2012/06/27 Kenken symposium

Long-Period Ground Motion as a New Urban Threat

都市の新たな脅威としての長周期地震動

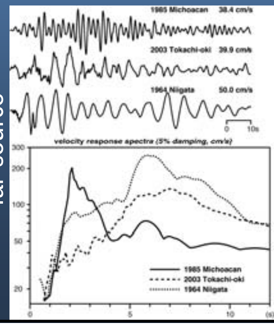
Kazuki Koketsu　纐纈一起

Earthquake Research Institute, University of Tokyo　東京大学地震研究所

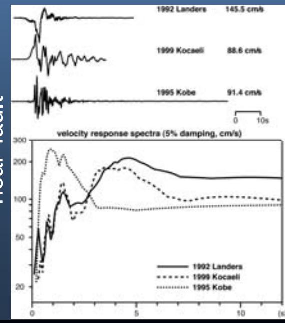
Background in the world (1)

Long-period ground motion becomes an important issue because of recent rapid increase of large-scale structures such as high-rise buildings, oil storage tanks, and long-span bridges. They can also affect long-period structures such as base-isolated buildings. Large subduction-zone earthquakes and moderate to large crustal earthquakes can generate far-source long-period ground motions in distant sedimentary basins with the help of path effects. Near-fault long-period ground motions are generated, for the most part, due to the source effects of rupture directivity.

far-source



near-fault



Background in the world (2)

Far-source ones mostly consist of surface waves with longer duration than that of near-fault ones. They can even be damaging in some circumstances; the worst example occurred in Mexico City due to the 1985 Michoacan earthquake. Further examples were provided by recent large events such as the 2003 Tokachi-oki, Japan, earthquake. In addition, long-period ground motions can be predicted only by numerical simulations, differently from short-period ground motions.

1985 Michoacan earthquake

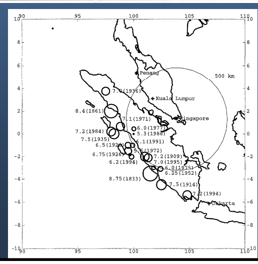
2003 Tokachi-oki earthquake

Situation in Singapore

Singapore in the 1960's

in the 1980's

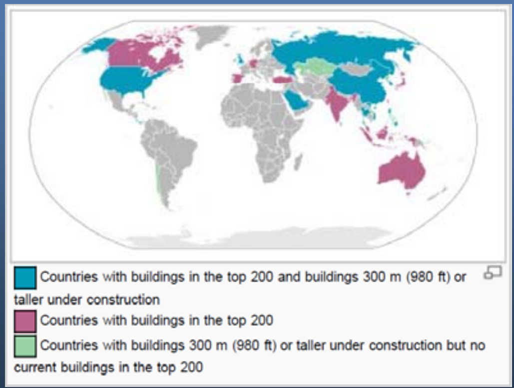
(Pan & Sun, 1995)



Large and shallow Sumatran earthquakes were felt by Singaporeans in high-rise buildings only in the 1980's or later. Its severity can be such that panic is produced.

(Pan, 1995)

Expansion to newly industrializing countries



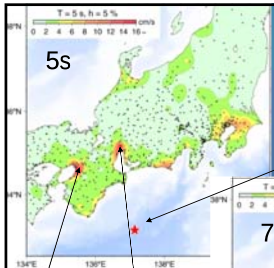
(from Wikipedia)

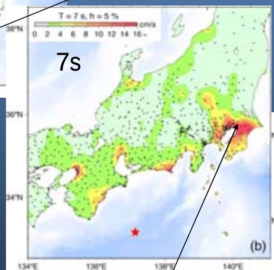
Shaking table tests for the effects of long-period ground motion on people in a high-rise building

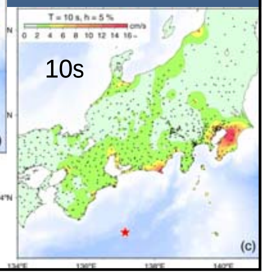
We think that the building itself should be all right but people inside are greatly affected by long-period ground motions.

Observational evidences of long-period ground motion (1):

2004 off Kii peninsula earthquake (Mw 7.4) excited well-developed far-source long-period ground motions at distant basins, which were observed more than 1,000 seismometers.

