2. Earthquake and Ground Motions

2.1. Consideration on the interface of seismological topics to building damages

Seismology can contribute to the construction engineering in the ways: 1) Estimation of probability of earthquake occurrence and 2) Estimation of Ground Motion (Fig. 2.1-1). As every seismic damages are due to ground shaking except the direct ground destruction by appearance of fault scarp, the latter is necessary for both probabilistic and deterministic analyses of seismic hazard and for the setting of design seismic force.

The damage survey of buildings is conducted after devastating earthquake with, at least two motivations. One is to grasp the reality of disaster: damage statistics, classification of the damaged buildings, etc. Another is collection of the information for improvement of buildings' quality. In latter case, it is necessary to know how the collapsed or damaged buildings have behaved at the devastating ground shaking. Seismology can contribute in this case via estimation of the devastating ground motion. If the disaster took place because of weakness of houses due to being badly constructed or not well designed, the same disaster may take place on all of houses constructed or designed in the same way. The appropriate counter measure may be improvement of construction technologies or renewal of design code in nation wide level. If the disaster took place because of stronger ground motion than expected, it may be

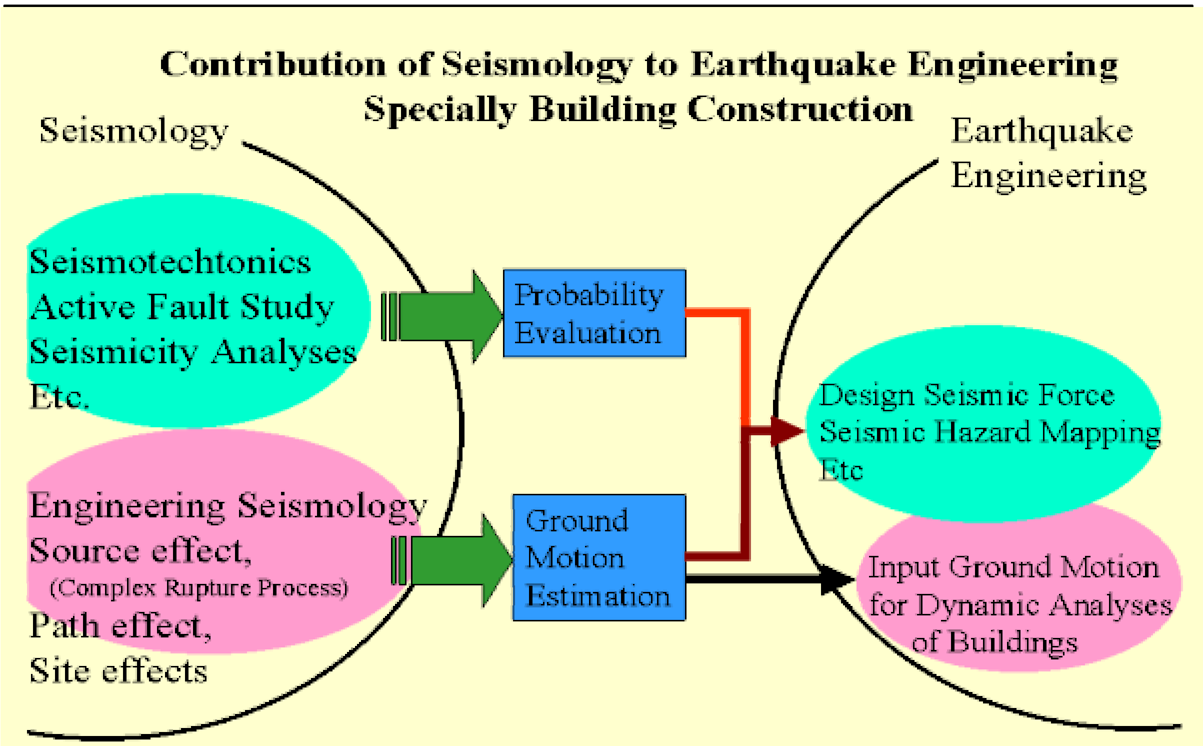


Fig. 2.1-1 Contribution of Seismology to the construction engineering

necessary to know which effect has played the main role.

The ground motion that destroys buildings consists of source, path and site effects as shown in Table2.1-1 and Fig. 2.1-2. If ground motion is stronger in an area than surroundings due to the site effect, the same disaster may repeat in the same site and other sites in the similar ground condition. If that is due to source effect, the disaster may repeat everywhere without any dependence on ground condition. In these cases, the appropriate countermeasures may different each other. Usually, these effects appear in combined way, therefore it is important to estimate the contribution of each effect quantitatively, for an accurate analysis.

Table 2.1-1 Three effects of Seismic Ground Motion

+	Model	Examples of Effect
Source Effect	Source Model	Directivity Effect Radiation Pattern Complex Source Process
Path Effect	Attenuation	Geometrical Spreading Energy Absorption Scattering
Site Effect	Amplification	Response of Shallow Soil Topographic Effect Basin Edge Effect

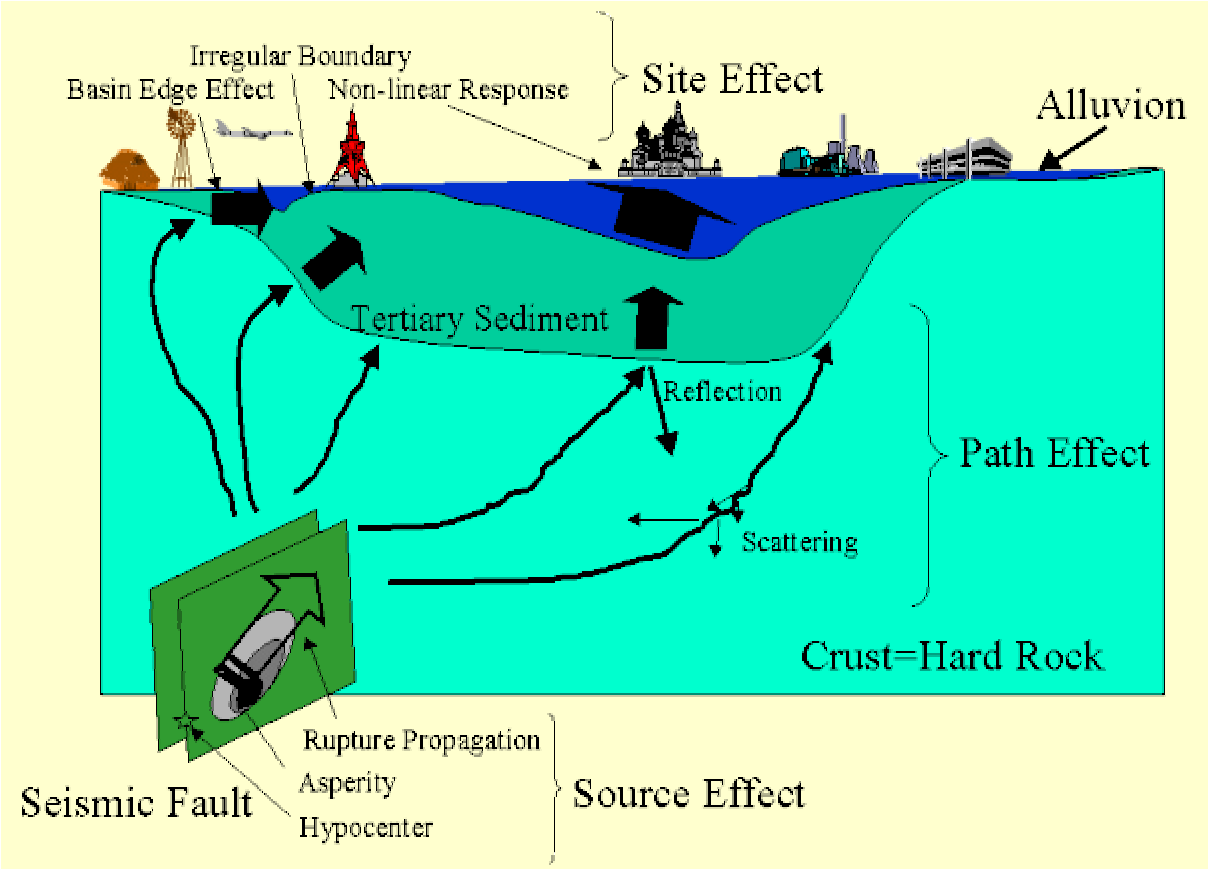


Fig. 2.1-2 Three effect composing ground motion at the surface

If ground motion data of devastating earthquake are available with damage survey results, analyses of dynamic characteristics of houses can be more accurate than the present level. Among various research topics related with seismic source, those related with building damages is classified as shown in Table 2.1-2.

Considering on the techniques used by seismologists for study of seismic source, the seismological topics related with source effect that shall be handled in the guideline are the followings: Hypocenter location & Magnitude, Focal Mechanism (including, Radiation Pattern, etc.) and Rupture Process (including Directivity, Asperity, etc.). For path effect: Wave Propagation in the crust and in the deep sediment (Quality factor, Attenuation Relation, etc) must be handled. Crustal Deformation is also necessary, because this causes damage independently from ground shaking and provides information about seismic source.

Table 2.1-2 Contribution of Information about Earthquake Source for Ground Motion Estimation

<table>
<tr><th rowspan="2">Seismological Data</th><th rowspan="2">Seismological Information</th><th rowspan="2">Source Model</th><th colspan="2">Ground Motion Estimation</th></tr>
<tr><th>Item</th><th>Necessary Data</th></tr>
<tr><td>Travel Time</td><td>Hypocenter Location</td><td rowspan="3">Point Source Model</td><td rowspan="3">PGA, PGV and Intensity (Far field)</td><td rowspan="3">Attenuation Relation or Empirical formula</td></tr>
<tr><td>Peak Amplitude</td><td>Magnitude</td></tr>
<tr><td>Polarity of Initial Motion</td><td>Focal Mechanism</td></tr>
<tr><td>Aftershock Distribution</td><td>Fault Plane</td><td>Finite Fault Model</td><td>PGA, PGV and Intensity (Not in source area)</td><td>Attenuation Relation or Empirical formula</td></tr>
<tr><td>Teleseismic Records</td><td rowspan="3">Complex Rupture Process</td><td rowspan="3">Asperity Model</td><td rowspan="3">Strong Ground Motion due to the main shock in the devastated area.</td><td rowspan="3">Ground Motion Records due to the aftershock in the devastated area.</td></tr>
<tr><td>Strong Motion Records</td></tr>
<tr><td>Geodetic Data</td></tr>
</table>

Besides of them, a topic is necessary to connect these seismological ones to building damage: Estimation of devastating ground motion. It seems better to put this topic in the group of "Seismic Motion". The topic: "site effect" must be included in this group. "Site effect" studies are usually done to clear up the cause of damage concentration and to detect the risky area for future earthquakes (Fig. 2.1-3).

A draft of the part of the guideline related with seismology is shown in the following pages. The sorting has been done especially by consideration on connecting these topics to building damages through seismic ground motion. Only exception is the fault scarp.

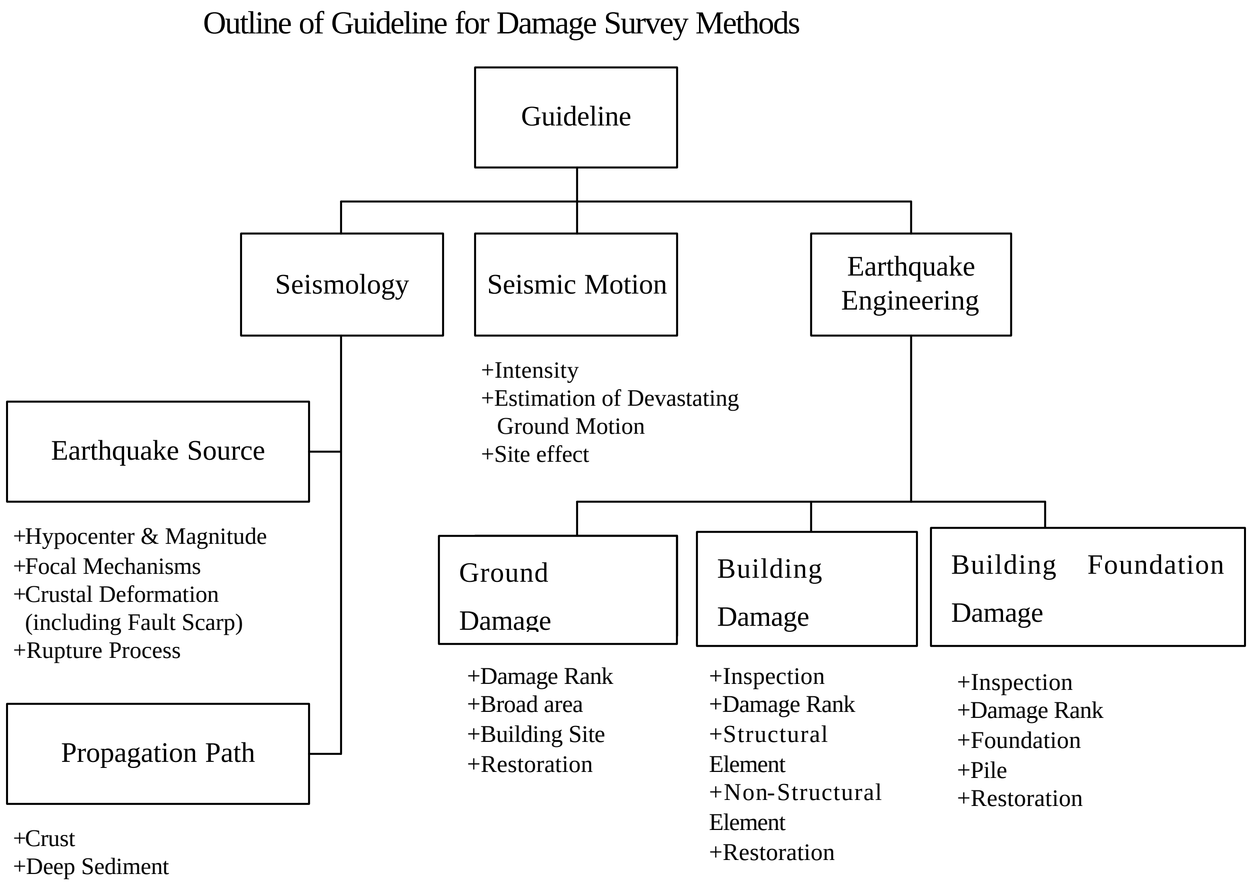


Fig. 2.1-3 Outline of Guideline for Damage Survey Methods

2. Earthquake Source

2.2.1. Hypocenter Location and Magnitude

1) Terminology

Hypocenter: Also known as the focus. The hypocenter is an underground point of the origin of an earthquake and where the fault moved.

Magnitude: A measure of the energy released in an earthquake.

Epicenter: The location on Earth's surface directly above the hypocenter or focus, of an earthquake. Typically, the area where the potential for the greatest damage occurs.

Aftershocks: Earthquakes less intense (weaker) than the main (strongest) earthquake. Typically seismic events begin with foreshocks, followed by the main shock and finally aftershocks.

2) Purpose or Target

Determination of location of earthquake and its size.

3) Grade

Table 2.2.1-1 Classification of topics

Accuracy	Item	Input Data or techniques	Examples or references
1	Epicentral Area	Intensity Distribution	Earthquakes in history Small & Shallow event outside of local network
2	Hypocenter location (insufficient accuracy)	Global Network	NEIC CTBTO
3	Hypocenter location (within the coverage)	Local Network	JMA(Japan) NRIAG(Egypt) BMG(Indonesia) PHIVOLCS(Philippine)

4) Examples (Description with figures)

Several global seismic observation networks (Fig.2.2.1-1)

Several national seismic observation networks (Fig.2.2.1-2)

5) Special Topics

Rough estimation of Distance & Direction with 1 station 3 components Data (DIMAS)

Joint Hypocenter Determination for aftershock sequence Magnitude determination & its variety

6) References

<Hypocenter Location>

Aki, K. and Richards, P. (1980): *Quantitative Seismology*, Vol. 2, Freeman.

Geiger, L. (1912): Probability method for the determination of earthquake epicenters from the arrival time only. *Bull. St. Louis Univ.* , 8, 60-71.

Klein, F. W. (1978): Hypocenter location program HYPOINVERSE Part 1: Users guide to versions 1,2,3 and 4, *USGS Open File Report*, 78-694.

Lee, W. H. K. and Lahr, J. C. (1975): HYPO71 (revised): A computer program for determining hypocenter, magnitude and first motion pattern of local earthquakes, *USGS Open File Report*, 1-116.

Lee, L. H. K. and Stewart, S. W. (1981): *Principles and Applications of Microearthquake Networks*, Academic Press.

Lee, W. H. K. and Valdes, C. M. (1989): User Manual for HYPO71PC, in IASPEI Software Library Volume 1. Toolbox for Seismic Data Acquisition, Processing and Analysis, Part III. Off-line Data Analysis, Edited by W. H. K. Lee, Published by International Association of Seismology and Physics of the Earth's Interior (IASPEI) in collaboration with Seismological Society of America, 203-236.

Lienert, B. R., Berg, E., and Frazer, N. (1986): HYPOCENTER: An earthquake location method using centered, scaled, and adaptively damped least squares, *Bull. Seism. Soc. Am.*, **76** (No. 5), 771-783.

Lienert, B. R. and J. Havskov (1995): A computer program for locating earthquakes both locally and globally, *Seism. Res. Lett.*, **66**, 26-36. (ftp://elepaio.soest.hawaii.edu/pub/lienert/)

<Magnitude>

Gutenberg, B. (1945). Amplitudes of surface waves and magnitudes of shallow earthquakes. *Bull. Seismol. Soc. Am.* **35**, 3-12.

Kanamori, H. (1977). The energy release in great earthquakes, *J. Geophy. Res.* **82**, 2981-2987.

