Building damage by the 2011 off the Pacific coast of Tohoku earthquake and coping activities by NILIM and BRI collaborated with the administration

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NILIM : National Institute for Land & Infrastructure Management
BRI : Building Research Institute

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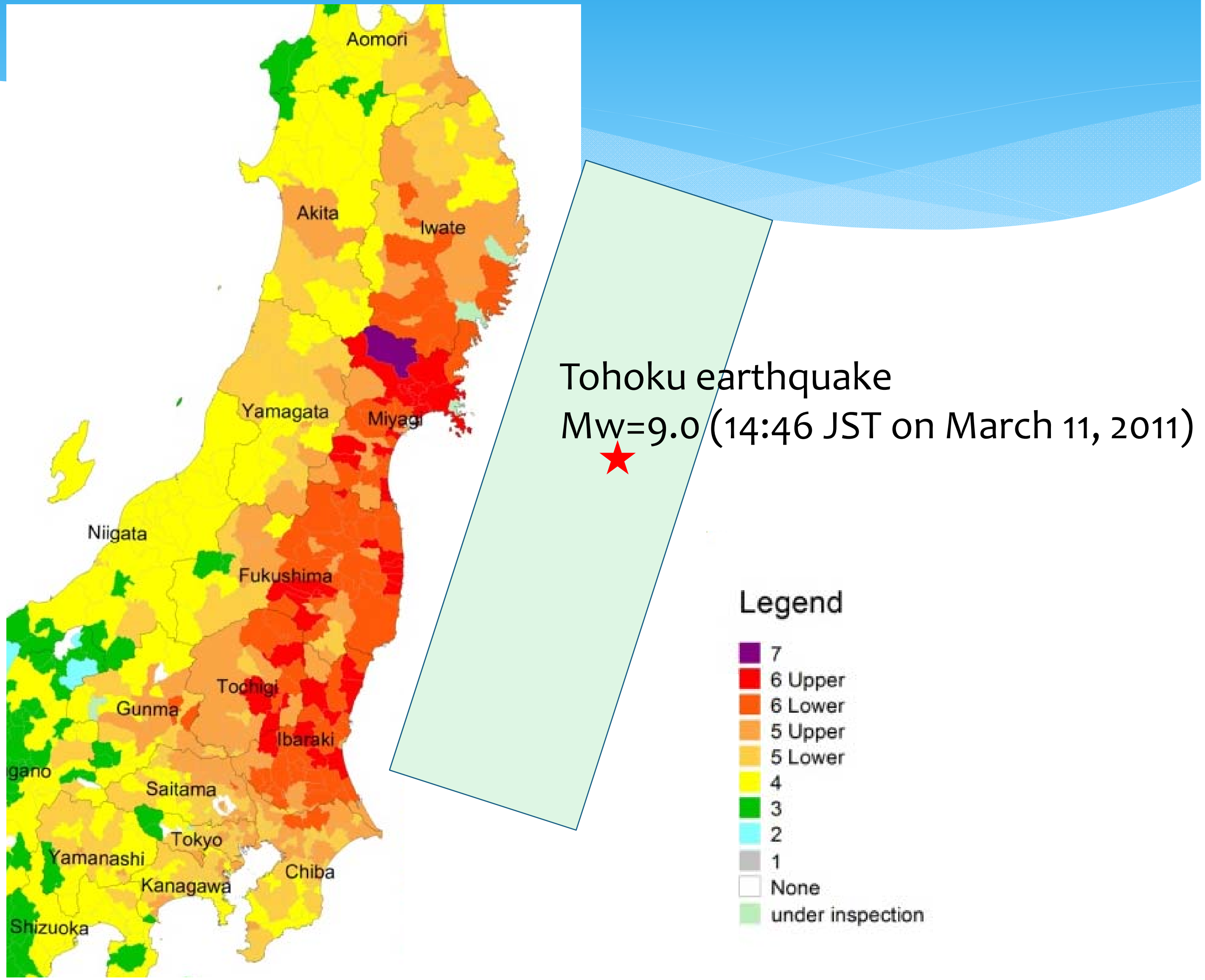
1. Outline

By Nishiyama, Isao

Field Survey

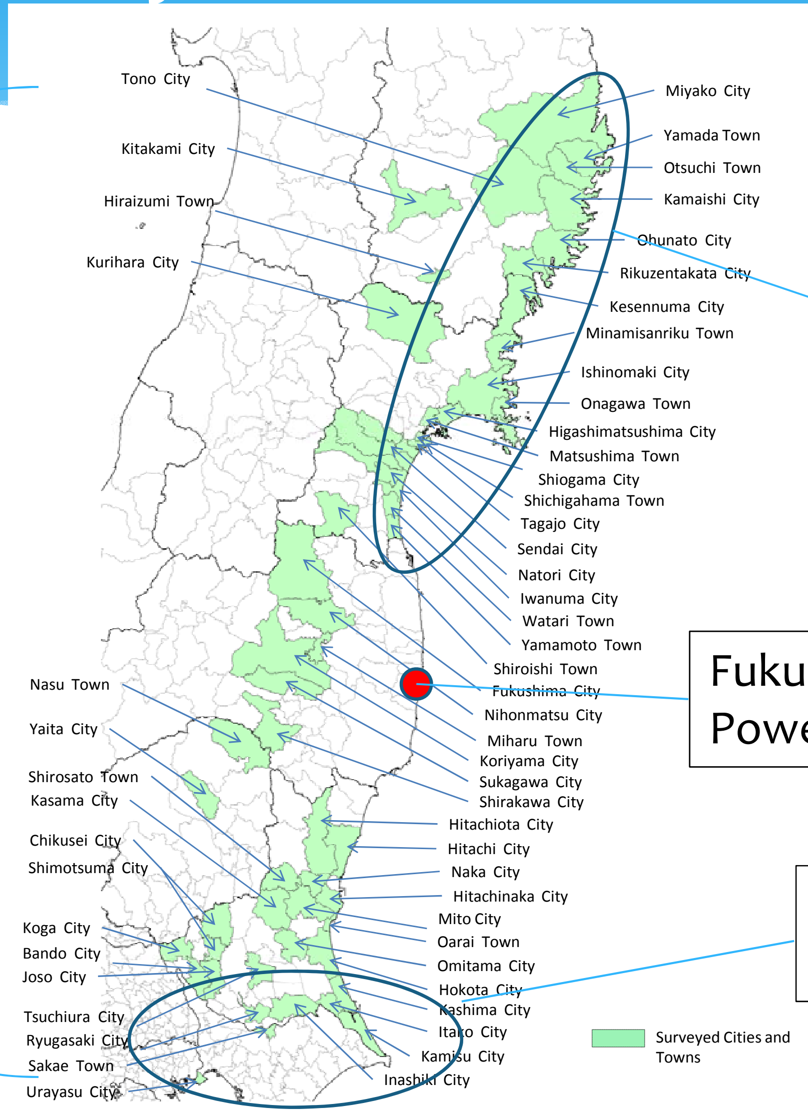
Quick Report (in Japanese) was published on May, 2011
and Summary Report (in English) will soon be available.

JMA Seismic Intensity & Hypocentral Region



Isao Nishiyama

Field Surveyed Cities and Towns



Tsunami-induced damage

Motion-induced damage

Fukushima Daiichi Nuclear Power Station

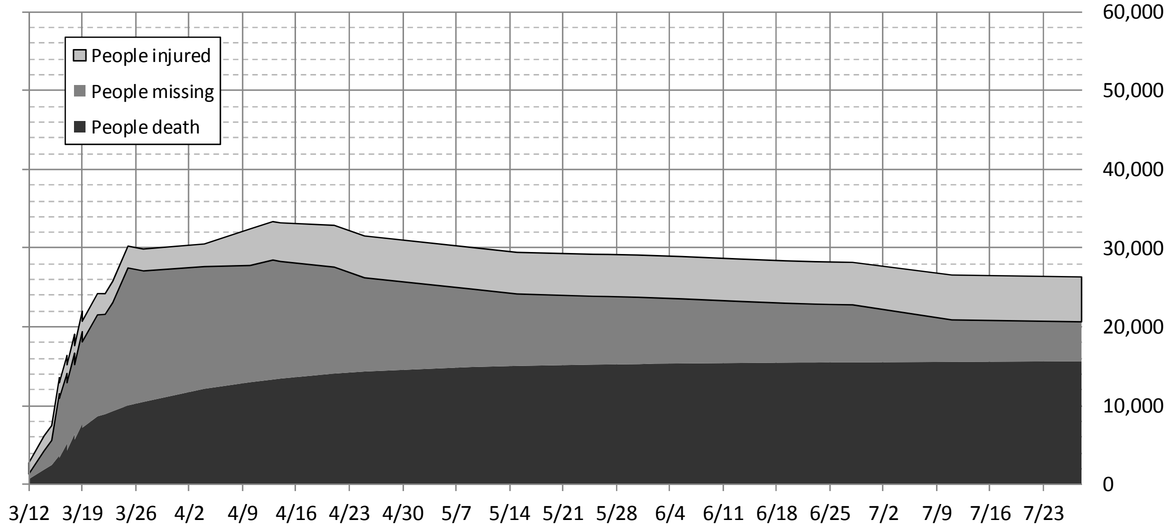
Liquefaction-induced damage of houses

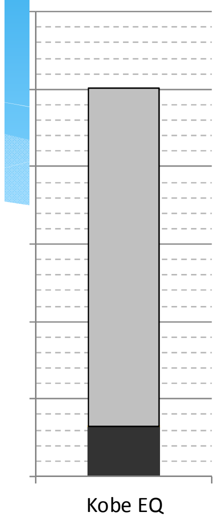
Isao Nishiyama

Surveyed Items

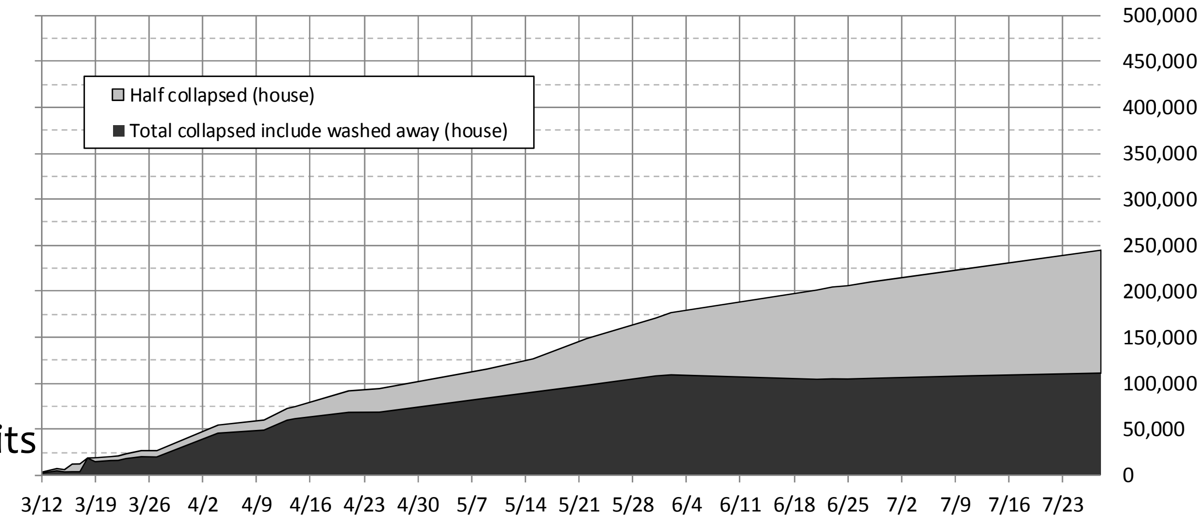
* Motion-induced damage
  * Wood houses, steel buildings, reinforced concrete buildings, residential land, non-structural elements, seismically isolated buildings,… etc.
* Tsunami-induced damage
  * Wood houses, steel buildings, reinforced concrete buildings.
* (Fire-induced damage…)

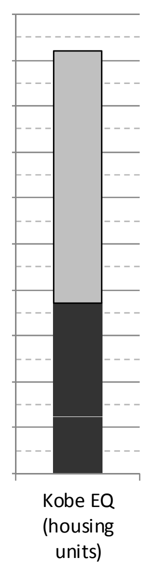
Damage Statistics (Tohoku vs. Kobe)





People Death
Tohoku: 15,700
Kobe: 6,434





Total Collapsed Buildings
Tohoku: 114,000 houses
Kobe: 186,175 housing units

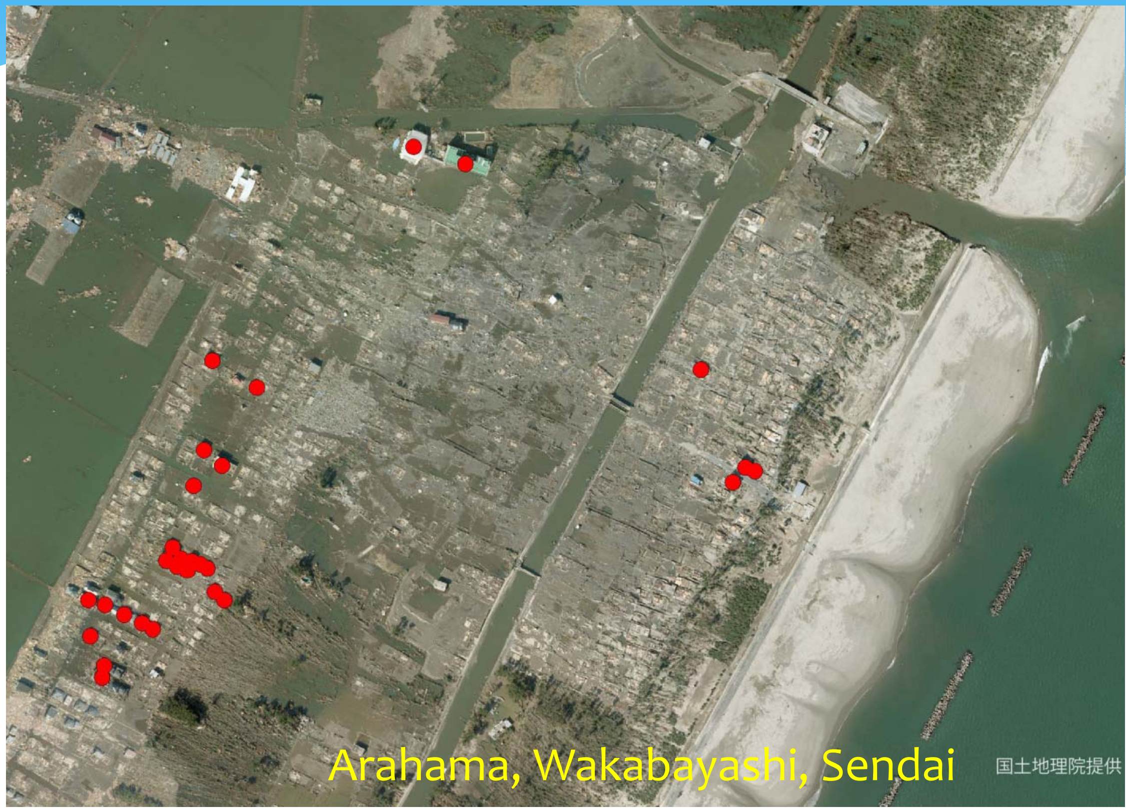
Isao Nishiyama

Coping Activities

Four Important Issues

* Tsunami Damage
* Non-structural Elements Damage, esp. Ceiling
* Long-period, Long-duration Ground Motion Effects
* Liquefaction Damage
* (Damper Damage in Seismically Isolated Building)

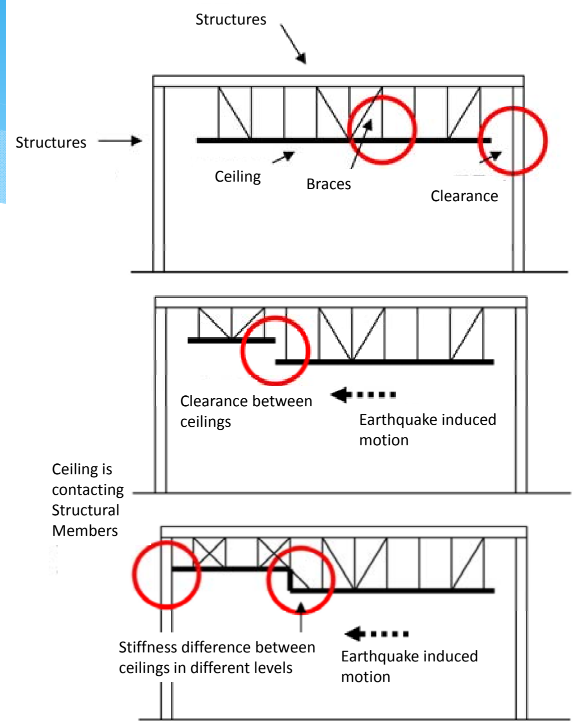
Tsunami



- Study on the design of tsunami evacuation buildings, i.e. estimation of tsunami load

More than half of the total inundation area was subjected to inundation height of 2m or less.

