Structural Performance Control Guidance

Masaki Maeda

Introduction (1)

- Purpose of structural design
  - Chap.20 in Japanese Building Standard Law

    "A building should be consist of safe structure against dead load, live load, snow, wind, soil and water pressure as well as shaking due to earthquake and impact."
  - Safety is the only requirement?
  - ➢ Building should keep function during life time with maintenance and repair, if necessary

    ➔ requirement for building structures has been upgraded and diversified with development of modern society.

Introduction (2)

- Requirement for building structures
  - Serviceability: maintain function of building
  - Repairability: repairable within reasonable repair costs
  - Safety: save human lives and household effects
- Sustainable building structures
  - effective use of natural resources
  - Reduction of environmental burden

Objective of lecture

- To learn basic concept and method for sustainable building structures with required performance against various loads and forces.
- To introduce following items;
  - Structural design method
  - Performance evaluation method
  - Theory of reliability and risk assessment

Contents of lecture

- Current seismic design standard
  - Allowable stress design and ultimate strength design
- Seismic evaluation and retrofit for existing buildings
  - Seismic capacity index, *Is*
  - Technique and example of seismic strengthening
- New seismic design and performance evaluation
  - Guideline for Earthquake Resistant Building
  - Guideline for Seismic Performance Evaluation
- Reliability analysis and risk assessment
  - Basic of reliability analysis by probabilistic approach
  - Seismic risk and prediction of damage to buildings
  - Concept of seismic risk management

Introduction (today's contents)

1. History of

Damage of RC buildings due to earthquake and seismic code

2. Action prior to EQs

Outline of seismic evaluation and retrofit

1. History of Damage of RC buildings due to earthquake and seismic code

Damage and seismic code in Japan

1891 Nohbi EQ
1923 Kanyto EQ M7.9 approx. 140,000 deaths

- 1924 Revision of Building Standard Law

1948 Fukui EQ M7.3 3895 deaths

- 1950 New Building Standard Law

1964 Niigata EQ M7.5 26 deaths
1968 Tokachi-oki EQ M7.9 52 deaths
shear failure of columns in RC buildings

- 1971 Revision of seismic code
  - enforcement of requirement for hoop in column

Damage and seismic code in Japan

1975 Ohita Chubu EQ M6.4 No death

- 1977 Seismic Evaluation Standard

1978 Miyagi-ken-oki EQ M7.4 28 deaths

- 1981 Revision of seismic code
  - 2nd level design

1983 日本海中部地震 M7.7 104 deaths(tsunami)
1993 Kushiro-oki EQ M7.8 2 deaths
1993 Hokkaido-nansei-oki EQ M7.8 230 deaths (tsunami)
1994 Hokkaido-toho-oki EQ M8.1 No death
1994 Sanriku Far-off EQ M7.5 3 deaths

Damage and seismic code in Japan

1995 Kobe EQ M7.2 over 6000 deaths
✓More damage to buildings design by old seismic code

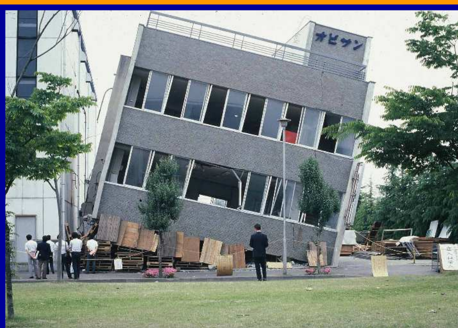
- 1995 Law for Promotion of Seismic Retrofit
  - Seismic retrofit of existing buildings
- 1997 Guideline for Design of Earthquake Resistant Building (AIJ, Architectural Institute of Japan)
- 1999 Revision of seismic code
  - Performance –based
- 2004 Guideline for Performance Evaluation (AIJ)

2004 Niigata Chuetsu EQ M6.8 68 deaths
2008 Iwate Miyagi EQ M7.2 17 deaths
2011 East Japan EQ M9.0 over 20,000 deaths

Damage of RC structures by EQ

Hakodate Univ. (1968 Tokachi-oki EQ)

Damage of RC structures by EQ



Collapse of buildings (1978 Miyagi-ken-oki EQ)

Damage of RC structures by EQ

Collapse of buildings (1978 Miyagi-ken-oki EQ)

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Damage of RC structures by EQ

Collapse of RC buildings
(1995 Kobe EQ)

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Damage of RC structures by EQ

Story collapse
(1995 Kobe EQ)

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Damage of RC structures by EQ

Story collapse
(1995 Kobe EQ)

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Damage of RC structures by EQ

Shear failure (1995 Kobe EQ)

