

1. Outline of seismic evaluation

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2

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**

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3

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, market
- Improve capacity upto the level required in current seismic code
- Seismic evaluation is applied.

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4

Structural seismic performance index, I_s

- $I_s = E_0 \times S_D \times T$
 - E_0 : basic structural capacity
= $C(\text{strength}) \times F(\text{ductility})$
 - S_D : shape factor
← irregularity in plan and elevation
 - T : age factor
← deterioration after construction

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5

Basic structural capacity, E_0

- $E_0 = \phi \times C \times F$
 - = horizontal strength \times deformation
 - ϕ : modification fac. for vibration mode
 - C : strength factor
= horizontal strength / weight W
(story shear coefficient)
 - F : ductility factor

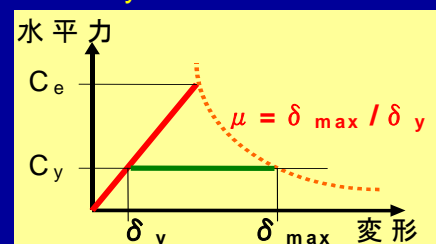
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6

Advantage of Japanese seismic evaluation

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



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7

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.

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8

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.

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9

Shape factor, S_D (1)

Reduce I_s value by irregularity plane and elevation

■ Shape in floor plan

- fairing → 
- slenderness → 
- necking → 
- Gap at Exp. Joint → 
- Atrium

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10

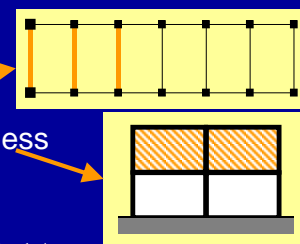
Shape factor, S_D (2)

■ Shape in elevation

- w/wo basement
- Uniformity of story height
- w/wo Soft story

■ Torsion

■ Unbalance of stiffness



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11

Age factor T

Reduce I_s 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

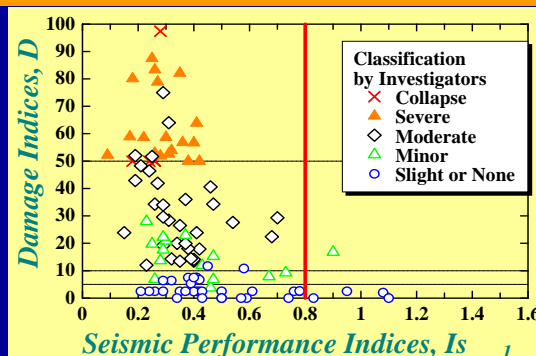
- Rust and corrosion of steel bars
- Carbonation and deterioration of concrete
- Aging and/or spalling of finishing
- etc

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12

I_s index vs. damage (1st level procedure)

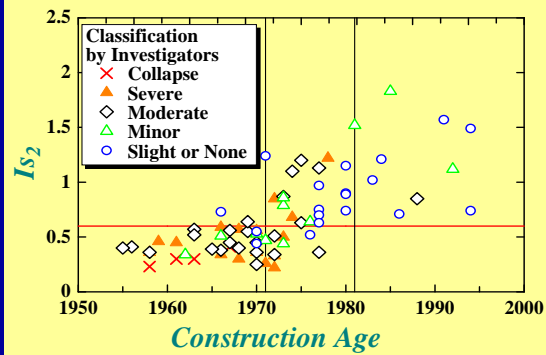


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13

Is index vs. damage (2nd level procedure)



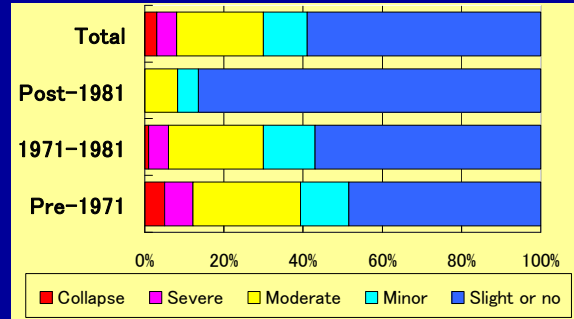
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14

Damage statistics (1995 Kobe EQ)

613 RC school buildings

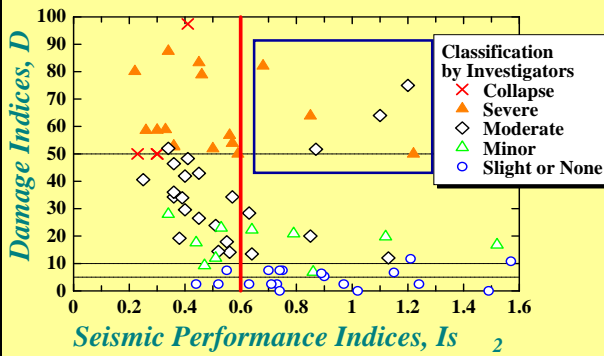


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15

Is index vs. damage (2nd level procedure)



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16

Judgment of seismic performance

$$I_s \geq I_{so}$$

$$C_T \cdot S_D \geq 0.3$$

criteria $I_{so} = E_s \cdot Z \cdot G \cdot U$

$E_s = 0.8$ (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

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

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17

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.

$$I_s = \phi \times C \times F \times S_D \times T$$

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18

2. Calculation of is-index

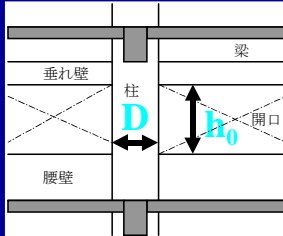
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20

Classification of members in 1st level procedure

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



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21

Shear failure in Extreme Brittle Column (1999 Taiwan EQ)

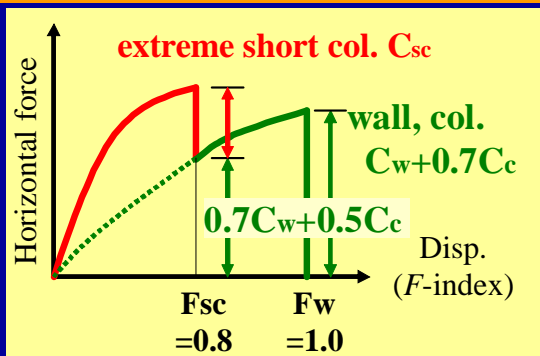


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22

E_0 -index in 1st level procedure (1)



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E_0 -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.