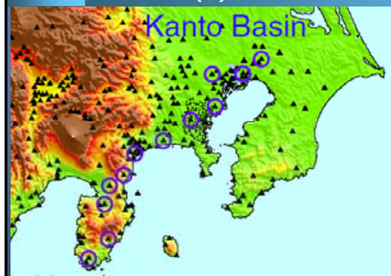


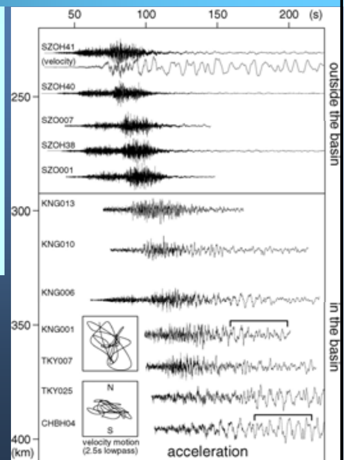




Distributions of response spectra

Observational evidences of long-period ground motion (2): Section of records



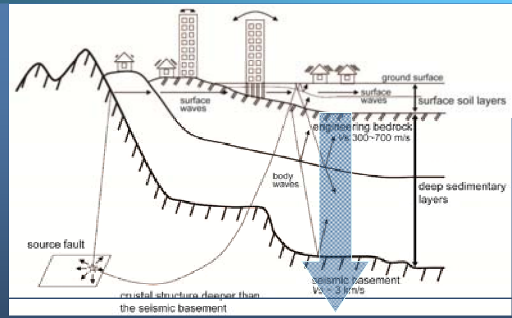


Far-source long-period ground motions were developed along a propagation path (Nankai trough zone). They were then amplified and lengthened in the Kanto basin.

Background in Japan

- The Headquarters for Earthquake Research Promotion (HERP) of the Japanese government set up ‘Section for Subsurface Velocity Structures (SSVS)’ (chair: K. Koketsu) under ‘Subcommittee for Evaluation of Strong Ground Motion’ of ‘Earthquake Research Committee.’
- National Research Institute for Earth Science and Disaster Prevention (NIED) and many other institutions constructed velocity structure models all over Japan. SVSS has started a 3-year project (PI: K. Koketsu), where those models are being updated for long-period ground motion hazard maps.
- The long-period ground motion hazard maps are being made by numerical simulation with the updated velocity structure models. The updated models will be combined into a Japan integrated velocity structure model at the end of the 3-year project.

Features (1)



- Velocity structure models control the accuracy of long-period ground motion hazard map more than source models.
- A velocity structure consists of three parts called `surface soil layers,’ `deep sedimentary layers,’ and `crustal structure deeper than the seismic basement.’
- Surface soil layers do not affect long-period ground motion so much as the other two parts, so we are concentrated into the two parts lower than the engineering bedrock.

Features (2)

- It was required to establish a standard modeling procedure for the lower parts of velocity structures in Japan, in order to keep their quality up.
- Models with which ground motions can be simulated well is more preferable than models with which geological entities can be recovered well.
- S-wave velocity structures are more important than P-wave velocity structures, because the main parts of long-period ground motions consist of S-waves and surface waves.
- Actual records of ground motions from small to moderate earthquakes are used as data, because they should work for models with which long-period ground motions can be simulated well.
- In the prediction of long-period ground motions from a large subduction-zone earthquake, the structures of the lower crust, upper mantle, and subducting plates are also necessary.

Standard Procedure of Modeling 3-D Velocity Structures (1) (Koketsu et al., *Tectonophysics*, 2009)

Step 1: Assume an initial layered model consisting of seismic basement and sedimentary layers from comprehensive overview of geological information, borehole data, and exploration results.

Step 2: Assign P-wave velocities to the basement and layers based on the results of refraction and reflection surveys, and borehole logging. Assign S-wave velocities based on the results of borehole logging, microtremor surveys, spectral-ratio analyses of seismograms, and empirical relationships between P- and S-wave velocities.

Step 3: Obtain the velocity structure right under engineering bedrock from the results of microtremor surveys referring to the results of borehole logging, since among 2-D or 3-D surveys only microtremor surveys are sensitive to shallow velocity distributions and the shapes of shallow interfaces.

Step 4: Compile data and information on faults and folds. Convert time sections from seismic reflection surveys and borehole logging into depth sections using the P- and S-wave velocities in Step 2.

