The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2167-17

Advanced School on Direct and Inverse Problems of Seismology

27 September - 8 October, 2010

Achievements of strong motion seismology and its future directions

Kojiro Irikura
Kyoto University
Japan

The Abdus Salam International Centre for Theoretical Physics (*ICTP*)
27 September - 9 October , 2010

Advanced School on Direct and Inverse Problems of Seismology

Monday 4, October

Achievements of strong motion seismology and its future directions

Kojiro Irikura: Kyoto University, Japan

Self-Introduction of Kojiro Irikura

Professor Emeritus, Kyoto University
Professor, Aichi Institute of Technology

Speciality:
Seismology, Strong Motion Seismology

Research Results:
- Simulation of Ground Motions from Large Earthquakes Using Empirical Green's Function Method
- Making "Recipe" for Predicting Strong Ground Motion
- Upgrading of Earthquake Early Warning System

Today's Topic

Part 1

1. Brief History of the Challenges to Reduce Earthquake Risks and Strong Motion Studies
2. The impacts of the 1995 Hyogo-ken Nanbu (Kobe) earthquake to Seismic Hazard and Risk Studies

Part 2

3. Scaling Relations of Fault Parameters for Inland Crustal Earthquakes
4. Recipe for Predicting Strong Ground Motions, Aiming to Earthquake Disaster Prevention
5. Application to Design Basis Ground Motion for Seismic Safety of Nuclear Power Plant- Lessons Learned from the 2007 Niigataken Chuetsu Oki Earthquake-

The Abdus Salam International Centre for Theoretical Physics (*ICTP*)
27 September - 9 October , 2010

Achievements of strong motion seismology and its future directions
-Chapter 1-

Brief History of the Challenges to Reduce Earthquake Risks and Strong Motion Studies

Earthquake Disaster Prevention in Europe

The 14th century Assisi earthquake
"Earthquake" by Giotto - God save us -

Giotto

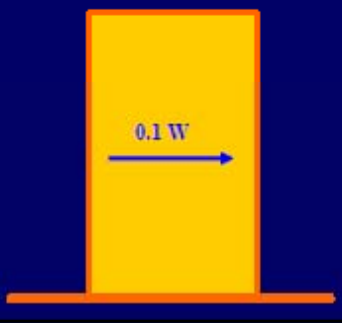
Earthquake Disaster Prevention in Japan

Pictures of the 1855 Edo (Tokyo) Ansei Earthquake (M6.9)
- Battles against underground catfishes -

Revision of Law Enforcement Regulations in 1924

Introduction of seismic design forces

- Maximum ground acceleration at University of Tokyo = 0.3 G
- Safety factor in allowable stress design = 3.0
- Seismic Coefficient = 0.3 / 3.0 = 0.1



Toshikata Sano (1880-1956)

Development of Strong Motion Accelerograph

1931 Professor Kyoji Suyehiro (1877-1932), First Director of Earthquake Research Institute, Tokyo Imperial University, invited by ASCE, gave a series of lectures in US universities.

1932 USCG Strong Motion Accelerograph (Montana)

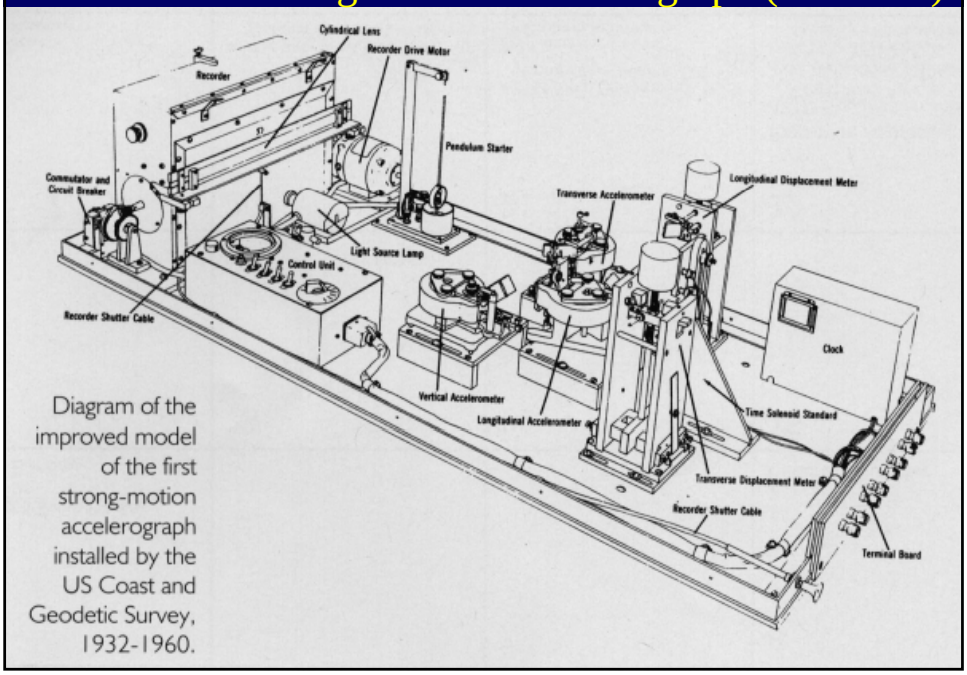


Diagram of the improved model of the first strong-motion accelerograph installed by the US Coast and Geodetic Survey, 1932-1960.

