

Residual seismic capacity of ductile RC frame with walls based on full-scale loading test

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Background Damage Example in 2011 Tohoku EQ



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Background

Damage Example in 2016 Kumamoto EQ

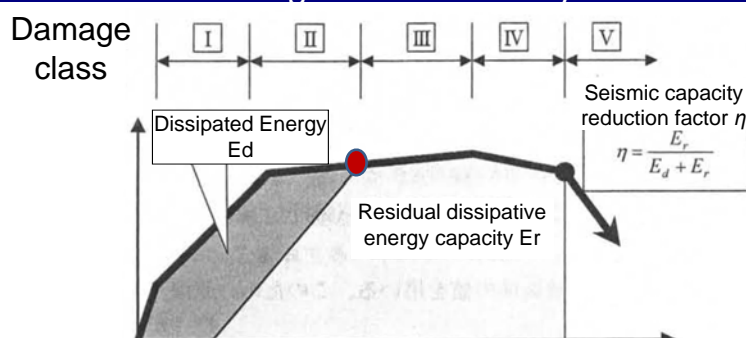


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Background

Concept of Residual Seismic Capacity

Damage Class of Local system



Damage class	Description of damage
I	Visible narrow cracks on concrete surface (Crack width is less than or equal to 0.2mm)
II	Visible clear cracks on concrete surface (Crack width is approximately 0.2-1.0mm)
III	Local crush of cover concrete , Remarkable wide cracks (Crack width is approximately 1.0-2.0mm)
IV	Remarkable crush of concrete with exposed reinforcing bars, Spalling off of cover concrete (Crack width is more than 2.0mm)
V	Buckling of reinforcing bars , Cracks in core concrete, Visible vertical and/or lateral deformation in columns and/or walls, Visible settlement and/or inclination of the building



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Background

Concept of Residual Seismic Capacity Damage Level of Global system

$$R = \frac{\sum_{j=0}^5 A_j}{A_{org}} \times 100 \quad (\%)$$

$$A_0 = S_0 + M_0 + W_0 + 2CW_0 + 6CWC_0$$

$$A_1 = 0.95S_1 + 0.95M_1 + 0.95W_1 + 1.9CW_1 + 5.7CWC_1$$

$$A_2 = 0.6S_2 + 0.75M_2 + 0.6W_2 + 1.2CW_2 + 3.6CWC_2$$

$$A_3 = 0.3S_3 + 0.5M_3 + 0.3W_3 + 0.6CW_3 + 1.8CWC_3$$


$$A_4 = 0.1M_4$$

$$A_5 = 0$$

$$A_{org} = S_{sum} + M_{sum} + W_{sum} + 2CW_{sum} + 6CWC_{sum}$$

R index : Residual seismic capacity ratio

[slight damage]	$R \geq 95$ (%)
[minor damage]	$80 \leq R < 95$ (%)
[moderate damage]	$60 \leq R < 80$ (%)
[severe damage]	$R < 60$ (%)
[collapse]	$R \approx 0$



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Objectives

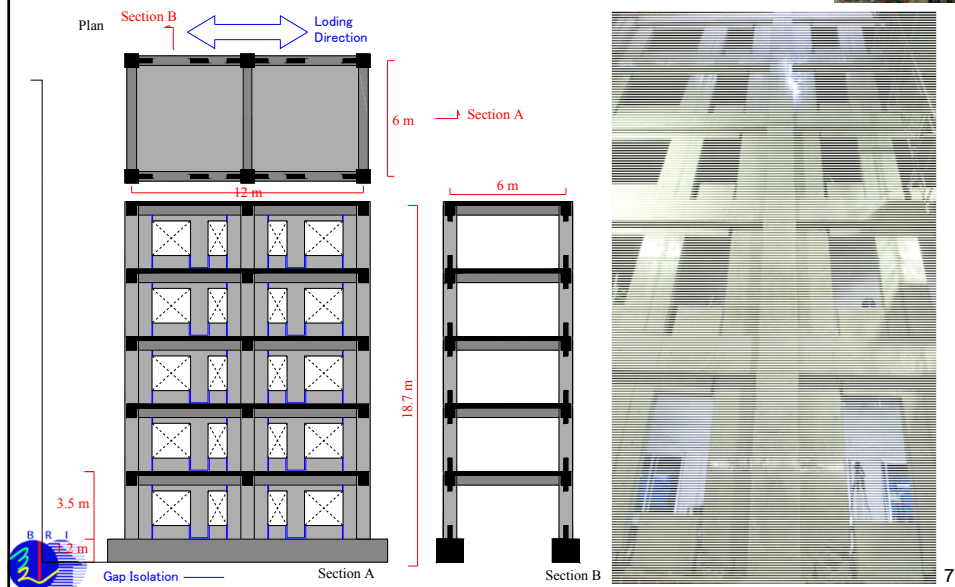
Verification of evaluation method for damaged RC building

