COUNTERMEASURES FOR LONG-PERIOD GROUND MOTIONS

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Kajima Corporation T. FUKUDA

Tokyo University of Science H. KITAMURA

Kobori Research Complex N. KOSHIKA

Introduction

Architecture Institute of Japan (AIJ) carried out the research requested by the Cabinet Office

A study of the effects of long-period ground motions on high-rise buildings

Introduction

■ Research Contents

Report-1(2007～2010)

Feature of long-period ground motion
Damage level judgment
Recover measures
Damage reduction measures
Future problems

Report-2 (2011 after the East Japan Earthquake)

A survey and research regarding to the influence induced by the unpredictable earthquake

Report-1

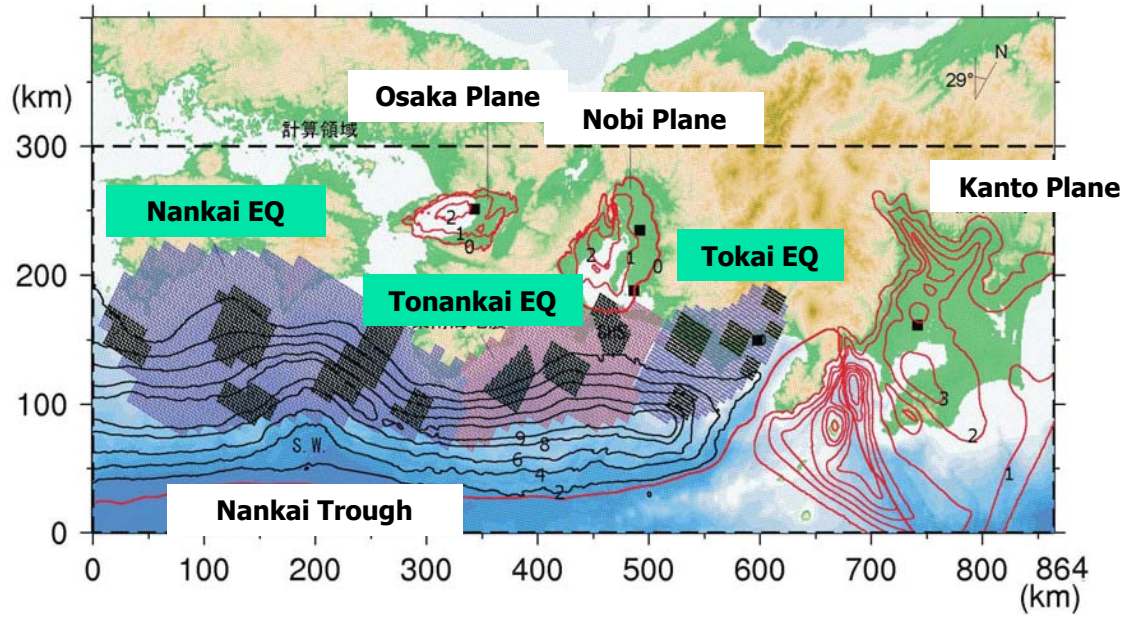
2007 - 2010

Report-1 (2007～2010)

1. Huge subduction earthquakes and regions of interest
2. Shaking and structural damage of high-rise buildings
3. Damage of furniture, non-structural members and MEP equipments
4. Post-earthquake emergency judgment and recovery measures in the early stage
5. Damage scenario and preparation
6. Education for society

1. Earthquakes and Regions of Interest

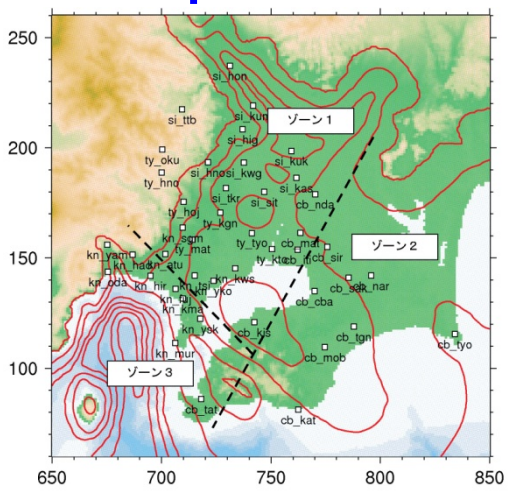
By expected Tokai, Tonankai and Nankai earthquakes, the existing high-rise buildings in Tokyo, Nagoya and Osaka area are likely to be shaken for considerably longer time than expected at the initial design



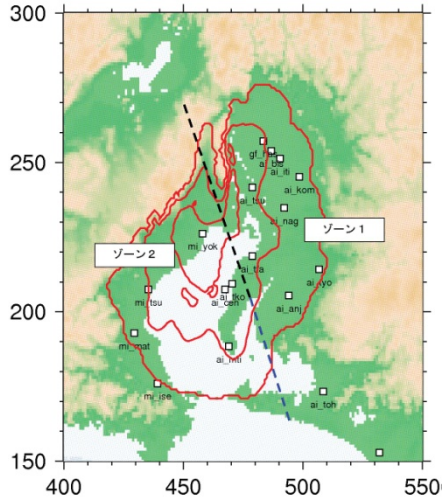
Earthquake Source Model for Expected Tokai, Tonankai and Nankai Earthquakes

1. Earthquakes and Regions of Interest

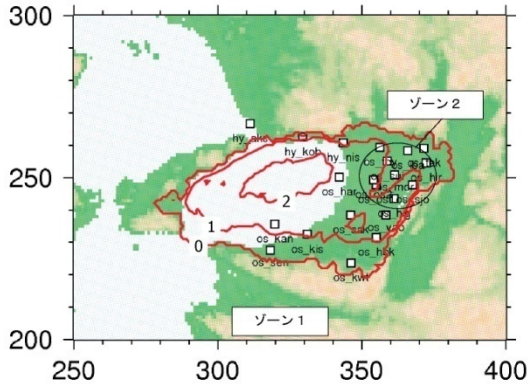
Expected max. response by mega earthquakes