Damage in El Centro by 1940 Imperial Valley Earthquake

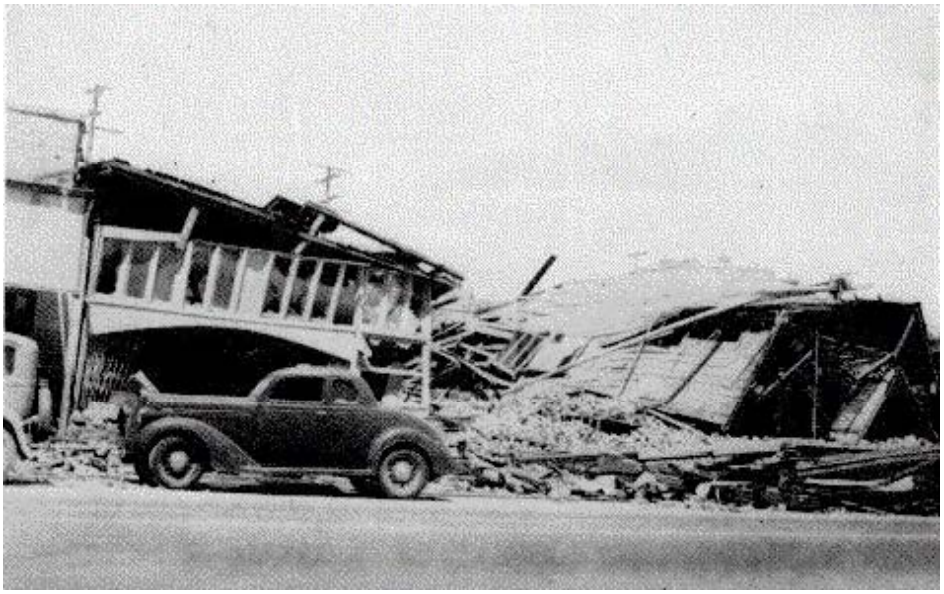
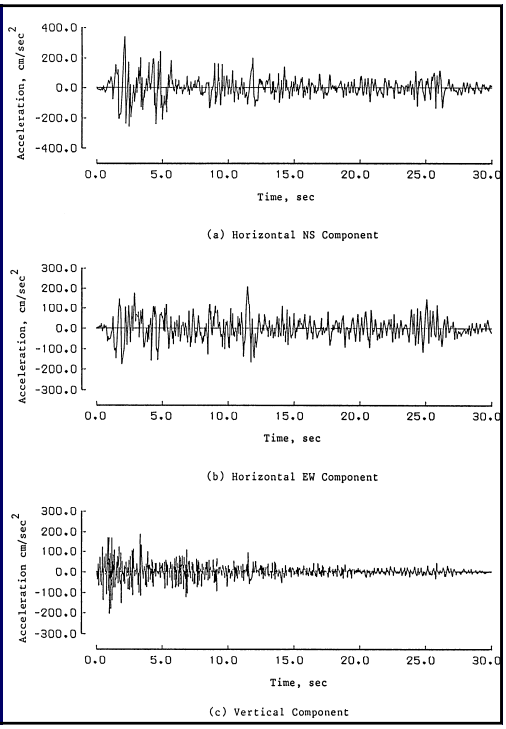


Photo: US Coast and Geodetic Survey

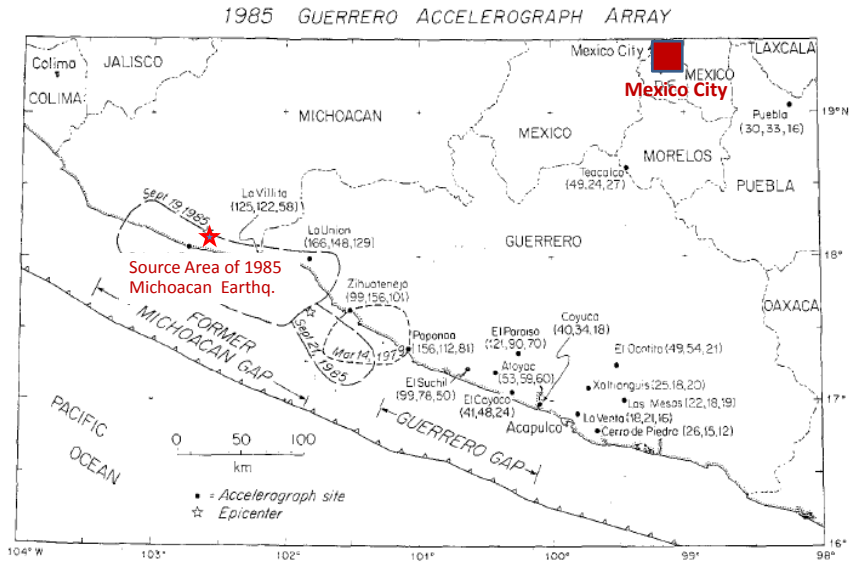
Strong Motion Accelerograph

- Long Beach EQ, 1933
  Out of scale
- Imperial Valley EQ, 1940
  El Centro Station
  Max. Acc.= 0.3 G

After Otani (2009)



1985 Michoacan, Mexico, Earthquake (Mw 8.0)



Singh et al. (1988)

Extensive damage of the twelve-story high ,reinforced concrete building of the Ministry of Communications and Transport

After George Pararas-Carayannis (2000)

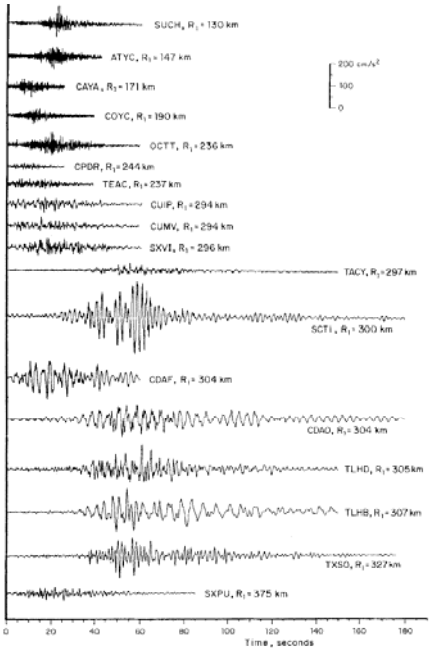
1985 Michoacan Earthquake

Acceleration Motions (EW comp.)

Caustal Area Close to the Source Area

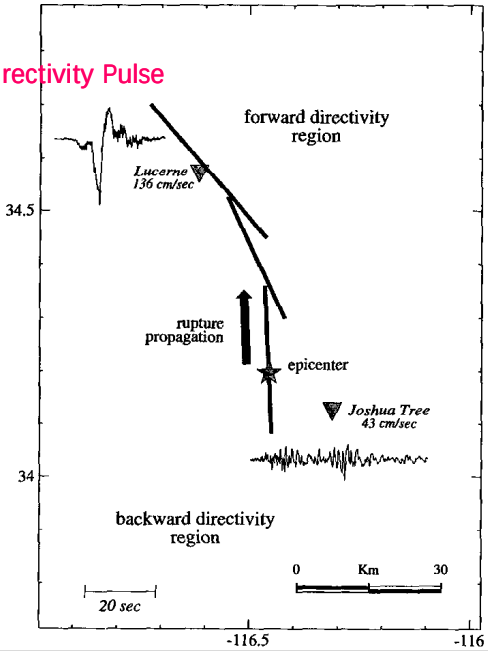
Mexico City Area More than 300 m away from the Epicenter

Singh et al. (1988)



1992 Landers Earthquake (Mw 7.3)

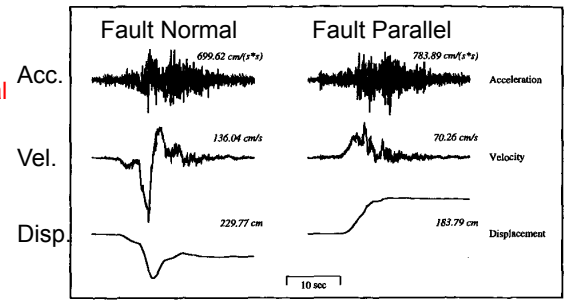
Rupture Directivity Pulse

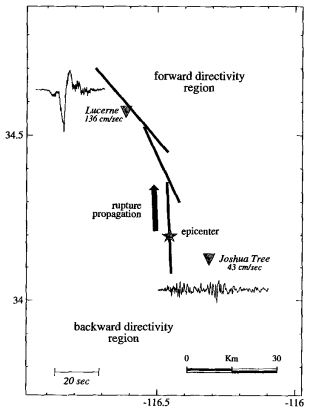


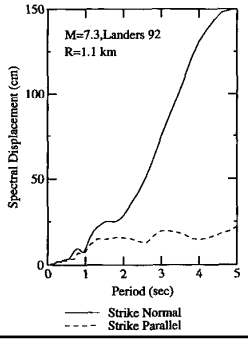
Somerville et al. (1997)