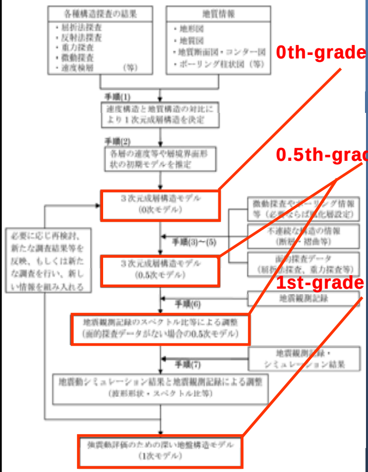
Step 5: Determine the shapes of interfaces between the layers and basement by inversions of geophysical-survey data (e.g., refraction traveltimes and gravity anomalies). In case of insufficient data, forward modeling is carried out. The depths of faults and folds in Step 4 are introduced into the inversions as constraints, or additional data to the forward modeling.

Step 6: Calibrate the P-and S-wave velocities in Step 2 and the interface shapes in Step 5 by inversion or forward modeling of spectral features of observed seismograms such as dominant periods of H/V (horizontal/vertical) spectral ratios.

Step 7: Adjust the velocities and interface shapes using inversion or forward modeling of time history waveforms of observed seismograms.

- 0th-grade model = Initial model after Steps 1 to 2
- 0.5th-grade model = Intermediate model after Steps 3 to 5
- 1st-grade model = Final model after Steps 6 to 7

Flow chart of "Standard Procedure of Modeling 3-D Velocity Structures"



From Appendix 2 of "2009 Long-Period Ground Motion Hazard Maps"

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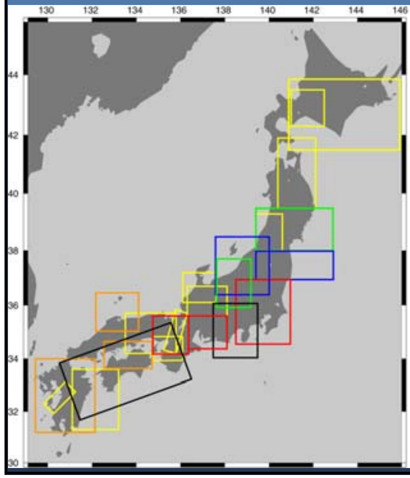
Progress towards a Japan integrated velocity structure model



- 1st grade by DaiDaiToku
- 1st grade by Itoshizu & Miyagi-oki
- 1st grade by Special Coordination Funds (in progress)
- 0.5th grade for National Seismic Hazard Maps for Japan (2005)
- 1st grade for National Seismic Hazard Maps for Japan (2009)
- 1st grade by Shuto-Chokka (in progress)

⬇

These models have been updated and combined into three wide-area 1st-grade models

⬇

They will then be combined into a Japan integrated velocity structure model.

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Progress towards long-period ground motion hazard maps

Three Wide Areas and Scenario Earthquakes

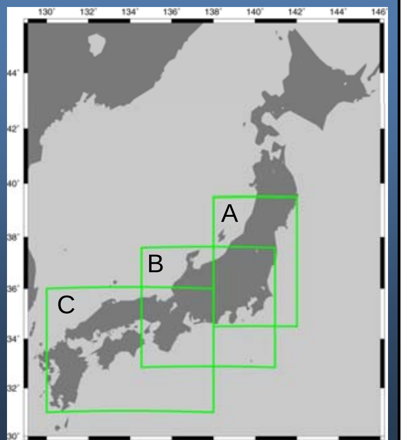
A: Miyagi-oki earthquake
B: Tokai & Tonankai earthquakes
C: Nankai earthquake

Occurrence Probability within 30 years from Jan. 1, 2008

A: nearly 100%
B: 87% & 66%
C: 55%

Release Date

A: September, 2009
B: September, 2009
C: January, 2012



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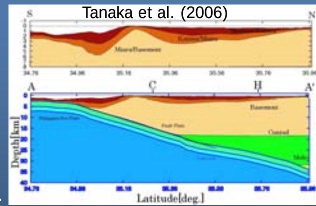
Example of development of a velocity structure model

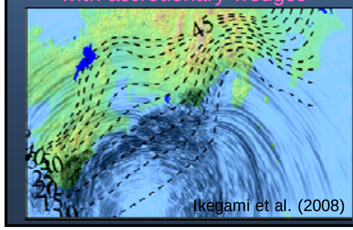
The structure of the accretionary wedge has mainly been improved for Region B, since it greatly affects long-period ground motions.