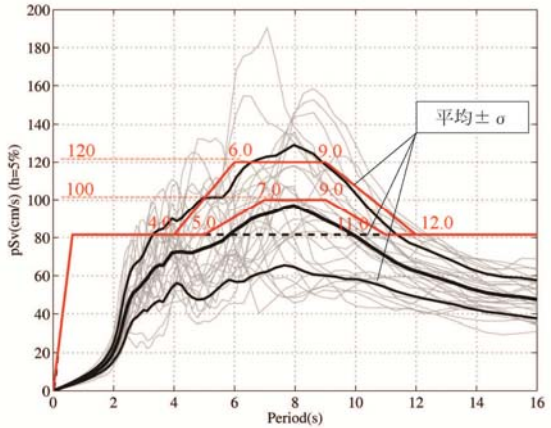
Kanto Plane



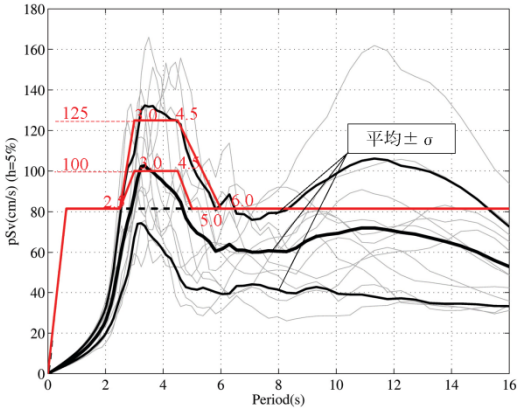
Nobi Plane



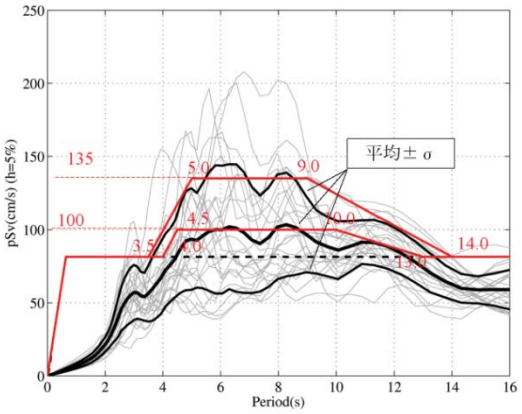
Osaka Plane



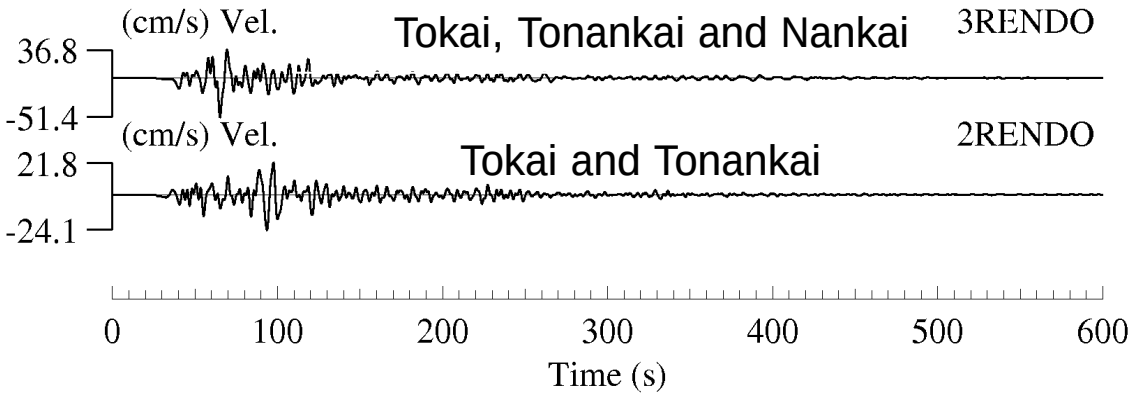
Tokyo



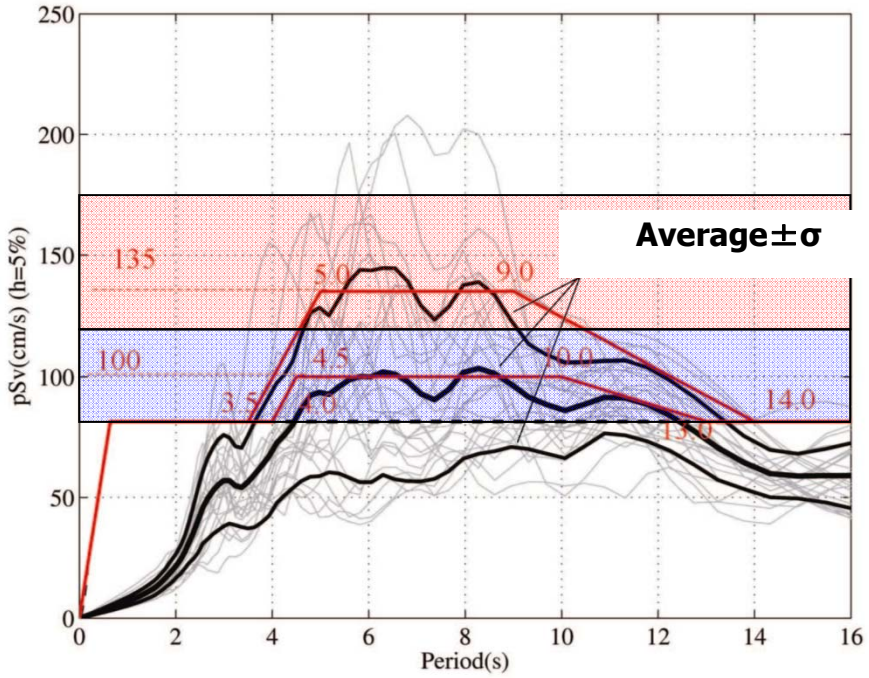
Nagoya



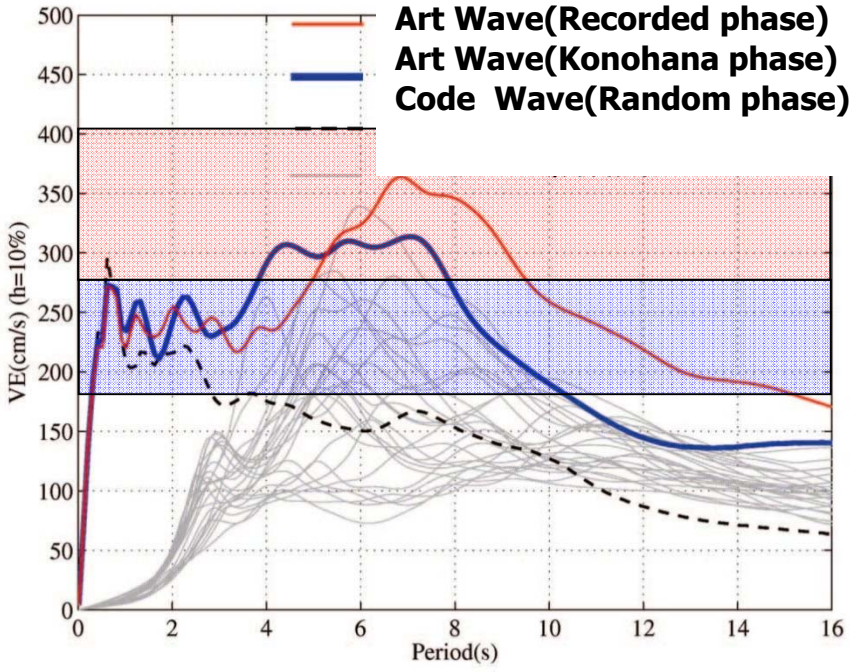
Osaka



Calculation Result in Osaka（NS Direction）



Velocity Spectrum in Osaka（*h*=5%）



Energy Spectrum in Osaka（*h*=10%）（**Average+1σ**）

2. Shaking and Damage of High-rise Buildings

- Large and long time shaking is induced in the high-rise buildings with the specific long natural period

- Number of high-rise buildings with natural period of longer than 2 sec. is about 1100

  630 in Kanto Plain

  170 in Osaka Plain

  40 in Nobi Plain

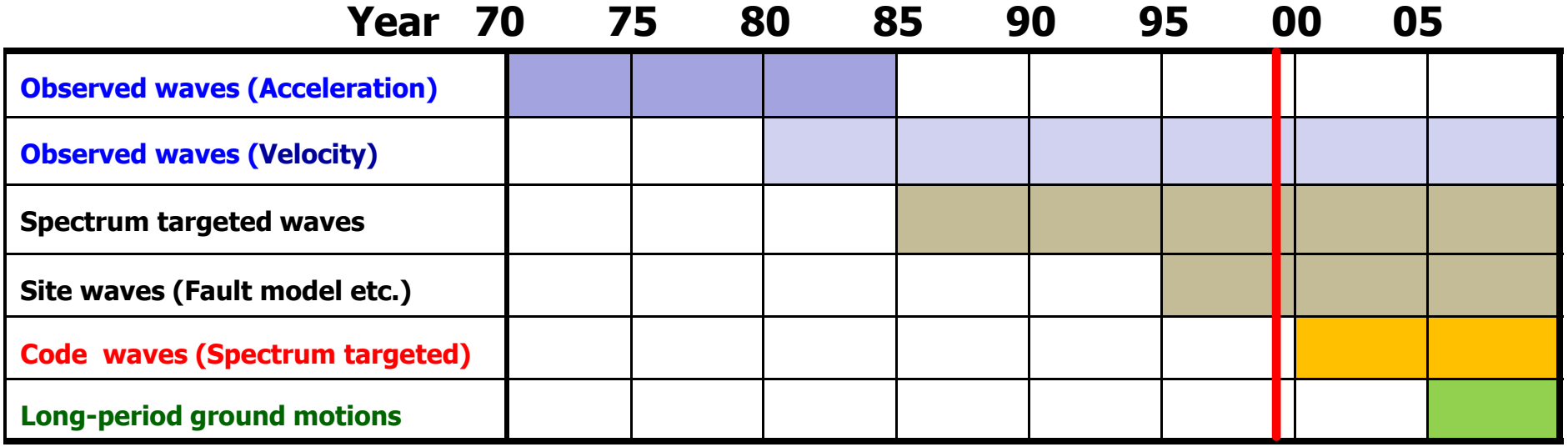
- Number of high-rise buildings with high possibility of large structural damages will be less than 100