1992 Landers Earthquake (Mw 7.3)

Difference between fault normal and fault-parallel motions

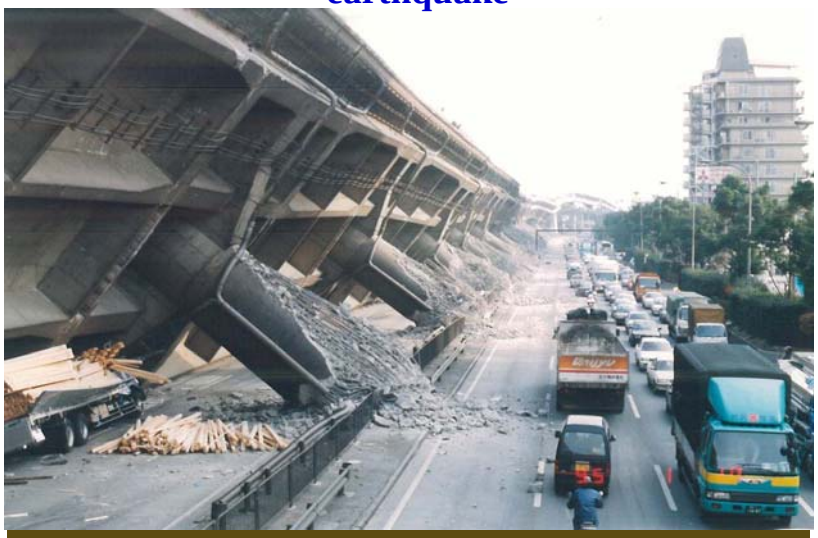






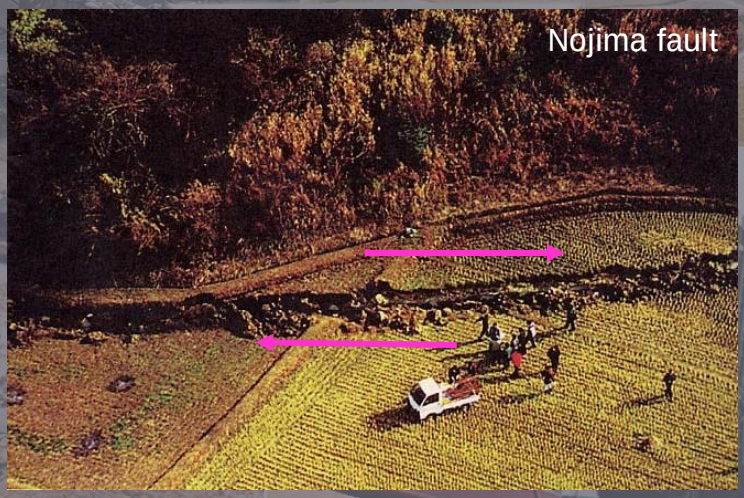
Somerville et al. (1997, SRL)

Damage due to the 1995 Hyogo-ken Nanbu(Kobe) earthquake

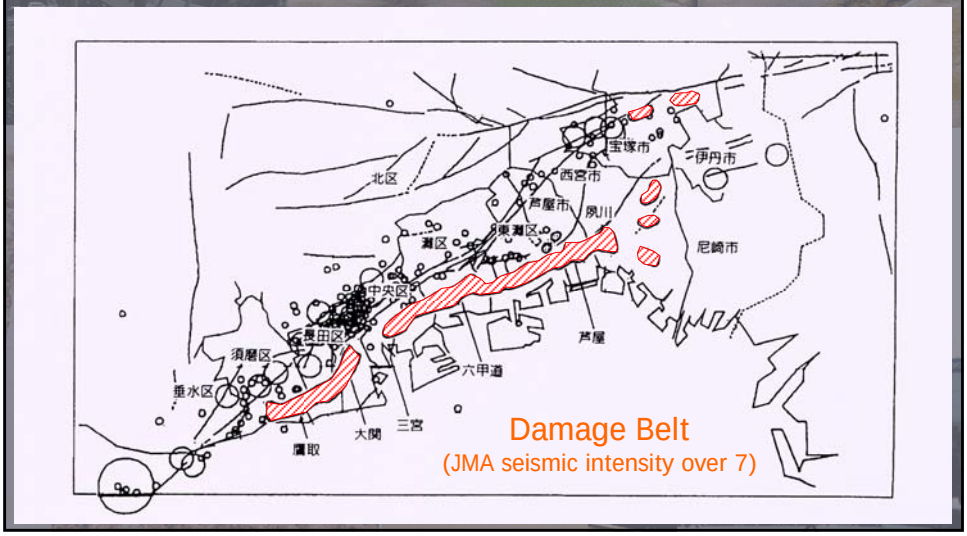


Collapse of Hanshin Expressway Running near Source Area

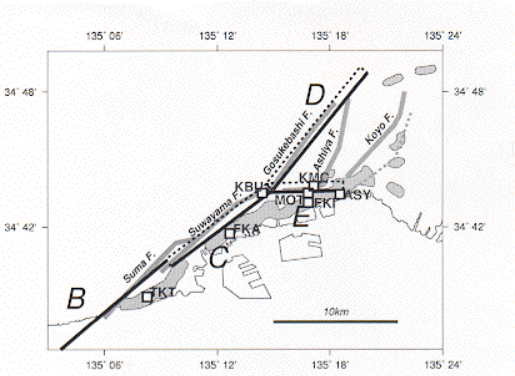
1995 Hyogo-ken Nanbu (Kobe) earthquake: Mw 6.9