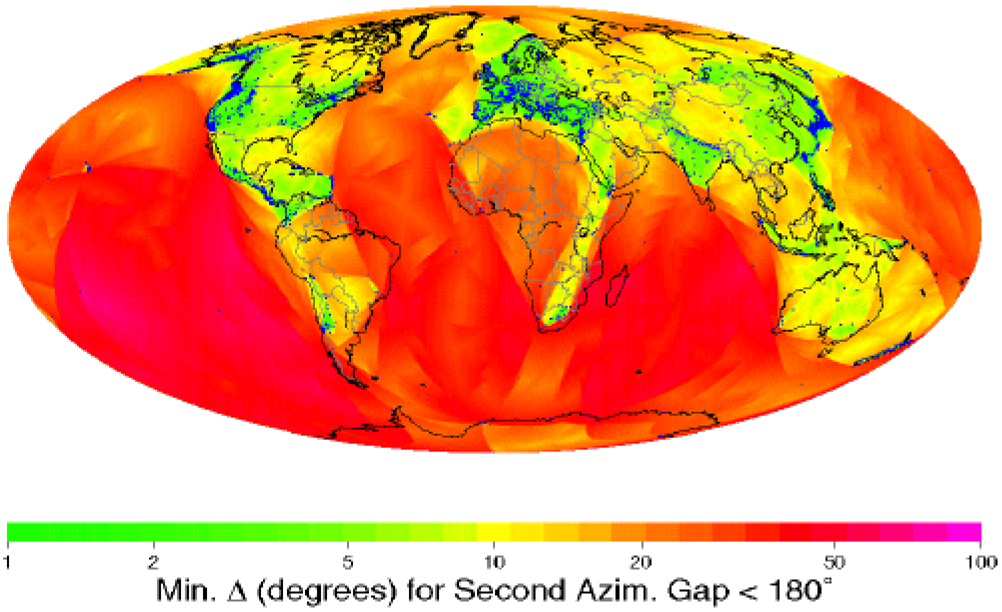
Lee, W. H. K., Bennett, R. E., and Meagher, K. L. (1972): A method of estimating magnitude of local earthquakes from signal duration, *Geol. Surv. Open-File Rep.(U.S.)*, **28**.

Richter, C. F. (1935): An instrumental earthquake magnitude scale. *Bull. Seismol. Soc. Am.* **25**, 1-32.

Tsumura, K. (1967): Determination of earthquake magnitude from total duration of oscillation, *Bull. Earthq. Res. Inst.*, Univ. Tokyo, **45**, 7-18.

1999 January - November Reporting Stations

Maps at a larger scale:	North America	South America	Europe	Africa	Central Asia	Eastern Asia	Australia & SW Pacific



In each year of the late 1990's, phase readings from around 2500 seismic stations were contributed to the ISC. Since these stations are operated independently, practices probably vary from one station to another too much to refer to them network. Nevertheless, the geographic distribution of reporting stations limits the detection threshold and location accuracy of events in the ISC Bulletin.

The world map above is one view of the joint capability of reporting stations. The shading on the map shows the smallest distance around each point that includes stations with a second azimuthal gap less than 180°. A second azimuthal gap smaller than 180° should ensure that no single arrival time controls a trade-off between origin time and epicentre. It also means that even if data from a critical station are unavailable, the first azimuthal gap at that location will still be less than 180°. Thus, earthquakes large enough to produce reliably measurable arrival times to these distances are most likely to have reliable epicentres computed by the ISC.

All of the stations (shown as blue triangles) that reported even a single phase reading during 1999 January - November are used to compute the distances. Reports for many stations are received by the ISC only occasionally; the assumption in preparing the map is that a report will be sent if there is any nearby seismic activity for which the data from a station will be important.

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Last modified: Mon Feb 4 09:16:49 GMT 2002

Fig.2.2.1-1 Global seismic observation network

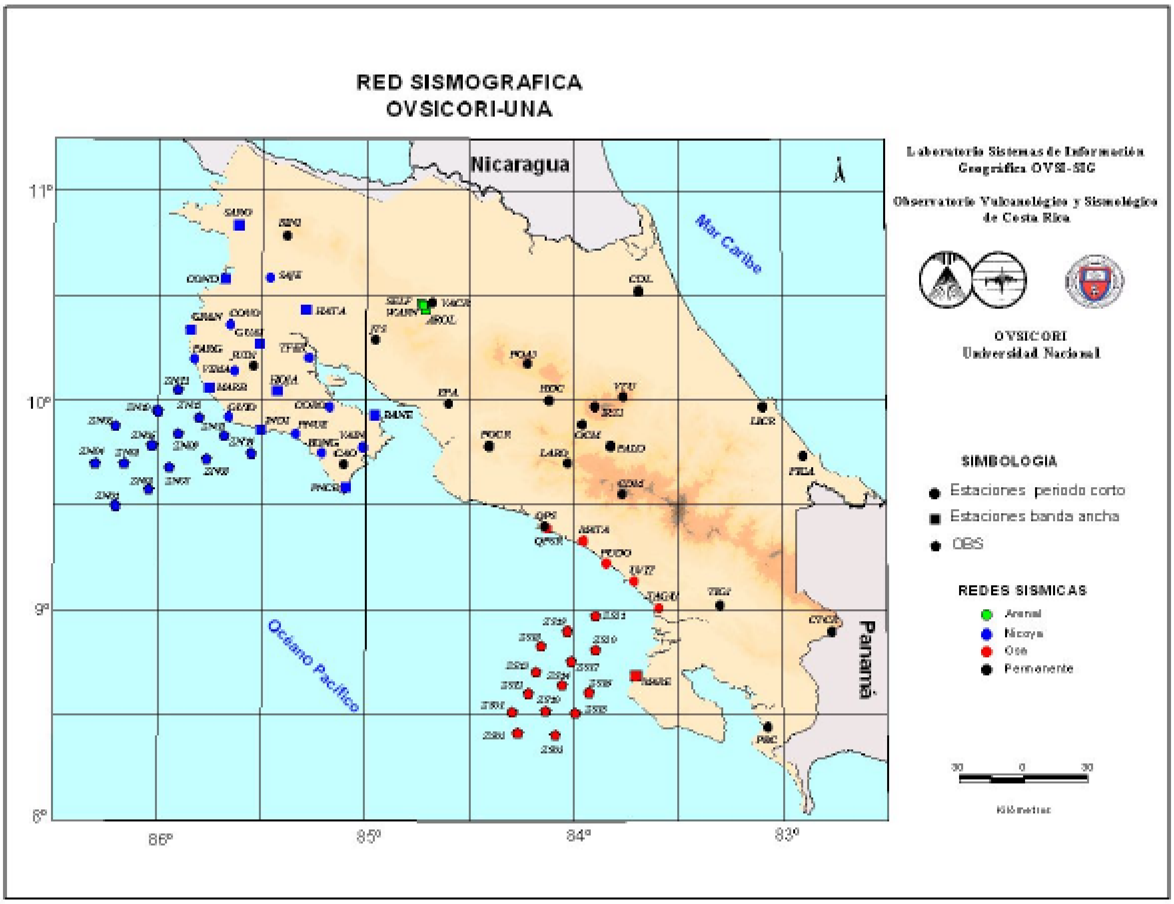

Fig.2.2.1-2 National seismic observation network

(http://www.ovsicori.una.ac.cr/estamap.html)

2.2.2. Focal Mechanism

1) Terminology

Fault plane solution: When an earthquake occurs, it is recorded on seismographs worldwide. Seismologists study the seismograph records (seismogram). By comparing the delay between the arrivals of the waves, they can determine the location of the focus and epicenter. By studying whether the needle on the seismograph first went up or went down for each seismogram, they can determine what kind of fault it was (strike-slip, dip-slip, etc.). By combining these two pieces of information, seismologists can determine the fault plane solution or focal mechanism for the earthquake, that is, where and how the fault moved.

Moment tensor: Generalized point source of an earthquake. Actual source of earthquake is not point but has finite space. However, considering the low frequency seismic waves, the source can be approximated by the moment tensor of the center of gravity.

Radiation Pattern: The phase and amplitude of seismic wave and wave front have their regularities corresponding to the direction of propagation. These regularities (patterns) are called Radiation pattern.

Multiples: Heterogeneous rock dose not collapse smoothly but has breaks. Such collapse process is called Multiples.

2) Purpose or Target

Determination of source mechanisms and fault plane

3) Grade

Table 2.2.2-1 Classification of topics

Accuracy	Item	Input Data or techniques	Examples or references
1	Two Nodal Plane	Polarity of P and S waves	Local Seismic Observation
2	Moment Tensor	Waveforms or Polarity/Amplitude of seismic waves	Harvard CMT Automated ERI CMT USGS Moment tensor solutions Freesia CMT (NIED)
3	Source Mechanisms of Multiplets	Waveforms or Polarity/Amplitude of seismic waves	Kikuchi & Kanamori (1991) Kuge (1999)

3) Examples (Description with figures)

Several WEB service for focal mechanism (Fig.2.2.2-1)

http://www.eri.u-tokyo.ac.jp/~http/AUTO_CMT/auto_cmt.html

http://www.seismology.harvard.edu/CMTsearch.html

http://wwwneic.cr.usgs.gov/neis/FM/qmom.html

http://argent.geo.bosai.go.jp/freesia/event/hypo/joho.html

4) Special Topic

Fault plane selection based on aftershock distribution

Empirical Green's tensor Method

5) References

Billington, S. (1982): A method to objectively sort P-wave first motion data for composite focal mechanism solutions, Bull. Seismol. Soc. Am., 72, 399-411.

Brillinger, D.R., A. Udias, , and B.A., Bolt (1980): A probability model for regional focal mechanism solutions, Bull. Seismol. Soc. Am., 70, 149-170.

Dreger, D. and D.H. Helmberger (1993): Determination of source parameters at regional distances with three-component sparse network data, J. Geophys. Res., 98, 8107-8125.

Dziewonski, A.M., T.-A. Chou and J.H. Woodhouse (1981): Determination of earthquake source parameters from waveform data for studies of global and regional seismicity, J. Geophys. Res., 86, 2825-2852.

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Fukuyama, E. Ishida, M., Dreger, D.S., and K. Kawai (1998): Automated Seismic Moment Tensor Determination by Using On-line Broadband Seismic Waveforms, Zisin 2, vol.51, 149-156.

Fukuyama, E. and D.S. Dreger (2000): Performance test of an automated moment tensor determination system for the future "Tokai" earthquake, Earth Planets Space, 52, 383-392.

Jost, M.L. and R.B. Hermann (1989): A student’s guide to and review of moment tensors, Seismol. Res. Lett., 60, 37-57.

Gubbins, D. (1990): Seismology and plate tectonics, Cambridge Univ. Press.

Kasahara, K. (1981): Earthquake mechanics, Cambridge Univ. Press.

Kawakatsu, H. (1995): Automated near-realtime CMT inversion, Geophys. Res. Lett., 22, 2569-2572.

Kostrov, B.V. and S. Das (1988): Principles of earthquake source mechanics, Academic Press.

Lay, T. and T.C. Wallace, 1995, Modern global seismology, Academic Press.

Lee, W.H.K., and S.W. Stewart, 1981, Principles and applications of microearthquake networks, Academic Press.

Mendingren, J.A. (1980): A procedure to resolve areas of different source mechanism when using the method of composite nodal plane solution, Bull. Seismol. Soc. Am., 70, 985-998.

Sipkin, S.A. (1982): Estimation of earthquake source parameters by the inversion of waveform data: synthetic seismograms, Phys. Earth Planet. Inter., 30, 242-259.

Stauder, W. (1960): S waves and focal mechanisms: The state of the question, Bull. Seismol. Soc. Am., 50, 333-346.

Thio, H.K. and Kanamori,H. (1995): Moment-tensor inversions for local earthquakes using surface waves recorded at TERRAscope, Bull. seism. Soc. Am., 85, 1021-1038.

Udias, A. and E. Buforn (1988): Single and joint fault-plane solutions from first-motion data, in Seismological Algorithms (ed. D.J. Doornbos), 443-453.

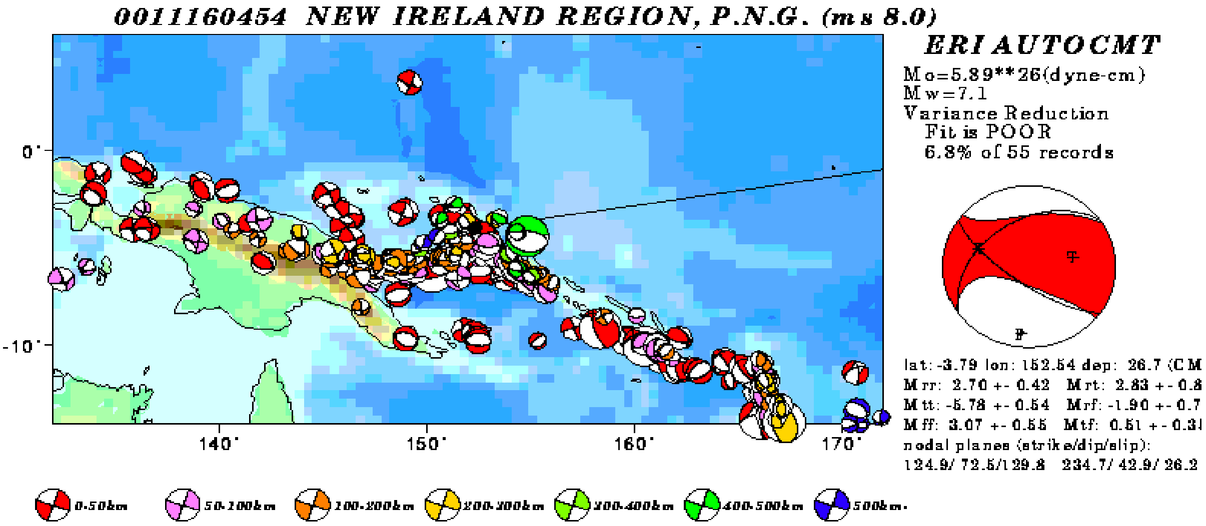


Fig.2.2.2-1 Several WEB service for focal mechanism

(http://www.eri.u-tokyo.ac.jp/)

2.2.3. Crustal Deformation (including Fault Scarp)

1) Terminology

Leveling: A survey used to ascertain which point on a survey rod is at the same elevation.

Triangulation: A trigonometric method of determining the position of a fixed point from the angles to it from two fixed points a known distance apart.

GPS (Global Positioning System): A system of satellites, computers, and receivers that is able to determine the latitude and longitude of a receiver on Earth by calculating the time difference for signals from different satellites to reach the receiver.

SAR (Synthetic Aperture Radar): Synthetic aperture radar complements photographic and other optical imaging capabilities because of the minimum constrains on time-of-day and atmospheric conditions and because of the unique response of terrain and cultural targets to radar frequencies.

2) Purpose or Target

Determination of Surface displacement due to earthquake

3) Grade

Table 2.2.3-1 Classification of topics

Accuracy	Item	Input Data or techniques	Examples or references
1	Existence	Eye witness	Historical descriptions
2	Relative displacement between two side of surface fault	Leveling Triangulation Trilateration	Luzon Eq.(1990)
3	Displacement relative to a far reference point	GPS, SAR Tidal observation Strong Motion Seismograms	Chi-Chi Eq.(1999)

4) Examples (Description with figures)

Result of field survey of the fault scarp (Fig. 2.2.3-1)

Result of secular displacement obtained by geometrical methods and by GPS (Fig. 2.2.3-2)

5) References

<Result of field survey of the fault scarp>

- See web site by the survey reports and photos of 1990 Luzon-EQ.

  http://www.phivolcs.dost.gov.ph/071690-LuzonEQ/LuzonEQ-Main.html

- Survey reports for the fault scarp

  The 16 July 1990 Luzon earthquake ground rupture, Raymundo S. Punongbayan, Rolly E. Rimando, Jessie A. Daligdig, Glenda M. Besana, Arturos S. Daag, Takeshi Nakarta, and Hiroyuki Tatsumi.

- Photos for the fault scarp in the ground surface

  http://www.phivolcs.dost.gov.ph/071690-LuzonEQ/GroundRuptures-Images.htm

  http://www.phivolcs.dost.gov.ph/071690-LuzonEQ/DaltonPassFault-Images.htm

  http://www.phivolcs.dost.gov.ph/071690-LuzonEQ/DigdigFault-Images.htm

<Result of secular displacement obtained by geometrical methods and by GPS>

(a) Geometrical methods

Bawden G. W. (2001): Source parameters for the 1952 Kern Country earthquake, California: A joint inversion of leveling and triangulation observations, J. Geophys. Res., 106, 771-785.

Genrich J.F.,Y. Bock, and R. G. Mason (1997): Crustal deformation across the Imperial Fault: Results from kinematic GPS surveys and trilateration of a densely spaced, small-aperture network, J. Geophys. Res, 102, 4985-5004.

Hodgkinson K. M,R. S. Stein, and G. Marshall (1996): Geometry of the 1954 Fairview Peak-Dixie Valley earthquake sequence from a joint inversion of leveling and triangulation data, , J. Geophys. Res., 101, 25437-25457.

Yu E,and P. Segall (1996): Slip in the 1868 Hayward earthquake from the analysis of historical triangulation data, J. Geophys. Res, 101, 16101-16118.

