depth: 10.05 km

Version 1
Created: 2012-02-05 16:20:49 GMT
For more information and latest version see
http://nuclearshakecast.iaea.org

These results are from an automated system and users should consider the preliminary nature of this information when making decisions relating to public safety. ShakeCast results are often updated as addtional or more accurate earthquake information is reported or derived.

Recent significant earthquakes in the region

- M6.9 Ghir, Iran at 4/10/1972 2:06
- M6.2 Karebas, Iran at 5/6/1999 23:00
- M6 IRAN at 8/11/1988 16:04
- M6 SOUTHERN IRAN at 5/27/1989 20:08
- M6 IRAN at 3/1/1994 3:49

FACILITY TYPE	FACILITY ID	FACILITY NAME	LATITUDE	LONGITUDE	DAMAGE LEVEL	MMI	PGA	PGV	PSA03	PSA10	PSA30
NPP	IRN1	Bushehr	28.8286	50.8873	GREEN	3.47	0.49	0.24	0.84	0.2	0.03

International Seismic Safety Centre

ShakeCast Report

Magnitude 5.0 - SOUTHERN IRAN

Version 1

Time: 2012-02-05 06:10:39 GMT
Location: 28.57 N/ 51.47 E
Depth: 10.05 km

Created: 2012-02-05 16:20:49 GMT
For more information and latest version see
http://nuclearshakecast.iaea.org

Recent significant earthquakes in the region

- M6.9 Ghir, Iran at 4/10/1972 2:06
- M6.2 Karebas, Iran at 5/6/1999 23:00
- M6 IRAN at 8/11/1988 16:04
- M6 SOUTHERN IRAN at 5/27/1989 20:08
- M6 IRAN at 3/1/1994 3:49

10,000+

Current Earthquake Database Inventory V1.5, 1973 – 2011

IAEA

15,000+

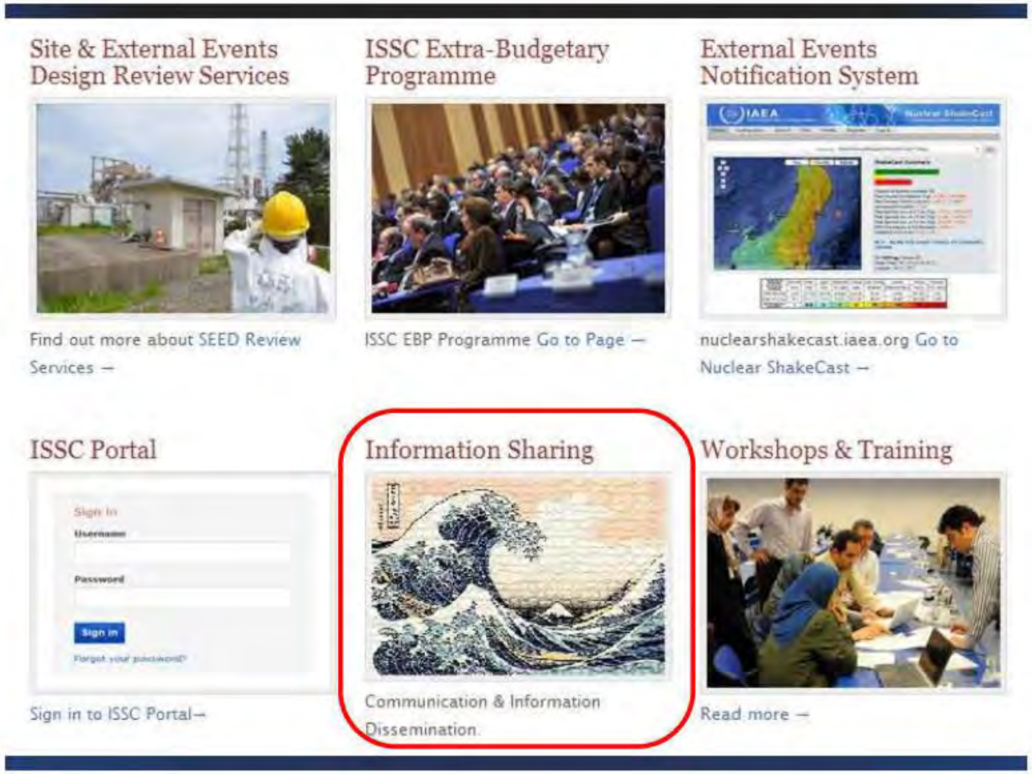
Next generation V2.0, even before 1973 and will be complete up to 2010

IAEA

Tsunami Database

Task 9.3 – Connected with WA5 Tsunami Hazards

IAEA



Site & External Events Design Review Services

Find out more about SEED Review Services →

ISSC Extra-Budgetary Programme

ISSC EBP Programme Go to Page →

External Events Notification System

nuclearshakecast.iaea.org Go to Nuclear ShakeCast →

ISSC Portal

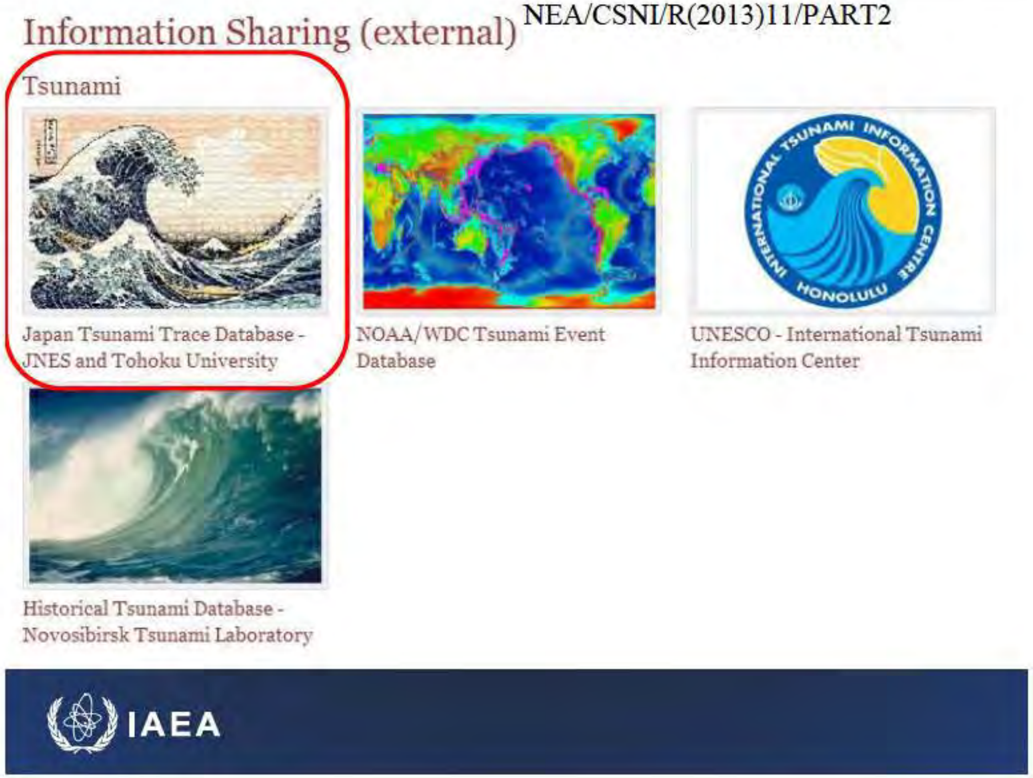
Sign in to ISSC Portal→

Information Sharing

Communication & Information Dissemination.

Workshops & Training

Read more →



Information Sharing (external)

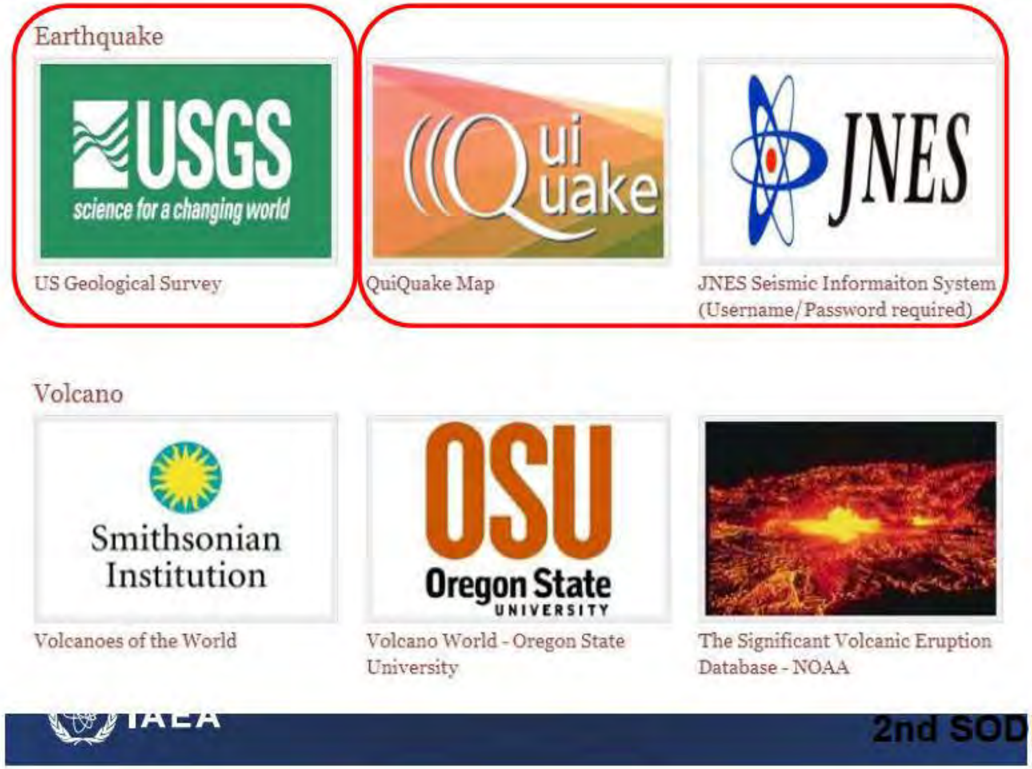
Tsunami

Japan Tsunami Trace Database - JNES and Tohoku University

NOAA/WDC Tsunami Event Database

UNESCO - International Tsunami Information Center

Historical Tsunami Database - Novosibirsk Tsunami Laboratory



Earthquake

US Geological Survey

QuiQuake Map

JNES Seismic Informaiton System (Username/Password required)

Volcano

Volcanoes of the World

Volcano World - Oregon State University

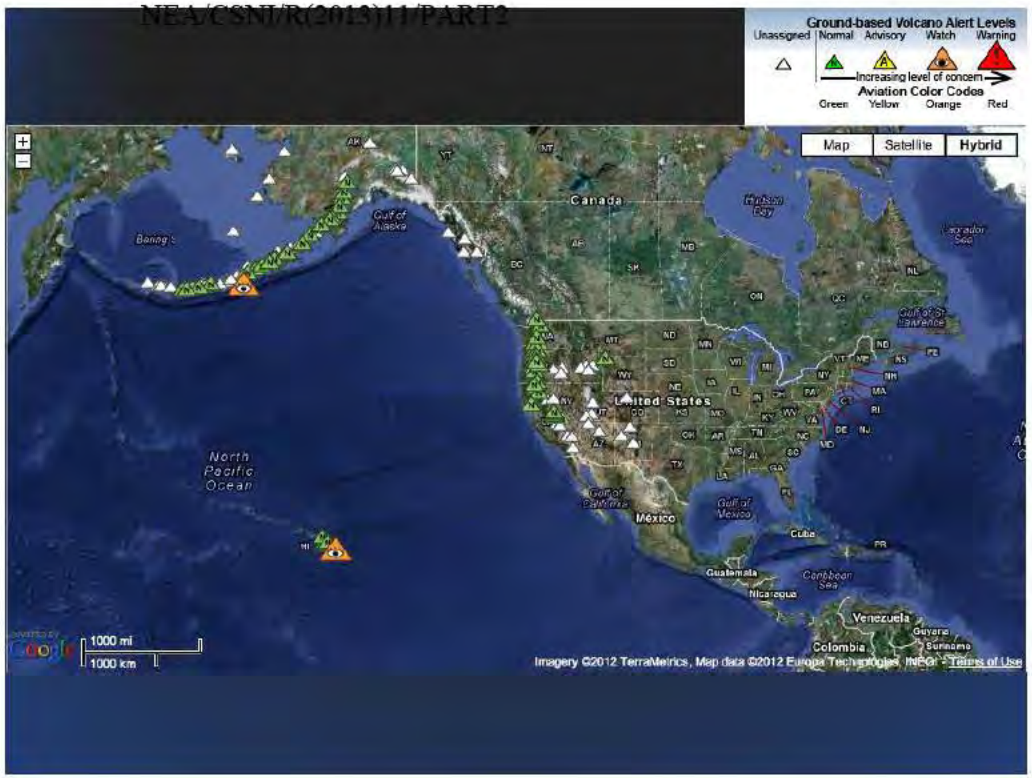
The Significant Volcanic Eruption Database - NOAA

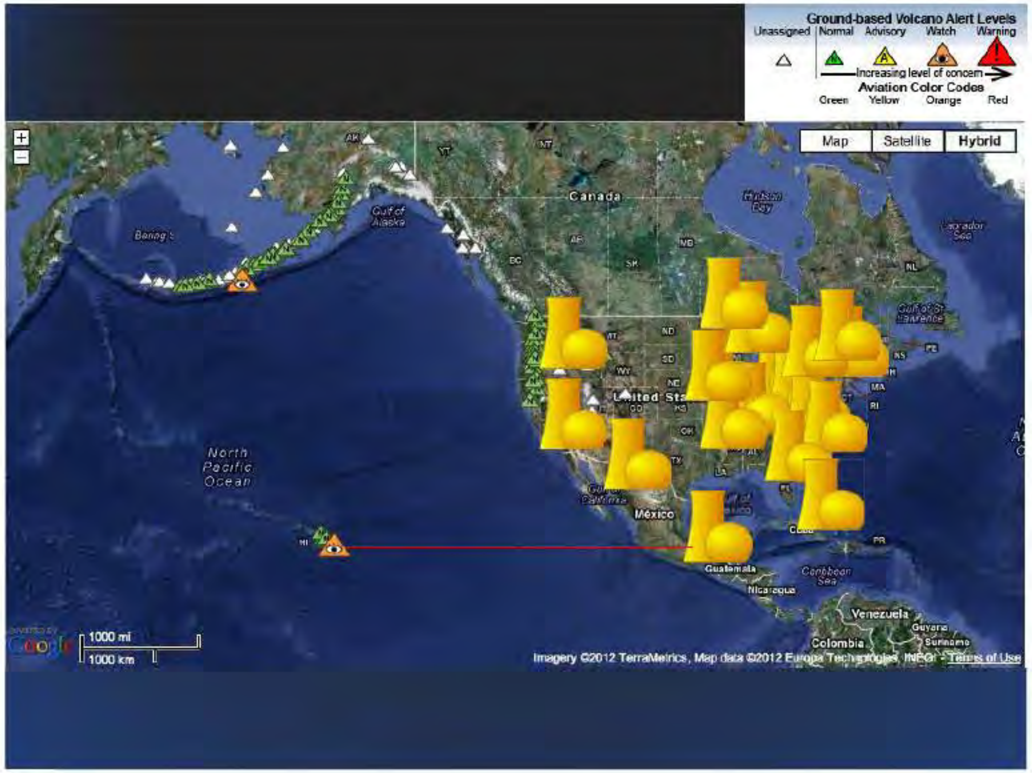
Volcano Database

Task 9.4

– Connected with WA6 Volcano Hazards

IAEA





Japan Earthquake Database

Task 9.5

IAEA

IAEA International Atomic Energy Agency

JNES

IAEA – JNES collaboration

Integrate regional earthquake data into the ISSC Portal

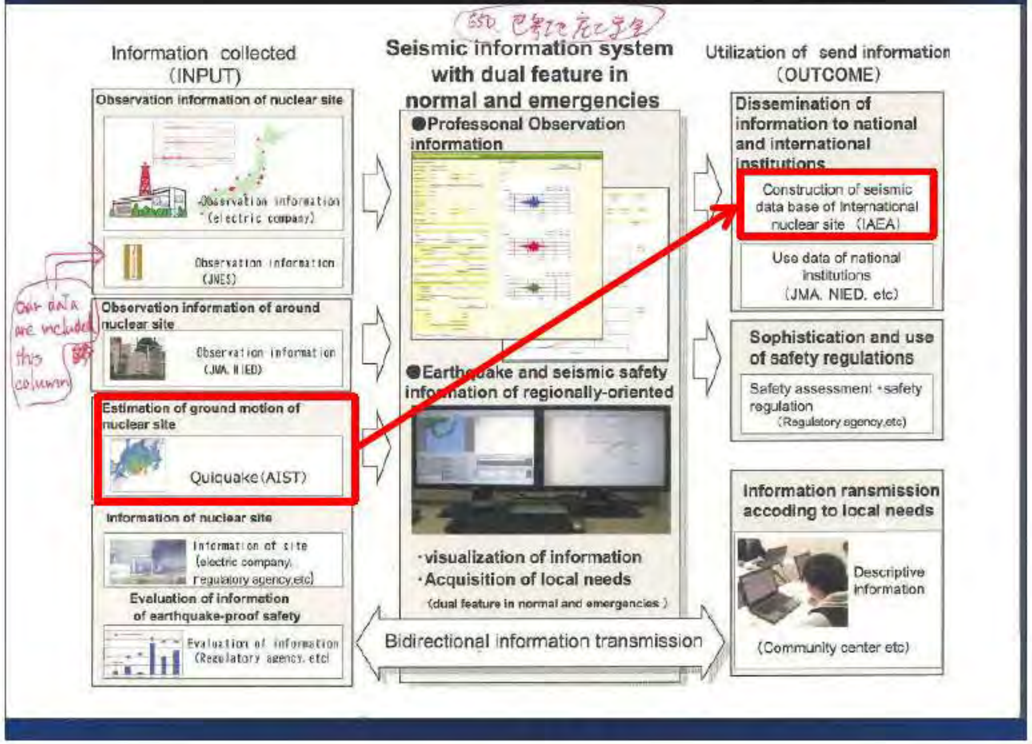
IAEA

Japan Earthquake Database – Phase 1

- Implementation of an interface between IAEA and JNES Seismic Information System.
- Data transfer started on 25 November 2011.

759	2012-01-31 21:30:05	f20120201052312.kmz
758	2012-01-31 21:30:03	f20120201052312.kml
757	2012-01-31 20:42:07	f20120201043505.kmz
756	2012-01-31 20:42:06	f20120201043505.kml
755	2012-01-31 05:46:23	f20120131133529.kmz
754	2012-01-31 05:46:22	f20120131133529.kml
753	2012-01-30 09:20:17	f20120130171039.kmz
752	2012-01-30 09:20:16	f20120130171039.kml
751	2012-01-30 08:45:15	s20120130031800.kmz
750	2012-01-30 08:45:13	s20120130031800.kml
749	2012-01-30 08:20:18	s20120129164600.kmz
748	2012-01-30 08:20:16	s20120129164600.kml
747	2012-01-30 08:19:18	f20120130161320.kmz
746	2012-01-30 08:19:16	f20120130161320.kml
745	2012-01-30 07:20:17	s20120128214400.kmz
744	2012-01-30 07:20:15	s20120128214400.kml
743	2012-01-30 07:00:22	s20120128142100.kmz
742	2012-01-30 07:00:21	s20120128142100.kml

IAEA



Information collected (INPUT)

Observation information of nuclear site

Observation information (electric company)

Observation information (JNES)

Observation information of around nuclear site

Observation information (JMA, NIED)

Estimation of ground motion of nuclear site

Quiquake (AIST)

Information of nuclear site

Information of site (electric company, regulatory agency, etc)

Evaluation of information of earthquake-proof safety

Evaluation of information (Regulatory agency, etc)

Seismic information system with dual feature in normal and emergencies

●Professonal Observation information

●Earthquake and seismic safety information of regionally-oriented

- visualization of information
- Acquisition of local needs

(dual feature in normal and emergencies)

Bidirectional information transmission

Utilization of send information (OUTCOME)

Dissemination of information to national and international institutions

Construction of seismic data base of International nuclear site (IAEA)

Use data of national institutions (JMA, NIED, etc)

Sophistication and use of safety regulations

Safety assessment・safety regulation (Regulatory agency, etc)

Information ransmission accoding to local needs

Descriptive information

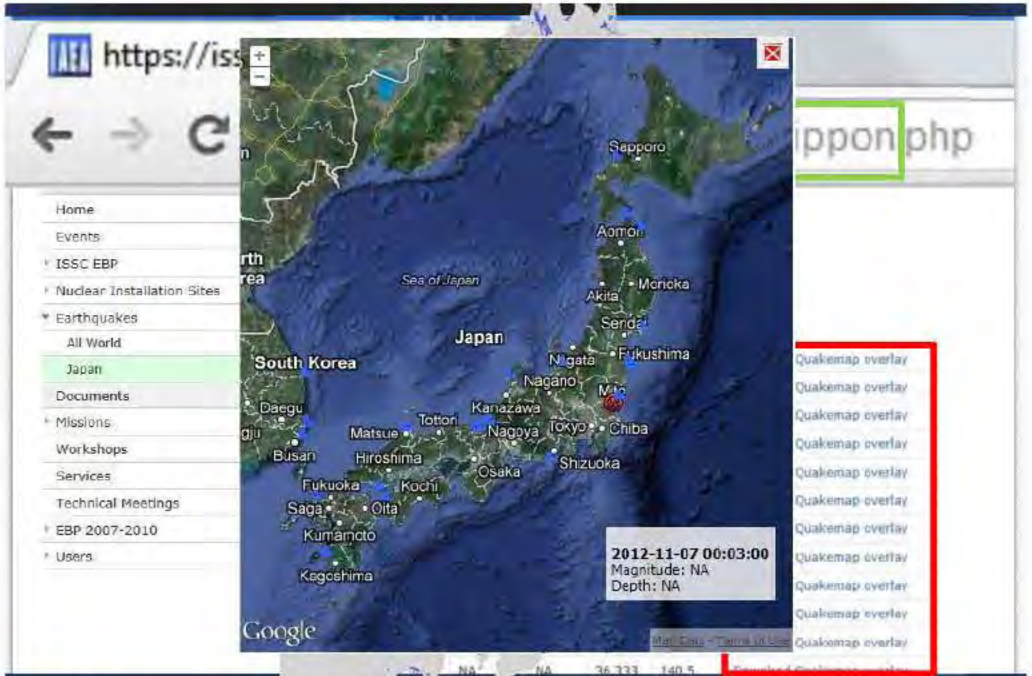
(Community center etc)

Our data are included this column

Japan Earthquake Database - Phase 2

- Implementation (showing) of Japan Earthquake Data on the ISSC Portal.
- Part 1: Completed
- Part 2: Live on December 2012.

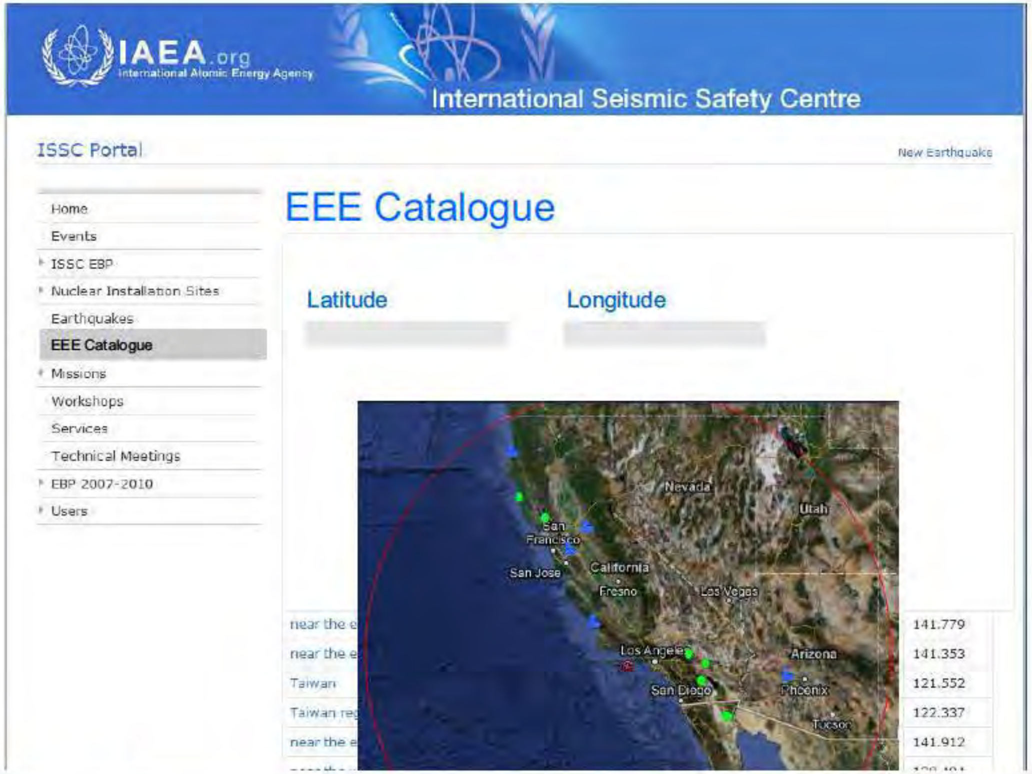
IAEA



2012-11-07 00:03:00
Magnitude: NA
Depth: NA

IAEA

Earthquake Environmental Effects (EEE) Catalogue on the ISSC Portal



EEE Catalogue

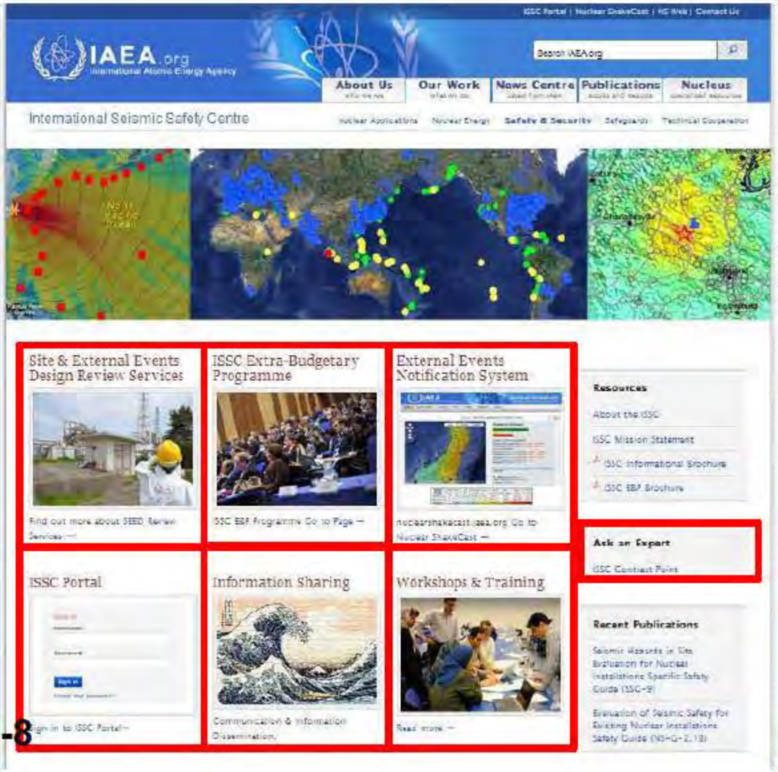
Latitude

Longitude

near the e	141.779
near the e	141.353
Taiwan	121.552
Taiwan reg	122.337
near the e	141.912

ISSC Web

issc.iaea.org



International Seismic Safety Centre

Site & External Events Design Review Services

Find out more about SEED Review Services →

ISSC Extra-Budgetary Programme

ISSC EBP Programme Go to Page →

External Events Notification System

nuclearshakecast.iaea.org Go to Nuclear ShakeCast →

ISSC Portal

Sign in to ISSC Portal→

Information Sharing

Communication & Information Dissemination.