The evaluation method for damaged building will be investigated using test data of a ductile RC specimen as follows;

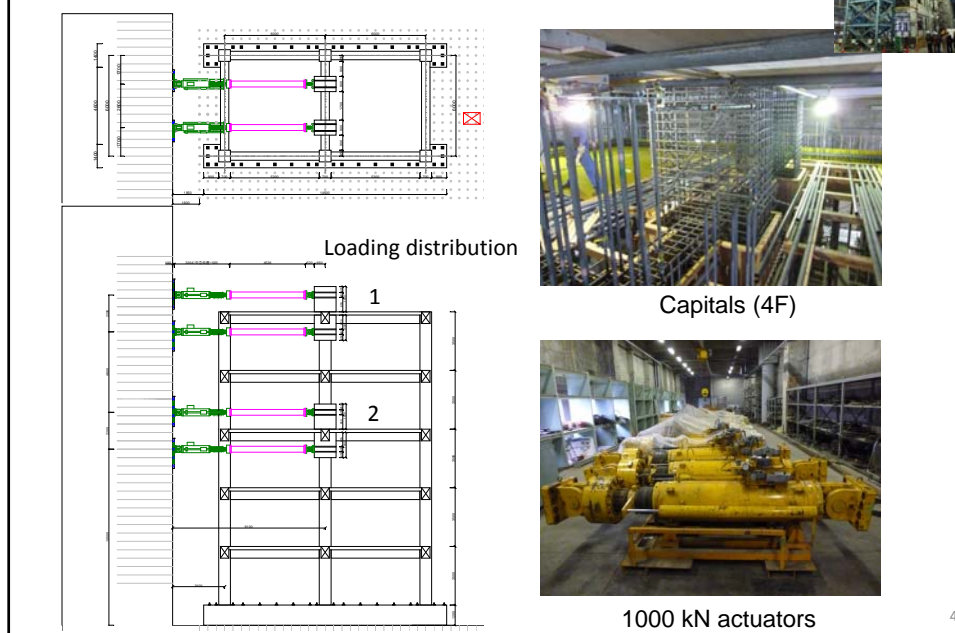
1. Calculate the **damage class** of each members (evaluation of Local system)
2. Calculate the **Residual seismic capacity ratio "R"** of building and determine the **damage level** of each story (evaluation of Global system)
3. Verify the result


