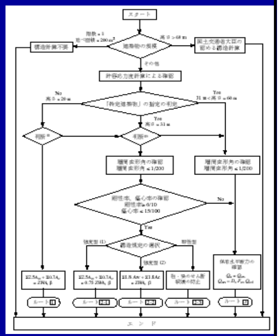
Seismic Code in Japanese Building Standard Law

Requirement for calculation

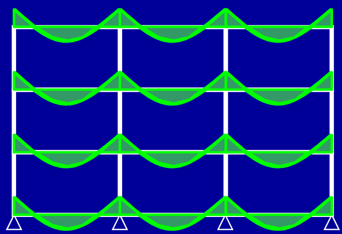
- No calculation
  - Single story, <200m^2
- Conventional method
  - Allowable stress design
  - Ultimate strength design
    - ✓Root1
    - ✓Root2-1,2-2,2-3
    - ✓Root3
- New method (2000-)
  - Capacity spectrum method
- Dynamic analysis
  - >60m height



Conventional method

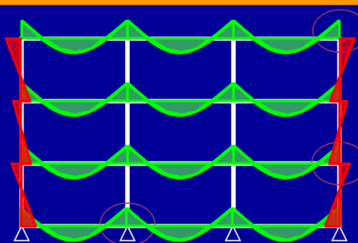
- 1st step (allowable stress design)
  - Long-term load = dead load + live load
    - ➔ serviceability limit state
  - Short-term load =
    - L. load + seismic load (moderate)
    - ➔ serviceability & repairability limit state
- 2nd step (ultimate strength)
  - = L. load + seismic load (large)
  - ➔ sefety & ultimate limit state

Stress by vertical load (F.E.M. in beams)



- Flexural moment at beam ends is transferred to columns due to the balance of Flexural moment of beams and columns at a node.
  - Generally, moment in an interior column is 0 or small, because of balance of moments in beams at both side.
  - Moment at an exterior end of a beam is transferred to the connecting exterior column.

Stress by vertical load (M. in columns)



M in column is equal to *M* at beam end.

to *M* at beam end. is divided to upper and lower columns.

If M at left and right beam ends are balanced, *M* in column is 0.

- *M* at beam ends are not same with F.E.M., because beam ends are not completely fixed. However, general tendency can be obtained by the method shown above.
- Accurate result can be obtained by slope deflection method and/or moment distribution method

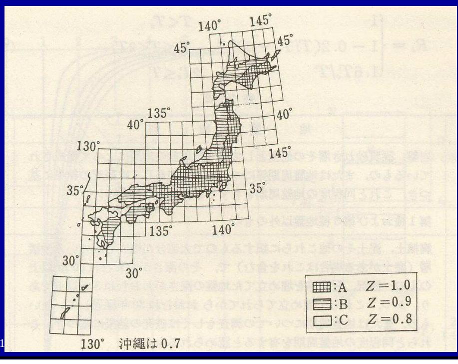
Story shear Qi and coefficient Ci

$C_i = Z \cdot R_t \cdot A_i \cdot C_0$, $Q_i = C_i \cdot W_i$

- Z : zone factor (0.7-1.0)
- R_t : vibration characteristic fac. (1.0-)
- A_i : story shear distributuion for *i*-th story (1.0-)
- C_0 : base shear coef.
  - ✓0.2 1st step (moderate EQ)
  - ✓1.0 2nd step (large EQ)
- W_i : weight of buildings *i*-th and upper stories

Zone factor Z

- A factor for the level of seismic activity at construction site



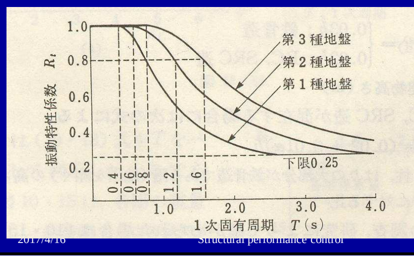
Vibration characteristic fac. Rt

- A factor for vibration period of building and soil type

$$R_t = 1 - 0.2\left(\frac{T}{T_c} - 1\right)^2$$

Period T of RC buildings

T=0.02H(sec) H: height(m)

