Damage due to Earthquakes and Improvement of Seismic Performance of Reinforced Concrete Buildings in Japan

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Summary

- History of Damaging EQ and Revision of Seismic Codes in Japan
- Damage to RC Buildings and Lessons from 1995 Kobe EQ
- Basic Concept of Seismic Capacity Evaluation
- Damage to RC Buildings due to recent EQs
  - 2011 East Japan EQ
  - 2016 Kumamoto EQ

Damaging EQ and Code Revision (1)

1891 Nohbi EQ M8.0

1923 Great Kantoh EQ M7.9 death:140000

◆ *1924 Introduction of Seismic design to building code*
Allowable stress design

1944 Nankai EQ M8？

1945 Toh-Nankai EQ M8？

1948 Fukui EQ M7.3 death:3895

◆ *1950 Building Standard Law*

1964 Niigata EQ M7.5 death:26

1968 Tokachi-oki EQ M7.9 death:52

Damage to RC buildings (shear failure)

◆ *1971 Revision (requirement for mimimum hoop spacing changed from 30cm to 10cm)*

Damage to RC Buildings (1968 Tokachi –oki EQ)

Hakodate Univ.

Damage to RC Buildings (1978 Miyagiken-oki EQ)

Obisan building

Damage to RC Buildings (1978 Miyagike-oki EQ)

Collapse of RC Building with soft (1978 Miyagike-oki EQ)

Damaging EQ and Code Revision (2)

- 1977 Guideline of Seismic Evaluation and Retrofit of Existing Buildings

1978 Miyagi-ken-oki EQ M7.4 Death:28

- *1981 Revision (Ultimate State Design)*

  $C_B = C_o \times D_s$ *(not less than 0.3 for RC)*

  C_B *: Design Base Shear Coefficient*

  C_o *: Design Spectrum*

  (not less than 1.0 g for peak acc.)

  D_s *: Reduction Factor by Ductility*
  (not less than 0.3 for RC)

Damaging EQ and Code Revision (3)

1983	Nihonkai-chubu EQ	M7.7	death:104 (Tsunami)
1993	Kushiro-oki EQ	M7.8	death:2
1993	Hokkaido-nansei-oki EQ	M7.8	death:230 (Tsunami)
1994	Hokkaido-tohou-oki EQ	M8.1	no death
1994	Sanriku-harukaoki EQ	M7.5	death:3
1995	Hyogoken-Nambu(Kobe) EQ	M7.2	death:6430

✓Severer damage to existing buildings

- 1995 Law for Promotion of Seismic Evaluation and Retrofit

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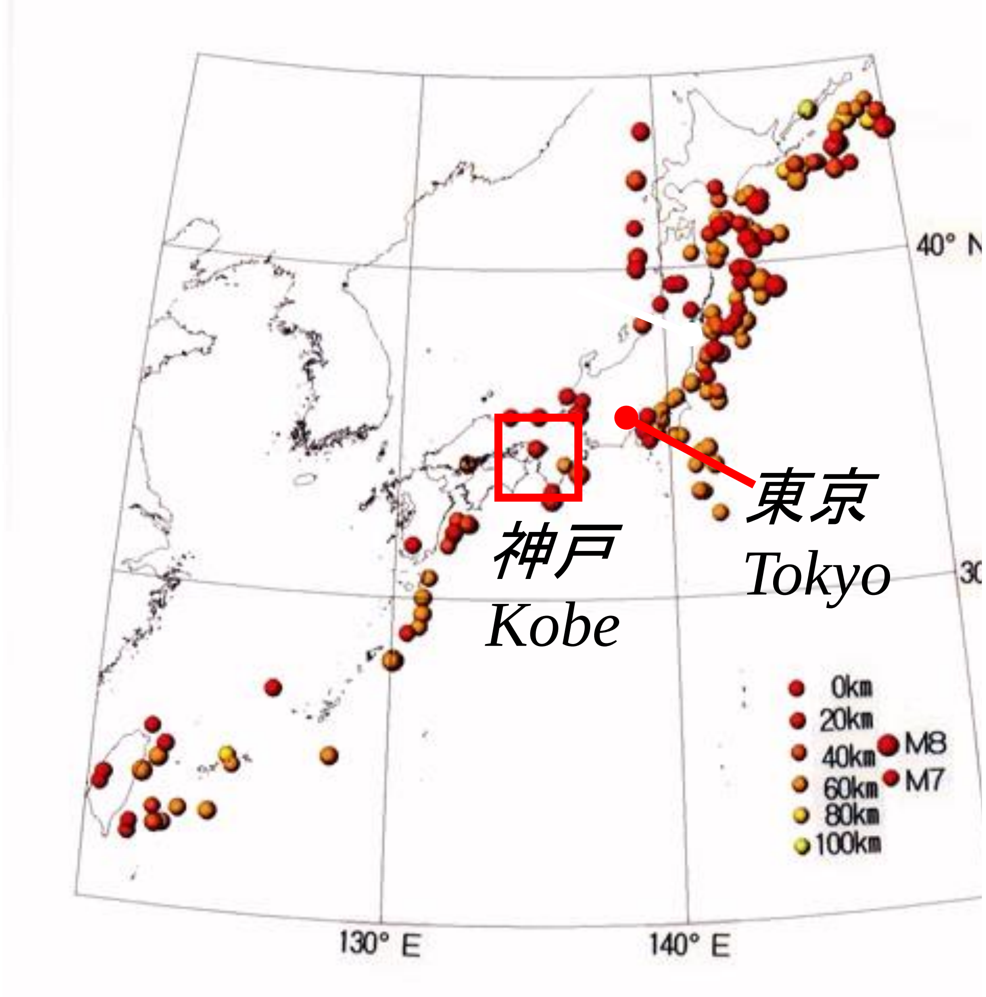
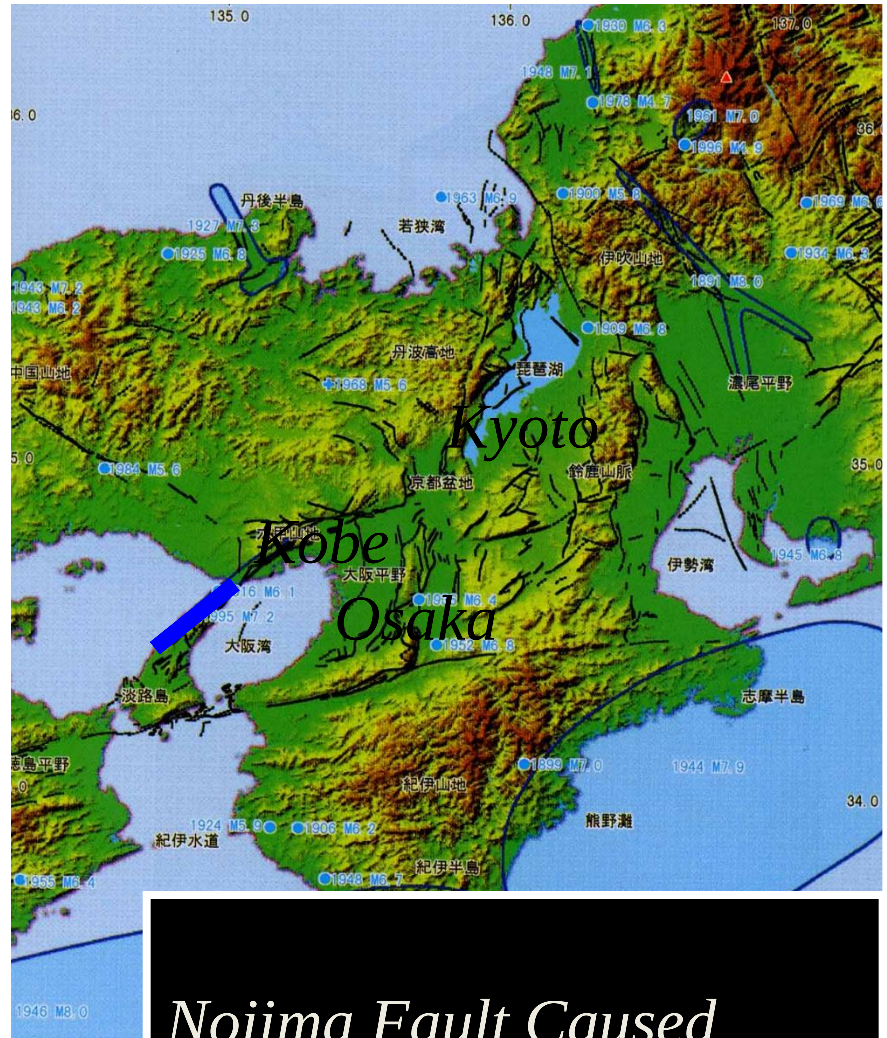
Damage to RC buildings and lessons from 1995 Kobe Earthquake





Nojima Fault Caused 1995 Hyogo-ken Nanbu Earthquake

Collapse of RC Building with soft first story

（1995 Kobe EQ）

Total collapse of RC Buildings

Total collapse

（1995 Kobe EQ）

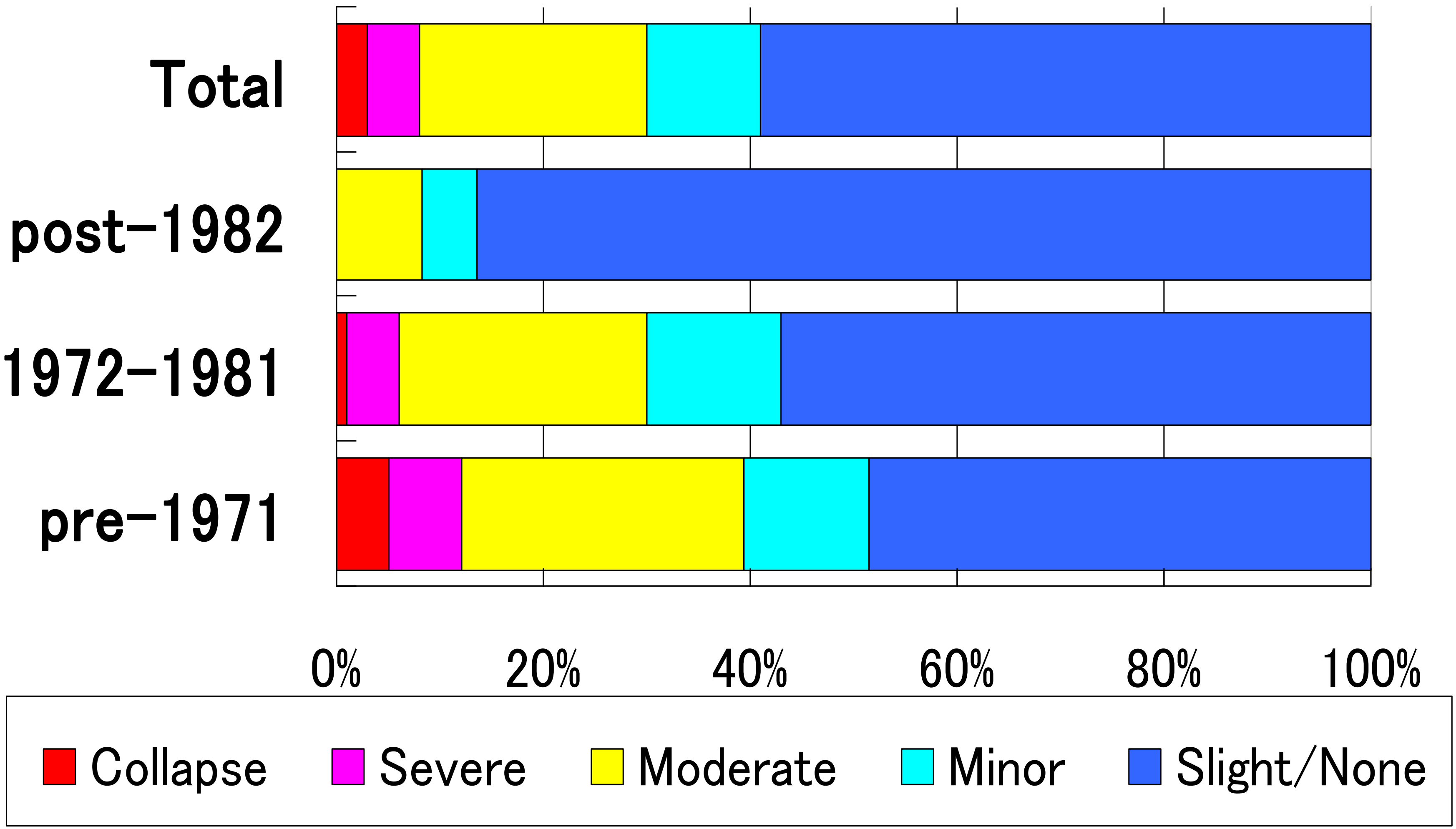
Damage in old and new Buildings

Few hoops (pre-1971)

Hoop spacing is 10cm (Post-1971)

Damage Statistics for RC school buildings

631 RC school buildings



New Law to Promote Seismic Retrofit

- 1995 Oct.

New Law to promote Seismic Evaluation and Retrofit of Pre-code Revision

- School, Hospital, Theater, Department Store, Hotel, Market etc.

($\geqq$ 3 stories and $\geqq$ 1,000m^2 total floor area)

- Equivalent capacity required in the current code
- Japanese *Guideline for Seismic Evaluation and Retrofit* are applied.