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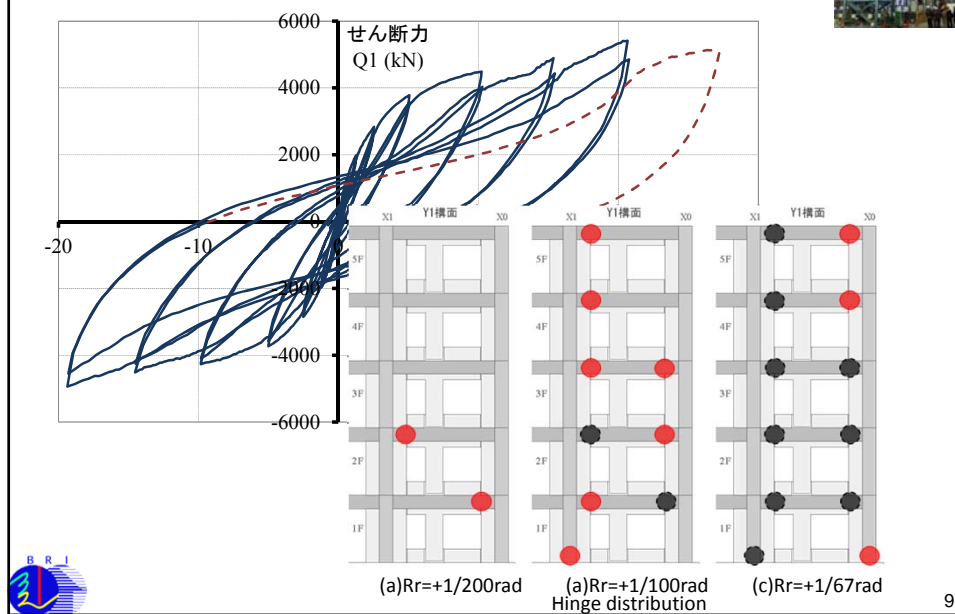
Full-scale static loading test for 5 story RC frame with walls at BRI (done in 2014)



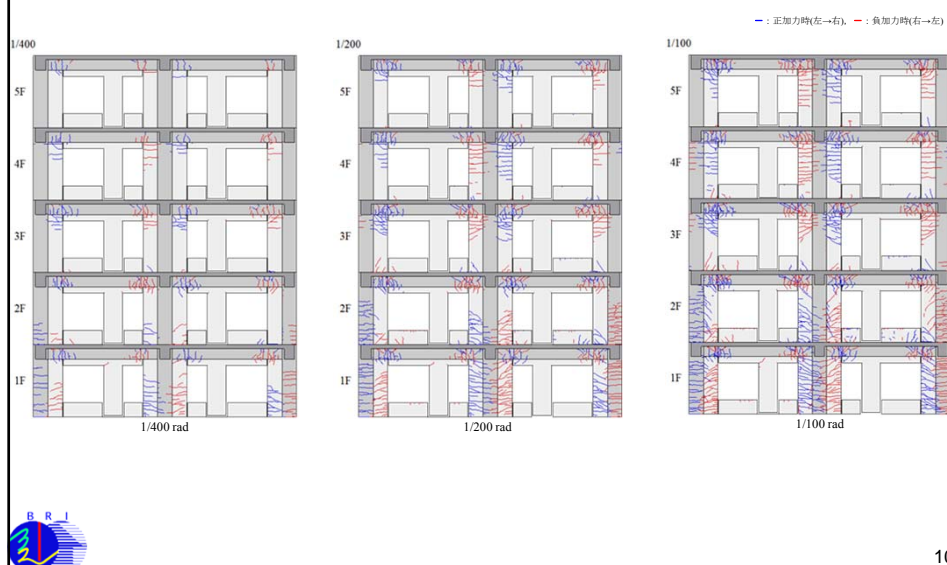
Loading set up (8 actuators)



Base shear-Overall drift angle



Measured Cracks



Damage classes for structural elements



Drift angle	2F beam				1F center column		1F north column		2F slab	
	B	HW	SW1	SW2	C	WW	C	WW	BT	S
1/1600										
1/800	I	I		I	I	I	I		I	I
1/400			I			II		I		II
1/200	III	II			II	II	II		II	II
1/100	IV	III		II	III	III			III	III
1/67		IV	II		V	V	-	-	IV	IV
1/50							IV	II(III)		