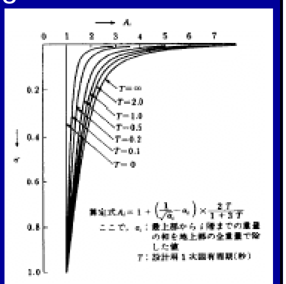


Story shear distribution Ai

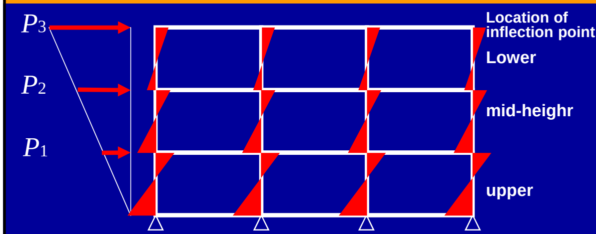
- A factor for story shear distribution along the height of a building

$$A_i = 1 + \left(\frac{1}{\sqrt{\alpha_i}} - \alpha_i\right)\frac{2T}{1+3T}$$

$\alpha_i = W_i / W_1$

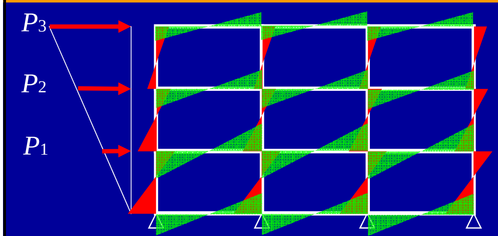


Stress due to seismic force in colmun



- Story shear is distributed in columns.
- Larger stress in lower story.

Stress due to seismic force in beam



- Flexural moment in column is transferred to beams.
  - Summation of moment in upper and lower columns at a node is divided to left and right beams.
- Stress for short-term load is

  stress for long-term load + stress for seismic force

Cal. for seismic force (2nd step)

- Root 1 (<20m)
  - Approximated strength by column and wall section area

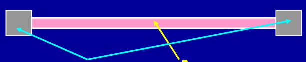
    $0.7A_c + 2.5A_w \geqq ZWA_i$
- Root 2 (<31m)
  - 2-1, 2-2: Approx. strength (similar with Root1)
  - 2-3: ensure ductility (prevent shear failure)
- Root 3
  - Cal. of ultimate lateral strength

Root 1 (approximated evaluation)

$0.7\sum Ac + 2.5\sum Aw \geqq Z\ W\ Ai$

- Column shear strength = 0.7N/mm² × total sectional area(mm²)

  average ultimate shear stress
- Wall shear strength= 2.5N/mm² × total sectional area(mm²)

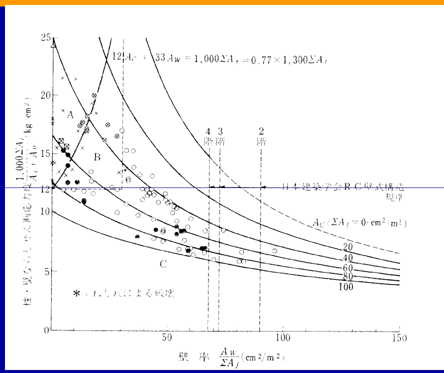


- Design seismic force =

  building weight × 1.0g(acceleration response)=∑W

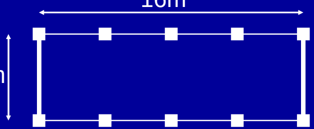
  (assuming Ds=1)

Shiga's diagram



example

evaluate seismic safety by the equation below for a 3-storied RC building structure with a floor plan shown in the figure below.



Column section: 600×600mm

Wall thicness: 180mm

$0.7\sum Ac + 2.5\sum Aw \geqq \sum W$

Answer 1

- Total weight of building∑W

  12kN/m² × 6m × 16m × 3story=3456 kN
- Shear strengths in columns 0.7∑Ac

  Both in X- and Y-direction

  0.7N/mm² × 600mm × 600mm × 10

  =2520000 N=2520 kN
- Shear strength in walls 2.5∑Aw

  X-dir.: 0

  Y-dir.: 2.5N/mm² × 180mm × 5400mm × 2

  =4860000 N=4860 kN

Answer 2

	shear strength 0.7∑Ac + 2.5∑Aw		total weight ∑W	
X-dir.	2520 + 0	<	3456	N.G.
Y-dir.	2520 + 4860	>	3456	OK