2. Shaking and Damage of High-rise Buildings

Design seismic wave
Ultimate structural performance level

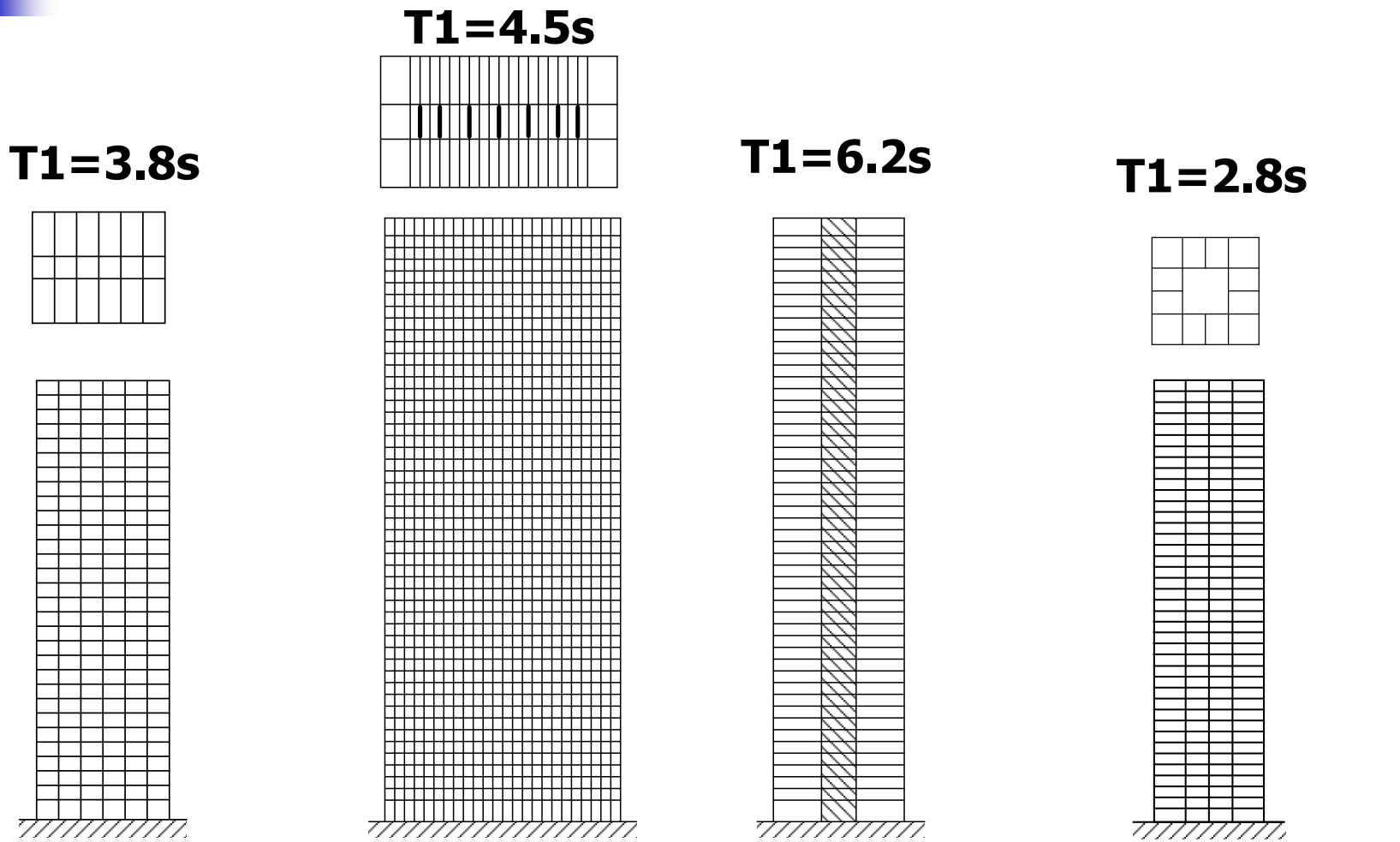
↓

depend on the construction time



Change of design seismic waves

High-rise Model Buildings



S30-Hotel
121.5m

S50-Office
197m

S50-Office
197m

RC40-Housing
129m

Building Function and Damage Judgment

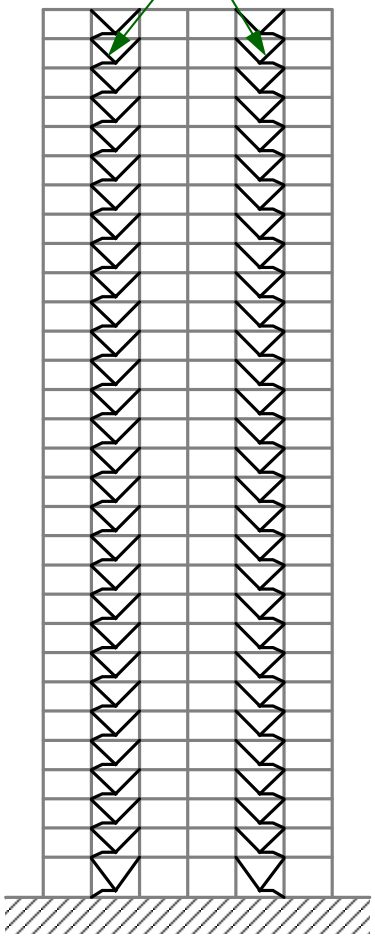
Building function and damage criteria of structural member (by JSCA performance table)

	Level λ		4	3	2	1	0
FUNCTION	Function		Functional	Keep main function	Keep specific function	Keep limited function	Nonfunctional
	Drift angle		＜1/200	1/200-1/150	1/150-1/100	1/100-1/75	＞1/75
	Acceleration (gal)		–	＜ 250	250-500	500-1000	＞ 1000
MEMBER	Damage level		No damage	Little damage	Small damage	Medium damage - Large damage	More than Large damage
	Ductility ratio		＜ 1.0	1.0-2.5	2.5-3.75	3.75-5.0	＞ 5.0
	Accumulated ductility Deformation ratio	C–1	0	0-5.4	5.4-12.0	12.0-21.5	＞ 21.5
		C–2	0	0-9.0	9.0-20.5	20.5-36.5	＞ 36.5
		C–3	0	0-3.5	3.5-7.5	7.5-13.5	＞ 13.5

Damage Judgment Result

Seismic Zone		Kanto1	Nobi1		Osaka1	Osaka2	
Building		50F-S Office	30F-S Hotel	40F-RC Housing	50F-S Office	50F-S Office	50F-S Office
FUNCTION	Drift angle	1/75	1/73	1/71	1/124	1/93	1/86
	Max. Acceleration	284	352 (657)	374 (440)	273 (479)	306	321
	Judge Level λ	**1**	**0**	**0**	**2**	**1**	**1**
	Function	**Keep limited function**	**Non-functional**	**Non-functional**	**Keep specific function**	**Keep limited function**	**Keep limited function**
MEMBER	Ductility Ratio	1.72	3.19	1.99	4.40	6.50	1.45
	Accumulated Ductility Ratio	28.7	24.1	—	74.5	26.3	2.7
	Judge Level λ	**1～0**	**1～0**	**3**	**0**	**0**	**3**
	Damage level	**Medium - Large damage**	**Medium - Large damage**	**Little damage**	**More than Large damage**	**More than Large damage**	**Little damage**

