Lateral force – disp. curve and limit state

Shear - disp. curve and limit state of members
- ✓ Evaluation of strength, stiffness, deformation
- ✓ Evaluation of Limit deformation by damage

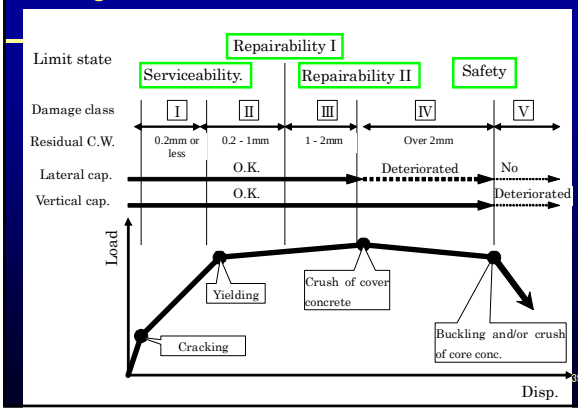
Push-over analysis

Story shear - disp. curve and limit state

Reduction to SDF system

Lateral force - disp. curve and limit state of SDF

Damage class and limit state of members



Performance and limit state of structural members

(2-1) Repairability L.S. I : Rapairable with relatively easy work and low cost. Some of bars yield slightly. Residual crack width is within 0.2 –1.0 mm. few damage to concrete.

(2-2) Repairability L.S. II : Repairable. Steel bars yield but no buckling. Residual crack widths are less than 1 to 2 mm. Crush of cover concrete is observed but core concrete is stable.

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Performance and limit state of structural members

(3) Safety L.S. : a structure is stable and sustain vertical load as well as seismic load. Strength and deformation are calculated by theoretical model and/or design equation proved their accuracy base on experiments.

➔ " Guidelines based on Inelastic Displacement Concept" can be applied.

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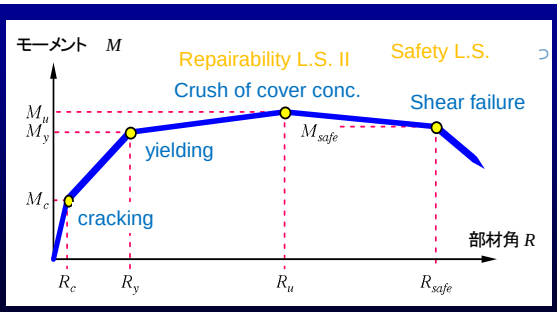
Flexural moment – rotation curve model

Four characteristic points and linear model



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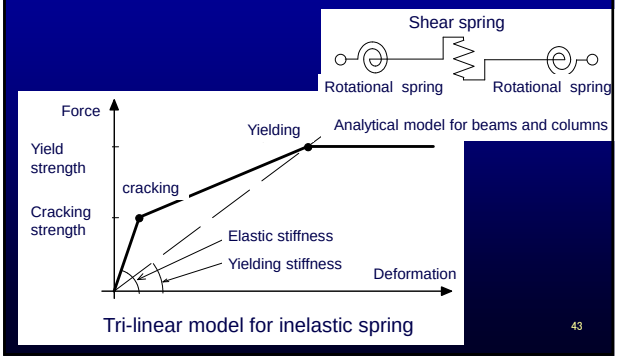
Analytical model of structural members



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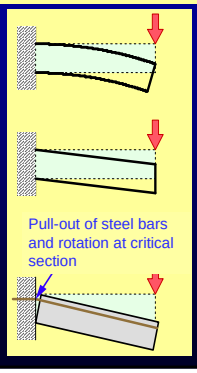
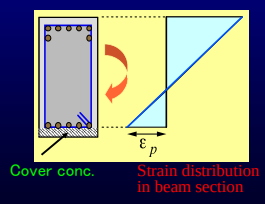
Deformation at flexural yielding



- Flexural deformation
  - Yielding moment is obtained by analysis of beam section based on Navier hypothesis
- Shear deformation
- Rotation due to bar pull-out from joint
- Rotation due to bar pull-out from beam

Deformation at crush of cover concrete

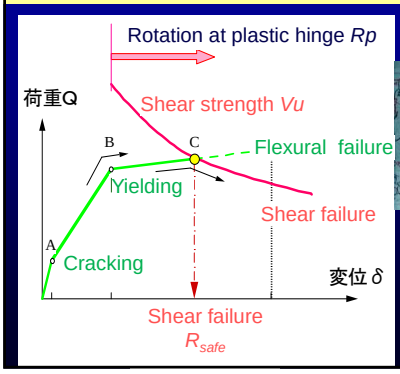
- Ignore cover concrete
- Strain in edge of core concrete reaches ultimate state



Flexural moment is calculated by section analysis.

