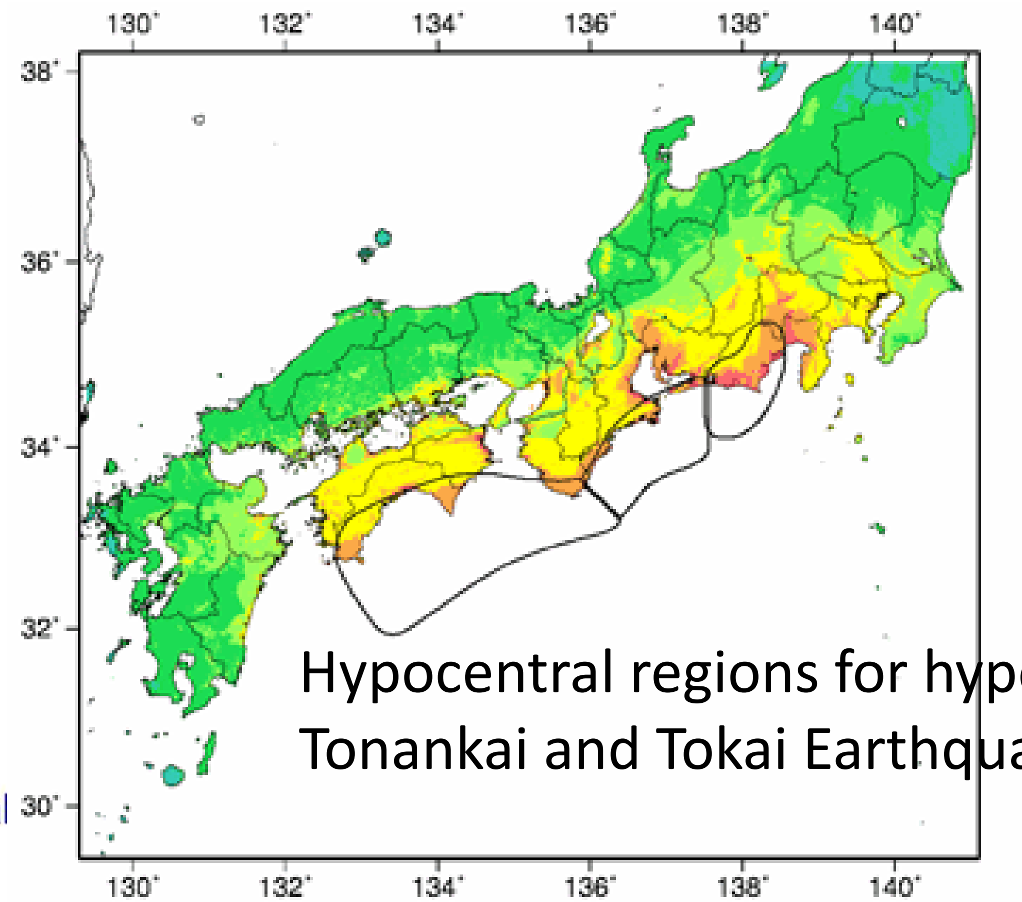
Dynamic Instability in High-Rise Steel Structures Subjected to Strong Ground Motions: A Review

Kohju Ikago

Tohoku University, Japan

Background

- The Great East Japan Earthquake
- Future Nankai Earthquake



Hypocentral regions for hypothetical Nankai, Tonankai and Tokai Earthquakes

Background

- P-Delta effect is not properly considered in design provisions
- High-rise structures are at the risk of dynamic instability even if they are designed in accordance with strong-column-weak-beam concept