Workshops & Training

Read more →

Resources

About the ISSC

ISSC Mission Statement

ISSC Informational Brochure

ISSC EBP Brochure

Ask an Expert

ISSC Contact Point

Recent Publications

Seismic Hazards in Site Evaluation for Nuclear Installations Specific Safety Guide (SSG-9)

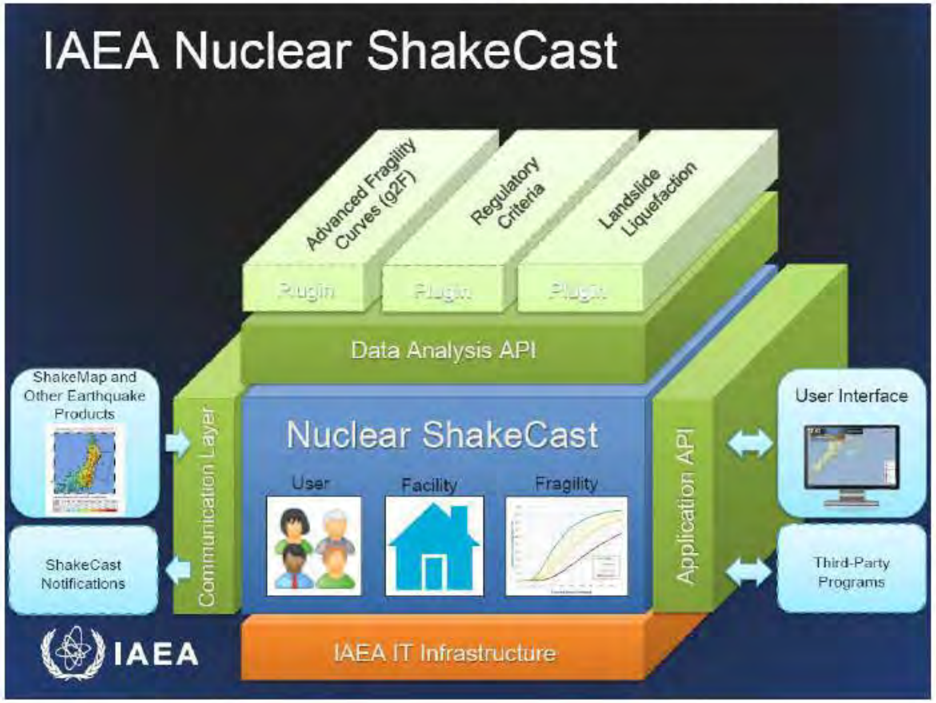
Evaluation of Seismic Safety for Existing Nuclear Installations Safety Guide (NS-G-2.13)

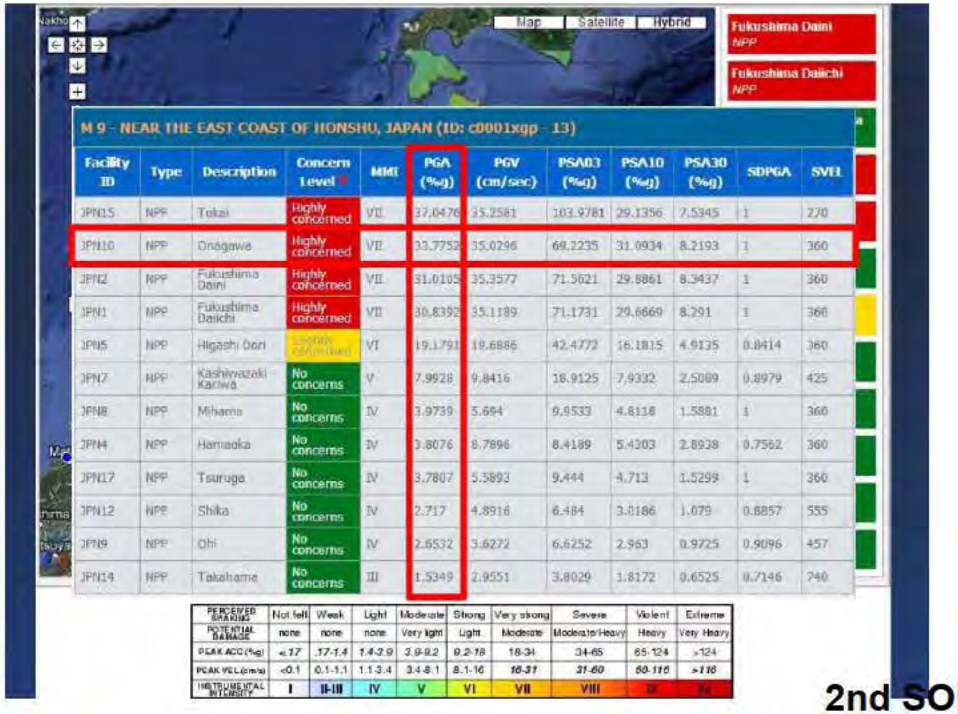
Earthquake Notification System

Task 9.7

IAEA

IAEA Nuclear ShakeCast





M 9 - NEAR THE EAST COAST OF HONSHU, JAPAN (ID: c0001xgp - 13)

Facility ID	Type	Description	Concern Level	MMI	PGA (%g)	PGV (cm/sec)	PSA03 (%g)	PSA10 (%g)	PSA30 (%g)	SDPGA	SVEL
JPN15	NPP	Tokai	Highly concerned	VII	37.0476	35.2581	103.9781	29.1356	7.5345	1	270
JPN10	NPP	Onagawa	Highly concerned	VII	33.7752	35.0296	69.2235	31.0934	8.2193	1	360
JPN2	NPP	Fukushima Daini	Highly concerned	VII	31.0105	35.3577	71.5621	29.8861	8.3437	1	360
JPN1	NPP	Fukushima Daiichi	Highly concerned	VII	30.8392	35.1189	71.1731	29.6669	8.291	1	360
JPN5	NPP	Higashi Dori	Slightly concerned	VI	19.1791	19.6886	42.4772	16.1815	4.9135	0.8414	360
JPN7	NPP	Kashiwazaki - Kariwa	No concerns	V	7.9928	9.8416	18.9125	7.9332	2.5089	0.8979	425
JPN8	NPP	Mihama	No concerns	IV	3.9739	5.694	9.9533	4.8118	1.5881	1	360
JPN4	NPP	Hamaoka	No concerns	IV	3.8076	8.7896	8.4189	5.4303	2.8938	0.7562	360
JPN17	NPP	Tsuruga	No concerns	IV	3.7807	5.5893	9.444	4.713	1.5299	1	360
JPN12	NPP	Shika	No concerns	IV	2.717	4.8916	6.484	3.0186	1.079	0.8857	555
JPN9	NPP	Ohi	No concerns	IV	2.6532	3.6272	6.6252	2.963	0.9725	0.9096	457
JPN14	NPP	Takahama	No concerns	III	1.5349	2.9551	3.8029	1.8172	0.6525	0.7146	740

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Experimental Tsunami Forecasting System

Task 9.8

IAEA

TsunamiCast

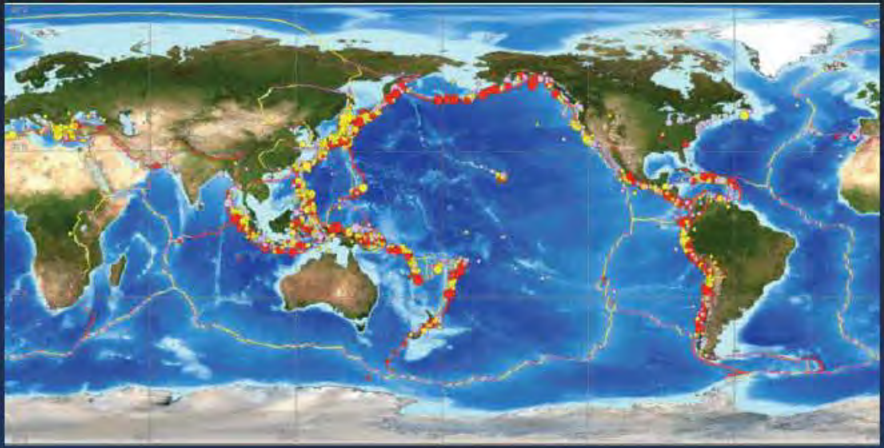
Wave height

Arrival time

Inundation

IAEA

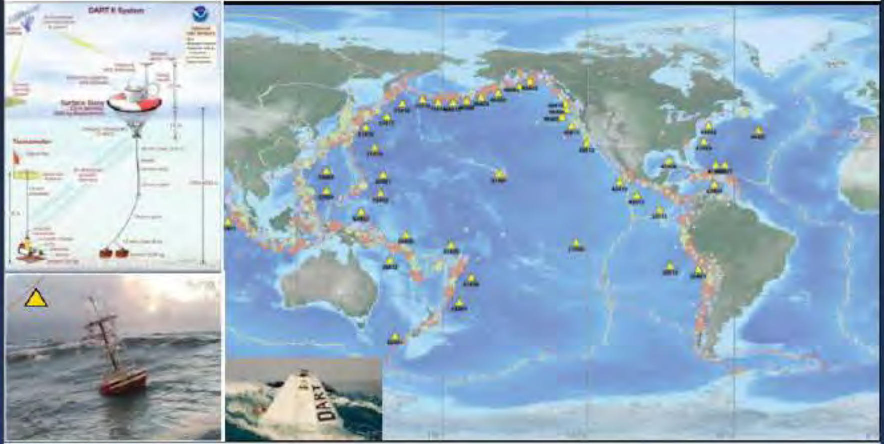
Tsunami Forecast



IAEA

Detection

⚠ Tsunameters



IAEA

Detection

⚠ Tsunameters

Inversion

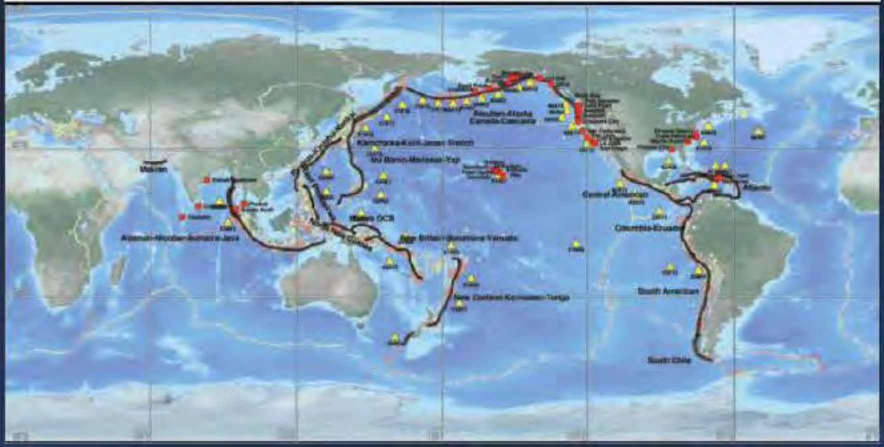
▦ model database

IAEA

Detection
▲ Tsunameters

Inversion
▦ model database

Coastal forecast
● SIM



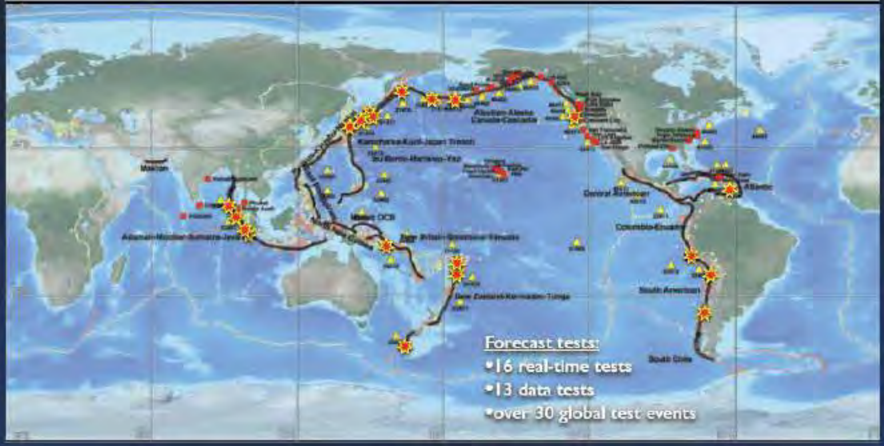
IAEA

Detection
▲ Tsunameters

Inversion
▦ model database

Coastal forecast
● SIM

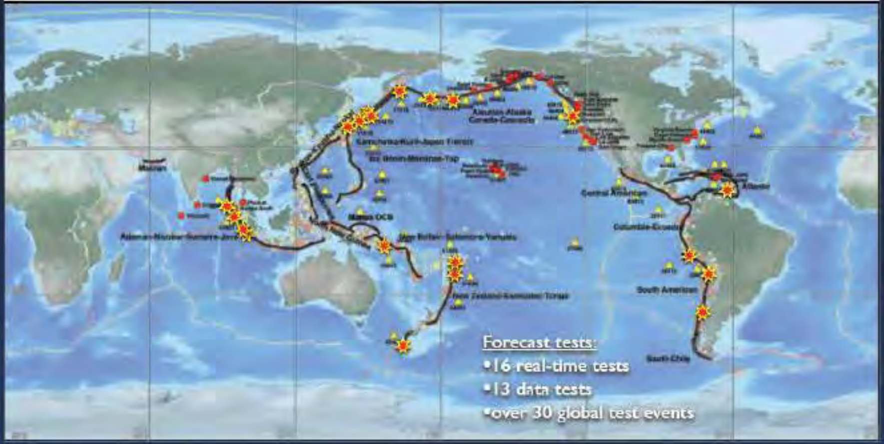
Verification
✸ Tsunami events



Forecast tests:
- 16 real-time tests
- 13 data tests
- over 30 global test events

IAEA

Detection ▲ Tsunameters → **Inversion** ▦ model database → **Coastal forecast** ● SIM → **Verification** ✸ Tsunami events



Forecast tests:
- 16 real-time tests
- 13 data tests
- over 30 global test events

IAEA

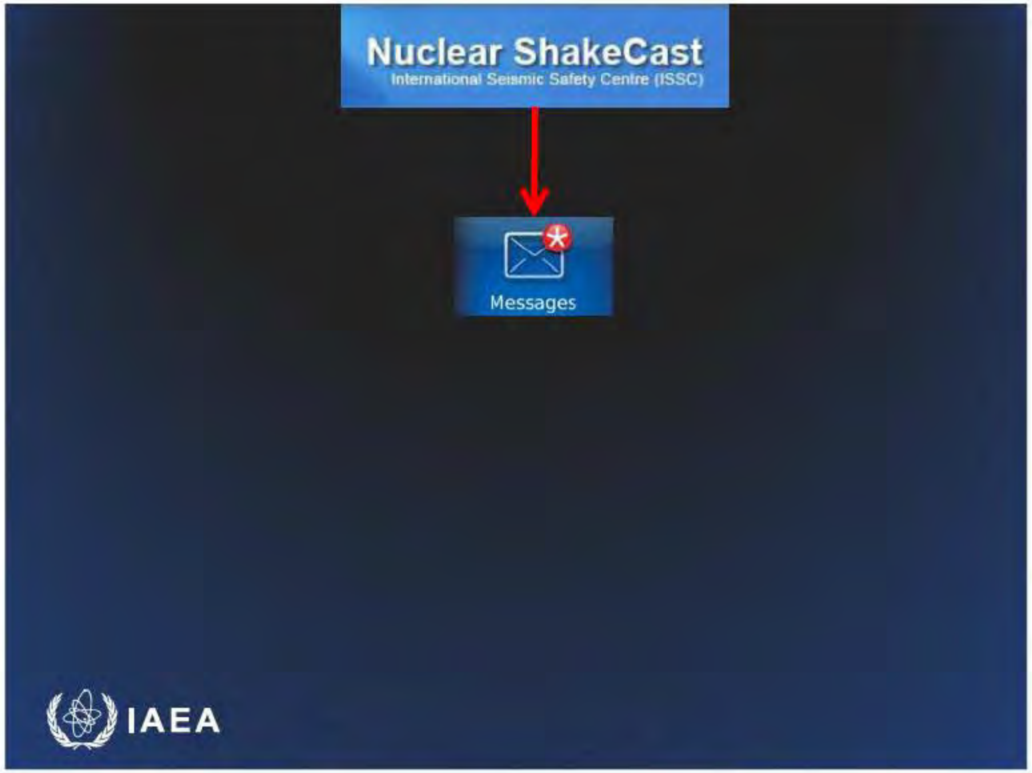
On-Call Duty 24/7/365

IAEA

Nuclear ShakeCast

International Seismic Safety Centre (ISSC)

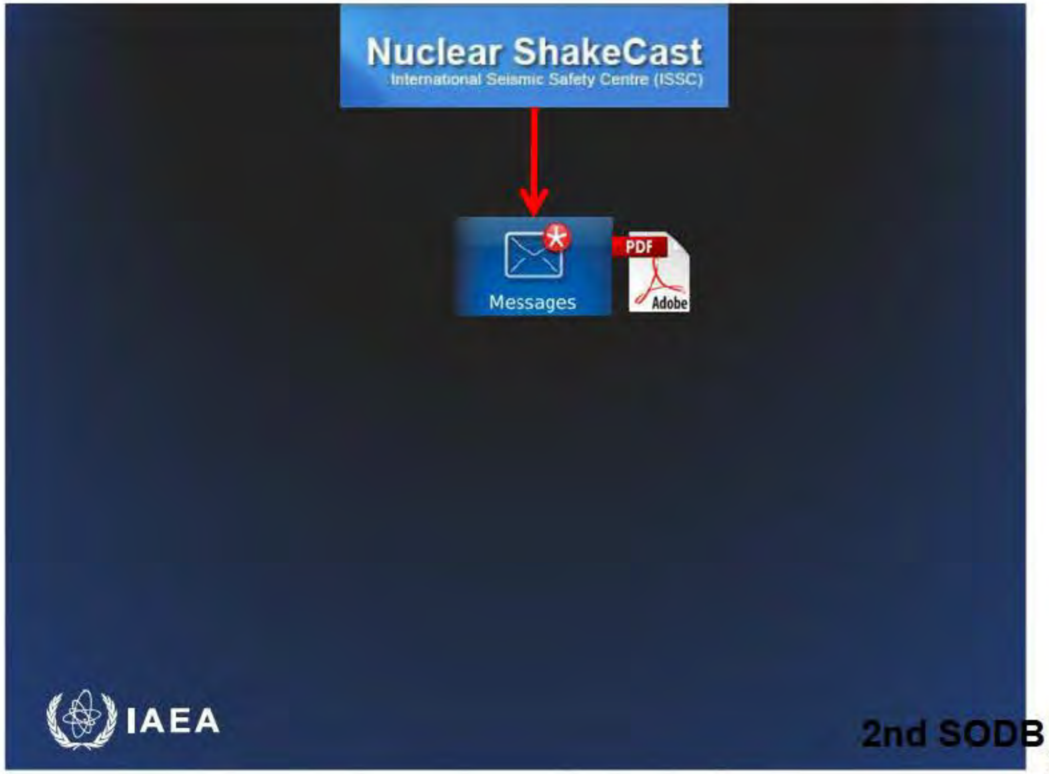
IAEA



Nuclear ShakeCast

International Seismic Safety Centre (ISSC)

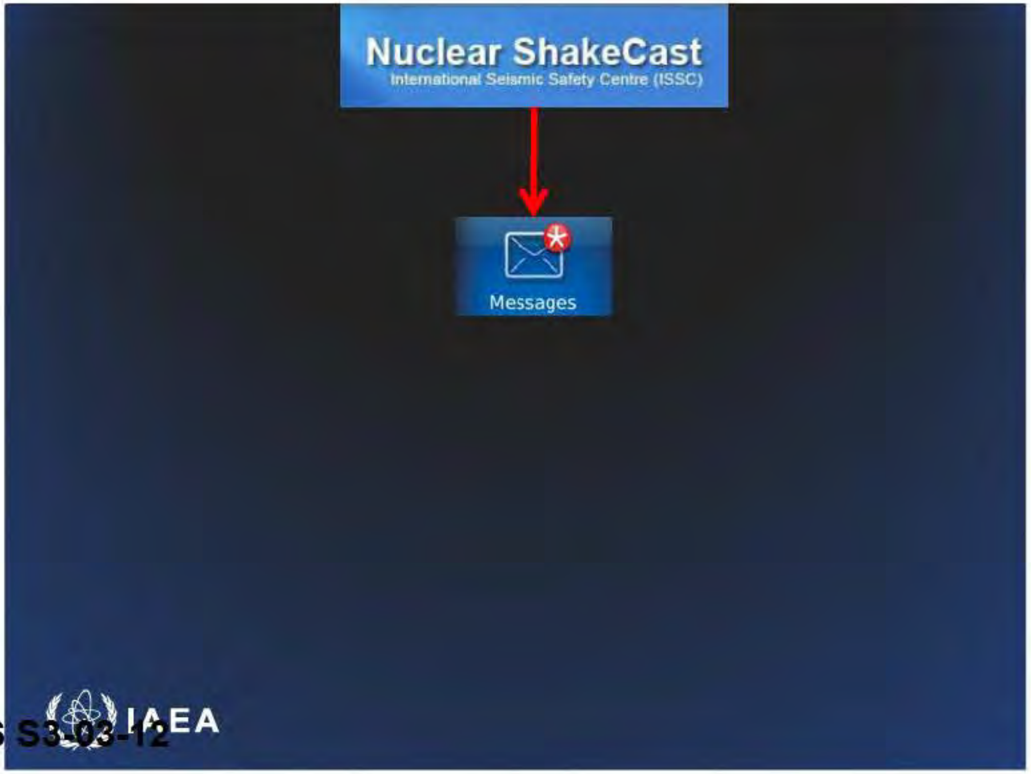
IAEA



Nuclear ShakeCast

International Seismic Safety Centre (ISSC)

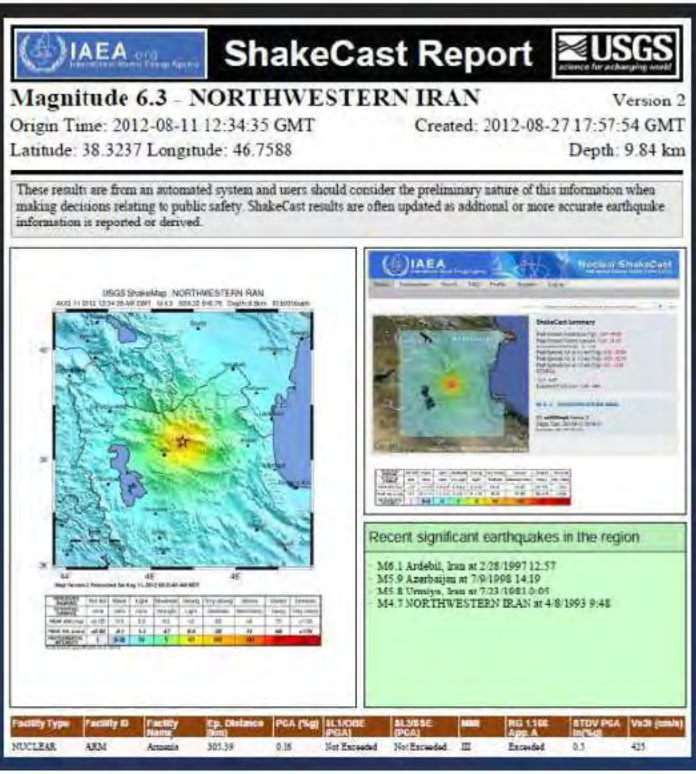
IAEA



Nuclear ShakeCast

International Seismic Safety Centre (ISSC)

IAEA



Magnitude 6.3 - NORTHWESTERN IRAN Version 2

Origin Time: 2012-08-11 12:34:35 GMT Created: 2012-08-27 17:57:54 GMT

Latitude: 38.3237 Longitude: 46.7588 Depth: 9.84 km

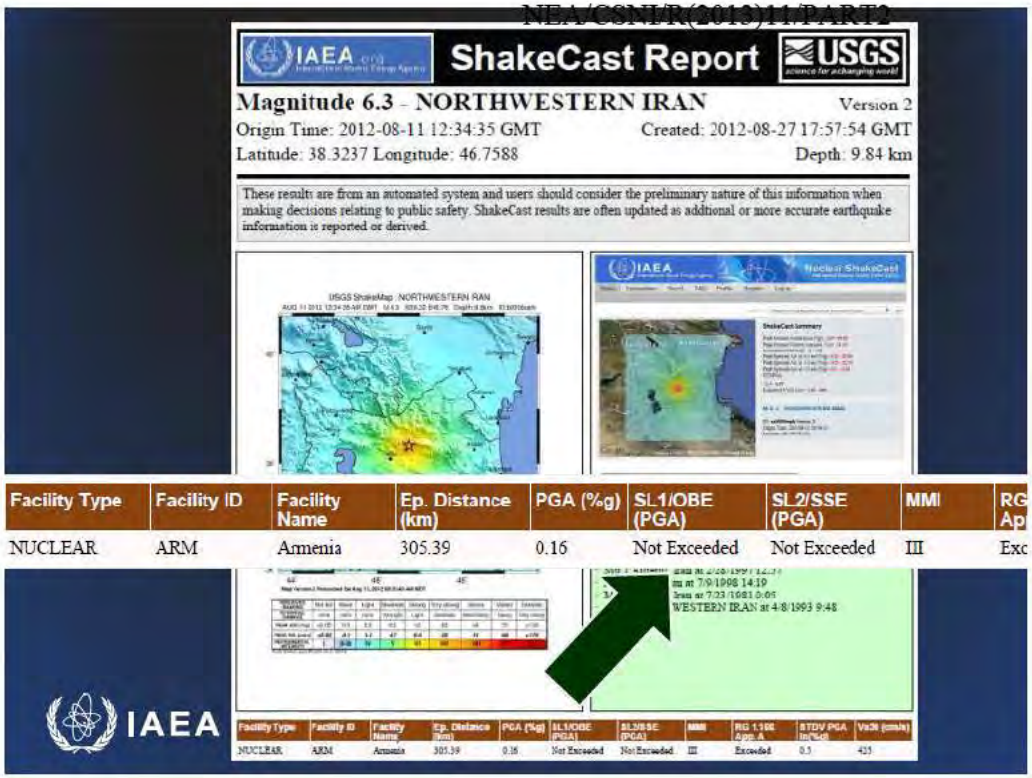
These results are from an automated system and users should consider the preliminary nature of this information when making decisions relating to public safety. ShakeCast results are often updated as addtional or more accurate earthquake information is reported or derived.

Recent significant earthquakes in the region

- M6.1 Ardebil, Iran at 2/28/1997 12:57
- M5.9 Azerbaijan at 7/9/1998 14:19
- M5.8 Urmiya, Iran at 7/23/1981 0:05
- M4.7 NORTHWESTERN IRAN at 4/8/1993 9:48

Facility Type	Facility ID	Facility Name	Ep. Distance (km)	PGA (%g)	SL1/OBE (PGA)	SL2/SSE (PGA)	MMI	RG 1.166 App. A	STDV PGA ln(%g)	Vs30 (cm/s)
NUCLEAR	ARM	Armenia	305.39	0.16	Not Exceeded	Not Exceeded	III	Exceeded	0.5	425

IAEA


Magnitude 6.3 - NORTHWESTERN IRAN Version 2

Origin Time: 2012-08-11 12:34:35 GMT Created: 2012-08-27 17:57:54 GMT

Latitude: 38.3237 Longitude: 46.7588 Depth: 9.84 km

These results are from an automated system and users should consider the preliminary nature of this information when making decisions relating to public safety. ShakeCast results are often updated as addtional or more accurate earthquake information is reported or derived.

