1. Outline of seismic evaluation

Why Seismic Evaluation?

- Buildings before 1981 seismic code
  - Prevent severe damage against F=0.2W
  - No check against larger seismic load
- Buildings after 1981
  - Prevent severe damage against F=0.2W
  - Prevent collapse against F=1.0W
  - No check against larger seismic load

  Seismic capacities of blds vary wide range
- *Seismic Evaluation*

Law for promotion of Seismic Retrofit

- Promote seismic evaluation and retrofit for buildings before 1981 according to previous code.
- Target: school, hospital, theater, department store, marcket
- Improve capacity upto the level required in current seismic code
- Seismic evaluation is applied.

Structural seismic performance index, Is

- $Is = E_0 \times S_D \times T$
  - E_0 : basic structural capacity

    $= C(\text{strength}) \times F(\text{ductility})$
  - S_D : shape factor

    ← irregularity in plain and elevation
  - T : age factor

    ← deterioration after construction

Basic structural capacity, E_0

- $E_0 = \varphi \times C \times F$

  =horizontal strength × deformation

  φ: modification fac. for vibration mode

  C : strength factor

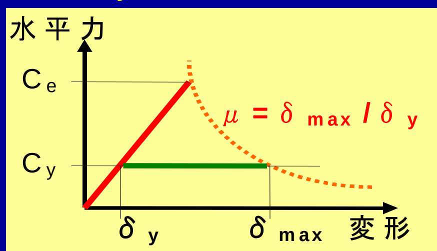
  =horizontal strength / weight W

  (story shear coefficient)

  F : ductility factor

Advantage of Japanese seismic evaluation

- Seismic performance of a building is evaluated by combination of strength and ductility with *Is*-index



Advantage of Japanese seismic evaluation

- Three levels of procedures are prepared: 1st - 3rd level
  - 1st level procedure (most simple)
    - ✓Approximated strength of col. And wall =sectional area × average shear stress
    - ✓Ductility is not taken into account i.e., shear failure is assumed.

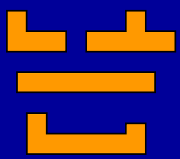
Advantage of Japanese seismic evaluation

- 2nd level procedure
  - ✓Strength and ductility are calculated including reinforcing bars.
  - ✓Beam is assumed stiff and strong enough.
- 3rd level procedure (most accurate)
  - ✓Strength and failure of beams are considered. Seismic capacity of frame is evaluated based on collapse mechanism.
- 2nd level procedure is more applicable for a building with story collapse mechanism.

Shape factor, S_D (1)

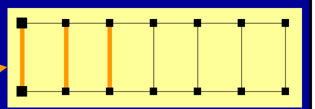
Reduce *Is* value by irregularity plane and elevation

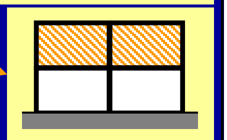
- Shape in floor plan
  - fairing
  - slenderness
  - necking
  - Gap at Exp. Joint
  - Atrium



Shape factor, S_D (2)

- Shape in elevation
  - w/wo basement
  - Uniformity of story height
  - w/wo Soft story
- Torsion
- Unbalance of stiffness



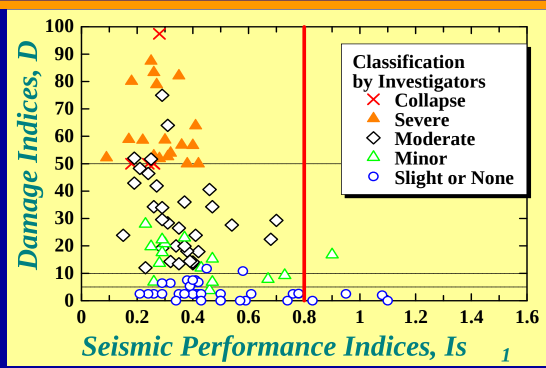


Age factor T

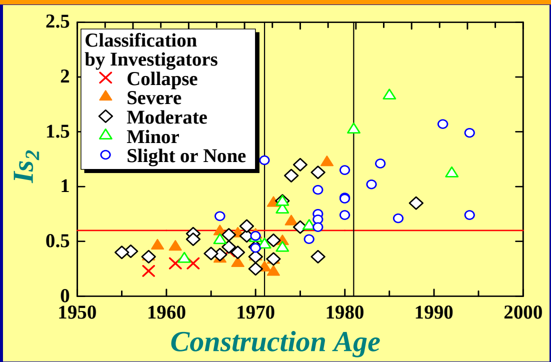
Reduce *Is* value by deterioration due to crack, deformation, aging tec.