(b) GPS

Hurst K. J, D. F. Argus, A. Donnellan, M. B. Heflin, D.C. Jefferson, G. A. Lyzenga, J. W. Parker, M. Smith, F. H. Webb, and J. F. Zumberge (2000): The coseismic geodetic signature of the 1999 Hector Mine Earthquake, Geophys. Res. Lett., 27, 2733-2736.

http://mekira.gsi.go.jp/gps/gps.html：Explanation of GPS

http://vldb.gsi-mc.go.jp/sokuchi/gps/chikaku.html：Crustal movement of Hyogo-ken Nambu Earthquake 1995.

http://www.scign.org/：Original data for above site

http://quake.geo.berkeley.edu/bard/bard.html：Network for North California

http://cais.gsi.go.jp/HENDOU/hendou.html：Crustal movement of the recent seismic activities by the Geographical Survey Institute.

http://vancouver-webpages.com/peter/：Several links

http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html：Explanation of GPS

(c) SAR

Baer G, D. Sandwell, S. Williams, and Y. Bock (1999): Coseismic deformation associated with the November 1995, M_w=7.1 Nuweiba earthquake, Gulf of Elat (Aqaba), detected by synthetic aperture radar interferometry, J. Geophys. Res., 104, 25221-25232.

Delouis B, P. Lundgren, J. Salichon, and D. Giardini (2000): Joint inversion of InSAR and teleseismic data for the slip history of the 1999 Izmit (Turkey) earthquake, Geophys. Res. Lett., 27, 3389-339.

Fujiwara S., T. Nishimura, M. Murakami, H. Nakagawa, and M. Tobita (2000): 2.5-D surface deformation of M6.1 earthquake near Mt Iwate detected by SAR interferometry, Geophys. Res. Lett., 27, 2049-2052.

Klinger Y., R. Michel, and J. Avouac (2000): Co-seismic deformation during the M_w 7.3 Aqaba earthquake (1995) from ERS-SAR interferometry, Geophys. Res. Lett., 27, 3651-3654,.

Massonnet D., M. Rossi, C. Carmona, F. Adragna, G. Peltzer, K. Feigl and T. Rabaute (1993): The displacement field of the Landers earthquake mapped by radar interferometry, Nature, 364, 138-142.

Massonnet D. and K. L. Feigl (1998): Application of ERS-1 radar interferometry to the Landers Earthquake, Review of Geophysics, 36, 4, 441-500.

Michel R., J. Avouac, and J. Taboury (1999): Measuring near field coseismic displacements from SAR images: application to the Landers earthquake, Geophys. Res. Lett., 26, 3017-3020.

Stramonde S., M. Tesauro, P. Briole, E. Sansosti, S. Salvi, R. Lanari, M. Anzidei, P. Baldi, G. Fornaro, A. Avallone, M F. Buongiorno, G. Franceschetti, and E. Boschi (1999): The September 26, 1997 Colfiorito, Italy, earthquake: modeled coseismic surface displacement from SAR interferometry and GPS, Geophys. Res. Lett., 26, 883-886.

http://www-radar.jpl.nasa.gov/sect323/InSar4crust/home.html：Jet Propulsion Laboratory in California web site.

web site for Landers Earthquake in 1992：

http://www-radar.jpl.nasa.gov/sect323/InSar4crust/LandersCo.html

http://topex.ucsd.edu/SAR/sar.html：UCSD-IGPP SAR Research Group

http://southport.jpl.nasa.gov/science/SAR_REFS.html：References web site for SAR

(d) Geodesy

Applications of Satellites to Geodesy, William M. Kaula, Dover Pubns.

Gps for Geodesy, Peter J. G. Teunissen (Editor), Alfred Kleusberg (Editor), Springer Verlag.

Geodesy: The Concepts, P. Vanicek, E. J. Krakwsky, Elsevier Science.

The History and Concepts of Modern Geodesy (Wiley Series in Surveying and Boundary Control), James R. Smith, John Wiley & Sons.

Satellite Altimetry and Earth Sciences: A Handbook of Techniques and Applications, Lee-Lueng Fu (Editor), Anny Cazenave, Academic Pr.

Practical Geodesy: Using Computers, Maarten Hooijberg, Marrten Hooijberg, Springer Verlag.

Geodesy, Wolfgang Torge, Walter De Gruyter.

Photo-1
Aerial Photo at Hokudan-town in Hyogo prefecture

Fault scarp on the surface ground during 1995 Hyogo-ken Nambu Earthquake

Photo-2
Fault scarp on the surface ground at Hokudan-town

Right-lateral strike-slip fault

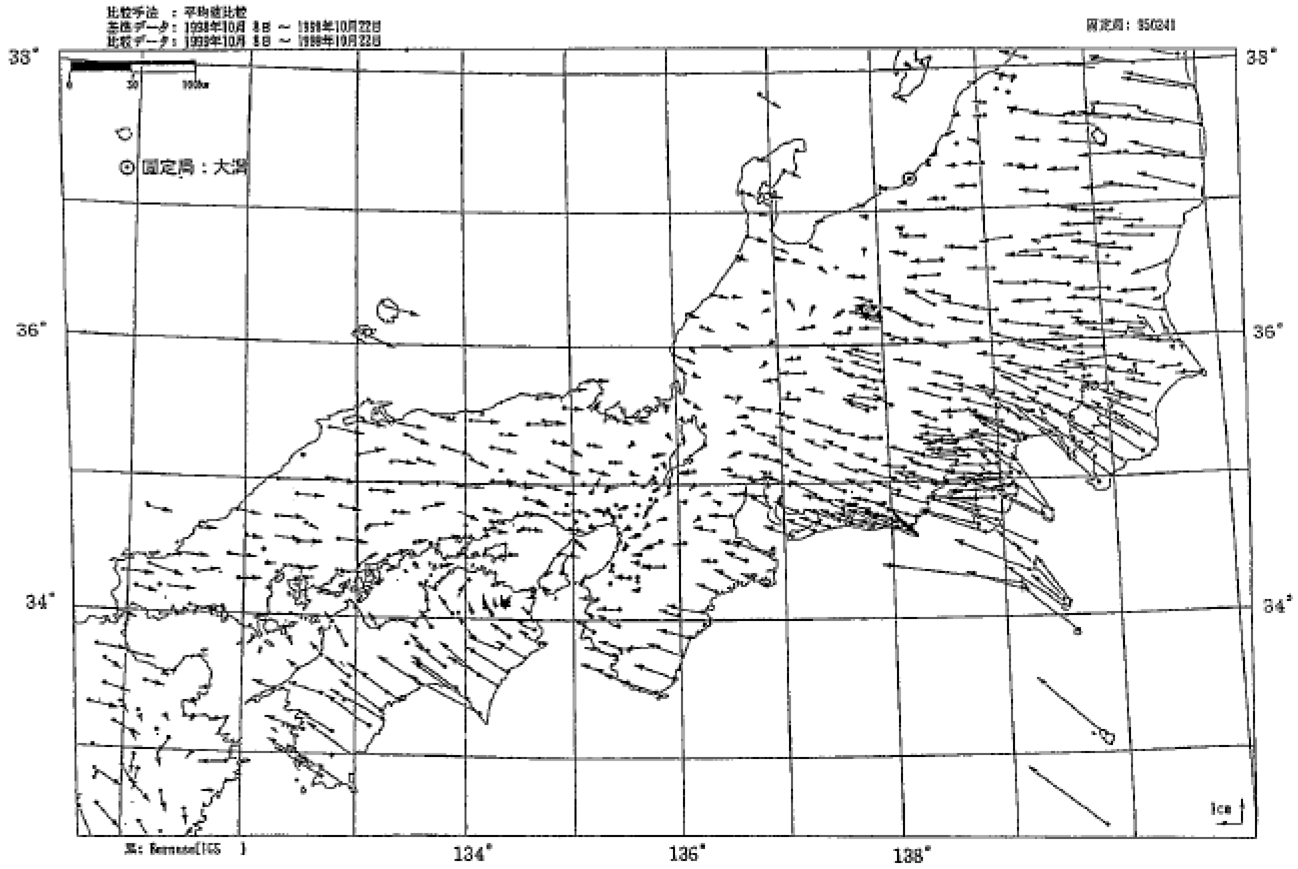
Horizontal displacement about 1.5m
Vertical displacement about 1.0m

Photo-3
Fault scarp on the surface ground at Hokudan-town

Cut off the U-shaped side ditch by the displacement of the fault

Horizontal displacement about 1.2m
Vertical displacement about 0.9m

Fig. 2.2.3-1 Result of field survey of the fault scarp
(The fault scarp of the Hyogo-ken Nambu Earthquake 1995)



GPS連続観測から求めた1998年10月～1999年10月間の水平変動(2)

Annual horizontal displacement velocities at permanent GPS sites during 1998/10-1999/10(2).

Fig. 2.2.3-2 Result of secular displacement obtained by geometrical methods and by GPS (http://www.gsi.go.jp/MAP/index.html)

2.2.4. Rupture Process

1) Terminology:

Source Process: Processes regarding to a seismic source are known generally as Source Process. As a theory that faults cause earthquakes became popular, a model which a source has not only a point but also the finite area, established. Then not only the geometric feature of the fault, but also process of the fault's motion, namely expansion of a fault plane or slip direction, became the theme of the studies.

Green's function: Solution of a differential equation with an impulse as the exciting force. Exact seismograms in a given medium can be viewed as the convolution of the source wavelet and medium's Green's function.

Inversion Technique: The process of solving the inverse problem. The determination of a distribution of parameters whose calculated response matches observations within given tolerance. In contrast to the direct, forward, or normal problem, which involves calculating what would have been observed from given model.

Source Time Function: Source time function is led by time differentiation of the seismic moment which is equivalent to displacement (wave) immediately after earthquake occurred.

2) Purpose or Target

Estimation of Fault Rupture Process

3) Grade

Table 2.2.4-1 Classification of topics

Accuracy	Item	Input Data or techniques	Examples or references
1	Result of Far-Field Waveform Inversion	Far-field Broad-Band Seismograms	Kikuchi & Kanamori (1982, 1986)
2	Result of Near-Field Waveform Inversion	Strong Motion Seismograms	Ide and Takeo (1996)
3	Result of Joint Inversion of far and near -field seismograms with geodetic data	Far-field Broad-Band Seismograms Strong Motion Seismograms Geodetic Data (including GPS)	Yoshida et al. (1996)

4) Examples (Description with figures)

Research papers of rupture process (Fig. 2.2.4-1)

5) References

Ide S., and M. Takeo (1997): Determination of constitutive relations of fault slip based on seismic wave analysis, J. Geophys. Res., 102, 27379-27391.

Fukuyama E., and K. Irikura (1986): Rupture process of the 1983 Japan Sea (Akita-oki) earthquake using a waveform inversion method, Bull. Seism. Soc. Am., 76, 1623-1640.

Kikuchi M., and H. Kanamori (1991): Inversion of complex body waves-III, Bull. Seismol, Soc. Am., 81, 2335-2350.

Yoshida S. (1995): Waveform Inversion Methods the Earthquake Source, J. phys. Earth, 43, 183-209.

Yoshida S., K. Koketsu, B. Shibazaki, T. Sagiya, T. Kato, and Y. Yoshida (1996): Joint Inversion of Near- and Far-field Waveforms and Geodetic Data for the Rupture Process of the 1995 Kobe Earthquake, J. phys. Earth, 44, 437-454.

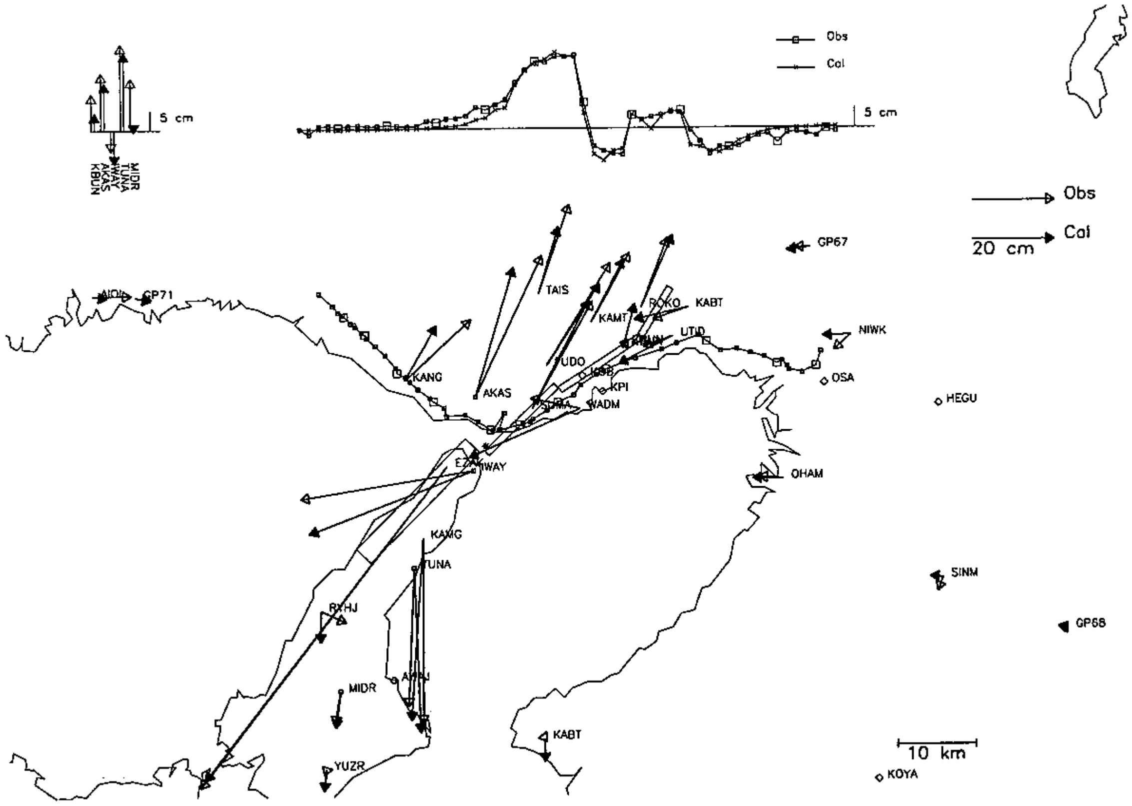


Fig. 6. Comparison between the geodetic data and calculated displacements from the inferred model (shown in Fig. 7) assuming the Nojima, Suma, Suwayama, and Gosukebashi faults.

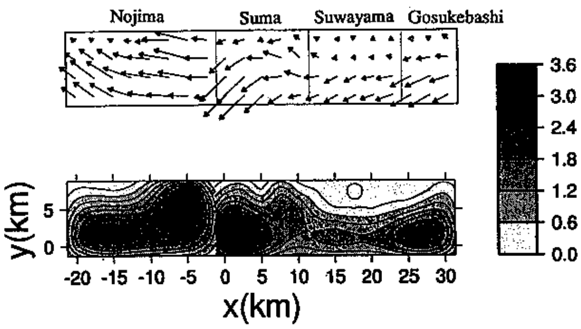


Fig. 7. Inversion solution assuming the Nojima, Suma, Suwayama, and Gosukebashi faults, which consist of subfaults with dimensions of $2.5 \times 2.5\,\mathrm{km}^2$. Top: Slip vectors of the southeast blok relative to the northwest block viewed from the southeast. Bottom: Slip magnitudes. The contour interval is 0.3 m. The area of $-21.25 < x < -1.25$ km corresponds to the Nojima fault.

Fig. 2.2.4-1 Research papers of rupture process

(Yoshida S., K. Koketsu, B. Shibazaki, T. Sagiya, T. Kato, and Y. Yoshida (1996): Joint Inversion of Near- and Far-field Waveforms and Geodetic Data for the Rupture Process of the 1995 Kobe Earthquake, J. phys. Earth, 44, 437-454.)

2.3. Propagation Path

2.3.1. Crust (Propagation & Attenuation)

1) Terminology

Attenuation Relation: A reduction in amplitude or energy caused by the physical characteristics of the transmitting media or system. Usually includes geometric effects such as the decrease in amplitude of a wave with increasing distance from a source. It is shown by the formula as to the maximum amplitude, magnitude and epicentral distance.

Geometric spreading: The decrease in wave strength(energy per unit area of wave front) with distance as a result of geometric spreading. A spherical wave traveling through the body of a medium continually spreads out so that the energy density decreases. For a point source the energy density decreases inversely as the square of the distance the wave has traveled. For energy which travels along a surface, the analogous term is cylindrical divergence, which varies inversely as the distance. Other mechanisms by which a seismic wave loses energy involve absorption and loss at interfaces by reflection (including diffraction, mode conversion, and scattering).

Reflection & Transmission: The energy or wave from a seismic source which has been reflected (returned) from an acoustic impedance contrast (reflector) or series of contrasts within the Earth. The objective of most reflection seismic work is to determine the location and attitude of reflectors from measurements of the arrival time of primary reflections and to infer the geologic structure and stratigraphy. A wave transmitted through an interface to that of the wave incident upon it.

Scattering and Attenuation: The irregular and diffuse dispersion of energy caused by inhomogeneities in the medium through which the energy is traveling. A reduction in amplitude or energy caused by the physical characteristics of the transmitting media or system. Usually includes geometric effects such as the decrease in amplitude of a wave with increasing distance from a source.

Quality factor: The ratio of 2π times the peak energy to the energy dissipated in a cycle; the ratio of 2π times the power stored to the power dissipated. The Quality factor of rocks is of the order of 50 to 300. Quality factor is related to other measures of absorption.

Guided Wave: An elastic wave propagated in a layer where the energy is trapped. The layer may (a) have lower velocity than those on either side of it (so that total reflection can occur at the boundaries) or (b) a layer boundary may be a free surface (so that the Reflectivity is nearly one). Instead of having sharp interfaces as boundaries, channels may also be produced by an increasing velocity gradient in either direction. Energy is largely prevented from escaping the channel because of repeated total reflection at the channel boundaries or because rays which tend to escape are bent back toward the Channel.

Lg-Wave: A short-period guided surface wave which travels in the continental crust. The ‘’ *g* ’’ refers to granitic layer.