Tanaka et al. (2006)



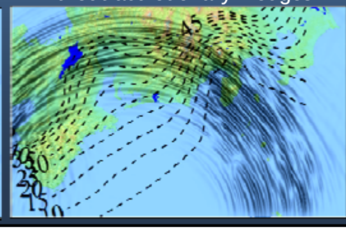
USGS earthquake glossary

with accretionary wedges



Ikegami et al. (2008)

without accretionary wedges



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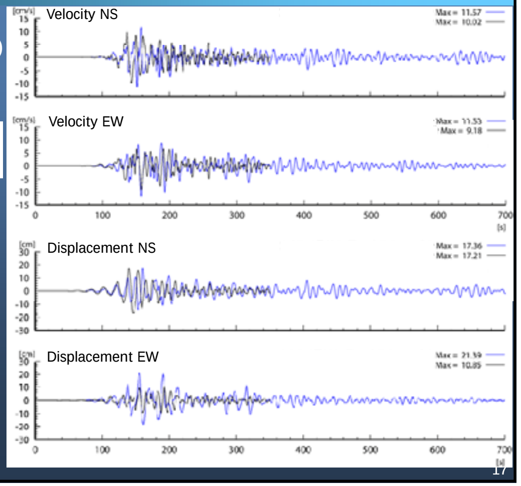
Performance of the Region B 1st-grade model (3)

★ 1944 Tonankai earthquake (M8.1)

● downtown Tokyo (Otemachi)

Observation (restored by Midorikawa et al., 2006)
Simulation (this study)



From Chapter 7 of "2009 Long-Period Ground Motion Hazard Maps"

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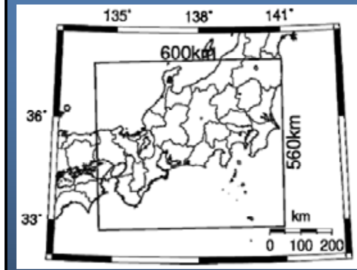
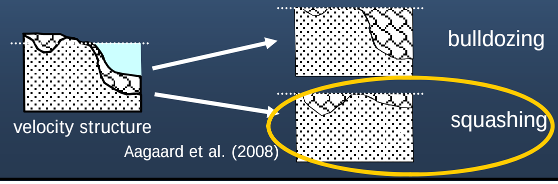
Numerical simulation of long-period ground motion



- FD code by Pitarka (1999)
- Grid Spacing
  - Horizontal: 0.25 km
  - Vertical: 0.2 km（depth 0~3km）
    0.4 km（depth 3~7km）
    0.8 km（depth 7~67km）
  - Number of Grids
    2401(EW)×2241(NS)×101(UD)
- Target Periods
  - 3.5s or longer（0.28Hz or lower)
- Computers
  - PC Cluster: 42 nodes
  - Total Memory: 120GB



Aagaard et al. (2008)

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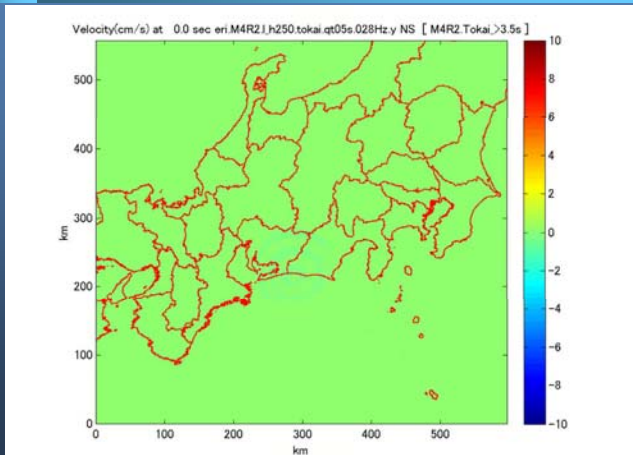
Simulation of long-period ground motion for the Tokai earthquake in Region B (NS)



Computed by the parallelized finite difference code by Pitarka (1998).