Facility Type	Facility ID	Facility Name	Ep. Distance (km)	PGA (%g)	SL1/OBE (PGA)	SL2/SSE (PGA)	MMI
NUCLEAR	ARM	Armenia	305.39	0.16	Not Exceeded	Not Exceeded	III

Facility Type	Facility ID	Facility Name	Ep. Distance (km)	PGA (%g)	SL1/OBE (PGA)	SL2/SSE (PGA)	MMI	RG 1.166 App. A	STDV PGA ln(%g)	Vs30 (cm/s)
NUCLEAR	ARM	Armenia	305.39	0.16	Not Exceeded	Not Exceeded	III	Exceeded	0.5	425

IAEA

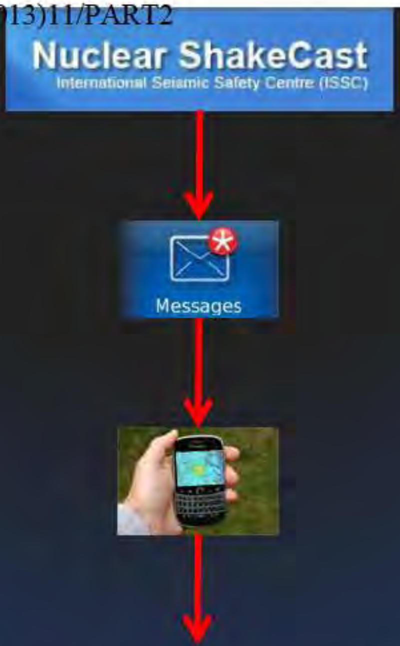
Nuclear ShakeCast

International Seismic Safety Centre (ISSC)

Messages

IAEA

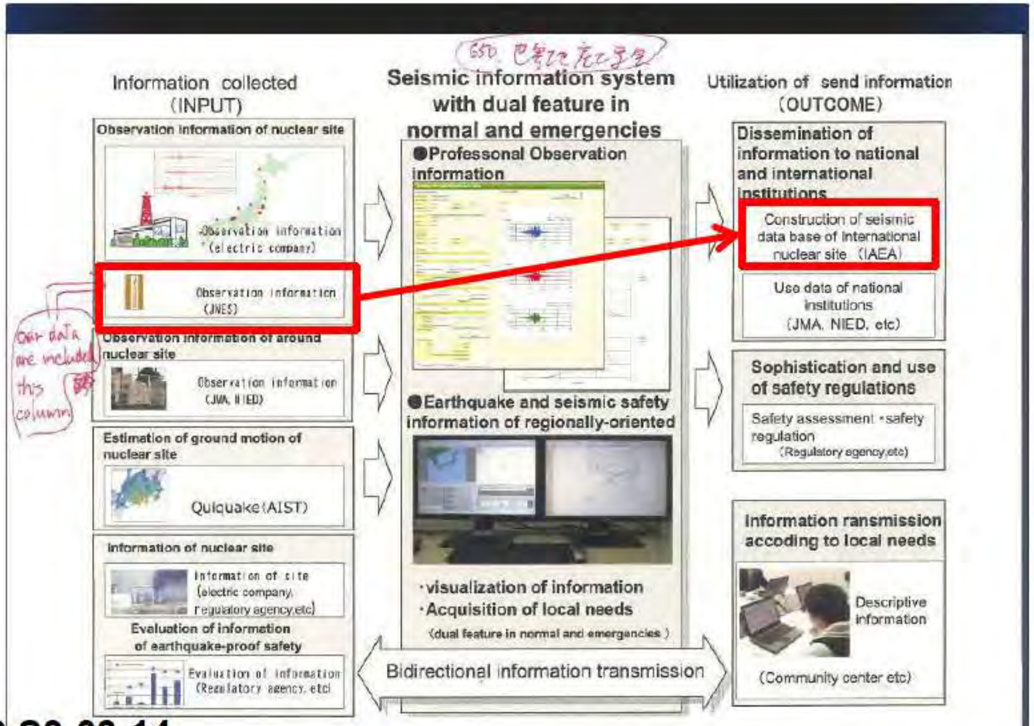
IAEA



IAEA Incident & Emergency Centre

One more thing..

Dissemination of Seismic Observation in Deep Borehole



[illegible]

Information collected (INPUT)

- **Observation information of nuclear site**
  - Observation information (electric company)
  - Observation information (JNES)
- **Observation information of around nuclear site**
  - Observation information (JMA, NIED)
- **Estimation of ground motion of nuclear site**
  - Quiquake (AIST)
- **Information of nuclear site**
  - Information of site (electric company, regulatory agency, etc)
- **Evaluation of information of earthquake-proof safety**
  - Evaluation of information (Regulatory agency, etc)

Our data are included this [illegible] column

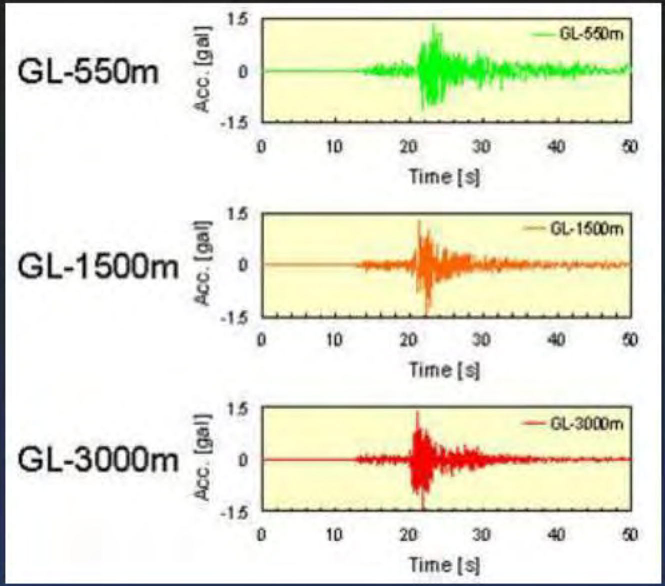
Seismic information system with dual feature in normal and emergencies

- ●Professonal Observation information
- ●Earthquake and seismic safety information of regionally-oriented
- ·visualization of information
- ·Acquisition of local needs
- (dual feature in normal and emergencies)

Bidirectional information transmission

Utilization of send information (OUTCOME)

- **Dissemination of information to national and international institutions**
  - Construction of seismic data base of international nuclear site (IAEA)
  - Use data of national institutions (JMA, NIED, etc)
- **Sophistication and use of safety regulations**
  - Safety assessment ･safety regulation (Regulatory agency, etc)
- **Information ransmission accoding to local needs**
  - Descriptive information (Community center etc)



IAEA

INTERNATIONAL SEISMIC SAFETY CENTRE

Thank you.

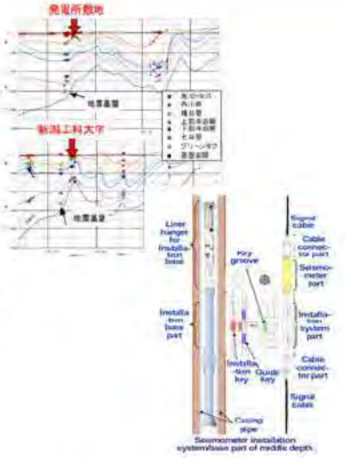
issc.iaea.org

Application of Seismic Observation Data in Borehole for the Development of Attenuation Equation of Response Spectra on Bedrock

Hongjun SI
Kozo Keikaku Eng. Inc., Japan

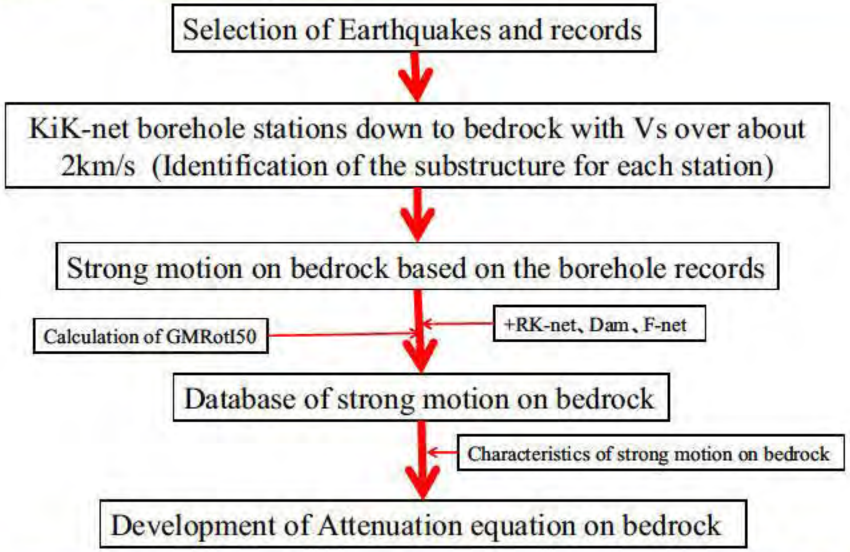
Background

- It is important to develop an attenuation relation for evaluating the strong motion on rock sites directly.
- So far, since the strong motions on bedrock have rarely been observed directly, it is difficult to develop an attenuation relationship on bedrock.
- However, recent vertical array, such as KiK-net, SOBD in Kashiwazaki provides us opportunity to estimate ground motion on bedrock.



SOBD in Kashiwazaki (Wu, 2010)

Development of GMPE for response spectra on bedrock based on the observation data at deep borehole



Selection of Earthquakes and records

KiK-net borehole stations down to bedrock with Vs over about 2km/s (Identification of the substructure for each station)

Strong motion on bedrock based on the borehole records

Calculation of GMRotI50

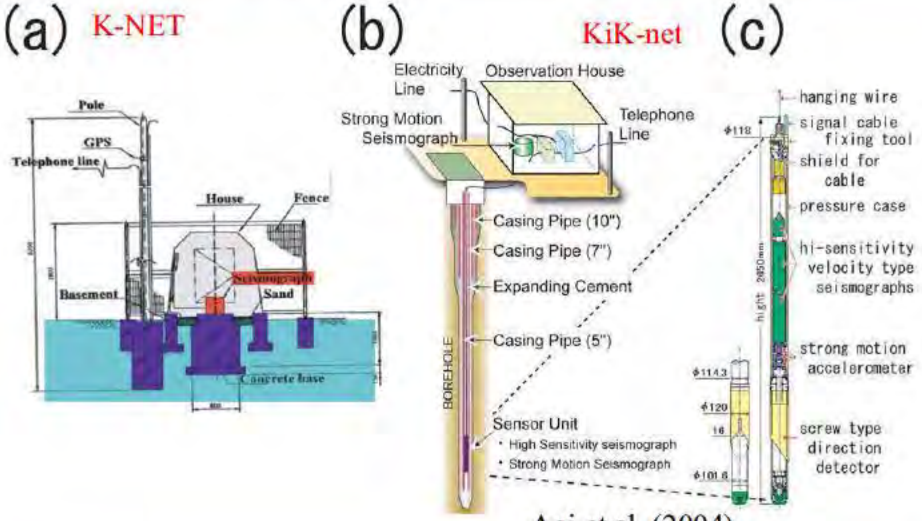
+RK-net、Dam、F-net

Database of strong motion on bedrock

Characteristics of strong motion on bedrock

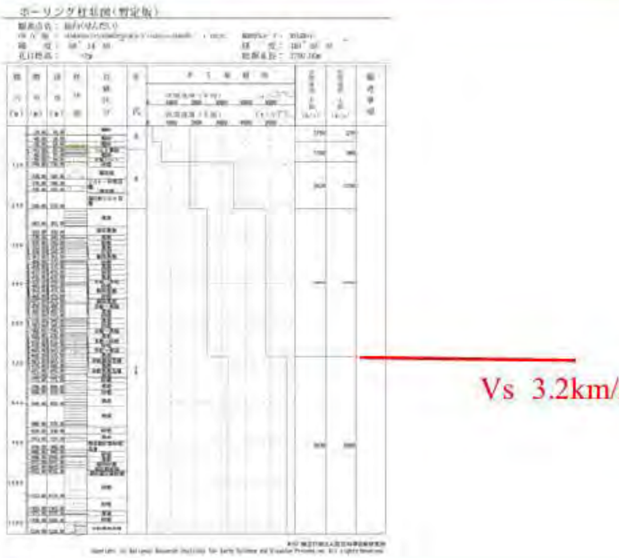
Development of Attenuation equation on bedrock

Strong motion observation on bedrock operated by NIED



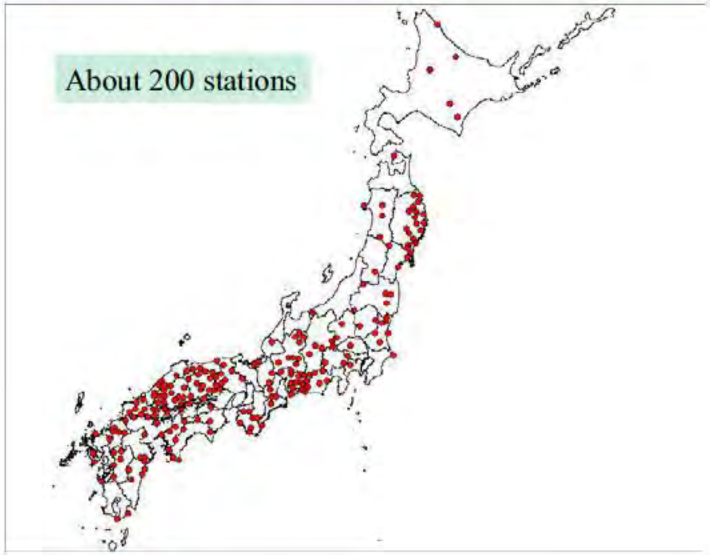
Aoi et al. (2004)

Example of the profile for observation station of KiK-net: MYGH01



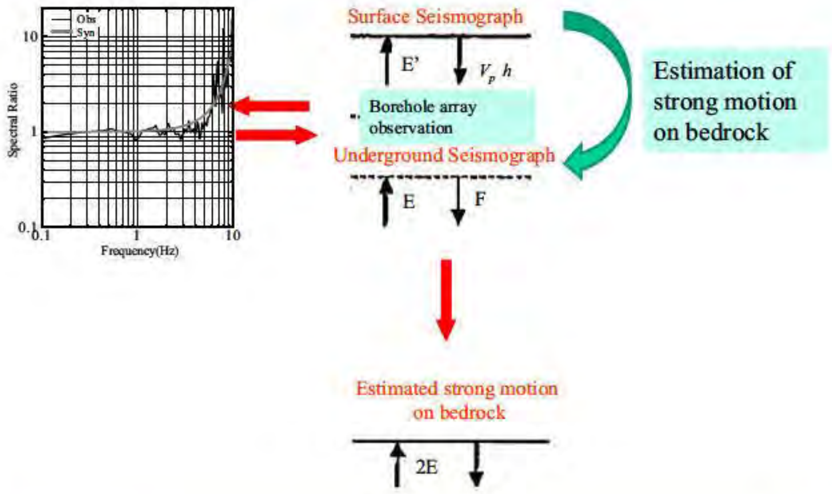
Vs 3.2km/s, Seismic bedrock

Observation stations of KiK-net with Vs of bedrock over 2km/s



About 200 stations

Estimation of strong motion on bedrock based on borehole data



Surface Seismograph

Borehole array observation

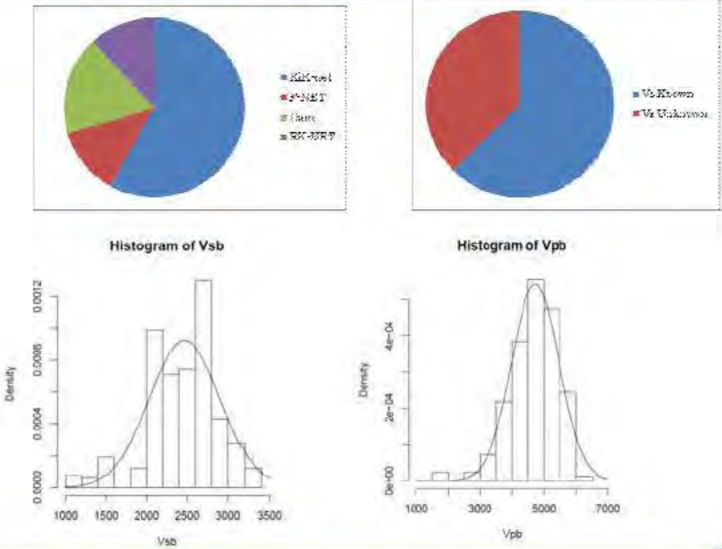
Underground Seismograph

Estimation of strong motion on bedrock

Estimated strong motion on bedrock

The 2nd Workshop on Seismic Observation in Deep Borehole (SODB) and its Applications

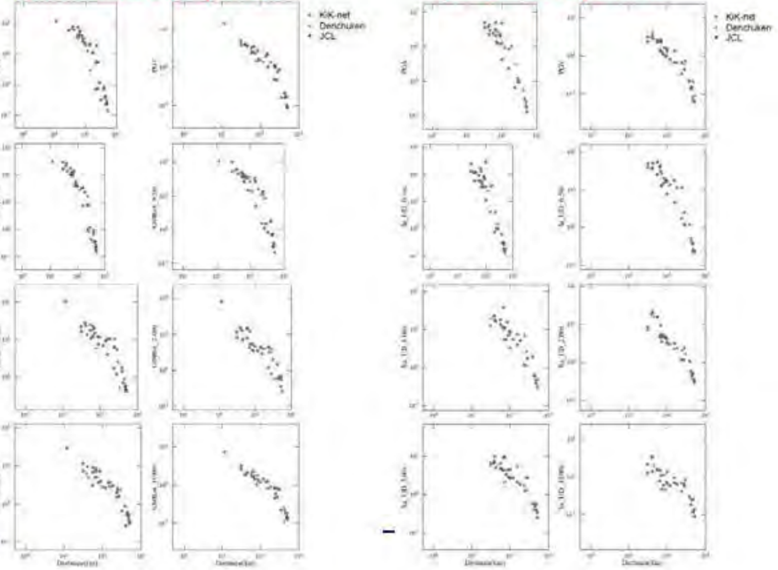
Category of the site conditions in the database



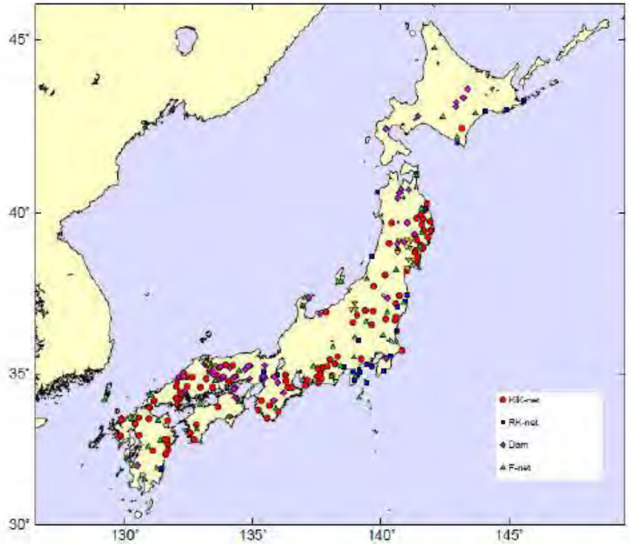
Characteristics of PGA, PGV and GMRotI50 on bedrock: the case for 2008 Iwate･Miyagi earthquake

Horizontal component

Vertical component

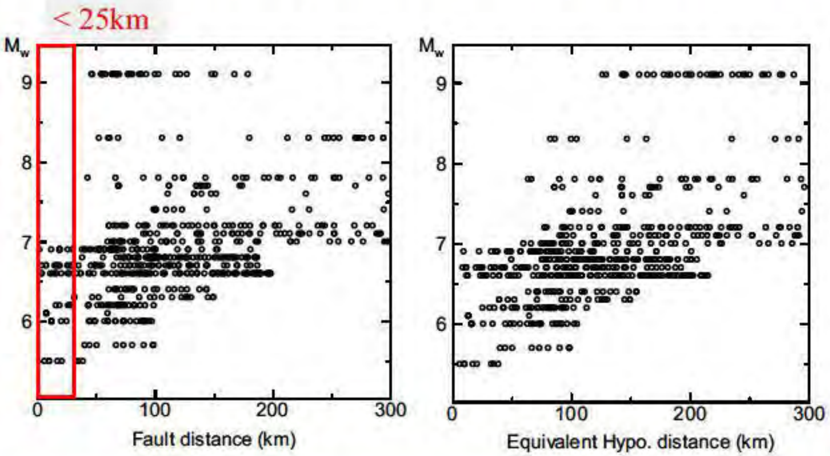


Distribution of observation stations used in this study



Distribution of Mw-Distance

Combined with the data from RK-net、Dam obs. Network, and F-NET, we derived an strong motion observation database on bedrock



Formulation of the GMPE on bedrock

$$\log\ A(T) = b(T) + g(X) - kX$$

$$A(T): GMRoTI50, PGA, PGV$$

$$g(X) = \begin{Bmatrix} -\log(X+C); D \le 30km \\ 0.6\log(1.7D+C) - 1.6\log(X+C); D > 30km\ \&\ X \ge 1.7D \end{Bmatrix}$$

$$C = 0.0055\ 10^{0\ 5M_w}, T < 0.5s$$

$$= 0.0028\ 10^{0\ 5M_w}, T \ge 0.5s$$

$$k = 0.003, T < 0.5s$$

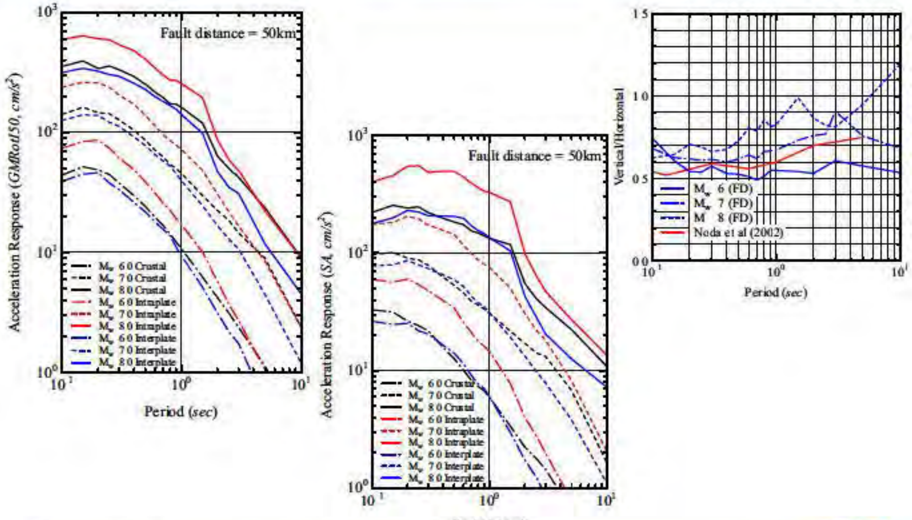
$$= 0.002, T \ge 0.5s$$

$$b(T) = \begin{Bmatrix} a_1(T)M_w + \sum d_i(T)S_i + h(T)D + \varepsilon_1(T) \\ a_2(T)M_w + \sum d_i(T)S_i + h(T)D + \varepsilon_2(T) \end{Bmatrix} \begin{pmatrix} a_1(T), \varepsilon_1(T): M \le 8.3 or M \le 7.5 if T \ge 2s \\ a_2(T), \varepsilon_2(T): M > 8.3 or M > 7.5 if T \ge 2s \end{pmatrix}$$

X is distance, adopted as fault distance (FD) and equivalent hypo. Distance (EHD). C 0 for EHD

The equation is constrained by the data from earthquakes with magnitudes ranged from Mw 5.5-9.0

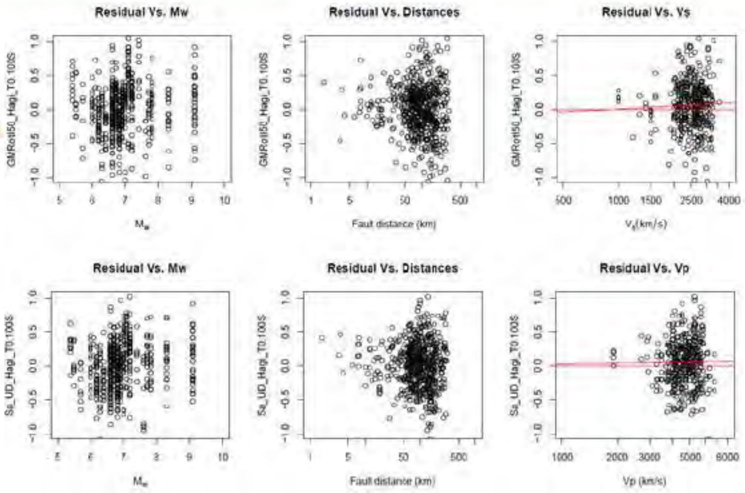
Predicted ground motion at distance of 50 km



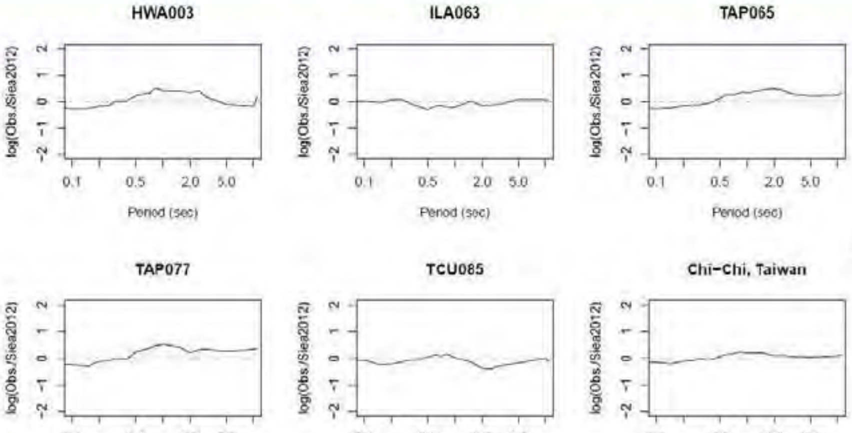
Residuals for response spectra at 0.1sec

Horizontal

Vertical

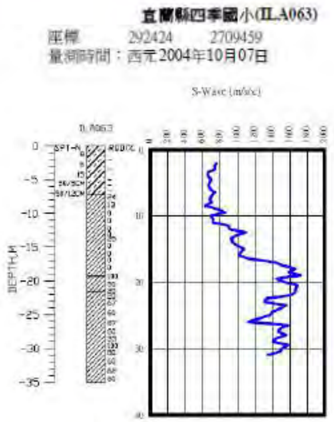


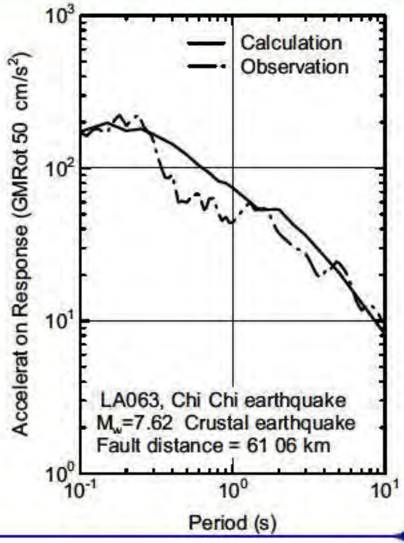
Application to M_w7.62 Chi-Chi earthquake



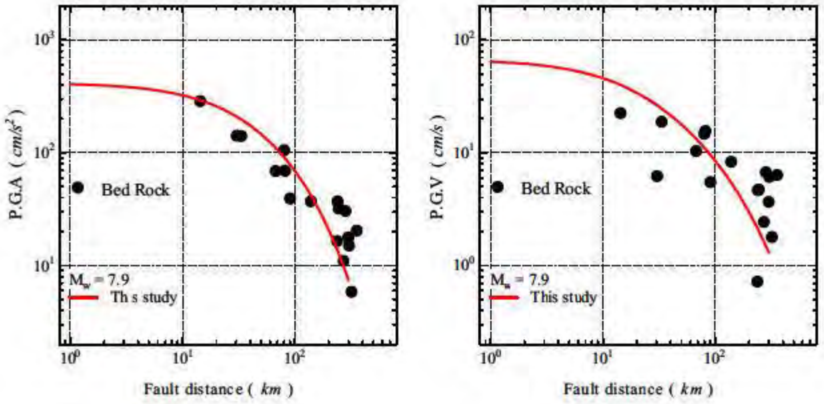
Station Name	Preferred Vs30 (m/s)
HWA003	1525.9
TAP065	1023.5
TAP077	1022.8
TCU085	999.7
LA063	998.5

M_w7.62 Chi-Chi earthquake: ILA063





Application to M_w7.9 Wenchuan earthquake



Conclusion remarks

- We have constructed a database of strong motion on bedrock, including the data derived in the near source area. Based on this database, a new attenuation relationship of response spectra on bedrock in Japan is under developed.
- Comparing with the strong motion data observed in the other countries implicated that the preliminary results of GMPE developed in Japan are applicable to the earthquakes in the other countries.