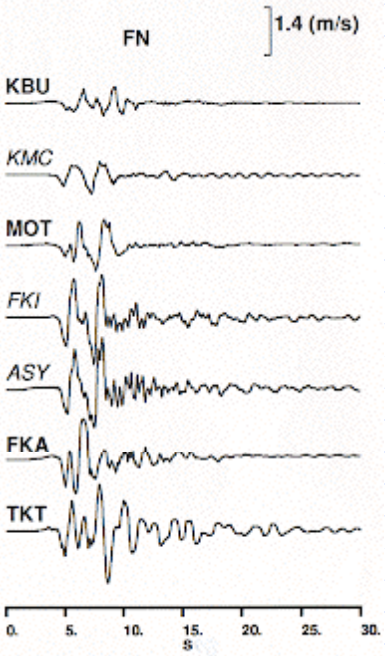


1995 Hyogo-ken Nanbu (Kobe) earthquake: Mw 6.9



Strong Ground Motions during1995 Kobe Earthquake





盆地側の観測点で顕著な2つのパルス波が記録された。このパルス波は1～2秒の周期をもち、木造家屋や中低層鉄筋コンクリート構造物に大きな被害を与えた。

Mechanism of Strong Motion Generation

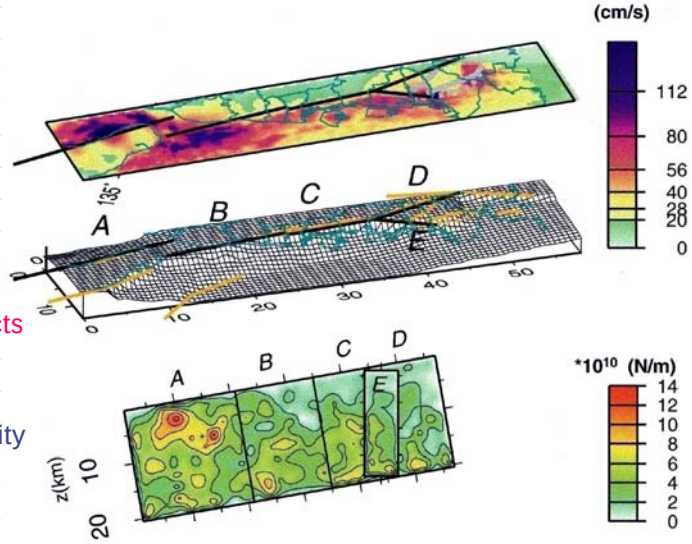
Site Amplification

Basin Shape
Velocity Structure

→ Basin Edge Effects

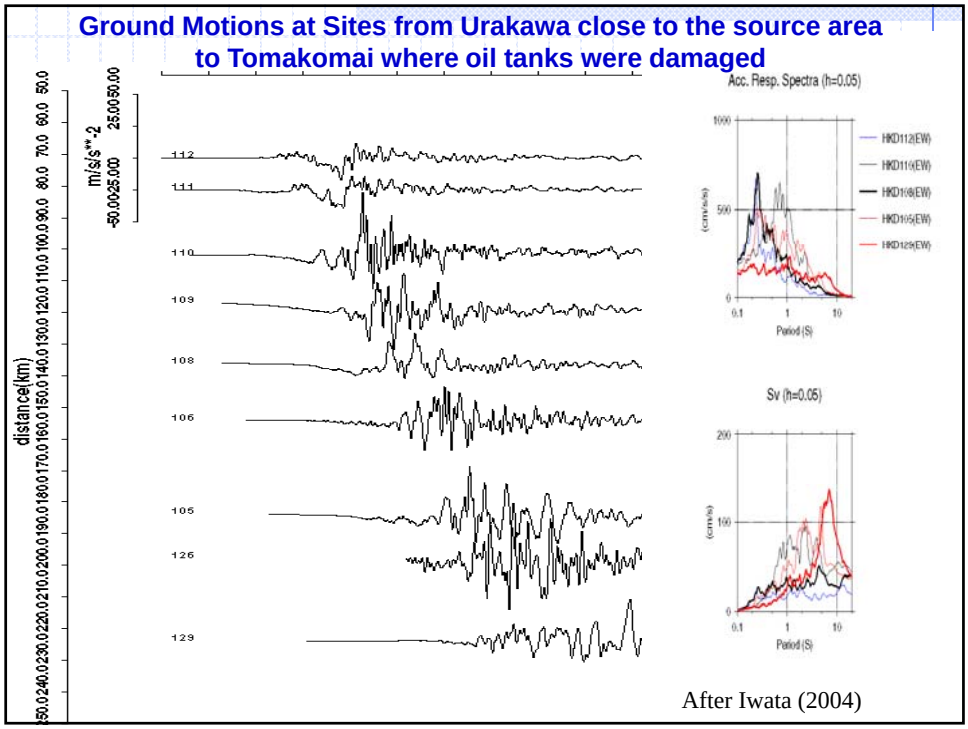
Source Heterogeneity
3 Asperities

→ Directivity Pulse

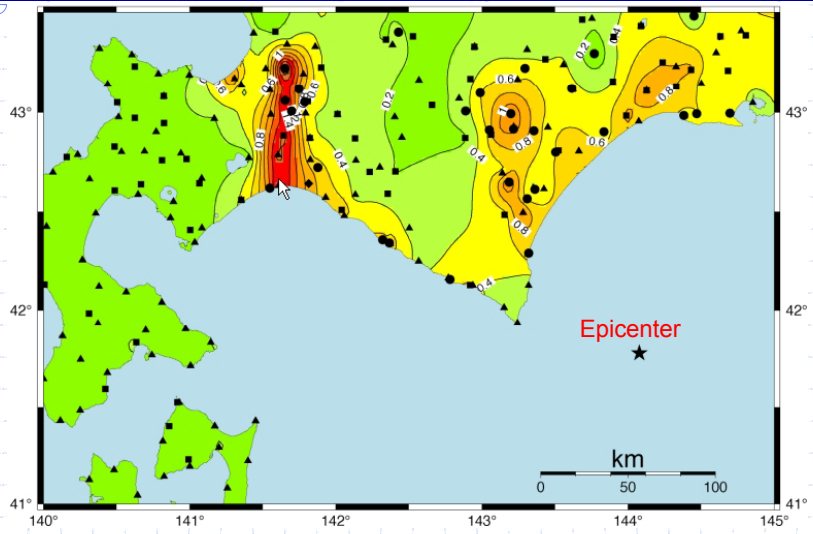


(Iwata et al., 1999)


2003 Tokachi-oki
earthquake: Mw8.0


Ground Motions at Sites from Urakawa close to the source area
to Tomakomai where oil tanks were damaged
Acc. Resp. Spectra (h=0.05)
Sv (h=0.05)
Period (S)
distance(km)
m/s/s**-2
After Iwata (2004)

Spatial Distribution of 1% Pseudo-Velocity Response Spectra of 7 seconds (m/s) observed during the 2003 Tokachi-oki earthquake