Deformation is summation of four components .

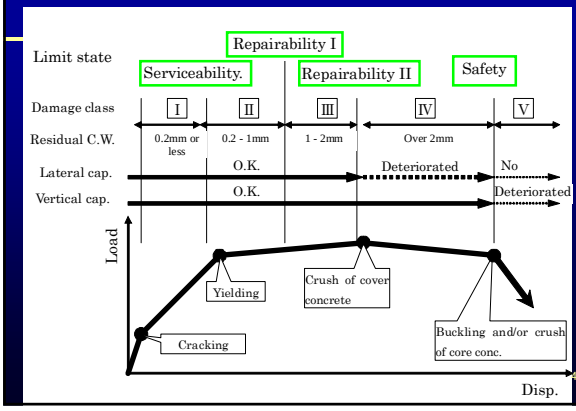
Shear failure after flexural yielding



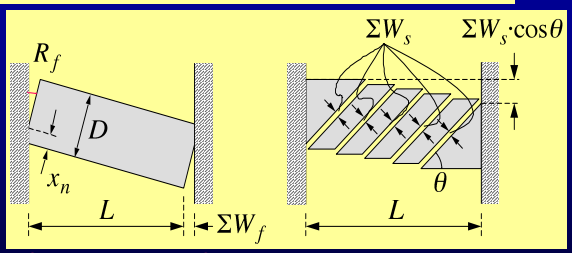
Diagonal cracks at flexural hinge region

$$R_{safe} = R_p + R_y$$

Crack width and limit state



Analytical model for deformation and crack width

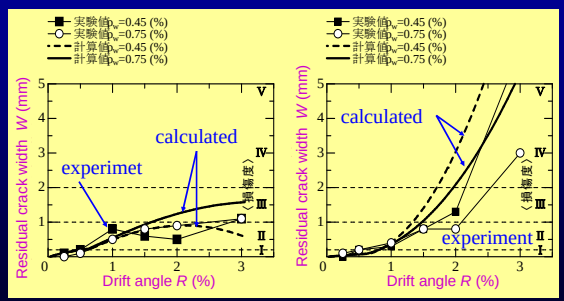


Deformation due to (a) flexural cracks and (b) shear cracks

$$R_f = \frac{\Sigma W_f}{D - x_n} = \frac{n_f \cdot \max W_f}{D - x_n}$$

$$R_s = \frac{\Sigma W_s \cdot \cos\theta}{L} = \frac{n_s \max W_s \cdot \cos\theta}{L}$$

Residual crack width and drift angle



(a) Flexural crack (b) Shear crack

Performance and limit state of non-structural members

Serviceability L.S.: Building function is maintained.

Repairability L.S. Ⅰ: Rapairable with relatively easy work and low cost. Residual crack width is within 1.0 mm. Few damage to concrete.

Repairability L.S. Ⅱ: Rapairable but severe damage to concrete walls. Doors and windows can not be opened due to damage. Assurance of safe escape from the building.

Safety L.S.: There is no hazard, such as fall down, fracture, turn and crush of elements, to human lives in and around the building.

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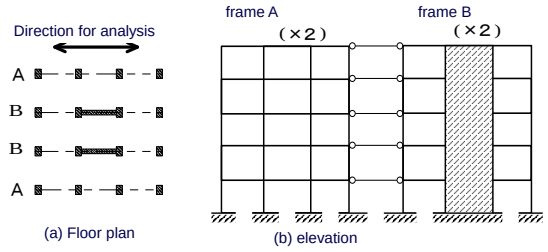
Analytical model of frame



Analytical combination of frames with different structural characteristics

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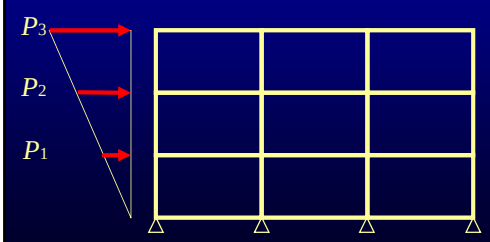
Push-over analysis

- Push-over analysis: an frame step by step analysis with incremental lateral load



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Limit state of a story and ratio of members with each damage class

	damage class of members				
Limit state	Ⅰ	Ⅱ	Ⅲ	Ⅳ	(Ⅴ)
Seiviceability	—	0%			
Repairability Ⅰ	—	a(30)	b(20)	0%	
Repairability Ⅱ	—	—	c(50)	0%	
Safety	—	—	—	—	(0%)