Basic Concept of Japanese Seismic Evaluation Guideline

Seismic Capacity Evaluation

Is-Index defined in the Japanese Seismic Evaluation Guideline (1977, revisided in2001)

$$Is = E_0 \times S_D \times T$$

E_0 : Basic structural seismic capacity index

S_D : Shape index (0.4 - 1.0)

T : Age index (0.5 - 1.0)

Basic Structural Index E_0

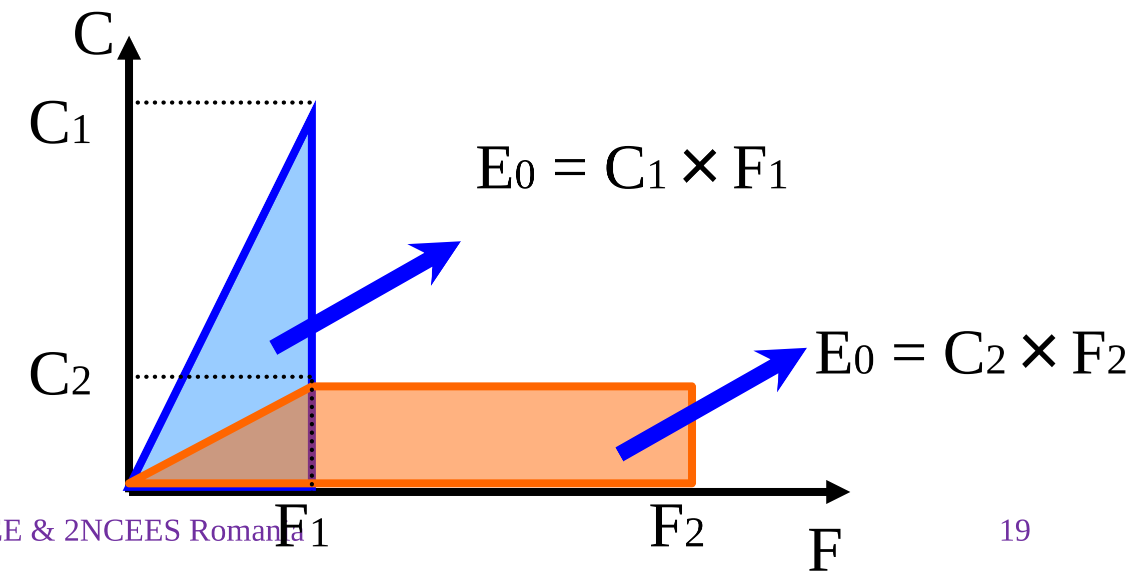
$E_0 = \phi \times C \times F$

ϕ : Mode Shape Factor (1.0 for 1st story)

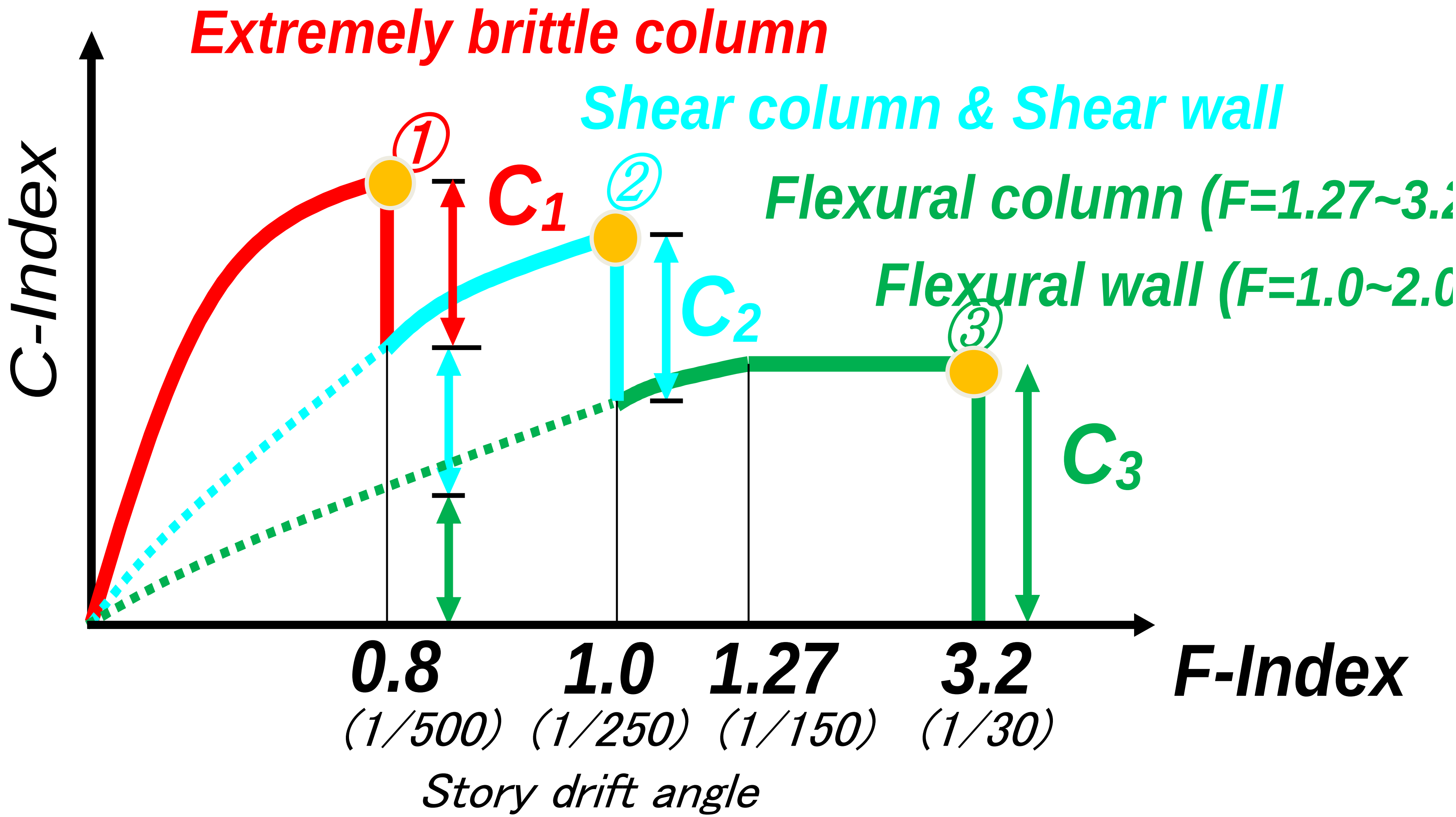
C : Strength Index (Story Shear Coefficient)

= *lateral strength / building weight*

F : Ductility Index (0.8, 1.0-3.2)

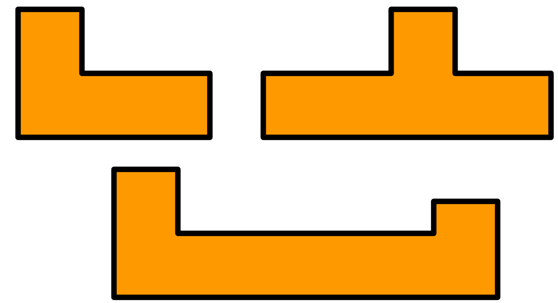


Basic Structural Index E_0 -(2)

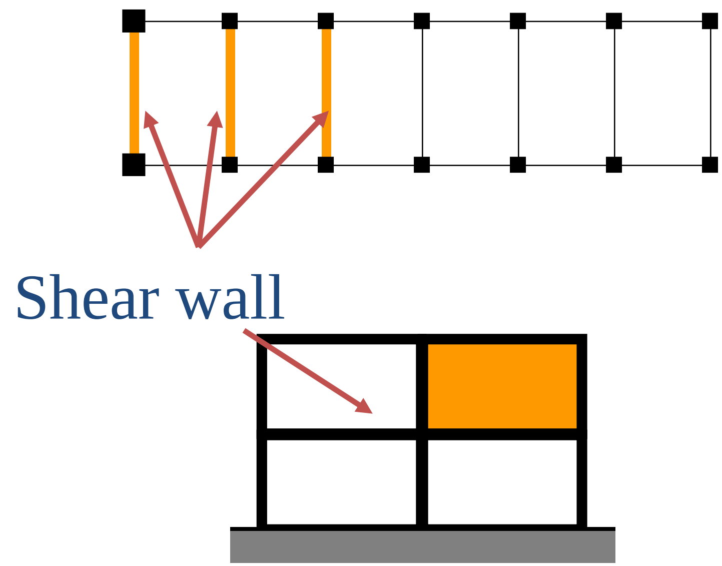


Shape Index S_D

A factor to modify *E_0-index* due to structural irregularity



- Irregular shaped plan
- Unbalanced distribution of stiffness (strength)
  - Torsion
  - Soft story mechanism



Age Index T

A factor to allow for the deterioration of original performance

- Structural Cracking and deflection
  - Crack by uneven settlement, shear crack
  - Deflection of a slab and/or beam
- Deterioration and aging
  - Rust of reinforcing bar
  - Crack by concrete expansion
  - Crack by a fire disaster

Seismic Capacity Evaluation

Is-Index defined in the Japanese Seismic Evaluation Guideline (1977, revisided in2001)

$$Is = E_0 \times S_D \times T$$

E_0 : Basic structural seismic capacity index

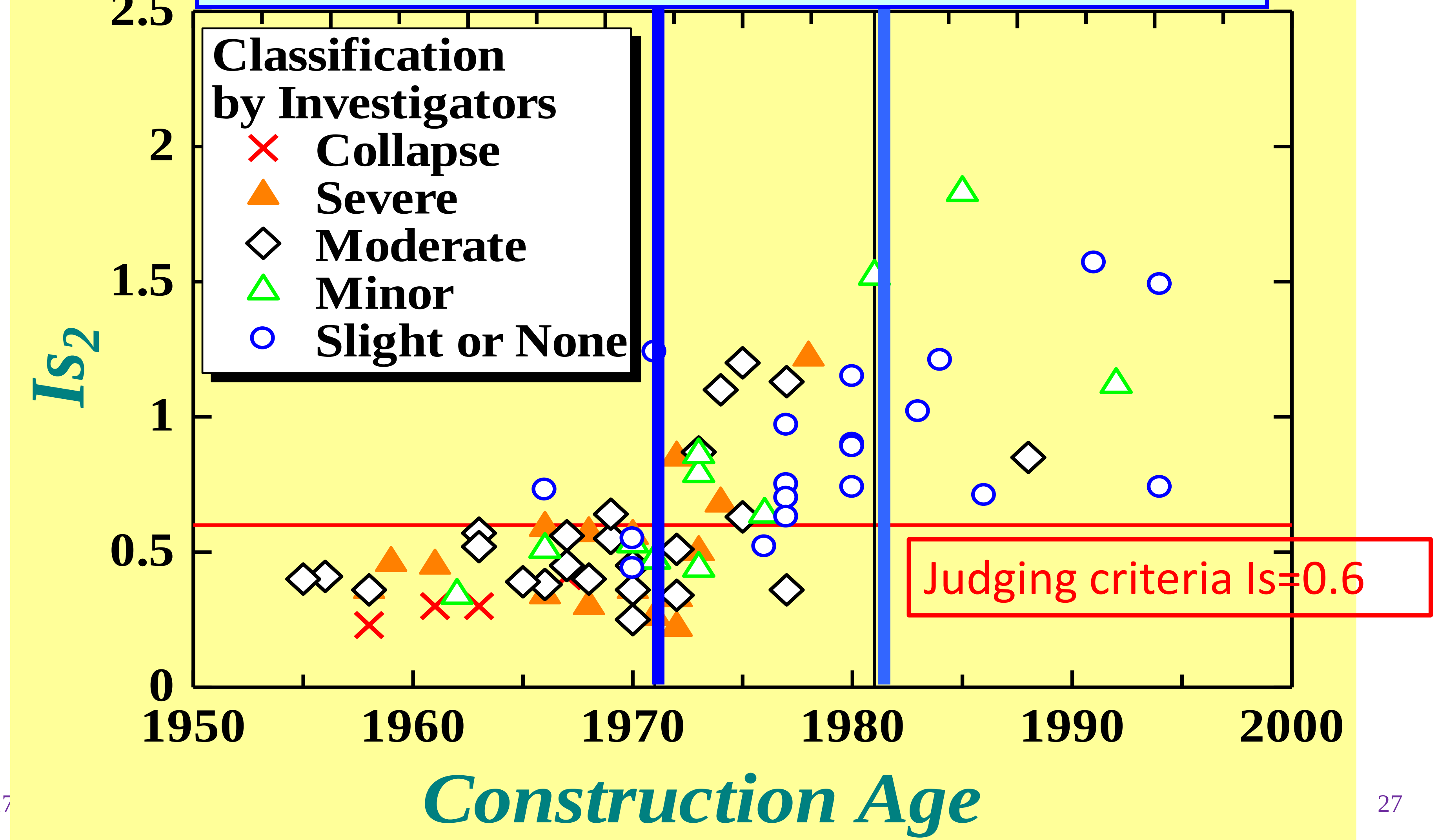
S_D : Shape index (0.4 - 1.0)

T : Age index (0.5 - 1.0)

