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

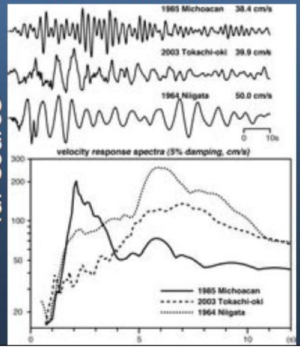
Earthquake Research Institute, University of Tokyo 東京大学地震研究所



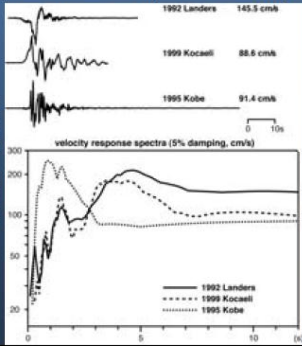
## Background in the world (1) 世界の背景 （1）

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.

遠地震源 far-source




near-fault 近地断層






## Background in the world (2) 世界の背景 （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.

メキシコ 1985 Michoacan earthquake

十勝沖 2003 Tokachi-oki earthquake

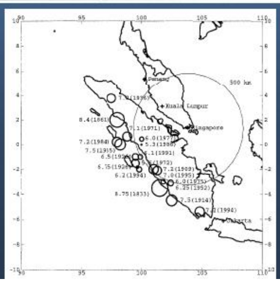


## Situation in Singapore シンガポールの状況

Singapore in the 1960's

in the 1980's

(Pan & Sun, 1995)



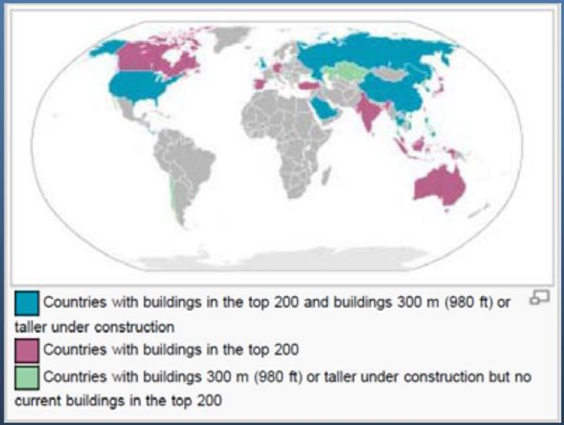
シンガポールではスマトラの巨大地震が、1980年代以降超高層ビル内で感じられる。

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

### 新興工業国への拡大




高い順200位内で300m以上ビルがある国

高い順200位以内ビルの国

300m以上のビルのある国

(from Wikipedia)



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

### 長周期地震動の高層建築居住者への影響に関する振動台実験

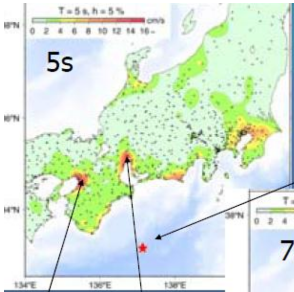

We think that the building itself should be all right but people inside are greatly affected by long-period ground motions.

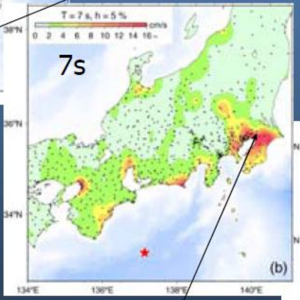
建物そのものは大丈夫だが、内部の人間は長周期地震動で大きな影響を受けるであろう。

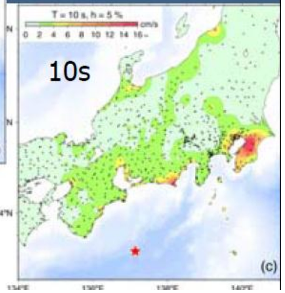


## Observational evidences of long-period ground motion (1):

### 長周期地震動の観測結果（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.

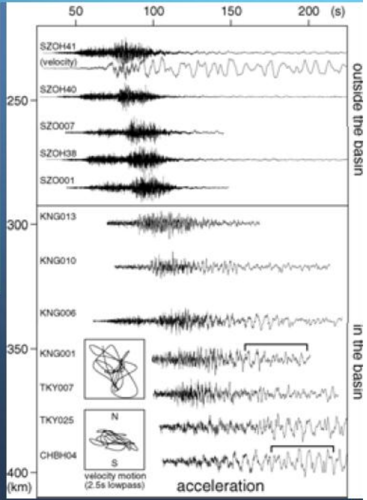
Osaka basin (Osaka)

Nobi basin (Nagoya)

Kanto basin (Tokyo)

Distributions of response spectra

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


### 長周期地震動の観測結果（2）

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.