- Crack and deformation in structural members
  - Subsidence, cracks and deformation in columns, beams and walls.
- Deterioration, aging
  - Rust and corrosion of steel bars
  - Carbonation and deterioration of concrete
  - Aging and/or spalling of finishing
  - etc

Is index vs. damage (1st level procedure)

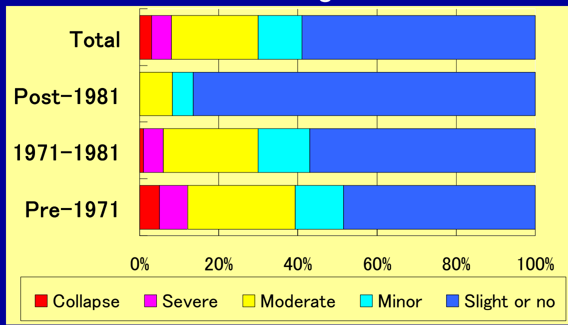


Is index vs. damage (2nd level procedure)

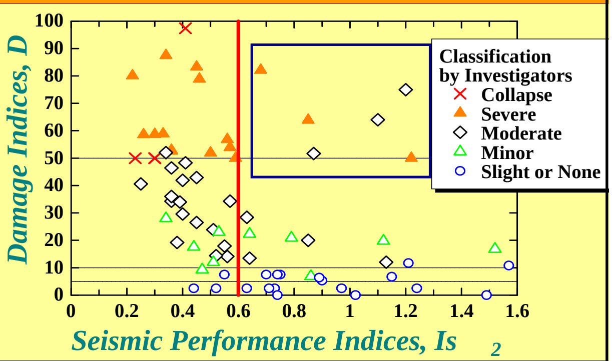


Damage statistics (1995 Kobe EQ)

- 613 RC school buildings



Is index vs. damage (2nd level procedure)



Judgment of seismic performance

$$Is \geqq Iso$$
$$C_T \cdot S_D \geqq 0.3$$

criteria $Iso = Es \cdot Z \cdot G \cdot U$

Es = 0.8(1st level), 0.6(2nd and 3rd level)

Z: zone fac.(0.7 - 1.0)

G: ground fac.(1.0, 1.25)

U: usage/importance fac.(1.0, 1.1, 1.2)

Cumulative strength index

$C_T = (n+1)/(n+i) \cdot (C_1 + \alpha_2 C_2 + \alpha_3 C_3)$

Comparison of Is-index and requirement in current code

- Required horizontal strength for new building

$$Q_{un} = D_s F_{es} A_i Z R_t C_0 \Sigma W$$

$$C_0 = \frac{1}{A_i} \times \frac{Q_{un}}{\Sigma W} \times \frac{1}{D_s} \times \frac{1}{F_{es}} \times \frac{1}{Z R_t}$$

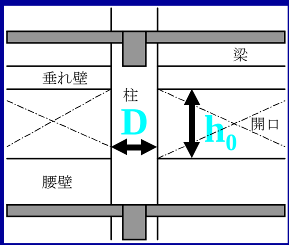
vibration mode | story shear coef. | ductility | Shape fac.