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

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24

C-index in 1st level procedure (1)

- Strength index, C
=horizontal strength Q_u /weight ΣW
- horizontal strength $Q_u = \text{area} \times \tau$
- Average shear stress in columns, τ
 - Extreme short col. ($h_0/D \leq 2$) $\tau = 1.5 \text{ N/mm}^2$
 - Col. ($2 < h_0/D \leq 6$) $\tau = 1.0 \text{ N/mm}^2$
 - Column ($6 < h_0/D$) $\tau = 0.7 \text{ N/mm}^2$

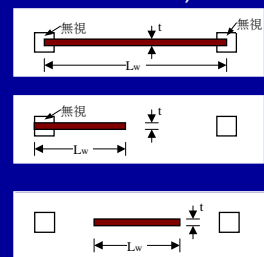
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25

C-index in 1st level procedure (2)

- Average shear stress in walls τ
 - Shear wall (with columns at both ends) $\tau = 3.0 \text{ N/mm}^2$
 - Column with wing wall $\tau = 2.0 \text{ N/mm}^2$
 - Wall without column $\tau = 1.0 \text{ N/mm}^2$



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26

Classification of members in 3rd level procedure

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

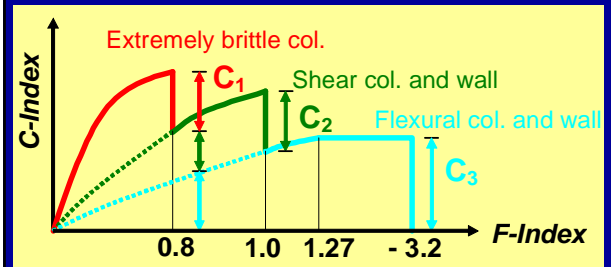
- Shear wall: ($F=1.0$)
- Flexural wall: ($F=1.0-2.0$)

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27

E_0 -index in 2nd level procedure (1)



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28

E_0 -index in 2nd level procedure (2)

- Without extremely brittle column

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

$$E_1 = C_1 \times F_1$$

$$E_2 = C_2 \times F_2$$

$$E_3 = C_3 \times F_3$$

Larger value
can be used

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

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29

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.

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30

E_0 -index in 2nd level procedure (3)

- With extremely brittle column (EBC)
 - If surrounding columns **do not sustain** vertical load after failure of a ECB, E_0 should be calculated by Eq.(5) including a EBC.
 - If surrounding columns **sustain** vertical load, E_0 can be calculated by
 - ✓ Eq.(4) ignoring a EBC
 - ✓ Eq.(5) ignoring a EBC
 - ✓ Eq.(5) including a EBC

Larger value
can be used

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31

C-index in 2nd level procedure (1)

- Strength of columns
 - Flexural strength cQ_{mu}

$$cQ_{mu} = \frac{cM_{u\pm} + cM_{u\mp}}{h_0}$$

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

- Shear strength cQ_{su}

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

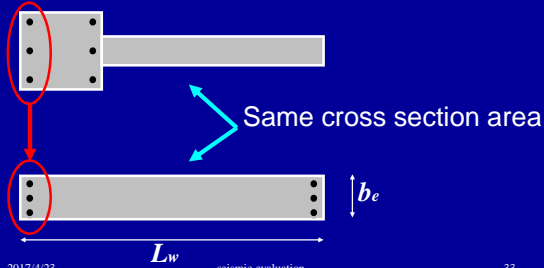
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32

C-index in 2nd level procedure (2)

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



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33

C-index in 2nd level procedure (3)

- Strength of shear wall

- Flexural strength ${}_w Q_{mu}$

$${}_w Q_{mu} = \frac{2 \cdot M_u}{h_w}$$

$${}_w M_u = a_t \cdot \sigma_y \cdot L_w + 0.5 \Sigma (a_w \cdot \sigma_w) L_w + 0.5 N \cdot L_w$$

- Shear strength ${}_w Q_{su}$

an equivalent rectangular section



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34

F-index of columns in 2nd level procedure

- $Q_{su} \leq Q_{mu}$

- $h_0/D \leq 2$: EBC $F=0.8$
- $h_0/D > 2$: Shear $F=1.0$

- $Q_{su} > Q_{mu}$ Flexural

- $h_0/D \leq 2$: $F=1.0$
- $h_0/D > 2$:

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

ductility fac.

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

margin of shear strength

ただし、 $1 \leq \mu \leq 5$

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35

F-index of walls in 2nd level procedure

- $Q_{su} \leq Q_{mu}$

- Shear wall $F=1.0$

- $Q_{su} > Q_{mu}$

- Flexural wall

$\frac{c \cdot Q_{su}}{c \cdot Q_{mu}} < 1.2$	$F=1.0$
$\frac{c \cdot Q_{su}}{c \cdot Q_{mu}} > 1.3$	$F=2.0$
linear interpolation	

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36

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., $h_0/D \leq 2$: ($F=0.8$)

- 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

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37

E₀-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)

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38