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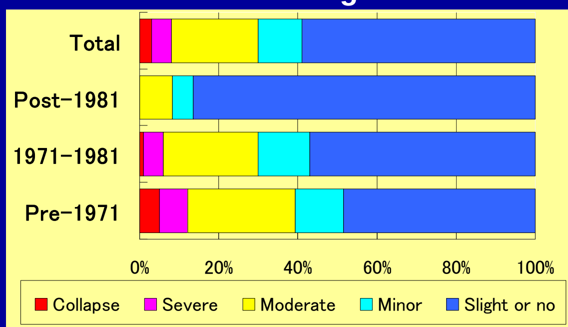
Damage statistics (Kobe EQ)

- 631 RC school buildings



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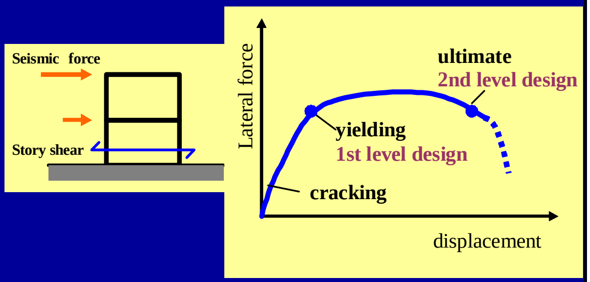
Seismic design in Building Law (1)



Seismic design in Building Law (2)

- Allowable sterss design (1st level design)

Seismic force＝weight ×acceleration response

＝m×0.2g

＝0.2W （W:weight of building）

Target of design:

Prevent severe damage against moderate earthquake

(serviceability, repaorability)

Seismic design in Building Law(3)

- Ultimate strength design

(2nd level design, after 1981)

Seismic force

＝ 1.0W×structural charactristic coef. *Ds*

RC: *Ds*＝0.3-0.55

in accordance with inelastic deformation capacity

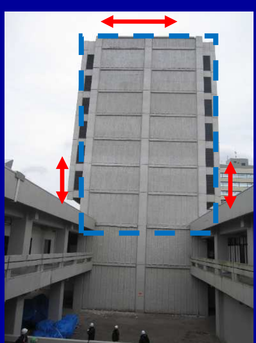
Target of design:

prevent collapse against large earthquake (safety)

2011 East Japan EQ

Severely damage school building (Shitigahama town)
Shear failure of RC wall

2011 East Japan EQ

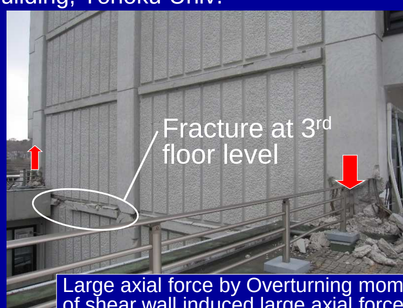


Severely damaged building
(Civil Eng. Building, Tohoku Univ.)

- Upper part of building, especially 3rd story, was damaged severely.
- Crush of concrete and buckling/fracture of steel at the bottom of column in 3rd story
- Shear wall deformed in north-south direction

2011 East Japan EQ

Failure of column bottom in 3rd story of Civil Eng. Building, Tohoku Univ.



Large axial force by Overturning moment in upper part of shear wall induced large axial force in columns.

2011 East Japan EQ

Penthouse of Electrical Building, Tohoku Univ.

RC wall and column failed totally.

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2011 East Japan EQ

Damage to non-structural elements

(apartment , Sendai city)

- Const. in 1979
- 11-storyed, SRC
- Seismically evaluated

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2011 East Japan EQ

Damage to basement

Junior High School, Ohsaki city)

ement of 60-70cm, inclination of 1/25 rad.

ement of 20cm, inclination of 1/200 rad.

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2011 East Japan EQ

Damage due to tsunami

(K. High School, Kesen-numa city)

Tsunami reached upto 3rd floor level.

Debris in building

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2011 East Japan EQ

Damage due to tsunami

(Ohkawa prim. School, Ishinomaki city)

Cantilever column of bridge collapsed.

Floor slab was uplifted and connection with beam fractured.

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2011 East Japan EQ

Damage due to tsunami

Onagawa, Miyagi pref.

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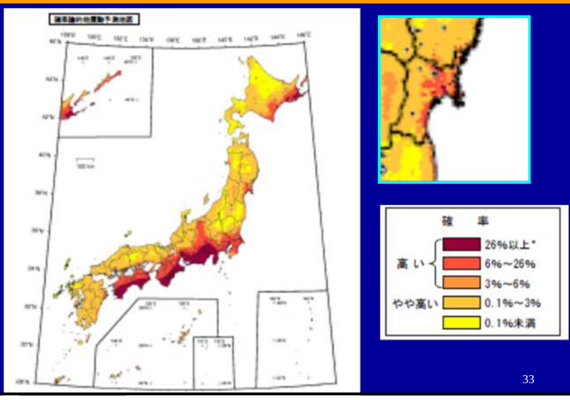
2. Seismic capacity and damage of buildings

Probability of exceedance of ground motion of intensity 6 with in 30 yrs.



What is seismic evaluation?