Study for Response Control



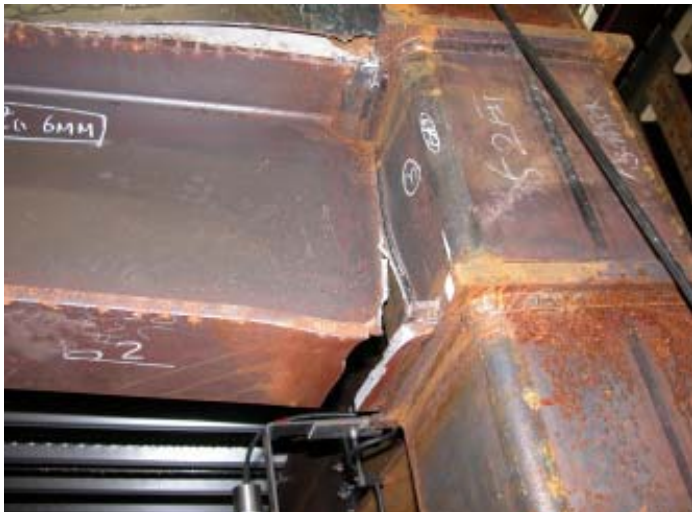
		30F-S Hotel	30F-S W/Damper
FUNCTION	Drift angle R(rad)	1/73	1/111
	Judge Level λ	0	2
	Building Function	Nonfunctional	Keep specific function
MEMBER	Ductility Ratio	3.19	1.80
	Accumulated Ductility Ratio	24.1	7.5
	Judge Level λ	1～0	2
	Damage level	**Medium - Large damage**	**Small damage**

Damage could be reduced within the allowable range by adding response control devices.

2. Shaking and Damage of High-rise Buildings

- Almost no possibility of collapsing of high-rise buildings during the 3-linkage of the Tokai, Tonankai and Nankai earthquakes

- Possibility of large damage like fracture of column-beam connections and residual deflection after earthquake



Fracture at beam-ends
（E-defense experiment）

Report-2

2011 after East Japan Earthquake

Report-2 (after 2011 East Japan Earthquake)

■ Survey and study

Surveys and studies for the character of long-period ground motions in the East Japan Earthquake and the damage of high-rise building

For professionals: building manager, structural engineer, construction engineer

- Observation record
- Damage survey
- Management after earthquake

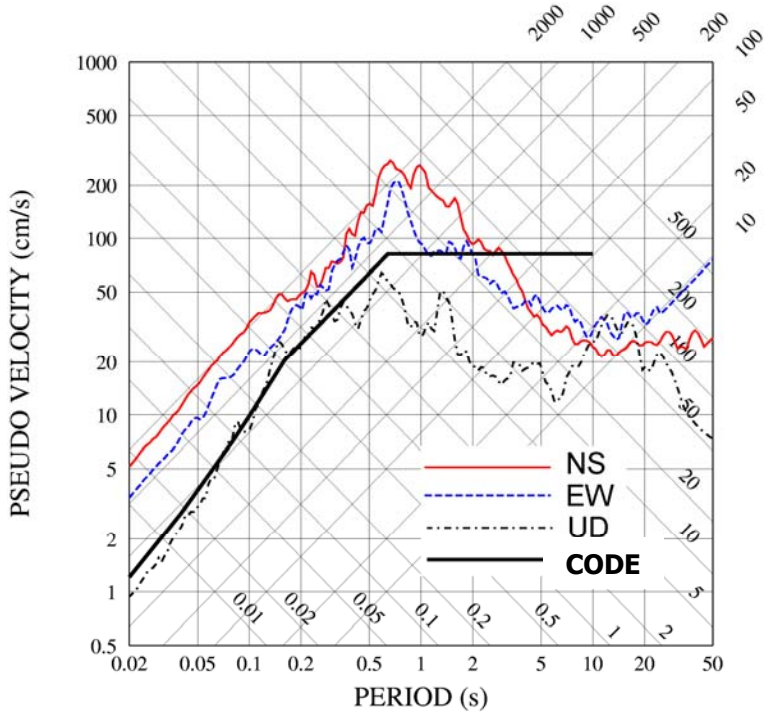
For building users and inhabitants: experienced earthquake in the building