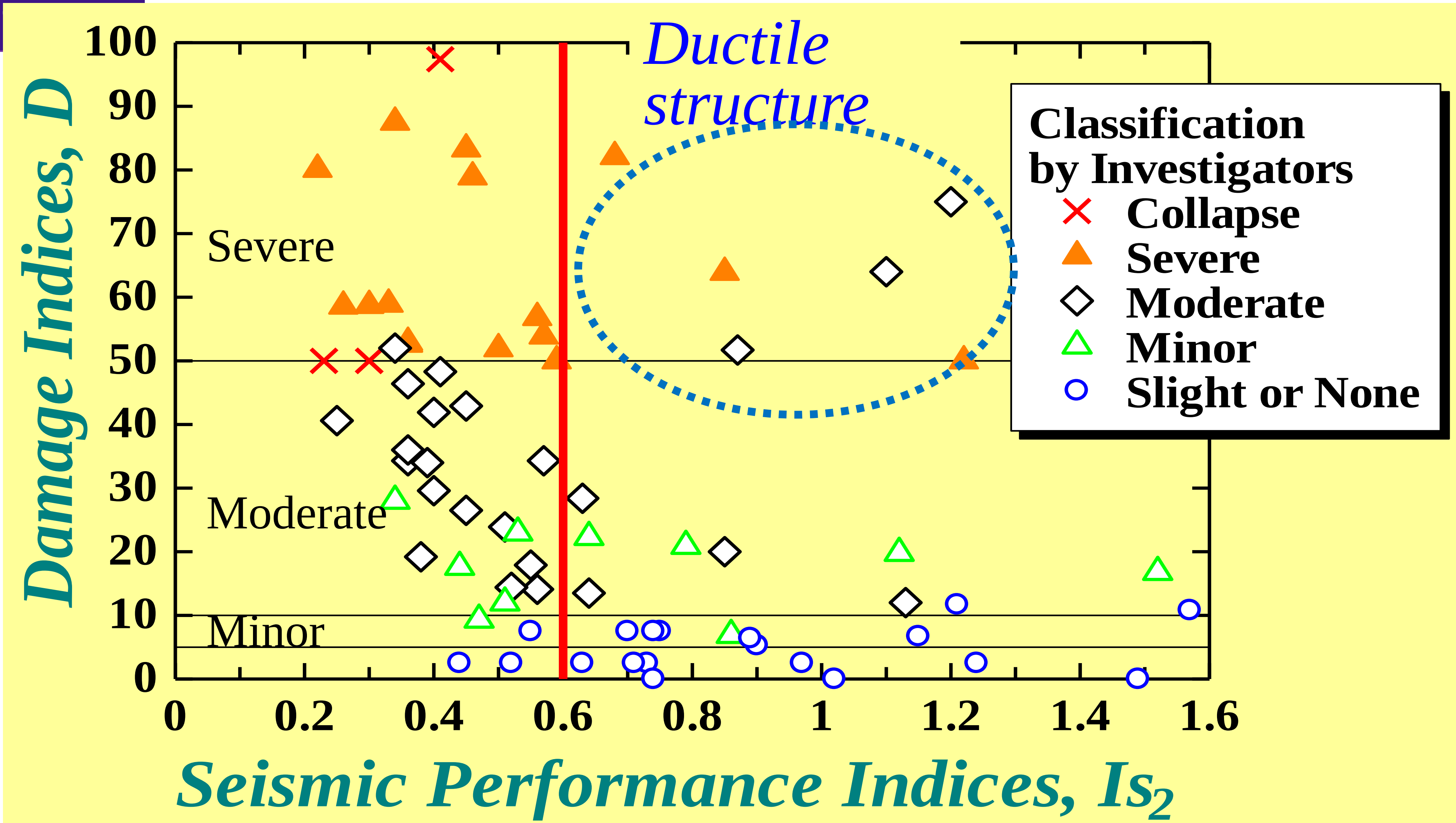
Seismic Capacity Is index vs. Construction Age

No severe damage when Is>0.6

➔Seismic retrofit of buildings before 1981



Damage Level vs. Seismic Capacity Is



Damaging EQ and Code Revision (4)

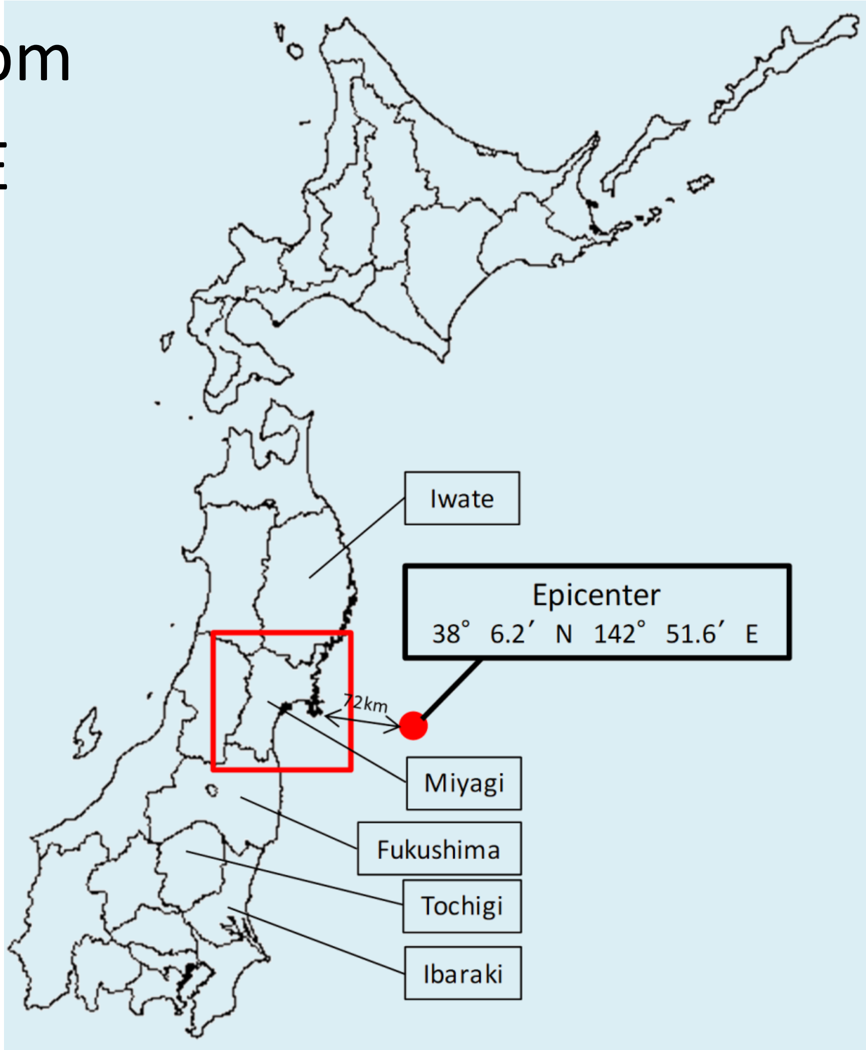
- *2000 Performance-based Design*

2000	Geiyo EQ	M6.7	death:2
2004	Niigata-ken-chuetsu	M6.8	death:68
2007	Miyagi-ken-oki EQ	M6.8	death:15
2011	Great East Japan EQ	M9.0	death:15894, missing: 2561 (Tsunami)
2016	Kumamoto EQ	M7.3	death: 88

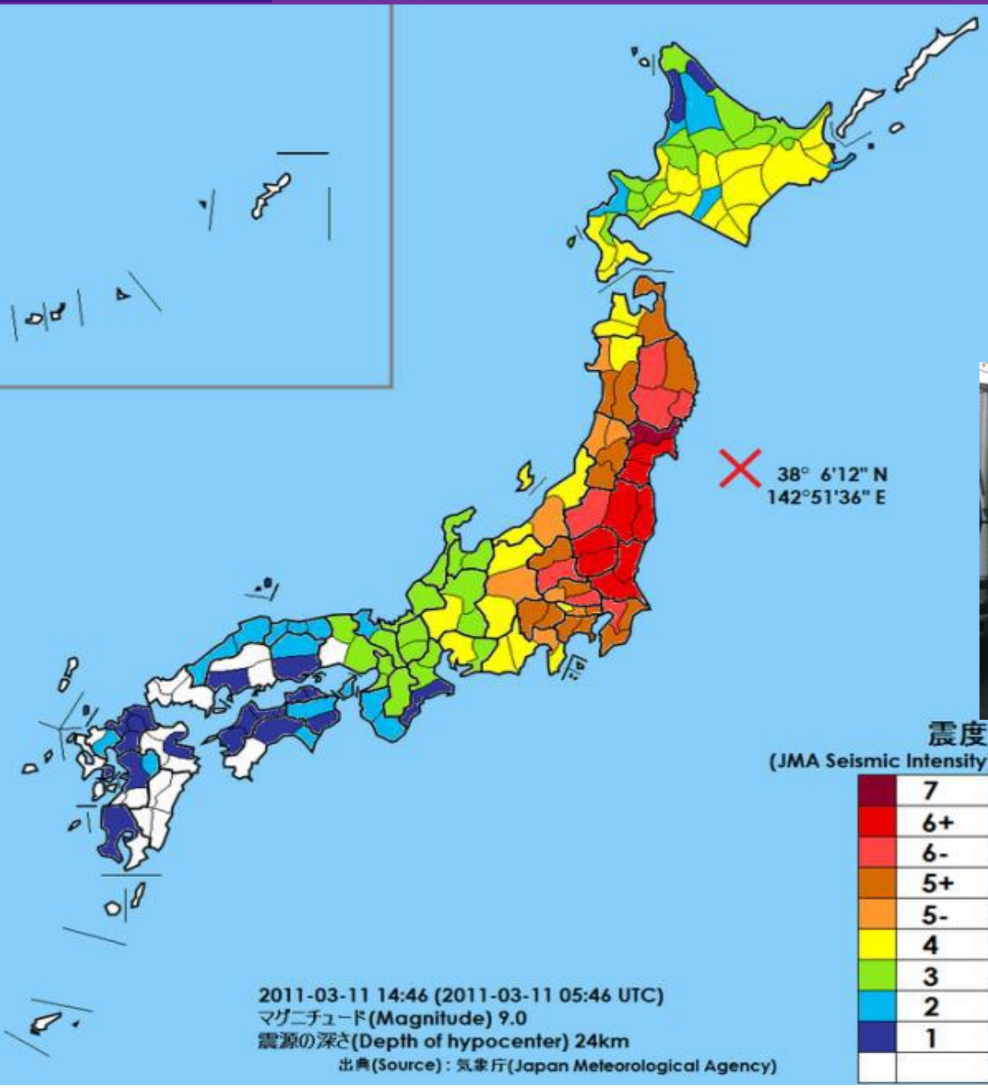
Damage to RC buildings due to 2011 East Japan Earthquake

Summary of 2011 East Japan EQ

- Date: March 11, 2011 at 14:46 pm
- Location: 38.06° N 142.51° E
- Depth: 24km
- Magnitude: 9.0



2011 East Japan Earthquake

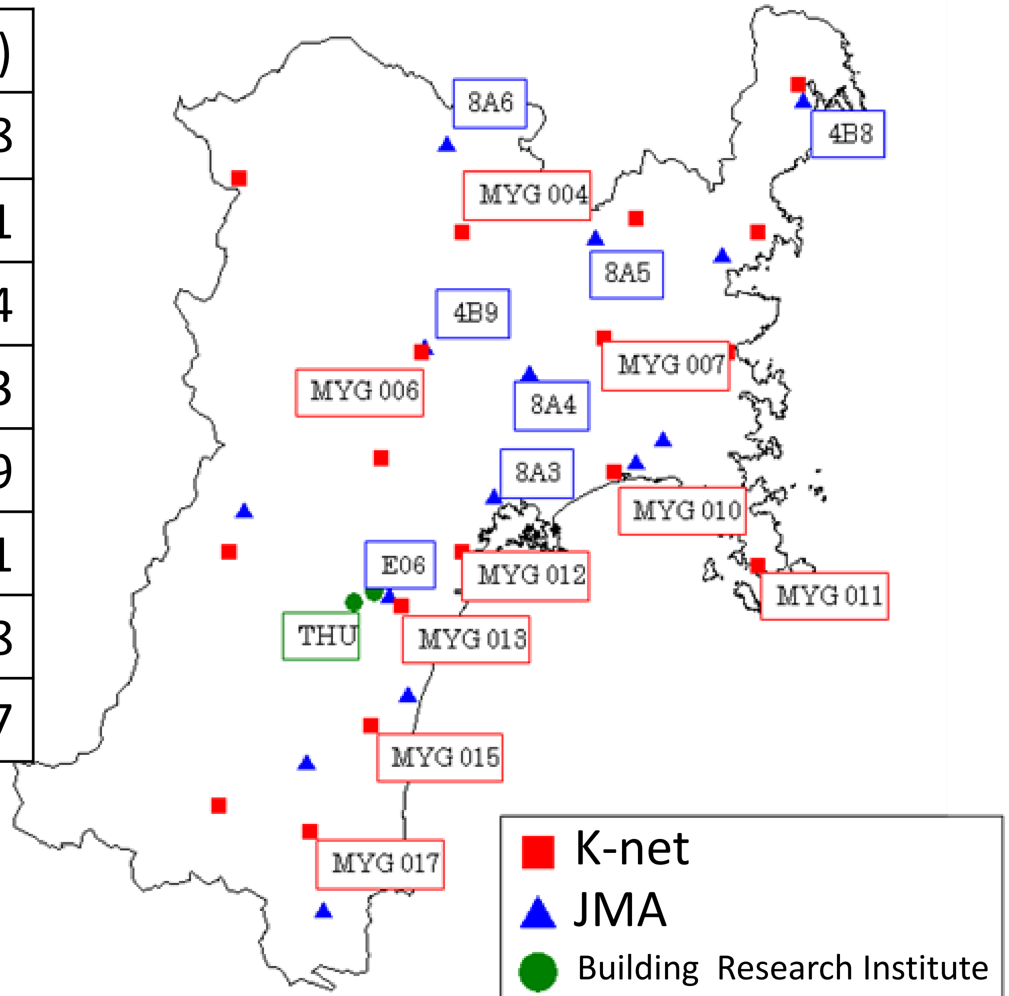


2011/03/11 14:46(JST)