Acknowledgement

- We thank NIED(National Research Institute for Earth Science and Disaster Prevention) for providing the strong motion observations by KiK-net, F-NET and K-NET, also the structure model nationwide on J-SHIS. The thanks also go to CRIEPI(Central Research Institute of Electric Power Industry), JCL(Japan Commission on Large Dams), NILIM(National Institute for Land and Infrastructure Management) and Miyagi county for providing the strong motion records. We thank Dr. Aoi, Dr. Kataoka, Prof. Koketsu, Dr. Miyake, Prof. Ohmachi, Dr. Shiba, and Dr. Tajima for their kind help.
- This study is a corporation with Prof. Midorikawa, Tokyo Tech., and funded by JNES (Japan Nuclear Energy Safety Organization).

Seismic Intensity Map Triggered by Observed Strong Motion Records Considering Site Amplification and Its Service based on Geospatial International Standard

Masashi Matsuoka

Tokyo Institute of Technology
(National Institute of Advanced Industrial Science and Technology)

Background and Objectives

- Currently, the seismic intensity information is released on the basis of the instrumental seismic intensity measured by approximately 4,200 seismographs installed throughout the nation. However, since the seismic motions vary depending on geologic and geomorphologic features, the ground motion at a location without a seismograph is not always consistent with the seismic intensity recorded by a seismograph close to the point.

- In order to take effective countermeasures against seismic disasters and implement business continuity plans (BCPs) for municipalities and private companies, the quick estimation of strong ground motions for wider area is very essential at the early stages of disaster response activities.

Background and Objectives

- A first step for solving the issue can be to establish wide-ranging, seamless, and consistent precision data on amplification capability of ground and estimate and release the strong ground motion map of the concerned areas immediately after the occurrence of an earthquake.

- Data and Platform
  - Data: strong ground motion network (NIED), geomorphologic map and amplification capability
  - Platform: GEO (Global Earth Observation) Grid (AIST)

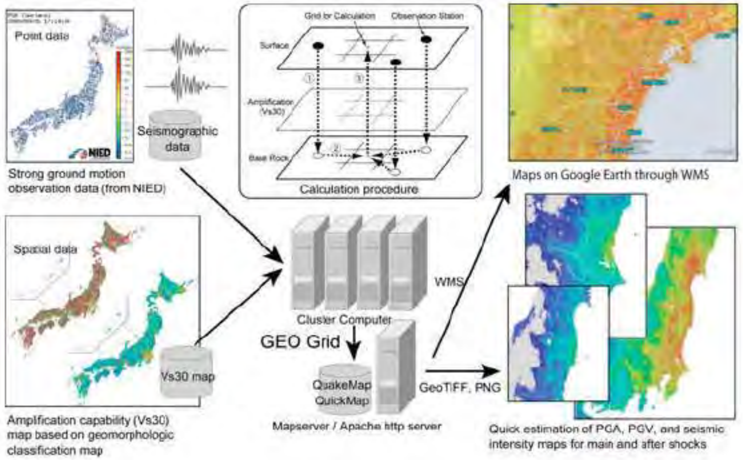
  GEO Grid aims at providing integrated service using a wide array of geoscientific information such as geologic maps and other digital geographically referenced data based on Grid and Web service technologies in accordance with international standards.

Contents

- QuiQuake (Quick estimation system for earthQuake maps triggered by observation records)
  - seismic event triggered quick estimation system for the generation of earthquake maps using earthquake observation records
- Amplification capability from geomorphologic condition
- Advantages of QuiQuake

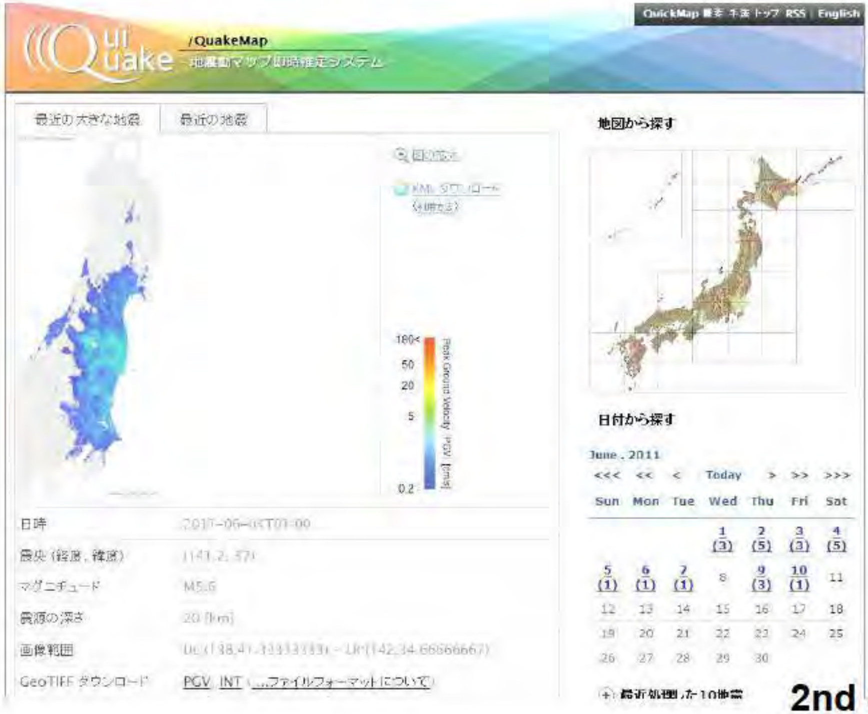
QuiQuake

QuiQuake is a system on GEO Grid which provides wide-ranging and detailed (250m-grid) strong ground motion maps for quick disaster response soon after the occurrence of an earthquake.



QuickMap and QuakeMap

- QuickMap http://qq.ghz.geogrid.org/QuickMap/index.en.html
  - QuickMap is calculated using the near real-time information of strong ground motion parameters of K-NET delivered by NIED right after an earthquake.
    - faster estimation
- QuakeMap http://qq.ghz.geogrid.org/index.en.html
  - QuakeMap which is calculated using the published seismic waveform records at seismic stations from the K-NET and KiK-net on the NIED portal site.
    - higher reliability



日時 [illegible]

震央 (経度, 緯度) (141.2, 37)

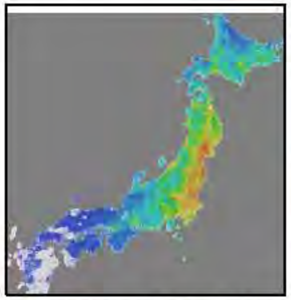
マグニチュード M5.6

震源の深さ 20 [km]

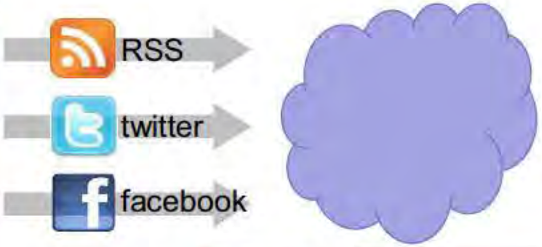
画像範囲 UL(138,41.33333333) – LR(142,34.66666667)

GeoTIFF ダウンロード PGV, INT (…ファイルフォーマットについて)

Dissemination to Social Media

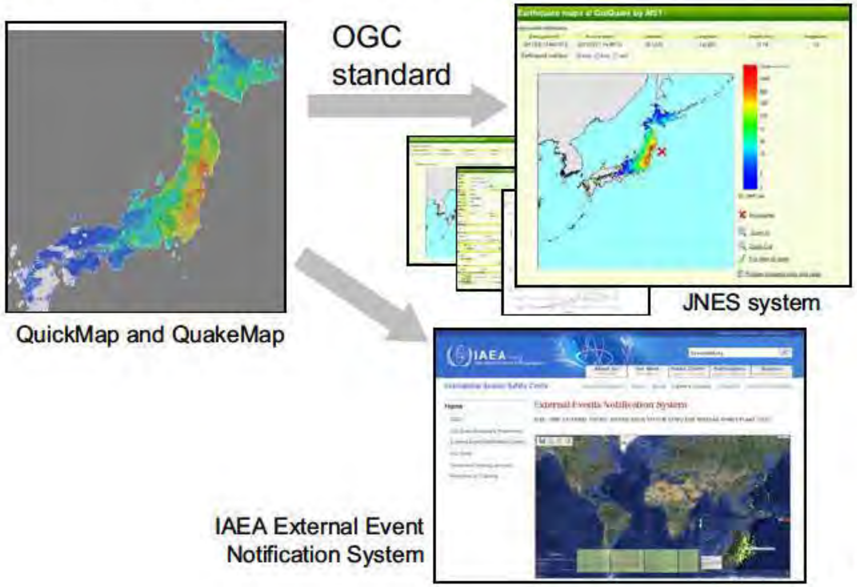


QuickMap and QuakeMap



QuickMap twitter log (@QuiQuake)

Dissemination to JNES and IAEA



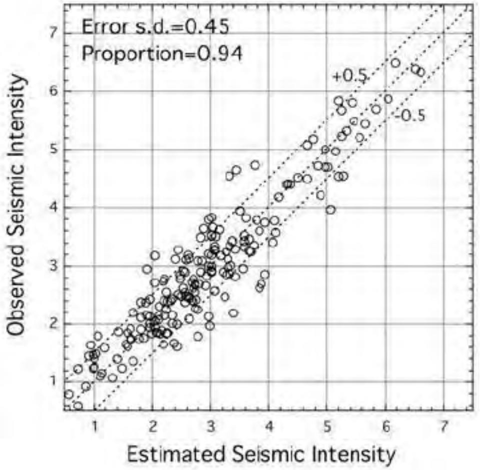
OGC standard

QuickMap and QuakeMap

JNES system

IAEA External Event Notification System

Accuracy of Estimation



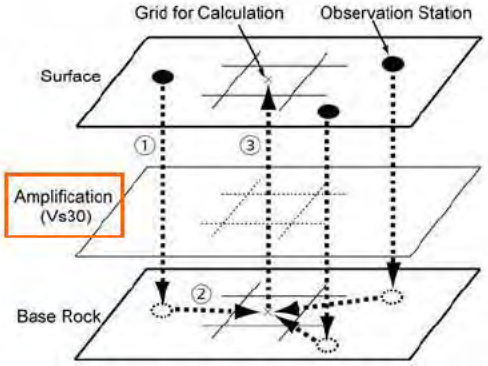
Comparison of the observed ground motion recorded by other organizations' seismic network stations and the estimated values at the stations estimated by Kriging using K-NET and KiK-net sites, and the amplification capability from Vs30 map for the 2004 Niigata-ken Chuetsu earthquake

Interpolation Algorism

① Estimating strong ground motion intensity value on base rock from the observed record divided by the amplification factor at the seismic station

② Calculating intensity value of the target grid on base rock by interpolating of surrounding values and also attenuation characteristics into consideration

③ Calculating intensity value on surface from multiplying by amplification factor

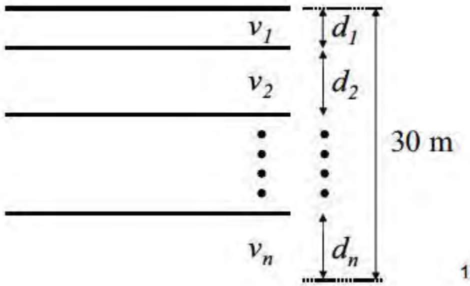


Free and Open Source Software: RASMO (Rapid Shake Map simulator with Observed records) developed by Kawasaki Lab/NIED

Amplification Capability Index

- For precise evaluation, soil profile data such as PS-logging is needed. However, for wider area, simple index from spatial information is useful because of the limitation of logging data.
- Average shear-wave velocity of ground in the upper 30m (Vs30) which has good correlation with PGV or seismic intensity amplification, is one of the available indices.

$$Vs30 \quad \frac{30}{\sum_{i=1}^{n} d_i / v_i} \quad [m/s]$$

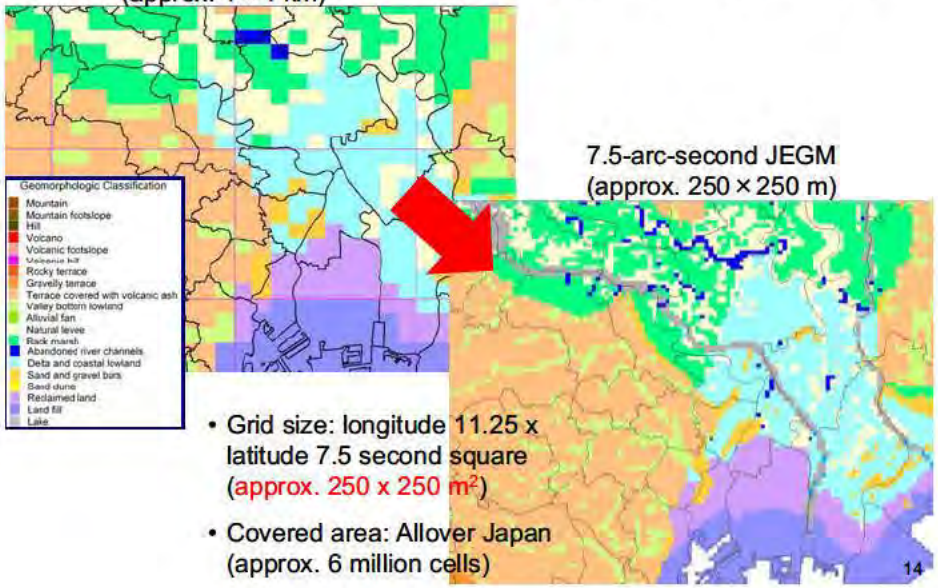


Japan Engineering Geomorphologic Classification Map (JEGM)

developed by Wakamatsu et al. (2004)

- Attribute: Geomorphologic classification, Surface geology, Slope gradient, and Relative relief
- Grid size: longitude 45 x latitude 30 second square (approx. 1 x 1 km^2)
- Covered area: Allover Japan (approx. 380,000 cells)

Upgrading JEGM


30-arc-second JEGM
(approx. 1 × 1 km)

7.5-arc-second JEGM
(approx. 250 × 250 m)

- Grid size: longitude 11.25 x latitude 7.5 second square (approx. 250 x 250 m^2)
- Covered area: Allover Japan (approx. 6 million cells)

Vs30 and Amplification Mapping Based on DEM and Geomorphology

In order to estimate Vs30 maps with better accuracy, geologic and/or geomorphologic information should be added to use.

Surface geology data derived from GSJ geologic map

7.5-arc-second Geomorphologic classification data

Description of Geomorphologic Classification

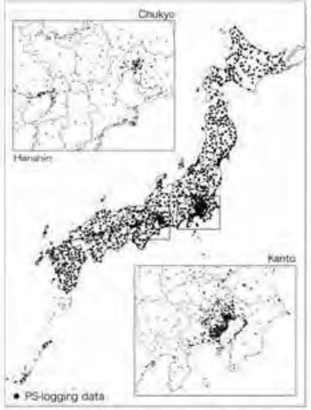
Geomorphologic classification has the information from both geology and topography.

Geomorphologic map unit	Definition and general characteristics	Subsurface soil condition	General depth of groundwater*
Mountain	Steeply to very steeply sloping topography with highest elevation and relative relief within a grid cell of approximately more than 200 m. Moderately to severely dissected	Pre Quaternary hard to soft rock.	Deep
Mountain footslope	Gently sloping topography adjoining mountains and comprised of material sourced from the mountains such as colluvium, talus, landslide and debris flow deposits	Loose debris and soils consisting of colluvium, talus, landslide, and debris flow deposits	Deep
Hill	Steeply to moderately sloping topography with higher elevation and relative relief within a grid cell of approximately 200 m or less. Moderately dissected	Pre-Quaternary and Quaternary hard to soft rock	Deep
Volcano	Steeply to moderately sloping topography with higher elevation and larger relative relief, comprised of Quaternary volcanic rocks and deposits	Quaternary hard to soft volcanic rock and/or deposits	Deep
Volcanic footslope	Gently sloping topography located around skirt of volcano including pyroclastic, mud and lava flow fields, and volcanic fan produced by dissection of volcanic body. Slightly dissected	Quaternary loose to dense volcanic deposits consisting of ash, scoria, pumice, pyroclastic flow, lava, debris avalanche, etc.	Deep
Volcanic hill	Moderately sloping topography composed of pyroclastic flow deposits. Moderately to severely dissected	Loose to moderately loose pyroclastic flow deposits such as ash, scoria and pumice	Deep
Rocky strath terrace	Fluvial or marine terrace with flat surface and step like form, including limestone terrace of emerged coral reef. Thickness of subsurface soil deposits is less than 5 m	Hard to soft rock	Deep
Gravelly terrace	Fluvial or marine terrace with flat surface and step-like form. Covered with subsurface deposits (gravel or sandy soil) of more than 5 m in thickness	Dense gravelly soil	Deep
Terrace covered with volcanic ash soil	Fluvial or marine terrace with flat surface and step like form. Covered with cohesive volcanic ash soil of more than 5 m in thickness	Stiff volcanic ash (cohesive soil)	Deep
Valley bottom plain	Long and narrow lowland formed by river or stream between steep to extremely steep slopes of mountain, hill, volcano and terrace	Moderately dense to dense gravel or boulder in mountain, but loose sandy soil to very soft cohesive soil in plain	Shallow
Alluvial fan	Semi cone-like form comprised of coarse materials which is formed at boundary between mountains and lowland. Slope gradient is more than 1/1000	Dense gravel with boulders to moderately dense sandy gravel	Deep in the central part of fan but shallow in the distal part of fan
Natural levee	Slightly elevated area formed along the riverbank by fluvial deposition during floods	Loose sandy soil	Shallow
Back marsh	Swampy lowland formed behind natural levees, dunes or bars and lowlands surrounded by mountains, hills and terraces	Very soft cohesive soil containing peat or humus	Very shallow
Abandoned river channels	Swampy shallow depression along former river course with elongate shape	Very loose sandy soil occasionally covered with soft cohesive soil	Very shallow
Delta and coastal lowland	Delta: flat lowland formed at the river mouth by fluvial accumulation. Coastal lowland: flat lowland formed along shoreline by emergence of shallow submarine deposits, including discontinuous lowlands along sea or lake shore	Loose fluvial sandy soil over-lying very soft cohesive soil	Shallow
Marine sand and gravel bars	Slightly elevated topography formed along shoreline, comprised of sand and gravel, which was washed ashore by ocean wave and/or current action.	Moderately dense to dense marine sand or gravel occasionally with boulder	Shallow
Sand dune	Wavy topography usually formed along shoreline or river, comprised of fine to moderately aeolian sand, generally overlies sandy lowland.	Very loose to loose fine to medium sand.	Deep at crest of dune but shallow near base of dune
Reclaimed land	Former bottom land adjoining sea, lake, lagoon, and river that has been reclaimed as land by drainage	Loose sand overlying very soft cohesive soil, sometimes covered with loose sandy fill	Very shallow
Filled land	Former water body such as sea, lake, lagoon, and river reclaimed as land by filling	Very loose to loose sandy fill overlying very soft cohesive soil or loose sandy soils	Very shallow to shallow

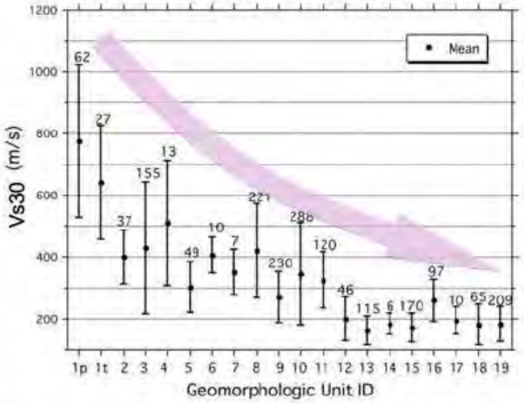
* Deep: deeper than 3 m below the ground surface, Shallow: within 3 m of the ground surface, Very shallow: within 1 m of the

K. Wakamatsu and M. Matsuoka: Development of the 7.5 Arc Second Engineering Geomorphologic Classification Database and its Application to Seismic Microzoning, Bulletin of Earthquake Research Institute, Vol.81, pp.317-324, 2006.

Relationship between Vs30 and Geomorphologic Unit



about 2,000 PS-logging data



1p: Mountain(Pre-Tertiary) 1t: Mountain(Tertiary) 2: Mountain footslope 3: Hill
4: Volcano 5: Volcanic footslope 6: Volcanic hill 7: Rocky strath terrace
8: Gravelly terrace 9: Terrace covered with volcanic ash soil
10: Valley bottom lowland 11: Alluvial fan 12: Natural levee 13: Back marsh
14: Abandoned river channels 15: Delta and coastal lowland 16: Marine sand and gravel bars 17: Sand dune 18: Reclaimed land 19: Filled land

Estimating Vs30 from Geographic Information

According to the sedimentation process, following indices are considered to estimate Vs30 for each geomorphologic unit.

explanatory valuables:

- Elevation (*Ev*)
- Slope gradient (*Sp*)
- Distance from mountain or hill of pre-Tertiary or Tertiary (*Dm*)

Multiple regression analysis

$$\mathrm{Vs30} \quad a + b \log Ev + c \log Sp + d \log Dm \pm \sigma$$

Regression Coefficient for Estimating Vs30

ID	Geomorphologic unit	Regression coefficient (Standard regression coefficient)				s.d.
		a	b	c	d	σ
1p	Mountain (pre-Tertiary)	2.900	0	0	0	0.139
1t	Mountain (Tertiary)	2.807	0	0	0	0.117
2	Mountain footslope	2.602	0	0	0	0.092
3	Hill	2.349	0	0.152 (0.219)	0	0.175
4	Volcano	2.708	0	0	0	0.162
5	Volcanic footslope	2.315	0	0.094 (0.382)	0	0.100
6	Volcanic hill	2.608	0	0	0	0.059
7	Rocky terrace	2.546	0	0	0	0.094
8	Gravelly terrace	2.493	0.072 (0.270)	0.027 (0.101)	-0.164 (-0.336)	0.122
9	Terrace covered with volcanic ash soil	2.206	0.093 (0.269)	0.065 (0.223)	0	0.115
10	Valley bottom lowland	2.266	0.144 (0.447)	0.016 (0.040)	-0.113 (-0.265)	0.158
11	Alluvial fan	2.350	0.085 (0.419)	0.015 (0.059)	0	0.116
12	Natural levee	2.204	0.100 (0.368)	0	0	0.124
13	Back marsh	2.190	0.038 (0.178)	0	-0.041 (-0.152)	0.116
14	Abandoned river channel	2.264	0	0	0	0.091
15	Delta and coastal lowland	2.317	0	0	-0.103 (-0.403)	0.107
16	Sand and gravel bars	2.415	0.000	0	0	0.114
17	Sand dune	2.289	0	0	0	0.123
18	Reclaimed land	2.373	0	0	-0.124 (-0.468)	0.123
19	Filled land	2.404	0	0	-0.139 (-0.418)	0.120

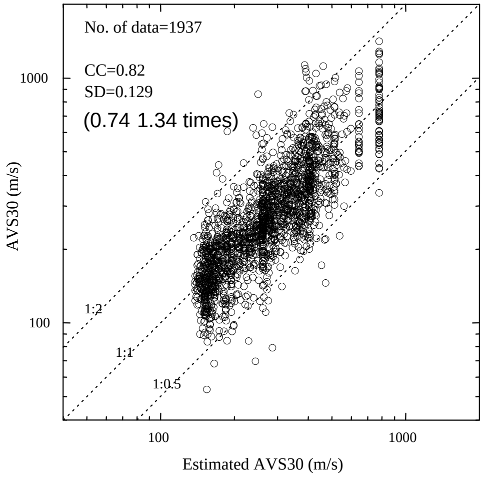
$\log AVS30 = a + b \log Ev + c \log Sp + d \log Dm \pm \sigma$

AVS30: Average S-wave velocity (m/s), *Ev*: Elevation (m), *Sp*: (Tangent of slope) * 1000,
Dm: Distance (km) from mountain or hill of pre-Tertiary or Tertiary

Discussion for Regression Coefficient

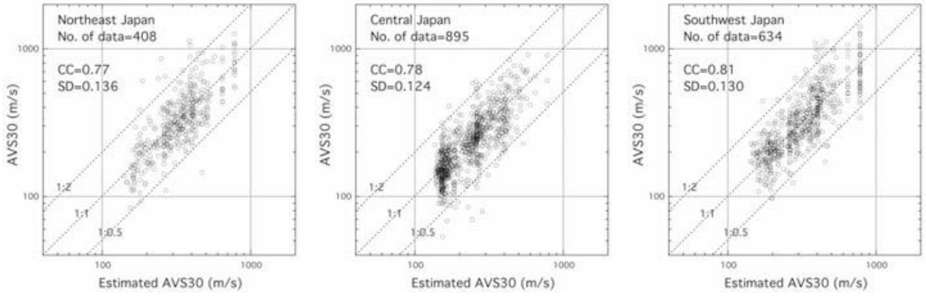
- What we can generalize from the regression coefficients is that the higher the elevation, the steeper the slope gradient and the shorter the distance from the mountain or hill, Vs30 values become larger.
- In the upstream region of a river (an area at a high altitude with steep slope gradient), the Vs30 becomes larger as the grain size of deposits is larger, and the closer the distance to the mountain or hill, the shallower the depth to a bedrock.
- The trend of the obtained regression coefficient is considered to be consistent with the sedimentary environment of the geomorphologic unit.

Relationship between Vs30 Estimated by Regression Analysis and Actual Vs30

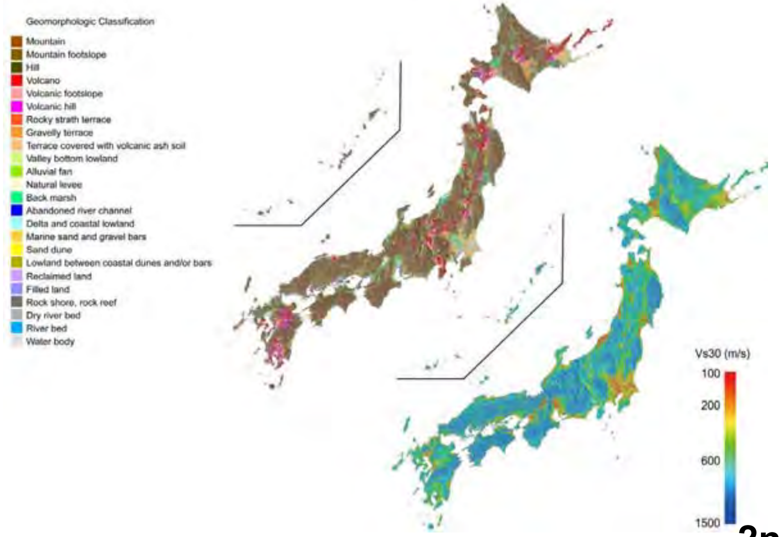


- Estimation by regression equation improved the estimation accuracy by ±0.129 of logarithmic standard deviation, which shows that Vs30 can be estimated more accurately than by existing empirical formula.