- Questionnaire for persons experienced the long-period ground motion

Intense of Ground Motions

Almost same as code design level

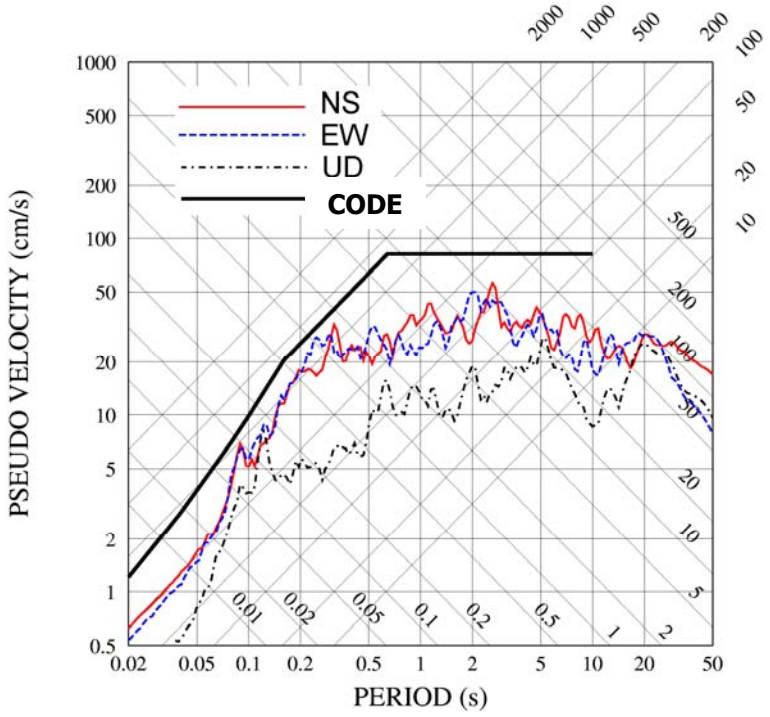
（More than 5 minutes）



K-NET SENDAI

About half of code design level

（More than 10 minutes）

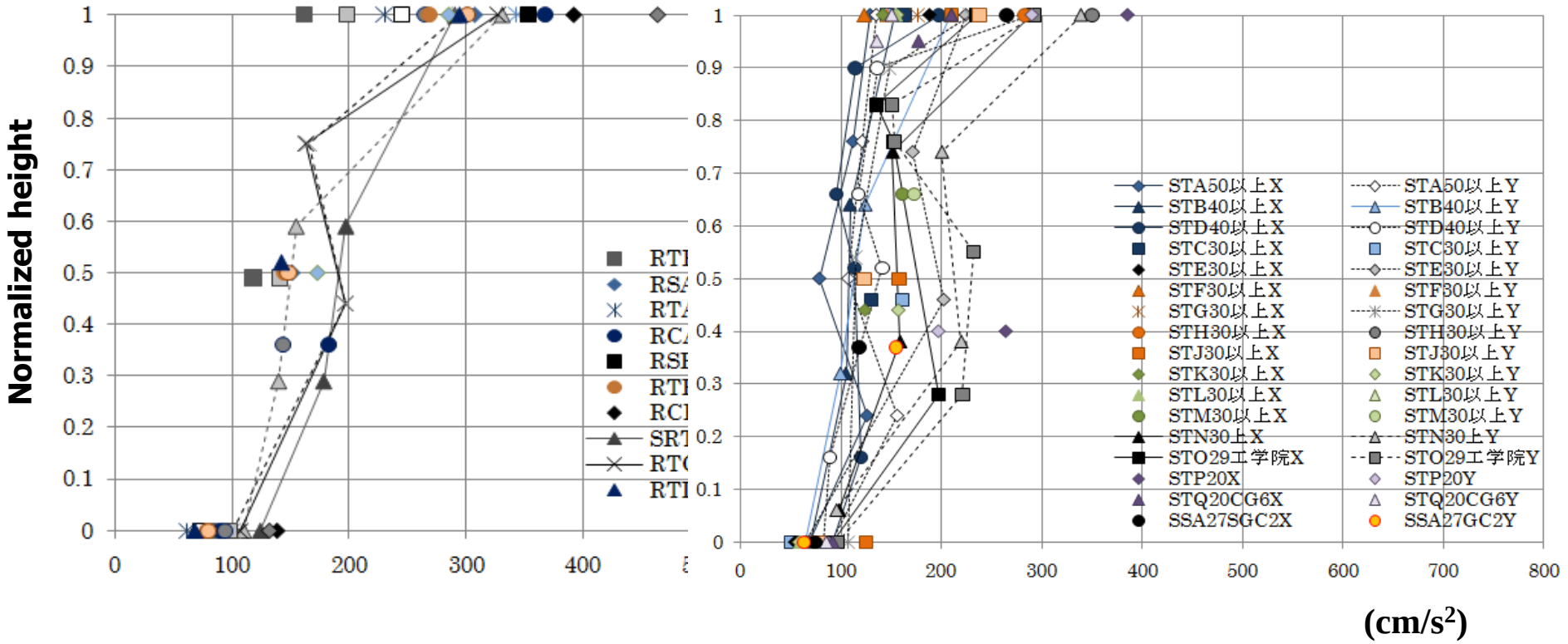


K-NET SHINJUKU

Acceleration

Top floor: 100～500cm/s^2

Ground level: 50～150cm/s^2



Reinforced concrete high-rise housing buildings in Kanto area

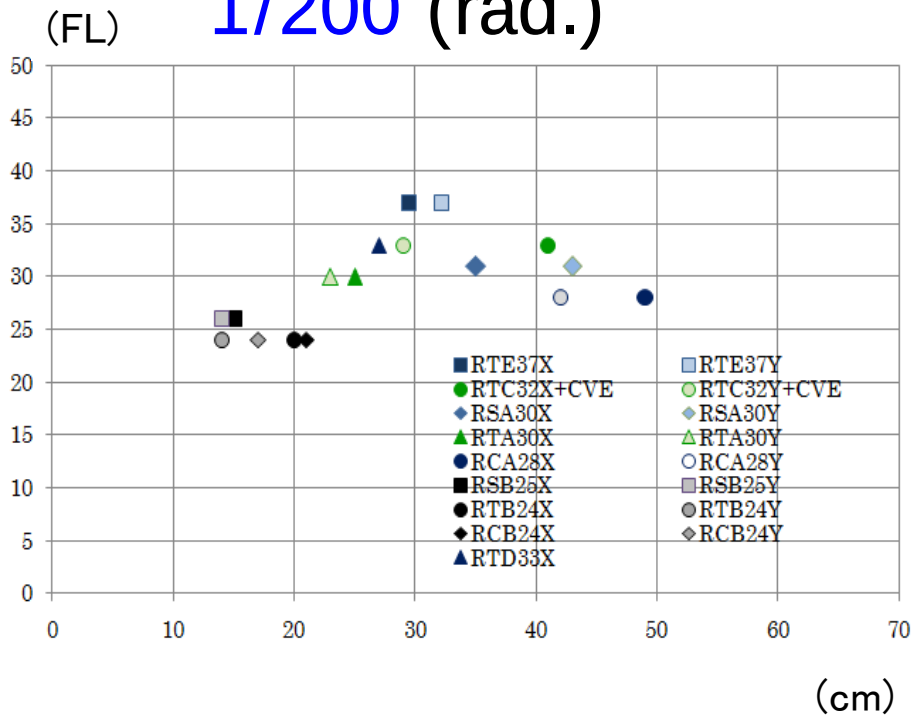
Steel high-rise office buildings in Kanto area

Maximum Drift

■ Maximum drift at top FL

50cm (one side)

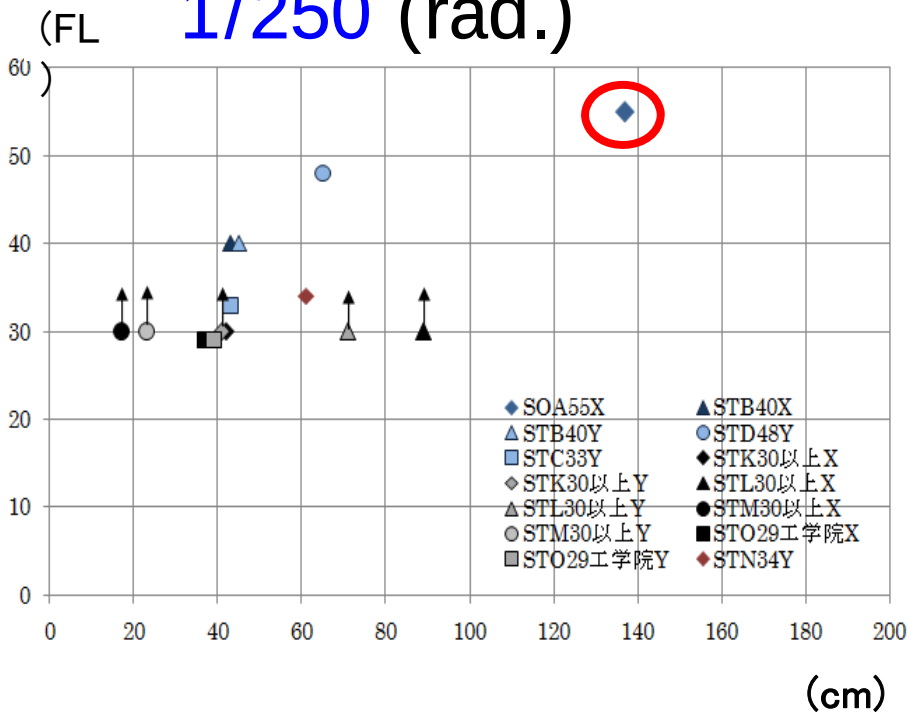
1/200 (rad.)



Reinforced concrete high-rise housing buildings in Kanto area

90cm (one side)

1/250 (rad.)