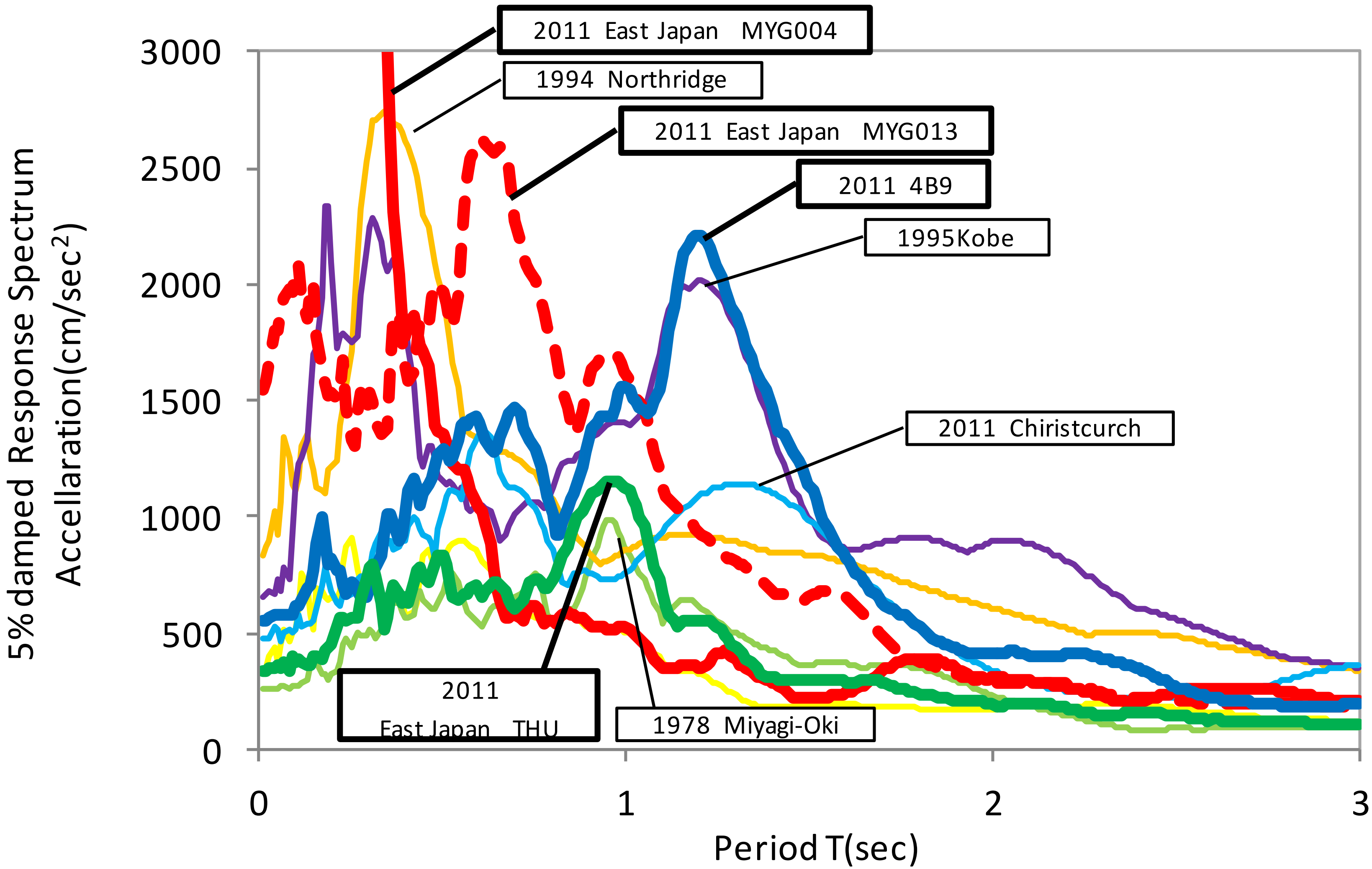
Some old RC building was Damaged

Seismic record in Miyagi pref.

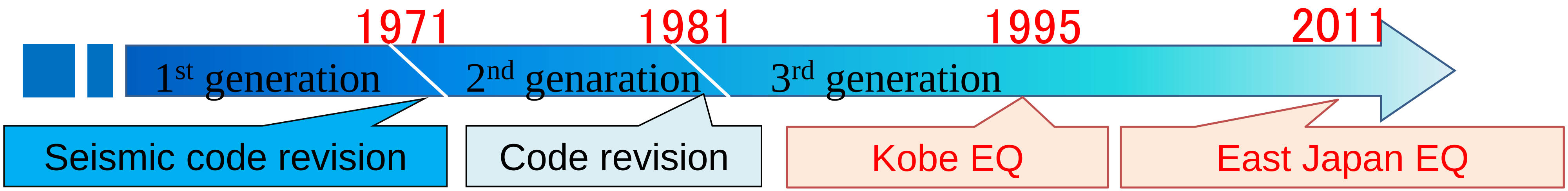
Station		PGA (gal)	PGV (kine)
MYG004 (Tsukidate)	NS	2699	118
	EW	1269	51
MYG013 (Sendai)	NS	1517	84
	EW	982	43
THU (Sendai)	NS	332	49
	EW	330	61
JMA 4B9 (Furukawa)	NS	550	78
	EW	456	87

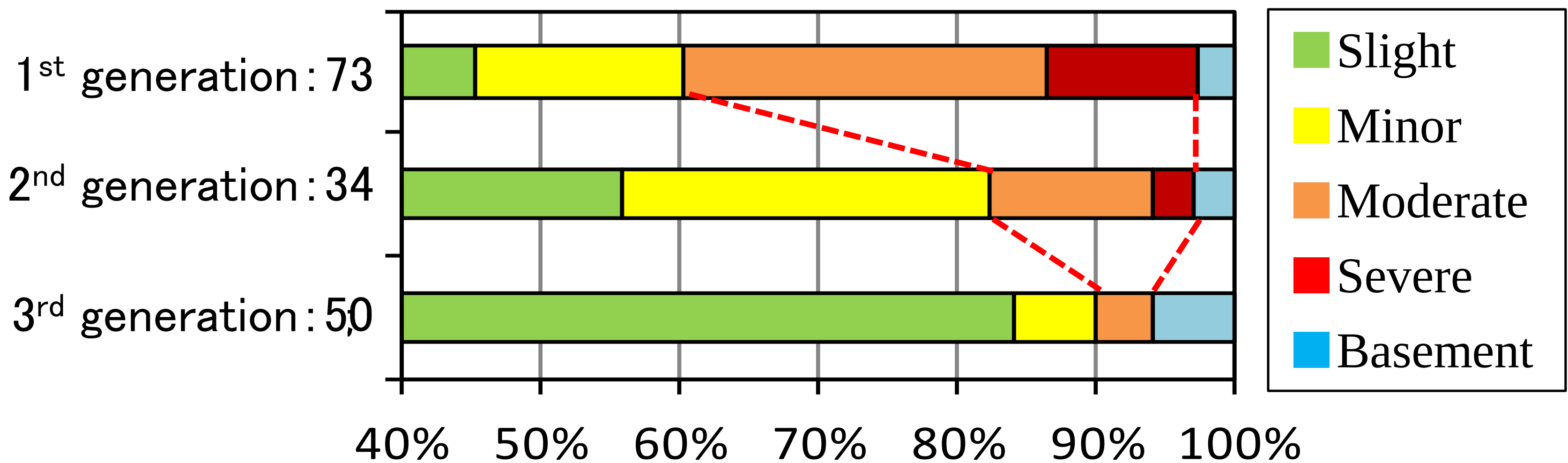


Acceleration spectrum



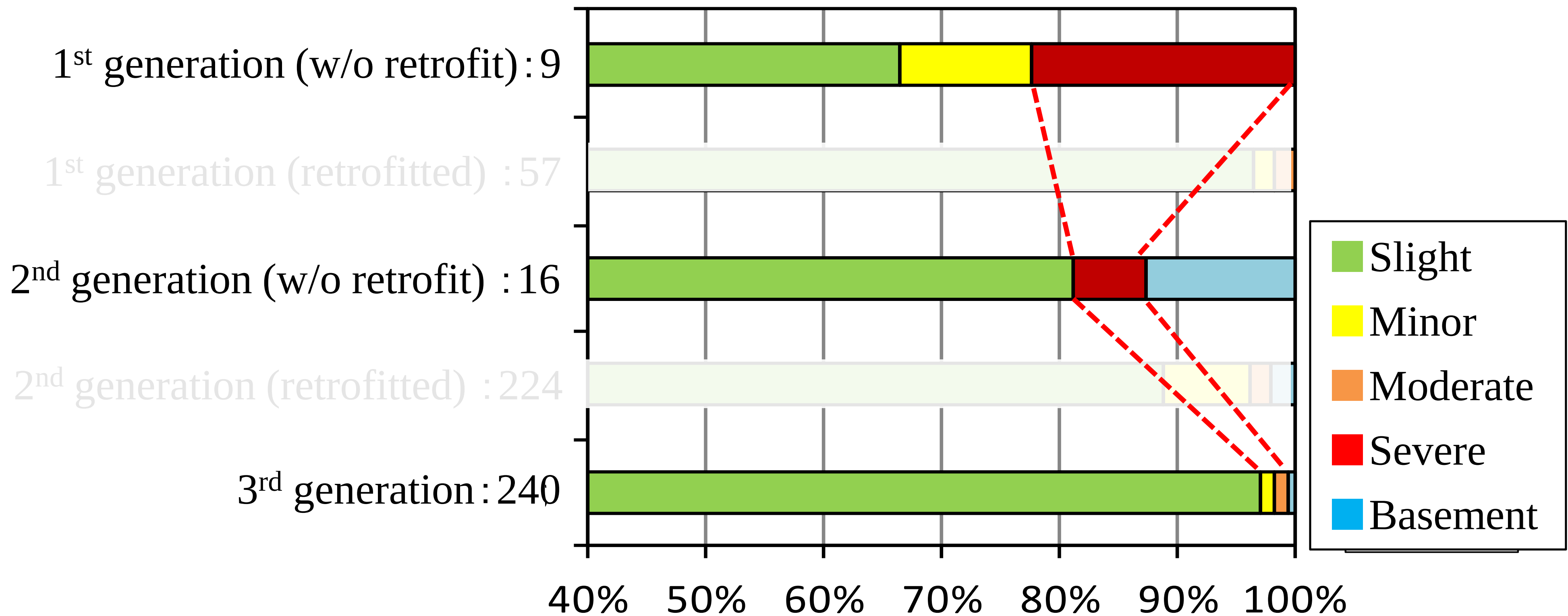
Damage ratio of RC school buildings due to 1995 Kobe Earthquake





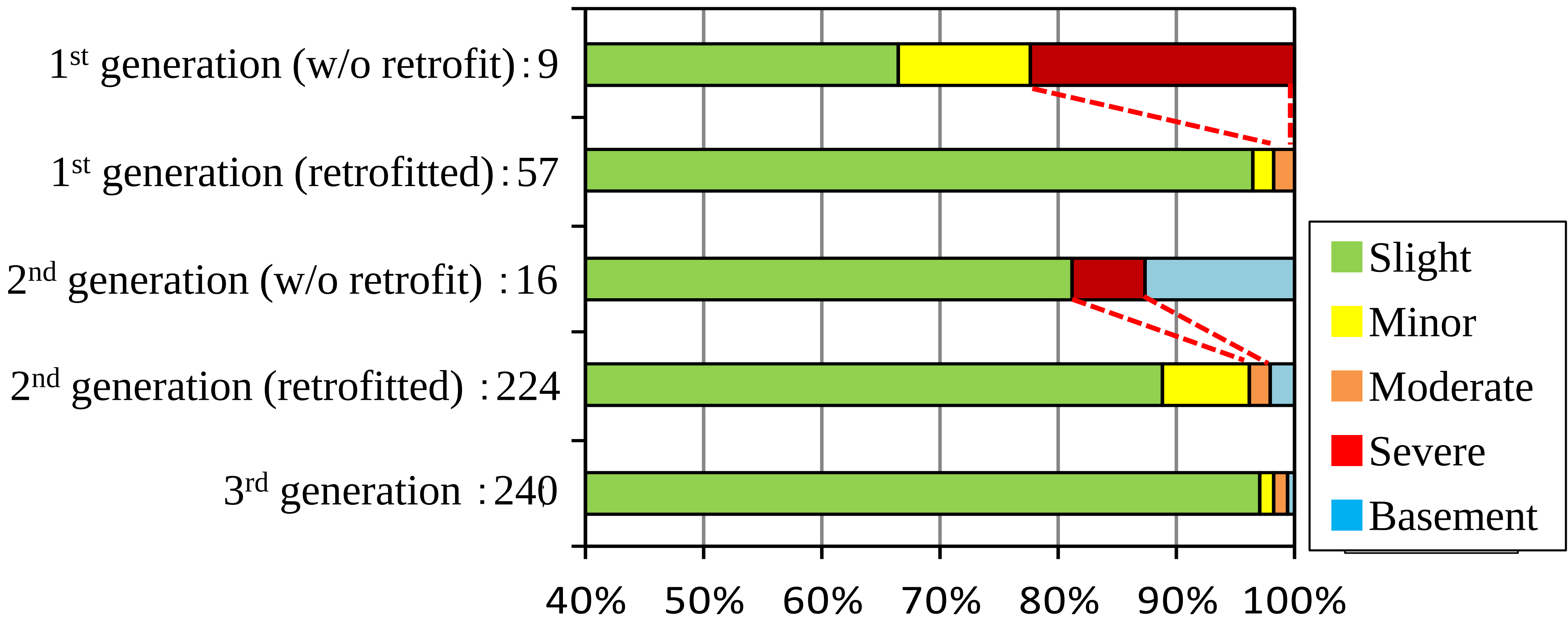
Less damage for new buildings owing to seismic code revision