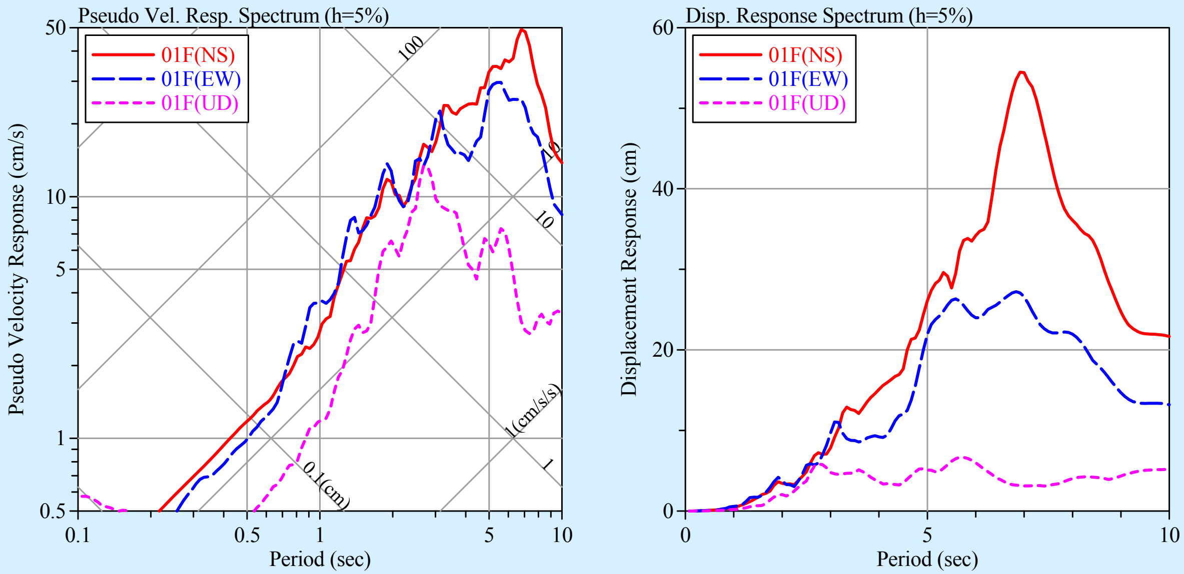
Non-structural Elements, esp. Ceiling



Previous technical advice (MLIT, 2003.10)

- Review of previous technical advice (right), and study on practical structural calculation methods

Long-period, Long-duration Ground Motion



Pseudo-velocity Displacement

Osaka prefectural government building (Sakishima)

- Tentative new proposal by MLIT and NILIM was announced for public comments Dec. 21, 2010. 3 months before Tohoku EQ.
- Background information was published in BRI.

Liquefaction

* Study on possible indication of expected performance w/wo countermeasures for residential houses (from the view of consumer protection)

(Damper in Seismically Isolated Bldg.)

* 

Fracture of Lead damper

LRB (Lead rubber bearing) ?

Countermeasures in Codes/Standards

Building Structural Codes/Standards Committee
Chaired by Tetsuo Kubo, Tokyo University
Field Survey on the Earthquake on April 21 and 22
First meeting was on June 8, second on August 18

→ **Draft of Building Structural Codes**

WG on Long-period earthquake ground motion
First meeting was on July 20

Public comments on Tentative New Proposal of countermeasures for long-period motion

Secretariat for supporting Committee and WG

TG on Building Structural Codes and Standards in general
First meeting on July 26

Collection of information by using grant-in-aid for maintenance and promotion of building standards

- 42.Effect of long-period motion on super high-rise buildings
- 21. Needs and seeds collection

Public comments or proposal of building structural codes from private

2. Building Damage due to Earthquake Ground Motions

By Fukuyama, Hiroshi

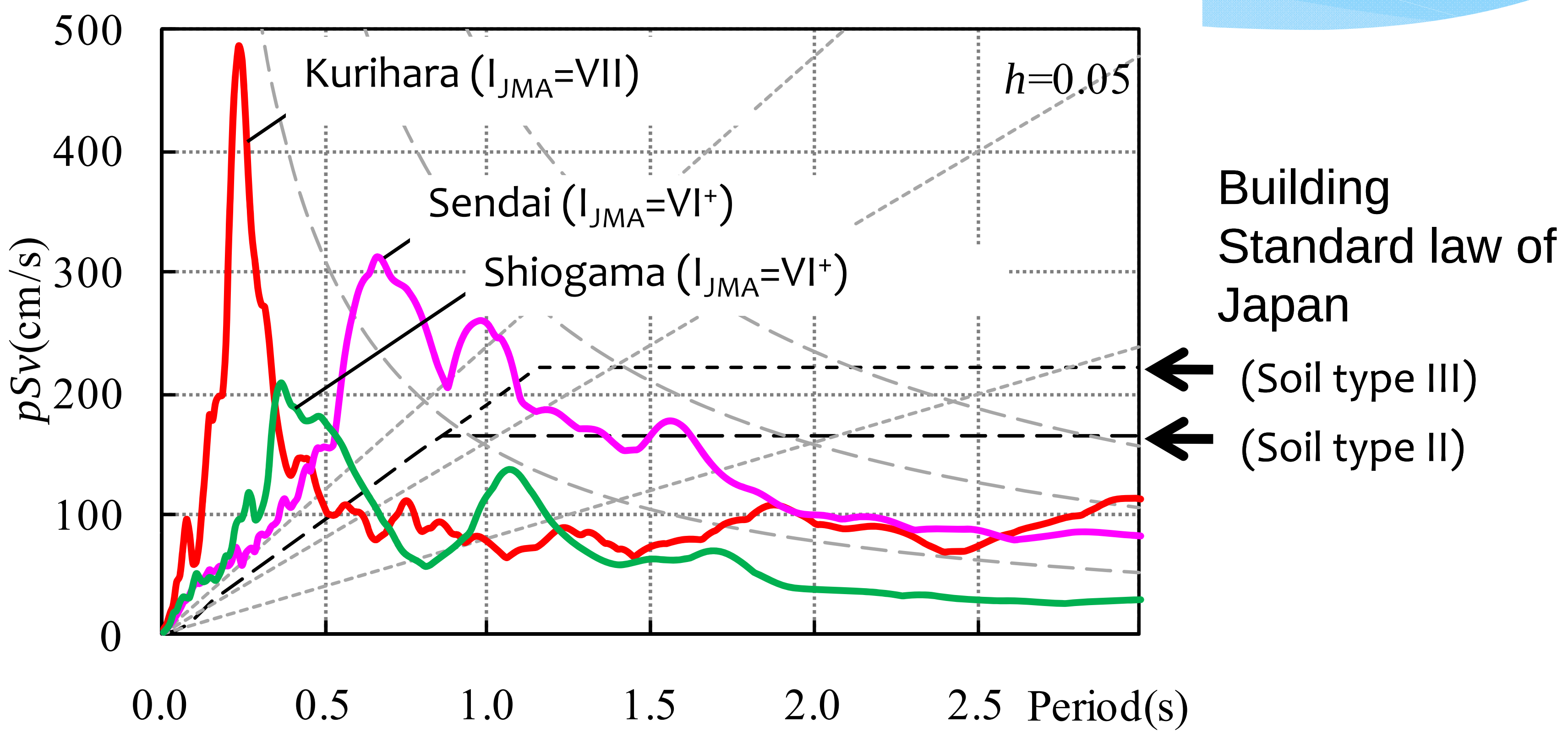
Damage to buildings caused by seismic motion <Summary>

Damage to buildings is not so severe whereas the seismic intensities were high and the disaster areas were extended to extremely large

- *Wood Structure*：Typical seismic damage was observed
- *RC Structure, Steel Structure*：Significant difference appears between before and after the new seismic design code (1981). Typical seismic damage was observed
- *Non-structural Elements*：Fall of suspended ceilings in large-scale spaces, exterior walls, and interior materials were observed
- *Residential Land*：Damage to developed grounds and sloping for residential houses were observed. Severe liquefaction damage occurred in very wide areas.

In Kurihara City, JMA seismic intensity of VII was recorded, predominant spectrum is observed in short period, i.e. less than 0.3s. But the power of spectrum in long period is lower than the limit value regulated in Building Standard Law of Japan for seismic design.

Building damage was not so significant on the whole even in the areas where seismic intensity of more than VI was recorded



Pseudo-velocity response spectrum at some K-NET observe points

Typical seismic damage to Wood Structures

Damage of houses with store (Inclination of 1st story)

Damage due to Bio-deterioration

Damage of Dozo (Japanese traditional wood storehouse coated with clay and plaster finish)

Collapse of 1st story

Collapse of 2nd story

Hiroshi Fukuyama

Typical seismic damage to RC Structures

Collapse of soft-1st story by shear failure of columns

Shear failure of non-structural walls

Pullout of anchor bolts of the exposed-type SRC column base

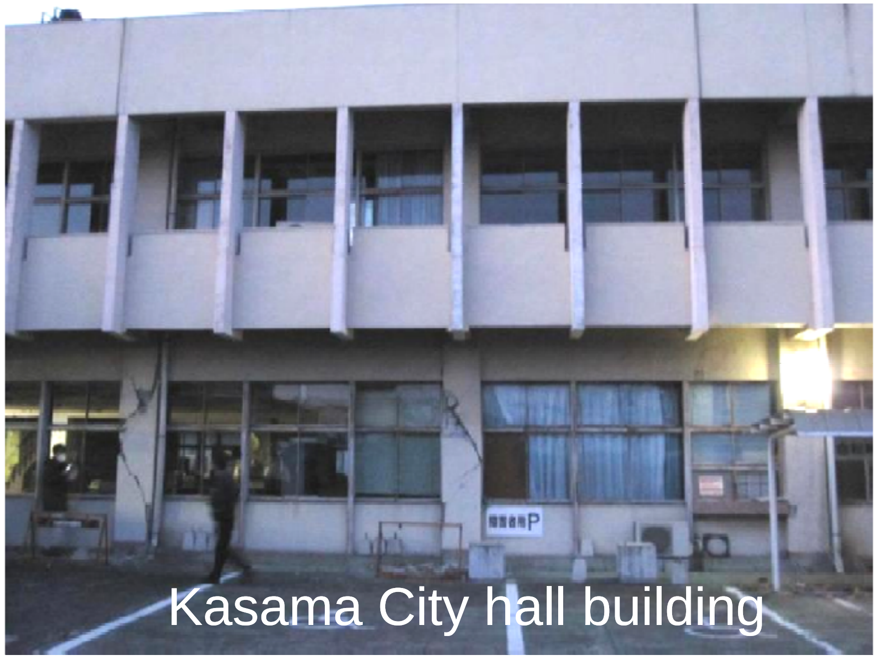
Shear failure of link-beam

Shear failure due to opening of shear wall

Typical seismic damage – RC structure (1)

• More than 10 local government office buildings designed by the old seismic code suffered from significant structural damage, shear failure of short columns and loss of axial load bearing capacity .
These building could not be used as an emergency operation center.

• Damage mitigation for functional continuity is strongly required.



Hiroshi Fukuyama

Typical seismic damage – RC structure (2)

- Most of the retrofitted buildings performed well to secure human lives by preventing collapse.

- Damage were observed in some retrofitted buildings

Typical seismic damage – RC structure (3)

Damage to non-structural walls of residential buildings retrofitted by oil damper

Courtesy of Mr. K. Watanabe of U.R.

Typical seismic damage to Steel Structures


Buckling of brace


Rupture of horizontal brace


Spalling of concrete at joint


Rupture of brace at joint


Buckling of diagonal member of latticed column


Dropping of extensive ceiling materials and exterior finish materials

Hiroshi Fukuyama

Typical seismic damage to Residential Land

Large-scale liquefaction and settled or tilted structures

Sand boiling and tilting of house

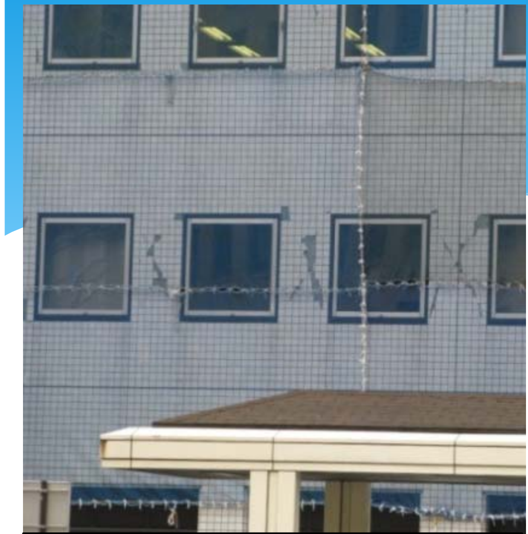
Failure of hooting caused by the ground damage

Land sliding on the slope of the developing hill

Damage of retaining wall and house movement

Hiroshi Fukuyama

Typical damage to Non-structural Elements



Cracking and spalling of tile

Failure of glass

Fall of exterior wall panels

Damage and fall of suspended ceiling

Typical damage to Seismically Isolated Buildings

Damage to cover-panels for fire protection

Damage to expansion joint

Peeled off of paint on U-shape dampers

Lead damper and crack on the surface

Hiroshi Fukuyama

Countermeasures

Most of the damage classified were observed in the previous earthquakes. Then previous revising of codes (or handbook) are effective for preventing the damage.

However, fall of suspended ceilings in large-scale spaces, liquefaction damage, and damper damage in seismically isolated building are forced to take prompt measures.

Detailed investigation on damage to retrofitted buildings and government office buildings are now on-going.