- Building by previous seismic code (-1981)
  - Seismic force of 0.2*W* ➡ escape damage
  - Unclear against larger EQ
- Building by current seismic code (1981-)
  - Seismic force of 0.2*W* ➡ escape damage
  - Seismic force of 1.0*W* ➡ prevant collapse
  - Unclear against larger EQ

  Seismic capacities of buildings vary in their structural characteristics.
- Numerical Evaluation of seismic capacity

Low for promotion of seismic upgrade

- Promotion of seismic evaluation and upgrade for existing building by previous seismic code
- Target: public buildings such as school, hospital, department store, supermarket and hotel
- Improve capacity up to the level in current code
- “Seismic Evaluation Standard” is applied.

Seismic capacity index Is

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

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

    ➡ irregularity of plan and elevation
  - T : age index

    ➡ deterioration after construction

Basic capacity index E_0

- $E_0 = \varphi \times C \times F$
  = lateral force × deformation

  φ : modification factor for vibration mode

  C : strength index

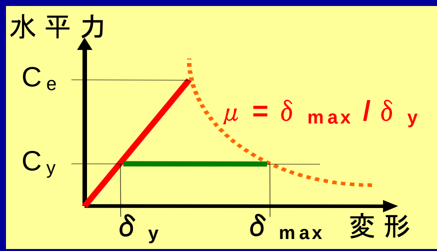
  = lateral strength Qu / building weight W

  (story shear coefficient)

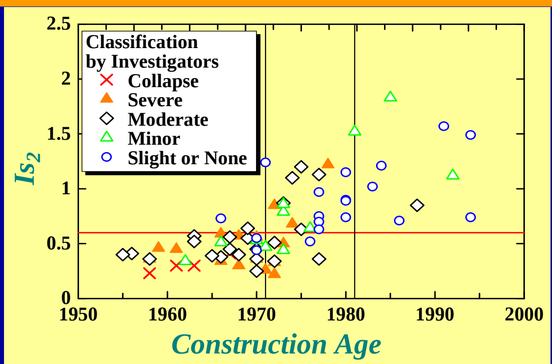
  F : ductility index

Characteristics of seismic index Is

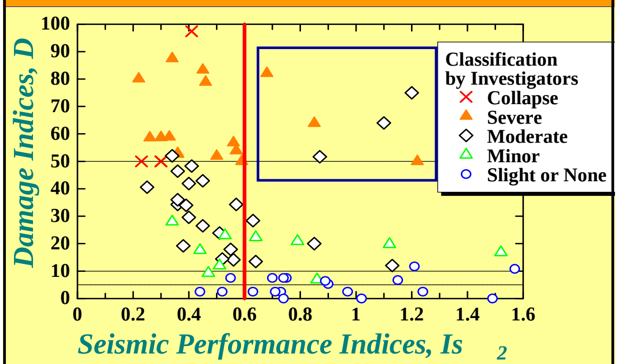
- **Seismic capacity of a building is evaluated by**
  - **Lateral strength and ductility**



Is-index and construction age

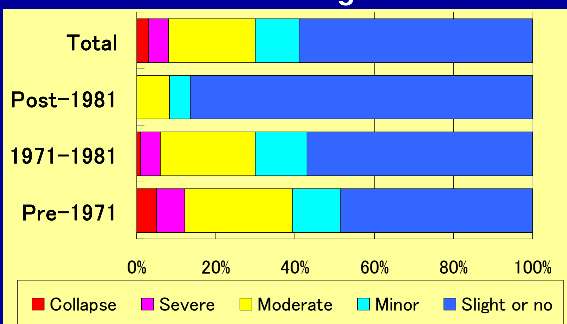


Is-index and damage level



Damage statistics (kobe EQ)

- **631 RC school buildings**



Judging criteria

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

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

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

Z: zone factor(0.7-1.0)

G: ground factor(1.0, 1.25)

U: usage factor(1.0, 1.1, 1.2)

Lateral strength index

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

Is index and requirement in seismic code

- Requirement of lateral strength in current code

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

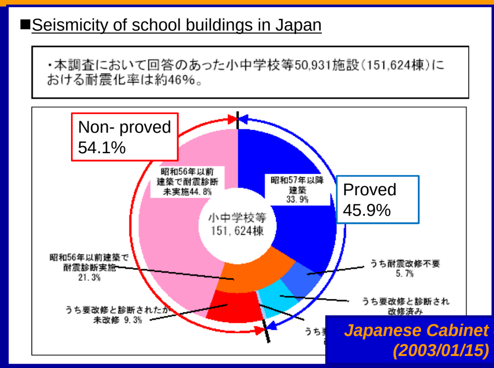
below is a variation of expression

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

Vibration mode / Story shear coef. / ductility / Shape index

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

Progress of seismic retrofit (2003)



Japanese Cabinet office (2003/01/15)

Progress of seismic retrofit (2011)