- $Is = \varphi \times C \times F \times S_D \times T$

2. Calculation of is-index

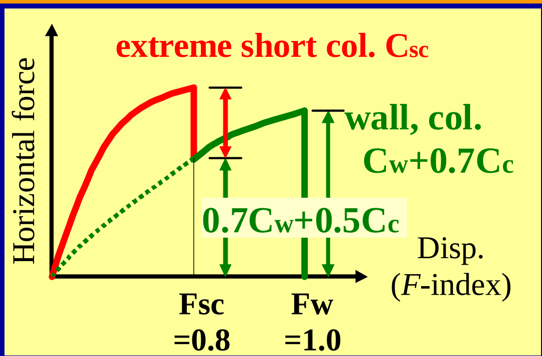
Classification of members *in 1st level procedure*

- Column, $h_0/D > 2$: (F=1.0)
- Extreme short col., $h_0/D \leqq 2$: (F=0.8)
- Wall: (F=1.0)



Shear failure in Extreme Brittle Column (1999 Taiwan EQ)

Eo-index in 1st level procedure (1)



Eo-index in 1st level procedure (2)

- Without extreme short col.

$$E_0 = \frac{n+1}{n+i}(C_w + \alpha_1 C_c) \times F_w$$

- With extreme short col.

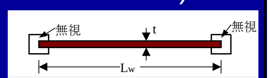
$$E_0 = \frac{n+1}{n+i}(C_{sc} + \alpha_2 C_w + \alpha_3 C_c) \times F_{sc}$$

C-index in 1st level procedure (1)

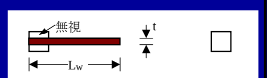
- Strength index, C
  =horizontal strength Q_u/weight ΣW
- horizontal strength Q_u=area × τ
- Average shear stress in columns, τ
  - Extreme short col.($h_0/D \leqq 2$) τ=1.5 N/mm²
  - Col. ($2 < h_0/D \leqq 6$) τ= 1.0 N/mm²
  - Column($6 < h_0/D$) τ= 0.7 N/mm²

C-index in 1st level procedure (2)

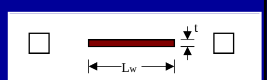
- Average shear stress in walls τ
  - Shear wall (with columns at both ends)
    τ =3.0 N/mm²



  - Column with wing wall
    τ =2.0 N/mm²



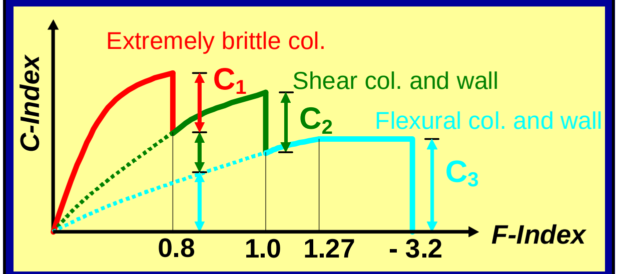
  - Wall without column
    τ =1.0 N/mm²



Classification of members *in 3rd level procedure*

- Extreme brittlr col., $h_0/D \leqq 2$: （*F*=0.8）
- Shear col., $h_0/D > 2$: （*F*=1.0）
- Flexural col.: （*F*=1.27-3.2）
- Shear wall: （*F*=1.0）
- Flexural wall: （*F*=1.0-2.0）

Eo-index in 2nd level procedure (1)



Eo-index in 2nd level procedure (2)

- Without extremely brittle column

$$E_0 = \frac{n+1}{n+i}\sqrt{E_1{}^2 + E_2{}^2 + E_3{}^2} \quad \textbf{Eq.(4)}$$

$$E_1 = C_1 \times F_1$$

$$E_2 = C_2 \times F_2$$

$$E_3 = C_3 \times F_3$$

Larger value can be used

$$E_0 = \frac{n+1}{n+i}(C_1 + \alpha_2 C_2 + \alpha_3 C_3) \times F_1 \quad \textbf{Eq.(5)}$$

Vertical load capacity in brittle columns

- If surrounding columns do not sustain vertical load after failure of a ECB, the building will collapse partially or totally.
- If surrounding columns sustain vertical load after failure of a ECB, the building may resist horizontal force with lateral strength in survived vertical members.