2) Purpose or target

Description of wave propagation in the crust

3) Grade

Table 2.3.1-1 Classification of topics

Accuracy	Item	Data or techniques	Examples or References
1	Attenuation Relation	Peak Values (PGA, PGV)	Several Attenuation Relations
2	Velocity Structure Regional Q-value	Conventional Methods	Research Papers of Q-structure
3	Velocity Structure Q-Structure	Travel Time Inversion Technique Spectral Shape Inversion Technique	Research Papers of Q-structure

4) Examples (Description with figures)

Several Attenuation Relations frequently used. (Fig. 2.3.1-1)

5) Special Topics

Coda Wave Analyses

6) References

Molas, G. L. and F. Yamazaki (1995): Attenuation of earthquake ground motion in Japan including deep focus events, Bull. Seism. Soc. Am., 85, 1343-1358.

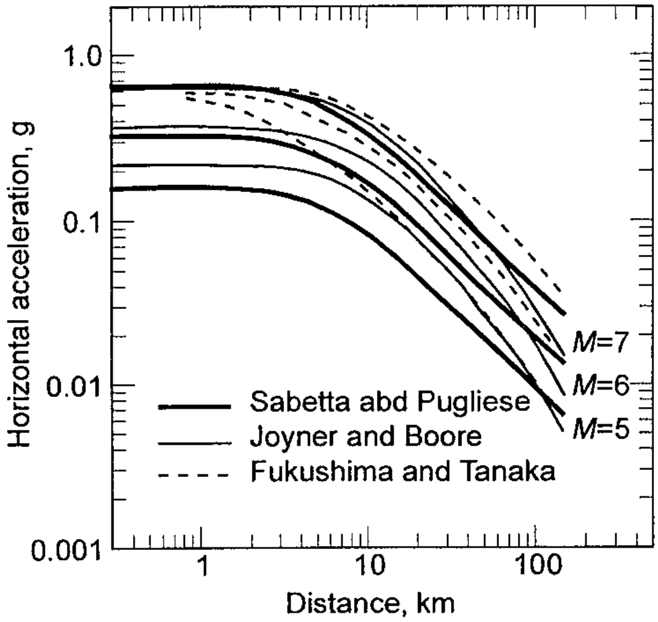
Fukushima, Y. (1996): Scaling Relations for Strong Ground Motion Prediction Models with M2

Terms, Bull. Seism. Soc. Am., 86, 329-336.

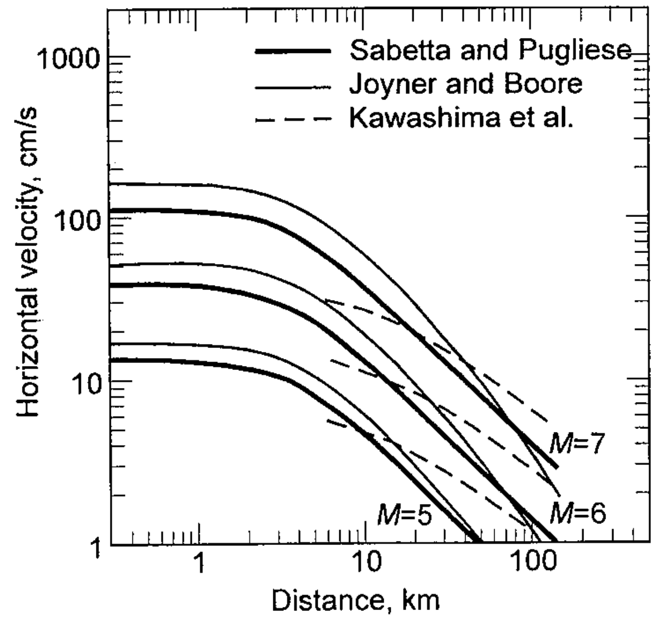
Youngs, R. R., S. -J. Chiu, W. J. Silva and J. R. Humphrey (1997): Strong ground motion attenuation relationships for subduction zone earthquakes, Seism. Res. Lett., 68, 58-73.

Somerville, P. G., N. F. Smith, R. W. Graves and N. A. Abrahamson (1997): Modification of Empirical strong motion attenuation relations to include the amplitude and duration effects of rupture directivity, Seism. Res. Lett., 68, 199-222.

in various seismic regions of the world and the results used for zonation purposes (e.g. Lasterico and Monge, 1972; Kuroiwa, 1982; Siro, 1982; Iglesias, 1988).



(a) Peak ground acceleration



(b) Peak ground velocity

Fig. 3.9. Comparison of proposed attenuation relations.

Fig. 2.3.1-1 Several Attenuation Relations frequently used.

(Manual for Zonation on Seismic Geotechnical Hazards (1999), Technical Committee for Earthquake Geotechnical Engineering, TC4, ISSMGE)

Table. 2.3.1-2 Several Attenuation Relations frequently used

(Manual for Zonation on Seismic Geotechnical Hazards (1999), Technical Committee for Earthquake Geotechnical Engineering, TC4, ISSMGE)

Peak acceleration	
Researchers: Data: Equation:	Joyner and Boore (1981) 182 North American records $\log A = 0.249 M_w - \log r - 0.00255r - 1.02 \pm 0.26$ $r = \sqrt{D^2 + 7.3^2}$ $5.0 \le M_w \le 7.7$
Researchers Data: Equation:	Sabetta and Pugliese (1987) 190 Italian records $\log A = 0.306 M_s - \log \sqrt{D^2 + 5.8^2} + 0.169 S_1 - 1.56 \pm 0.17$ $4.6 \le M_s \le 6.8$
Researchers: Data: Equation:	Fukushima and Tanaka (1990) 486 Japanese records $\log A = 0.41 M_s - \log(R + c(M_s)) - 0.0034R - 1.69 \pm 0.21$ $c(M_s) = 0.032 \times 10^{0.41 M_s}$ $6.0 \le M_s \le 7.9$
Peak Velocity	
Researchers: Data: Equation:	Joyner and Boore (1981) 62 North American records $\log V = 0.49 M_w - \log r - 0.00256r + 0.17 S_2 - 0.67 \pm 0.22$ $r = \sqrt{D^2 + 4.0^2}$ $5.3 \le M_w \le 7.4$
Researchers: Data: Equation:	Sabetta and Pugliese (1987) 190 Italian records $\log V = 0.455 M_s - \log \sqrt{D^2 + 3.6^2} + 0.133 S_3 - 0.71 \pm 0.22$ $4.6 \le M_s \le 6.8$
Researchers: Data: Equation:	Kawashima et al. (1984) 197 Japanese records $\log V = 0.37 M_J - 1.17 \log(d + 30) + S_4 \pm 0.24$ $5.0 \le M_J \le 7.9$

A: Peak acceleration in g
V: Peak ground velocity in cm/s
M_w: Moment Magnitude
M_s: Surface wave Magnitude
M_J: Japan Meteorological Agency Magnitude
D: Closest distance to surface projection of fault rupture in km
R: Shortest distance to fault rupture in km
d: Epicentral distance in km
S_1: 0 at stiff and deep soil sites and 1 at shallow soil sites
S_2: 0 at rock soil sites and 1 at soil sites
S_3: 0 at stiff soil sites and 1 at shallow and deep soil sites
S_4: 0.56 at hard soil sites, 0.71 at intermediate soil sites and 0.81 at soft soil sites

2.3.2. Deep Sediment (Propagation & Attenuation)

1) Terminology

Basin induced Surface Wave: Generally bedrock in a basin is not flat and neither sediments over the bedrock. Therefore, as the body wave inserts into the basin, a secondary wave occurs from the place where the shape of the bedrock changes, like its edge. Greater the ratio of impedance between sediment and base rock, greater the surface wave.

Basin Edge Effect: The effect the secondary wave occurs at the edge departments of the basin.

2) Purpose or Target

Cause of damage concentration and estimation of input motion at the engineering bedrock

3) Grade

Table 2.3.2-1 Classification of topics

Accuracy	Item	Data or techniques	Examples or references
1	Ignore	+	Boore (1983)
2	Estimation of Velocity Structure	Geophysical Prospecting	San Fernando Basin Kanto Basin Euroseistest at Thessaroniki Ashigara Valley etc.
3	Calibration of Velocity Structure using observed earthquake records	Numerical Simulation	

4) Examples

Geophysical Prospecting: Refraction Method (Fig. 2.3.2-1)
Reflection Survey (Fig. 2.3.2-2)
Array Microtremor Observation (Fig. 2.3.2-3)

5) References

Kawase H. (1996): The cause of damage belt in Kobe: " The basin-edge effect," Constructive interference of the direct S-wave with the basin-induced diffracted/Rayleigh waves, Seismological Research letters, Vol67, No.5, pp.25-34.

Graves, R. W., A. Pitarka and P. G. Somerville (1998): Ground-motion amplification in the Santa Monica area: Effects of shallow basin-edge structure, Bull. Seismol. Soc. Am. Vol88, No.5, pp.1224-1242.

Wald, D. J. and R. W. Graves (1998): The seismic response of Los Angeles basin, California, Bull. Seismol. Soc. Am., Vol.88, pp.337-356.

Sato, T., R. W. Graves and P. G. Somerville (1999): Tree-dimensional Finite-difference simulations of long-period strong motions in the Tokyo metropolitan area, Bull. Seismol. Soc. Am., Vol.89, 3, pp.579-607.

Seo, K. (1978): Earthquake motions modulated by deep soil structure, Proceeding of the fifth Japan earthquake engineering symposium, pp.281-288.

Yamanaka, H., K. Seo, and T. Samano (1989): Effects of sedimentary layers on surface-wave propagation, Bull. Seismol. Soc. Am., Vol.79, pp.631-644.

Ohba, T., and I. Toriumi (1992): Influence of size of plains on earthquake motion characteristics, Proceeding of 10th World conference on Earthquake Engineering, 2, pp.623-628.

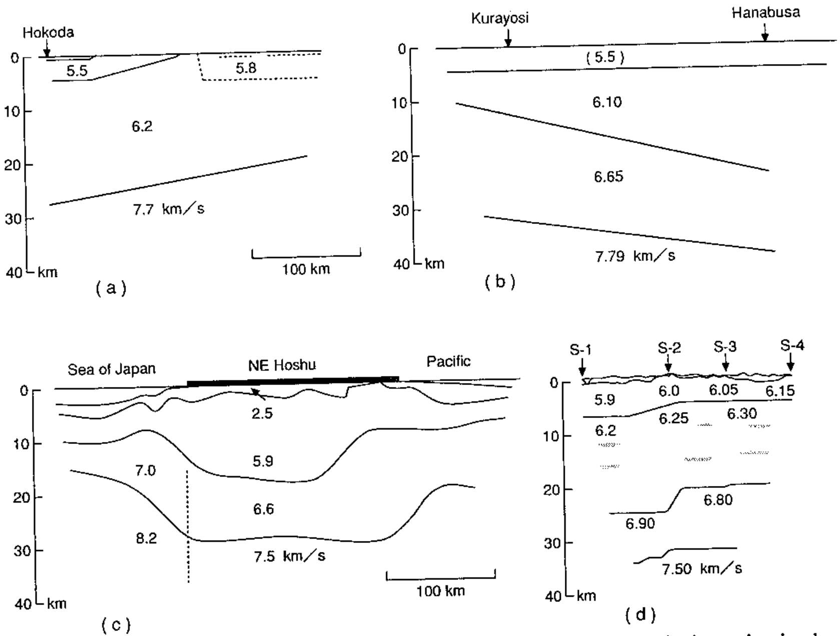


Fig. 4. Examples of crustal models in the Japanese Islands obtained from explosion seismic observations. (a) Hokoda Profile, NE Honshu [Matuzawa *et al.* (1959)], (b) Kurayosi-Hanabusa Profile, SW Honshu [Yoshii *et al.* (1974)], (c) Kesennuma-Oga Profile, NE Honshu [Yoshii and Asano (1972)], (d) Kuji–Ishinomaki Profile, NE Honshu [Iwasaki *et al.*(1993)]

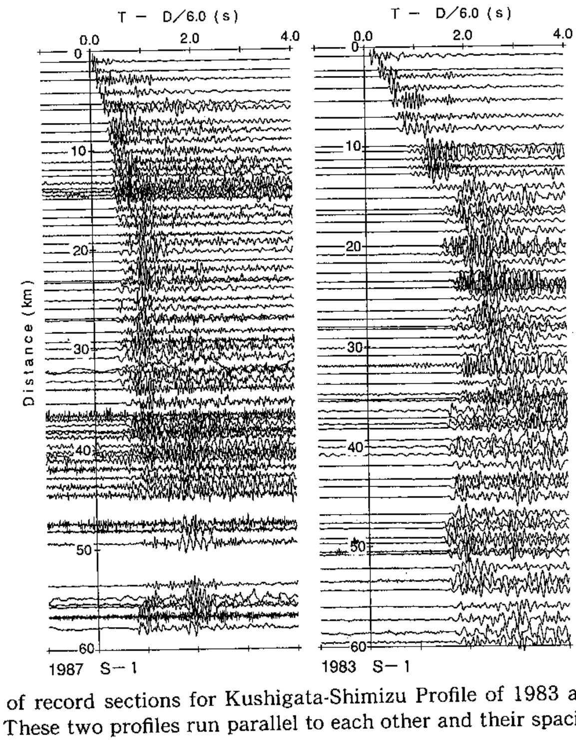
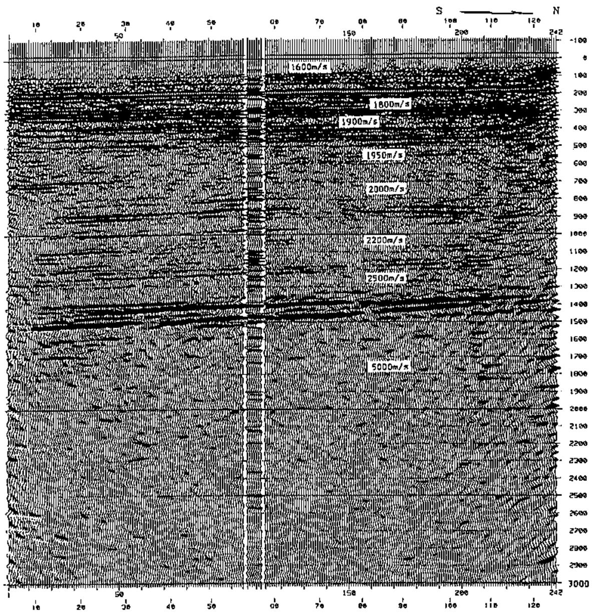
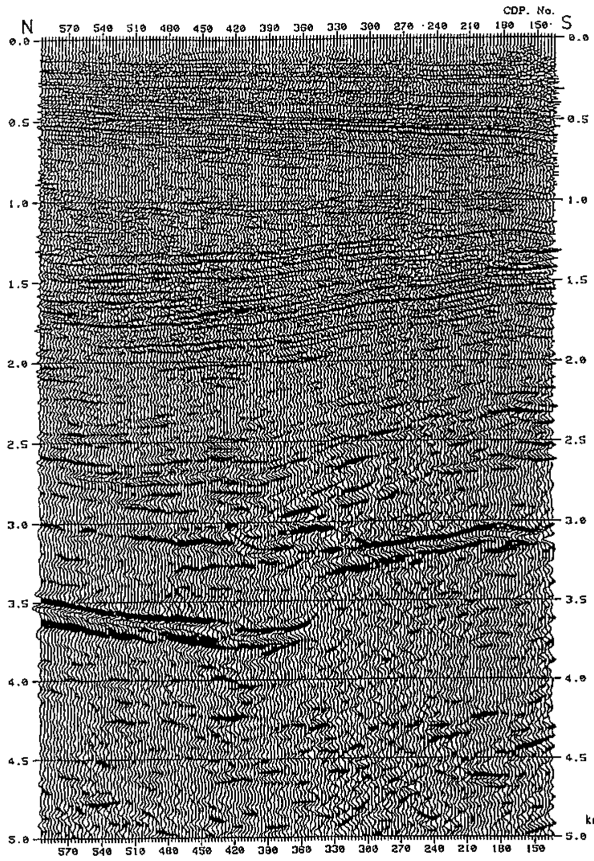


Fig. 5. Comparison of record sections for Kushigata-Shimizu Profile of 1983 and Hayakawa-Shizuoka Profile of 1987. These two profiles run parallel to each other and their spacing is only about 10 km.

Fig. 2.3.2-1 Geophysical Prospecting-Refraction Method



Cross section from seismic reflection survey at Shimohsa seismic observation point.
The VSP results also are shown in the center of this figure.
(Yamamizu, F., Kasahara, K., Suzuki, H., Ikawa, T., Adachi, I.(1993): Seismic Reflection Profiling around the Simohasa Deep-Well, PROGRAMME and ABSTRACTS, S.S.J., 1993-No.2.)



The sonic prospecting cross section at the Tokyo-Bay.The North Tokyo-Bay fault is crossing in the bedrock at the center of the figure.