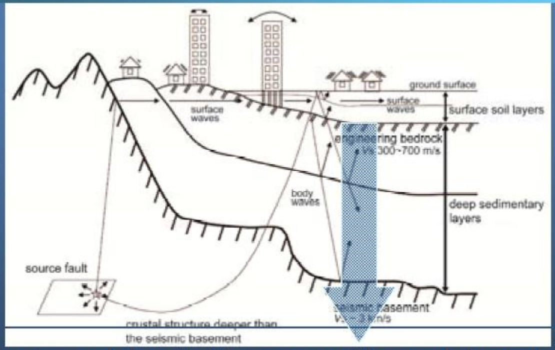
## Background in Japan　日本の背景

- 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.' 地震調査研究推進本部 地下構造モデル検討分科会（纐纈主査）
- 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.

長周期地震動のハザードマップは新しい速度構造モデルによる数値計算で作成中。



## Features (1)　特徴 （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)　特徴 （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) 3D速度構造モデル

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.

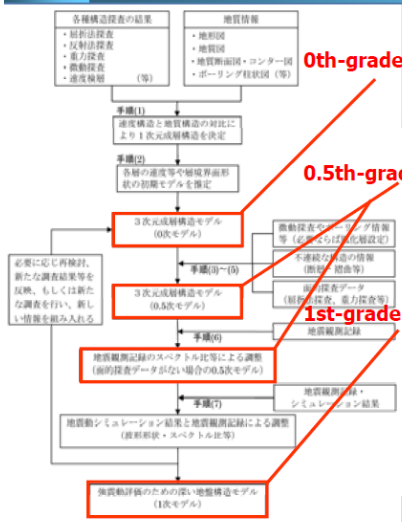
Step 5: Determine the shapes of interfaces between the layers and basement by inversions of geophysical-survey data (e.g., refraction traveltimes and gravity anomalies). In case of insufficient data, forward modeling is carried out. The depths of faults and folds in Step 4 are introduced into the inversions 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" 3次元速度構造モデルの標準手順




3次元成層構造モデル(0次モデル)

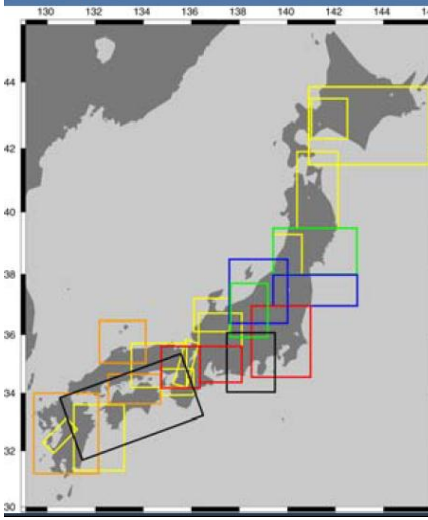
3次元成層構造モデル(0．5次モデル)

強震動評価のための
深い地盤構造モデル(1次モデル)

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



## Progress towards a Japan integrated velocity structure model 日本の統合速度構造モデルの前進に向けて



- 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.



## Progress towards long-period ground motion hazard maps 長周期地震動ハザードマップの前進に向けて

Three Wide Areas and Scenario Earthquakes 3広域とシナリオ地震

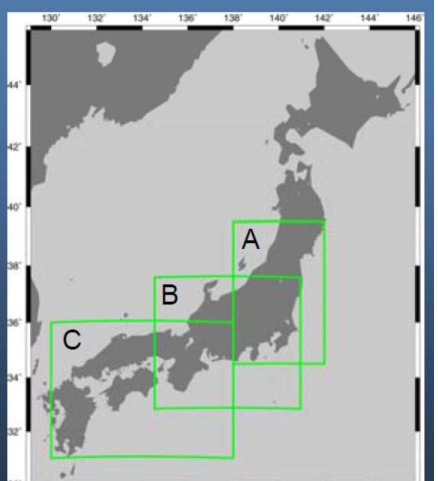
A: Miyagi-oki earthquake
B: Tokai & Tonankai earthquakes
C: Nankai earthquake

Occurrence Probability within 30 years from Jan. 1, 2008 30年以内発生確率

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

Release Date 発表日

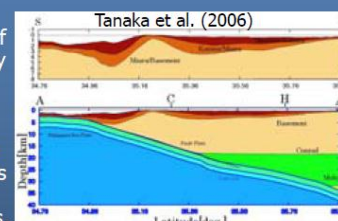
A: September, 2009
B: September, 2009
C: January, 2012