3. Damage to Buildings in Inundation Areas due to Tsunami

By Okuda, Yasuo

Purpose of Investigation

The purpose of this investigation is

1) To understand an overview of buildings damaged by tsunami,
2) To obtain basic data and information required to evaluate mechanisms for causing damage to the buildings
3) To contribute to tsunami load and tsunami-resistant designs for buildings such as tsunami evacuation buildings

by means of

1) collecting building damage cases by tsunami
2) classifying the damage patterns for different structural categories,
3) making a comparison between the calculated tsunami force acting on buildings and the strength of the buildings

Investigation Team for Tsunami Damage

NILIM: 8 members

Isao Nishiyama
Akiyoshi Mukai
Ichiro Minato
Atsuo Fukai
Shuichi Takeya
Hitomitsu Kikitsu
Hiroshi Arai
Tomohiko Sakata

BRI: 19 members

Juntaro Tsuru
Masanori Iiba
Wataru Gojo
Yasuo Okuda
Bun-ichiro Shibazaki
Hiroto Kato
Takashi Hasegawa
Norimitsu Ishii
Haruhiko Suwada
Toshikazu Kabeyasawa
Nobuo Furukawa
Shoichi Ando
Hiroshi Fukuyama
Taiki Saito
Koichi Morita
Tsutomu Hirade
Tadashi Ishihara
Yushiro Fujii
Yasuhiro Araki

Summary of Damage in Inundation Area Due to Tsunami

1. about **106,000** houses were completely destructed or missing **mainly in Iwate, Miyagi and Fukushima prefectures**
2. about 100,000 houses were partially damaged
3. about 106,000 houses were below partially damaged

Total: about 370,000

Prefecture	City, Town, Village	Human Damage: Dead	Human Damage: Missing	Human Damage: Injury	House Damage: Complete Destruction or Missing	House Damage: Partial Damage	House Damage: Below Partial Damage	House Damage: Fire
Aomori	Hachinohe	1	1	17	250	769		2
	Hashikami	0	0	0	12	8	1	
	Total	1	1	17	262	777	1	2
Iwate	Hirono	0	0	0	10	16	5	
	Kuji	2	2	8	65	210		
	Noda	38		17	309	169		1
	Hudai	0	1	1				
	Tanohata	14	19	8	225	45	4	
	Miyako	420	124	33	3,669	1,006	176	6
	Yamada	597	256	Unknown	2,789	395	120	2
	Otsuchi	796	653	Unknown	3,677			2
	Kamaishi	881	299	Unknown	3,188	535	120	
	Ofunato	331	118	Unknown	3,629		Unknown	2
	Rikuzentakata	1,546	569	Unknown	3,159	182	27	
	Total	4,625	2,041	67	20,720	2,558	452	13
Miyagi	Kesen-numa	1,004	410	Unknown	8,533	2,313	3,248	8
	Minamisanriku	550	437	Unknown	3,167	144	Unknown	5
	Onagawa	535	414	2	2,939	337	640	5
	Isinomaki	3,153	890	Unknown	19,065	3,354	10,199	23
	Higashimatsushima	1,044	104	Unknown	4,589	4,672	2,471	1
	Matsushima	2	0	37	213	1,321	1,184	2
	Rifu	1	1	1	59	508	1,732	
	Shiogama	20	1	10	682	2,784	3,973	8
	Shichigahama	66	6	Unknown	729	460	1,067	
	Tagajo	188	3	Unknown	1,662	2,993	5,097	15
	Sendai	704	33	2,276	19,922	41,344	56,347	39
	Natori	911	82	Unknown	2,786	922	8,060	12
	Iwanuma	183	1	293	720	1,545	2,403	1
	Watari	256	5	44	2,459	1,032	1,985	3
	Yamamoto	670	23	90	2,200	1,042	1,086	2
	Total	9,287	2,410	2,753	69,725	64,771	99,492	124
Fukushima	Shinchi	107	3	3	548	Unknown		
	Soma	454	5	71	1,049	643	3,092	
	Minamisoma	633	38	59	4,682	975		
	Namie	141	43					
	Futaba	29	6	1	58	5		
	Okuma	73	1		30			
	Tomioka	19	6					
	Naraha	11	2	5	50			
	Hirono	2	1		Unknouwn	Unknown		
	Iwaki	308	39	4	6,585	18,931	21,800	3
	Total	1,777	144	143	13,002	20,554	24,892	3
Ibaraki	Kitaibaraki	5	1	188	339	1,569	5,745	3
	Takahagi	1		19	131	728	3,213	
	Hitachi			166	403	3,016	11,229	4
	Tokai	4		5	56	104	3,150	2
	Hitachinaka	2		27	79	720	5,863	1
	Oarai	1		6	10	268	1,087	
	Hokota			15	96	524	4,863	3
	Kajima	1			368	1,726	2,567	4
	Kamisu			6	139	1,660	3,011	3
	Total	14	1	432	1,621	10,315	40,728	20
Chiba	Choshi			19	23	105	1,938	
	Asahi	13	2	12	336	931	2,358	
	Total	13	2	31	359	1,036	4,296	0
Sum Total		15,717	4,599	3,443	105,689	100,011	169,861	162

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Classification of Damage Patterns Reinforced Concrete Buildings
(1) Collapse of first floor

A case where column capitals and bases on the first floor in a building were subject to flexural failure and subsequently to story collapse was seen in two-story buildings.

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(2) Overturning

Overturning was observed in 4-story or lower buildings. In all overturned buildings, the maximum inundation depth exceeded their height. Overturning types include building that felt sidelong and buildings that turned upside down.

(3) Movement and washed away

Most of the overturned buildings were moved from their original positions. It is estimated that large buoyancy acted on the buildings. Moved and overturned buildings left no dragged traces on the ground.

(4) Tilting by scouring

When tsunami acted on a building, a strong stream was generated around the corner of the building, resulting in many large holes on the ground that were bored by scouring. In one case, a building on mat foundation fell into a hole bored by scouring.

(5) Fracture of wall

In one damaged building, a 300 mm-thick shear wall with double layer bar arrangement and a support span of more than 10 m and without no 2-story floor was bent inside by a tsunami wave pressure.

(6) Debris impact

Debris impact was seen in most of the non-structural members such as window and ceiling materials. The number of cases of clear damage to skeletons was not large, but in one observed case, a multi-story wall in an apartment house was probably bored by debris impact .

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Classification of Damage Patterns Steel buildings (1,2) Movement and washed away

Debris impact was seen in most of the non-structural members such as window and ceiling materials. The number of cases of clear damage to skeletons was not large, but in one observed case, a multi-story wall in an apartment house was probably bored by debris impact .

(3) Overturning

One case, in which a whole building including foundation is overturned, was confirmed. Most of the ALC panels of claddings were left.

(4) Collapse

Damage cases of skeleton collapse include story collapse of the first floor in a 2-story steel building and partial collapse of a warehouse on the coast.

(5) Large residual deformation

Slight tilting was often observed in steel buildings with only a skeleton left. In one case, a gabled roof frame building did not collapsed despite large residual deformation.

(6) Full fracture and washed away of cladding and internal finishing materials

Cladding materials such as ALC panel were almost fully fractured and washed away, and a steel frame as a skeleton was left. This case was often seen.

Damage to wood houses (1)

In the case of a maximum inundation depth more than about 6 m (equivalent to a height of eaves of 2-story wooden house), the number of 1-story and 2-story Wood Houses that remained was almost zero.

In the case of a maximum inundation depth of about 1 m, most of wood houses remained.

Damage to wood houses (2)

A tsunami wave force was reduced possibly due to many openings in the direction affected by tsunami or on the whole plane, or a wooden house remained despite washout of columns and external walls in the corner of the building.

Database for Investigated Buildings

Outer dimensions of about 100 buildings and dimensions of their skeletons were measured in the site investigation.

Building name, address, purpose, construction year, designation as tsunami evacuation building, structure category, number of stories, outer dimension, distance from seacoast (river), GPS position, altitude, surrounding circumstances, damage situations, etc., were included in the database.

建物番号	RT-12			調査日	2011年4月6日
名称	診療所				
所在地	陸前高田市高田町馬場前			建設年	不明
用途	病院・診療所			津波避難ビル	指定なし
構造種別	S造	（ラーメン構造）			
建物規模	階数	3 階 （地下 階）		高さ：	9.6 m
	平面寸法	21.5 m × 7 m			
建物位置	海岸からの距離	約1200 m	標高	5 m (GPS)	
	立地条件	陸前高田駅前交差点近く。平坦な市街地			
最大浸水深		9 m	周辺建物の痕跡より		
津波後の状況	建物の状態	原位置に残存	1×5スパン、外装材が脱落しているが躯体に損傷は見られない		
	躯体の被害	被害なし			
	非構造部材の被害	被害あり	外装材の脱落		
備考					

- 外装材は、ほぼ全て剥落している
- 1階柱□-300x300、桁行梁H-300x150x6.5x9、梁間梁H-396x199x7x11
- 津波作用面の反対側に隣接するRC造2階建て躯体の被害は軽微であった

写真1　建物外観

写真2　建物内部

写真3　建物の柱梁部材

写真4　隣接するRC建物

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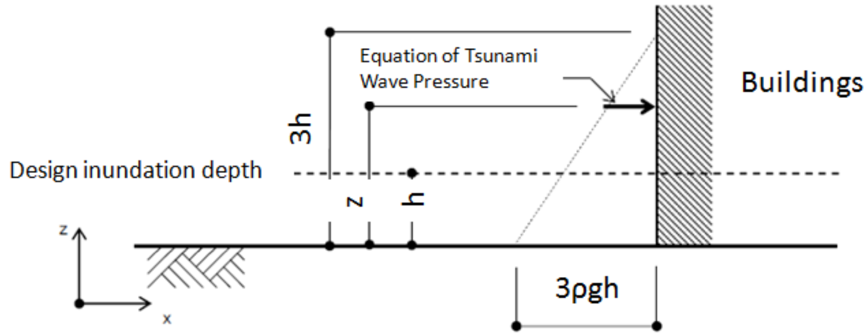
Discussion on Guidelines for Tsunami Evacuation Buildings by the Cabinet Office, Japan

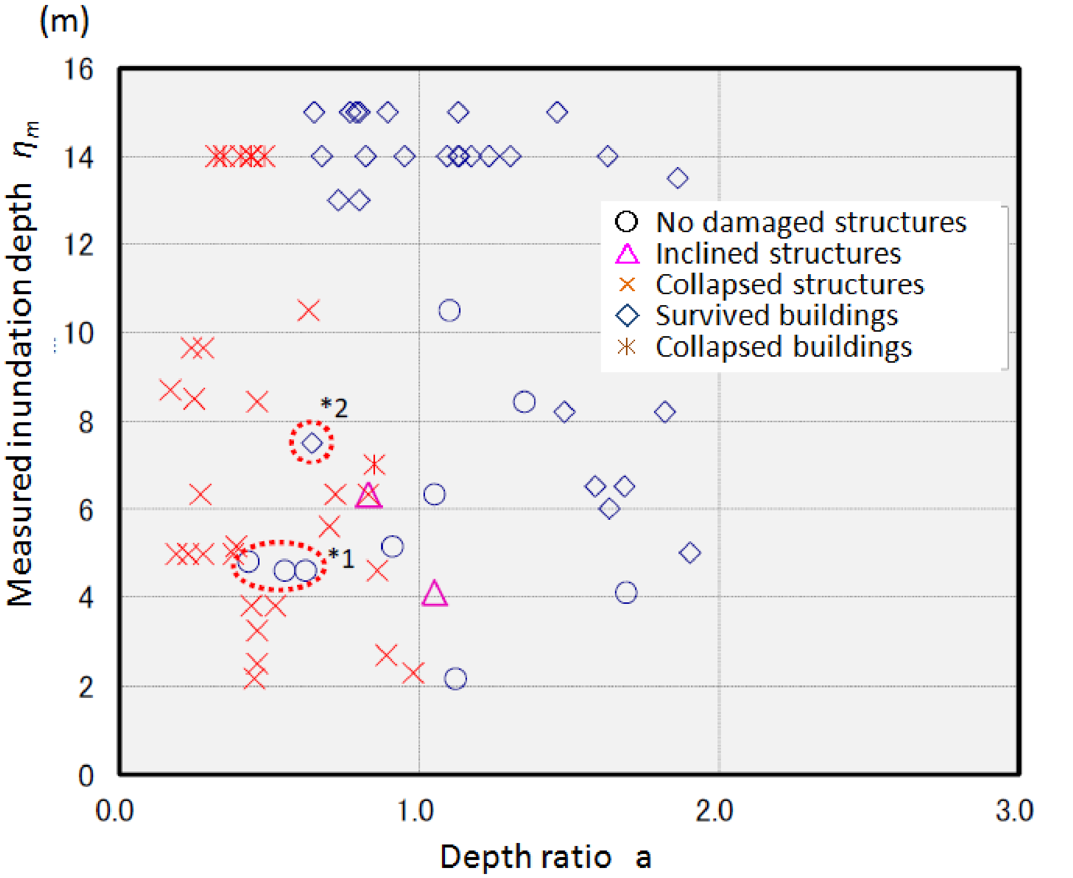


Equation of Tsunami Wave Pressure: $q_x = \rho\, g\, (3h - z)$ (1)

q_x: design tsunami wave pressure (kN/m^2)
ρ: density of water (t/m^3)
g: gravitational acceleration (m/s^2)
h: design inundation depth (m)
z: height from the ground ($0 \leqq z \leqq 3h$) (m)

In the Cabinet Office guidelines, the design tsunami load for the tsunami evacuation buildings was adopted as the tsunami wave pressure eq. (1), hydrostatic pressure of 3 times design inundation depth, based on the maximum envelope of the experimental result in Japan.

Damage Situations of Buildings and Structures with Some Obstacles for Tsunami Effect



A depth ratio is defined as eq. (2).

$$a = \frac{\eta_e}{\eta_m} \quad (2)$$

a : depth ratio

η_e : depth of the hydrostatic pressure equivalent to the strength of the buildings and structures (m)

η_m : measured inundation depth (m)

This figure plots damage situations of buildings and structures with some obstacles for tsunami effect for a and η_m. A boundary line of damage situations of buildings and structures can be drawn at the depth ratio a =1 where η_m<10m.

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Conclusions

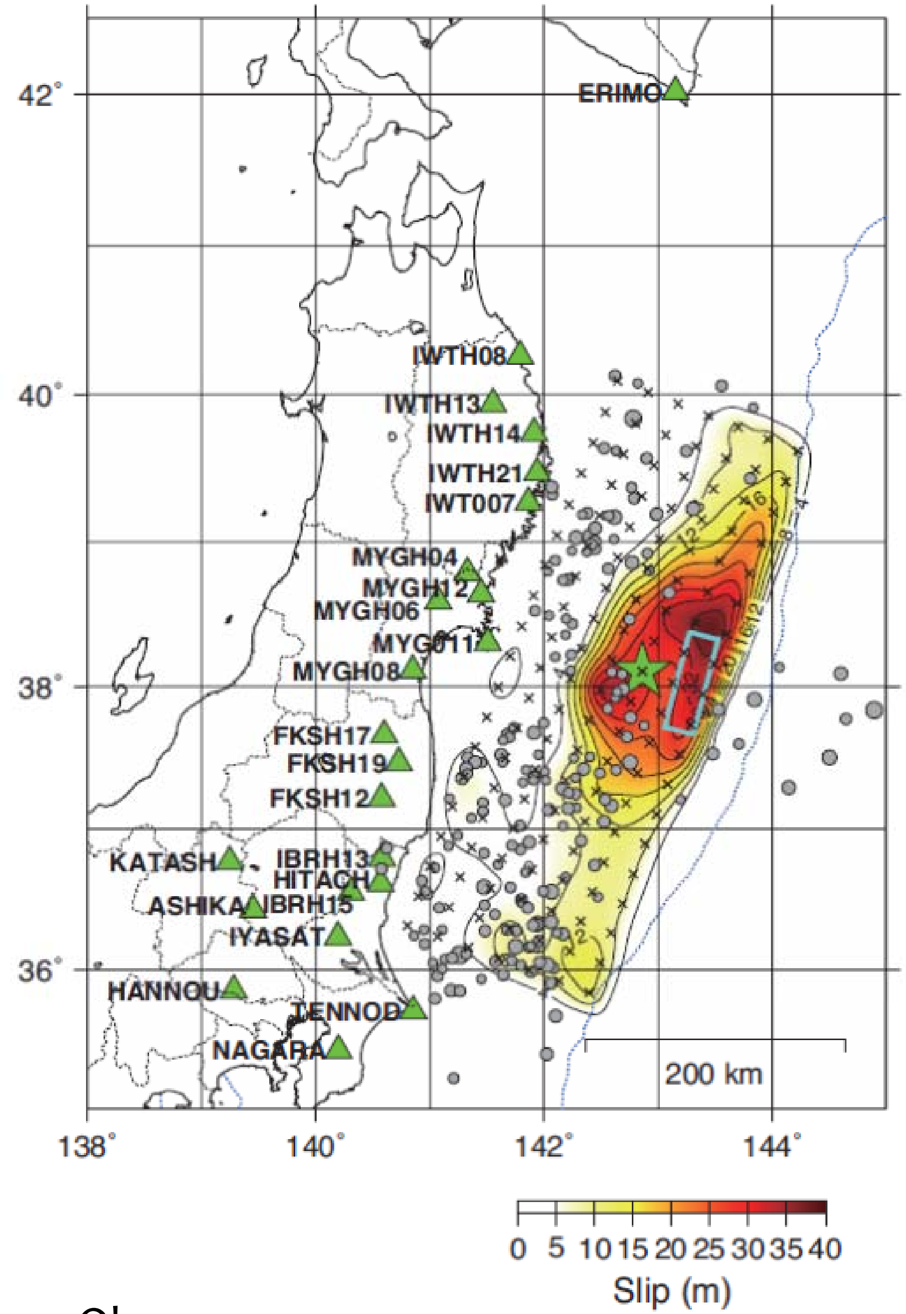
This section's conclusions are as follows;