Eo-index in 2nd level procedure (3)

- With extremely brittle column (EBC)
  - If surrounding columns do not sustain vertical load after failure of a ECB, Eo should be calculated by Eq.(5) including a EBC.
  - If surrounding columns sustain vertical load, Eo can be calculated by
    - ✓Eq.(4) ignoring a EBC
    - ✓Eq.(5) ignoring a EBC
    - ✓Eq.(5) including a EBC

    } Largest value can be used

C-index in 2nd level procedure (1)

- Strength of columns
  - Flexural strength ${}_cQ_{mu}$

$${}_cQ_{mu} = \frac{{}_cM_{u上} + {}_cM_{u下}}{h_0}$$

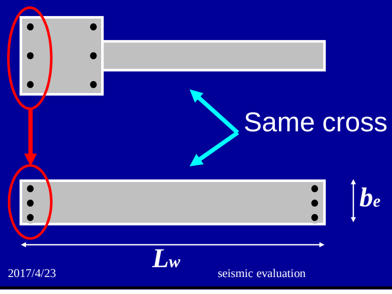
$$M_u = 0.8 \cdot a_t \cdot \sigma_y \cdot D + 0.5N \cdot D\left(1 - \frac{N}{bDF_c}\right)$$

  - Shear strength ${}_cQ_{su}$

$$Q_{su} = \left\{\frac{0.053\, p_t^{0.23}(18 + F_c)}{M/(Q \cdot d) + 0.12} + 0.85\sqrt{p_w \cdot {}_s\sigma_{wy}} + 0.1\sigma_o\right\} b \cdot (0.8D)$$

C-index in 2nd level procedure (2)

- Strength of columns with wing wall is calculated by an equivalent rectangular section



C-index in 2nd level procedure (3)

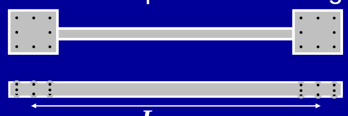
- Strength of shear wall
  - Flexural strength $_wQ_{mu}$

$$_wQ_{mu} = \frac{2\,{}_wM_u}{h_w}$$

$$_wM_u = a_t \cdot \sigma_y \cdot L_w + 0.5\Sigma(a_w \cdot \sigma_w)L_w + 0.5N \cdot L_w$$

  - Shear strength $_wQ_{su}$

an equivalent rectangulara section



F-index of columns in 2nd level procedure

- $Q_{su} \leqq Q_{mu}$
  - $h_0/D \leqq 2$: EBC F=0.8
  - $h_0/D > 2$: Shear F=1.0
- $Q_{su} > Q_{mu}$ Flexural
  - $h_0/D \leqq 2$: F=1.0
  - $h_0/D > 2$:

$$F = \frac{\sqrt{2\mu - 1}}{0.75(1 + 0.05\mu)}$$

$$\mu = 10\left(\frac{{}_cQ_{su}}{{}_cQ_{mu}} - 1\right)$$

ただし、$1 \leqq \mu \leqq 5$

ductility fac. (μ)

margin of shear strength ($\frac{{}_cQ_{su}}{{}_cQ_{mu}}$)

F-index of walls in 2nd level procedure

- $Q_{su} \leqq Q_{mu}$
  - Shear wall F=1.0
- $Q_{su} > Q_{mu}$
  - Flexural wall

$$\frac{{}_cQ_{su}}{{}_cQ_{mu}} < 1.2 \qquad F = 1.0$$

$$\frac{{}_cQ_{su}}{{}_cQ_{mu}} > 1.3 \qquad F = 2.0$$

linear interpolation

Classification of members in 3rd level procedure

Consider failure and strength in beams

- Col. with flexural beam: (F=3.0)
- Col. with shear beam: (F=1.5)
- Rotation wall: (F=3.0)

Extreme brittle col., $h_0/D \leqq 2$:	(F=0.8)
Shear col., $h_0/D > 2$:	(F=1.0)
Flexural col.:	(F=1.27-3.2)
Shear wall:	(F=1.0)
Flexural wall:	(F=1.0-2.0)

2nd level procedure

E_0-index and C-index in 3rd level procedure

- E_0-index, C-index, F-index can be calculated by basically in the same method in 2nd level procedure.

⇓

Applied to a building in which plastic hinges and/or failure occurs in beams rather than columns.
(total collapse mechanism with beam yielding type)