Relationship between Estimated Vs30 and Actual Vs30 (comparison by areas)



Estimated Vs30 Map Using DEM and Geomorphologic Data



Site Amplification Capability Map from Estimated Vs30 Map

PGA:

$$\log Amp = b \log (Vs30 / 600) \pm 0.200$$

$$b = -0.773 \; (\gamma'_{eff} < 3 \text{ x } 10^{4})$$
$$= 2.042 + 0.799 \log \gamma'_{eff} \; (\gamma'_{eff} \geq 3 \text{ x } 10^{4})$$

$$\gamma'_{eff} = 0.4 \, PGV / Vs30$$

PGV:

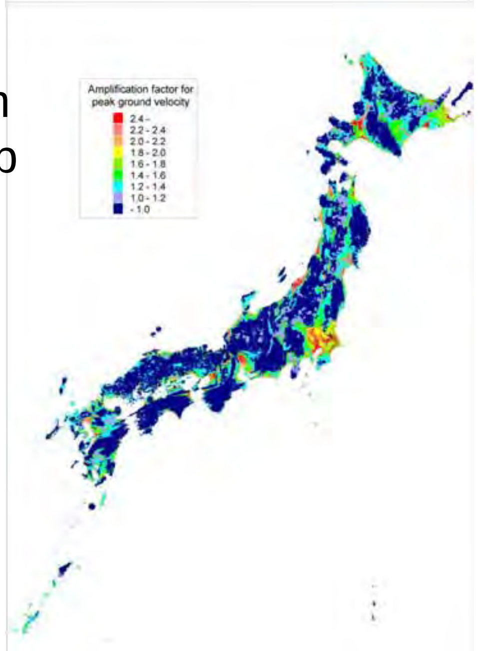
$$\log Amp = 0.852 \log (Vs30 / 600) \pm 0.166$$

(Fujimoto and Midorikawa, 2006)

I_{JMA}:

$$Amp = 3.74 \quad 1.34\, b \log Vs30 \pm 0.18$$

(Midorikawa et al., 2008)



PGV Amplification Map

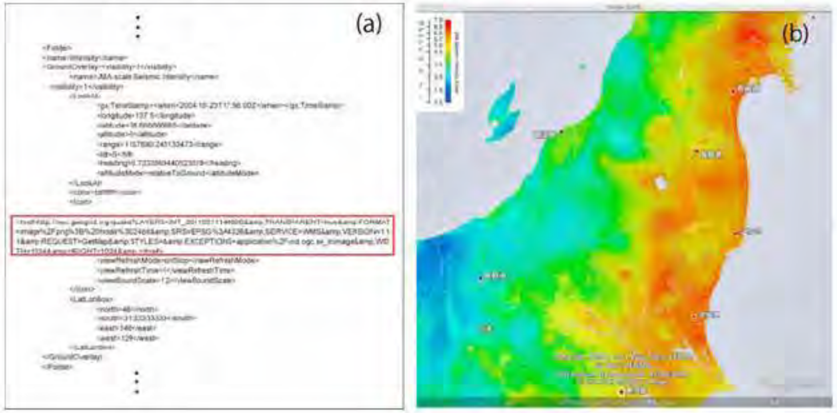
Advantages of QuiQuake

- OGC (Open Geospatial Consortium) standard
  - WMS (Web Map Service)
  - WCS (Web coverage Service)
  - KML
- Automatic and multi-task computation

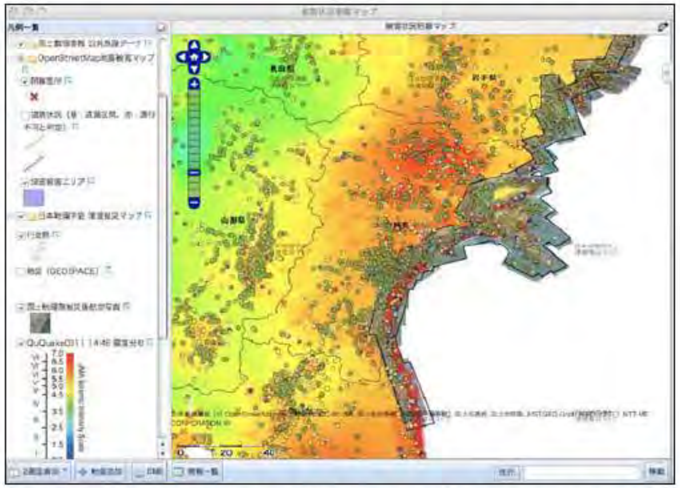
KML (WMS)

The example of KML document with WMS URI of QuakeMap imagery of the I_{JMA} distribution covering the 2011 Tohoku, Japan earthquake affected area is displayed on Google Earth

Red rectangle highlights the inserted WMS URI

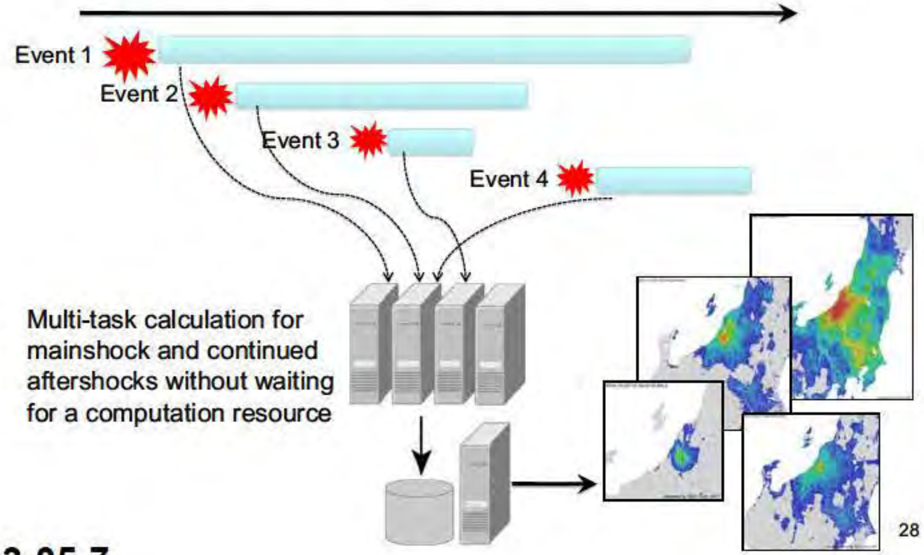


On Other Portal Sites



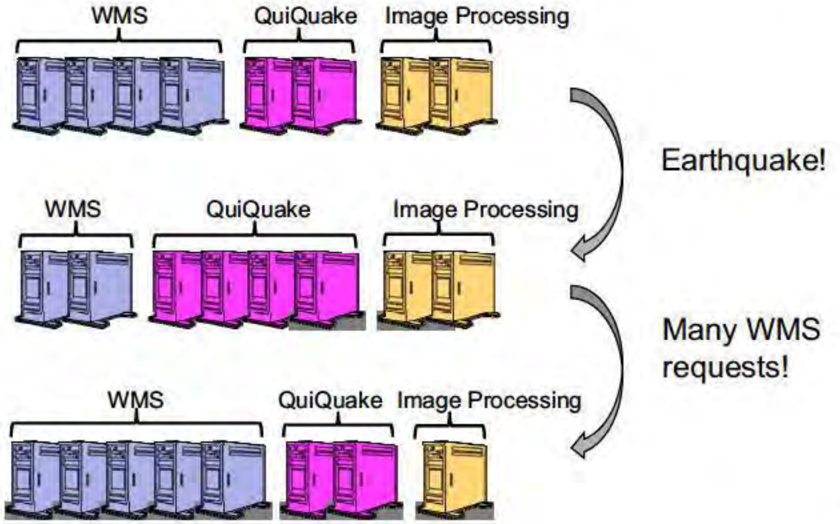
ALL311 activity operated by NIED (http://all311.ecom-plat.jp/) utilizes GEO Grid and other contents through WMS.

Automatic and Multi-task Computation



Multi-task calculation for mainshock and continued aftershocks without waiting for a computation resource

To Elastic System (Cloud)



Conclusions

- The QuiQuake, which provides a 250-m resolution strong ground motion maps covering wide area, for quick disaster response right after an earthquake occurrence throughout Japan, is presented.
- In this system, an amplification capability map of ground motion (Vs30 map) based on Japan Engineering Geomorphologic Classification Map (JEGM) and seismic observation records from K-NET and KiK-net released by the National Research Institute for Earth Science and Disaster Prevention (NIED) are processed on a GEO Grid cluster computer of AIST.
- The use of the GEO Grid system in producing strong ground motion maps offers the following advantages:

  fully automatic, quick, and multi task computing for mainshock and continued aftershocks,

  publication of the maps through Open Geospatial Consortium (OGC) compliant Web GIS server, and

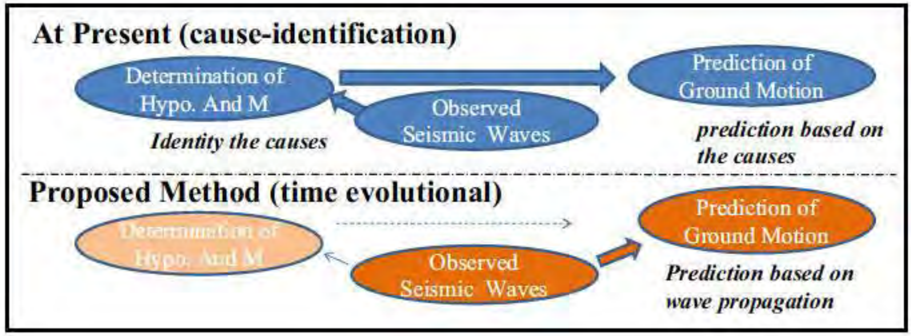
  possibility to expand more stabilized and redundant operations by Virtual Machine in external servers and Cloud system.

Real-Time Prediction of Earthquake Ground Motion

－Time Evolutional Prediction and Real Time Correction of Site Amplification Factors－

at Kashiwazaki, 2012/11/9

Mitsuyuki HOSHIBA (Meteorological Res., Inst., JMA, Japan)



At Present (cause-identification)

Identity the causes

prediction based on the causes

Proposed Method (time evolutional)

Prediction based on wave propagation

Weak point of methods based on hypo., M (and source characteristics)

Using Observed wave field

Modeling source characteristics

Source is represented by limited number of parameters
- Hypo. x,y,z
- Magnitude, M
- O.T. , t_0
- (source extent, Σ)
- (Directivity, φ)
- (fc, fmax)
- ・・・

$$|\text{Obs.} - f(x, y, z, t_0, M, \varphi, \Sigma, \ldots)|^2 \rightarrow 0$$
$$(\neq 0)$$

Impossible to reproduce 100% consistent with Obs.

⇩

Deviate from real Obs.

Time Evolutional Prediction using Wave Propagation Theory

Time evolutional prediction ;

$$u(\boldsymbol{r}, t_c+\Delta t) = \mathcal{H}(u(\boldsymbol{r}, t_c), \dot{u}(\boldsymbol{r}, t_c), \nabla u(\boldsymbol{r}, t_c), \nabla^2 u(\boldsymbol{r}, t_c))$$

$$\frac{1}{v^2}\ddot{u}(\boldsymbol{r},t) = \nabla^2 u(\boldsymbol{r},t)$$

Time evolution of waves is given … by surrounding wavefield

Hypo. And M are NOT required

Finite difference method

$$u(\boldsymbol{r},t+\Delta t) \approx \Delta t\{\Delta t\, v_0^2 \nabla^2 u(\boldsymbol{r},t) + \dot{u}(\boldsymbol{r},t)\} + u(\boldsymbol{r},t)$$

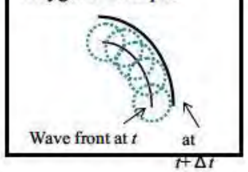
Boundary integral equation method (Kirchhoff integral)

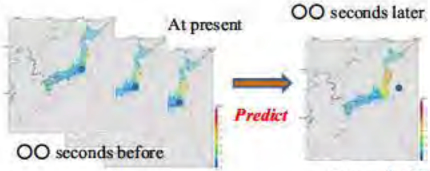
$$u(\boldsymbol{r},t+\Delta t) = \int (u(\boldsymbol{r}_1,t) * \frac{\partial G(\boldsymbol{r},\Delta t,\boldsymbol{r}_1,0)}{\partial n} - G(\boldsymbol{r},\Delta t,\boldsymbol{r}_1,0) * \frac{\partial u(\boldsymbol{r}_1,t)}{\partial n}) dS$$

Kirchhoff-Fresnel integral (high freq. approximation)

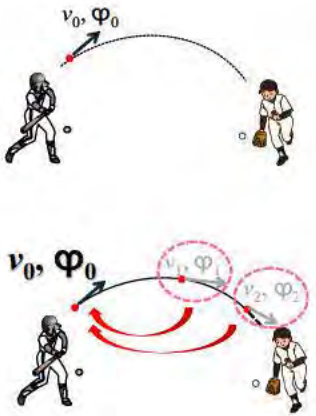
$$u(\boldsymbol{r},t+\Delta t) \approx \int \frac{1}{v}(\cos\theta + \cos\theta')\, G(\boldsymbol{r}-\boldsymbol{r}_1, t-|\boldsymbol{r}-\boldsymbol{r}_1|/v) * \dot{u}(\boldsymbol{r}_1, t-|\boldsymbol{r}-\boldsymbol{r}_1|/v) dS$$

Huygens Principle





Cause-Identification Prediction



Time Evolutional Prediction

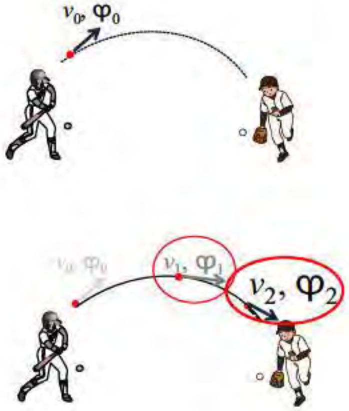
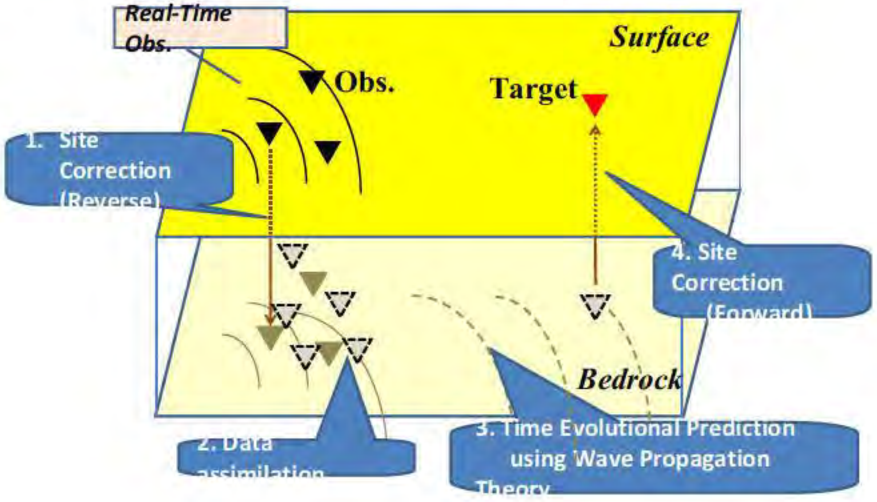


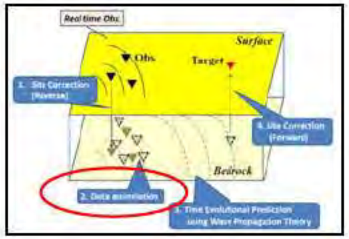
Image of real Time Prediction of Earthquake Ground Motion



Procedures should be preformed in real-time manner

Data Assimilation

Data assimilation is a technique to produce artificially denser network, which is widely used for numerical weather forecast and oceanography.



$$u_p(\boldsymbol{r}, t_c+\Delta t) \quad \mathcal{H}(u_a(\boldsymbol{r}, t_c))$$

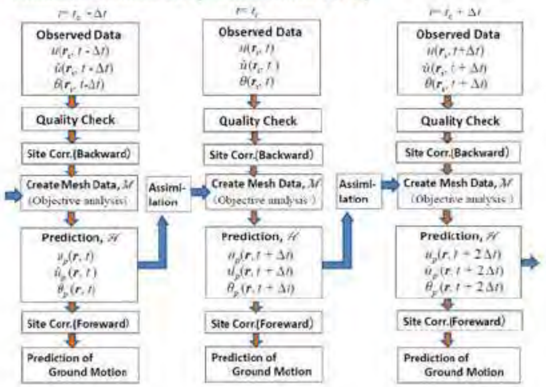
$$u_a = u_p + w(u_o \quad u_p)$$

w 1: Observation is reliable

◊

0: Prediction is reliable

Prediction of wavefield at $t=t_c+\Delta t$ from wavefield at $t=t_c$



$t=t_c-\Delta t$

Observed Data
$u(\boldsymbol{r}_v, t-\Delta t)$
$\dot{u}(\boldsymbol{r}_v, t-\Delta t)$
$\theta(\boldsymbol{r}_v, t-\Delta t)$

Quality Check

Site Corr.(Backward)

Create Mesh Data, $\mathcal{M}$ (Objective analysis)

Prediction, $\mathcal{H}$
$u_p(\boldsymbol{r}, t)$
$\dot{u}_p(\boldsymbol{r}, t)$
$\theta_p(\boldsymbol{r}, t)$

Site Corr.(Foreward)

Prediction of Ground Motion

Assimi-lation

$t=t_c$

Observed Data
$u(\boldsymbol{r}_v, t)$
$\dot{u}(\boldsymbol{r}_v, t)$
$\theta(\boldsymbol{r}_v, t)$

Quality Check

Site Corr.(Backward)

Create Mesh Data, $\mathcal{M}$ (Objective analysis)

Prediction, $\mathcal{H}$
$u_p(\boldsymbol{r}, t+\Delta t)$
$\dot{u}_p(\boldsymbol{r}, t+\Delta t)$
$\theta_p(\boldsymbol{r}, t+\Delta t)$

Site Corr.(Foreward)

Prediction of Ground Motion

Assimi-lation

$t=t_c+\Delta t$

Observed Data
$u(\boldsymbol{r}_v, t+\Delta t)$
$\dot{u}(\boldsymbol{r}_v, t+\Delta t)$
$\theta(\boldsymbol{r}_v, t+\Delta t)$

Quality Check

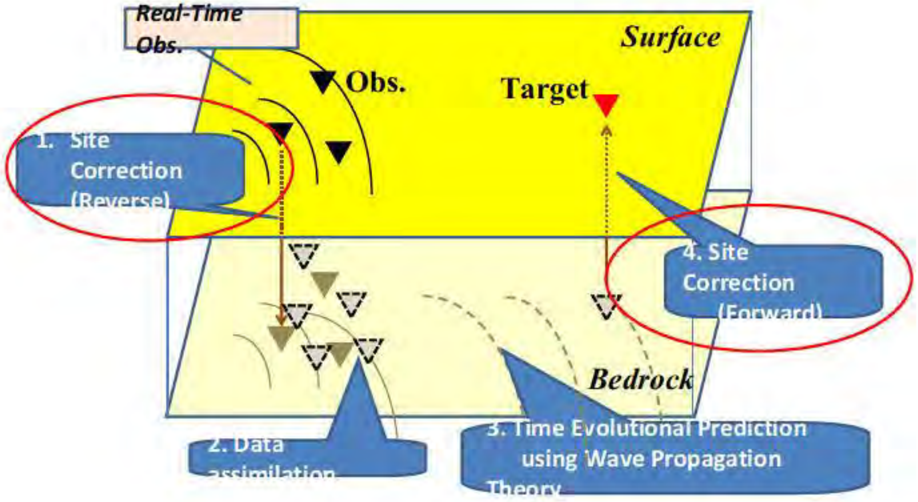
Site Corr.(Backward)

Create Mesh Data, $\mathcal{M}$ (Objective analysis)

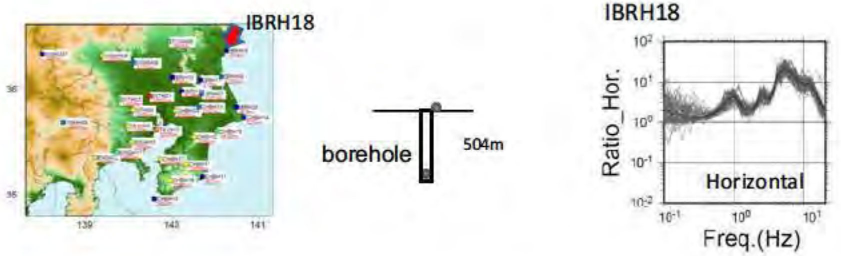
Prediction, $\mathcal{H}$
$u_p(\boldsymbol{r}, t+2\Delta t)$
$\dot{u}_p(\boldsymbol{r}, t+2\Delta t)$
$\theta_p(\boldsymbol{r}, t+2\Delta t)$

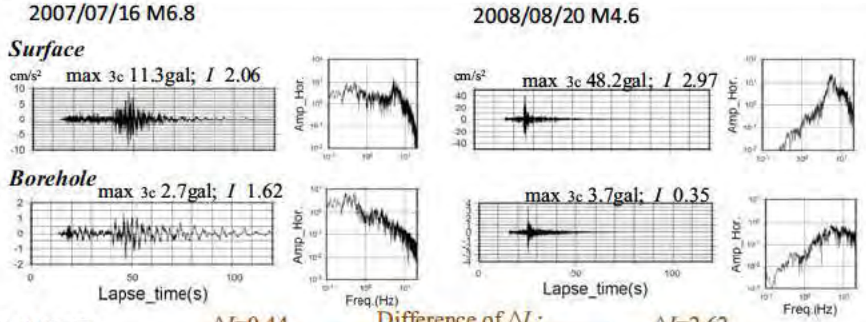
Site Corr.(Foreward)

Prediction of Ground Motion



Procedures should be preformed in real-time manner



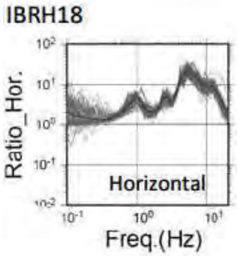


ΔI=0.44 Difference of ΔI : ΔI=2.62

Site Amplification Factors

Amp. → M, PGA, PGV Intensity, Pd

Dominant Freq. → τ_c



- Scalar → Frequency Dependent

Amp. factor of PGV, PGA, Intensity — Spectrum

- In real time

Operation in Freq. domain → Operation in time domain

Create causal filter reproducing the frequency-dependent site factor

Modeling site factor using causal IIR-Filter

$$F(s) = G_0 \prod_{n=1}^{N}\left(\frac{\omega_{2n}}{\omega_{1n}}\right)\cdot\frac{s+\omega_{1n}}{s+\omega_{2n}}\cdot\prod_{m=1}^{M}\left(\frac{\omega_{2m}}{\omega_{1m}}\right)^2\cdot\frac{s^2+2h_1\omega_{1m}s+\omega_{1m}{}^2}{s^2+2h_2\omega_{2m}s+\omega_{2m}{}^2}$$

$$F_n(s) = \left(\frac{\omega_{2n}}{\omega_{1n}}\right)\cdot\frac{s+\omega_{1n}}{s+\omega_{2n}}$$

$$F_m(s) = \left(\frac{\omega_{2m}}{\omega_{1m}}\right)^2\cdot\frac{s^2+2h_1\omega_{1m}s+\omega_{1m}{}^2}{s^2+2h_2\omega_{2m}s+\omega_{2m}{}^2}$$

$$s = \frac{2}{\Delta T}\frac{1-z^{-1}}{1+z^{-1}} \qquad \omega \rightarrow \frac{2}{\Delta T}tan\left(\frac{\omega\Delta T}{2}\right)$$

$$F_n(z) = g_0\cdot\frac{a_0+a_1z^{-1}}{1+b_1z^{-1}}$$

$$g_0 = \frac{tan(\frac{\omega_{2n}\Delta T}{2})}{tan(\frac{\omega_{1n}\Delta T}{2})}\cdot\frac{1}{1+tan(\frac{\omega_{2}\Delta T}{2})}$$

$$a_0 = 1+tan(\frac{\omega_{1n}\Delta T}{2})$$

$$a_1 = tan\left(\frac{\omega_{1n}\Delta T}{2}\right)-1$$

$$b_1 = \frac{tan\left(\frac{\omega_{2n}\Delta T}{2}\right)-1}{1+tan(\frac{\omega_{2n}\Delta T}{2})}$$

$$F_m(z) = g_0\cdot\frac{a_0+a_1z^{-1}+a_2z^{-2}}{1+b_1z^{-1}+b_2z^{-2}}$$

$$g_0 = \left\{\frac{tan(\frac{\omega_{2m}\Delta T}{2})}{tan(\frac{\omega_{1m}\Delta T}{2})}\right\}^2\cdot\frac{1}{1+2h_2\,tan\left(\frac{\omega_{2m}\Delta T}{2}\right)+tan^2\left(\frac{\omega_{2m}\Delta T}{2}\right)}$$

$$a_0 = 1+2\,h_1\,tan\left(\frac{\omega_{1m}\Delta T}{2}\right)+tan^2\left(\frac{\omega_{1m}\Delta T}{2}\right)$$

$$a_1 = 2h_1\,tan\left(\frac{\omega_{1m}\Delta T}{2}\right)-2$$

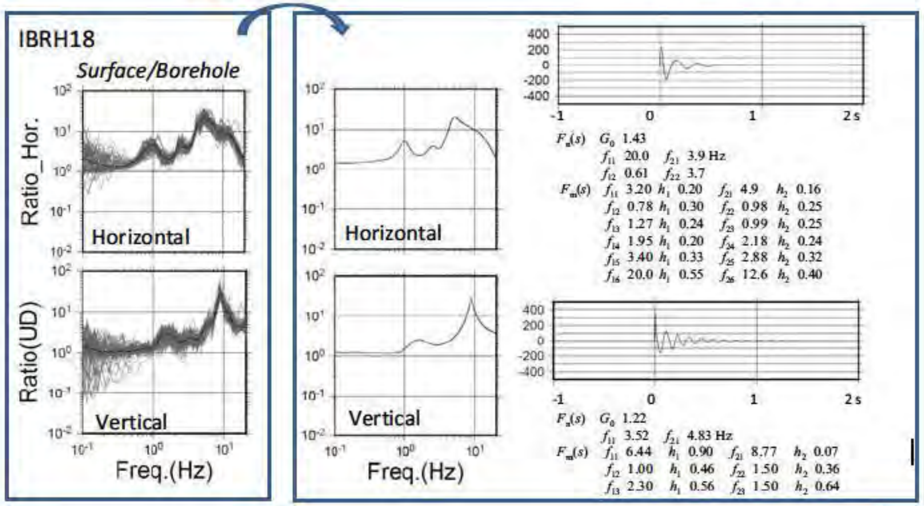
$$a_2 = 1-2h_1\,tan\left(\frac{\omega_{1m}\Delta T}{2}\right)+tan^2\left(\frac{\omega_{1m}\Delta T}{2}\right)$$

$$b_1 = \frac{2\,tan^2\left(\frac{\omega_{2m}\Delta T}{2}\right)-2}{1+2\,h_2\,tan\left(\frac{\omega_{2m}\Delta T}{2}\right)+tan^2\left(\frac{\omega_{2m}\Delta T}{2}\right)}$$

$$b_2 = \frac{1-2h_2\,tan\left(\frac{\omega_{2m}\Delta T}{2}\right)+tan^2\left(\frac{\omega_{2m}\Delta T}{2}\right)}{1+2h_2\,tan\left(\frac{\omega_{2m}\Delta T}{2}\right)+tan^2\left(\frac{\omega_{2m}\Delta T}{2}\right)}$$

Approximate !