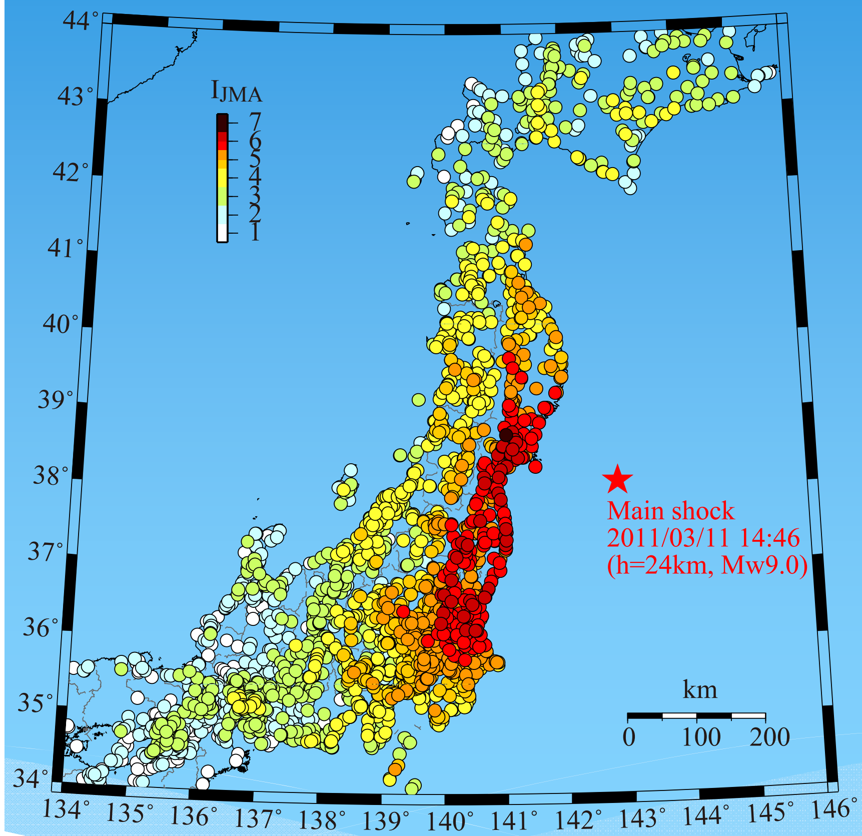
1) The damage patterns for different structural categories were classified and the factors that had caused various types of damage were briefly discussed.
2) The database of the investigated buildings and structures was made.
3) Based on the database, we plotted the damage situations of the investigated buildings and structures for the measured inundation depth and the depth ratio. A boundary line of damage situations of buildings and structures can be drawn at the depth ratio a =1 where η_m <10m.

4. Ground Motions of the Tohoku earthquake and Recent Activity on Long-period Motions for Design of Building Structures

By Okawa, Izuru

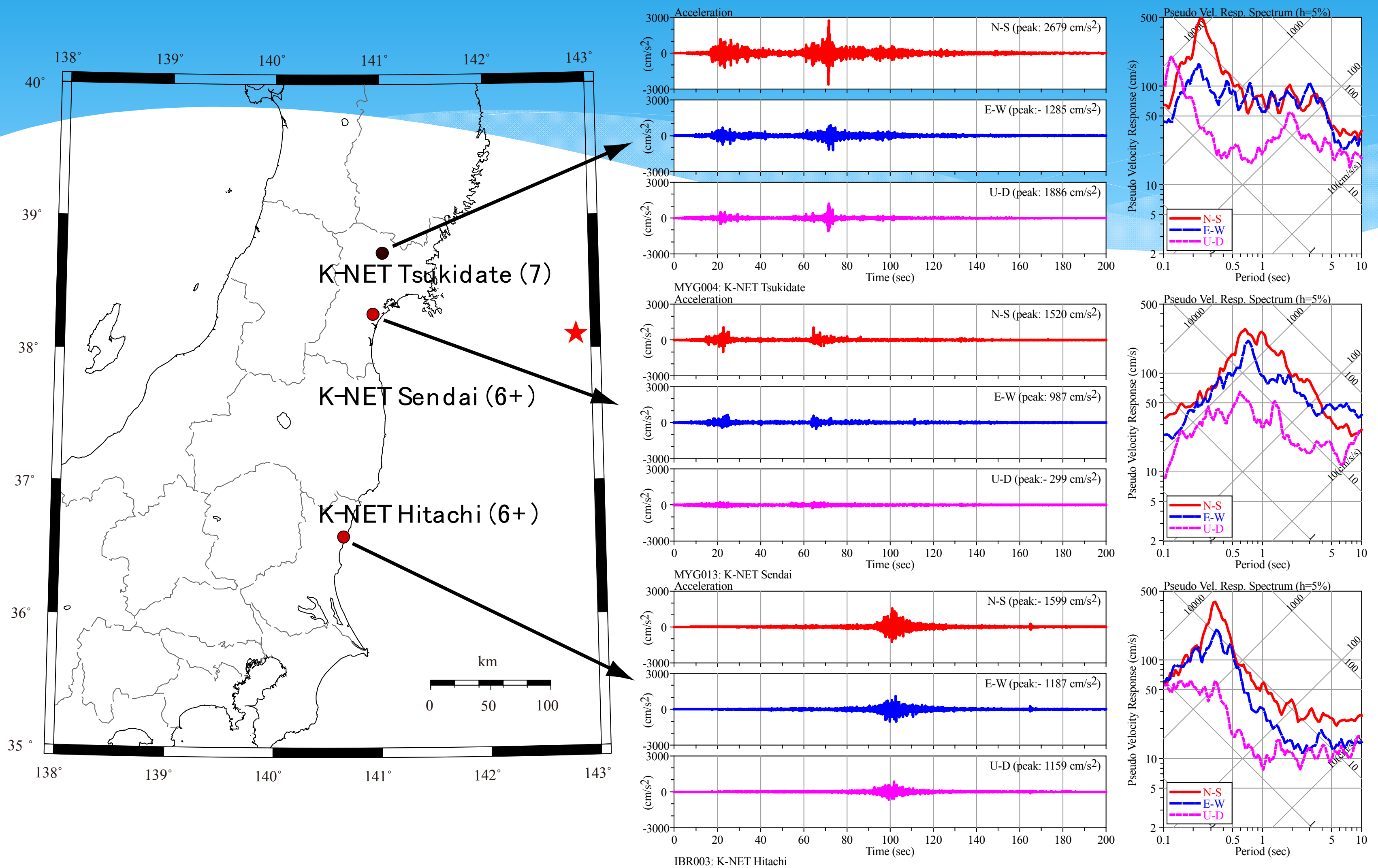
The 2011 off the Pacific coast of Tohoku Earthquake





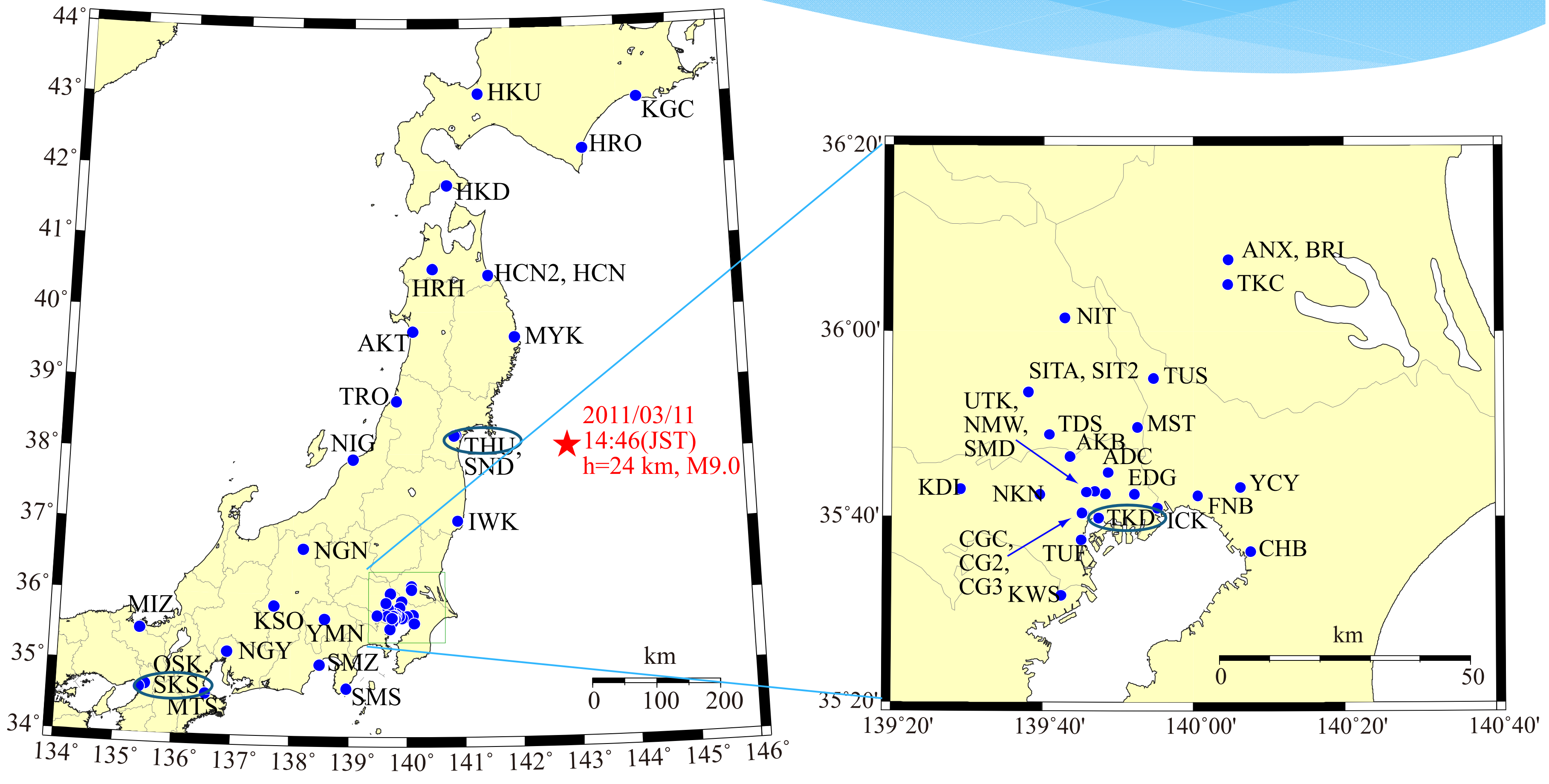
Izuru Okawa

Examples of observed motions



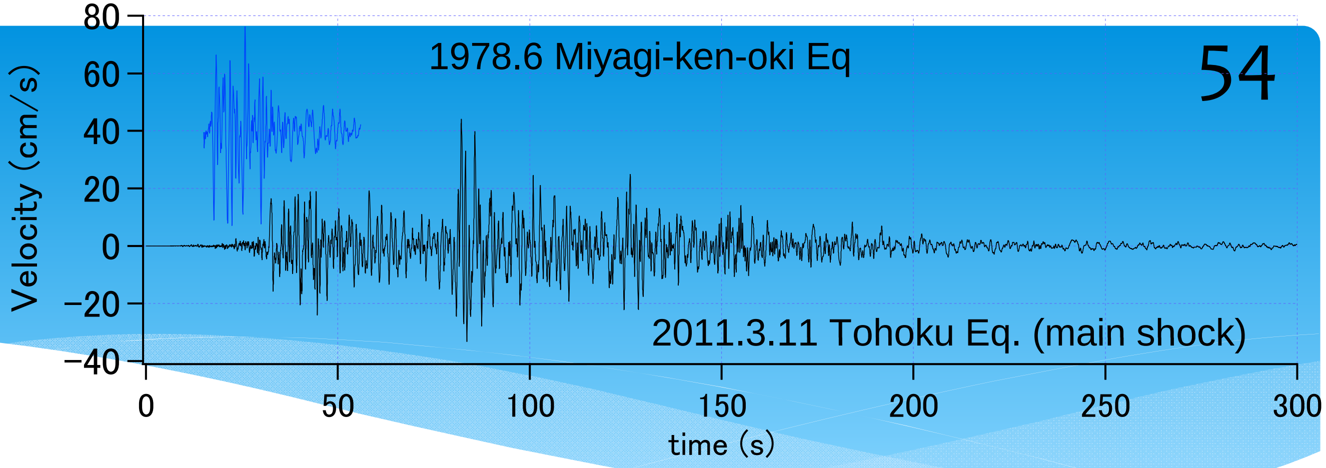
Izuru Okawa

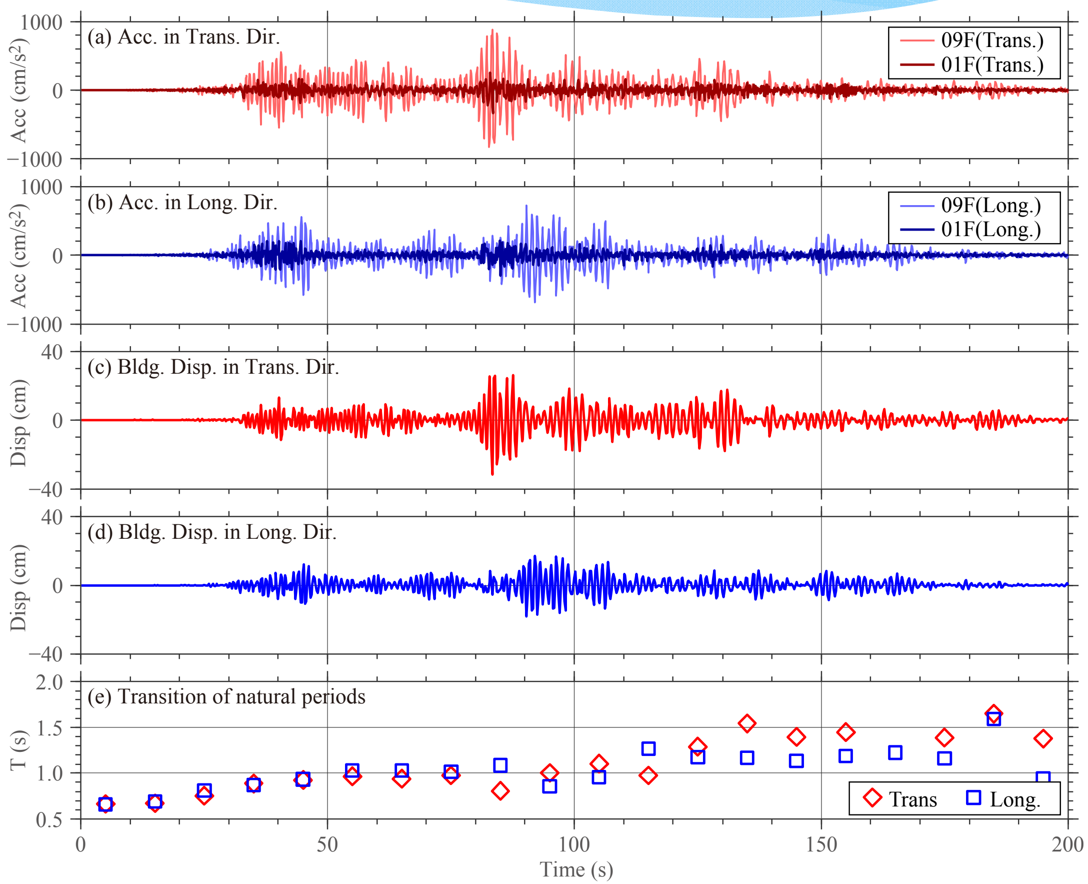
BRI Strong motion observation network (Instrumentation in Buildings)