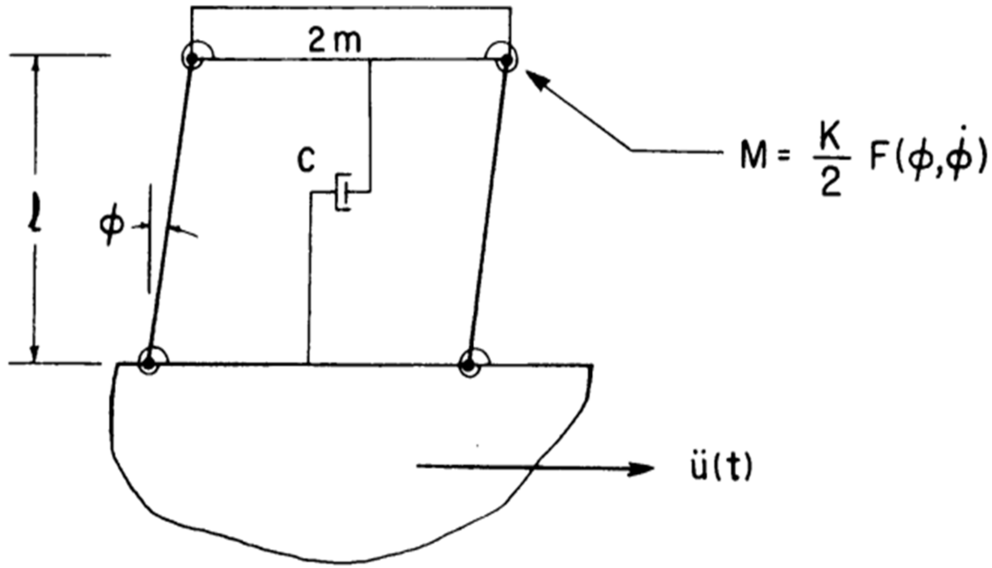
A Brief Review of the literature

- Accumulation of inelastic deformation in one direction due to P-Delta effect
- Drifting (ratcheting) at lower stories of building
- Condition for dynamic instability
- Seismic response of high-rise buildings subjected to long-period ground motions

ACCUMULATION OF INELASTIC DEFORMATION IN ONE DIRECTION

Jennings and Husid (1968)

- Analysis using an SDOF system considering P-Delta effect



SDOF model for studying gravity effects

Jennings and Husid (1968)

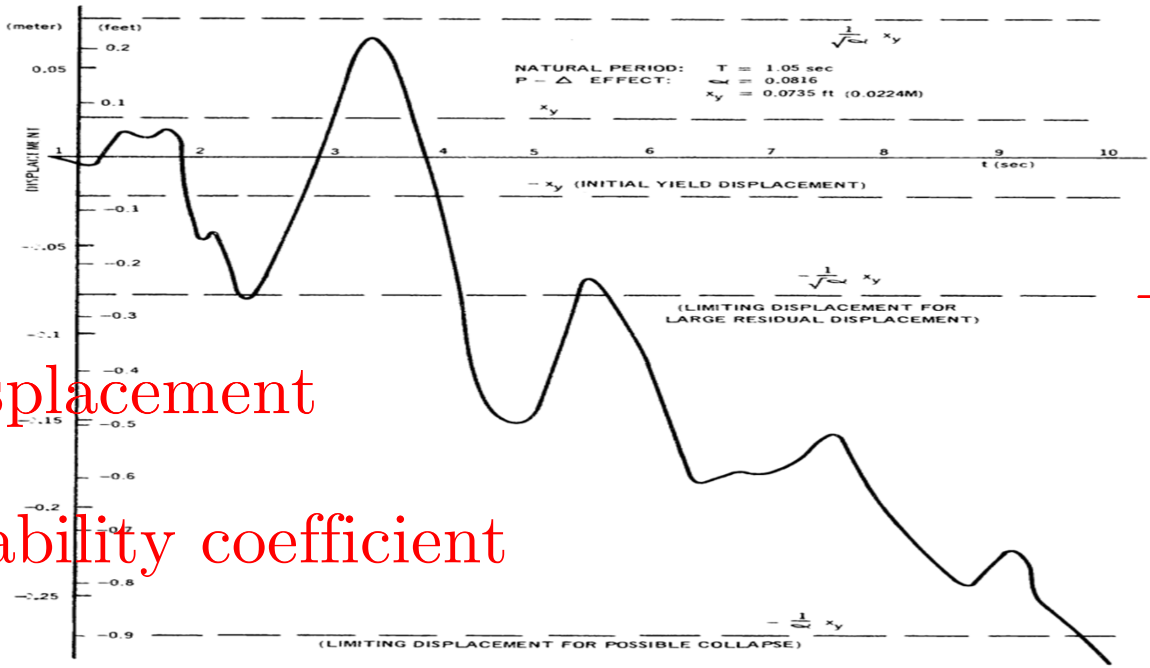
- Analysis using an SDOF system considering P-Delta effect