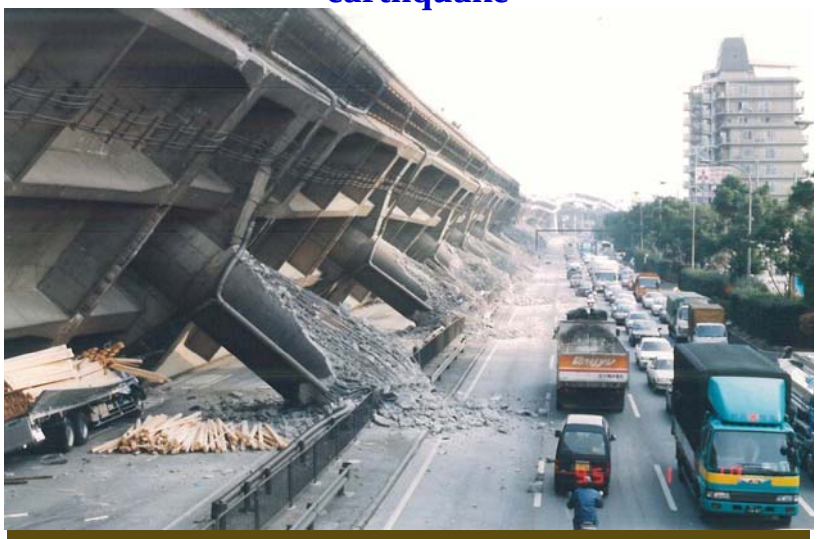


The Abdus Salam International Centre for Theoretical Physics (*ICTP*)
27 September - 9 October , 2010

Achievements of strong motion seismology and its future directions -Chapter 2-

The impacts of the 1995 Hyogo-ken Nanbu (Kobe) earthquake to Seismic Hazard and Risk Studies

Damage due to the 1995 Hyogo-ken Nanbu(Kobe) earthquake



Collapse of Hanshin Expressway Running near Source Area

After the 1995 Kobe Earthquake, what changed!

0. Reconsider earthquake disaster prevention

Earthquake prediction programs have not functioned for reducing earthquake disasters.

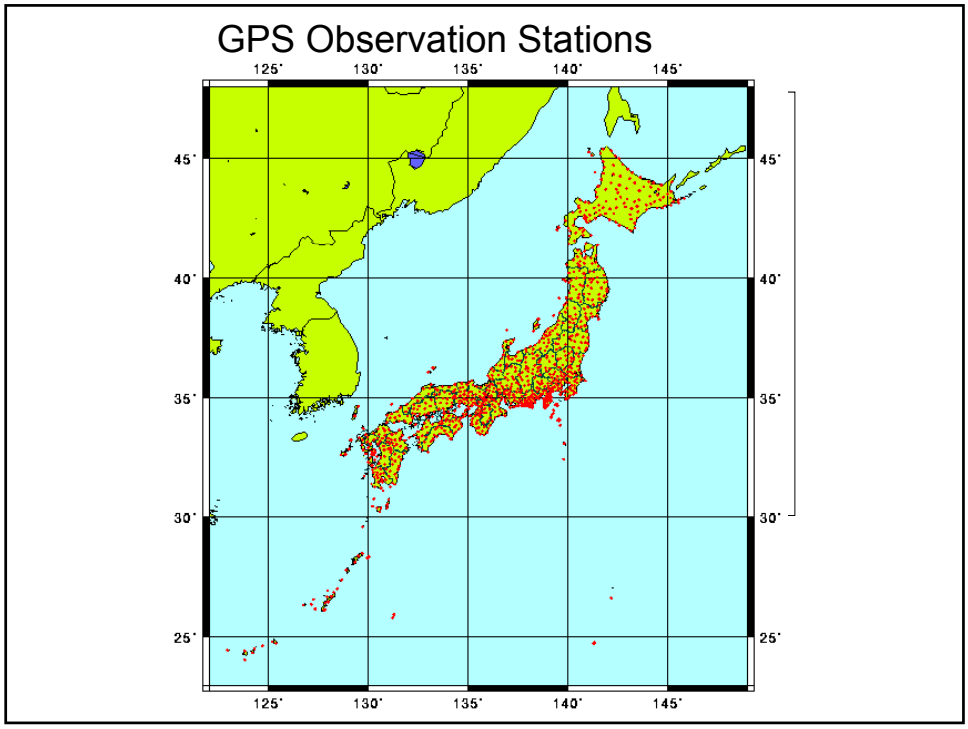
1. Know earthquakes

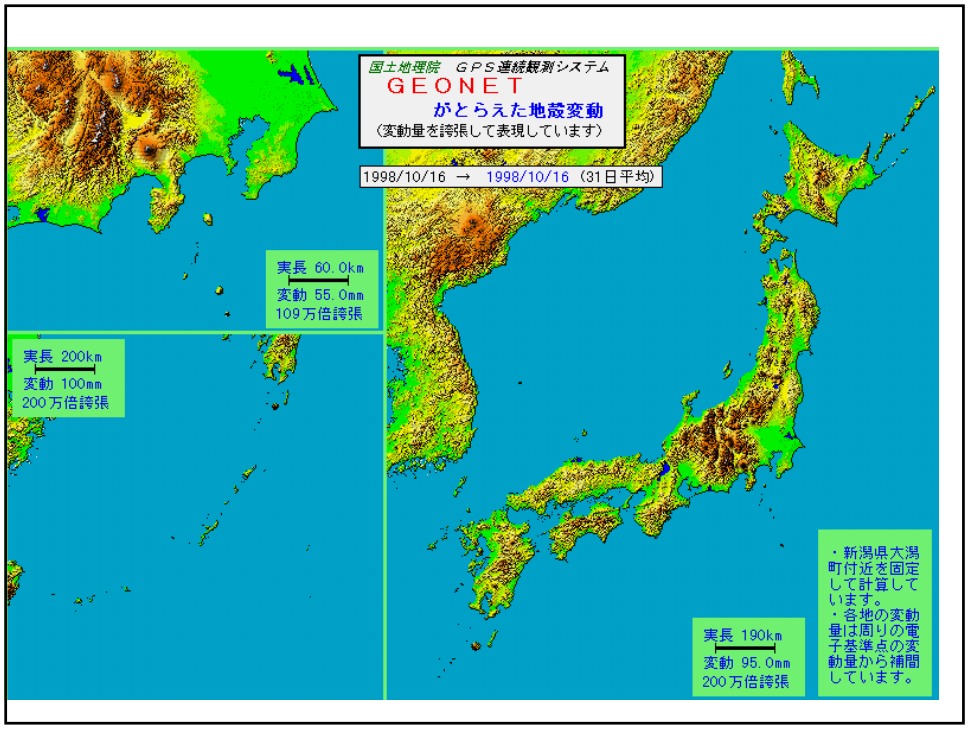
Promote basic researches and observations related to earthquakes.

2. Prepare for earthquakes

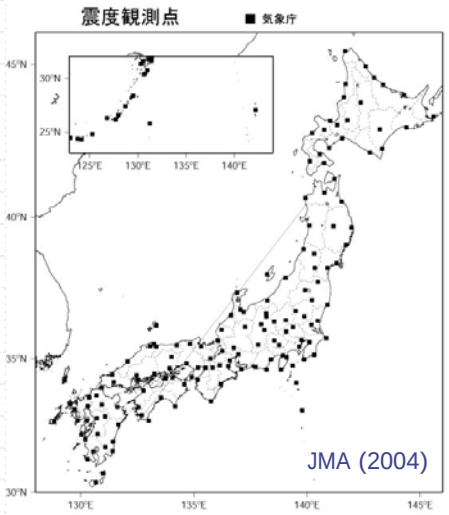
Promote earthquake engineering researches and cooperation between earthquake engineers , Earth scientists, and societal scientists for mitigating earthquake disasters and managing seismic risk.