In this analysis , 0.1 20Hz



$F_n(s)$ G_0 1.43
f_{11} 20.0 f_{21} 3.9 Hz
f_{12} 0.61 f_{22} 3.7
$F_m(s)$ f_{11} 3.20 h_1 0.20 f_{21} 4.9 h_2 0.16
f_{12} 0.78 h_1 0.30 f_{22} 0.98 h_2 0.25
f_{13} 1.27 h_1 0.24 f_{23} 0.99 h_2 0.25
f_{14} 1.95 h_1 0.20 f_{24} 2.18 h_2 0.24
f_{15} 3.40 h_1 0.33 f_{25} 2.88 h_2 0.32
f_{16} 20.0 h_1 0.55 f_{26} 12.6 h_2 0.40

$F_n(s)$ G_0 1.22
f_{11} 3.52 f_{21} 4.83 Hz
$F_m(s)$ f_{11} 6.44 h_1 0.90 f_{21} 8.77 h_2 0.07
f_{12} 1.00 h_1 0.46 f_{22} 1.50 h_2 0.36
f_{13} 2.30 h_1 0.56 f_{23} 1.50 h_2 0.64

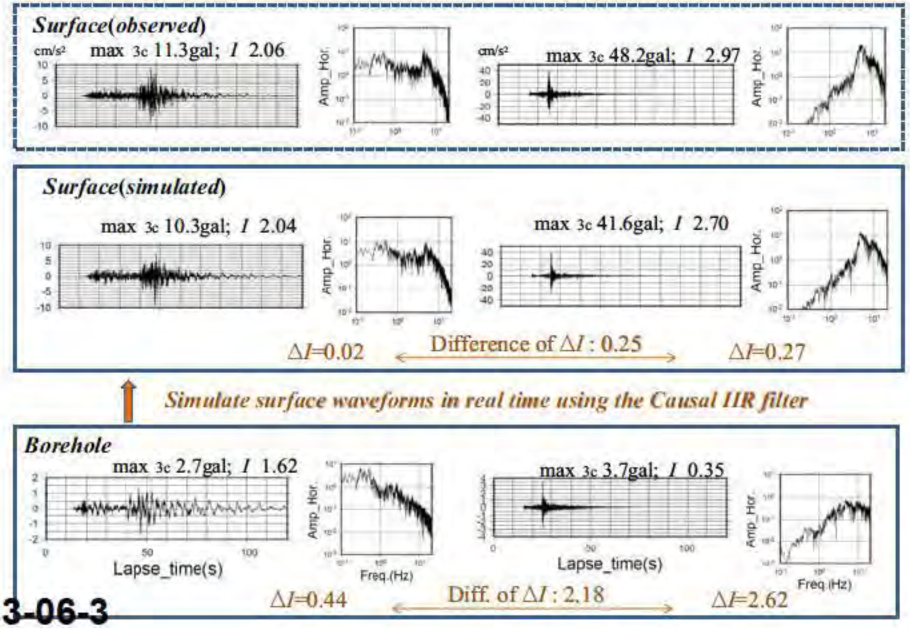
$$F_n(s) = \left(\frac{\omega_{2n}}{\omega_{1n}}\right)\cdot\frac{s+\omega_{1n}}{s+\omega_{2n}} \qquad F_m(s) = \left(\frac{\omega_{2m}}{\omega_{1m}}\right)^2\cdot\frac{s^2+2h_1\omega_{1m}s+\omega_{1m}{}^2}{s^2+2h_2\omega_{2m}s+\omega_{2m}{}^2}$$

$f_{1n} = \omega_{1n}/2\pi \quad f_{2n} = \omega_{2n}/2\pi$

$f_{1m} = \omega_{1m}/2\pi \quad f_{2m} = \omega_{2m}/2\pi$

IBRH18

2007/07/16 M6.8 — 2008/08/20 M4.6



Surface(observed)

max 3c 11.3gal; I 2.06 — max 3c 48.2gal; I 2.97

Surface(simulated)

max 3c 10.3gal; I 2.04 — max 3c 41.6gal; I 2.70

ΔI=0.02 ← Difference of ΔI : 0.25 → ΔI=0.27

Simulate surface waveforms in real time using the Causal IIR filter

Borehole

max 3c 2.7gal; I 1.62 — max 3c 3.7gal; I 0.35

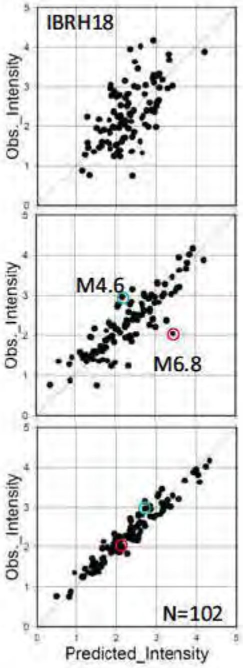
ΔI=0.44 ← Diff. of ΔI : 2.18 → ΔI=2.62

Predicted Intensity :

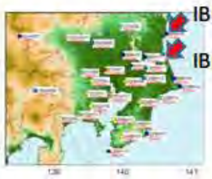
From Hypo. And M

From Seis. Intensity at borehole (ΔI=1.82)

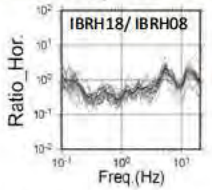
Applying the filter to waveform at borehole



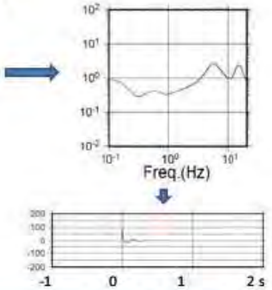
Prediction of ground motion using neighbor station



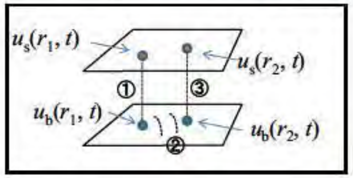
Dist. 27.6km



(relative) site factor



When hypo. distance >> $|r_1\ r_2|$;



Data assimilation has not yet applied in this simulation

① $u_b(r_1, t)\ \ f_1^{\ 1}(t) * u_s(r_1, t)$

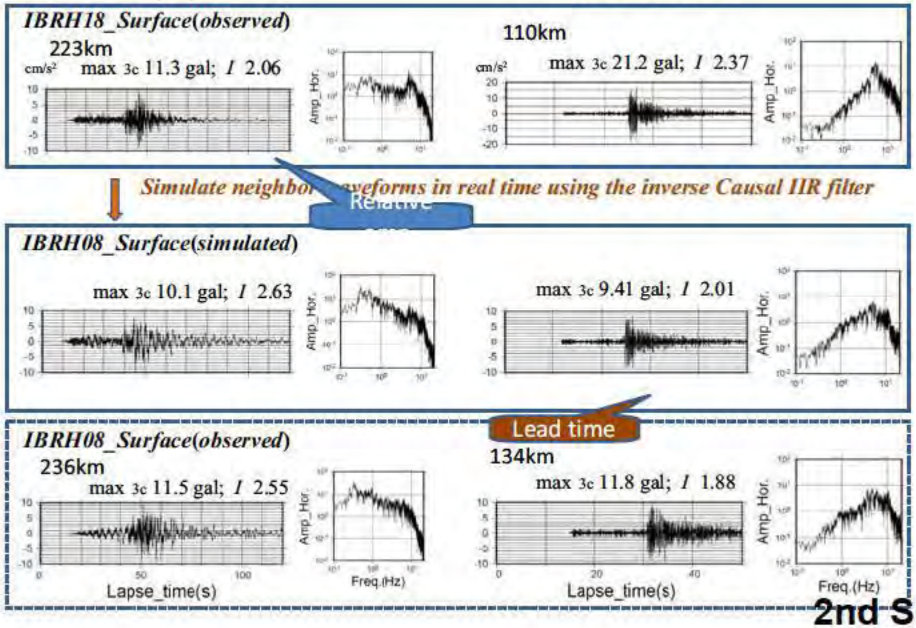
② $u_b(r_2, t+\Delta t)$
$u_b(r_1, t+\Delta t - |r_2 - r_1| \cos(\theta' - \theta)/v_0)$

③ $u_s(r_2, t)\ \ f_2(t) * u_b(r_2, t)$

$u_s(r_2, t+\Delta t)\ \ \{f_2(t) * f_1^{\ 1}(t)\} *\ u_s(r_1, t+\Delta t - |r_2 - r_1| \cos(\theta' - \theta)/v_0)$

$\{f_2(t) * f_1^{\ 1}(t)\}$: relative site amp. factor

2007/07/16 M6.8 2004/08/19 M5.0



IBRH18_Surface(observed)

223km max 3c 11.3 gal; *I* 2.06

110km max 3c 21.2 gal; *I* 2.37

Simulate neighbor aveforms in real time using the inverse Causal IIR filter

IBRH08_Surface(simulated)

max 3c 10.1 gal; *I* 2.63

max 3c 9.41 gal; *I* 2.01

IBRH08_Surface(observed)

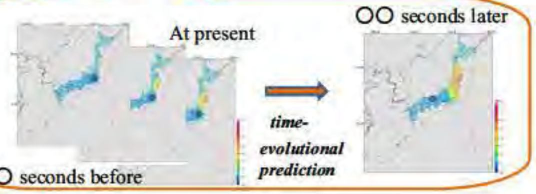
236km max 3c 11.5 gal; *I* 2.55

134km max 3c 11.8 gal; *I* 1.88

Summary

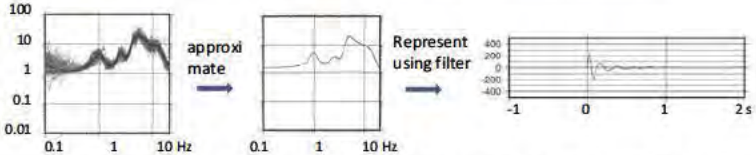
1. For real time prediction of earthquake ground motion ;

Causes identification prediction (Rapid estimation of Hypo. and M) → ***Time evolutional prediction*** (based on wave propagation)



2. For real time correction of site amplification factor ;

Spectrum ratio (frequency domain) → ***Causal IIR filter*** (time domain)



Remark : Waveform data from KiK-net (NIED) are used.

The 2nd International Workshop on Seismic Observation in Deep Borehole and Its Applications

Development and Examination of Real-time Automatic Scram System Using Deep Vertical Array Seismic Observation System

Dec. 7-9, 2012,
Niigata Institute of Technology (NIIT)

Katsunori SUGAYA
Japan Nuclear Energy Safety Organization (JNES)

Contents

Ⅰ. Background and Objectives
Ⅱ. Principle of Real-time Automatic Scram System
Ⅲ. Project Plan of Real-Time Automatic Scram System
Ⅳ. Observed Seismic Data and Travel Time of P-wave and S-wave
Ⅴ. Immediate Technical Implementation
Ⅵ. Summary and Future Proposition

Ⅰ. Background and Objectives (1/2)

■ Treatment of Scram on Japanese Seismic Design Guide

- The safety shutdown system is composed by the seismograph installed on reactor building basement, and the control rods which can be inserted automatically in the case of about 80 % of the S2 level seismic motion.
- However, a scram failure will be fearful because of the current insufficient accident management operating the control rod insert while strong shaking of earthquake.

■ Lesson learned from Fukushima Daiichi NPP Accident

- There made us clarify significance to respond beyond designed seismic motions and tsunami heights, so that means lessons learned from the 3.11 Tohoku Earthquake/Tsunami, and Fukushima NPP accident.
- Safety measure considerations, namely to avoid the scram failure by the shaking, are needed for preventing severe accidents.

■ Development of *3,000 meters deep ground seismic observation system*

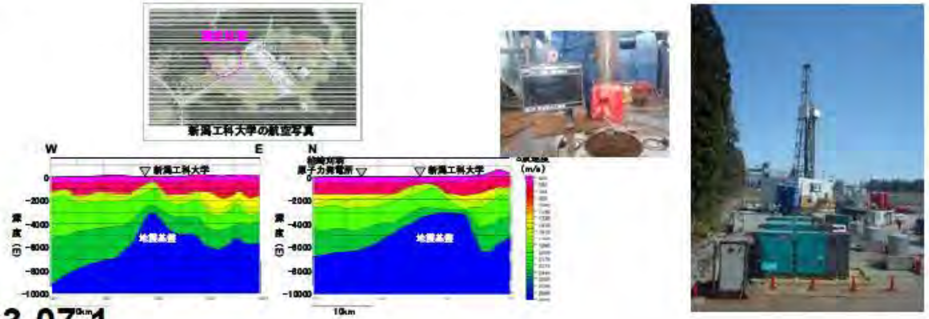
- JNES has already developed ***the 3,000 meters deep ground seismic observation system*** on the site of Niigata Institute of Technology in the framework of collaborative program, and are observing many seismic motions at the several depth points, in order to obtain specific data of 3-dementional deep ground structures; which is particularly targeted from the seismic basement to the ground surface around NPPs

---

Ⅰ. Background and Objectives (2/2)

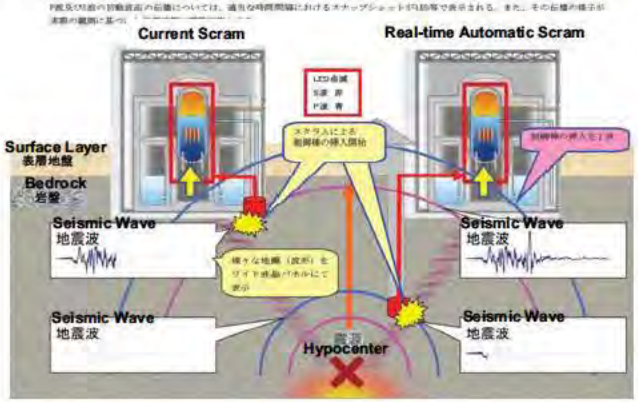
■ Objectives

- Following clarification of the deep ground structures, development of ***the real-time automatic scram system*** is launching in application of the seismograph, based on the concept which is establishment of the initiation to insert the control rods before the secondary wave arrives at reactor building. Technical experience of the scram system will be considered with testing by natural and artificial seismic waves.
- Practical use of the both systems will be the first achievement around the world, and the products will be made in contributions to the IAEA EBP.



Ⅱ. Principle of Real-time Automatic Scram System

The concept of the Real-Time Automatic Scram is the system that seismograph of the system installed in deep underground is able to detect the primary wave (P wave), and to make insert the control rod before the secondary wave (S wave) arriving at reactor building.



Ⅲ. Project Plan of Real-Time Automatic Scram System

(1) Overview of Projects

① Development of Visualization for Automatic Scram Confirmation

There are needs to confirm function of automatic scram system, with creating the deducted control rod insert system.

However this will develop visual system for confirmation by CG pictures function.

② Development of Seismic Simulator

The seismic simulator having function of making artificial seismic wave will be developed, because of the needs to confirm the system function of (1) above under several seismic conditions, due to the bias of seismic occurrence location or mechanism if data is composed only by natural earthquake.

③ Verification of Real-Time Automatic Scram Function

The control rod insert's visualization function will be confirmed by using two ways which set up the artificial and natural seismic waves, according as data will be few for the verification because of low frequency occurrence of natural seismic large amplification.

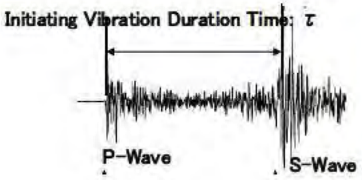
④ Development of Scram Procedure System

The setting change of scram initiating trigger level such as observed seismic acceleration and signal duration time on the seismograph installed 3,000 meters depth will be developed, and also the recording function of dataset such as scram time, acceleration values observed at deep underground and ground surface will be developed.

(2) Simulation of P-Wave and S-Wave Travel Time

■Simulating Conditions:

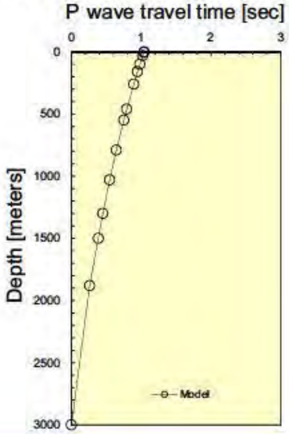
- Aim of simulation: Accumulation of data seismograph observed are ongoing suitably. Aim of the simulation is to set up analytical ideas as the various case studies start-line which has specific actions such as the observed data utilization and consideration of the local geological characteristics.
- Sketch of earthquake: Occurrence of surrounding seismograph of 3,000m depth
- Sketch of layer along 3,000m depth: Values at deep ground on Site of Niigata Institute of Technology (see table on the below)
- Observed seismic waveform: P-wave, S-wave, Initiating vibration duration time τ
- Signal for Scram: Seismograph installed at 3,000m of depth detects P-wave and sends the signal.
- Transmission time of the signal: 0 sec

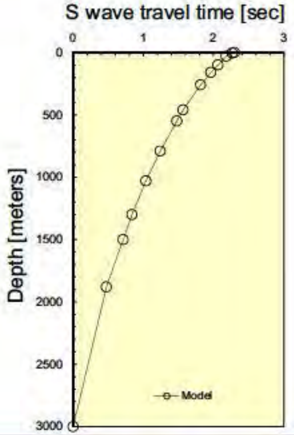


Faults

Depth (m)	Layer thickness (m)	P-wave velocity (m/s)	P-wave travel time (s)	S-wave velocity (m/s)	S-wave travel time (s)
0	5	1000	1.0	150	2.3
5	25	1510	1.0	290	2.3
30	70	1740	1.0	600	2.2
100	60	1740	1.0	600	2.1
160	100	1890	1.0	680	2.0
260	200	1960	0.9	800	1.8
460	90	2220	0.8	1020	1.6
550	240	2220	0.8	1020	1.5
790	240	2520	0.6	1170	1.2
1030	270	2770	0.6	1360	1.0
1300	200	3070	0.5	1590	0.8
1500	380	3070	0.4	1590	0.7
1880	1120	4280	0.3	2370	0.5
3000			0.0		0.0

■Simulation Results:



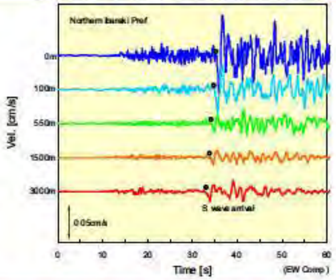


- P-wave travel time is about 1.0 second.
- S-wave travel time is about 2.3 second.
- In this analysis, it was about 3.3 second in total which means origin was the P-wave detection at 3,000m depth seismograph, after that, passing simultaneous reach ground of the wave with the S-wave detection at the seismograph, and finality was the S-wave reach ground.

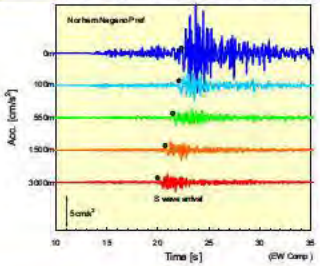
Ⅳ. Observed Seismic Data and Travel Time of P-wave and S-wave

(1) Examples of Observed Seismic Waveform

The earthquake at the north of Ibaragi Prefecture (2012 2 19, Mj : 5 2, H:7 2km, R:233km)

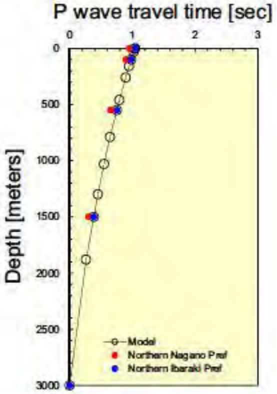


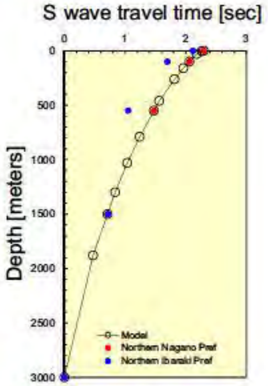
The earthquake at the north Nagano Prefecture (2012 7 10、 Mj : 5 2, H:8 5km, R:60km)



- Seismic waves were observed in the two earthquakes below.
- The earthquake at the north of Ibaragi Prefecture : 19 February 2012, Mj : 5.2, Depth H:7.2km, Hypocenter Distance R:233km
- The earthquake at the north of Nagano Prefecture : 10 July 2012 , Mj : 5.2, Depth H:8.5km, Hypocenter Distance R:60km
- Initiating vibration duration time τ of the earthquakes are as follows.
- The τ of the earthquake at the north of Ibaragi Prefecture : about 27 sec
- The τ of the earthquake at the north of Nagano Prefecture : about 8 sec

(2) Comparison of P/S Wave Travel Time Analysis with Observed Records



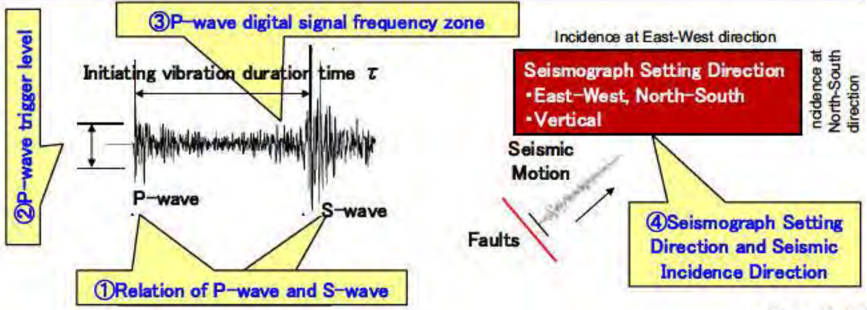


- The analysis results of P-wave travel time using the earthquake at the north of Ibaragi Prefecture and the north of Nagano Prefecture are in harmonizing with observation result.
- The analysis results of S-wave travel time using the north of Nagano Prefecture are in harmonizing with observation results, however in the case of using the north of Ibaragi Prefecture, the travel time of observed has a little different from analyzed one.
- It will be accumulating data, and making analysis and consideration of trend and factor of the P-wave and S-wave travel time.

Ⅴ. Immediate Technical Implementation

Significant research technical terms:

① Grasp on S-wave amplification related to P-wave amplification
② Setting condition on trigger level of P-wave
③ Grasp on sensitive signal detecting related to digital signal frequency zone
④ Detecting seismic motion direction arrived related to seismograph setting direction (Horizontal on East-West and North-South, Vertical)
⑤ Relation of initiating vibration duration time τ (P−S time lag) hypocenter distance



Seismograph Setting Direction
- East-West, North-South
- Vertical

Ⅵ. Summary and Future Proposition

- JNES has developed “Real-time Automatic Scram System” using deep ground seismograph of “Deep Vertical Array Observation System” with 3,000 meters boring, and it is considering consistent technology of the scram system.
- “Deep Vertical Array Observation System” is in partial operation since February 2012, and it is observing many seismic motions.
- Quantitative consideration of consistent technology of the “Real-time Automatic Scram System” has been launched in using data of observed seismic motions.
- JNES will make an international contribution so that results of the research could be reflected on Safety Report related to “Real-Time Safety Assessment System (RTSS)” which is under development in the framework of IAEA Extra Budgetary Project.

Practical Application of Site-specific Earthquake Early Warning (EEW) System

Katsuhisa Kanda

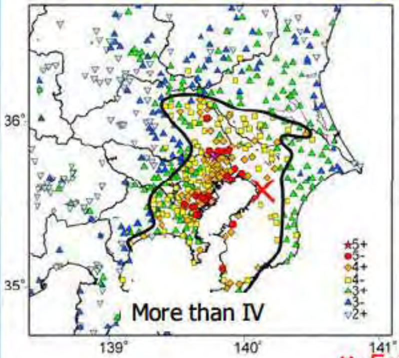
Kobori Research Complex Inc., Tokyo

Objectives of research

1. **To improve estimation method of JMA seismic intensity of earthquake early warning (EEW) information based on site-specific data**
2. **To develop on-site warning (OSW) system to improve timing of warning and reduce the false alarms**
3. **To develop application to practical use in construction company**
4. **To develop integrated system to apply to system shutdown**

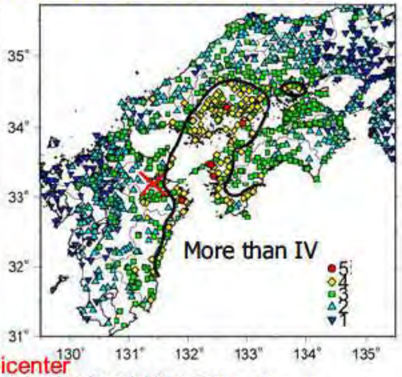
1 Improvement of JMA Seismic Intensity Estimation for EEW

JMA seismic intensity is not always reduced in a concentric fashion



× : Epicenter

2005/7/23 Chiba, Japan
(M6.0, Depth73km)



2006/6/12 Oita, Japan
(M6.2,Depth146km)

Seismic intensity distribution can't be precisely explained using attenuation relationship.

Improvement of seismic intensity estimation

- Standard method: Attenuation relationship + soil amplification factor

⇩

- Analysis based on seismic intensity database including recent and historical earthquakes
- Considering source, path and local site effects

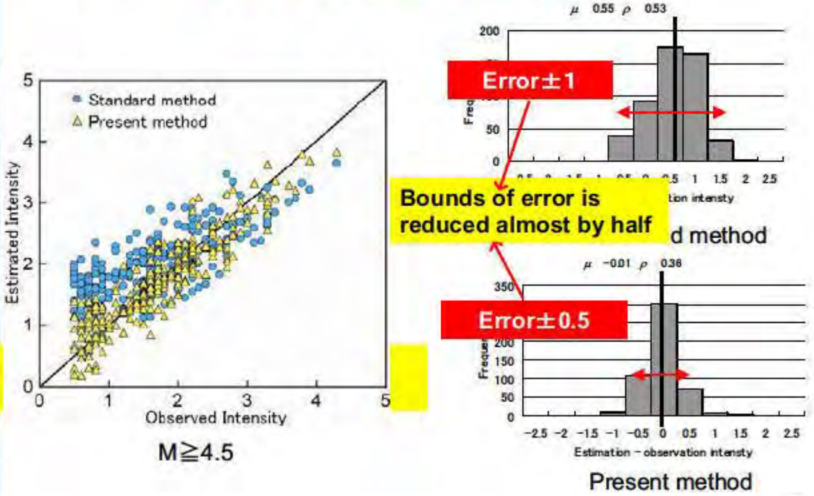
⇩

- Original attenuation relationship for each site + epicenter, depth correction factors

---

Comparison of accuracy

(Tokyo, 1997-2007)



M≧4.5

Error±1

Bounds of error is reduced almost by half

Error±0.5

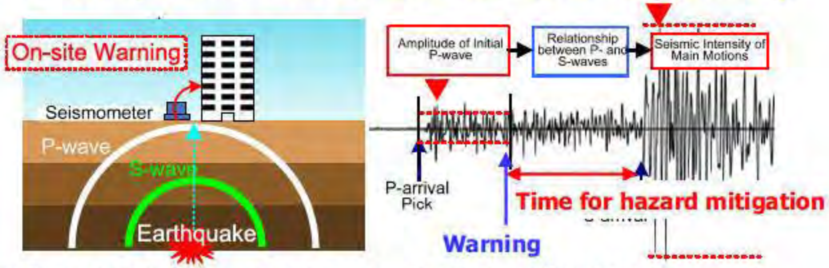
d method

Present method

---

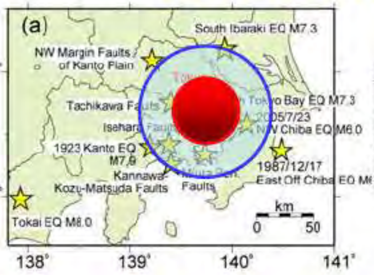
2 Development of On-site Warning(OSW)

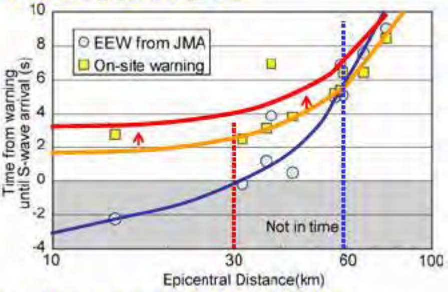
Concept of P-wave On-site Warning(OSW)



- **P-wave pick-up sensors are installed on the soil surface at a site or on the basement of a building.**
- **The warning can be issued before S-wave arrival taking advantage of the difference between the velocities of P and S waves.**
- **The intensity estimation method is based on the empirical amplitude relationship between P and S waves.**

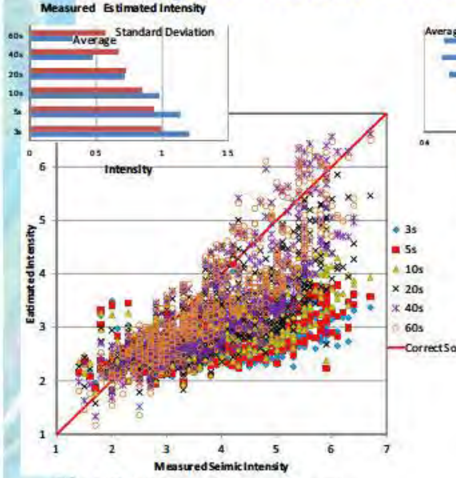
Comparison of time for seismic hazard mitigation



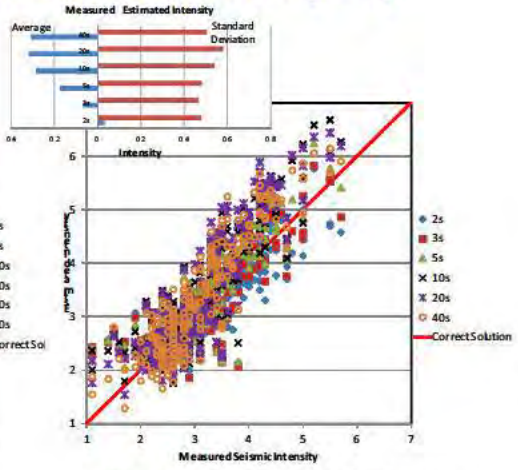


- The on-site warning is faster than EEW from JMA for earthquakes within about 60km epicentral distance.
- In particular, within about 30km, the EEW information may not be transmitted before S-wave arrival.
- If deep borehole data is available in real-time, on-site warning is more effective.