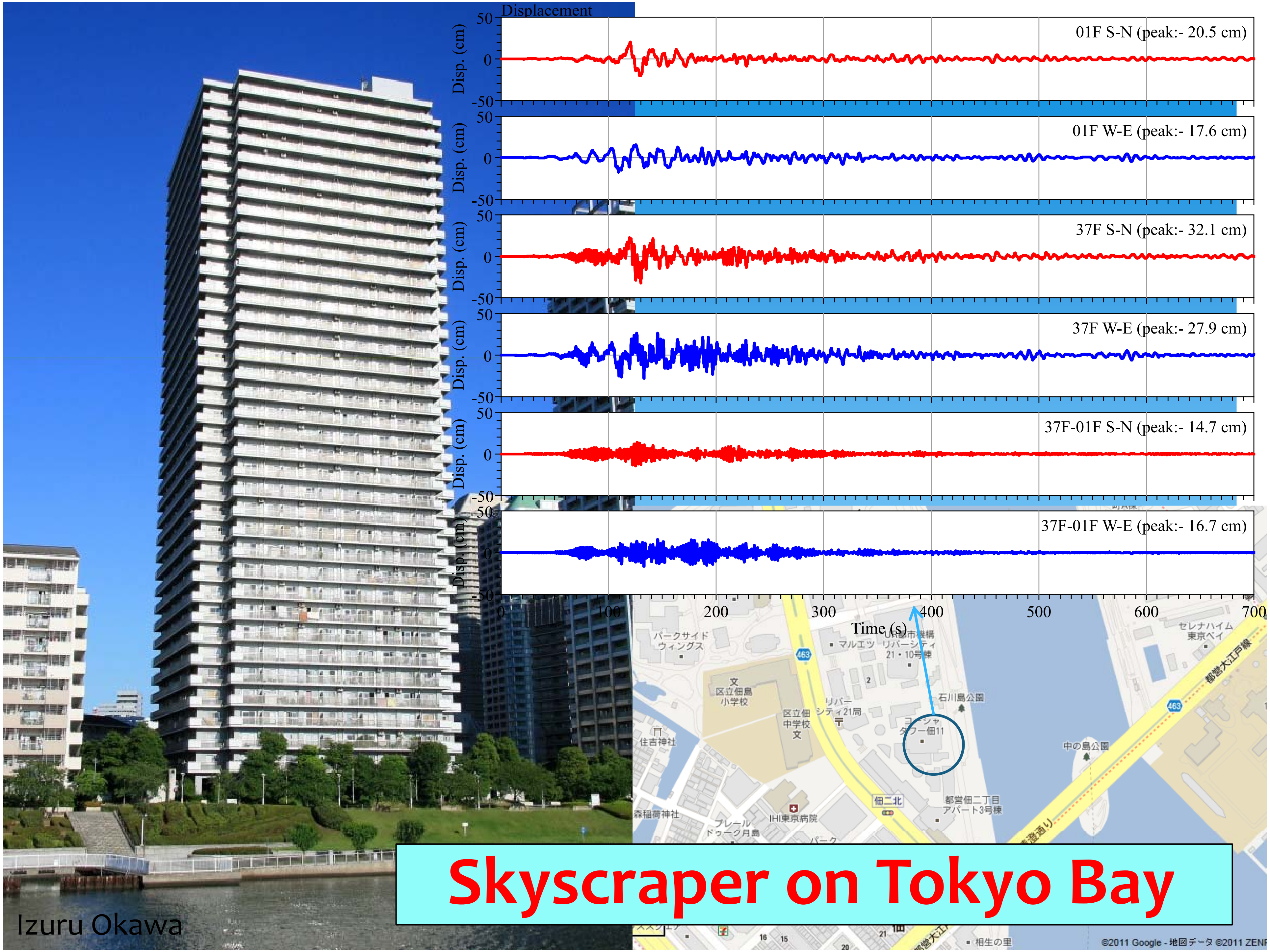
Izuru Okawa

Tohoku university





Izuru Okawa



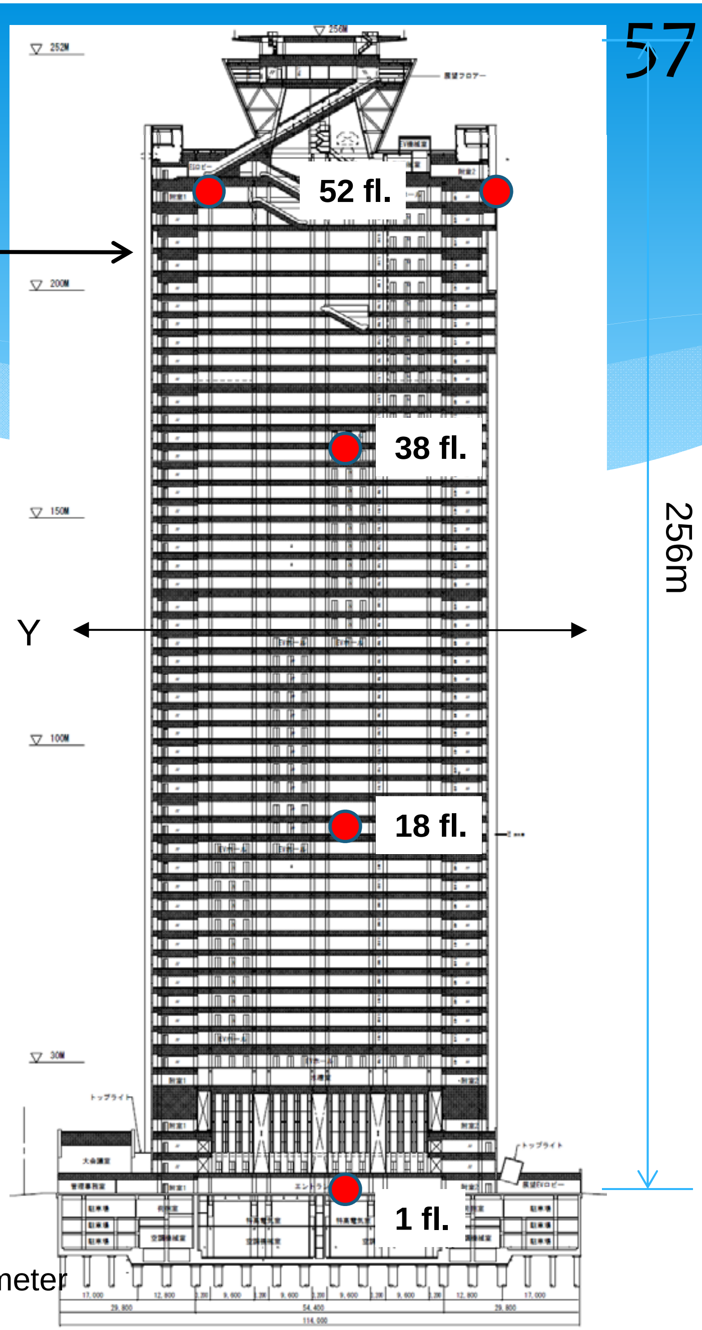
Displacement
01F S-N (peak:- 20.5 cm)
01F W-E (peak:- 17.6 cm)
37F S-N (peak:- 32.1 cm)
37F W-E (peak:- 27.9 cm)
37F-01F S-N (peak:- 14.7 cm)
37F-01F W-E (peak:- 16.7 cm)
Disp. (cm)
50
0
-50
0
100
200
300
400
500
600
700
Time (s)
石川島公園
中の島公園
住吉神社
IHI東京病院
都営大江戸線
©2011 Google - 地図データ ©2011 ZENR
Skyscraper on Tokyo Bay
Izuru Okawa

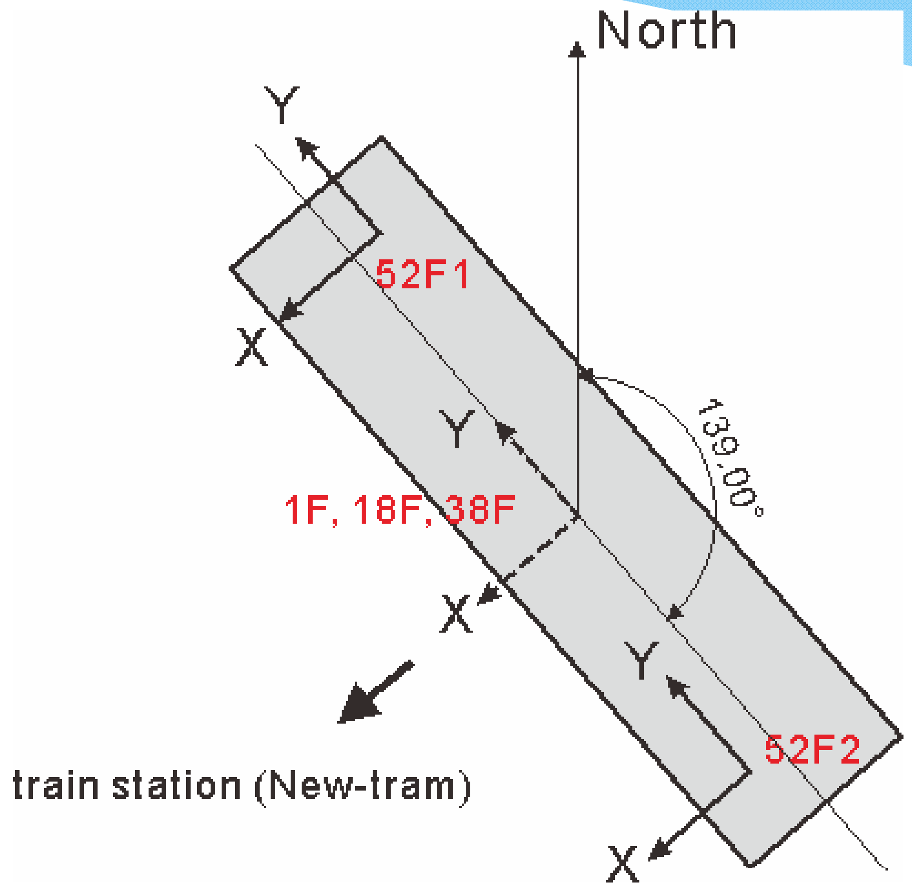
Skyscraper on Osaka Bay, tallest in western Japan, with more than 700 km epic. distance.

Osaka Sakishima office

Skyscraper on Osaka Bay

Osaka Sakishima office





Sensor locations on the plan

● accelerometer

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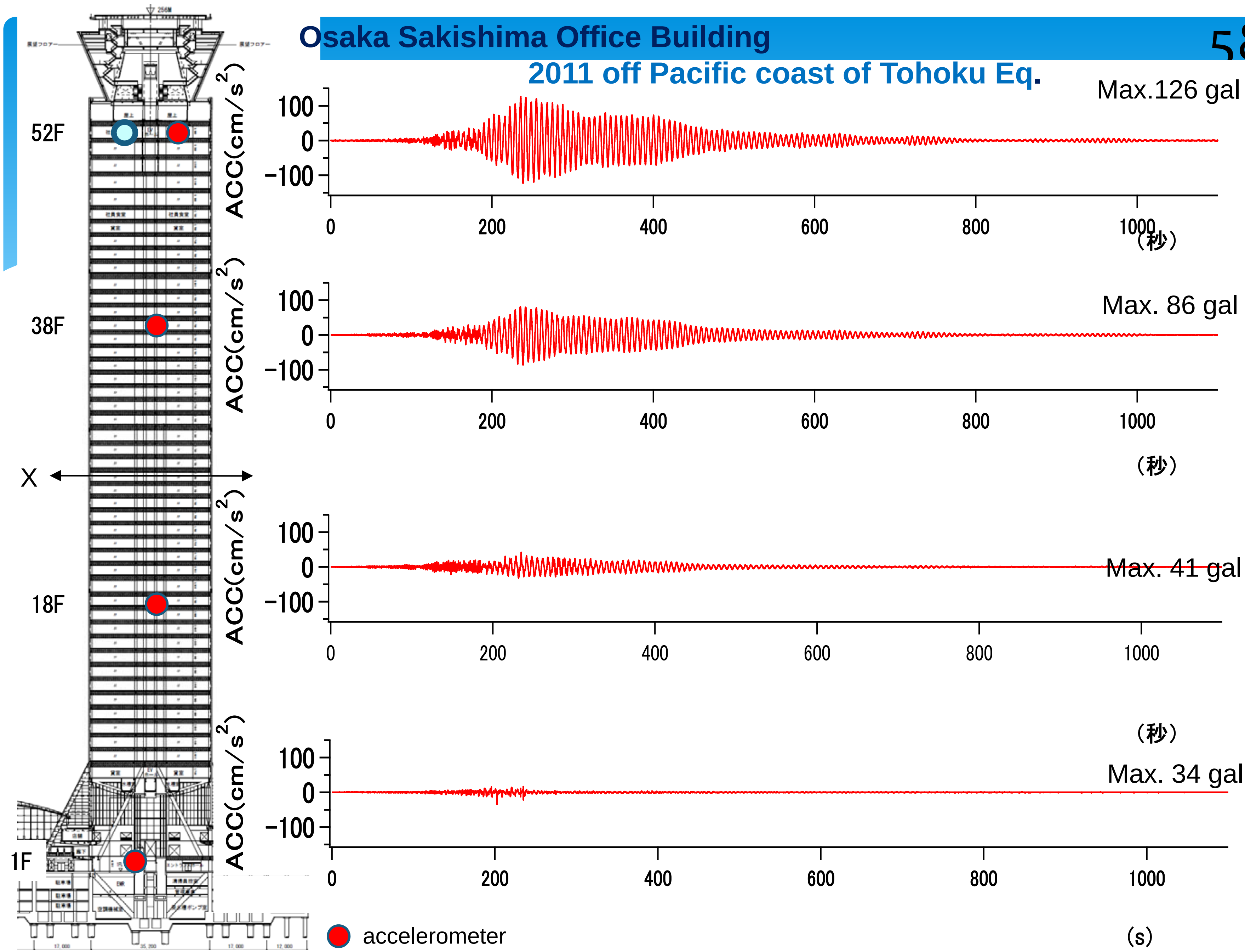
Osaka Sakishima Office Building

2011 off Pacific coast of Tohoku Eq.