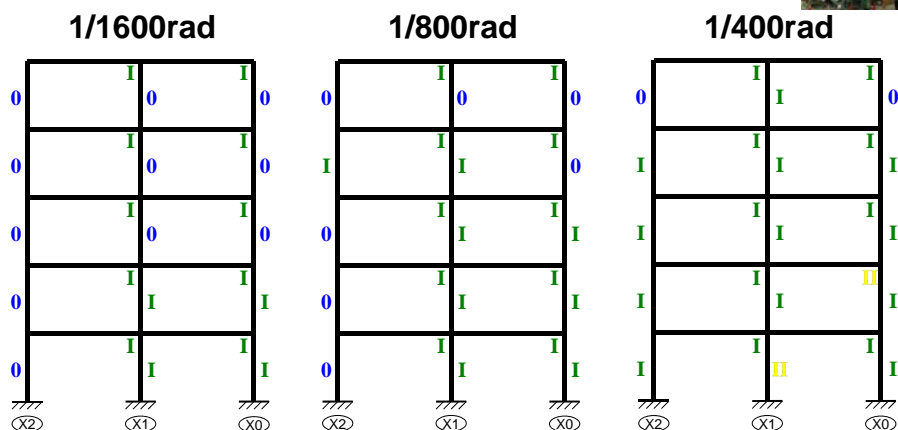
B: Beam, HW: Hanging wall, SW1: Standing wall (large), SW2: Standing wall (small), C: Column, WW: Wing wall, BT: Beam top face, S: Slab



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Damage classes of structural elements

-small drift angle range



Beam DC \doteq Column DC (most of members are DC0 or I)



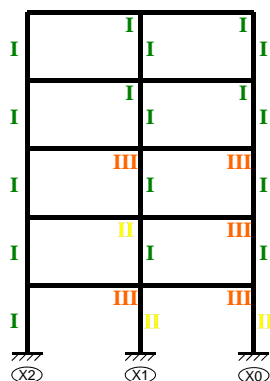
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Damage classes for structural elements

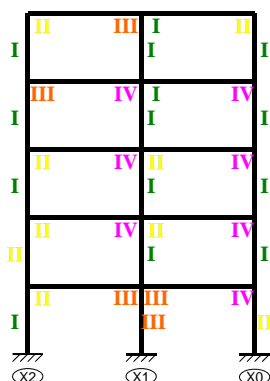
-large drift angle range



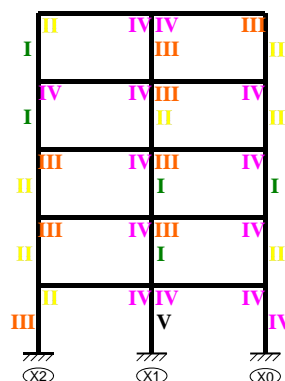
1/200rad



1/100rad



1/50rad



Beam DC >> Column DC (Excluding Column at 1st floor)



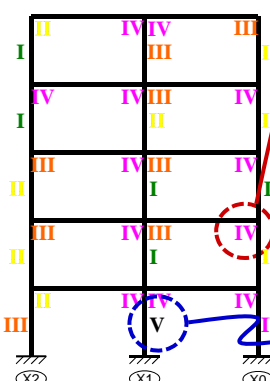
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Damage classes for structural elements

-final drift angle



1/50rad



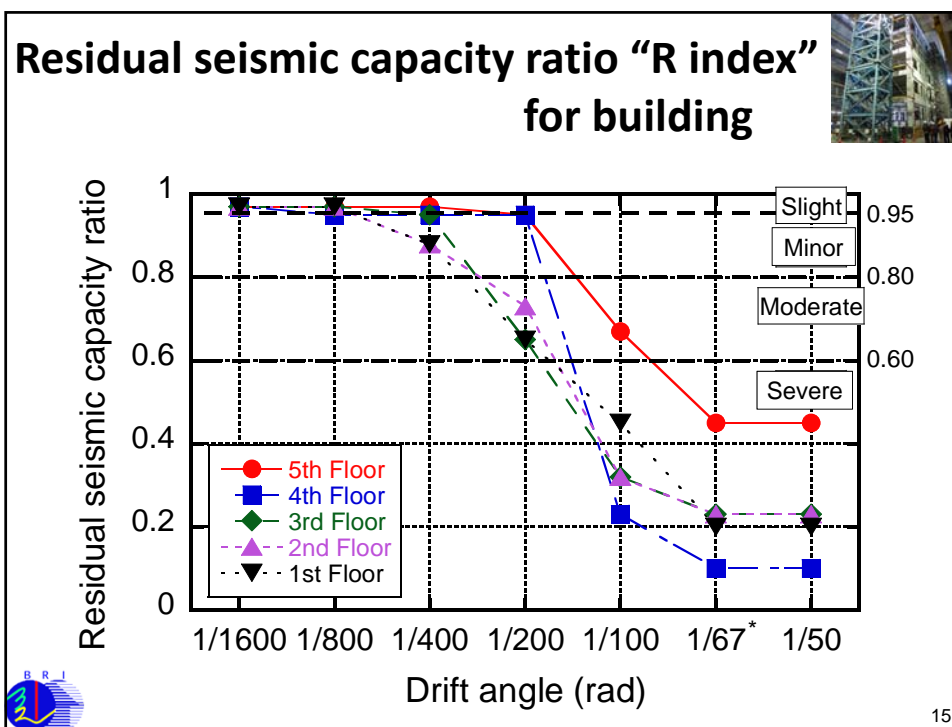
Beam at 3rd floor: large crack around structural gap