Damage ratio of RC school buildings due to 2011 East Japan Earthquake



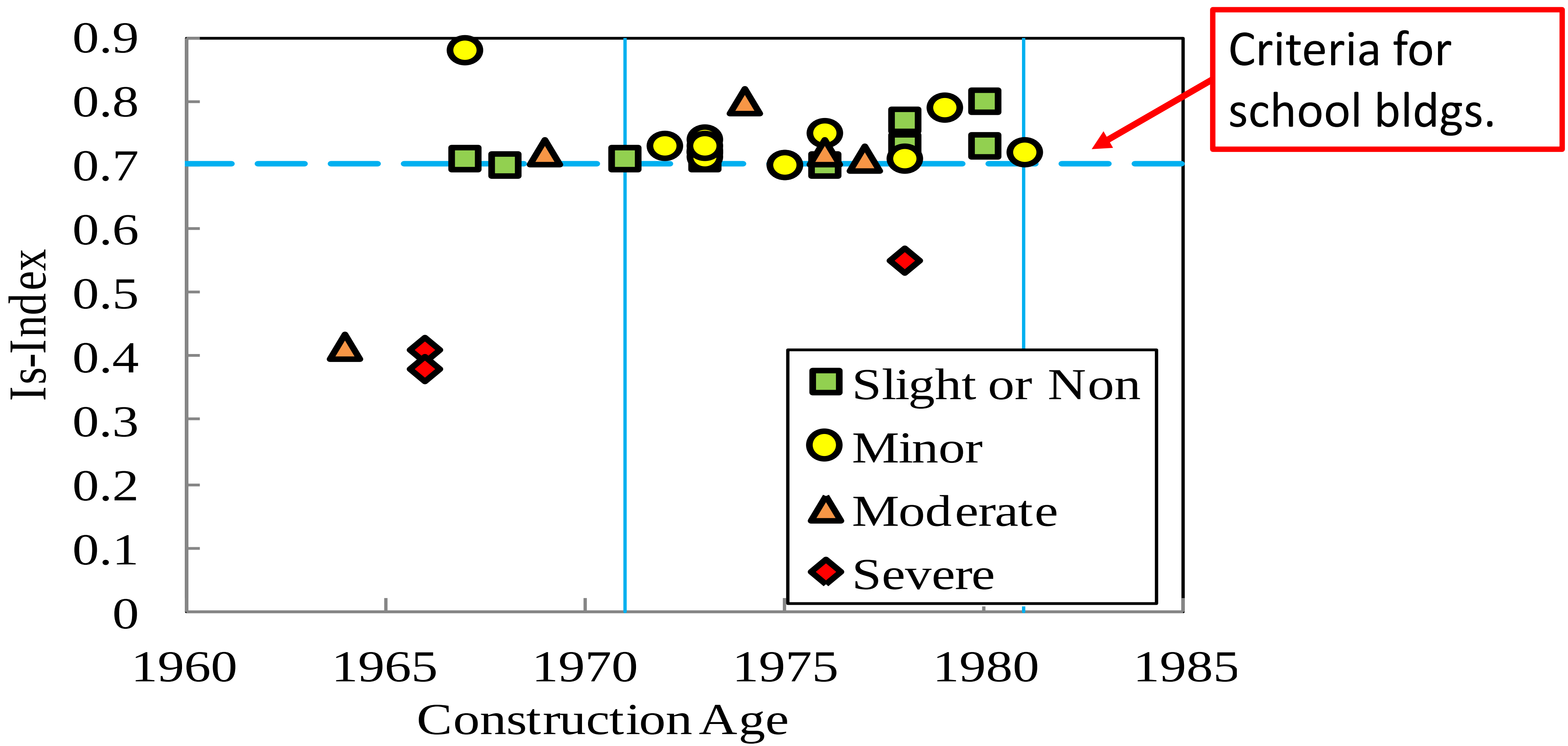
Less damage to new buildings

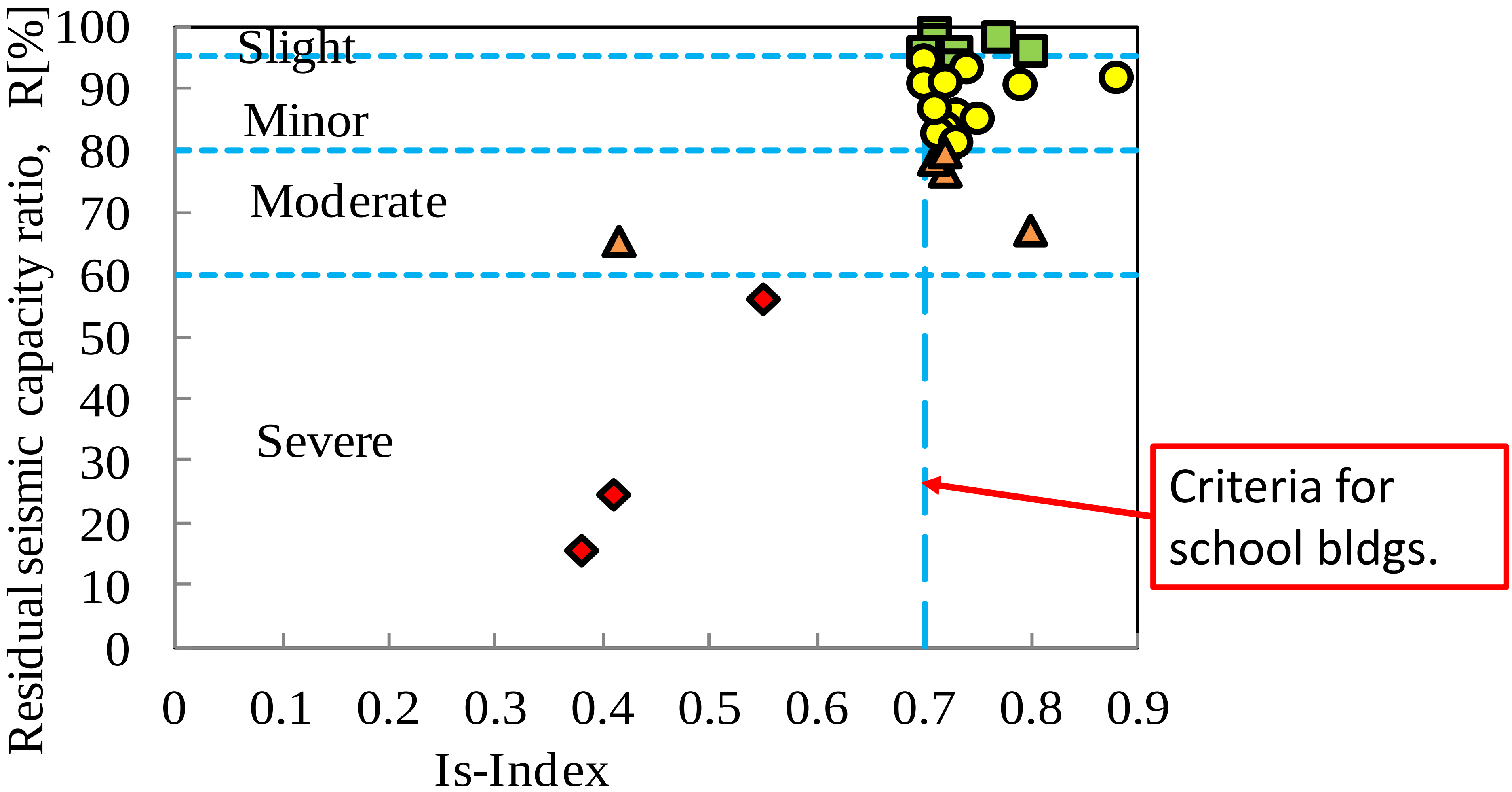
Damage ratio of RC school buildings due to 2011 East Japan Earthquake



Less damage for retrofitted buildings

Seismic Capacity Is index vs. Construction Age 2011 East Japan





Residual seismic capacity ratio, R[%]
100
90
80
70
60
50
40
30
20
10
0
Slight
Minor
Moderate
Severe
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Is-Index
Criteria for school bldgs.

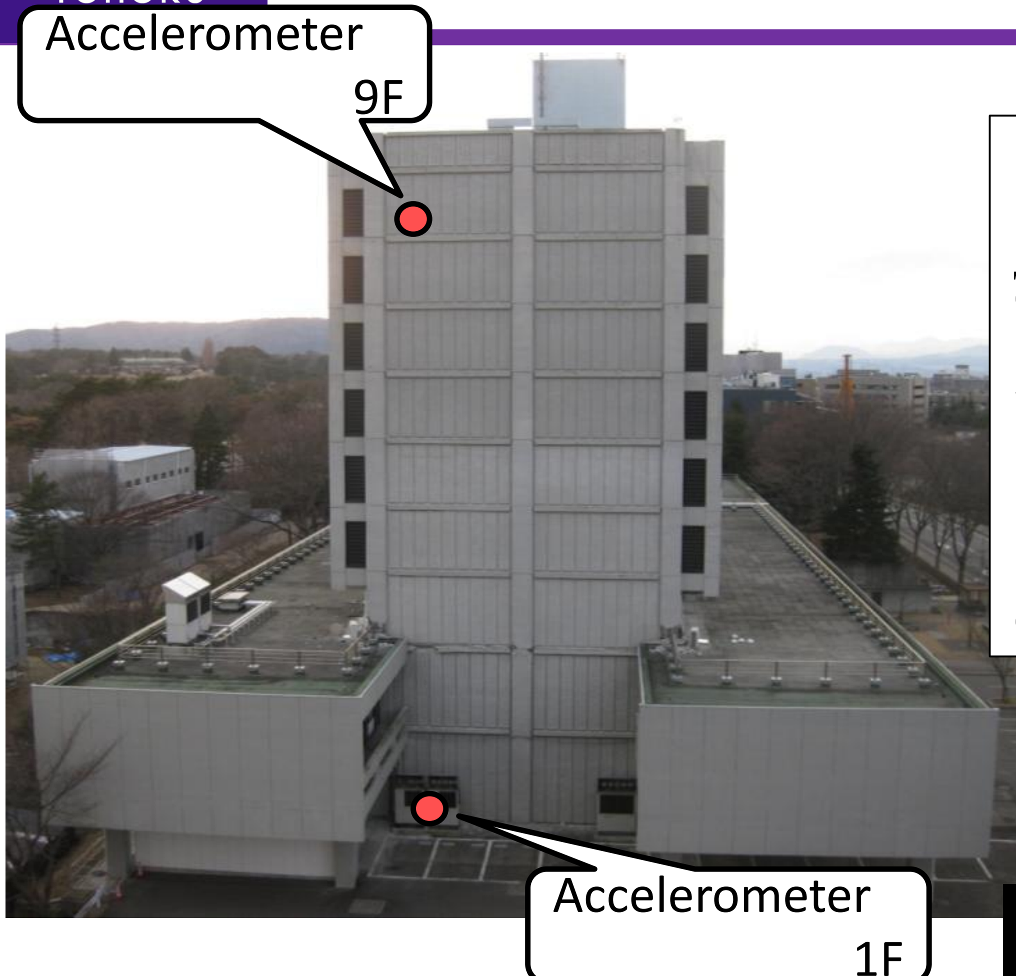
Summary of damage

- Seismic capacity of existing RC school buildings in Miyagi prefecture were much improved owing to *seismic evaluation & retrofit*.
- Good correlation between Is-index and damage level is observed.

however,

- Some of *retrofitted* and *evaluated-safe* buildings suffered from damage, even though they escaped collapse. Those buildings were un-functional and some were demolished.

Building of civil eng. and architecture, Tohoku Univ.