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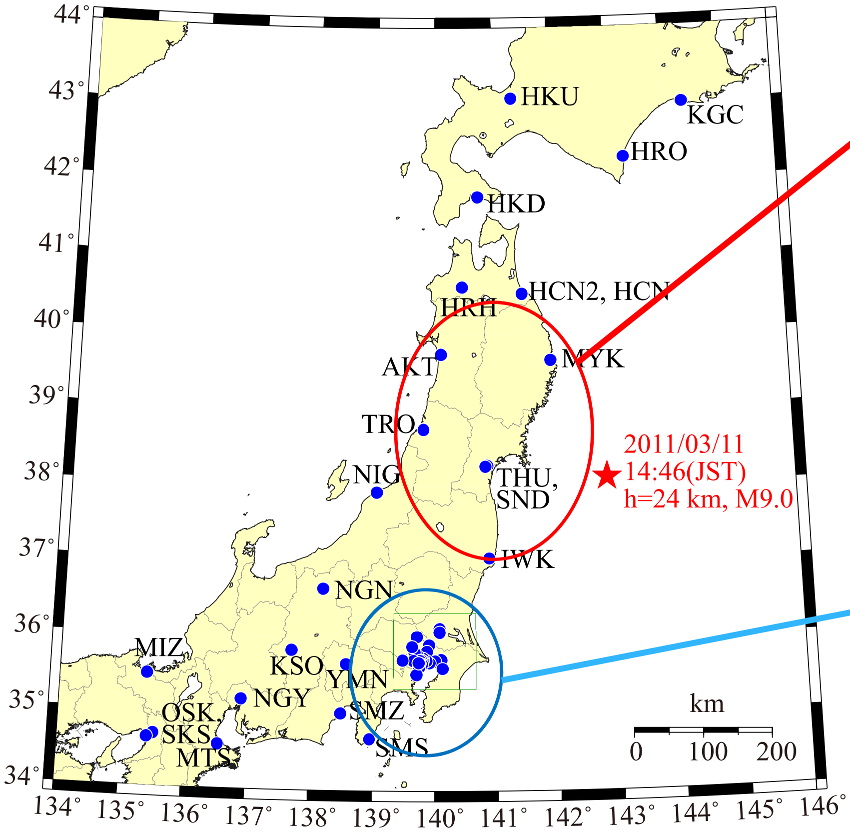
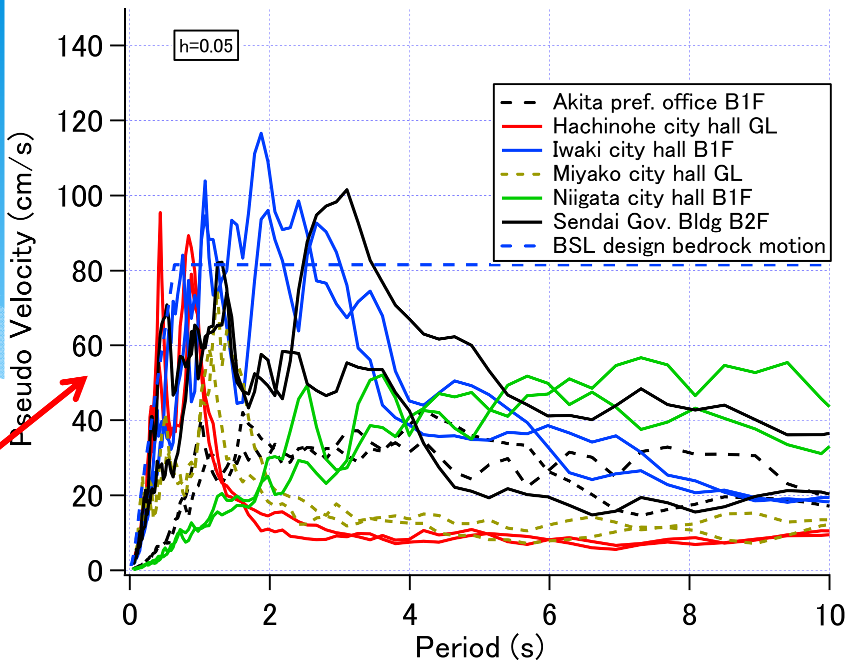
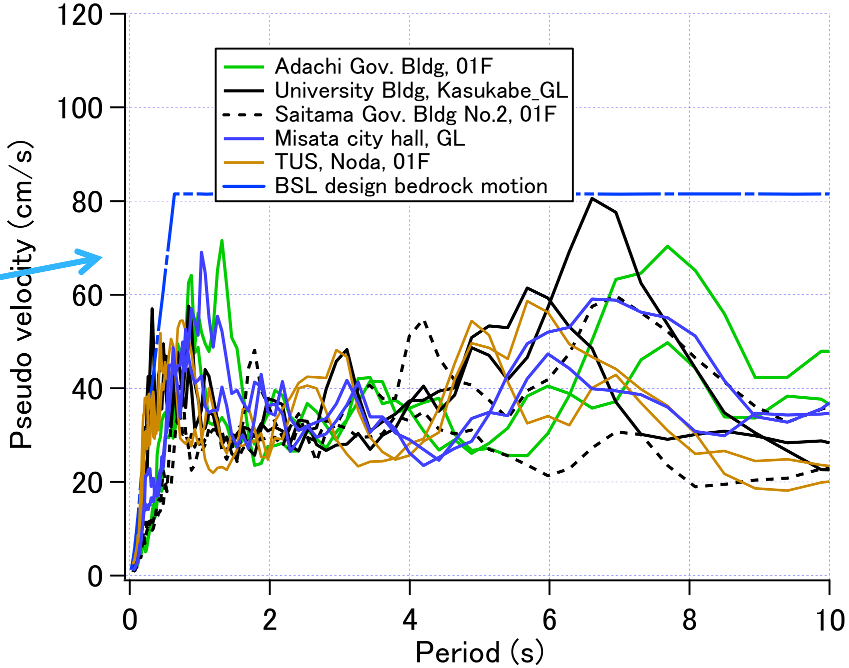
Pseudo velocity spectrum of observed motions







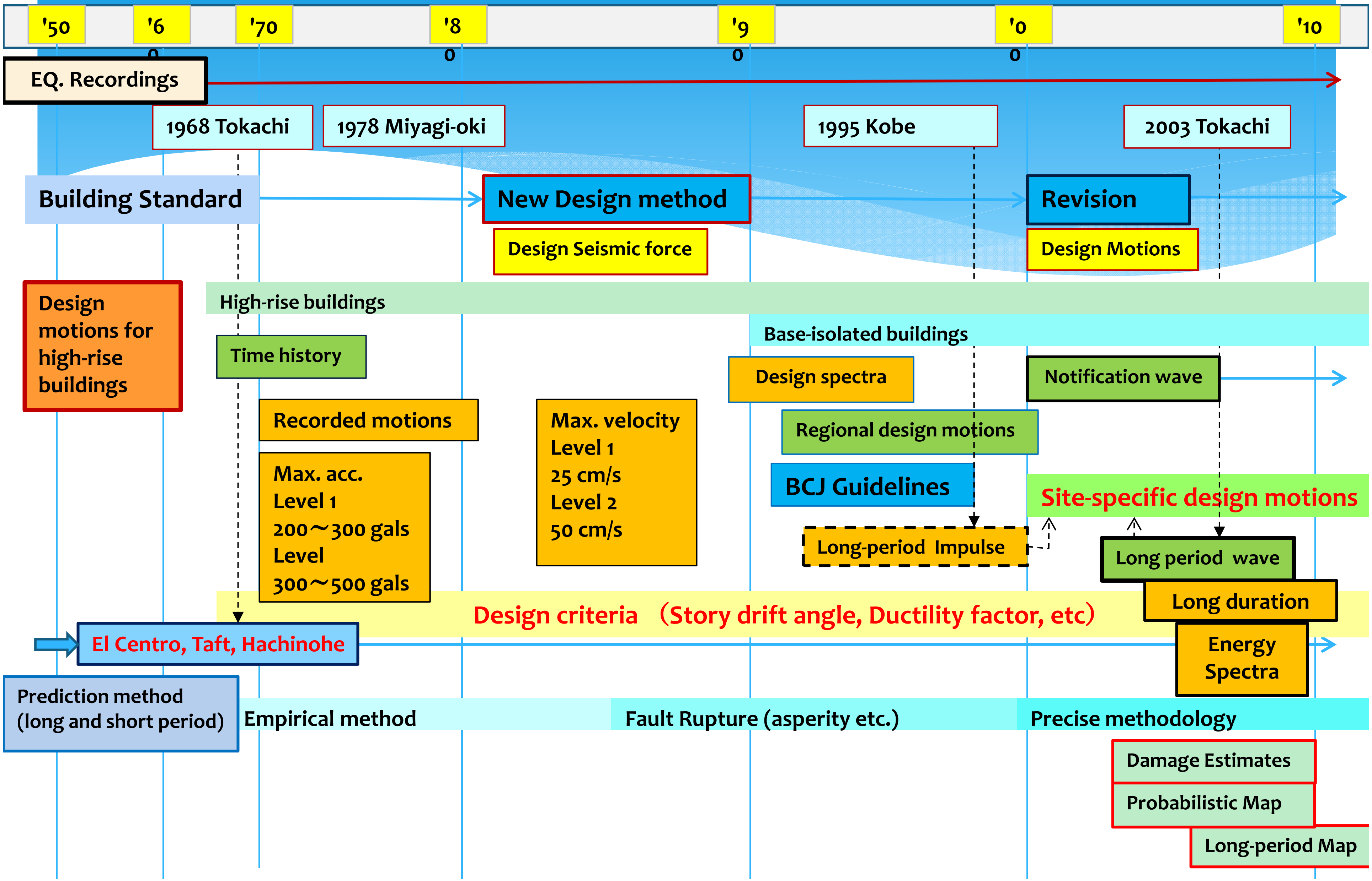
Izuru Okawa

MLIT & NILIM proposal for tentative measures for the safety of high-rise buildings

Background

* Fire of large oil storage tank due to the effect of long-period earthquake motions
* Concerns of the effect of Long-period earthquake ground motions to high-rise and SI buildings
* Earthquake occurrence probability is high for major subduction-zone earthquakes such as Nankai, Tonankai and Tokai earthquakes
* Various projects on earthquake damage evaluations for subduction-zone earthquakes
* MLIT funding for safety measures for long-period buildings (Selected Research Group + BRI)

Design earthquake motions for high-rise buildings



Design Motions Currently Used for Tall Buildings (>60m)

1. BSL Notification spectrum compatible motions (Fig.1)
2. Modified Recorded motions (Vmax=25,50cm/s)
3. Site-specific motions

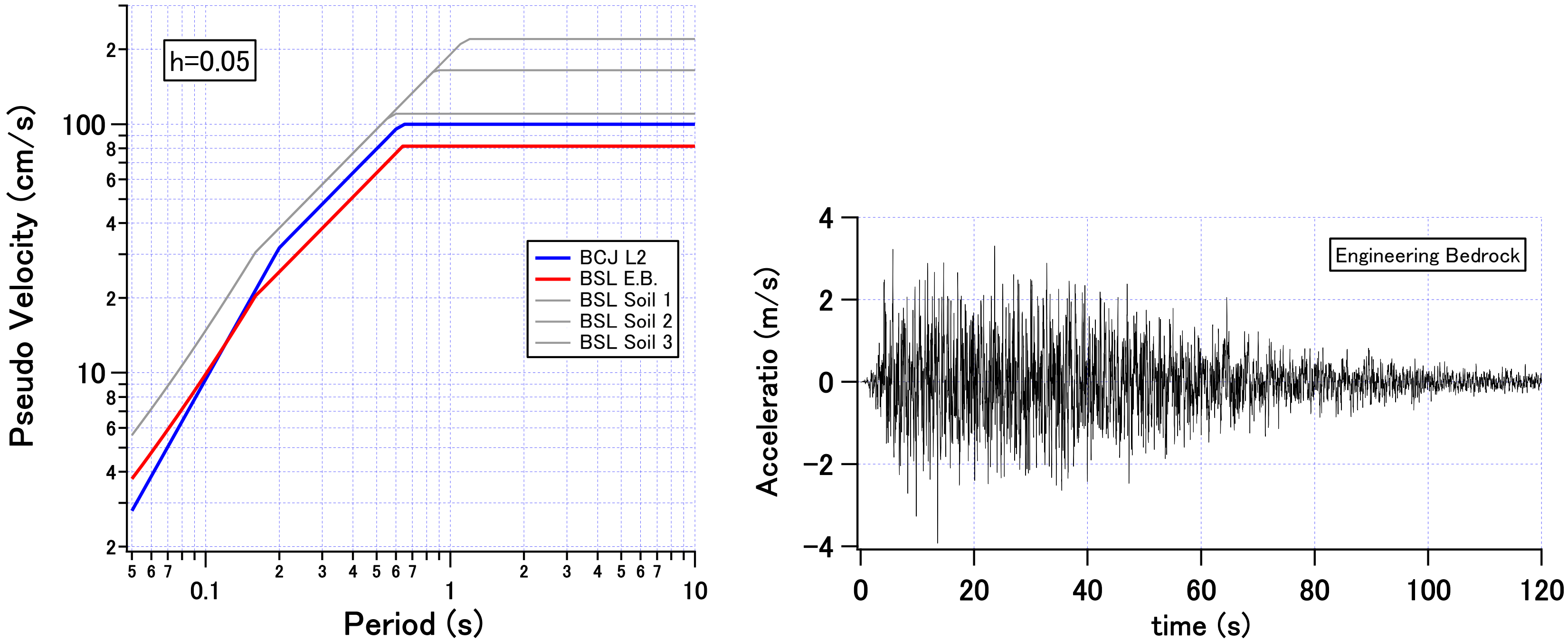


Fig.1 BCJ (L2) and BSL Design Spectra and BSL wave for Engineering Bedrock

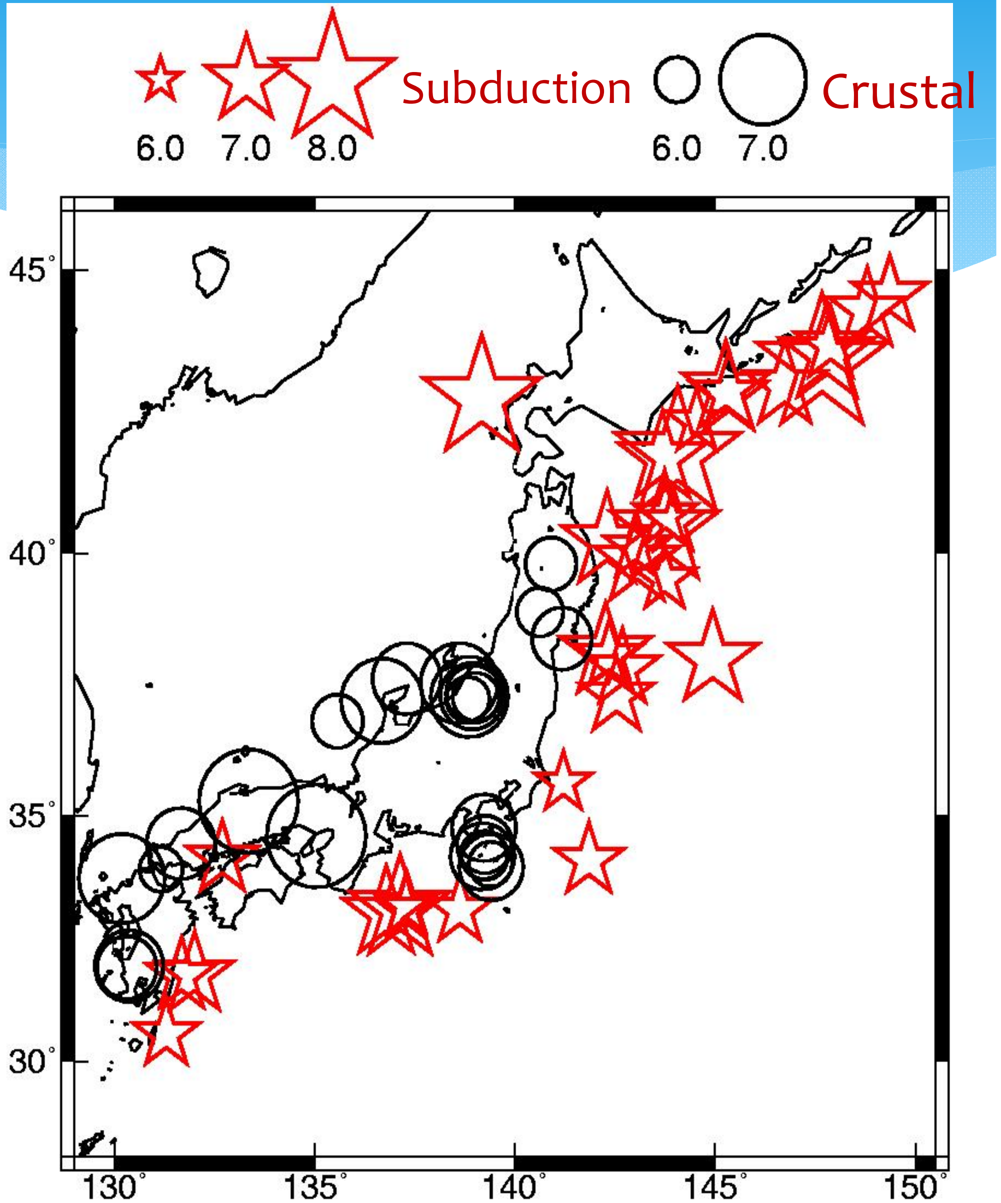
Ground motion parameters and prediction model