Column with wing-walls at 1st floor: compressive crush of concrete




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Damage level of each story

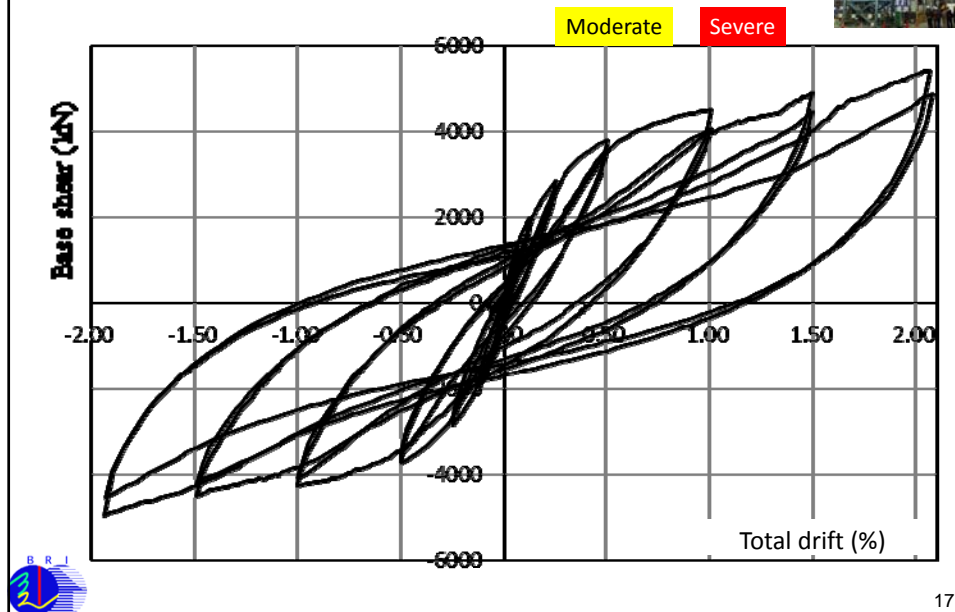


Total drift angle	5th floor	4th floor	3rd floor	2nd floor	1st floor
1/1600	Slight	Slight	Slight	Slight	Slight
1/800				Minor	Minor
1/400			Moderate	Moderate	
1/200	Moderate	Severe	Severe	Severe	Severe
1/100	Moderate	Severe	Severe	Severe	Severe



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Verification of calculated damage level



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Conclusions

Damage Class of structural elements(Local system)

- ✓ Up to $R=1/400\text{rad}$: Beam DC \approx Column DC (Most of DC : 0, I)
- ✓ After $R=1/200\text{rad}$: Beam DC \gg Column DC (Excluding 1st floor)

Damage Level of Whole building(Global system)

- ✓ All beams have hinge (Overall collapse mechanism)
 - ⇒ Damage level of every floor is almost same.
- ✓ The result of damage level is "Medium" and "Severe" at $R=0.5\%$ and 1.0% , when horizontal capacity increases.
 - Damage level seems to be overestimated, since the evaluation of residual crack width of the members is conservative.
 - ⇒ Not only crack width but other damage information such as **number and length of cracks for ductile members** should be evaluated.

We will investigate "reparability" of damaged building in terms of post- EQ functional use.



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