Alternative according to engineers judgment

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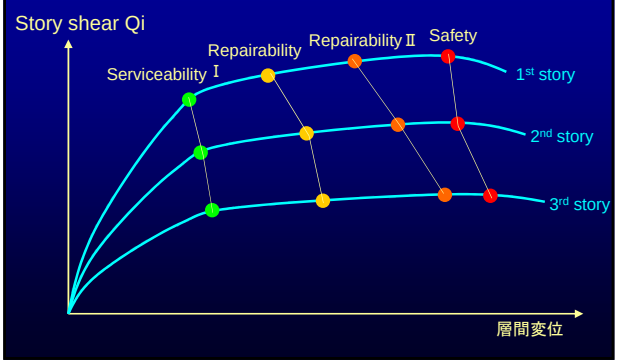
Story shear vs. inter-story drift and limit state



Reduction to single-degree-of-freedom system

- Effective mass

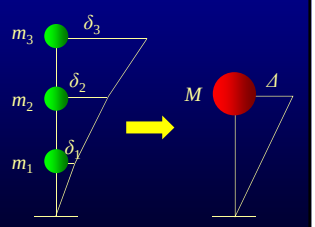
$$M = \frac{\{\sum(m_i \cdot \delta_i)\}^2}{\sum(m_i \cdot \delta_i^2)}$$

- Base shear coef.

$$C_B = Q_1/M$$

- Representative disp.

$$\Delta = \frac{\sum(m_i \cdot \delta_i^2)}{\sum(m_i \cdot \delta_i)}$$



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Example

Calculate effective mass and representative displacement for a system with uniform mass and inverted tri-angler displacement distribution.

$m_1 = m_2 = m_3 = m,\ \delta_1 = \delta,\ \delta_2 = 2\delta,\ \delta_3 = 3\delta$

- Effective mass

$$M = \frac{\{\sum(m_i \cdot \delta_i)\}^2}{\sum(m_i \cdot \delta_i^2)} = \frac{(1+2+3)^2\, m^2\delta^2}{(1^2+2^2+3^2)\, m\delta^2} = 2.57m$$

- Representative displacement

$$\Delta = \frac{\sum(m_i \cdot \delta_i^2)}{\sum(m_i \cdot \delta_i)} = \frac{(1^2+2^2+3^2)\, m\delta^2}{(1+2+3)\, m\delta} = 2.33\delta$$

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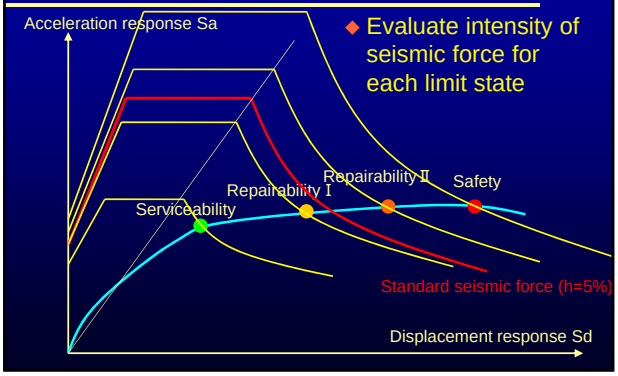
Sa – Sd curve



- Evaluate intensity of seismic force for each limit state

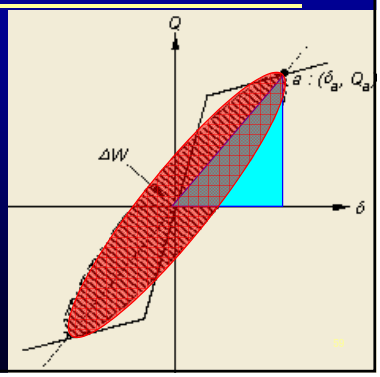
Damage to RC building structures

Story collapse of soft first story
(1995 Kobe EQ)

Equivalent damping factor h_{eq}

- Equivalent damping due to hysteretic energy dissipation

$$h_{eq} = \frac{1}{4\pi}\frac{\Delta W}{W}$$



Intensity of seismic force for limit state

- Evaluate intensity of limit seismic force considering the effect of damping

Reduction factor for response spectrum according to damping of structure

$$F_h = \frac{1.5}{1+10h}$$

Damping factor h

$h = 0.05+0.25(1-1/\sqrt{\mu})$

μ : ductility

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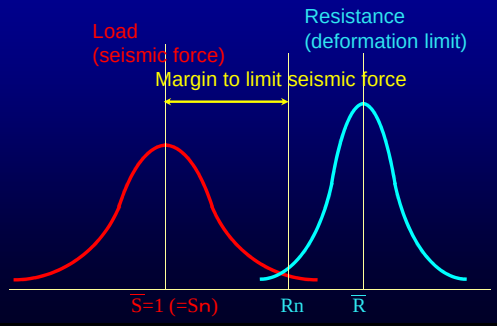
Evaluation of seismic reliability

- Probability of exceedance of limit state



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