→ **Importance of Hazard and Risk Assessment**
Role of the national government


GPS Observation Stations
125°
130°
135°
140°
145°
45°
40°
35°
30°
25°

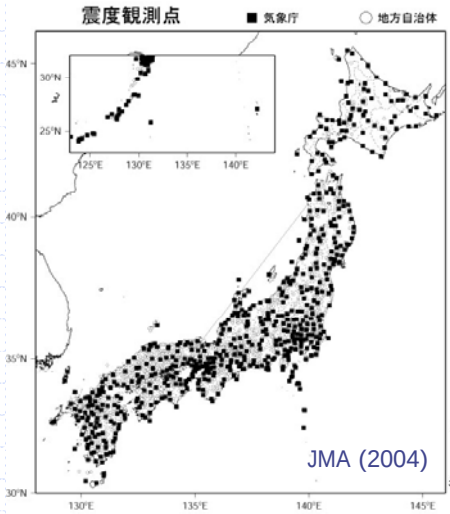

国土地理院　ＧＰＳ連続観測システム
ＧＥＯＮＥＴ
がとらえた地殻変動
（変動量を誇張して表現しています）
1998/10/16 → 1998/10/16 （31日平均）
実長 60.0km
変動 55.0mm
109万倍誇張
実長 200km
変動 100mm
200万倍誇張
実長 190km
変動 95.0mm
200万倍誇張
・新潟県大潟町付近を固定して計算しています。
・各地の変動量は周りの電子基準点の変動量から補間しています。

Seismic Network (before 1995 Kobe)

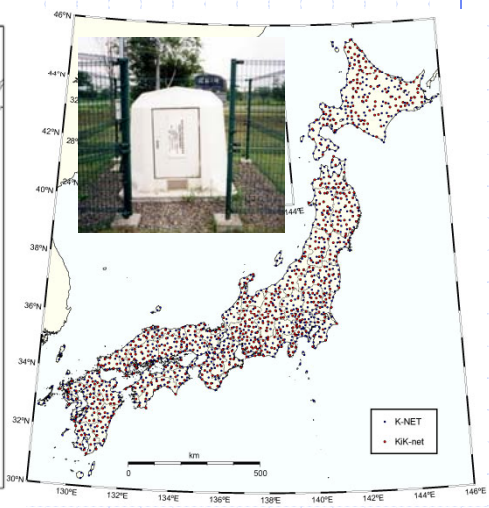


JMA (2004)

Seismic Network (after 1995 Kobe)



JMA (2004)



NIED (2004)

Programs defining the Seismic Hazard in Japan

1. Headquarters for Earthquake Research Promotion

Long-term Evaluation:

Evaluate probabilities of the next occurrence of large earthquakes for major active faults and subduction-zones along troughs.

Strong Ground Motion Evaluation

Construct seismic hazard maps, probabilistic and deterministic.

Probabilistic hazard map: predicted likelihood of ground motion level occurring in a given area within a set period of time.

Shaking map for scenario earthquakes: strong ground motion from hypothetical source models for specified active faults

2. Central Disaster Management Council

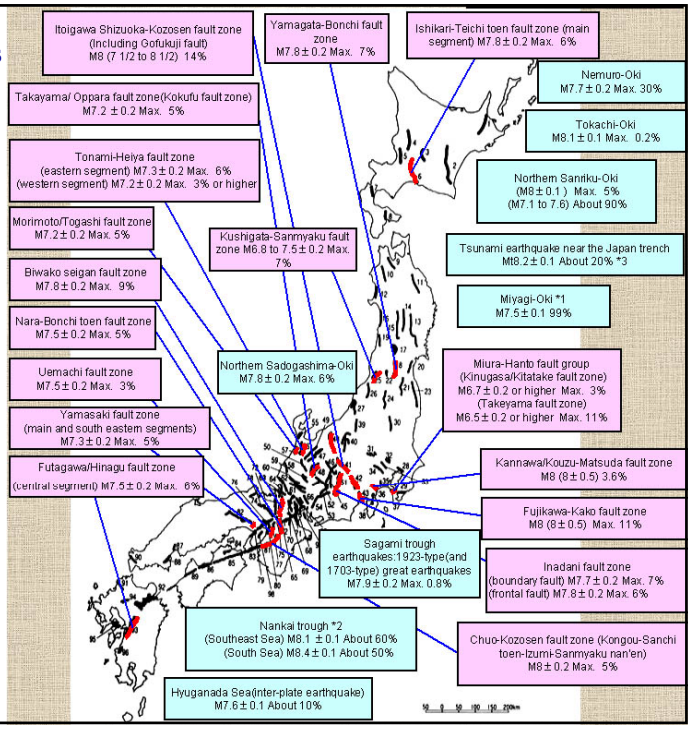
Conduct damage assessments from specific disastrous earthquakes estimating the extents and sizes of the disasters and their impact on individuals and public facilities

Evaluation of Probabilistic Seismic Hazard Map

1. Evaluation of probability of earthquake occurrences
2. Evaluation of probability of strong-motion level
   * PGV on the engineering bedrock using attenuation-distance relation (Si & Midorikawa 1999)
   * PGV on the ground surface using site amplification (Fujimoto & Midorikawa 2008)
   * JMA seismic intensity Empirical formula (Midorikawa et al. 1999)
3. Evaluation of probabilistic seismic hazard for each earthquake
4. Evaluation of probabilistic seismic hazard for all earthquakes

Long-term Evaluations of Active Faults and Subduction-zone Earthquakes

(Predicted magnitude and probability of occurrence within 30 years)



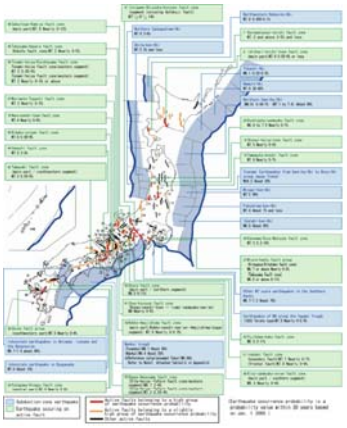
(Earthquake Research Committee, 2004)

Long-term Forecast (continued)

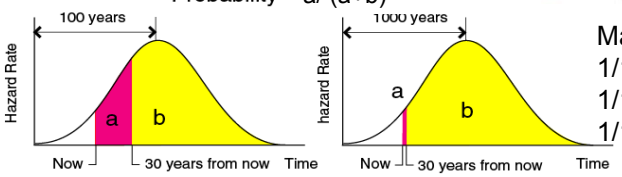
Japanese Govt. announcement

Next 30 years
- Miyagi-oki 99 %
- Nankai Trough 50-60 %
- ISTL (inland fault) 14%
- most active faults < 5%