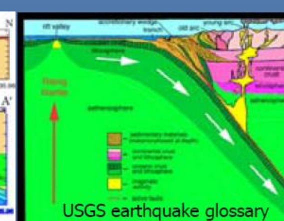




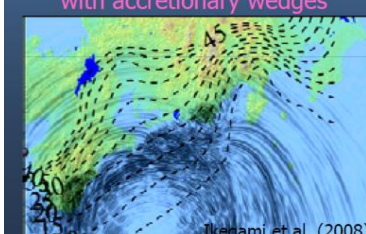

## Example of development of a velocity structure model 速度構造モデルの開発例

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

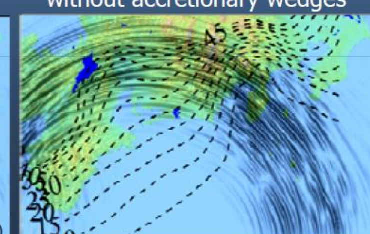



with accretionary wedges




without accretionary wedges

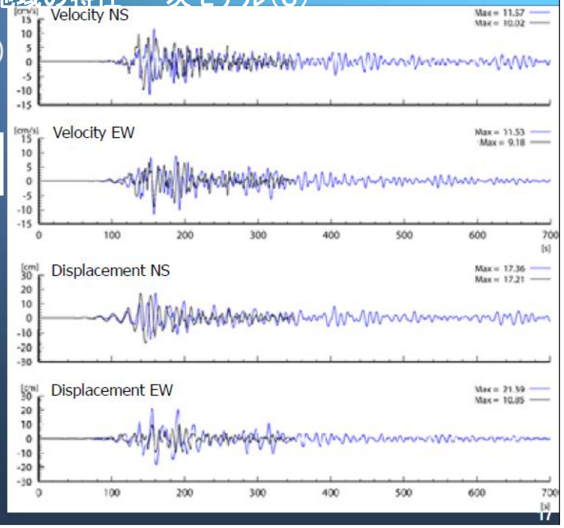


## Performance of the Region B 1st-grade model (3)
## B地域の特性　一次モデル(3)

★ 1944 Tonankai earthquake (M8.1)

● downtown Tokyo (Otemachi)

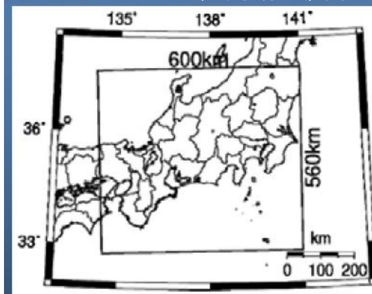
Observation (restored by Midorikawa et al., 2006)
Simulation (this study)




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



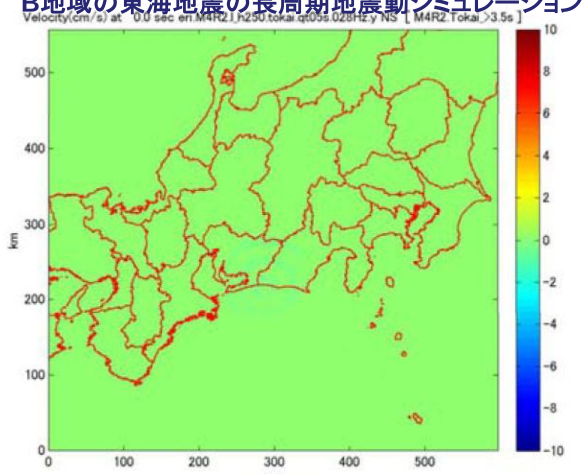
## Numerical simulation of long-period ground motion
## 長周期地震動の数値シミュレーション