Fig. 2.3.2-2 Geophysical Prospecting -Reflection Survey

(Kato, S. (1994): Structure of the North Tokyo-Bay fault, Symposium on Future Science Technology)

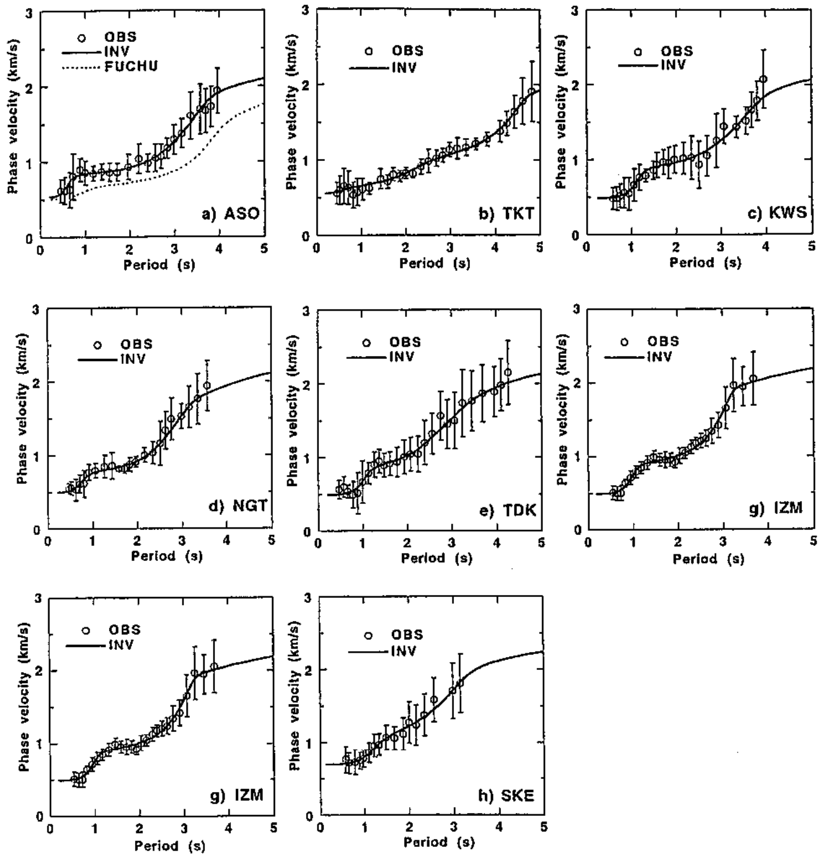


Fig. 7. Comparison of observed phase velocities with theoretical ones at all sites. Open circles indicate the observed phase velocities of microtremors with standard deviations shown by bars. Solid lines show theoretical phase velocities for fundamental Rayleigh waves in inverted subsurface structural models shown in Fig. 6.

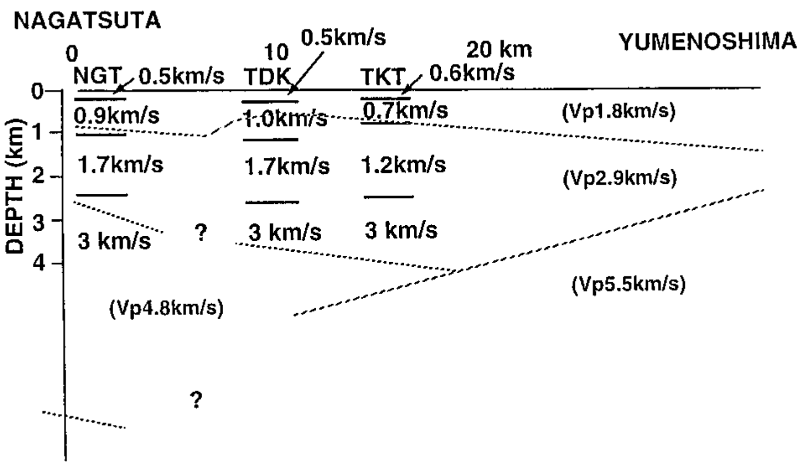


Fig. 9. Comparison of S-wave profiles from microtremor array measurements with P-wave profile from seismic refraction survey between Yumenoshima, Tokyo and Nagatsuta, Yokohama city. The P-wave profile was from seismic refraction surveys by YAMANAKA *et al.* (1986).

Fig. 2.3.2-3 Geophysical Prospecting-Array Microtremor Observation

(Yamanaka, H., Sato, H,. Kurita, K. and Seo, K. (1999): Array Measurements of Long-period Microtremors in Southern Kanto Plain, Japan, Journal of the Seismological Society of Japan)

2.4. Seismic Motion

2.4.1. Intensity

1) Terminology:

Intensity: In seismology, intensity refers to an earthquakes effect at a particular location. Intensity, which may be measured by factors such as the presence (or absence) of cracks in walls, and even of mass panic, is distinguished from magnitude, which refers to the amount of energy released by an earthquake. Magnitude is expressed by the strength of the vibrations of the ground. Several scales are used to measure earthquake intensity, including the famous Mercalli scale.

History of Intensity: The intensity of the earthquakes is valued according to the Richter scale (Charles Francis Richter 26/4/1900 - 30/9/1985) or the modified Mercalli scale (Giuseppe Mercalli 21/5/1850 - 19/3/1914). The first scale furnishes an evaluation (**magnitude**) of the quantity of freed energy, while the seconds scale assigns a degree to the effects on the environment. In the 1902 Mercalli proposed the first composed scale from 10 degrees, in succession the Americans H.O. Wood and F. Neumann modified it adding 2 degrees at the end of adapt it to the constructive customs in California conventions. For the same motive in Western Europe is in use the **MCS** scale (Mercalli, Cancani, Sieberg), but in Oriental Europe be used the **MKS** scale (Medvedv, Karnik, Sponheuer). For a real comparison of the intensity of the earthquakes, and not only of the effects, has stayed introduced the scale of the magnitudo or Richter. From notice that already the Cancani (1856-1904), had introduced a gradation not empirical, assigning at 1° of the own scale the value of 2.5 mm/s^2, and at 12° the value of 10000 mm/s^2.

2) Purpose or Target

Simplified measure of seismic ground motion

3) Important Points:

Simplicity for determination

Relation with damages that depends on the construction type

Relation with other intensity scales

4) Grade

Table 2.4.1-1 Classification of topics

Accuracy	Item	Input Data or techniques	Examples or references
1	Reports of Eye witness & Feelings by Local Habitants, non-specialist	Explanation Table of Intensity Scale	MM Scale, MSK Scale, JMA Scale, PEIS Scale Questionnaire Survey
2	Systematic Damage Survey by Specialists	Explanation Table of Intensity Scale Explanation Table of Damage of Buildings	MM Scale, MSK Scale, JMA Scale, PEIS Scale Damage Index (P.R.China)
3	Strong Motion Observation	Strong Motion Observation Network with Broadcast System	JMA-Intensity Information Taiwan-Strong Motion Network Tri-NET

5) Examples: (Description with figures)

Intensity Scale (Explanation table) (Table 2.4.1-2)

Modified Melcali Scale

MSK Scale

Europian Macro Seismic Scale

JMA Intensity Scale, based on digital strong motion record

Intensity Scale based on Damage Index, P. R. China

Intensity Scale based on PGA, Chinese Taipei

PEIS (PHIVOLCS Earthquake Intensity Scale)

Format and method for in-site survey of Intensity (Fig.2.4.1-1)

Study results of relation with other intensity scales (Fig.2.4.1-2)

Intensity information system with strong motion observation network (Fig.2.4.1-3)

6) References

<Intensity>

Grunthal, G. (ed.) (1993): Europian Macro Seismic Scale 1992, Cahiers du Centre Europeen de Geodynamique et de Seismologique, Vol. 7, Luxemborg.

Grunthal, G. (ed.) (1998): Europian Macro Seismic Scale 1998, Cahiers du Centre Europeen de Geodynamique et de Seismologique, Vol. 15, Luxemborg.

(http://www.gfz-potsdam.de/pb5/pb53/projekt/ems/index.html)

A Reference of MSK Intensity Scale (MSK-64):

Modified Melcali Intensity Scale of 1931:

(http://quake.ualr.edu/public/mercalli.htm)

Modified Melcali Intensity Scale of 1956:

(http://www.abag.ca.gov/bayarea/eqmaps/doc/mmi_plain.html)

A Reference of CSB Intensity Scale based on Damage Index

PHIVOLCS Home Page (http://www.phivolcs.dost.gov.ph/)

JMA Home Page:(http://www.kishou.go.jp/english/index.html)

JWA intensity information service (http://tenki.or.jp/quake.html)

Udias, A. (1999): Principles of Seismology, Cambridge University Press,.

<Data for comparison of intensity scales>

Explanation Table of Rossi Forel Intensity Scale

(http://www.seismo.nrcan.gc.ca/magnitudes/rossi_e.html)

Explanation Table of MSK Intensity Scale

(http://www.uea.ac.uk/env/all/teaching/env3a02/MSK_SCA.doc)

Explanation Table of Modified Melcali Intensity Scale of 1931 in

(http://quake.ualr.edu/public/mercalli.htm)

Explanation Table of Modified Melcali Intensity Scale of 1956 in

(http://www.abag.ca.gov/bayarea/eqmaps/doc/mmi_plain.html)

Short form of Europian Macro Seismic Scale 1992 in Udias (1999).

Short form of Europian Macro Seismic Scale 1998, in

(http://www.gfz-potsdam.de/pb5/pb53/projekt/ems/index.html)

CSB (P. R. China) Intensity Scale based on Damage Index

CSB (P. R. China) Damage Index

PHIVOLCS Earthquake Intensity Scale

(http://www.phivolcs.dost.gov.ph/soepd2/index_peis.html)

JMA Intensity Scale by Intensity Meter

(http://www.kishou.go.jp/know/shindo/keisoku.html)

Explanation Table of Intensity Scale (JMA)

(http://www.kishou.go.jp/know/shindo/shindokai.html)

Table 2.4.1-2(1) Intensity Scale (Explanation table)

(Manual for Zonation on Seismic Geotechnical Hazards (1999), Technical Committee for Earthquake Geotechnical Engineering, TC4, ISSMGE)

Table 3.2 Definition of the Modified Mercalli intensity scale (Richter, 1958)

I.	Not felt. Marginal and long-period effects of large earthquakes.
II.	Felt by persons at rest, on upper floors, or favorably placed.
III.	Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
IV.	Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frames creak.
V	Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.
VI	Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows dished, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken (visibly, or heard to rustle).
VII	Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.
VII I	Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel wall thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.
IX	General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. (General damage to foundations) Frame structures, if not bolted, shifted off foundations. Frame racked. Serious damage to reservoirs. Underground pipes broken. conspicuous cracks in ground. In alluvial areas sand and mud ejected, fountains, sand craters.
X	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.
XI	Rails bent greatly. Underground pipelines completely out of service.
XII	Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

Masonry A. Good workmanship, mortar, and design; reinforced especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.

Masonry B. Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.

Masonry C. Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.

Masonry D. Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

Table 2.4.1-2(2) Intensity Scale (Explanation table) http://www.kishou.go.jp/know/shindo/explane.html

JMA Scale	People	Indoor Situations	Outdoor Situations	Wooden Houses	Reinforced-Concrete Buildings	Lifelines	Ground and Slopes
0	Imperceptible to people.						
1	Felt by only some people in the building.						
2	Felt by most people in the building. Some people awake.	Hanging objects such as lamps swing slightly.					
3	Felt by most people in the building. Some people are frightened.	Dishes in a cupboard rattle occasionally.	Electric wires swing slightly.				
4	Many people are frightened. Some people try to escape from danger. Most sleeping people awake.	Hanging objects swing considerably and dishes in a cupboard rattle. Unstable ornaments fall occasionally.	Electric wires swing considerably. People walking on a street and some people driving automobiles notice the tremor.				
5 Lower	Most people try to escape from a danger. Some people find it difficult to move.	Hanging objects swing violently. Most Unstable ornaments fall. Occasionally, dishes in a cupboard and books on a bookshelf fall and furniture moves.	People notice electric-light poles swing. occasionally, windowpanes are broken and fall, unreinforced concrete-block walls collapse, and roads suffer damage.	Occasionally, less earthquake-resistant houses suffer damage to walls and pillars.	Occasionally, cracks are formed in walls of less earthquake-resistant buildings.	A Safety device cuts off the gas service at some houses. On rare occasions water pipes are damaged and water service is interrupted.(Electrical service is interrupted at some houses)	Occasionally, cracks appear in soft ground. and rockfalls and small slope failures take place in mountainous districts.
5 Upper	Many people are considerably frightened and find it difficult to move.	Most dishes in a cupboard and most books on a bookshelf fall. Occasionally, a TV set on a rack falls, heavy furniture such as a chest of drawers falls, sliding doors slip out of their groove and the deformation of a door frame makes it impossible to open the door.	In many cases, unreinforced concrete-block walls collapse and tombstones overturn. Many automobiles stop because it becomes difficult to drive. Occasionally, poorly-installed vending machines fall.	Occasionally, less earthquake-resistant houses suffer heavy damage to walls and pillars and lean.	Occasionally, large cracks are formed in walls, crossbeams and pillars of less earthquake-resistant buildings and even highly earthquake-resistant buildings have cracks in walls.	Occasionally, gas pipes and / or water mains are damaged.(Occasionally, gas service and / or water service are interrupted in some regions)	

6 Lower	Difficult to keep standing.	A lot of heavy and unfixed furniture moves and falls. It is impossible to open the door in many cases.	In some buildings, wall tiles and windowpanes are damaged and fall.	Occasionally, less earthquake-resistant houses collapse and even walls and pillars of highly earthquake-resistant houses are damaged	Occasionally, walls and pillars of less earthquake-resistant buildings are destroyed and even highly earthquake-resistant buildings have large cracks in walls, crossbeams and pillars.	Gas pipes and / or water mains are damaged.(In some regions, gas service and water service are interrupted and electrical service is interrupted occasionally.)	Occasionally, cracks appear in the ground, and landslides take place.
6 Upper	Impossible to keep standing and to move without crawling.	Most heavy and unfixed furniture moves and falls. Occasionally, sliding doors are thrown from their groove.	In many buildings, wall tiles and windowpanes are damaged and fall. Most unreinforced concrete-block walls collapse.	Many, less earthquake-resistant houses collapse. In some cases, even walls and pillars of highly earthquake-resistant houses are heavy damaged	Occasionally, less earthquake-resistant buildings collapse. In some cases, even highly earthquake-resistant buildings suffer damage to walls and pillars.	Occasionally, gas mains and / or water mains are damaged.(Electrical service is interrupted in some regions. Occasionally, gas service and / or water service are interrupted over a large area.)	
7	Thrown by the shaking and impossible to move at will.	Most furniture moves to a large extent and some jumps up.	In most buildings, wall tiles and windowpanes are damaged and fall. In some cases, reinforced concrete-block walls collapse.	Occasionally, even highly earthquake-resistant buildings are severely damaged and lean.	Occasionally, even highly earthquake-resistant buildings are severely damaged and lean.	(Electrical service gas service and water service are interrupted over a large area.)	The ground is considerably distorted by large cracks and fissures, and slope failures and landslides take place, which occasionally change topographic features.

(1) Instrumental seismic intensity is a numerical one indicating the strength of the seismic motion at a site and measured with a seismic intensity meter. The JMA seismic intensity scale announced officially is obtained from the instrumental seismic intensity.

(2) Lifelines are utilities for power, communication, transportation and water supply.

(3) The descriptions given in ( ) of the "lifelines" describe situations concerning electrical, gas and water service in particular for information.

Table 2.4.1-2(3) Intensity Scale (Explanation table)

(http://www.gfz-potsdam.de/pb5/pb53/projekt/ems/core/emsa_cor.htm)

Classifications used in the European Macroseismic Scale (EMS)

Differentiation of structures (buildings) into vulnerability classes

(Vulnerability Table)

	Type of Structure	Vulnerability Class A	B	C	D	E	F
MASONRY	rubble stone, fieldstone	O					
	adobe (earth brick)	O	—				
	simple stone	·····	O				
	massive stone		—	O	·····		
	unreinforced, with manufactured stone units	·····	O	·····			
	unreinforced, with RC floors		—	O	·····		
	reinforced or confined			·····	O	—	
REINFORCED CONCRETE (RC)	frame without earthquake-resistant design (ERD)	·····	—	O	·····		
	frame with moderate level of ERD		·····	—	O	—	
	frame with high level of ERD			·····	—	O	—
	walls without ERD		·····	O	—		
	walls with moderate level of ERD			·····	O	—	
	walls with high level of ERD				·····	O	—
STEEL	steel structures			·····	—	O	—
WOOD	timber structures		·····	—	O	—	

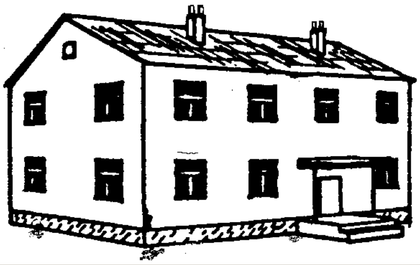
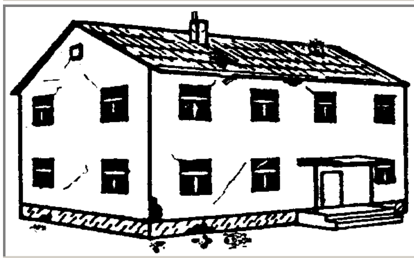
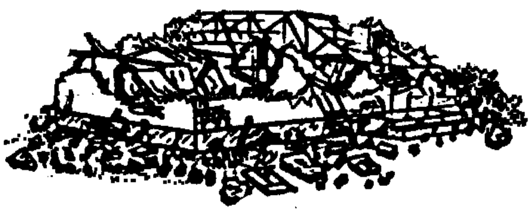
O most likely vulnerability class; — probable range;
····· range of less probable, exceptional cases

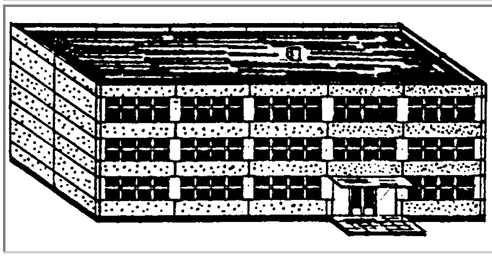
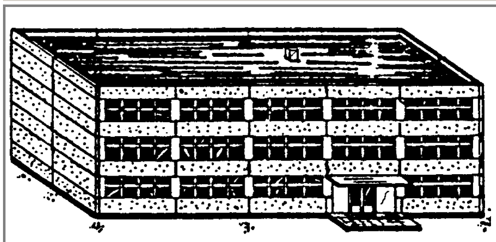
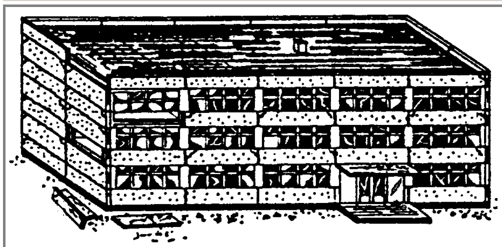
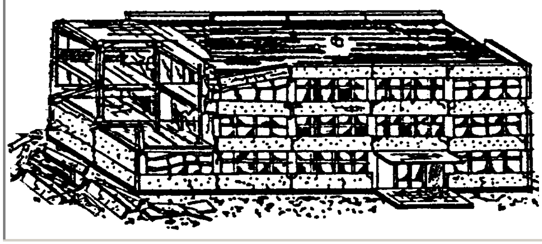
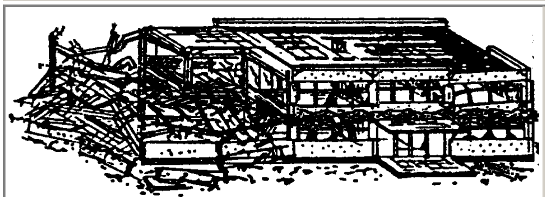
The masonry types of structures are to be read as, e.g., simple stone masonry, whereas the reinforced concrete (RC) structure types are to be read as, e.g., RC frame or RC wall.