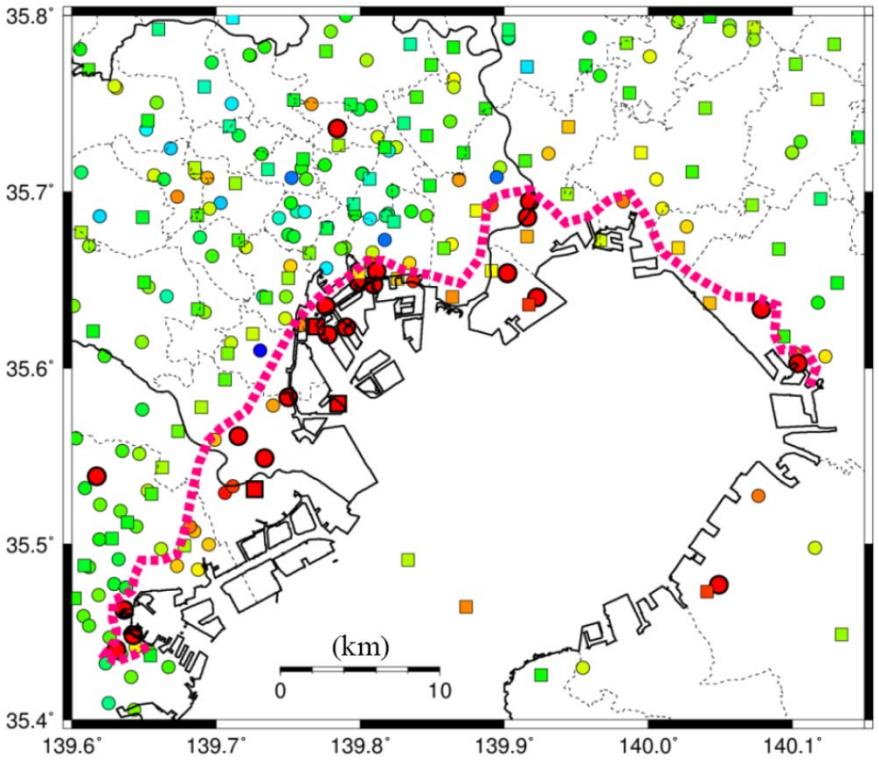


Steel high-rise office buildings in Kanto area

Amplification by Soil Condition

High-rise buildings (T_1=2-4 sec) along Tokyo Bay

→ Shaking was about 2 times

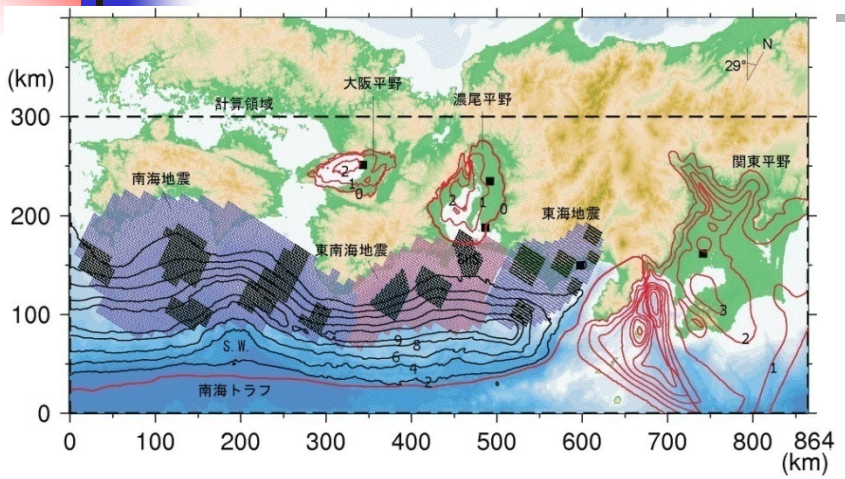


Large shaking induced area

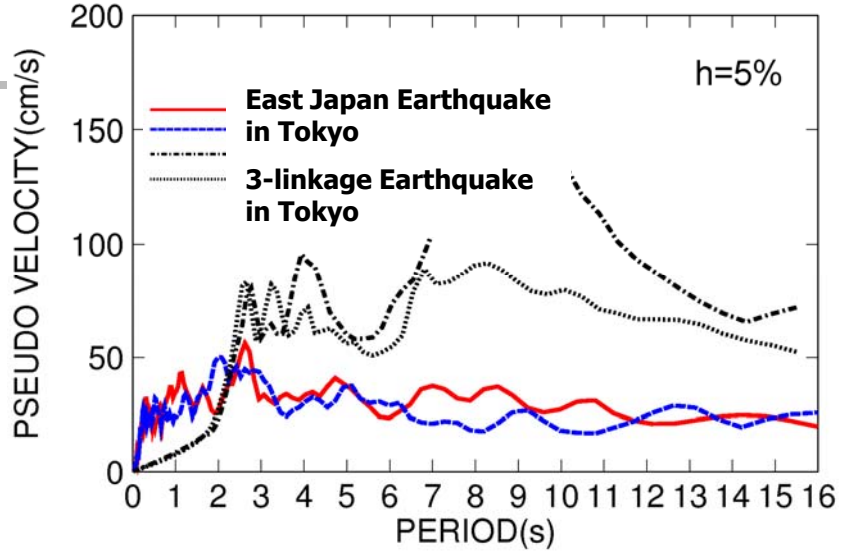
Conclusion

Lessons from the Earthquake

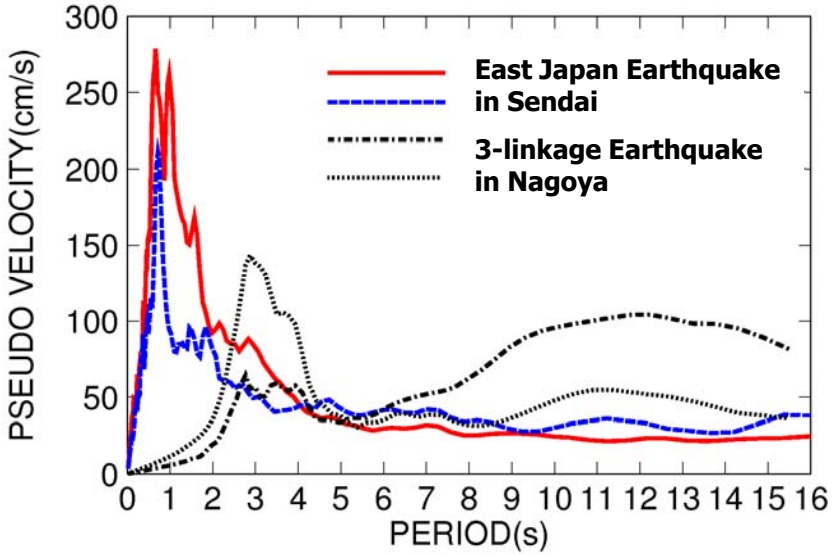
Lessons from the Earthquake



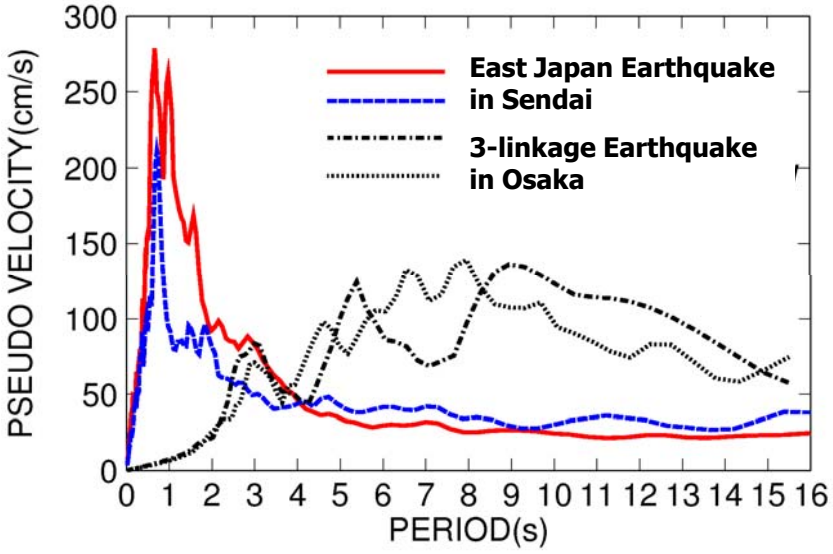
Source model for 3-linkage Earthquake



Comparison at Tokyo



Comparison at Nagoya



Comparison at Osaka

Lessons from the Earthquake

Prevent Earthquake damage

- Predict long-period ground motions
- Diagnose high-rise buildings in advance and determine building damage at an early stage
- Carried out the seismic retrofit using response control devices
- Non-structural members and equipment should reinforce a seismically effective method at the time of retrofit
- At least one unit of elevator should has high seismic performance

■ Acknowledgement

The Long-period Building Investigation WG of AIJ

Prof. H. KITAMURA: Chairman

Dr. N. KOSHIKA: Chief

Working Group members

END

2. Shaking and Damage of High-rise Buildings

Conclusion

- Specific period induces large shaking and long shaking time → depending on area
- Structural characters like the natural period, damping character, structural system, strength and ductility of high-rise buildings