Equation of motion:

$$\ddot{\phi} + 2n\omega_0\dot{\phi} + \frac{K}{ml^2}F(\phi,\dot{\phi}) - \frac{g}{l}\sin\phi = -\frac{\ddot{u}(t)}{l}\cos\phi$$

Sun, Berg and Hanson (1973)

- Collapse caused by negative post-yield stiffness due to P-Delta effect



$$-\frac{x_y}{\sqrt{\alpha}}$$

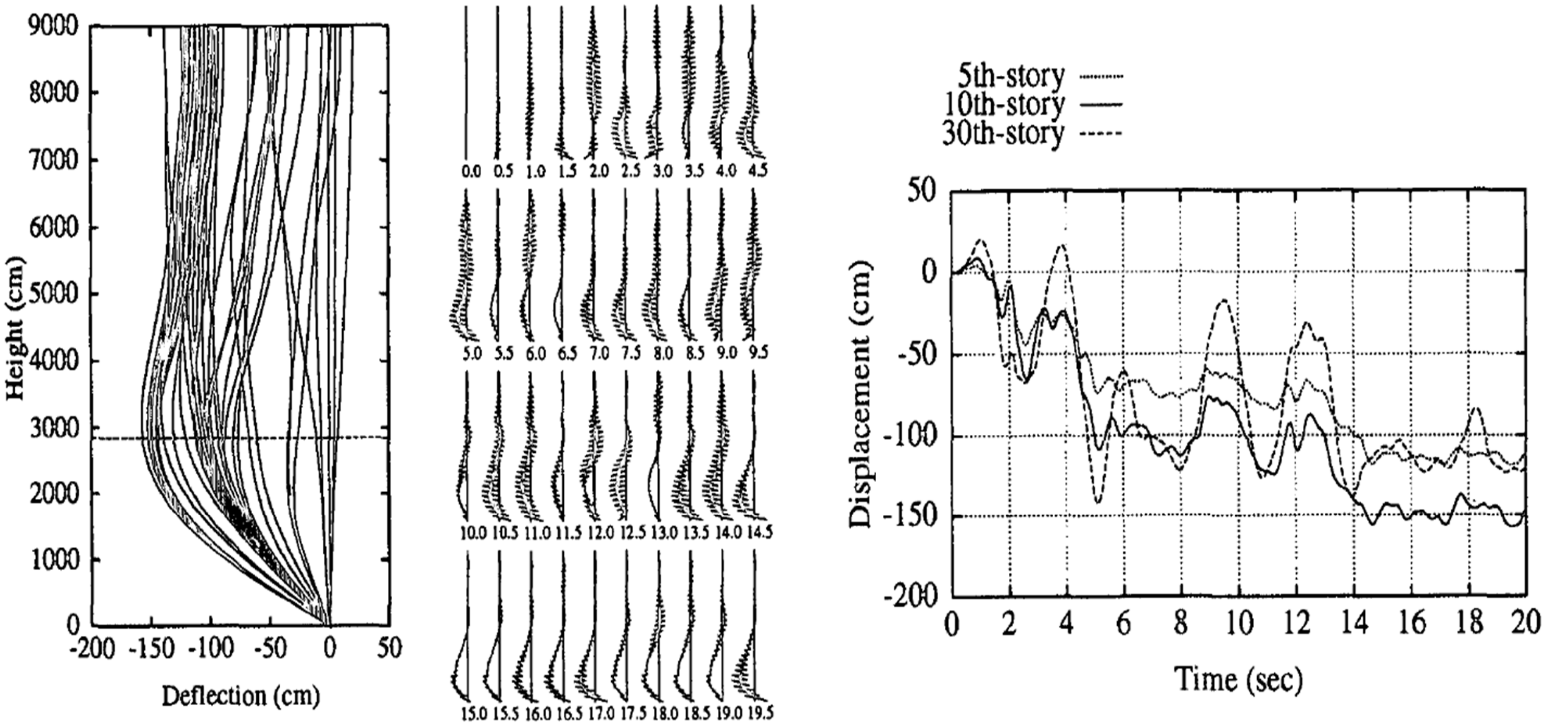
x_y : yield displacement

$\alpha = \dfrac{mg}{kh}$: stability coefficient

$$-\frac{x_y}{\alpha}$$

DRIFTING AT LOWER STORIES OF BUILDING

Uetani and Tagawa (1996,1998)