1. Spectral Properties
   1) Acceleration response spectrum (h=0.05, 0.01)
   2) Energy Spectrum (h=0.10)
   3) Site amplification coefficient
2. Time history Properties
   1) Site factors with phase properties controlling waveforms and duration time

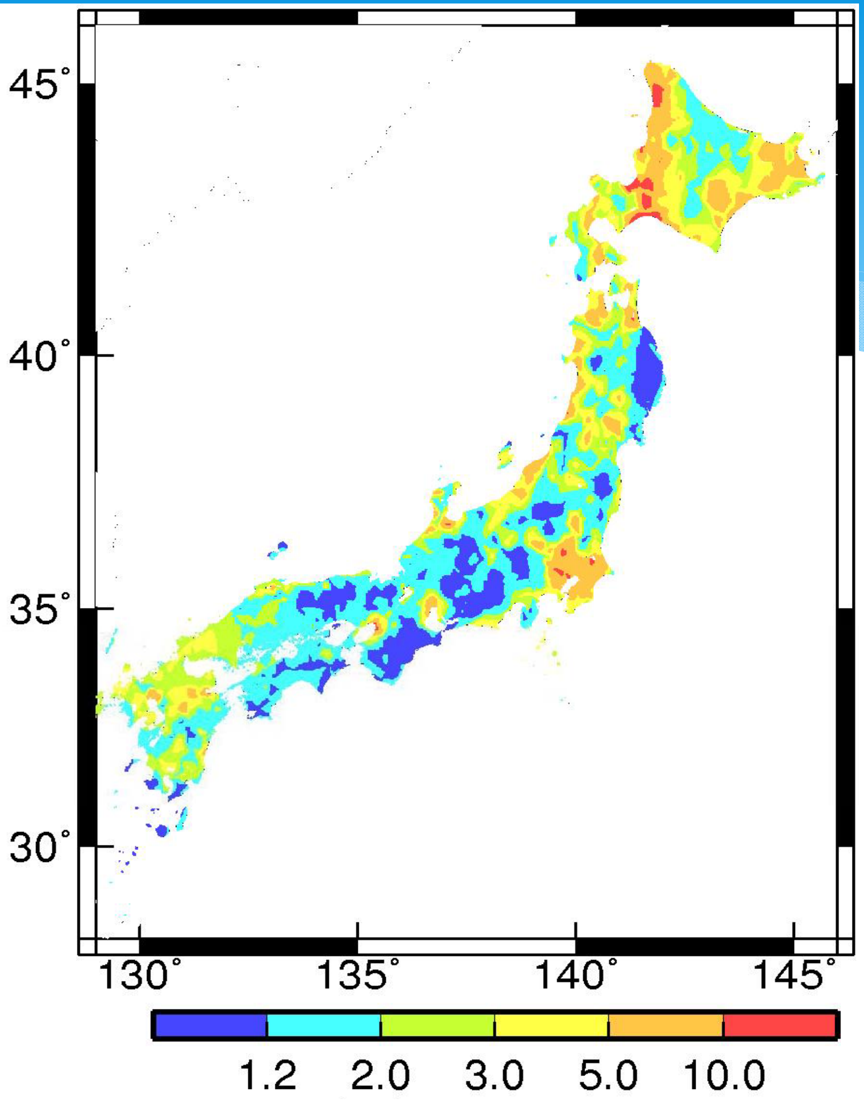
Used Earthquake Data（Subduction, Crustal Eqs.）

- Subduction：Mj≧6.5,
Hypocentral dist.≦400km
- Crustal：Mj≧6.0,
Hypocentral dist. ≦350km
- Focal depth≦60km
  Mj：JMA magnitude

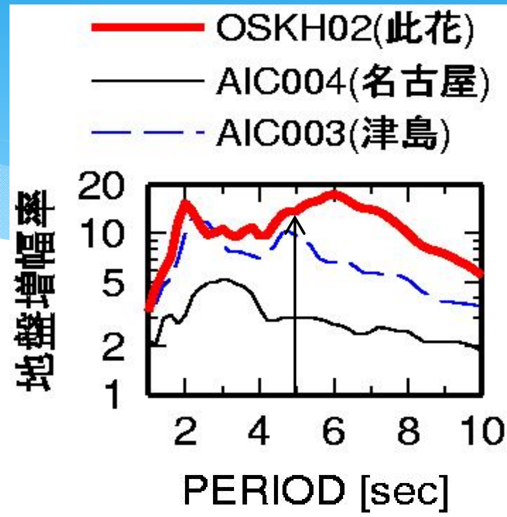
K-NET, KiK-net, JMA data were used in this study

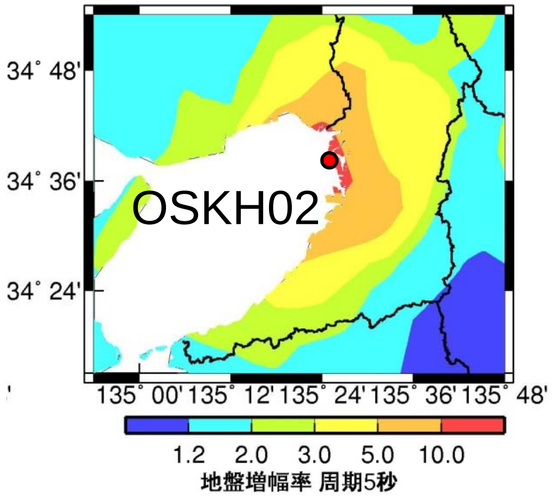


Site amplification coefficient Cj(T)

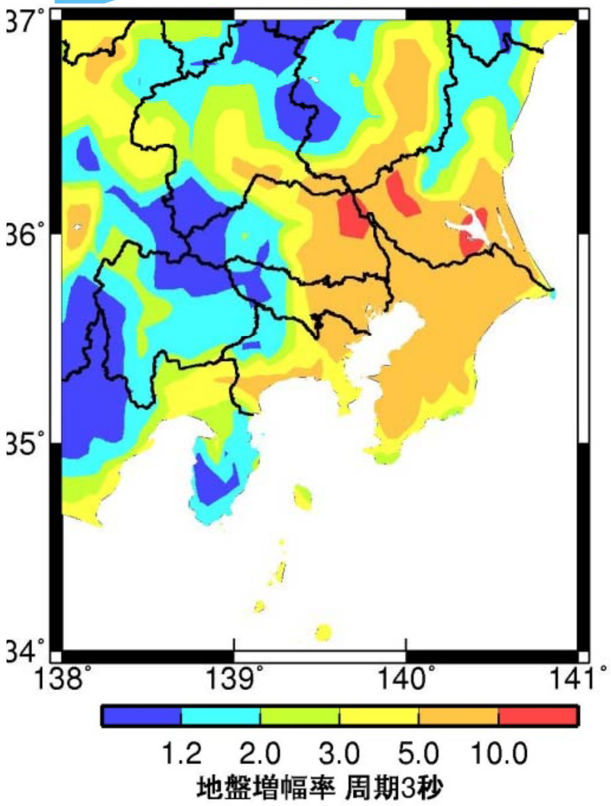


Site amplification coefficient at T=5 sec.

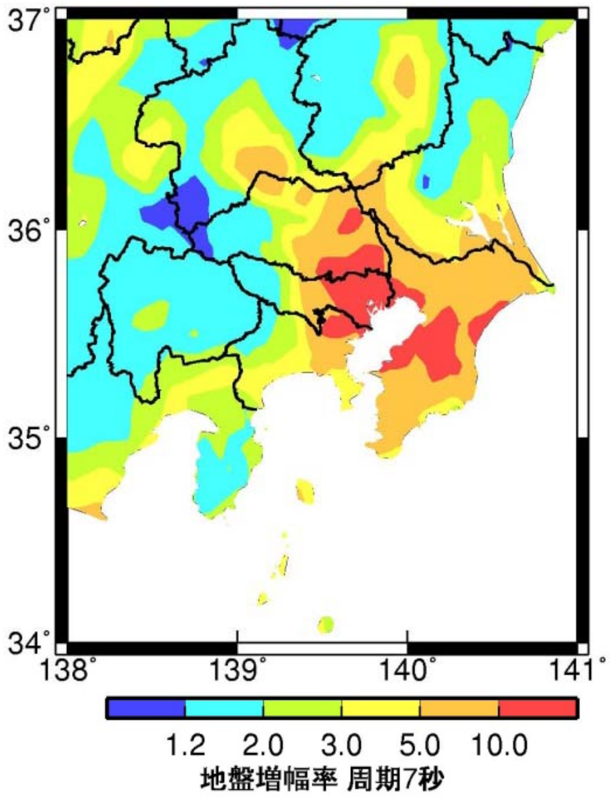




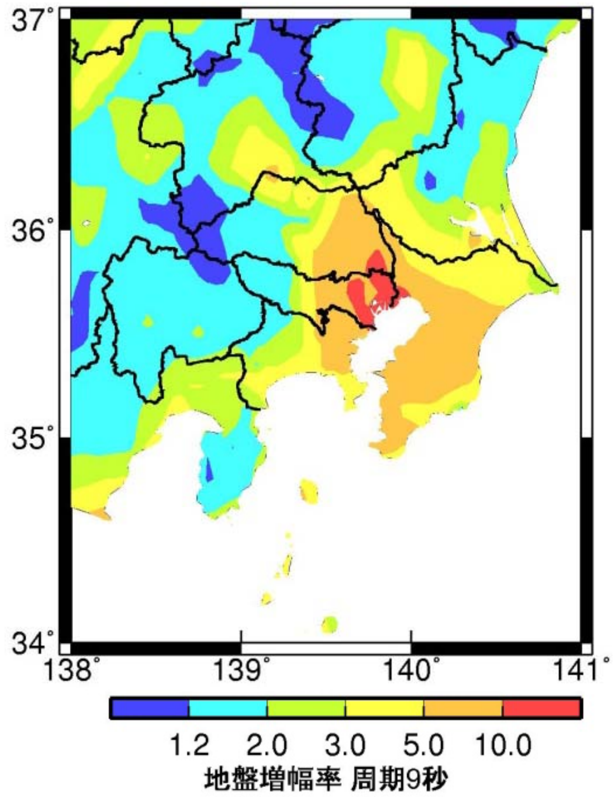
Site amplification factors for Sa(5%) horizontal components



3 sec.



7 sec.



9 sec.

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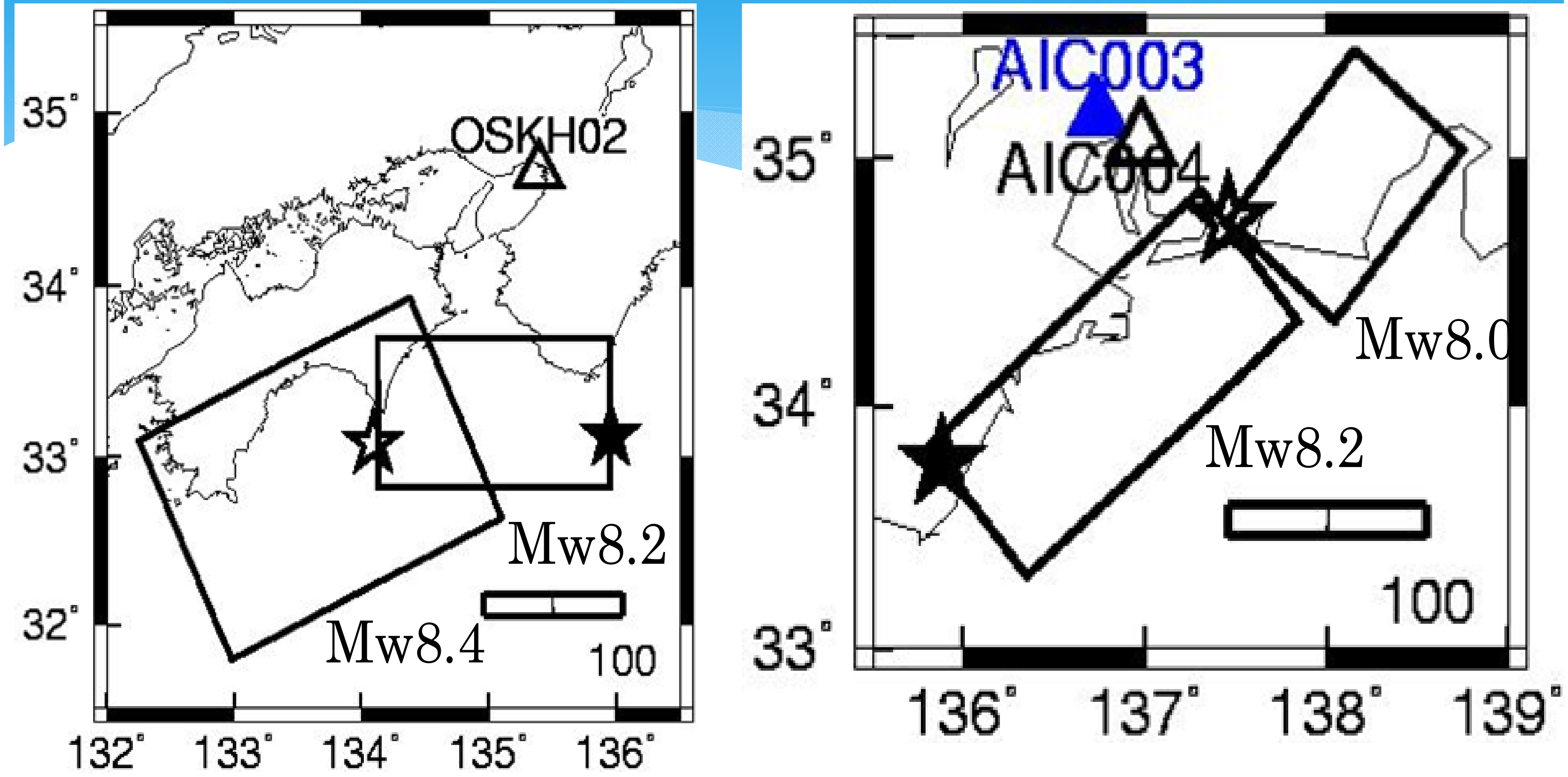
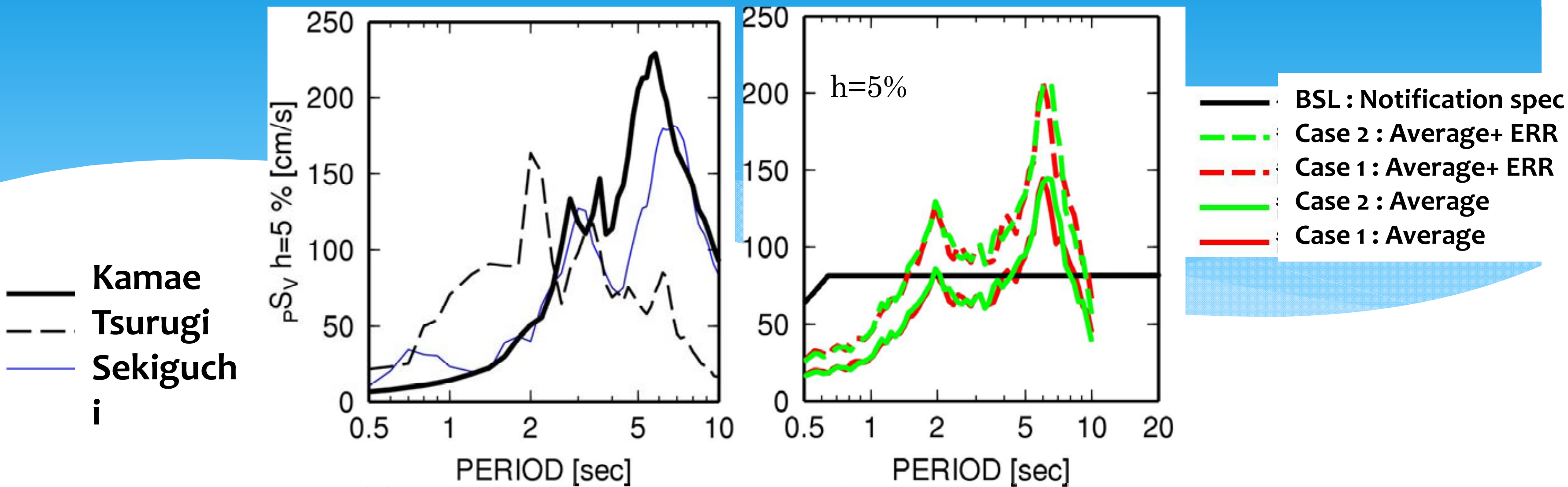
Simulated ground motion for large earthquakes