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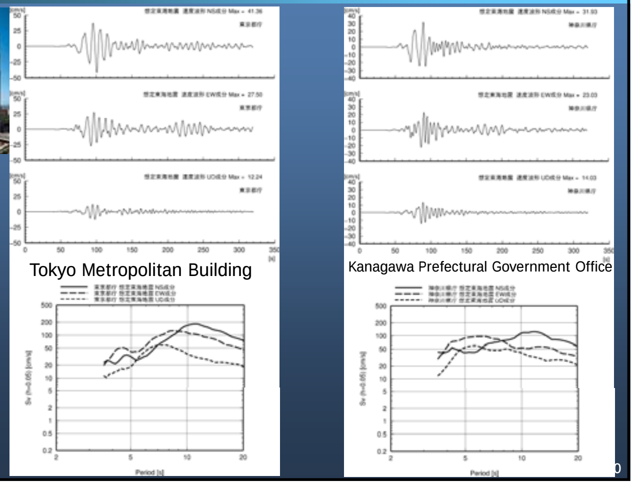
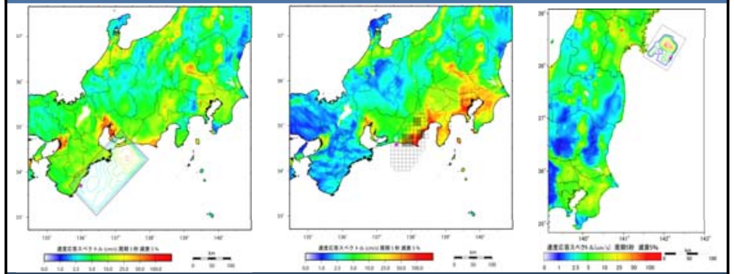
Simulated ground motion waveforms and response spectra (Tokai earthquake)



From Chapter 2 of "2009 Long-Period Ground Motion Hazard Maps"

Long-period ground motion hazard map (1)

Distribution of velocity response spectra (5 s)

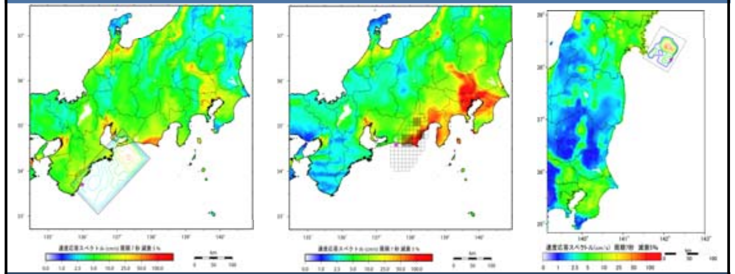


Tonankai earthquake | Tokai earthquake | Miyagi-oki earthquake

From Chapters 2, 3 and 4 of "2009 Long-Period Ground Motion Hazard Maps"

Long-period ground motion hazard map (2)

Distribution of velocity response spectra (7 s)

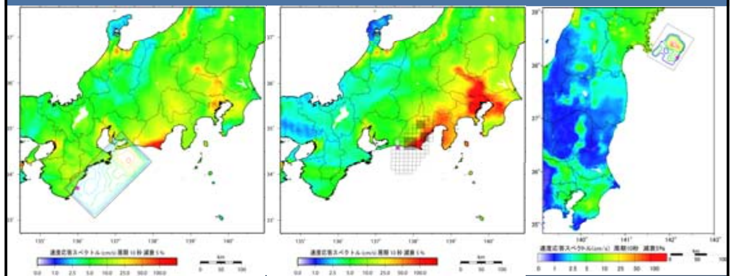


Tonankai earthquake | Tokai earthquake | Miyagi-oki earthquake

From Chapters 2, 3 and 4 of "2009 Long-Period Ground Motion Hazard Maps"

Long-period ground motion hazard map (3)

Distribution of velocity response spectra (10 s)

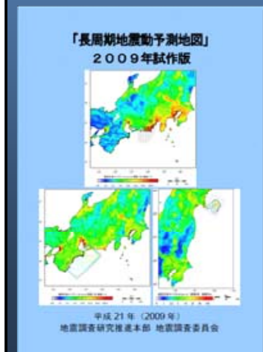


Tonankai earthquake | Tokai earthquake | Miyagi-oki earthquake

From Chapters 2, 3 and 4 of "2009 Long-Period Ground Motion Hazard Maps"

Report, press release, and TV program

Report in Japanese
http://www.jishin.go.jp/main/chousa/09_choshuki/choshuki2009.pdf
Press Release in Japanese
http://www.jishin.go.jp/main/chousa/09_choshuki/choshuki2009_kohyo090917.pdf



TV program in Japanese
http://www.nhk.or.jp/megaquake/p_highlight.html/