See section 2 of the Guidelines and Background Materials for more details, also with respect to the use of structures with earthquake resistant design

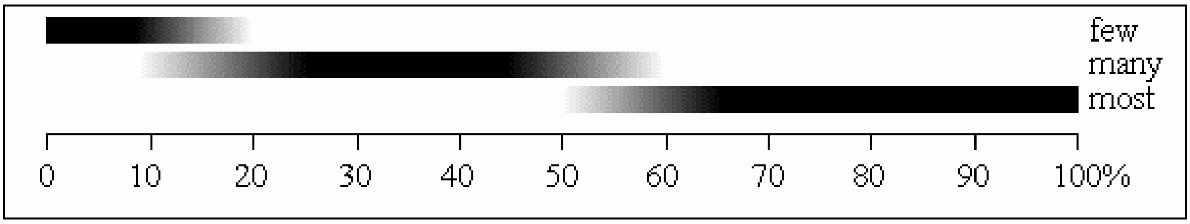
Classification of damage

Note: the way in which a building deforms under earthquake loading depends on the building type. As a broad categorisation one can group together types of masonry buildings as well as buildings of reinforced concrete.

Classification of damage to masonry buildings	
	**Grade 1: Negligible to slight damage** **(no strucutural damage, slight non-structural damage)** Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.
	**Grade 2: Moderate damage** **(slight structural damage, moderatenon-structural damage)** Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.
	**Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)** Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).
	**Grade 4: Very heavy damage** **(heavy structural damage,very heavynon-structural damage)** Serious failure of walls; partial structural failure of roofs and floors
	**Grade 5: Destruction** **(very heavy structural damage)** Total or near total collapse.

Classification of damage to buildings of reinforced concrete	
	**Grade 1: Negligible to slight damage** **(no structural damage,slight non-structural damage)** Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.
	**Grade 2: Moderate damage** **(slightstructuraldamage,moderatenon-structural damage)** Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
	**Grade 3: Substantial to heavy damage** **(moderatestructuraldamage,heavynon-structural damage)** Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of conrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.
	**Grade 4: Very heavy damage** **(heavy structural damage,** **very heavy non-structural damage)** Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.
	**Grade 5: Destruction** **(very heavy structural damage)** Collapse of ground floor or parts (e. g. wings) of buildings.

Definitions of quantity



Definitions of intensity degrees

Arrangement of the scale:
a) Effects on humans
b) Effects on objects and on nature
(effects on ground and ground failure are dealt with especially in Section 7)
c) Damage to buildings

Introductory remark:
The single intensity degrees can include the effects of shaking of the respective lower intensity degree(s) also, when these effects are not mentioned explicitly.

I. Not felt
a) Not felt, even under the most favourable circumstances.
b) No effect.
c) No damage.

II. Scarcely felt
a) The tremor is felt only at isolated instances (<1%) of individuals at rest and in a specially receptive position indoors.
b) No effect.
c) No damage.

III. Weak
a) The earthquake is felt indoors by a few. People at rest feel a swaying or light trembling.
b) Hanging objects swing slightly.
c) No damage.

IV. Largely observed
a) The earthquake is felt indoors by many and felt outdoors only by very few. A few people are awakened. The level of vibration is not frightening. The vibration is moderate. Observers feel a slight trembling or swaying of the building, room or bed, chair etc.
b) China, glasses, windows and doors rattle. Hanging objects swing. Light furniture shakes visibly in a few cases. Woodwork creaks in a few cases.
c) No damage.

V. Strong
a) The earthquake is felt indoors by most, outdoors by few. A few people are frightened and run outdoors. Many sleeping people awake. Observers feel a strong shaking or rocking of the whole building, room or furniture.
b) Hanging objects swing considerably. China and glasses clatter together. Small, top-heavy and/or precariously supported objects may be shifted or fall down. Doors and windows swing open or shut. In a few cases window panes break. Liquids oscillate and may spill from well-filled containers. Animals indoors may become uneasy.
c) Damage of grade 1 to a few buildings of vulnerability class A and B.

VI. Slightly damaging
a) Felt by most indoors and by many outdoors. A few persons lose their balance. Many people are frightened and run outdoors.
b) Small objects of ordinary stability may fall and furniture may be shifted. In few instances dishes and glassware may break. Farm animals (even outdoors) may be frightened.
c) Damage of grade 1 is sustained by many buildings of vulnerability class A and B; a few of class A and B suffer damage of grade 2; a few of class C suffer damage of grade 1.

VII. Damaging
a) Most people are frightened and try to run outdoors. Many find it difficult to stand, especially on upper floors.
b) Furniture is shifted and top-heavy furniture may be overturned. Objects fall from shelves in large numbers. Water splashes from containers, tanks and pools.
c) Many buildings of vulnerability class A suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class B suffer damage of grade 2; a few of grade 3.
A few buildings of vulnerability class C sustain damage of grade 2.
A few buildings of vulnerability class D sustain damage of grade 1.

VIII. Heavily damaging
a) Many people find it difficult to stand, even outdoors.
b) Furniture may be overturned. Objects like TV sets, typewriters etc. fall to the ground. Tombstones may occasionally be displaced, twisted or overturned. Waves may be seen on very soft ground.
c) Many buildings of vulnerability class A suffer damage of grade 4; a few of grade 5.
Many buildings of vulnerability class B suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class C suffer damage of grade 2; a few of grade 3.
A few buildings of vulnerability class D sustain damage of grade 2.

IX. Destructive
a) General panic. People may be forcibly thrown to the ground.
b) Many monuments and columns fall or are twisted. Waves are seen on soft ground.
c) Many buildings of vulnerability class A sustain damage of grade 5.
Many buildings of vulnerability class B suffer damage of grade 4; a few of grade 5.
Many buildings of vulnerability class C suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class D suffer damage of grade 2; a few of grade 3.
A few buildings of vulnerability class E sustain damage of grade 2.

X. Very destructive
c) Most buildings of vulnerability class A sustain damage of grade 5.
Many buildings of vulnerability class B sustain damage of grade 5.
Many buildings of vulnerability class C suffer damage of grade 4; a few of grade 5.
Many buildings of vulnerability class D suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class E suffer damage of grade 2; a few of grade 3.
A few buildings of vulnerability class F sustain damage of grade 2.

XI. Devastating
c) Most buildings of vulnerability class B sustain damage of grade 5.
Most buildings of vulnerability class C suffer damage of grade 4; many of grade 5.
Many buildings of vulnerability class D suffer damage of grade 4; a few of grade 5.
Many buildings of vulnerability class E suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class F suffer damage of grade 2; a few of grade 3.

XII. Completely devastating
c) All buildings of vulnerability class A, B and practically all of vulnerability class C are destroyed. Most buildings of vulnerability class D, E and F are destroyed. The earthquake effects have reached the maximum conceivable effects.

Table 2.4.1-2(4) Intensity Scale (Explanation table)

(http://www.phivolcs.dost.gov.ph/soepd2/index_peis.html)

PHIVOLCS Earthquake Intensity Scale

Intensity Scale	Description
I	**Scarcely Perceptible** - Perceptible to people under favorable circumstances. Delicately balanced objects are disturbed slightly. Still Water in containers oscillates slowly.
II	**Slightly Felt** - Felt by few individuals at rest indoors. Hanging objects swing slightly. Still Water in containers oscillates noticeably.
III	**Weak** - Felt by many people indoors especially in upper floors of buildings. Vibration is felt like one passing of a light truck. Dizziness and nausea are experienced by some people. Hanging objects swing moderately. Still water in containers oscillates moderately.
IV	**Moderately Strong** - Felt generally by people indoors and by some people outdoors. Light sleepers are awakened. Vibration is felt like a passing of heavy truck. Hanging objectsswing considerably. Dinner, plates, glasses, windows and doors rattle. Floors and walls of wood framed buildings creak. Standing motor cars may rock slightly. Liquids in containers are slightly disturbed. Water in containers oscillate strongly. Rumbling sound may sometimes be heard.
V	**Strong** - Generally felt by most people indoors and outdoors. Many sleeping people are awakened. Some are frightened, some run outdoors. Strong shaking and rocking felt throughout building. Hanging objects swing violently. Dining utensils clatter and clink; some are broken. Small, light and unstable objects may fall or overturn. Liquids spill from filled open containers. Standing vehicles rock noticeably. Shaking of leaves and twigs of trees are noticeable.
VI	**Very Strong** - Many people are frightened; many run outdoors. Some people lose their balance. motorists feel like driving in flat tires. Heavy objects or furniture move or may be shifted. Small church bells may ring. Wall plaster may crack. Very old or poorly built houses and man-made structures are slightly damaged though well-built structures are not affected. Limited rockfalls and rolling boulders occur in hilly to mountainous areas and escarpments. Trees are noticeably shaken.
VII	**Destructive** - Most people are frightened and run outdoors. People find it difficult to stand in upper floors. Heavy objects and furniture overturn or topple. Big church bells may ring. Old or poorly-built structures suffer considerably damage. Some well-built structures are slightly damaged. Some cracks may appear on dikes, fish ponds, road surface, or concrete hollow block walls. Limited liquefaction, lateral spreading and landslides are observed. Trees are shaken strongly. (Liquefaction is a process by which loose saturated sand lose strength during an earthquake and behave like liquid).
VIII	**Very Destructive** - People panicky. People find it difficult to stand even outdoors. Many well-built buildings are considerably damaged. Concrete dikes and foundation of bridges are destroyed by ground settling or toppling. Railway tracks are bent or broken. Tombstones may be displaced, twisted or overturned. Utility posts, towers and monuments mat tilt or topple. Water and sewer pipes may be bent, twisted or broken. Liquefaction and lateral spreading cause man- made structure to sink, tilt or topple. Numerous landslides and rockfalls occur in mountainous and hilly areas. Boulders are thrown out from their positions particularly near the epicenter. Fissures and faults rapture may be observed. Trees are violently shaken. Water splash or stop over dikes or banks of rivers.
IX	**Devastating** - People are forcibly thrown to ground. Many cry and shake with fear. Most buildings are totally damaged. bridges and elevated concrete structures are toppled or destroyed. Numerous utility posts, towers and monument are tilted, toppled or broken. Water sewer pipes are bent, twisted or broken. Landslides and liquefaction with lateral spreadings and sandboils are widespread. the ground is distorted into undulations. Trees are shaken very violently with some toppled or broken. Boulders are commonly thrown out. River water splashes violently on slops over dikes and banks.
X	**Completely Devastating** - Practically all man-made structures are destroyed. Massive landslides and liquefaction, large scale subsidence and uplifting of land forms and many ground fissures are observed. Changes in river courses and destructive seiches in large lakes occur. Many trees are toppled, broken and uprooted.

Table 2.4.1-2(5) Intensity Scale (Explanation table)

(http://www.seismo.nrcan.gc.ca/magnitudes/rossi_e.html)

1883 Rossi-Forel Scale of Earthquake Intensity

Note: The Rossi-Forel scale is one of the first scales designed to describe the effects of an earthquake, at a given place, on natural features, on industrial installations and on human beings. The intensity differs from the magnitude which is a quantity describing the strength of an earthquake. Due to its limitations, particularly in respect to the relation with ground acceleration, it has been replaced by the Modified Mercalli scale.

- **I.** Recorded by a single seismograph or by some seismographs of the same pattern, but not by several seismographs of different kinds; the shock felt by an experienced observer.
- **II.** Recorded by seismographs of different kinds; felt by a small number of persons at rest.
- **III.** Felt by several persons at rest; strong enough for the duration or direction to be appreciable.
- **IV.** Felt by several persons in motion; disturbance of moveable objects, doors, windows, creaking of floors.
- **V.** Felt generally by everyone; disturbance of furniture and beds; ringing of some bells.
- **VI.** General awakening of those asleep; general ringing of bells; oscillation of chandeliers, stopping of clocks; visible disturbance of trees and shrubs; some startled persons leave their dwellings.
- **VII.** Overthrow of moveable objects, fall of plaster, ringing of churchbells, general panic, without damage to buildings
- **VIII.** Fall of chimneys, cracks in the walls of buildings.
- **IX.** Partial or total destruction of some buildings.
- **X.** Great disasters, ruins, disturbance of strata, fissures in the earth's crust, rockfalls from mountains.

Table 2.4.1-2(6) Intensity Scale (Explanation table)

(http://www.uea.ac.uk/env/all/teaching/env3a02/MSK_SCA.doc)

Seismic Intensity Scale MSK (up-dated version from 1980[1])

Classification of the Scale

I. Types of Structures (buildings not antiseismic)

A: buildings of fieldstone, rural structures, adobe houses, clay houses;

B: ordinary brick buildings, large block construction, half-timbered structures, structures of hewn blocks of stone;

C: precast concrete skeleton construction, precast large panel construction, well-built wooden structures.

II. Definition of quantity

Single, few	:	$\leq$ 10%
Many	:	20-50%
Most	:	$\geq$ 60%

III. Classification of damage to buildings

Grade 1:	Slight damage:	Fine cracks in plaster; fall of small pieces of plaster
Grade 2:	Moderate damage:	Small cracks in walls, fall of fairly large pieces of plaster; pantiles slip off; cracks in chimneys; parts of chimneys fall down.
Grade 3:	Heavy damage:	Large and deep cracks in walls; fall of chimneys.
Grade 4:	Destruction:	Gaps in walls; parts of buildings may collapse; separate parts of the buildings lose their cohesion; inner walls and filled-in walls of the frame collapse.
Grade 5:	Total damage:	Total collapse of buildings.

IV. Arrangement of the scale

a) Persons and surroundings

b) Structures

c) Nature

1 After: Report on the Ad-hoc Panel Meeting of Experts on Up-dating of the MSK-64 Seismic Intensity Scale, Jena (GDR), 10-14 March 1980, Gerl. Beitr. Geophys., Leipzig (GDR), 90 (1981) 3, p.261-268.

Intensity degrees

I. Not noticeable

a) The intensity of the vibration is below the limit of sensibility; the tremor is detected and recorded by seismographs only.
b) -
c) -

II. Scarcely noticeable (very slight)

a) Vibration is felt only by individual people at rest in houses, especially on upper floors of buildings.
b) –
c) –

III. Weak

a) The earthquake is felt indoors by a few people, outdoors only in favourable circumstances. The vibration is weak. Attentive observers notice a slight swinging of hanging objects, somewhat more heavily on upper floors.
b) -
c) -

IV. Largely observed

a) The earthquake is felt indoors by many people, outdoors by few. Here and there people awake, but none is frightened. The vibration is moderate. Windows, doors and dishes rattle. Floors and walls creak. Furniture begins to shake. Hanging objects swing slightly. Liquids in open vessels are slightly disturbed. In standing motor cars the shock is noticeable.
b) -
c) -

V. Strong

a) The earthquake is felt indoors by most, outdoors by many. Many sleeping people awake. A few run outdoors. Animal become uneasy. Buildings tremble throughout. Hanging objects swing considerably. Pictures swing out of place. Occasionally pendulum clocks stop. Unstable objects may be overturned or shifted. Open doors and windows are thrust open and slam back again. Liquids spill in small amounts from well-filled open containers. The vibration is strong, resembling sometimes the fall of a heavy object in the building.
b) Damages of grade 1 in few buildings of type A is possible.
c) Sometimes change in flow of springs.

VI. Slight damage

a) Felt by most indoors and outdoors. Many people in buildings are frightened and run outdoors. A few persons lose their balance. Domestic animals run out of their stalls. In few instances dishes and glassware may break, books fall down. Heavy furniture may possibly move and small steeple bells may ring.
b) Damage of grade 1 is sustained in single buildings of type B and in many of type A. Damage in few buildings of type A is of grade 2.
c) In few cases cracks up to widths of 1 cm are possible in wet ground; in mountains occasional land-slips; change in flow of springs and in level of well-water are observed.

VII. Damage to building

a) Most people are frightened and run outdoors. Many find it difficult to stand. The vibration is noticed by persons driving motor cars. Large bells ring.
b) In many buildings of type C damage of grade 1 is caused; in many buildings of type B damage

is of grade 2. Many buildings of type A suffer damage to grade 3, few of grade 4. In single instances land-slips of roadway on steep slopes; locally cracks in roads and stone walls.

c) Waves are formed on water, and water is made turbid by mud stirred up. Water levels in wells change, and the flow of springs changes. In few cases dry springs have their flow restored and existing springs stop flowing. In isolated instances parts of sandy or gravelly banks slip off.

VIII. Destruction of buildings

a) General fright; few people show panic, also persons driving motor cars are disturbed. Here and there branches of trees break off. Even heavy furniture moves and partly overturns. Hanging lamps are in part damaged.

b) Many buildings of type C suffer damage of grade 2, and few of grade 3. Many buildings of type B suffer damage of grade 3, and few of grade 4. Many buildings of type A suffer damage of grade 4, and few of grade 5. Memorials and monuments move and twist. Tombstones overturn. Stone walls collapse.

c) Small land-slips in hollows and on banked roads on steep slopes; cracks in ground up to widths of several centimetres. New reservoirs come into existence. Sometimes dry wells refill and existing wells become dry. In many cases change in flow and level of water or wells.