Root3 (Ultimate strength design)

Required story shear Qun ≦ lateral strength Qu

- Required story shear

  Qun = Ds･Fe･Fs･Qi (Co=1.0 or more)

  Ds: ductility factor (0.3-0.55)

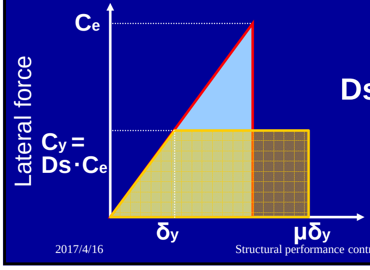
  Fe: shape fac. (eccentricity in plan)

  Fs: shape fac.

  (unbalance of stiffness along height)

Ductility factor Ds

- Newmark's law for uniform energy dissipation
  - Energy dissipation of an elastic system is equal to that of inelastic system
  - A system with lower strength but large deformation capacitu can resist against an EQ.



$$Ds = \frac{1}{\sqrt{(2\mu-1)}}$$

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Regulation of Ds values

架構の性状	架構の形式 〈い〉 剛接架構又はこれに類する形式の架構 (frame)	〈ろ〉 〈い〉欄及び〈は〉欄に掲げるもの以外のもの (combined)	〈は〉 各階に生ずる水平力のうち当該階の耐力壁又は筋かいに…分…形式の架構 (wall)
(1) 架構を構成する部材に生ずる応力に対してせん断破壊…急激に低下する破壊…こと等のため，塑性変形の度が特に高いもの (ductile)	0.3	[illegible]	0.4
(2) (1) に掲げるもの以外のもので架構を構成する部材に生ずる応力に対してせん断破壊その他の耐力が急激に低下する破壊が生じ難いこと等のため，塑性変形の度が高いもの	0.35	0.4	0.45
(3) (1)及び(2) に掲げるもの以外のもので架構を構成する部材に塑性変形を生じさせる応力に対して当該部材にせん断破壊が生じないこと等のため，耐力が急激に低下しないもの	0.4	0.45	0.5
(4) (1)から(3) まで…のもの (brittle)	0.45	0.50	0.55

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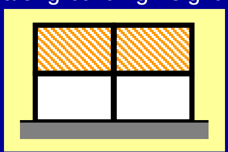
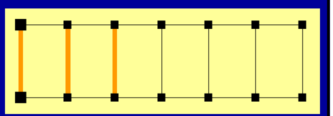
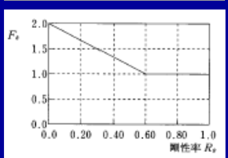
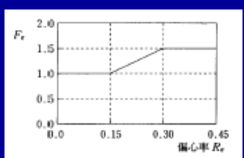
Shape factors Fe & Fs

- Unbalance of stiffness along building height
- Eccentricity of stiffness in plan









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Calculation of lateral strength of frame

- Cal. of ultimate moment in beam and column.
  - beam：$M_u = 0.9a_t \cdot \sigma_y \cdot d$
  - column：$M_u = 0.8a_t \cdot \sigma_y \cdot D + 0.5N \cdot D \cdot (1 - N/bD\sigma_B)$
- Decide hinge location at each node coparing strengths of beams and columns and draw moment diagram.
- Lateral strength can be obtained by summation of shear in all the columns in a story.

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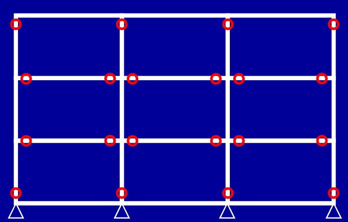
Lateral strength



- Compare Mu in beams and in columns.
- Assume plastic hinge at ends of member with smaller Mu
- Distribute Mu at plastic hinges to members without hinges

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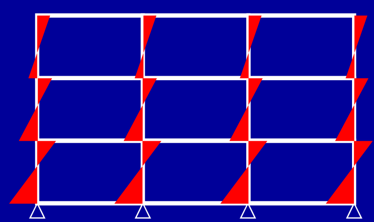
Moment diagram in column



- Lateral strength (story shear) can be obtained by summation of shear in all the columns in a story.

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