Strong motion Observe

1968年 Constructed

1978年 Miyagi Oki earthquake

Moderate damage

2001年 Seismically Retrofitted

2011年 Great East Japan earthquake

Severe damage

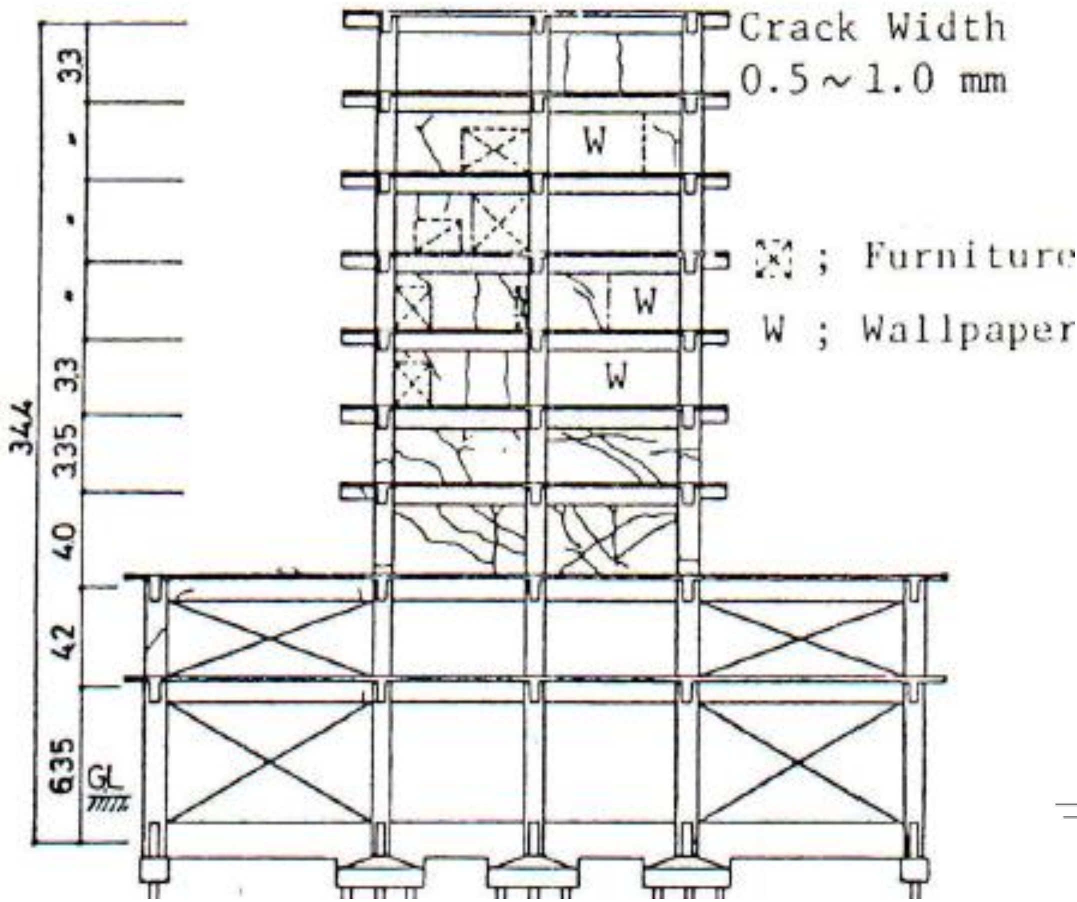
experience large earthquake

retrofitted ⇒ severe damage

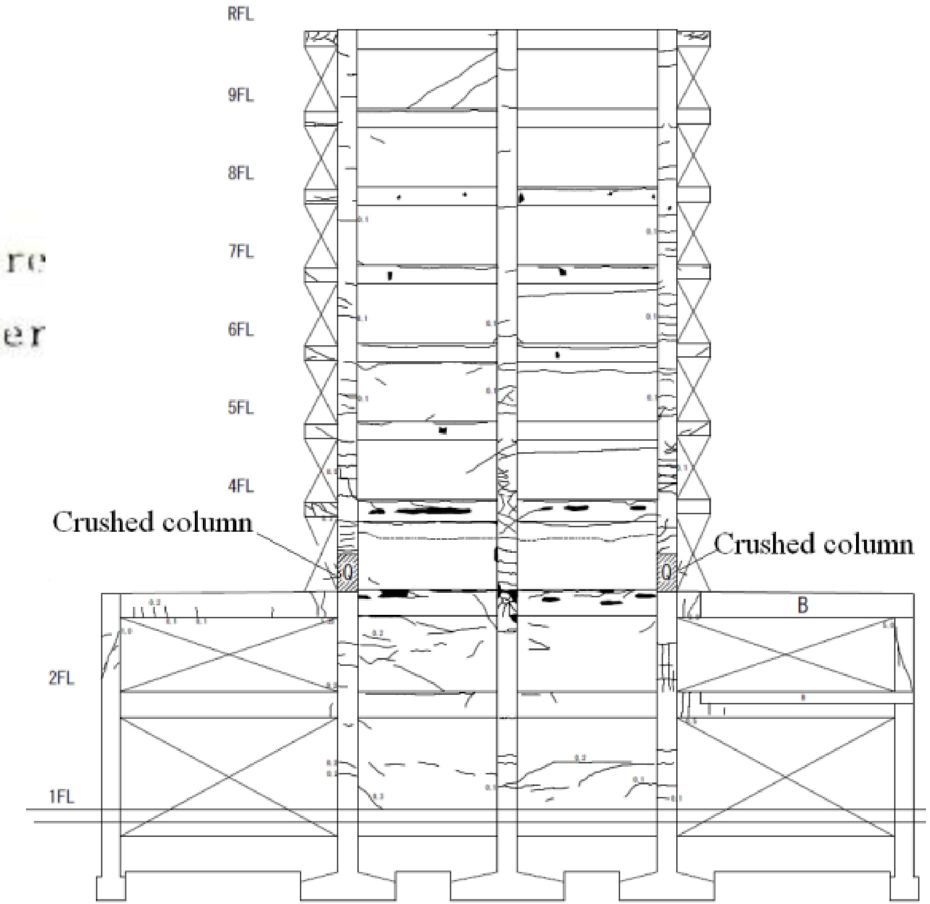
Strong motion was observed over 40years

Damage (crack) pattern

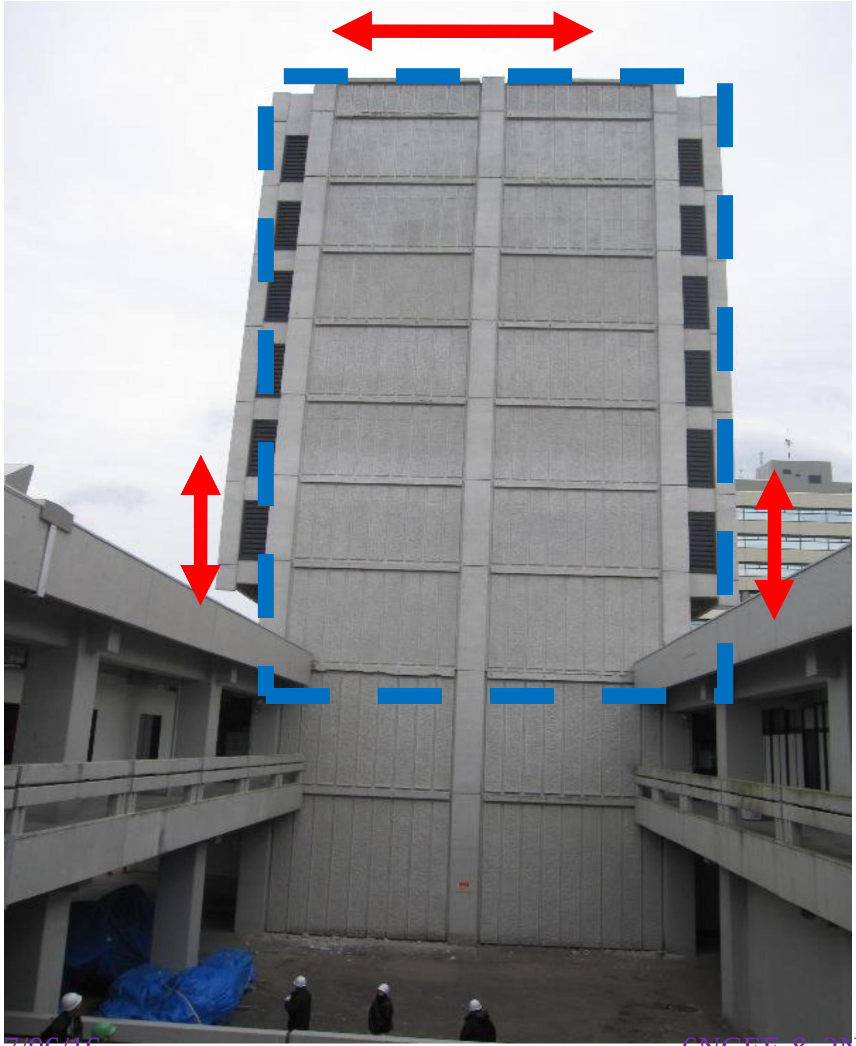
1978 EQ



2011 EQ



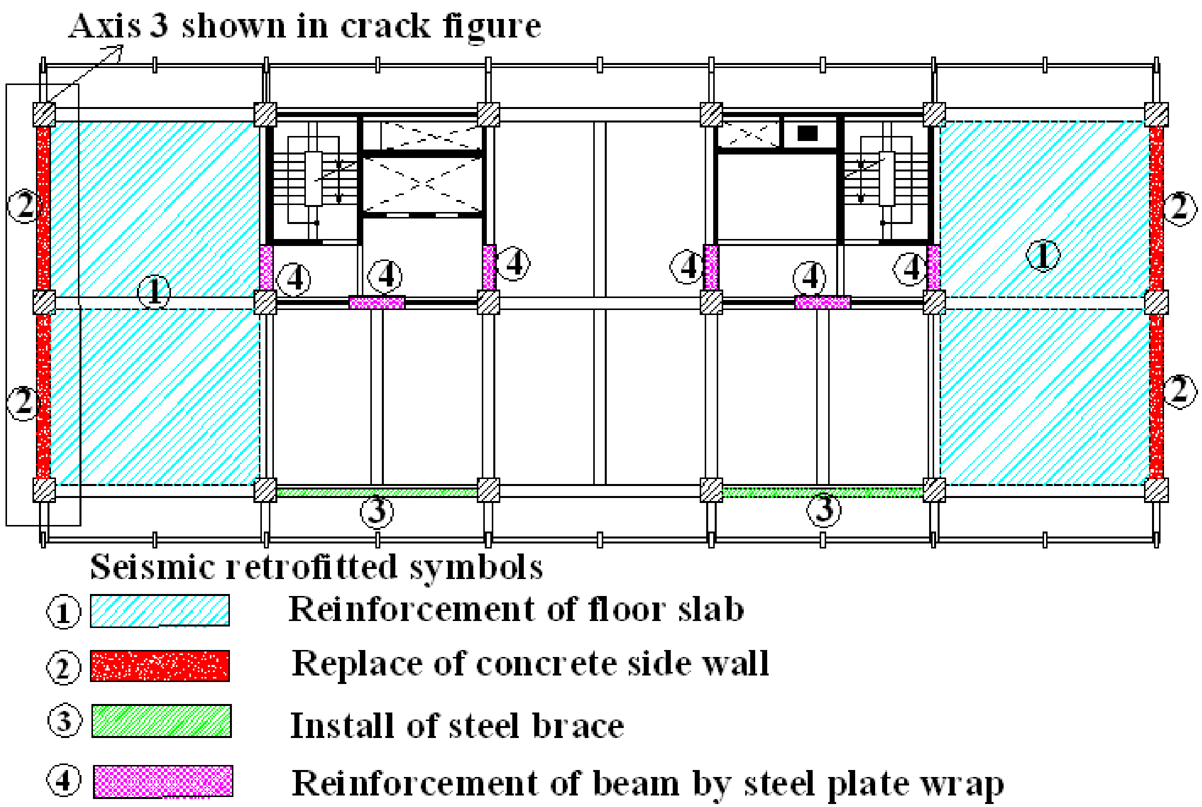
Damage to Building of civil eng.



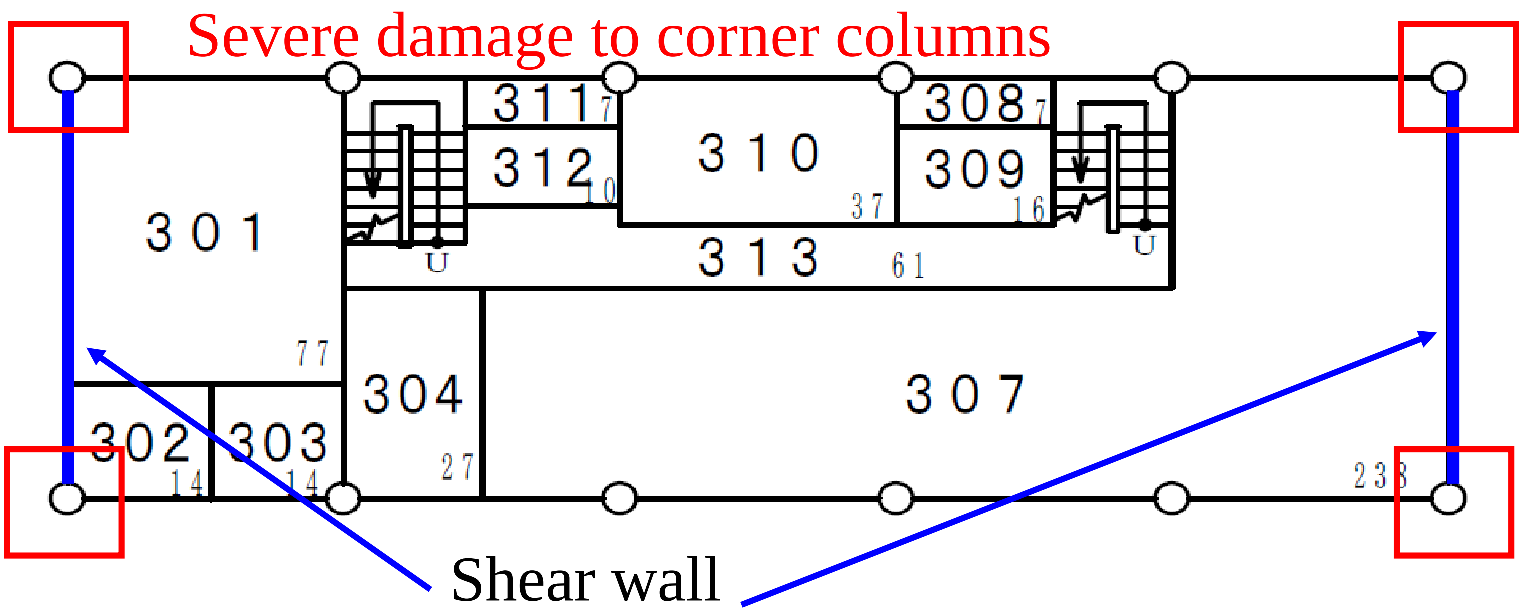
- 3rd story was most severely damaged.
- Large displacement occurred in shear wall.
- Spalling and crush of concrete, fracture and buckling of rebars are observed in corner columns.

3rd floor plan and seismic retrofit

- Damage levels are classified by residual seismic capacity ratio R.
- Correlation between damage level and Is-index are observed.