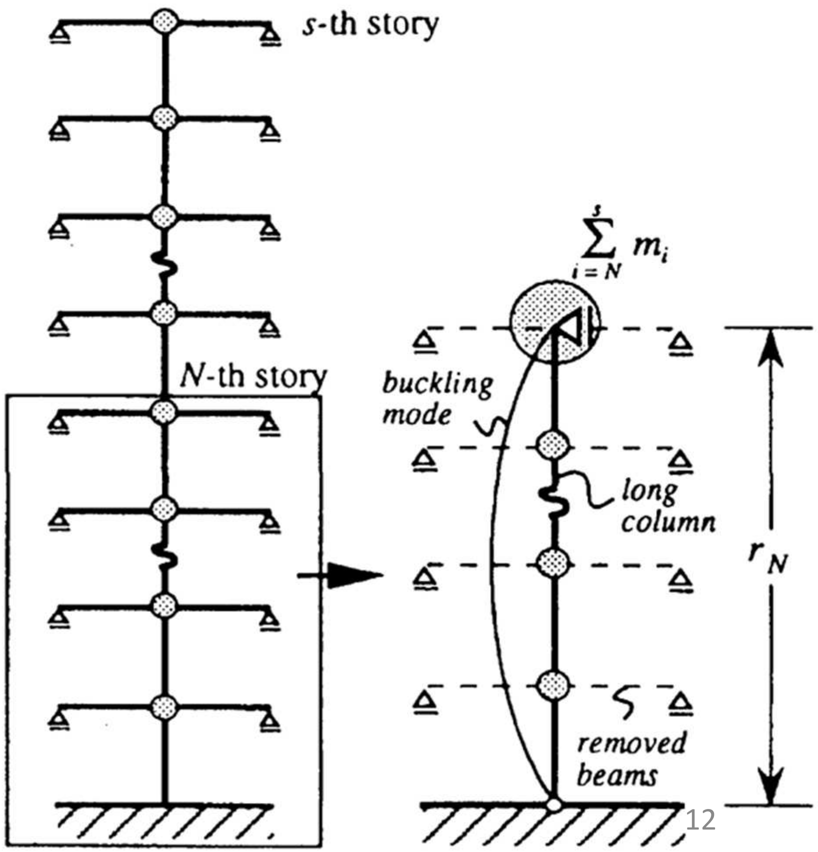


(a) Column deformation (b) Column bending moment (c) Time histories of 5,10 and 30th story (horizontal displacement)

CONDITION FOR DYNAMIC INSTABILITY

Uetani and Tagawa (1996)

- The critical height of the dynamic deformation concentration region can be predicted by using Euler buckling
- If Euler buckling occur in the long column, the effective buckling length corresponds to the height of the deformation concentration region.



Bernal (1998)

- Condition for dynamic instability
  - At least one of the eigenvalues of the momentary stiffness matrix is negative.

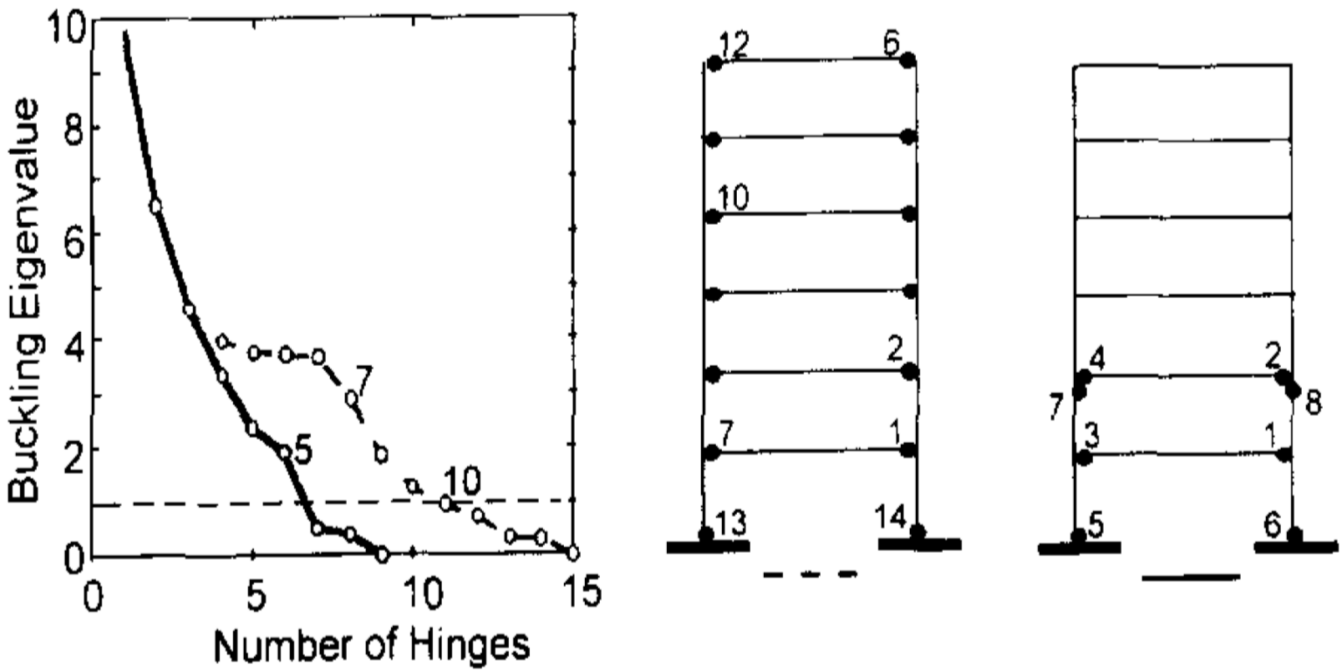
$$(\mathbf{K}_t - \mathbf{K}_g)\phi = \lambda\phi$$