JMA seismic intensity estimation for OSW (Estimation time after P-wave pick)



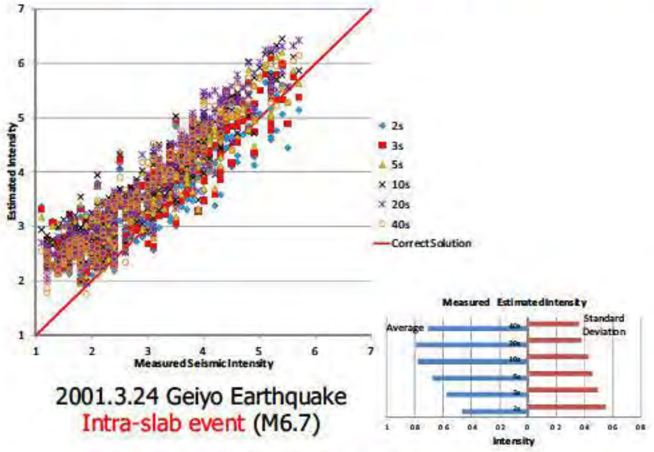
2011.3.11 Tohoku Earthquake
Plate boundary event (M9.0)



2008.6.14 Iwate-Miyagi Earthquake
Inland shallow event (M7.2)

K-NET observation data

JMA seismic intensity estimation for OSW (Estimation time after P-wave pick)



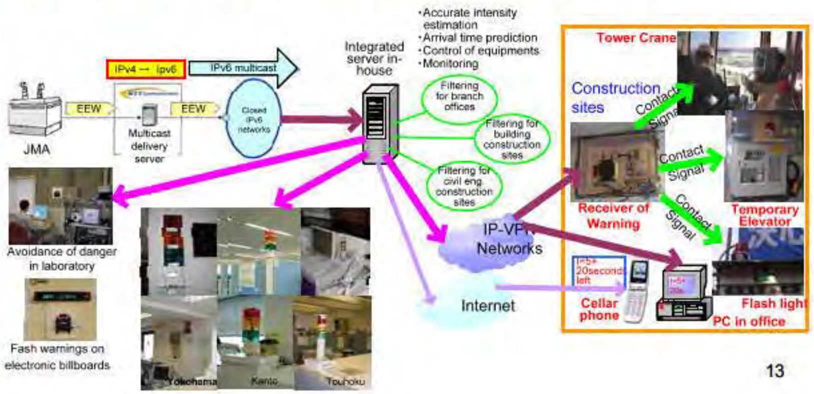
2001.3.24 Geiyo Earthquake
Intra-slab event (M6.7)

K-NET observation data

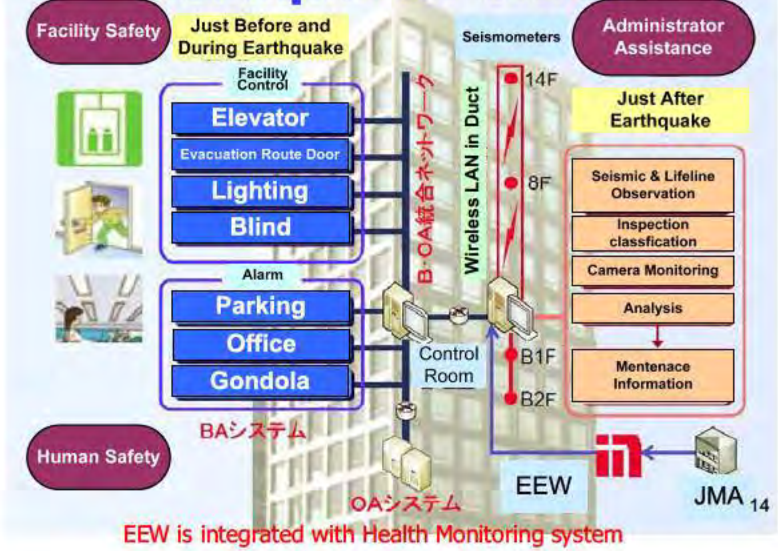
3 Application in Construction Company

System configuration of EEW

- Integrated server can intensively receive and process EEW information from JMA and can extensively deliver it to a whole construction company.
- EEW information can be transmitted through company networks to headquarters, branch offices and construction sites for about 1 second.



Integrated system in headquarter office



EEW is integrated with Health Monitoring system

Ceiling alarm lamps in offices

Other displays and alarm lights

Tricolor Desktop Display

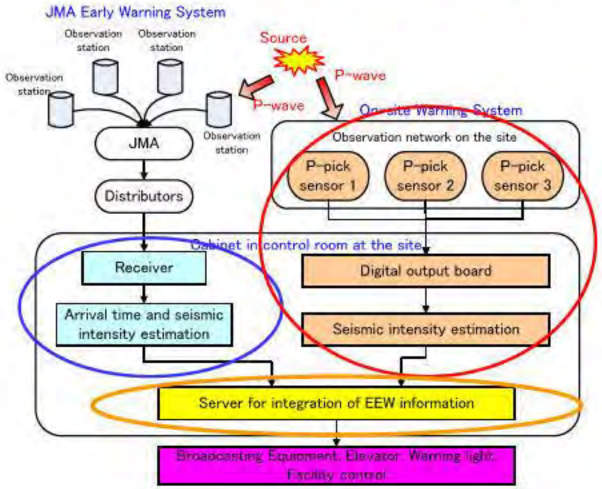
Desktop Small Display

→ Good Design Award in 2008

Desktop Large Display

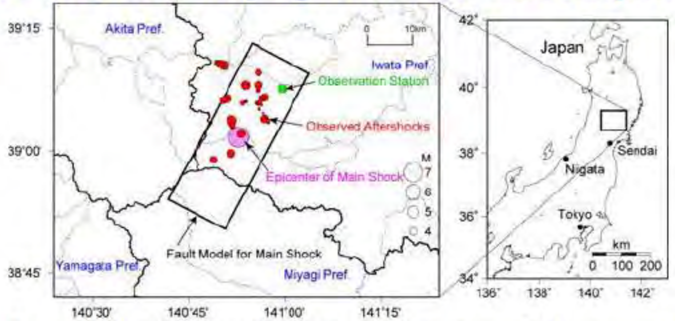
Tricolor Alarm Lights

Combination system of EEW from JMA and OSW



Example in construction site

Measures against aftershocks of the 2008 Iwate-Miyagi Inland Earthquake



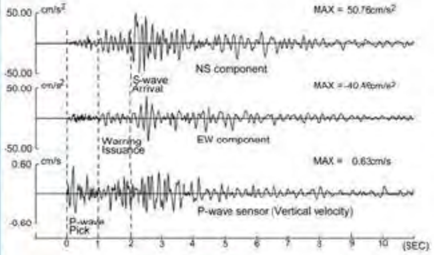
- **EEW from JMA which had been operating since 2007 was output to the site after the arrival of the S-wave in the main shock.**
- **Since the aftershocks were quite active, we installed the on-site warning system and modified EEW to integrated warning system.**

Alarm devices in construction site office

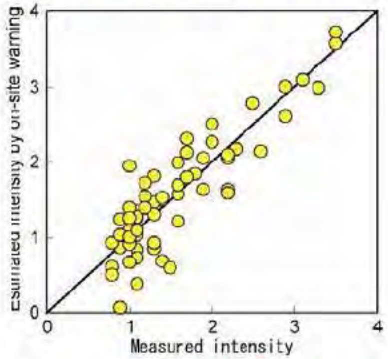
Red:**I=5~7**
Yellow:**I=3~4**
Green:**I=1~2**

→Dam construction site (more than I=3)
Field workers
Damped motor lorries
Elevators

Results of OSW against aftershocks of 2008 Iwate-Miyagi inland earthquake



Example of time series observed on July 14, 2008

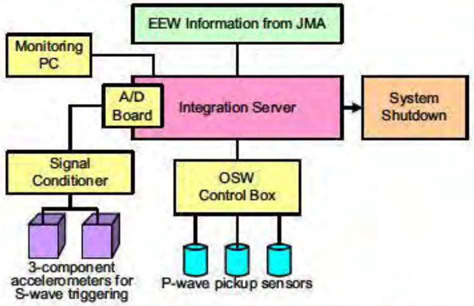


Accuracy of JMA seismic intensity estimation (July – September, 2008)

4 Integrated EEW System for Shutdown of High-Reliability System

Robust and reliable integrated EEW system for system shutdown

- The OSW by itself is used only for near-field earthquakes.
- The EEW from JMA combined with OSW is for the others.
- In case of underestimation by the OSW and EEW from JMA, accelerometer installed on the target floor in a building is used as S-wave triggering.



For critical facilities such as precision machine and semiconductor factories

Combination of EEW from JMA and OSW using Bayesian estimation

- JMA intensity I_E is estimated by average of EEW and OSW weighted using their lognormal standard deviations and corrected by offset of mean value.

EEW from JMA OSW

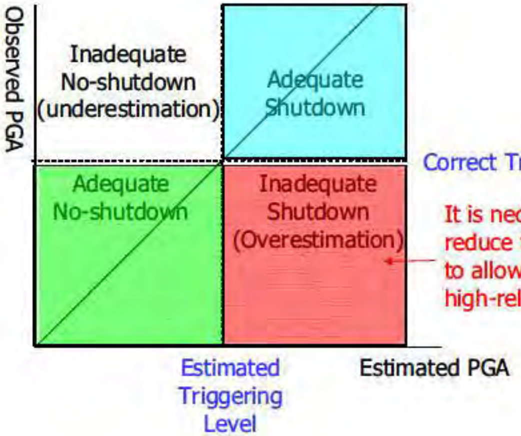
$$I_E = \frac{\beta_{AO}^2}{\beta_{AJ}^2 + \beta_{AO}^2}(I_J + \bar{\gamma}_J) + \frac{\beta_{AJ}^2}{\beta_{AJ}^2 + \beta_{AO}^2}(I_O + \bar{\gamma}_O)$$

$$I_E = 0.3 I_J + 0.7 I_O + 0.4$$

		EEW from JMA		OSW	Combination	
Time after P-wave Pick (s)	Time of 2011/3/11	M	Estimated Intensity I_J	Estimated Intensity I_O	Estimated Intensity I_E	Estimated peak ground acceleration (Gal)
0	14:47:38	7.7	3.1			
3	14:47:41	7.7	3.1	2.9	3.4	22
5	14:47:43	7.7	3.1	3.0	3.4	24
10	14:47:48	7.9	3.3	3.0	3.5	26
20	14:47:58	7.9	3.3	3.2	3.6	29
40	14:48:18	8	3.5	3.4	3.8	36
60	14:48:38	8.1	3.6	3.5	3.9	41
Measured Intensity					3.6	
Measured peak ground acceleration						54

Example at K-NET Shinjuku(TKY008), Tokyo at the Tohoku earthquake

Idea of adequate system s24hutdown Using EEW from JMA and OSW



Correct Triggering Level

It is necessary to reduce this probability to allowable level for high-reliability system

Thank for attention!

The 2nd Workshop on Seismic Observation
in Deep Borehole and Its Applications

Utilization of Real-time Seismic Hazard Information to Make Facilities More Resilient

November 9, 2012

Yukio Fujinawa,

Genesis Inc.

SUMMARY

1) **Japan has a long history of borehole measurements on crustal activities including 4 deep boreholes of 3km deep in Tokyo.**
2) **Methods of borehole data usage are presented for Earthquake Early Warning (EEW) , imminent earthquake prediction and crustal health monitoring.**
3) **Firstly presented the hybrid system for seismic hazard evaluation system using regional EEW and on-site vertical and horizontal seismic observation data.**
4) **Seismic hazard estimation by the hybrid system has been proved sufficient for BCM of important facilities through several major earthquakes.**
5) **The deep borehole electric measurement has succeeded to find particular variations which define the nucleation stage of earthquake occurrence. The variations are supposed to be induced by the micro-cracks through the electro-kinetic effect.**
6) **The crustal health check is proposed by establishing vertical electric variation monitoring network in and surrounding the large scale facility both for maintenance of the plant and CSR to neighboring region.**

CONTENTS

1. **Introduction**
2. **Earthquake Early Warning**
3. **Imminent Earthquake Forecast**
4. **Emergent Response**
5. **Sharing of Disaster Mitigation Information**

---

1. Introduction

Earthquake Hazard Mitigation

I. Mitigation Counter Measure Phases

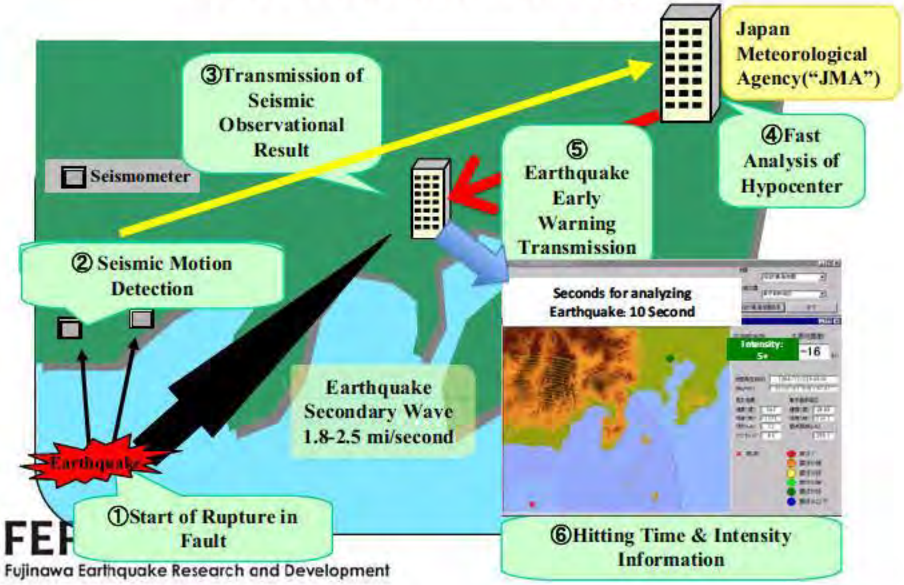
1. PREPAREDNESS
2. EMERGENT RESPONSE
3. RECOVERY

Ⅱ. Eample in Japan (Main Policies Making by Central Disaster Mitigation Council)

1. Targets(Ex.):Tokai EQ. ,Tonankai-Nankai EQ. Mega-city EQ. >Hazard Assessment,
2. Numerical Aims(Ex.) : Decreasing by Half of Death and Economic Loss in Decade
3. **Means**:
   ①Rate of House Reinforce>90%,
   ②Tsunami Hazard Map
   ③ New Means ? >R&D >**Earthquake Early Warning**
   Imminent Earthquake Prediction

2. Earthquake Early Warning (EEW)

EEW Scheme in Japan



FEF
Fujinawa Earthquake Research and Development

Present State of Utilization of EEW

The past four years of the EEW use in Japan can be summarized as follows:

(1) The EEW system has contributed substantially to saving lives. About 90% of the Japanese population is familiar with the EEW system and wants the system to be used at any TPO of severe shock.

(2) The EEW system has several shortcomings, identified in experiences that occurred from the testing phase to the present (including the 9.0 Tohoku earthquakes).

(4) The vast majority of the EEW system's users are receiving only EEWg (general public) alerts. The EEWa (advanced user) alerts are more effective, with higher accuracy and longer lead times. The development of application systems for automated or semi-automated operations has not widespread yet.

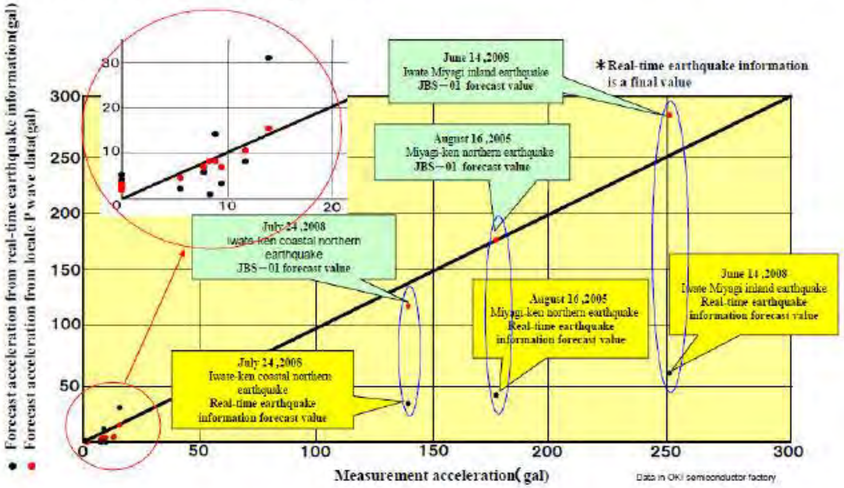
(5) Additional on-site seismic data can provide more accurate EEWs and longer lead times compared to the current system. By using seismic control systems, almost all mission critical facilities such as nuclear power plants, hospitals and important factories can increase the quality of their BCP and PCM.

Hybrid System Using Regional EEW and on-site Data

- Solver to overcome shortcomings of the EEW based of regional network data
- Pre-EEW system: on-site data
- Hybrid System: Sythetic hazard evaluation Using EEW and on-site data
- Practical System has been working since 2005 in the semiconductor factory

Performance of the Hybrid System

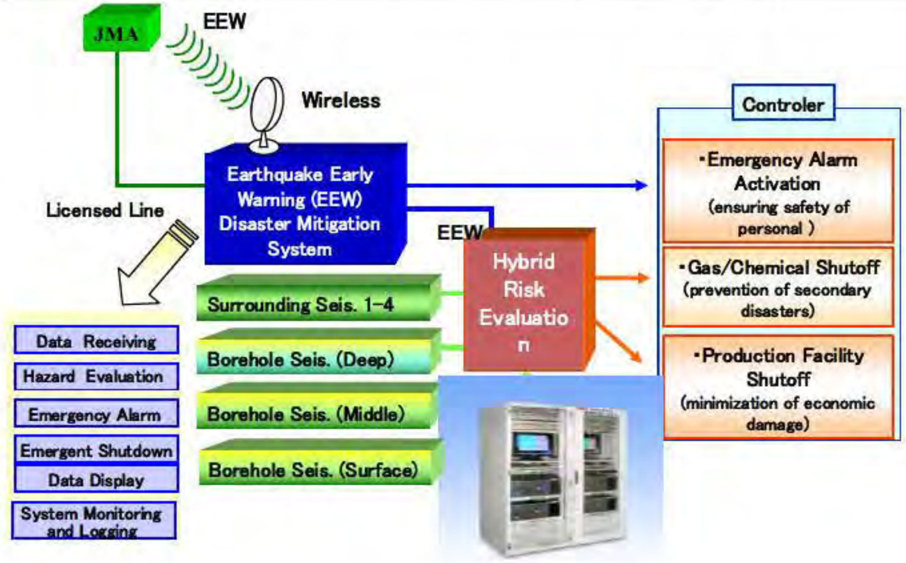
Predictive value comparison



＊Real-time earthquake information is a final value

Data in OKI semiconductor factory

Hybrid System for Synthetic Evaluation using Vertical and Horizontal Seismograph



JMA

EEW

Wireless

Licensed Line

Earthquake Early Warning (EEW) Disaster Mitigation System

EEW

Hybrid Risk Evaluation

Surrounding Seis. 1-4

Borehole Seis. (Deep)

Borehole Seis. (Middle)

Borehole Seis. (Surface)

Data Receiving

Hazard Evaluation

Emergency Alarm

Emergent Shutdown

Data Display

System Monitoring and Logging

Controler

- ・Emergency Alarm Activation (ensuring safety of personal)
- ・Gas/Chemical Shutoff (prevention of secondary disasters)
- ・Production Facility Shutoff (minimization of economic damage)

Hazard Evaluation Method

1. Data **:**

  1) EEW (regional surface data) : Seew

  2) On-site data (surface) : Sobs

2. Evaluation scheme

  1) Hybrid : EEW & On-site Data : Ssyn

  2) Synthetic Evaluation of Hazard

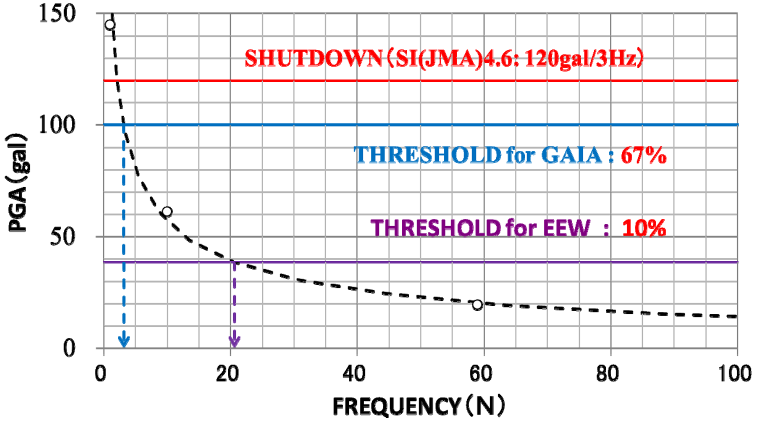
  3) On-site data Evaluation < Empirical Parameters

3. Product: Gaia Sensor (REIC + OKI > Genesis Inc.)

Time Sequence of Control by Hybrid EEW (2011/03/11 14:46)

	2011/3/11:14h		IWT 009			
	TIME	event	(NS) OBS. (gal)	EEW (est.) (gal)	JBS(est.)	comments
	46m18.1s	origin time				
	40.2	EQ detect				
	45.6	1st EEW		0.4		
	46.7	2nd EEW		4		
	47.7	3rd EEW		15		
	48.8	4th EEW		27		EEWg (M7.2)
	49.6	P arrival				P(e)arrival:44”.2
	49.8	5th EEW		7		
	61.7	Peak 1	28			95 (Sa(P))
	62	9th EEEW		52.7		
	63	S Arriv.	79			270 (Sa(P))
	65.4	Peak 2	123			401
	75	Maximum.	664			

Performance of Automatic Control



Seismic Hazard Forecast using Deep Borehole Data

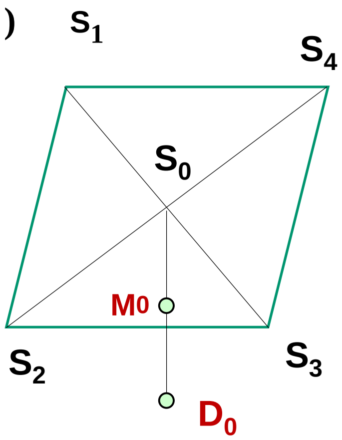
1. Addition of deep data: *we have designed*

1) on-site data (surface: S_0)

2) local network data (M_0, D_0, S_1-S_4):

3) EEW(regional network data)

4) Hybrid of 1) & 2), 3)



2. Near Field Case (D_0 first)

1) One data arrival & non-arrival method

2) Two data A-NA method

3. Earthquake Prediction

1) Development Stage of EQ Prediction

(1) Research on EQ Precursory Phenomena

(2) Taxonomical Classification: almost completed

(3) Statistical Evaluation: preliminary stage

(4) Fundamental Modeling: hypothetical stage

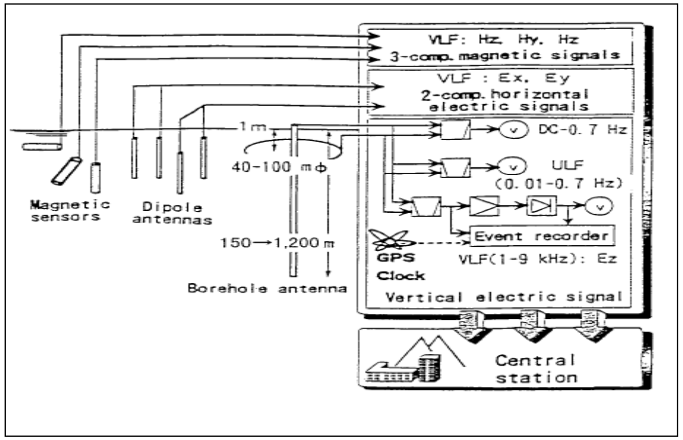
2) R/D to ensure security of more serious concern

(1) There was apparent progress in 2011.

(2) Needs to conduct extensive experiments

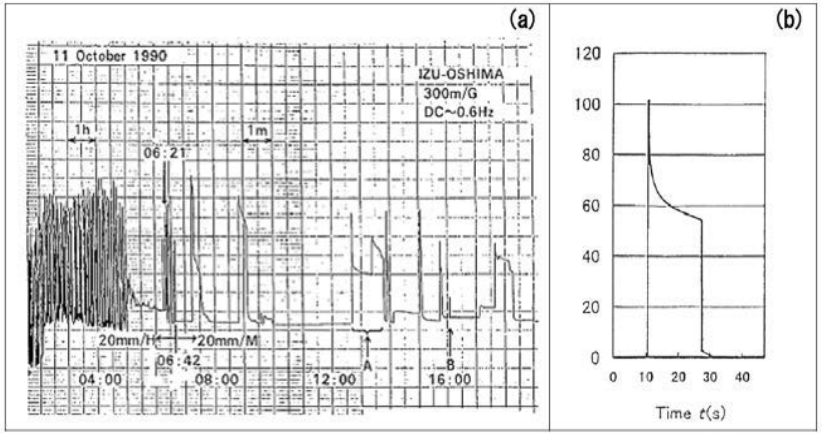
(3) Expect a complete scenarios of emergent preparedness using EEW and forecast

Underground Electric Field Measurement



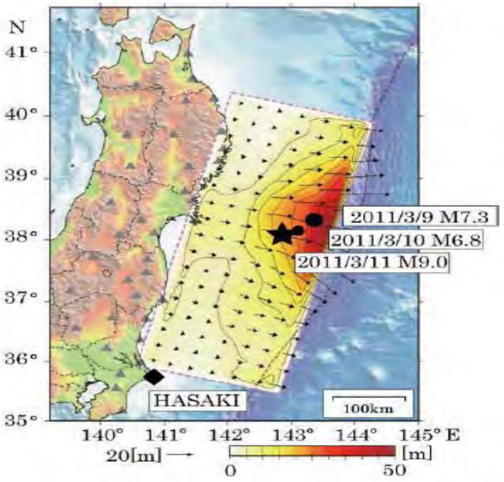
We have been observing electric field variations related with earthquake occurrence to find anomalous phenomena to be applied for prediction. The detection sensor is to measure vertical components of electric field by a special antenna made of a vertical casing pipe that is set into a borehole. We have been using 13 boreholes ranging from 100 ～ 1,800 m deep since 1989.

Pulse-Like Characteristic Electric Field Variations

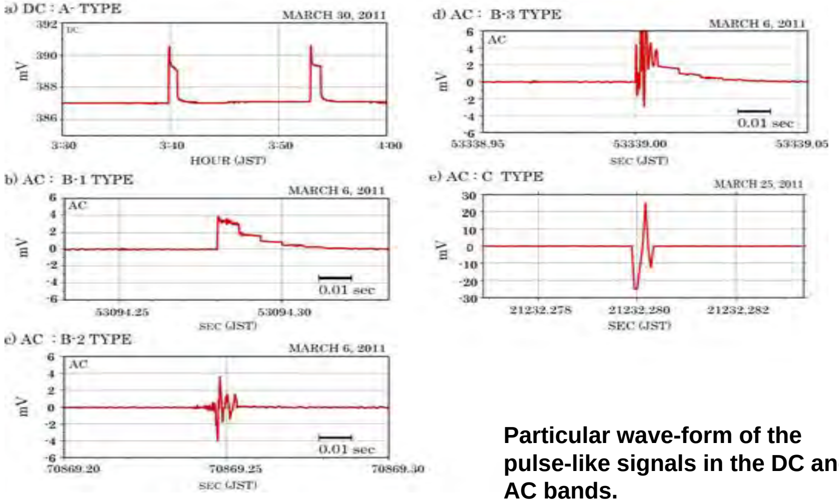


The particular pulse-like variations similar to the time evolution of geyser (GUV) have been detected in association with seismic swarms and volcanic eruption activities . The signals have never been detected in a normal state, and have been observed in almost all volcanic eruption activities and seismic swarms near the observation points.