- 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



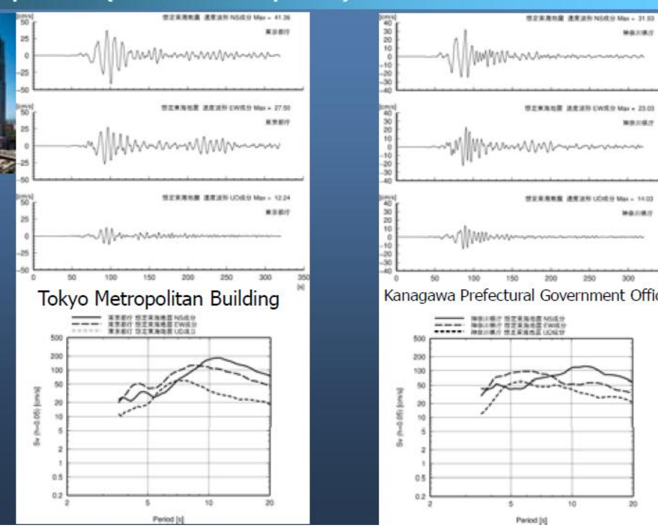

## Simulation of long-period ground motion for the Tokai earthquake in Region B (NS)
## B地域の東海地震の長周期地震動シミュレーション




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



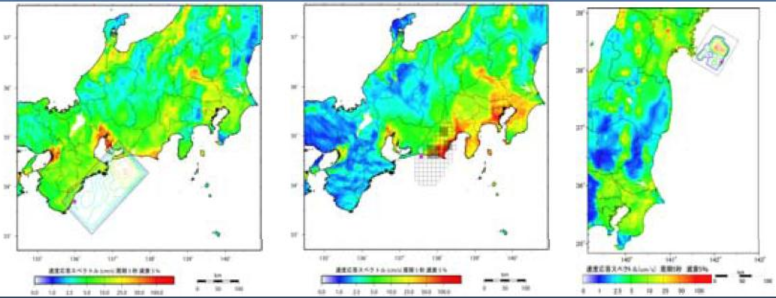
## Simulated ground motion waveforms and response spectra (Tokai earthquake) 地震波形と応答(東海地震)




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

## Long-period ground motion hazard map (1)
## 長周期地震動のハザードマップ（1）

Distribution of velocity response spectra (5 s)
速度応答スペクトルの分布（5秒）



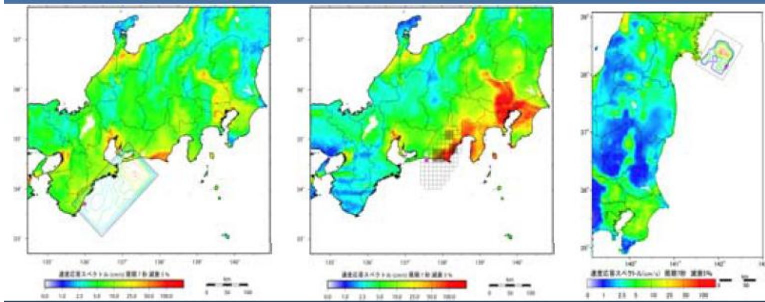
| Tonankai earthquake | Tokai earthquake | Miyagi-oki earthquake |
| --- | --- | --- |
| 東南海地震 | 東海地震 | 宮城沖地震 |

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



## Long-period ground motion hazard map (2)
## 長周期地震動のハザードマップ（2）

Distribution of velocity response spectra (7 s)
速度応答スペクトルの分布（7秒）



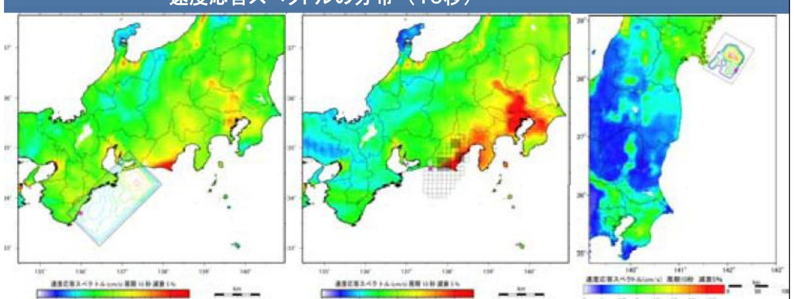
| Tonankai earthquake | Tokai earthquake | Miyagi-oki earthquake |
| --- | --- | --- |
| 東南海地震 | 東海地震 | 宮城沖地震 |

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



## Long-period ground motion hazard map (3)
## 長周期地震動のハザードマップ（3）

Distribution of velocity response spectra (10 s)
速度応答スペクトルの分布（10秒）



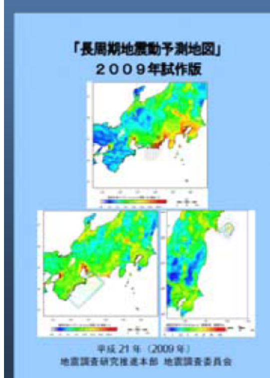
| Tonankai earthquake | Tokai earthquake | Miyagi-oki earthquake |
| --- | --- | --- |
| 東南海地震 | 東海地震 | 宮城沖地震 |

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



## Report, press release, and TV program
## 報告書、記者発表とテレビ番組

Report in Japanese 報告書
http://www.jishin.go.jp/main/chousa/09_choshuki/choshuki2009.pdf
Press Release in Japanese 日本語記者発表
http://www.jishin.go.jp/main/chousa/09_choshuki/choshuki2009_kohyo090917.pdf




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