Damage to columns in 3rd story



Damage to shear wall and columns in 3rd story

High axial load in column due to oveturnning moment

Damage to corner columns in 3rd story

Primary School Buildings

3 stories RC building,

Const. in 1974

- West side structure

  Is=0.8 > Iso(required)

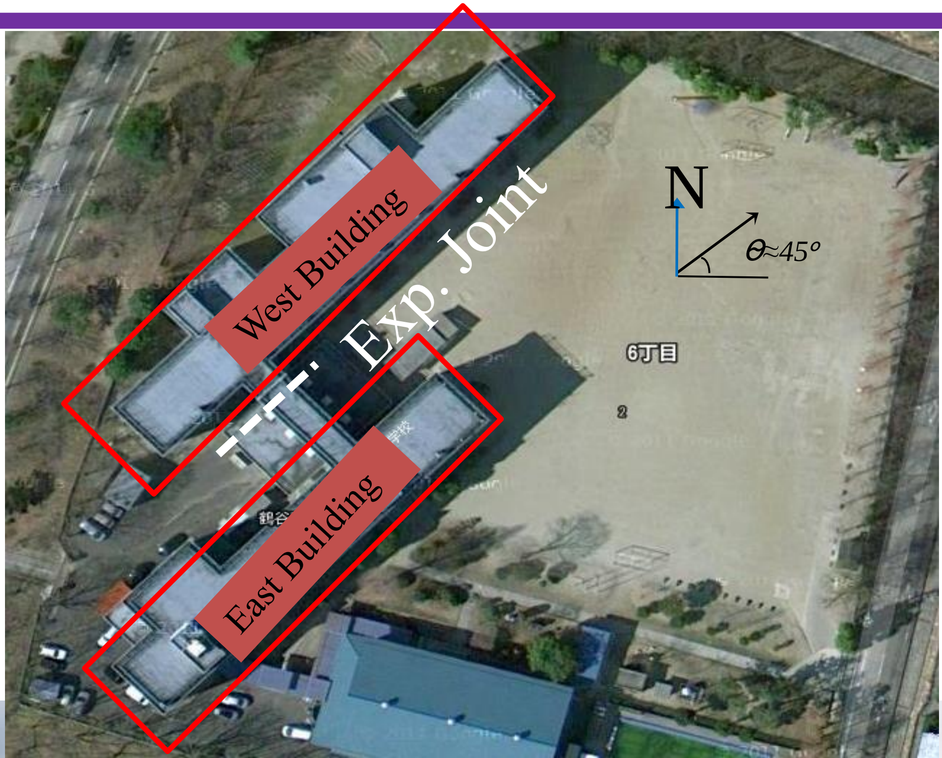
No Retrofit was needed

  moderate damage

- East side structure

  Seismically retrofitted

  slight damage



Seismic Capacity

	C	F	SD	T	Is
East Building *before* retrofit	**0.66**	**1**	0.88	0.98	**0.57**

	C	F	SD	T	Is
East Building *after* retrofit	**0.88**	**1**	0.88	0.98	**0.75**

Slight damage

	C	F	SD	T	Is
West Building	**0.5**	**1.75**	0.93	0.98	**0.8**

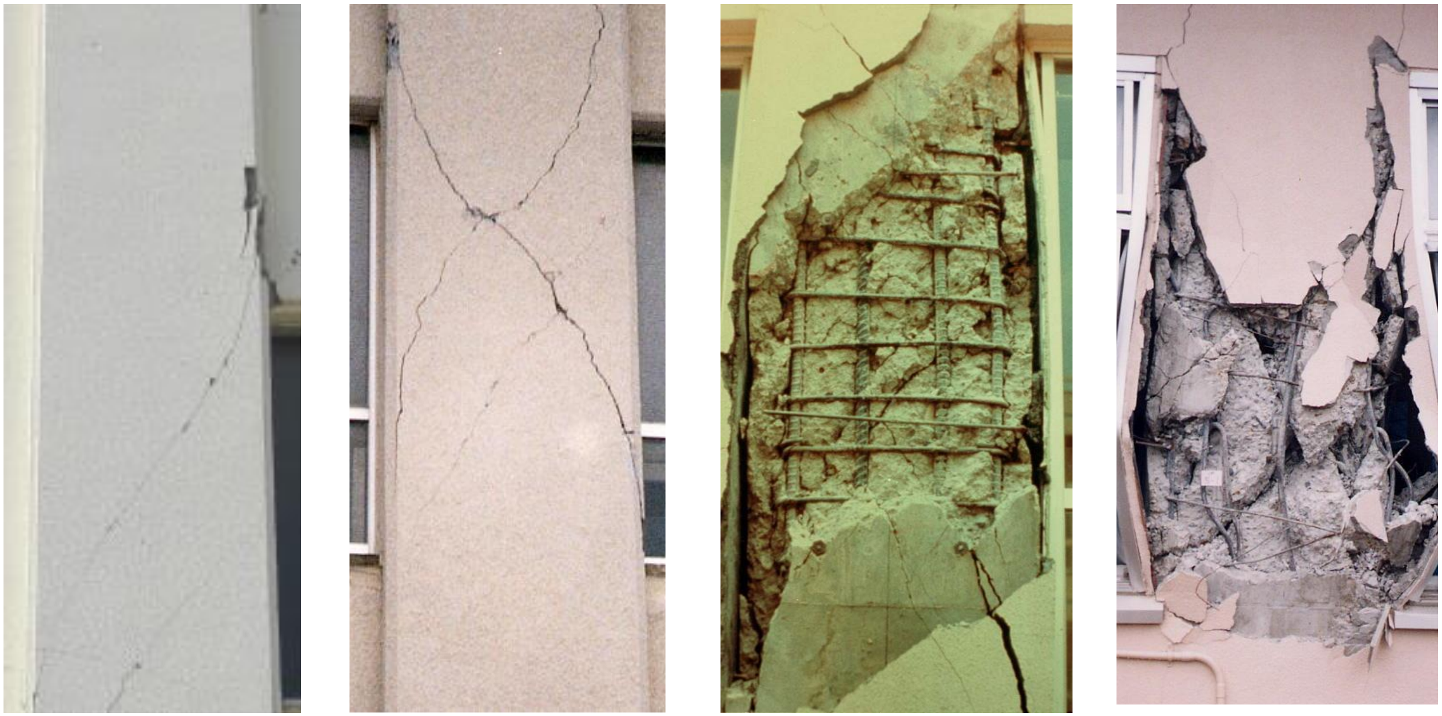
Ductility = Damage

Moderate

Shear failure of column and wall observed in un-retrofitted west building

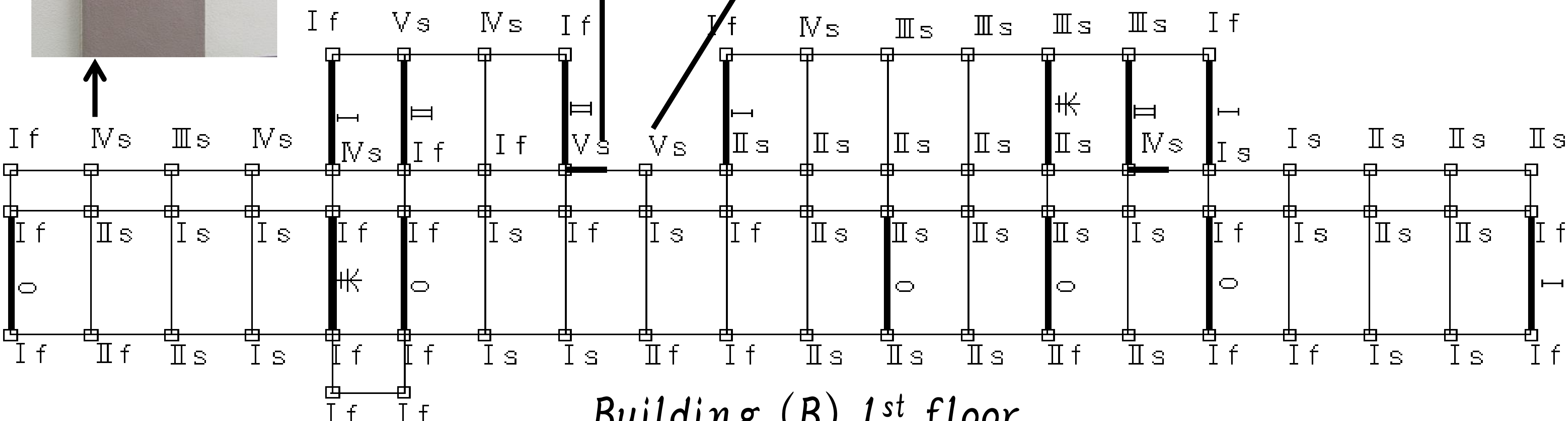
Short column failed in shear

Damage classification of "*Post-earthquake Damage Evaluation Standard*" used in Japan



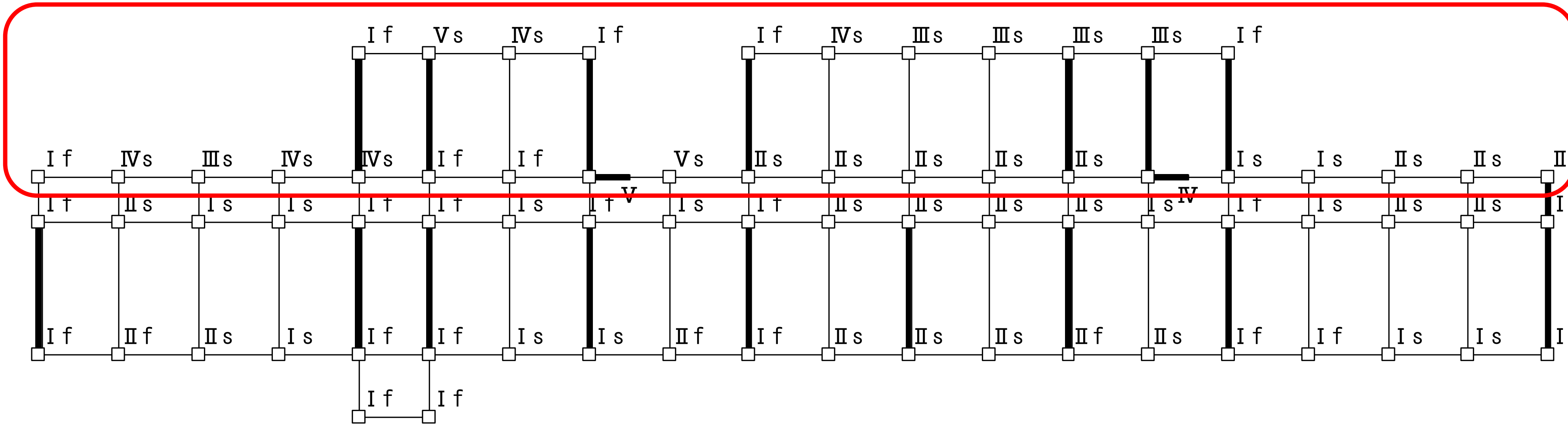
II　III　IV　V

Damage distribution in west building

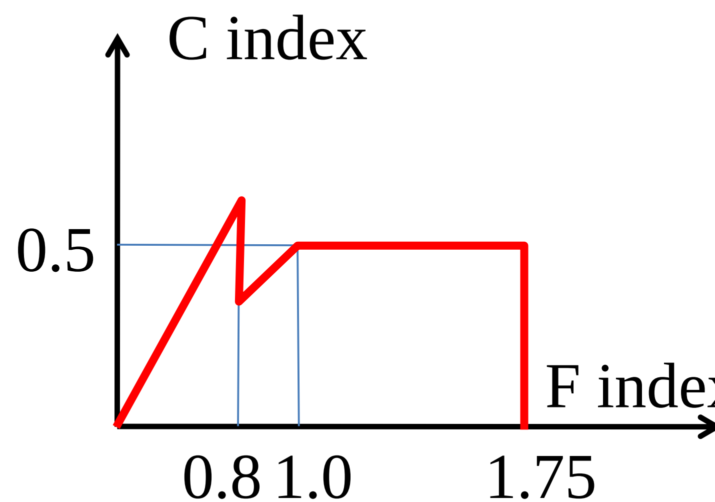


Building (B) 1st floor

Damage distribution



- Damage was concentrated to short columns in North side corridor.
- Is= strength index X ductility=C X F = 0.5 × 1.75 =0.8 by ignoring brittle short column.
- The damage pattern agree with seismic evaluation results.



Less damage to retrofitted building

Seismically retrofitted by steel bracing

Effect of seismic retrofit was observed

Damage to non-structural concrete walls in apartment

- Const. in 1979
- 11 story, SRC
- Enough is-index, but…

Damage to non-structural elements

RC non-structural walls failed in shear

- RC moment frame structure escaped from major damage.
- However,…. Demolished.