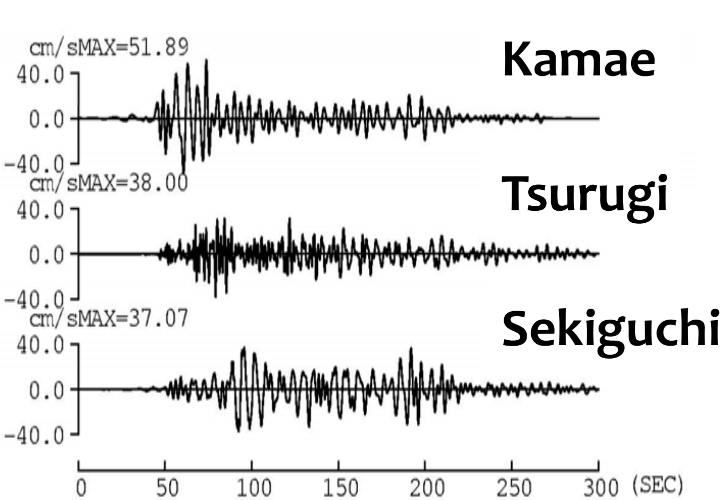
(a) Nankai earthquake

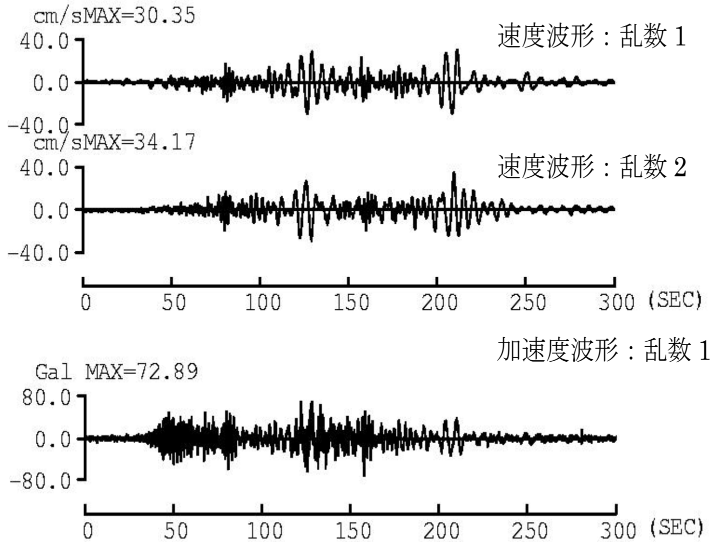
(b) Tokai-Tonankai earthquake

Simulated ground motion for Nankai earthquake



(a) 既往の予測波 (b) 本研究の予測波





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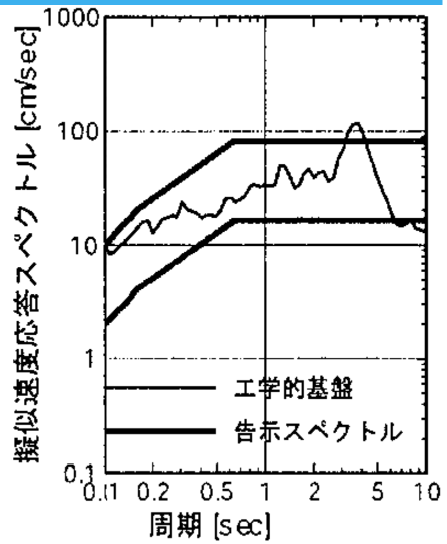
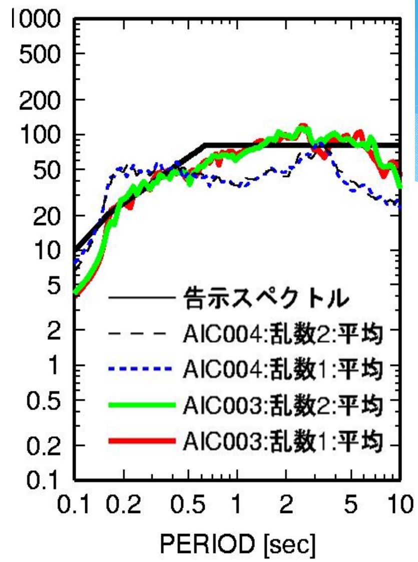
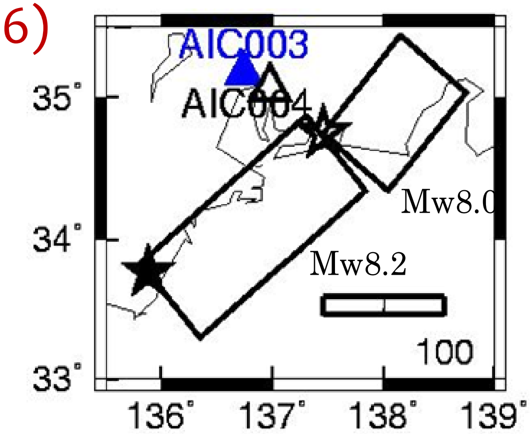
Simulated ground motion for Tonankai-Tokai earthquake

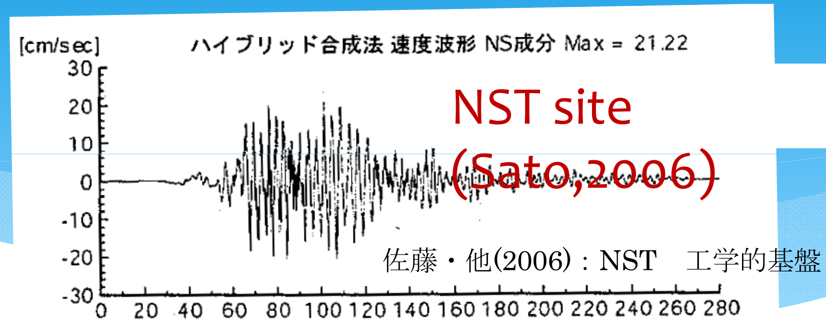


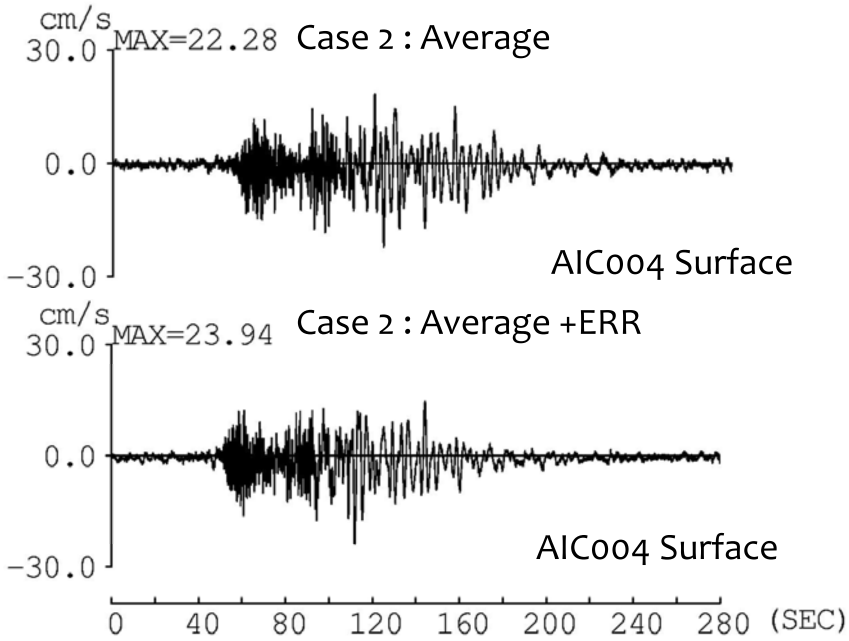


NST site
(Sato,2006)

This study





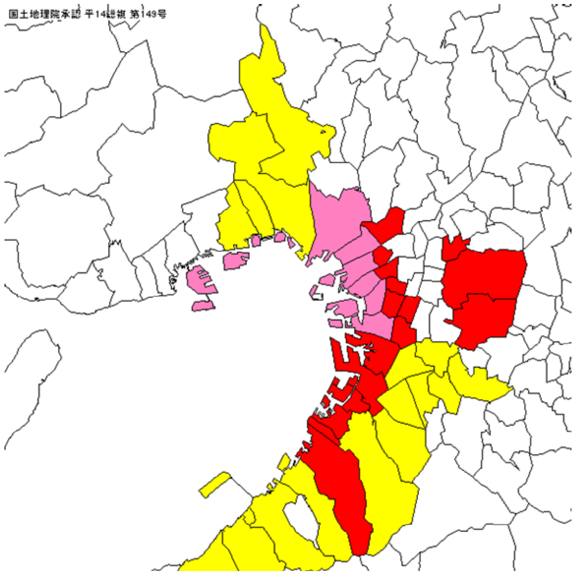


MLIT proposal for tentative measures for the safety of high-rise buildings

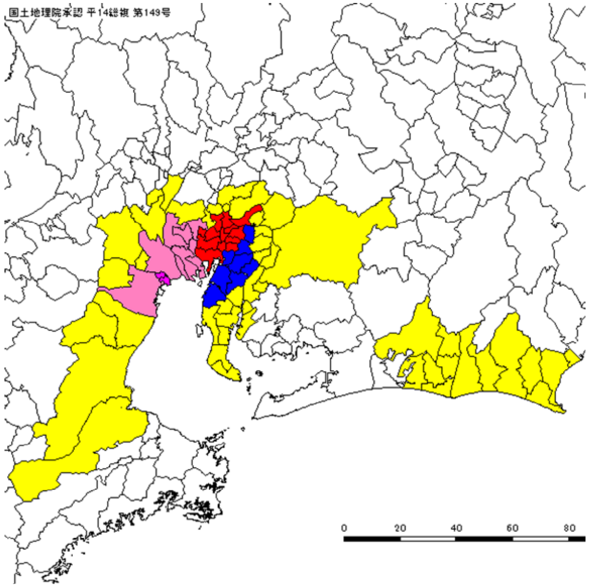
- With MLIT funding, the methodology is constructed.
- Long-period earthquake ground motions for specific sites can be evaluated including time histories.
- Earthquake motions for verification generated for three major subduction-zone earthquakes

  →Nankai, Tonankai and Miyagi-oki earthquakes
- Long-period earthquake motions for 9 zoning sites in urban area were proposed for existing and new ones.
- Public comments to this proposal were invited.
- The 2011 Tohoku earthquake occurred.

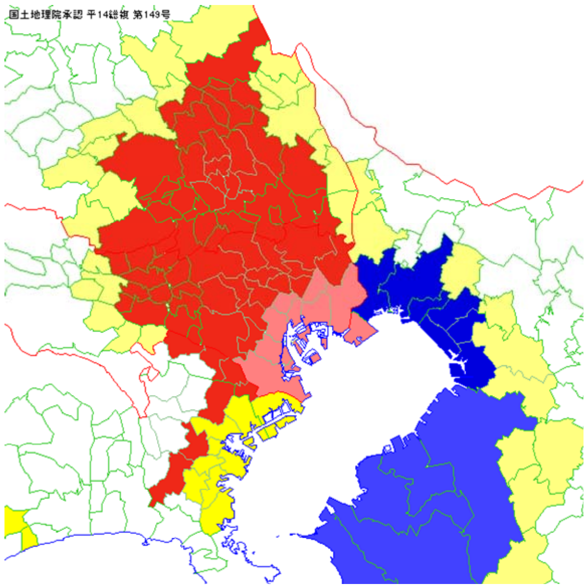
Nine Zonings in Urban Areas



Osaka

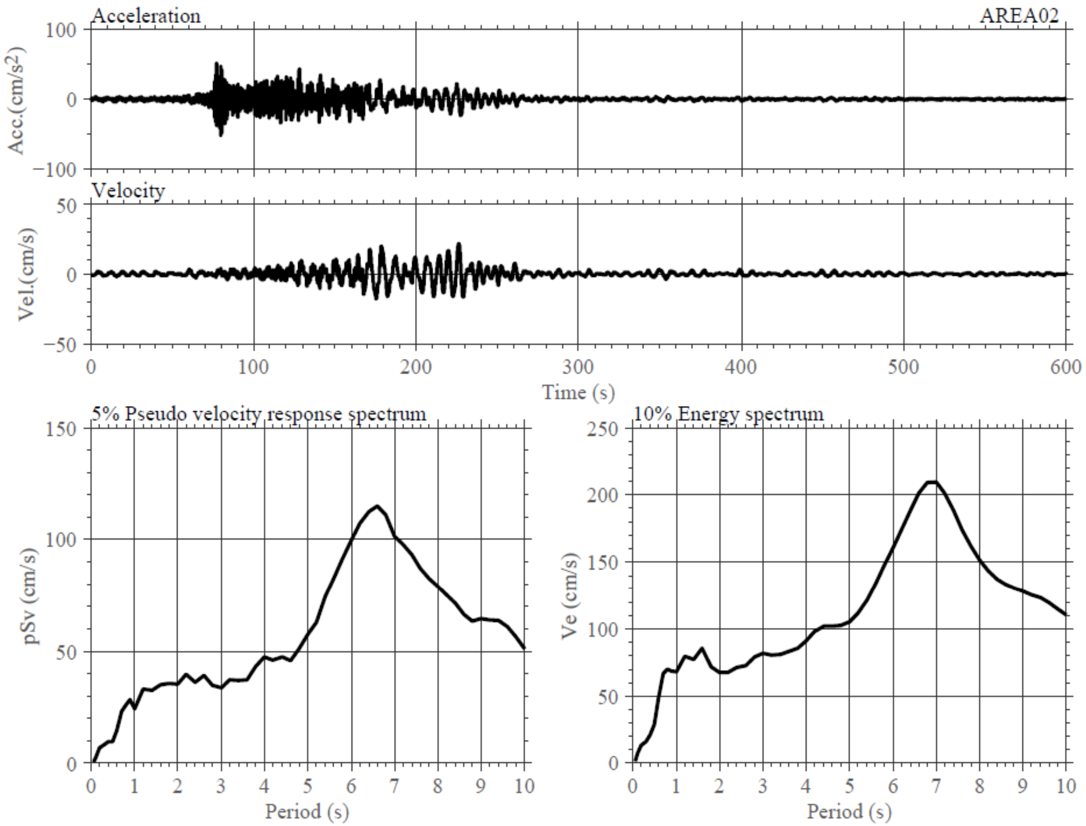


Nagoya



Tokyo

Area 9 (representing Tokyo Bay area)



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End