IX. General damage to buildings

a) General panic; considerable damage of furniture. Animals run to and fro in confusion and cry.

b) Many buildings of type C suffer damage of grade 3, a few of grade 4. Many buildings of type B show damage of grade 4, a few of grade 5. Many buildings of type A suffer damage of grade 5. Monuments and columns fall. Reservoirs may show heavy damage. In individual cases railway lines are bent and roadways damaged.

c) On flat land overflow of water, sand and mud is often observed. Ground cracks to widths of up to 10cm, in slopes and river banks more than 10cm; furthermore a large number of slight cracks in ground; falls of rock, many landslides and earth flows; large waves on water.

X. General destruction of buildings

b) Many buildings of type C suffer damage of grade 4, a few of grade 5. Many buildings of type B show damage of grade 5, most of type A collapse. Dams, dykes and bridges may show severe to critical damage. Railway lines are bent slightly. Road pavement and asphalt show waves.

c) In ground, cracks up to widths of several decimetres, sometimes up to 1 metre. Broad fissures occur parallel to water courses. Loose ground slides from steep slopes. Considerable landslides are possible from river banks and steep coast. In coastal areas displacement of sand and mud; water from canals, lakes, rivers etc. thrown on land. New lakes occur.

XI. Catastrophe

b) Destruction of most and collapse of many buildings of type C. Even well built bridges and dams may be destroyed and railway lines largely bent, thrusted or buckled; highways become unusable; underground pipes destroyed.

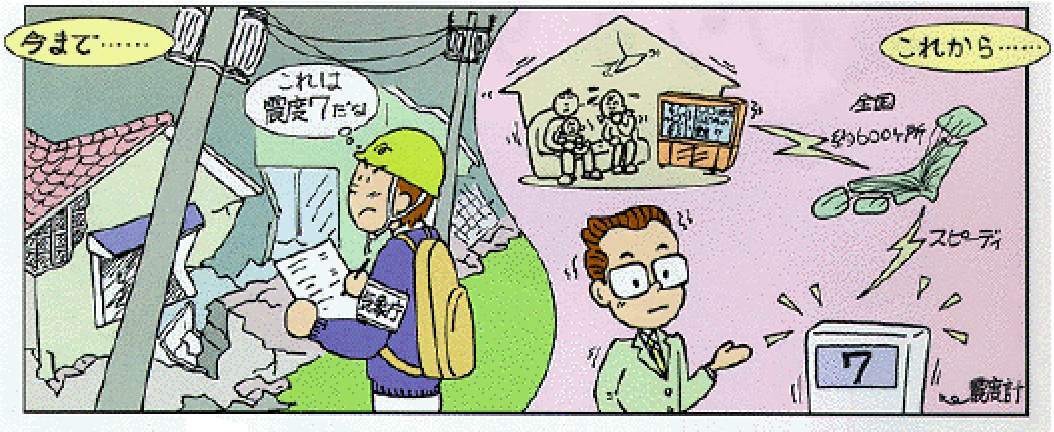
c) Ground fractured considerably by broad cracks and fissures, as well as by movement in horizontal and vertical directions; numerous landslides and falls of rock. The intensity of the earthquake requires to be investigated specially.

XII. Landscape changes

b) Practically all structures above and below ground are heavily damaged or destroyed.

c) The surface of the ground is radically changed. Considerable ground cracks with extensive vertical and horizontal movement are observed. Falls of rock and slumping of river banks over wide areas; lakes are dammed; waterfalls appear, and rivers are deflected. The intensity of the earthquake requires to be investigated specially.

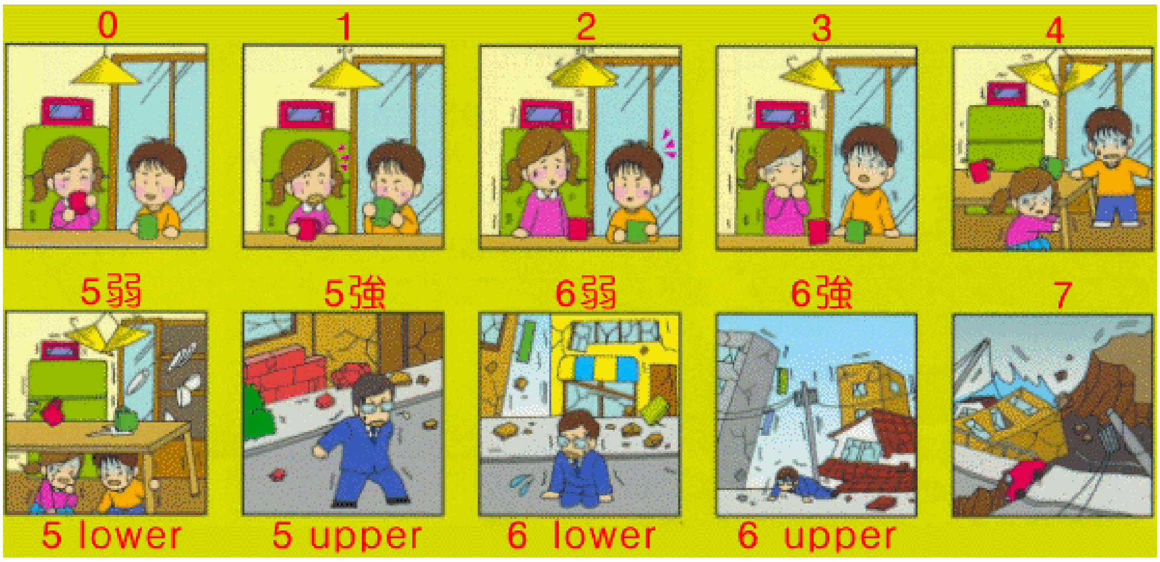
Seismic Intensity is now measured with "Seismic Intensity Meters"



In the past,seismic intensity was estimated from a compilation of human perception and the resultant casualties.

Since 1 April 1996, it has been measured automatically with seismic intensity meters and announced rapidly to the public and officials. There are about 600 JMA seismic intensity observation stations throughout Japan as of April 1996

The Seismic Intensity is now divided into 10 scales.



Because "intensity 5" or "intensity 6" didn't necessarily correspond to the same degree of damage, "intensity 5" and "intensity 6" have been divided into two scales "intensity 5 Lower" and "intensity 5 Upper" and "intensity 6 Lower" and "intensity 6 Upper" respectively, since 1 October 1996. The intensity is now divided into 10 scales as a result.

Fig.2.4.1-1 Format and method for in-site survey of Intensity

(http://www.kishou.go.jp/know/shindo/shindokai.html)

Table 3.5 Questionnaire sheet for seismic intensity survey (Murakami and Kagami, 1991)

1. When the earthquake occurred, you were
   1 in your town
   2 somewhere else
2. The address where you were located at the time of the earthquake, if known
   street
   city
   state, zip
   If not, approximate location is
3. The place was
   1 flat land
   2 on a top of hill
   3 on a slope
   4 in a valley
4 You were
   1 indoors
   2 outdoors
   3 in a vehicle
5. Check your activity when the earthquake occurred
   1 moving
   2 standing
   3 sitting
   4 lying
   5 other (please specify)
6. *If you were inside a building,* the type of the building was
   1 house
   2 mobile home
   3 *apartment*
   4 office
   5 other (please specify)
7. What was the building mainly made of?
   1 brick or block
   2 wood
   3 concrete
   4 steel
   5 other (please specify)
8. How old is the building?
   1 built before 1935
   2 built between 1935 and 1965
   3 *built after 1965*
   4 don't know
9. How many floors did the building have ?
10. *What floor were you on?*
11. Did you feel the earthquake
   1 yes
   2 no
12. How many to those around you felt the shaking?
   1 nobody
   2 few
   3 many
   4 all
   5 don't know
13. If anyone was sleeping, did the sleeping people awake?
   1 a few people woke up
   2 many woke up
   3 all woke up
   4 no one was sleeping
14. Would you say the vibration you felt was
   1 light
   2 moderate
   3 strong
   4 violent
15. How long do you *think the* shaking lasted?
   1 sudden (less than 10 seconds)
   2 short (10-30 secs.)
   3 *long (30-60 secs.)*
   4 very long (more than 1 min)
16. Were you frightened during the shaking?
   1 not al all
   2 a little bit
   3 quite
   4 almost panic
17. What did you do during the shaking?
   1 stayed where I was
   2 tried to protect myself, someone, or some valuables
   3 moved to another room
   4 *tried to exit building*
   5 other (please specify)
18. If you tried to, was it difficult to move?
   1 *easy to move*
   2 difficult but possible to move
   3 couldn't move
   4 fell down
   5 didn't try to move
19. Was the vibration noticed in your car?
   1 not in a car
   2 noticed in parked car
   3 noticed in moving cars
   4 difficult to control car
20. Did you see any trees, poles or parked cars move?
   1 none moved
   2 some moved slightly
   3 some moved violently
   4 branches broke off
   5 *don't know*
21. Did hanging objects like pictures and lamps swing ?
   1 no
   2 some moved slightly
   3 some moved a lot
   4 some fell or were damaged
   5 don't know
22. What happened to windows, doors or dishes?
   1 they rattled
   2 they swung open or close
   3 some dishes broke
   4 some windows broke
   5 don't know
23. Did you see the liquids in open vessels move?
   1 some moved a little
   2 some moved a lot
   3 some spilled
   4 don't know
24. Did shelf goods move?
   1 none moved
   2 *a few shifted or overturned*
   3 many fell off shelves
   4 all fell off shelves
   5 don't know
25. *What happened to furniture ?*
   1 furniture did not shake
   2 It shock slightly
   3 It moved a little
   4 It moved and overturned
   5 considerable damage to furniture
   6 don't know
26. Damage to walls of the building
   1 none
   2 fine cracks in plaster
   3 pieces of plaster fell off
   4 there were large and deep cracks
   5 one or more walls collapsed
27. Damage to foundation of the building
   1 none
   2 foundation cracked
   3 building moved on foundation
   4 *building moved off foundation*
   5 foundation destroyed
   6 don't know
28. Was there damage to chimneys, *parapets and ornaments?*
   1 none
   2 some cracked
   3 some fell
   4 most fell down
   5 don't know
29. Was there damage to stone or brick walls, tombstones or monuments in neighborhood?
   1 no damage
   2 small cracks
   3 big cracks
   4 collapses
   5 don't know
30. Were there ground cracks, rockfalls and landslide in your neighborhood?
   1 none
   2 *few*
   3 many
   4 numerous
   5 don't know
31. Was your telephone, water, gas or electricity interrupted after the earthquake?
   1 no interruption
   2 for a few hours
   3 for a few days
   4 for a week
   5 longer
   6 don't know
32. Was you or your family injured due to the earthquake?
   1 no
   2 yes, slightly
   3 treated by doctor
   4 hospitalized (what injury)

Questions 26, 27 and 28 refer to your *building, OR to neighboring building* if you were outdoors.

Fig.2.4.1-1(2) Format and method for in-site survey of Intensity

(Manual for Zonation on Seismic Geotechnical Hazards (1999), Technical Committee for Earthquake Geotechnical Engineering, TC4, ISSMGE)

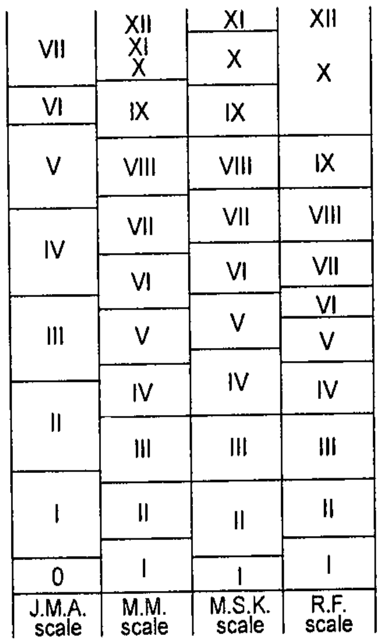
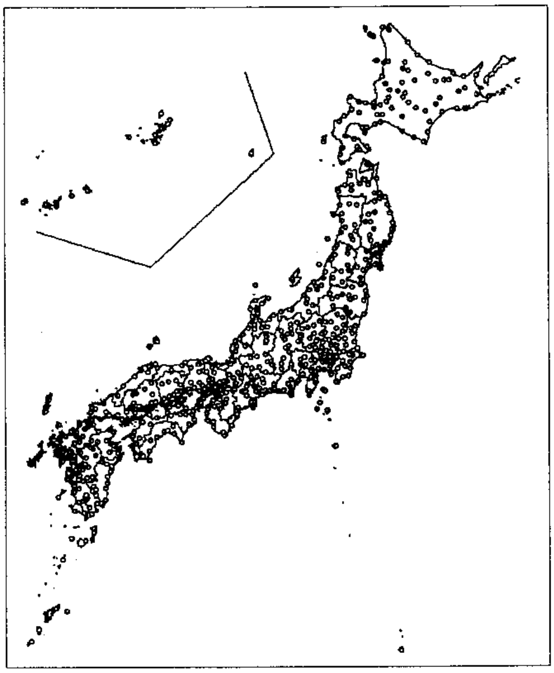


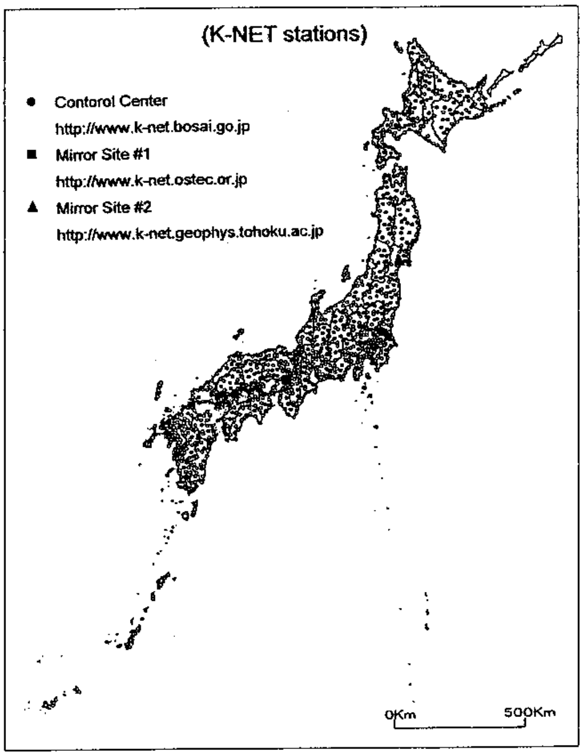
Fig. 3.7. Approximate correspondence between the J.M.A., M.M., M.S.K. and R.F. intensity scales (Seismological Division, J.M.A., 1971).

Fig.2.4.1-2 Study results of relation with other intensity scales

(Manual for Zonation on Seismic Geotechnical Hazards (1999), Technical Committee for Earthquake Geotechnical Engineering, TC4, ISSMGE)



The observation networks of JMA with 574 observation points.



The observation networks of K-NET with 1000 observation points.

Fig.2.4.1-3 Intensity information system with strong motion observation network in Japan (Yamazaki, H. (1999): Ground motion monitoring for Real-time Earthquake Disaster Prevention, Proceeding of the first Real-time Earthquake Disaster Prevention Symposium, p 7)

2.4.2. Estimation of devastating ground motion

1) Terminology

ω^{-2} **Spectral Model:** Proposed by Aki(1967) and Brune (1970). Source spectra S(f) is determined as follows;

$$S(f)=M_o \cdot (2\pi f)^2 / (1+(f/fc)^2)$$

where

fc: Corner Frequency

Mo: Seismic moment

This model is used to explain the spectra of observed ground motion.

Osaki Spectra: A method of analysis. Characteristics of seismic frequency at the Brock are determined from a set of observed spectra, magnitude and epicenter. Mainly, it is used for an earthquake-proof design of a nuclear power plant.

Near Field Ground Motion: The ground motion in the field near a source. Relationships near a source involve both effects which attenuate rapidly with distance as well as those which attenuate more slowly (such as geometrical spreading).

Empirical Green's Function Method: Seismic records of micro earthquakes contain characteristics of the path between focus and an observing point, and of observing site. When large earthquake occurs at the same focal point, the path of large a earthquake is the same as the path of a micro earthquake. Considering that the micro earthquakes are calculated by using Green’s function, we can estimate the seismic waves of the large earthquake by employing the rule of the scaling.

2) Purpose or Target

Estimation of ground motion due to the main shock in the devastated area

3) Grade

Table 2.4.2-1 Classification of topics

Accuracy	Item	Input Data or techniques	Examples or references
1	Estimated Peak Value Estimated Response Spectra by Empirical Formulae Stochastic modeling	Interpolation Attenuation Relation Empirical Formulae Spectral Model	Osaki Spectra ω^{-2} Spectral Model Boore(1983)
2	Synthetic Strong Motion in the time domain based on complex source model	Recorded or Simulated Aftershock Records	Irikura & Kamae. (1996)
3	Observed Strong Motion in the time domain	Dense Strong Motion Observation Network	Chi-Chi Eq.(1999) Tottori-Seisbu (2000)

4) Examples (Description with figures)

Research papers of strong ground motion estimation (Fig.2.4.2-1)

5) Special topics

Effect of Surface Geology on Seismic Ground Motion

6) References

<Empirical Techniques>

<Empirical Estimation in the Frequency Domain>

Boore, D. M., W. B. Joyner and T. E. Fumal (1997): Equations for estimating horizontal response spectra and peak acceleration from western North American earthquakes: a summary of recent work, Seism. Res. Lett, 68, 128-153.