Probability of Kobe eq. in 1995
0.02-8 %



Probability = a/ (a+b)



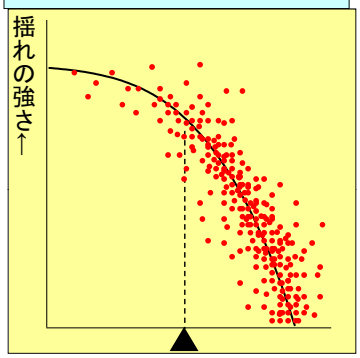
Max probability for 30 yrs
1/100 yr event ~ 90 %
1/1000 yr event ~ 20 %
1/10000 yr event ~ 2 %

Probabilistic Seismic Hazard Map

Long-term Forecast

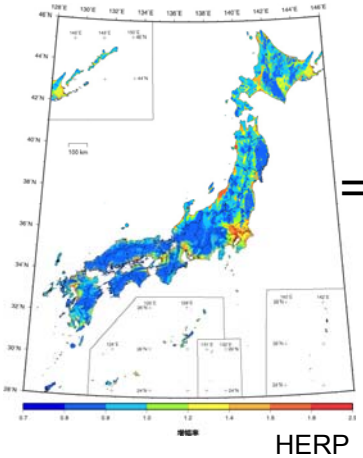
×

Ground motion – Distance Attenuation Relation



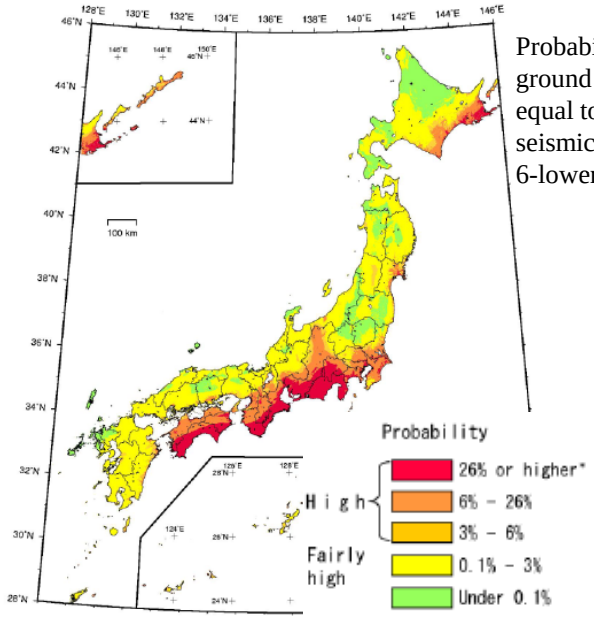
×

Surface Amplification



＝ PSHM

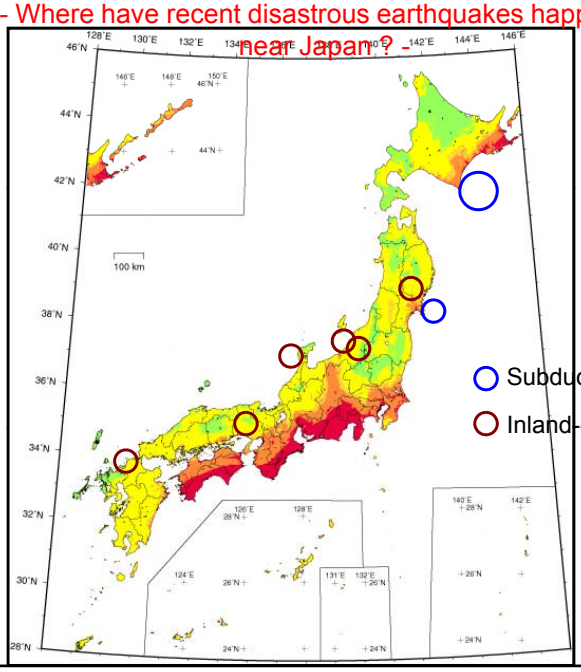
Probabilistic Seismic Hazard Map (2005)



Probability of ground motions equal to or larger than seismic intensity (JMA) 6-lower within 30years.

Probabilistic Seismic Hazard Map (2005)

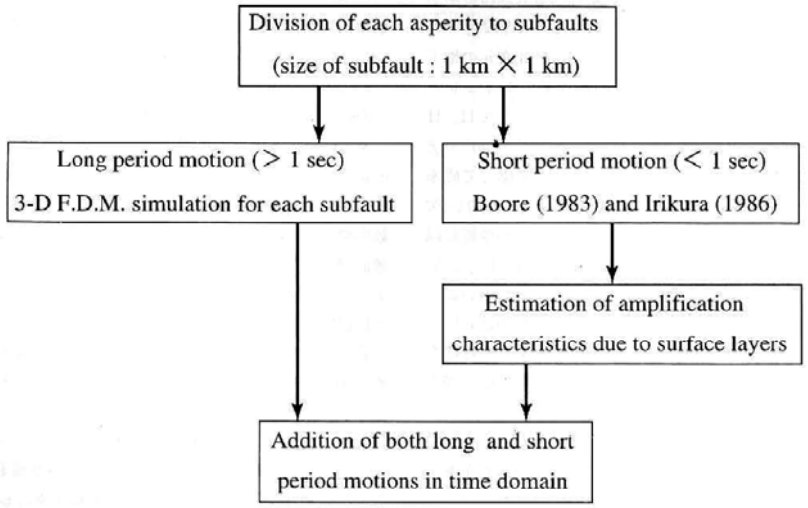
- Where have recent disastrous earthquakes happened near Japan? -



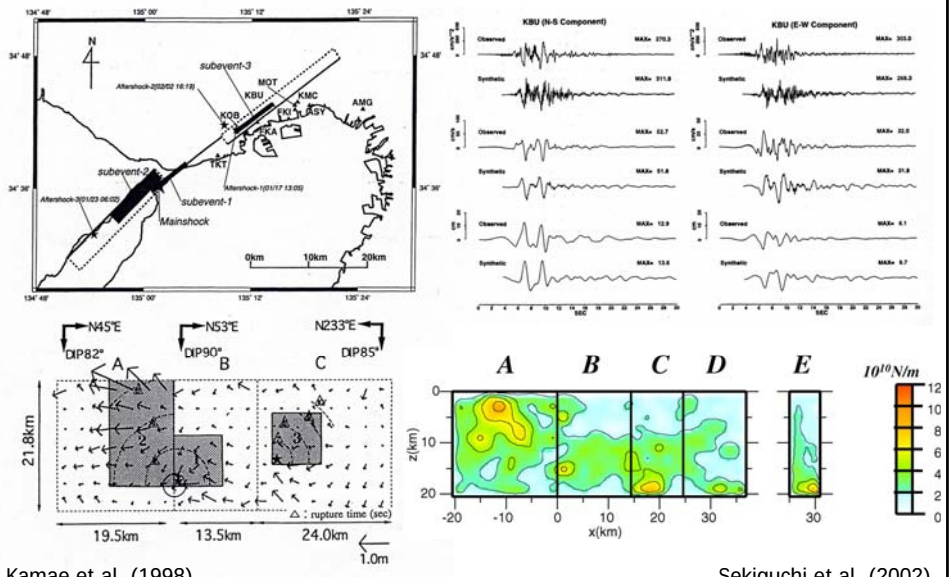
Evaluation of Deterministic Seismic Hazard Map