Observation Site and Rupture Image of " 3.11"

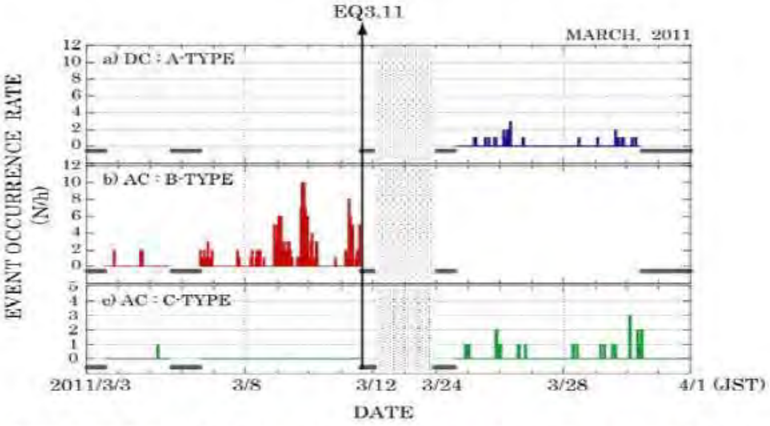


Geographical relationship between the observation site HASAKI and the rupture zone and displacement distribution of the Tohoku Earthquake (revised from NIED, 2011). Here we show that there are typical pulse-like waveforms of electric field variations associated with micro-cracks just before and around the Great Tohoku Earthquake on March 11.



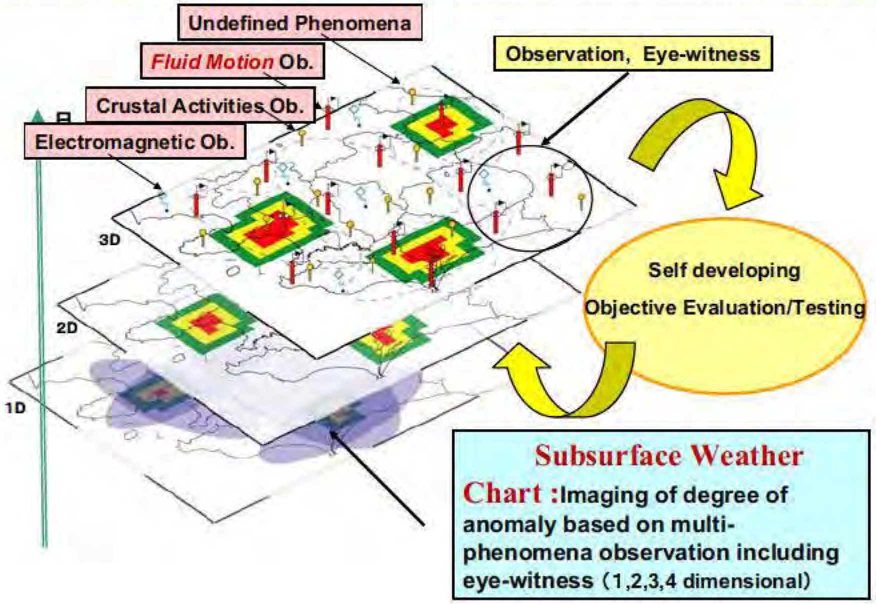
Particular wave-form of the pulse-like signals in the DC and AC bands.

a) type A variation is the same as observed at the time of volcanic activities, b) Type B1 is similar to GUV except the smaller duration of several tens of ms and several steps in the process of decreasing. c) Type B 2 is a wave packet with a carrier frequency of a few hundred Hz and duration of several ms. d) Type B 3 is the compound of B 1 and B 2. e) Type C wave form in the AC band.



The time evolution of B type anomalies had a strong similarity with that of acoustic emissions just before rupture in the rock experiment, and that of the pre-shocks before the main shock . The B-type variations can be used to infer the occurrence time of the main shock before several days, suggesting that variation of Type B is a key phenomenon for following the fault zone regime in terms of approaching to final rupture associated super-micro crack just before the main shock.

Underground Sub-surface Weather Map



Subsurface Weather Chart : Imaging of degree of anomaly based on multi-phenomena observation including eye-witness（1,2,3,4 dimensional）

4. Utilization for Emergency Response

1. Emergency Response Support

1）. To assist the reduction of the second hazards using the Hybrid system

2. For Evacuated People

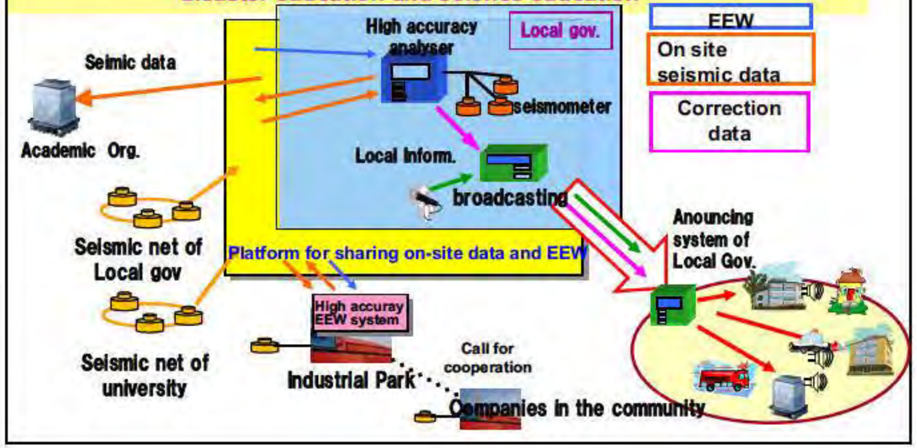
1） Issue confident Information to make people to feel safe

2） Assist to take appropriate actions

5 . Sharing of Disaster Mitigation Information

accuracy and confidence

- **community based efforts for effective disaster mitigation**
- **disaster education and science education**



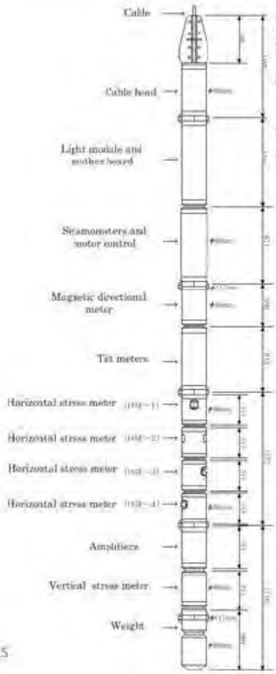
Thank you very much

Multi-component observation in deep boreholes, and its applications to earthquake prediction research and rock mechanics

Hiroshi Ishii
Tono Research Institute of Earthquake Science (TRIES),
Association for the Development of Earthquake Prediction (ADEP)

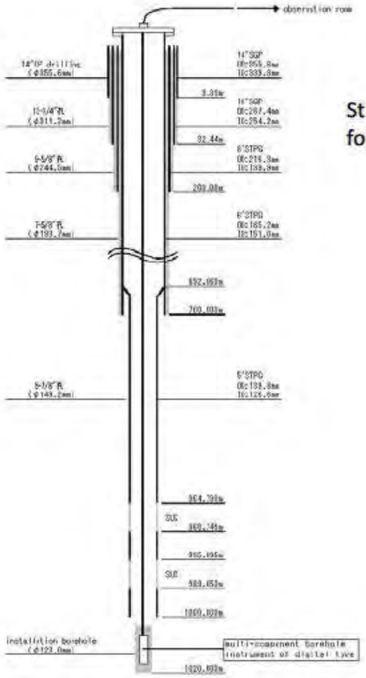
Summary

1. We have developed multi-component borehole instrument that can be operated in deep boreholes like 1 km depth. It is equipped with stress meters, strain meters, tilt meters, seismometers, magnetometers and thermometers and arbitrary combination of the sensors can be possible.
2. Stress meter is recently developed and it can observe both stress and strain.
3. Reliability of stress meter was confirmed by use of invariant quantity of elastic theory and other tests.
4. Data obtained from stress meter will offer new information concerning seismology and rock mechanics in future.



Multi component borehole instrument (type equipped with stress meter

Total length: 7.843m
Total weight: 285kg



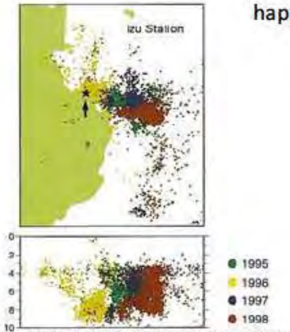
Structure of borehole for installation

Multi-component instrument and tower in case of installation

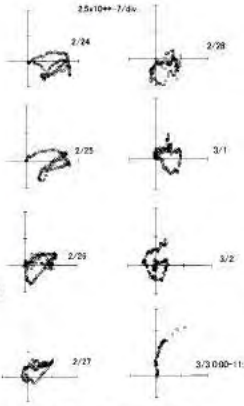
Installation of multi-component instrument

Cable drum and head quarters

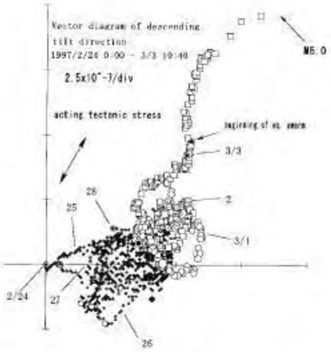
Tilt and strain variation for earthquake swarm happened in Izu peninsula



Earthquake Observation Center, E.R.I., Univ. of Tokyo

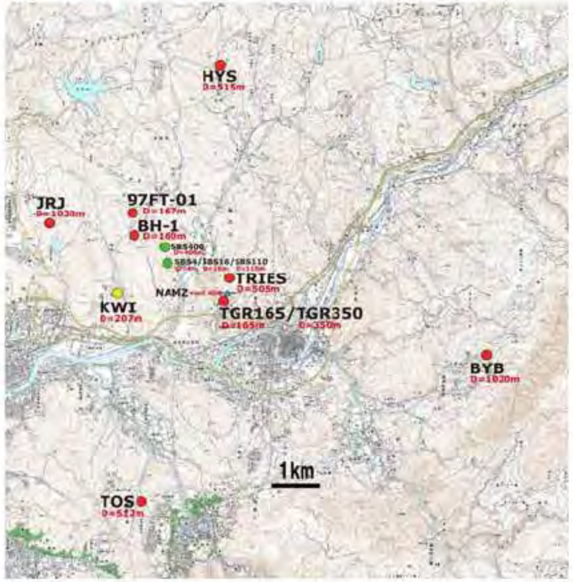


. Daily vector diagram of descending tilt direction from 2 / 24 to 3 / 3.



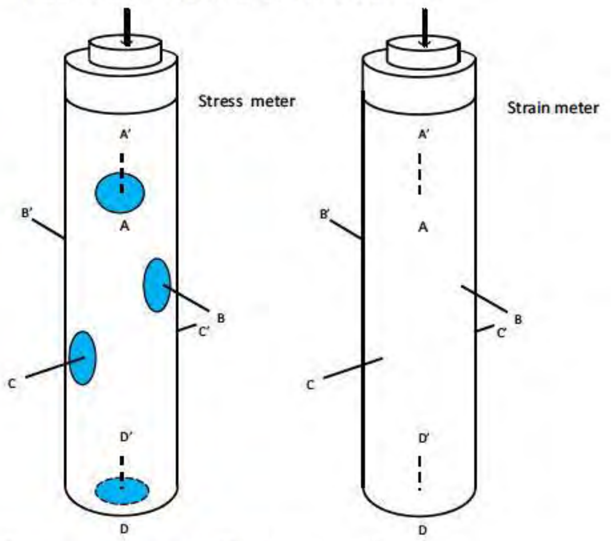
Vector diagram of descending tilt direction from 2 / 24 to 3 / 3.

Distribution of borehole station operated by Tono Research Institute of Earthquake Science (TRIES): Red numerals indicates depth of borehole



Development of stress meter

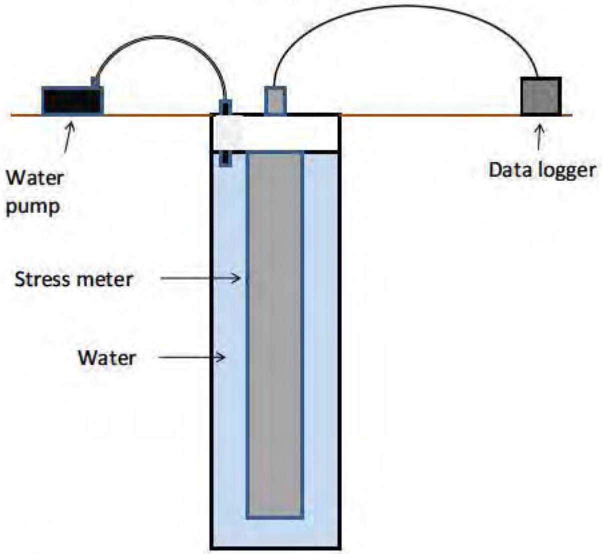
Outside view of stress meter and strain meter



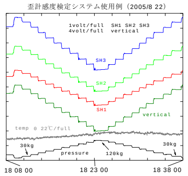
Stress meter can record both stress and strain.
Stress meter can not effected by deformation of container

Inside picture of stress meter for horizontal and inclined components

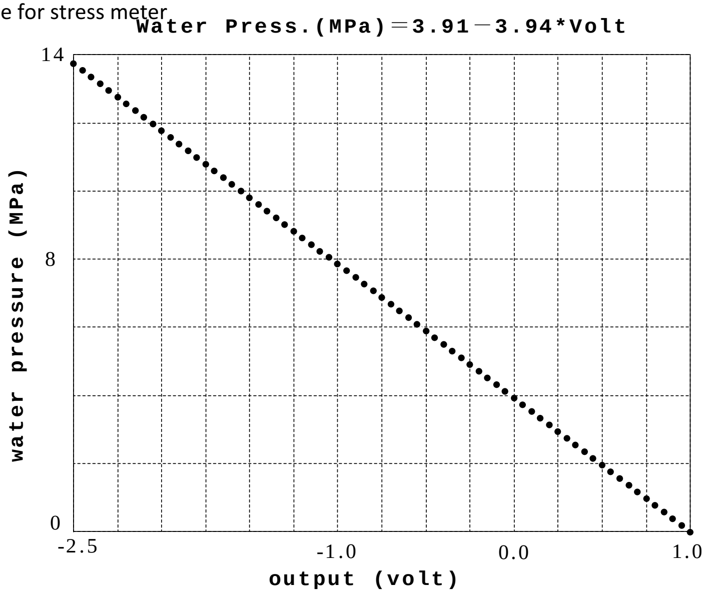
Schematic depiction of calibration of stress meter



Scene of calibrating stress meter

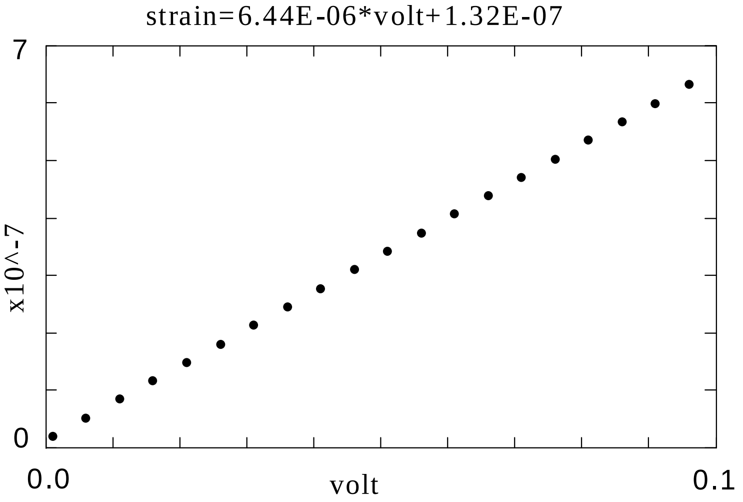


An example of calibration showing relationship between water pressure and output voltage for stress meter



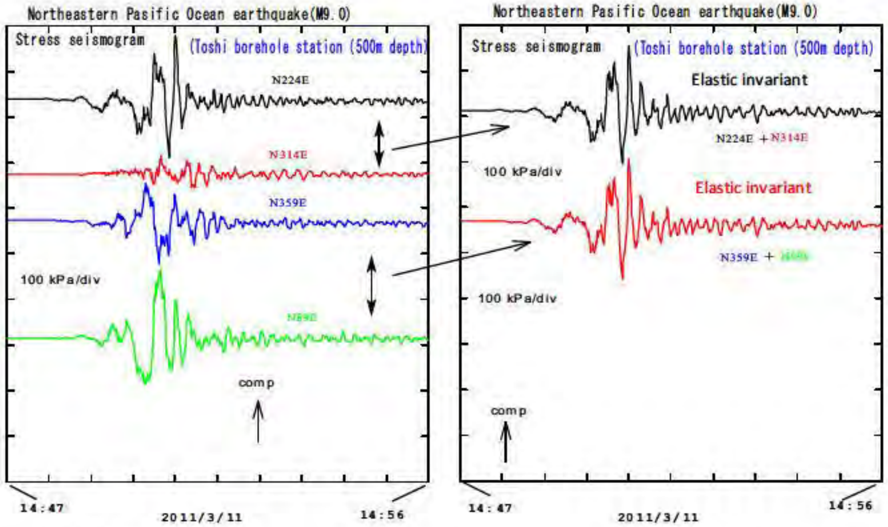
応力計の水圧と出力電圧の関係の例

An example of calibration showing relationship between strain and output voltage for stress meter

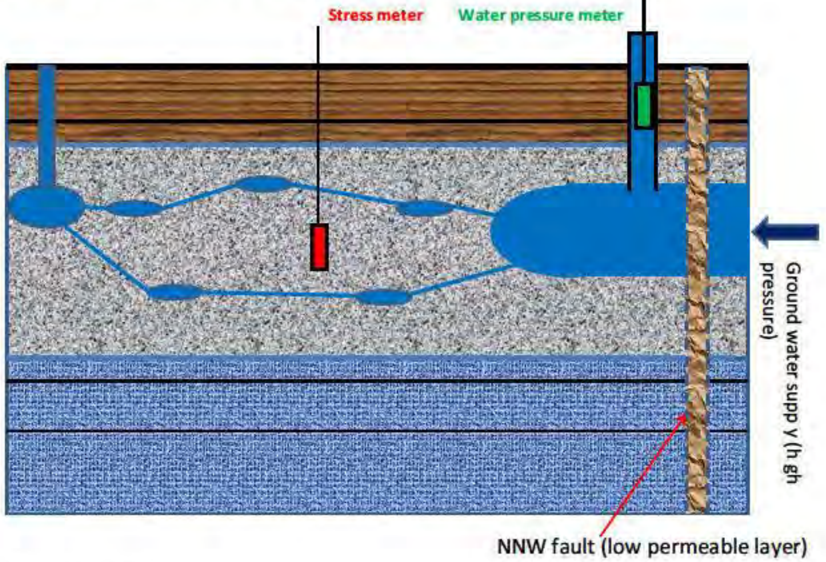


3 examples showing reliability of Stress meter

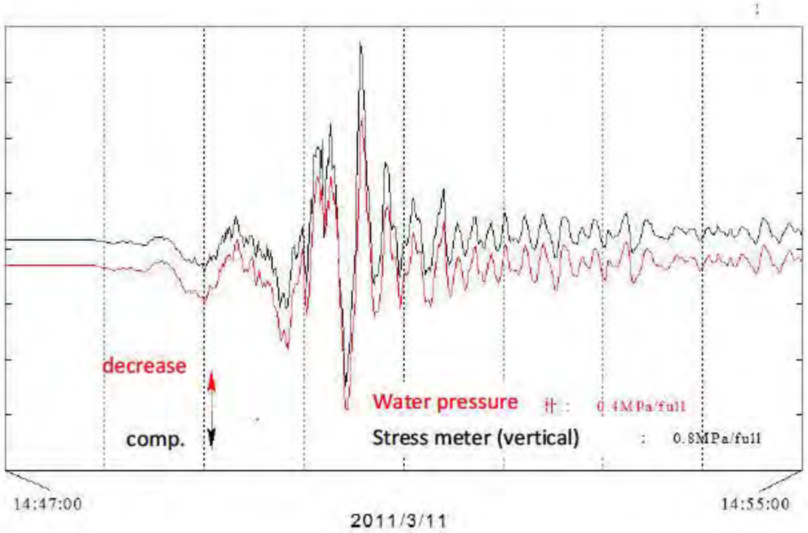
Elastic invariant obtained from different components coincides



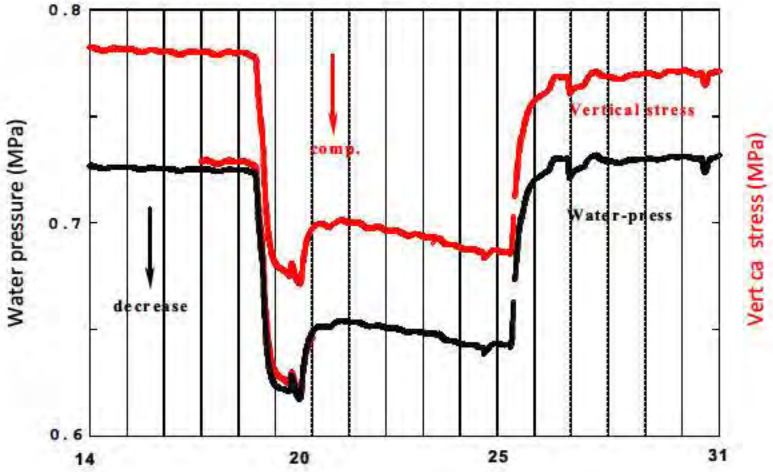
Schematic depiction showing arrangement of water pressure meter , stress meter and aquifer



Comparison of data between stress meter(vertical comp.) and water pressure meter for Northern Pacific Ocean Earthquake (2011/3/11 M9.0)

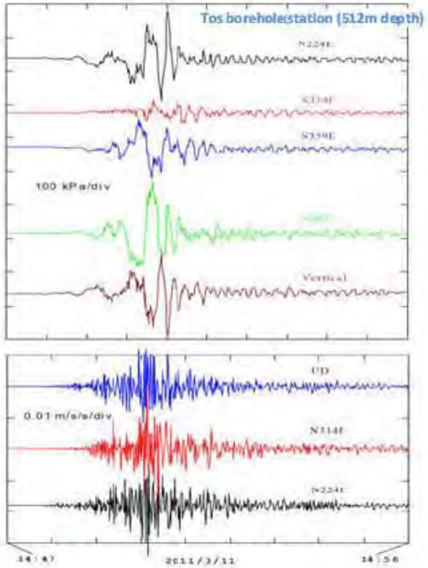


Comparison of data between stress meter(vertical comp.) and water pressure meter for spring water (2012/7/14 – 7/31)



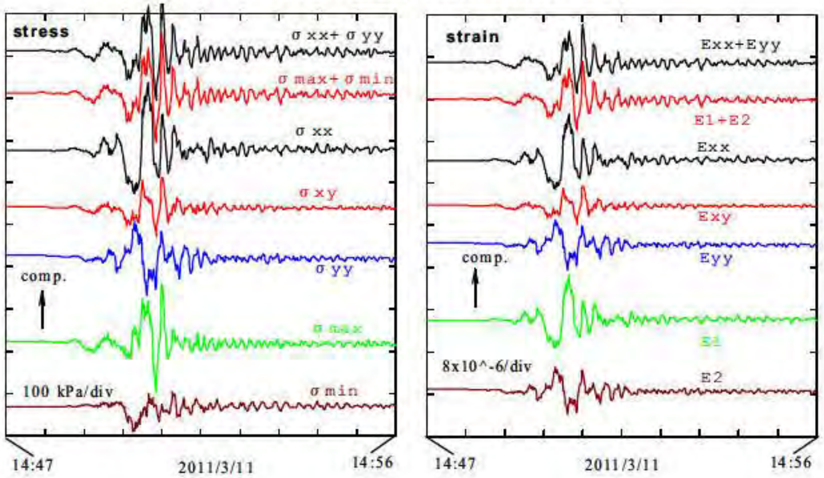
Observed examples

Stress seismogram and seismogram for Northern Pacific Ocean Earthquake (2011/3/11 M9.0)

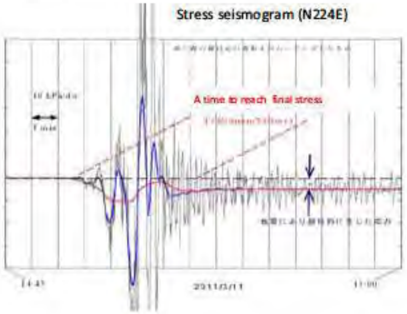


Stress meter can observe both stress and strain

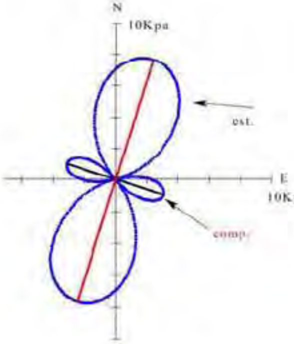
Stress and strain obtained from stress meter of TOS borehole station for Northern Pacific Ocean Earthquake (2011/3/11 M9.0)

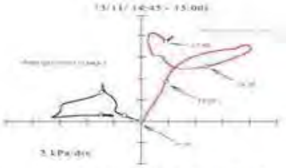


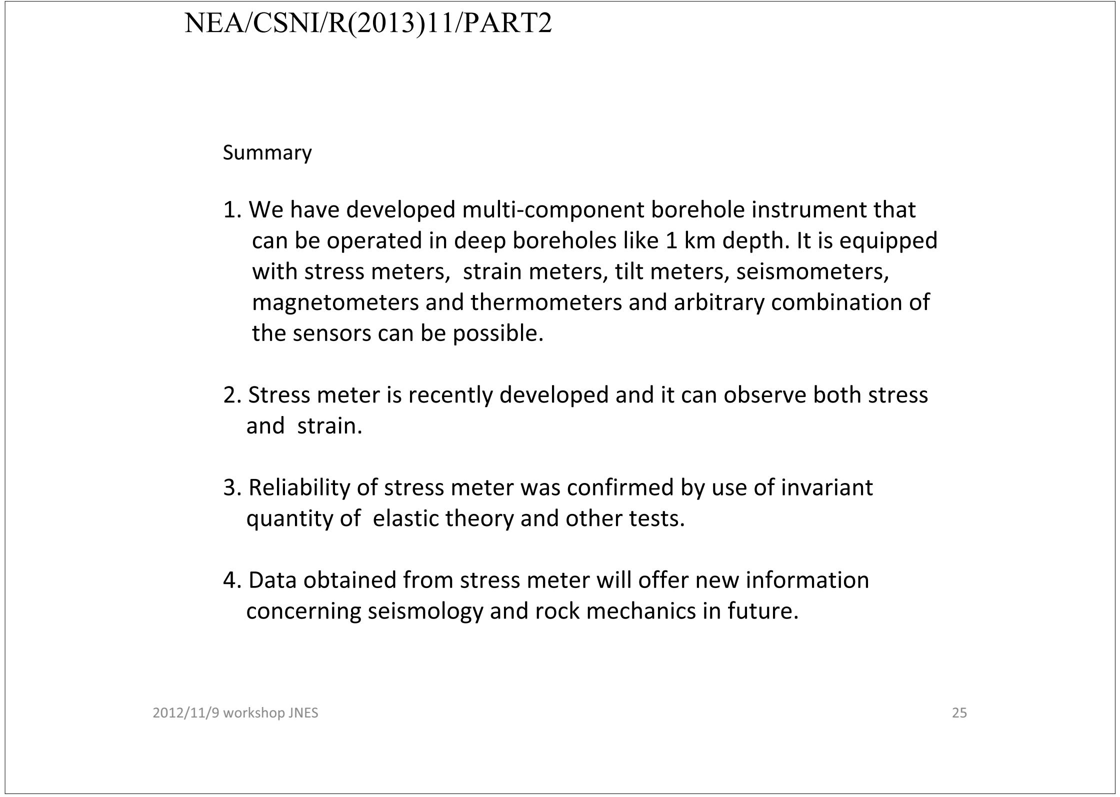
Stress change produced at TOS station by Northern Pacific Ocean Earthquake (2011/3/11 M9.0)


Stress seismogram (N224E)

Final stress




Time variation of principal stress



Summary

1. We have developed multi-component borehole instrument that can be operated in deep boreholes like 1 km depth. It is equipped with stress meters, strain meters, tilt meters, seismometers, magnetometers and thermometers and arbitrary combination of the sensors can be possible.

2. Stress meter is recently developed and it can observe both stress and strain.

3. Reliability of stress meter was confirmed by use of invariant quantity of elastic theory and other tests.

4. Data obtained from stress meter will offer new information concerning seismology and rock mechanics in future.