Spudich, P., W. B. Joyner, A. G. Lindth, D. M. Boore, B. M. Margaris and J. B. Fletcher (1999): SEA99 A revised ground motion prediction relation for use in extensional tectonic regimes, Bull. Seism. Soc. Am., 89, 1156-1170.

Satoh, T., H. Kawase, and T. Sato (1997): Statistical Spectral Model of Earthquakes in the Eastern Tohoku District, Japan, Based on the Surface and Borehole Records Observed in Sendai, Bull. Seism. Soc. Am., 87, 446 - 462.

<Wave Form Synthesis: Stochastic Methods>

Boore, D. M. (1983): Stochastic simulation of high-frequency ground motions based on seismological models of the radiation spectra, Bull. Seism. Soc. Am., 73, 1865-1894.

Herrero, A. and P. Bernard (1994): A kinematic self-similar rupture process for earthquakes, Bull. Seism. Soc. Am., 84, 1216-1228.

Zeng, Y., J. G. Anderson and G. Yu (1994): A composite source model for computing realistic synthetic strong ground motions, Geophys. Res. Lett., 65, 725-728.

<Wave Form Synthesis Based on Seismic Fault Model: Deterministic Methods>

Irikura, K. and K. Kamae (1994): Estimation of strong ground motion in broad-frequency band based on a seismic source scaling model and an empirical Green's function technique, ANNALI DI GEOFISICA, XXXVII, 1721-1743.

Kamae, K., K. Irikura and A. Pitarka (1998): A technique for simulating strong ground motion using hybrid Green's function, Bull. Seism. Soc. Am., 88, 357-367.

<Data provided by Dense Strong Ground Motion Net Work>

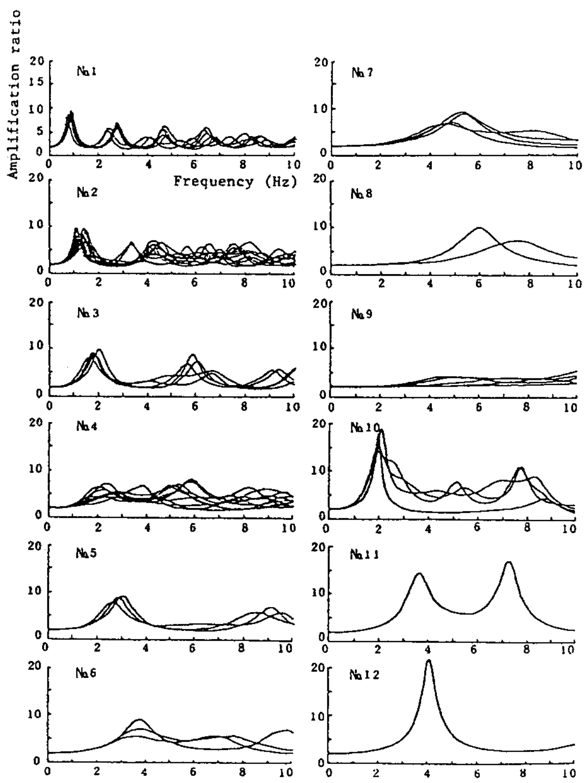
Taiwan Strong Motion Instrumentation Program (TSMIP) (http://www.cwb.gov.tw/)

TriNET Home Page (http://www.trinet.org/)

Kyoshin Net (K-NET) (http://www.k-net.bosai.go.jp/index_e.html)

Digital Strong-Motion Seismograph Network (KiK-net)
(http://www.kik.bosai.go.jp/kik/index_en.shtml)

Yokohama City Dense Strong Motion Observation Network
(http://www.city.yokohama.jp/me/bousai/eq/index.html)



Computed site response for various ground patterns (Shima and Imai, 1982).

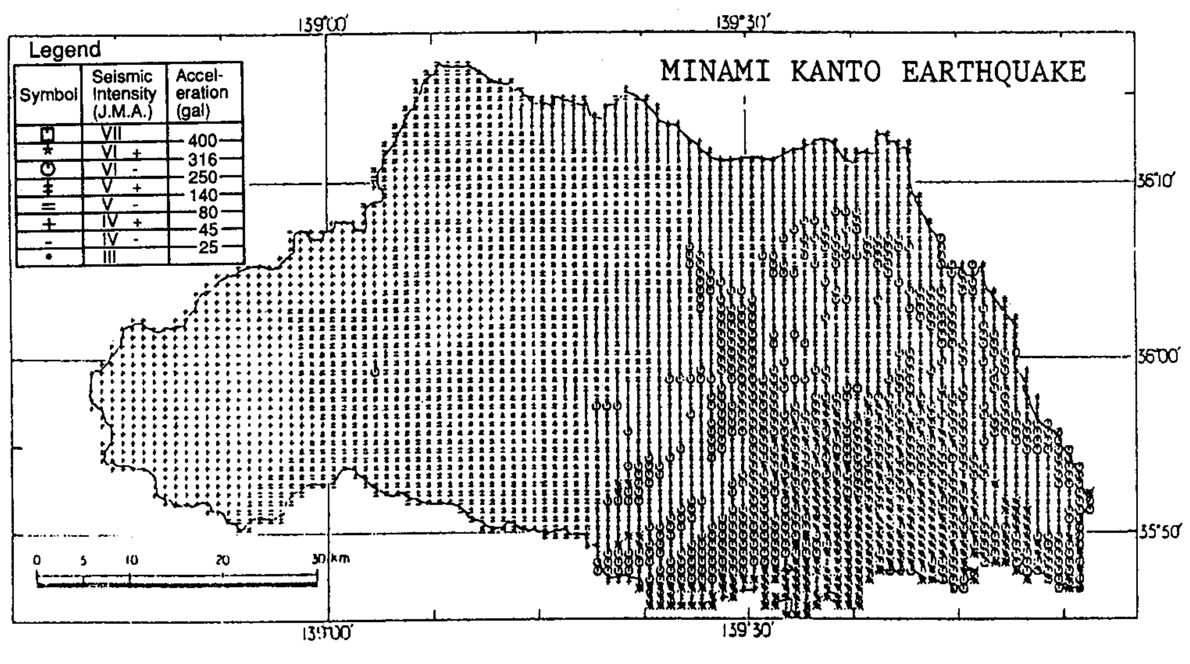


Fig. 3.28 Estimated seismic intensity map of Saitama Prefecture for the Kanto earthquake (Shima and Imai, 1982)

Fig.2.4.2-1 Research papers of strong ground motion estimation

(Shima, E. and Imai, T. (1982): Estimation of Strong Ground Motions due to the Future Earthquakes, A Short Technical Report, Proc. Third Intern'l Conf. On Recent Microzonation, Vol.3, pp.1417-1427.)

2.4.3. Site effect

1) Terminology

Seismic Bedrock: Any solid rock, such that exposing at the surface or overlain by unconsolidated material. Shear wave velocity of such layers is shown about 3 km/s.

Engineering Bedrock: A layer which would be a foundation of a building. In most of the cases, S-wave velocity of Engineering Bedrock is the range between 300 m/s and 700 m/s.

2) Purpose or Target

Cause of Damage Concentration and Detection of the risky area for future earthquakes

3) Grade

Table 2.4.3-1 Classification of topics

Accuracy	Item	Input Data or techniques	Examples or references
1	Amplification factor based on the statistical estimation of geological and geomorphological units	Geological Maps Geomorphological Maps Aerophotographs Intensity Distribution	Existent Microzonation Maps
2	Amplification factor based on the ground classification or predominant period	Microtremor observartion Simplified Geotechnical Study for ground classification	Predominant Period Nakamura's H/V spectral ration Geological Column, PS-Logging, Geophysical Prospecting etc.
3	Dynamic response of ground	Geotechnical Study for non-linear soil properties Non Linear Analyses of Ground Response Strong Motion Observation	Soil Test in Laboratory and in-site Numerical Simulation Vertical Strong Motion Array

4) Examples (Description with figures)

EuroSeis test (Fig.2.4.3-1)

Ashigara Valley (Fig.2.4.3-2)

5) References

Gutierrez, C. and S. K. Singh (1992): A site effect study in Acapulco, Guerrero, Mexcico: Comparison of results from strong-motion and microtremor data, BSSA Vol.82, No.2, pp.642-659.

Sato, T., H., Kawase, and T. Sato (1995): Evaluation of Local Site Effect and Their Removal from Borehole Records Observed in the Sendai Region, Japan, BSSA, Vol.85, No.6, pp.1770-1789.

Sato, T., H., Kawase, and T. Sato (1997): Statistical Spectral Model of Earthquakes in the Eastern Tohoku District, Japan, Based on Surface and Borehole Records Observed in Sendai, BSSA, Vol.87, No.2, pp.446-462.

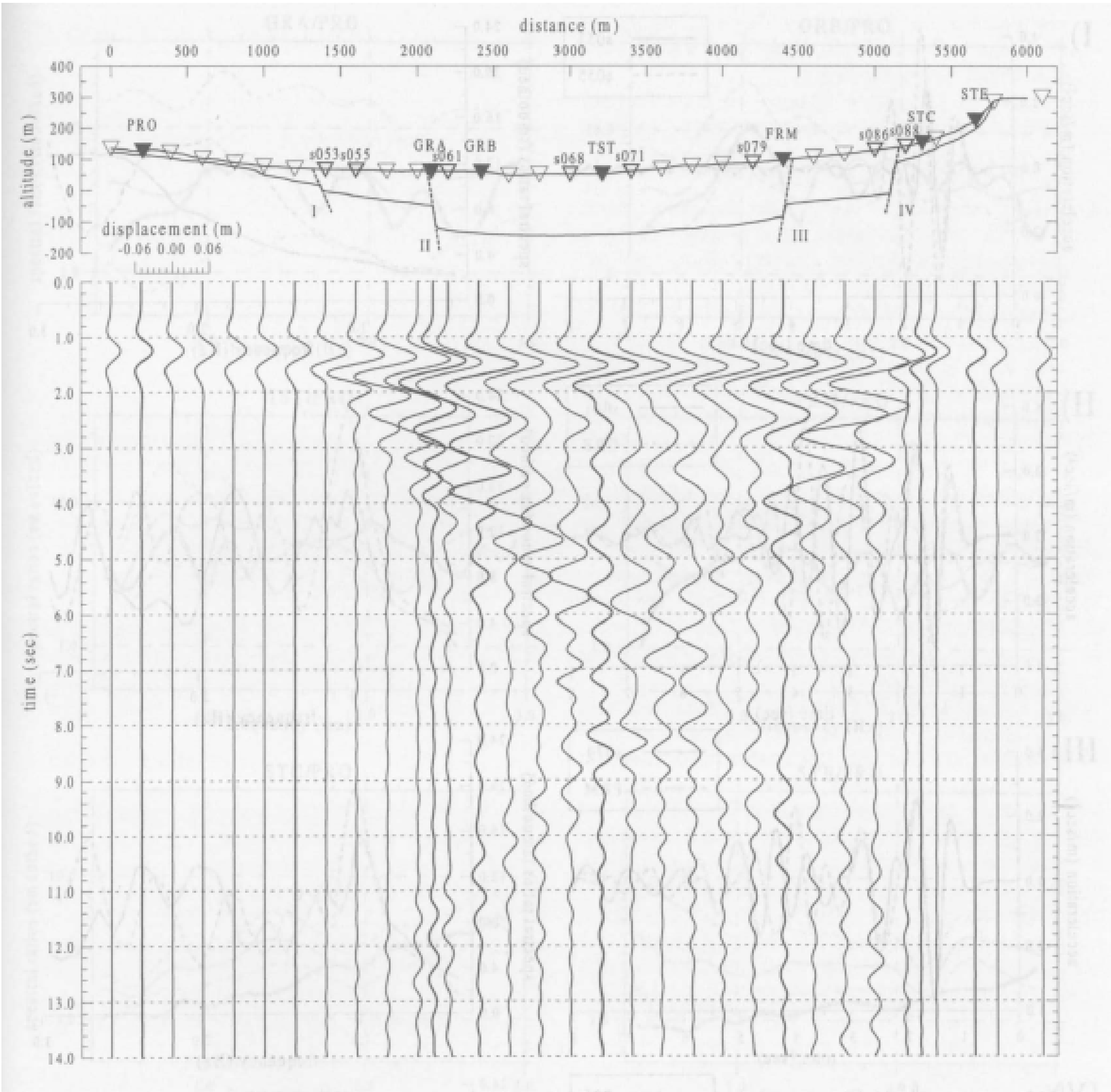
Okawa, I., Y. Kitagawa and T. Kashima (1991): EARTHQUAKE OBSERBATION ON VARIOUS SOIL CONDITIONS AND ANALYSIS OF THE RECORDS, Proc of Fourth International conference on Seismic Zonation, Sep,Vol.II, pp.295-302.

Lachet C. and P. Y. Bard (1994): Numerical and Theoretical Investigation on the Possibilities and Limitations of Nakamura's Technique, Jour. Phys. Earth, 42, pp.377-397.

Wakamatsu, K. and Y. Yasui (1996): Possibility of Estimation for Amplification Characteristics of Soil Deposits Based on Ratio of Horizontal to Vertical Spectra of Microtremors, Proc of Eleventh World Conference on Earthquake Engineering, Vol.II, pp.215-220.

Chavez-Garcia F. J. and J.Cuenca (1998): Site effects and microzonation in Acapulco, Earthquake Spectra, Vol.14, 1, pp.75-93.

Sengara, I.W. and I. G. M. Susila (2000): Macrozonation Methodology and Soil Characteristics Parameters in the Newest Proposed Indonesia Seismic Code, Proc. of Indonesia Earthquake & Tsunami Disaster in Building and Housing.



Displacement time-histories calculated on the surface of the valley for 1 Hz Ricker wavelet.

Fig.2.4.3-1 EuroSeis test

(S.V.Tolis, (1998): A2D simulation of Euroseistest near Thessaloniki, Greece, The effects of Surface Geology on Seismic Motion)

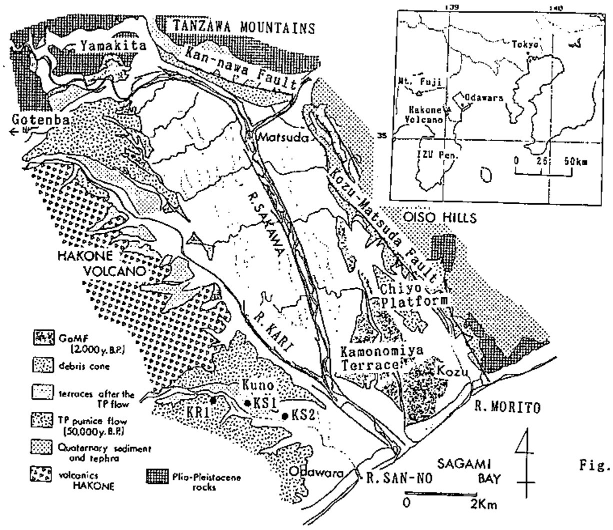


Fig. 2 Subsurface Geological Map of the Ashigara Valley
(modified Yamazaki et al., 1982)

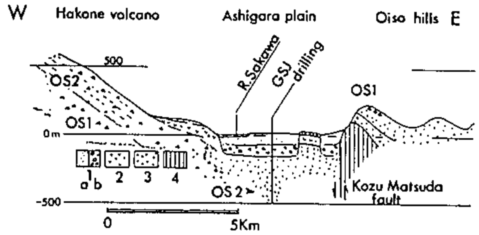


Fig. 3 Schematic Profile of the relationship between Ashigara Valley and Oiso Hills, Hakone Volcano
(after Yamazaki et al., 1982)

1a Alluvium (sand or clay)
1b Alluvium (gravel)
2 Pumice flow deposit
3 Middle Pleistcene series
4 Ashigara Group (Pleistcene to Pliocene)

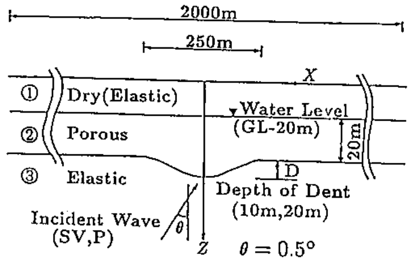
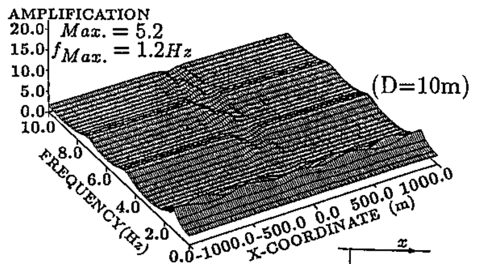
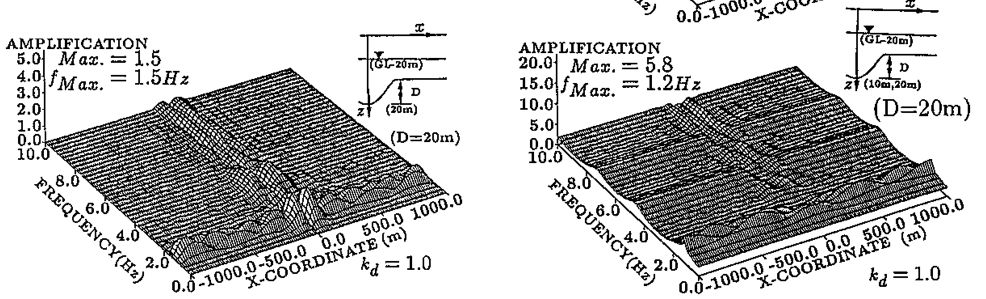


Fig.4 Configuration of studied soil medium.





(b) Induced vertical motion(D=20m)

(a) Horizontal motion

Fig.5 Frequency response characteristics on a surface due to incident plane SV wave in a layered medium with subsurface irregularity

Fig.2.4.3-2 Ashigara Valley

(Symposium on THE EFFECTS OF SURFACE GEOLOGY SEISMIC MOTION, 1992)