  - **K**t: incremental tangential stiffness matrix
  - **K**g: geometric stiffness

Bernal (1998)

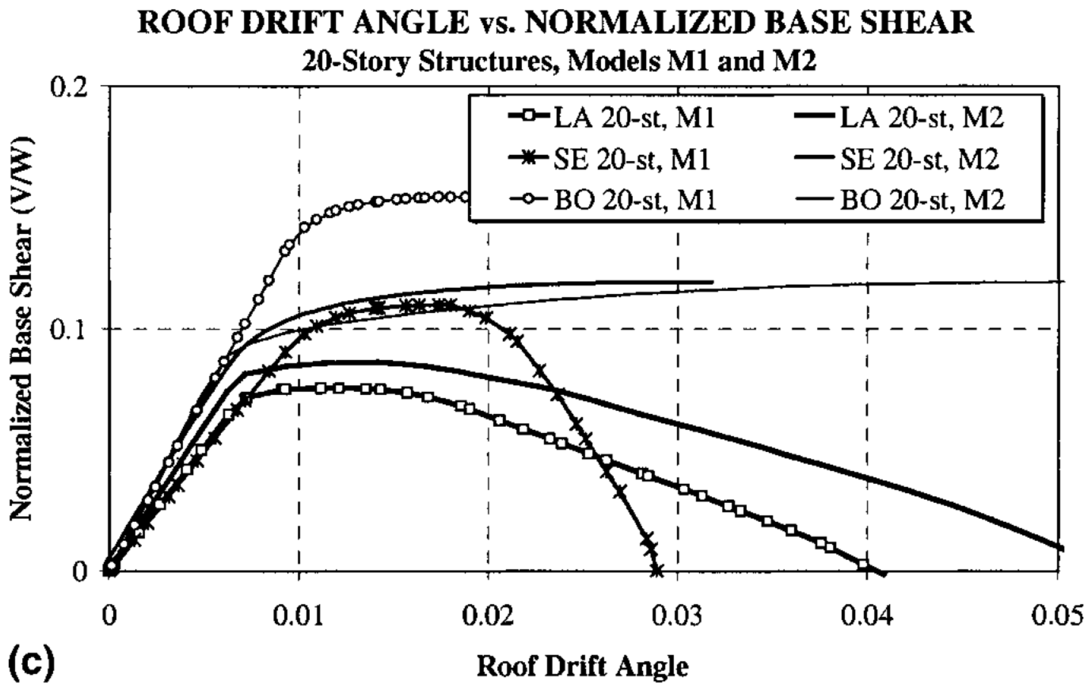
$$(\mathbf{K}_t - \mathbf{K}_g)\phi = \lambda\phi \Leftrightarrow \mathbf{K}_t\boldsymbol{\varphi} = \eta\mathbf{K}_g\boldsymbol{\varphi}$$

$$\lambda = 0 \Leftrightarrow \eta = 1, \phi = \boldsymbol{\varphi}$$



Guputa and Krawinkler (2000)