1. Evaluation of probability of earthquake occurrences
2. Selection of specific active faults with high probability earthquake occurrence
3. Modeling seismic sources using characterized source model based on the recipe of strong motion prediction.
4. Modeling velocity structures from source to site and site amplification factors based on surface geology
5. Calculation of strong ground motions using hybrid method combining stochastic Green's function method and numerical simulation method

Hybrid Method for simulating strong ground motions



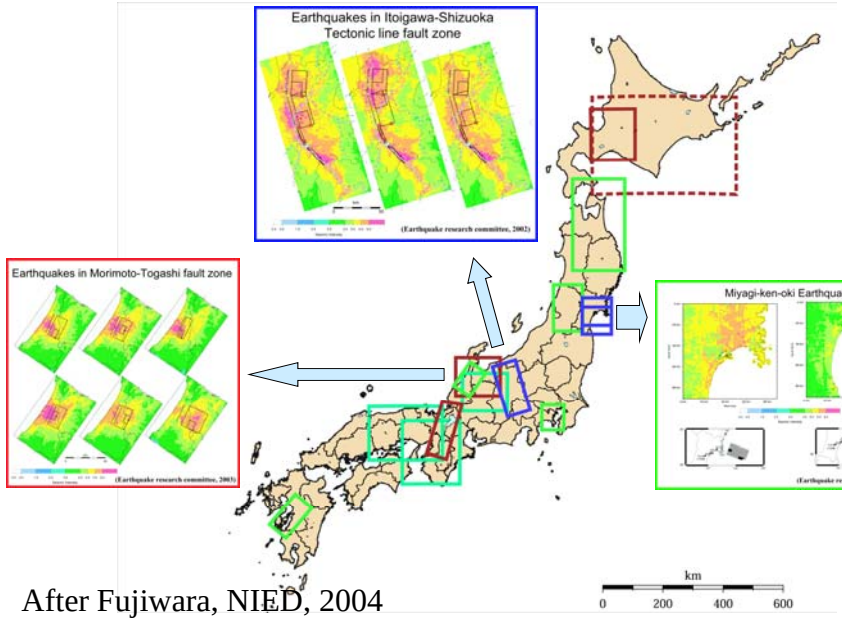
Rupture Directivity Pulse is dependent on Asperity Size



Kamae et al. (1998)

Sekiguchi et al. (2002)

Deterministic Seismic Hazard Map



After Fujiwara, NIED, 2004

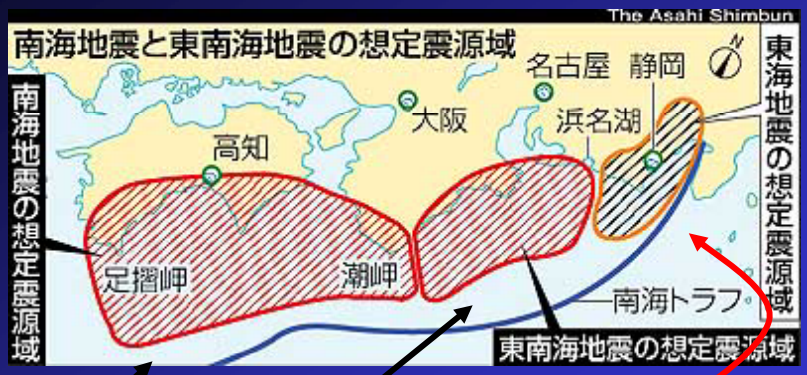
Shaking Maps and Damage Assessments for Specific Disastrous Earthquake in Japan

(Central Disaster Management Council, Japan)

Conduct prediction of strong ground motions and estimate the extents and sizes of the disasters and their impact on individuals and public facilities for specific disastrous earthquakes:

Examples:
The Tokai earthquake (published in 2001).
The Tonankai and Nankai earthquake (published in 2003)
The earthquakes directly under Tokyo (published in 2005)

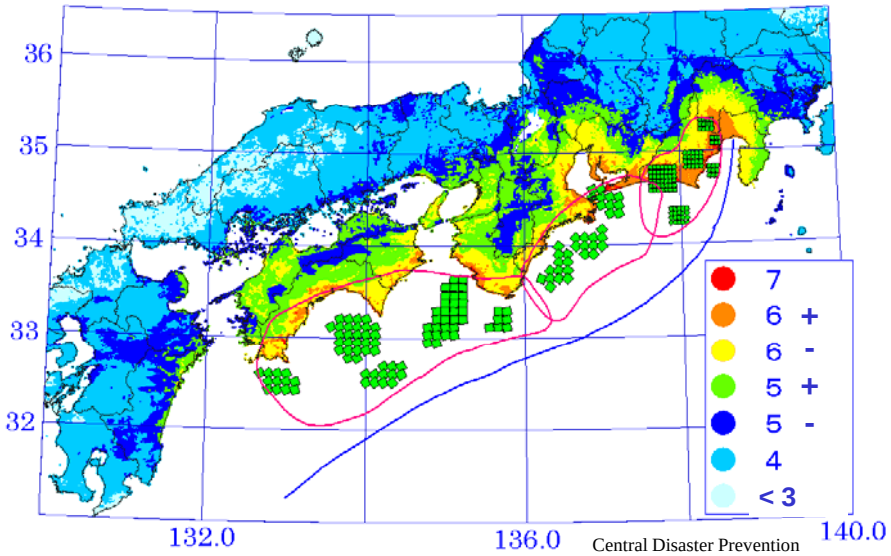
Nankai-Trough Earthquakes



The Asahi Shimbun (2001)

Nankai earthquake Tonankai earthquake Tokai earthquake

Source Model and Seismic Intensity Map for Hypothetical Tokai-Tonankai-Nankai Earthquake



Central Disaster Prevention Council（2003）

Summary

1. The Hyogo-ken Nanbu (Kobe) earthquake in Japan was aware of the importance of strong motion prediction rather than earthquake forecasting to reduce future earthquake disasters.

2. The “National Seismic Hazard Map” published first on March, 2005, and newly improved edition come out on 22 July, 2009. This “Hazard Map” has been making as one of the national projects integrating all fields of earthquake researches such as active fault, earthquake forecast and strong motion prediction studies after the Kobe earthquake.

3. Strong ground motions are deterministically estimated based on the characterized source model and the hybrid simulation method, the stochastic Green’s function method for short period motions and numerical simulation methods such as the Discrete Wave Number Method and the Finite Difference Method for long-period motions .