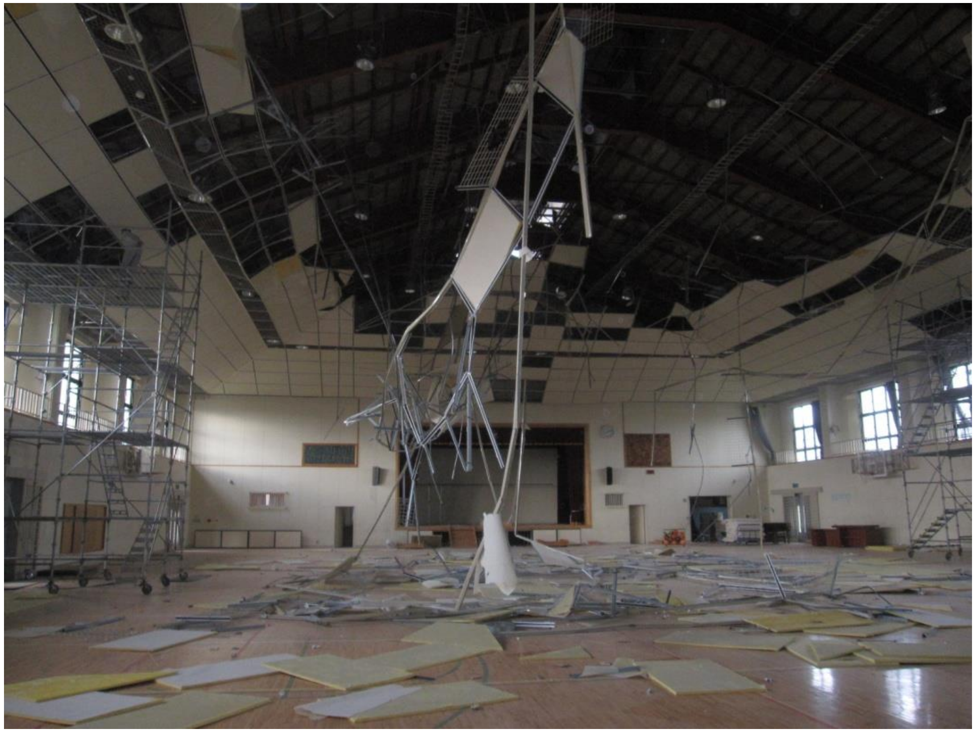
Damage to Non structural element

- Gym

  constructed about 10 years ago

  - Rehabilitated after Iwate-Miyagi EQ in 2008
  - Again damaged by 2011 earthquake

Non structural element damage
(Junior high school gym in Kurihara city)



Large parts of the ceiling fell down
（3/11, and also in 4/7）

The fixed parts after 2008 EQ
escaped damage

Damage by tsunami

Onagawa town

Minami Sanriku town

Damage by tsunami

Most of students and teachers were killed by tsunami.

Damage by tsunami


Passage collapsed due to tsunami.


Bottom of column of passage.

Damage to buildings due to 2016 Kumamoto Earthquake

Affected area & Epicenter

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Damage in Mashiki town

- Local destructive damage
- Some of current code timber houses suffered collapse or sever damage

Madage in Mashiki town

- Damage to steel and RC strucutures




Damage in Minami Aso village

- Land slides around Aso Mt.

Results of Quick Inspection in Kumamoto

	inspected number	Green	yellow	Red
Kumamoto city	30,487	14,126	10,514	5,847
Ratio[%]	100	46	35	19
Mashiki town	9,769	3,006	2,957	3,806
Ratio[%]	100	31	30	**39**
Uto city	1,265	506	531	228
Ratio[%]	100	40	42	18

Damage to RC buildings

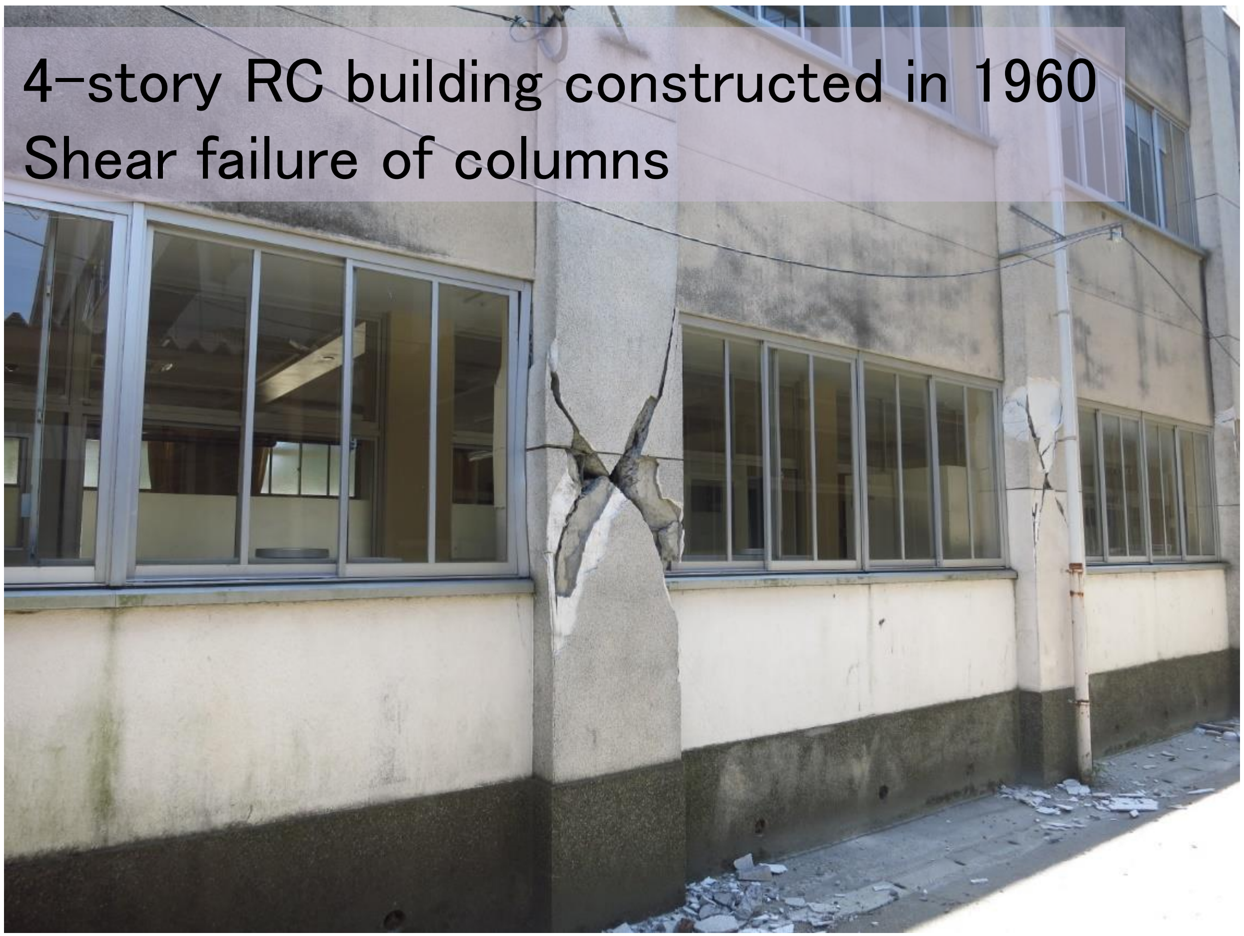
- ◆ Un-retrofitted buildings designed by old seismic code.
- ◆ Soft first story collapse.
- ◆ Non-structural elements (nonstructural wall, ceiling etc.).

➔Most of the damage was similar to those observed in the past earthquakes

Important point is to speed up retrofit schemes to existing vulnerable buildings

Building designed by old seismic code without retrofitting

- Buildings of high school C

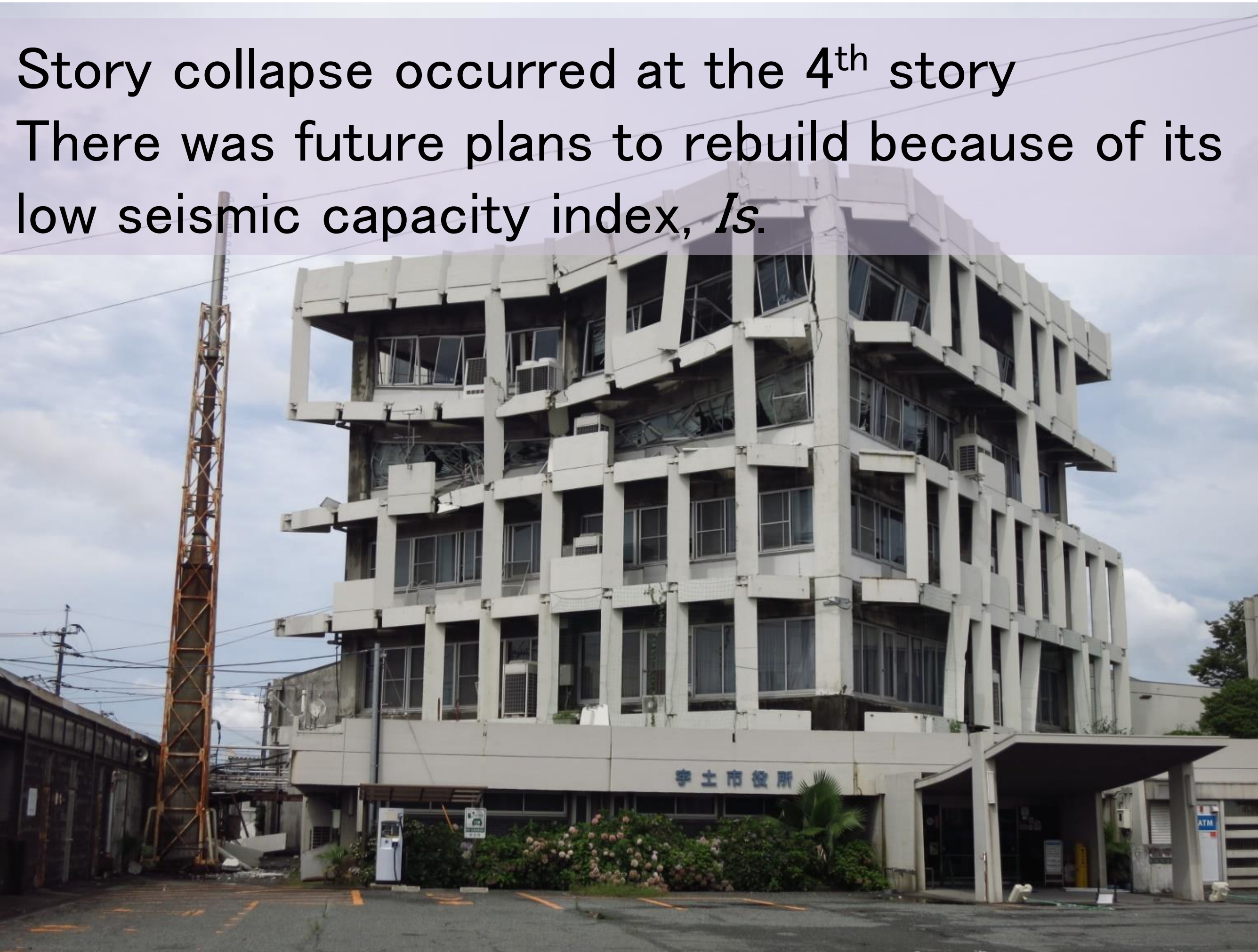


Building designed by old seismic code without retrofitting

◆City hall (5-story, RC)

Story collapse occurred at the 4th story

There was future plans to rebuild because of its low seismic capacity index, *Is*.



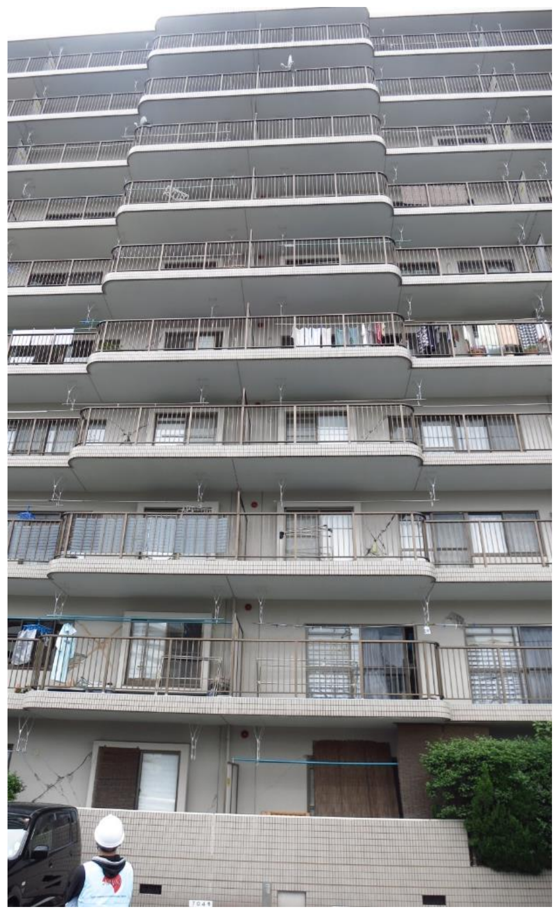
Building with soft first story

- ◆ Apartment K
  - 7-story, RC, designed by old seismic code, without retrofitting
  - L shape plan, core wall for EV and staircase located on one side.

Collapse in soft first story

Damage to non-structural concrete walls

- Apartment G
  - Damage to structure elements is slight, nonstructural wall failed in shear.

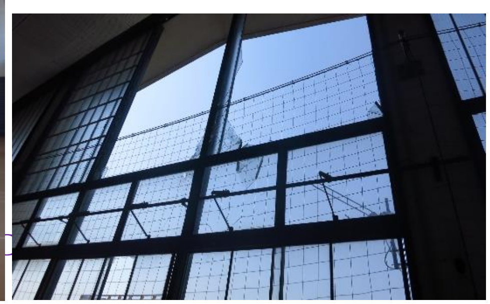


Damage to non-structural elements

◆ School gym

- Falling of ceiling, exterior wall (window sash and glass)
- Damage of the steel frame-RC column joint






Damage Statistics of Public School Buildings in Kumamoto City

◆Public school buildings for damage assessment

RC buildings + corridors connecting buildings (121 in total) were assessed.

Note 1: Total number of buildings and passages is 911.

Note 2: Ratio of buildings satisfying the current design code is 100%.

Concluding remarks
- preparedness for coming earthquakes -

- Seismic upgrading
  - Progressive for Public buildings. Almost completed for school bldgs. Private buildings are the problem.
  - Damage to disaster management facilities may be a big obstacle to recovery of damaged community.
  - Soft first story collapse was repeated.
  - Collapse of old timber housed induced casualty.
- Non-structural elements
  - Non-structural damage does not affect safety but function.
  - Fall of ceiling boards may cause casualty.
  - Structural engineer should be responsible seismic design of whole building structure including non-structural elements.