- Negative slope of the roof displacement-normalized shear force



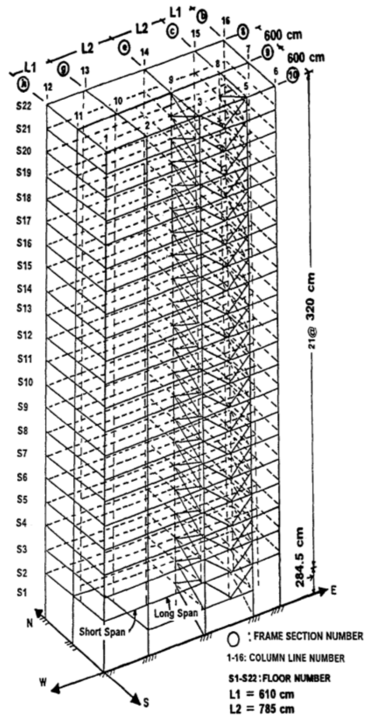
(c)

SEISMIC RESPONSE OF HIGH-RISE BUILDINGS SUBJECTED TO LONG-PERIOD GROUND MOTIONS

Osteraas and Krawinkler (1989)
Ger *et al*. (1993)

- 21-story Pino Suarez complex building collapsed in the 1985 Mexico City Earthquake

(Photo Credit: USGS)



Ger *et al*. (1993)

Osteraas and Krawinkler (1989) Ger *et al*. (1993)

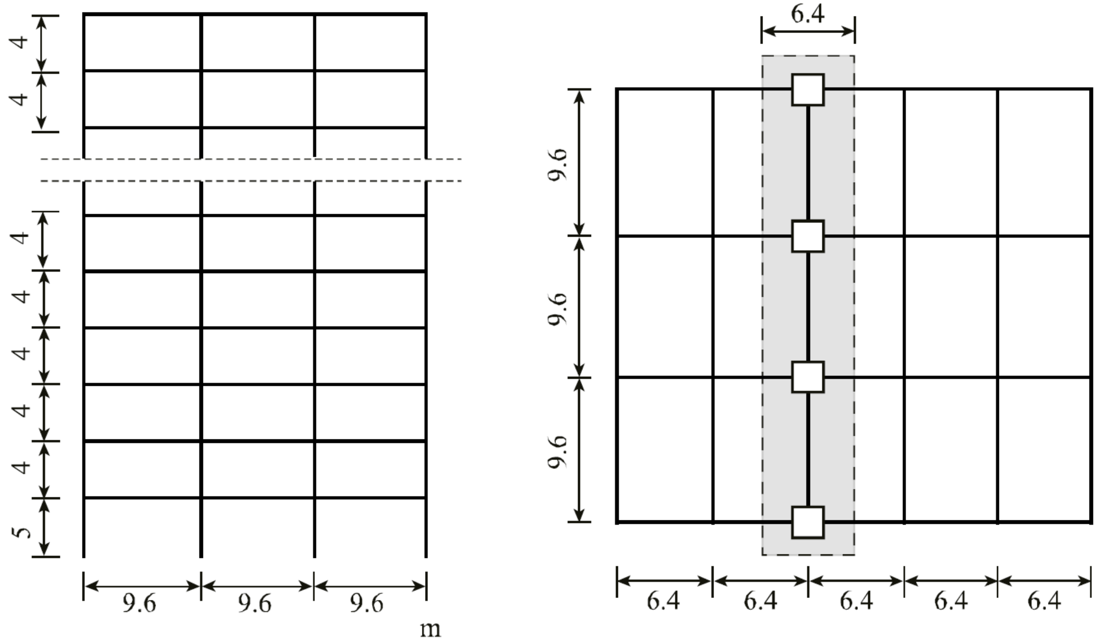
- A yield mechanism that is attributed to column yielding occurred in a certain lower story lead to the collapse.
- Buckling of braces, local buckling of columns, and the P-Delta effect are taken into account.
- The analysis by Osteraas and Krawinkler (1989) observed single directional accumulated deformations which might be attributed to the P-Delta effect.