  → depending on the height and designed time
- Shaking and damage level of high-rise buildings will be different on each high-rise building

3. Damage of non-structural members

Damage of non-structural members

Movement, overturning and falling of furniture and fixtures

very likely to occur

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can be prevented

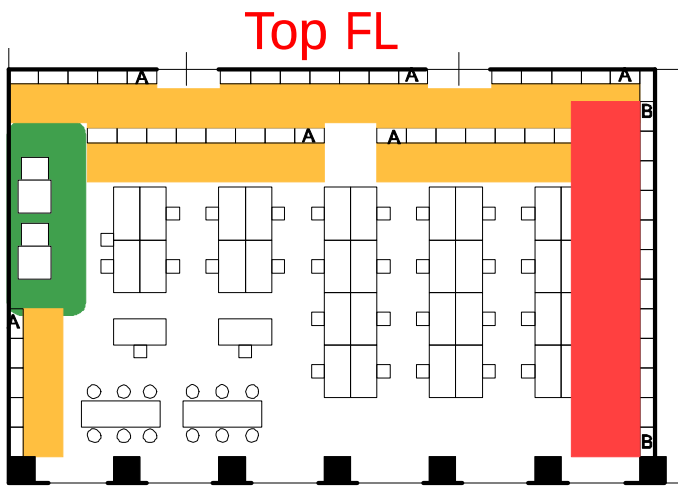
by fixing appropriately.

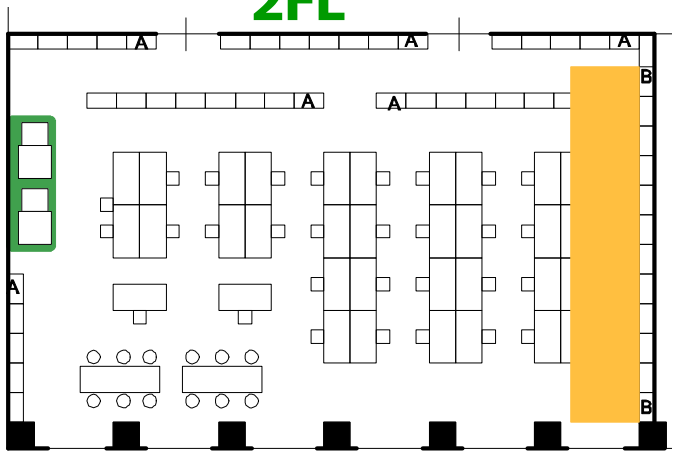
Expected Damage on Furniture

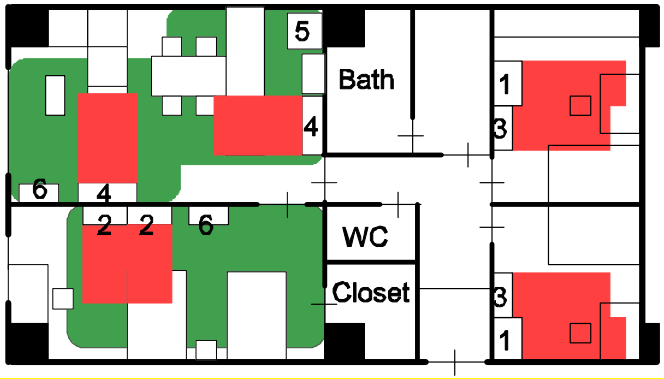
High overturning possibility
overturning possibility
Slip

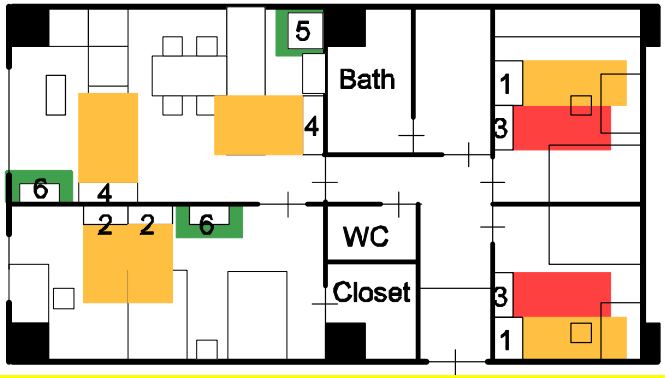
50F Office (Osaka)

40F Housing (Nobi)









Upper FL : Most of furniture will be overturned.
Furniture with caster will move around 2 to 3 m.
Evacuation route and doors will be blocked.
Lower FL : Slender furniture will be overturned.
Furniture with caster will move several dozens cm

Experiment Result at E-Defense

【Without Countermeasures】

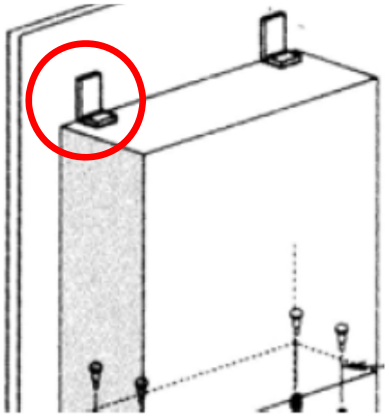
【 With Countermeasures 】

Human injuries will increases, as overturning of furniture increases. Countermeasures can reduce human suffering.

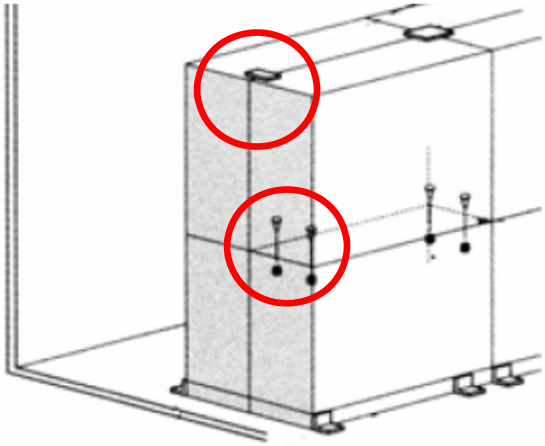
Countermeasures for furniture

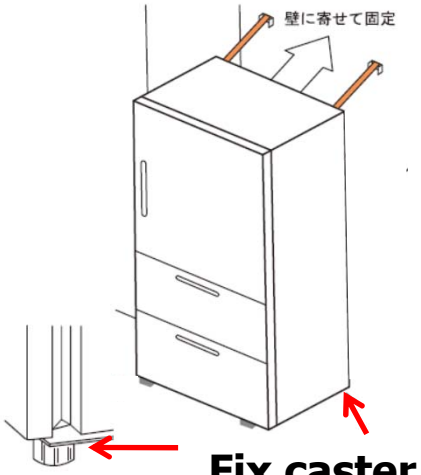
Building users

Fix



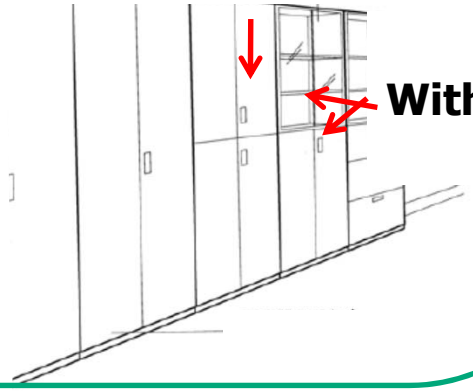
Connect





Fix caster

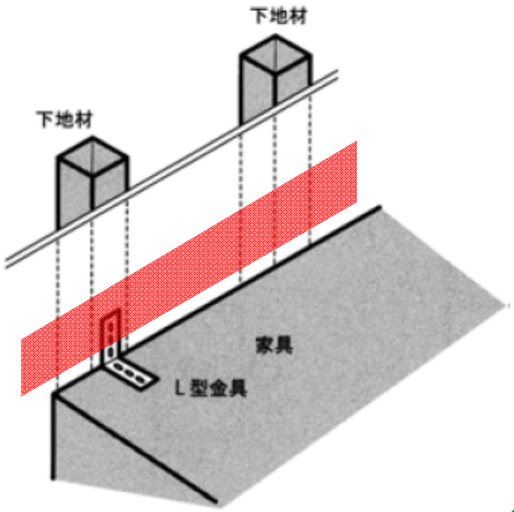
Scattering prevention film on glass



With latch

Building

Arrange secondary members to fix furniture



@Tokyo Fire Department HP）

Non-structural members and equipment

- Damage of non-structural members (ceiling material, finishing material etc.) and mechanical equipment (plumbing equipment etc.) has been observed widely in high-rise buildings located from Sendai to the Tokyo metropolitan area

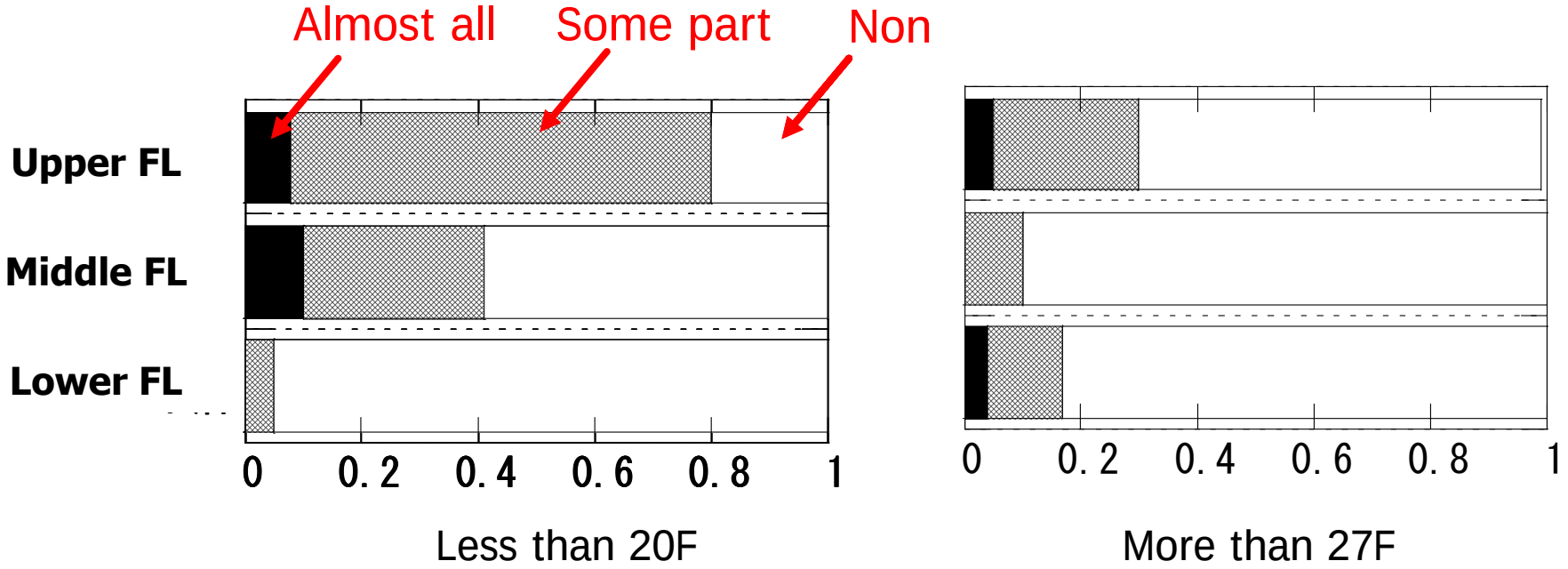
- Similar damage was also observed in some high-rise building in Osaka

Elevators

- A large number of elevators in the Tokyo metropolitan area had stopped in emergency mode
- Recovery measure had been taken immediately
- At least one elevator became operational in most buildings three days after the earthquake
- About 9,000 of total 370 000 units elevators were suffered some damage
  - Catching of main and other cables with elevator equipments: 24%
  - Falling off of counterweight: 49 units

Furniture and Fixtures

- Upper floors: slipping, falling and overturning
- Middle and lower floors: small damage



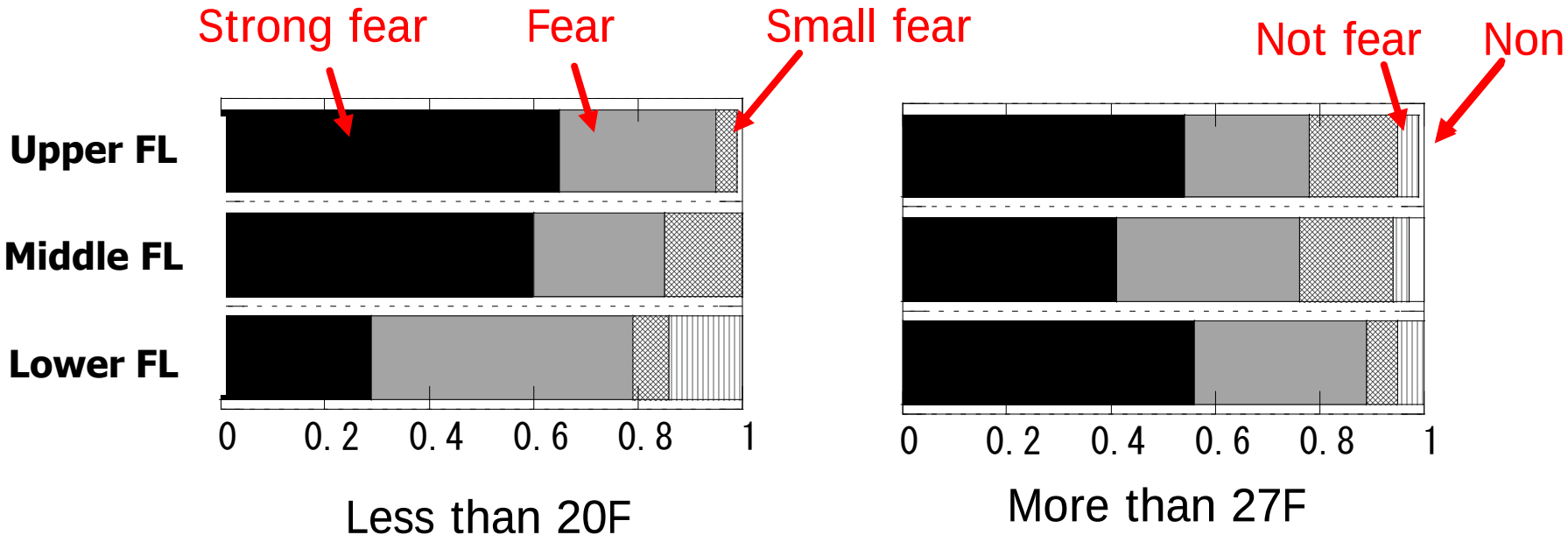
Damage level in High-rise buildings of Tokyo metropolitan area

Difficulty of Act

- More than 80% of the people stayed in the upper floors felt difficulty for moving or walking
- Act normally if the floor response velocity was less than 20cm/s
- Felt the difficulty for standing if response velocity was about 40cm/s
- Not act anything if response velocity was more than 70cm/s

Feeling of Fear

- More than 80% of the people felt intense fear during the earthquake
- Felt like seasickness, nausea and dizziness, felt as if shaking after the earthquake



Less than 20F

More than 27F

Lessons from the Earthquake

Reduce Earthquake damage

- Moving to a safe place and protecting the personal safety is the top priority matter
- An action of building users and occupants, and role of administrator in office buildings should be clarified through the daily anti-disaster drills
- Taking advantage of the emergency earthquake information system and the damage judgment system based on the earthquake observations