Osteraas and Krawinkler (1989)
Ger *et al*. (1993)

- Ger *et al.* (1993) compared the analyses with and without P-Delta effect, and pointed out that the collapse behavior was not simulated by the analysis without P-Delta effect.
- A symmetric structural plan in order to avoid torsional motions, strong connections, enhanced ductility in the girders, and strong columns for not having plastic hinges and local buckling developed in the columns are important to avoid collapse of structures.

Araki *et al*. (2011)

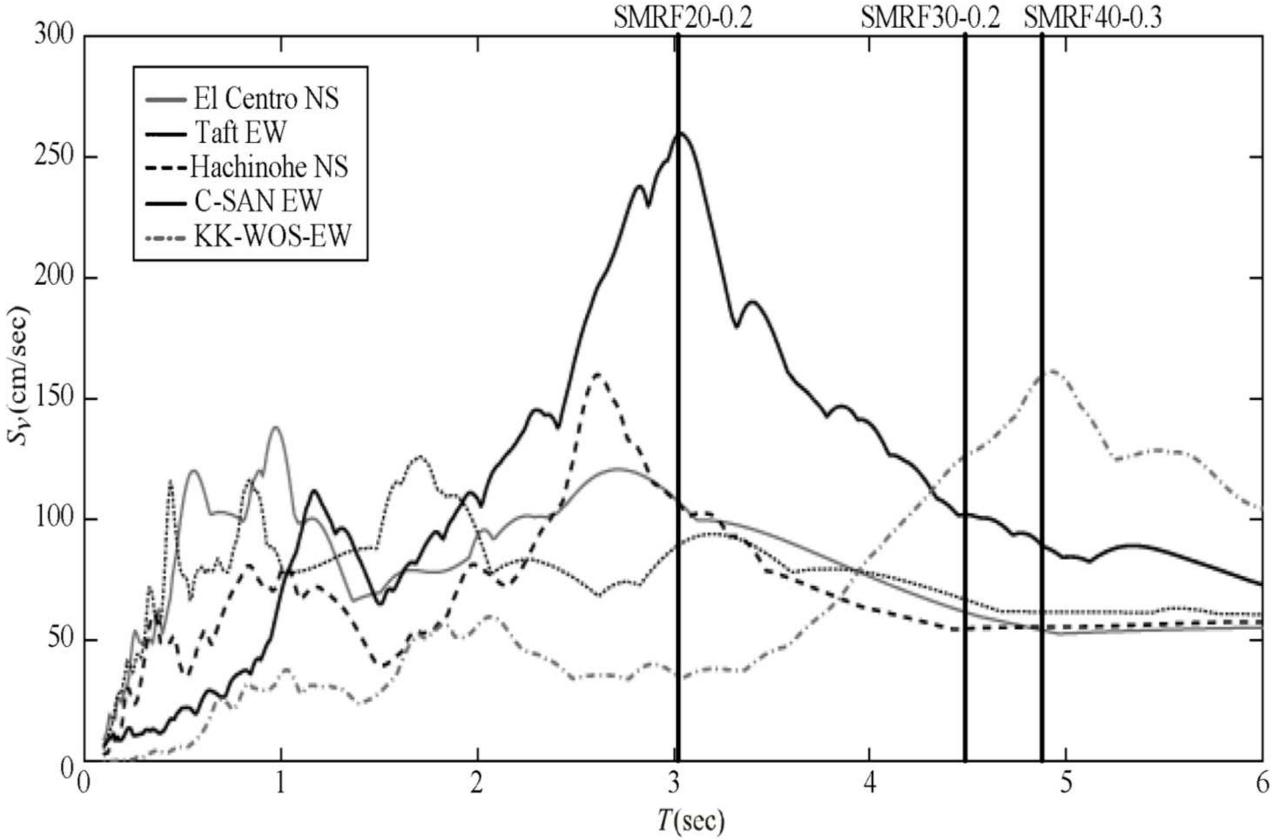
- 9 SMRF models (20, 30, 40 story buildings) in accordance with the Japanese design practice in the 1980s.
- Hypothetical Tonankai and Nankai Earthquakes



(a) (b)

Araki *et al*. (2011)

- Drifting took place in 3 of 9 models designed in accordance with design practice in the 1980s



Conclusions

- A brief review on the literature regarding dynamic instability is provided.
- Dynamic instability might occur even if the structure is designed in accordance with the recent design provisions.
- P-Delta effect must be taken into account in design practice for high-rise structures to understand the actual safety margins.