ASCE 41:
On the Integration of FEMA 440 Recommendations

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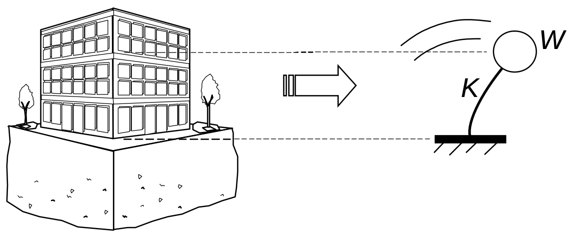
Overview

- **Structural dynamics and inelastic response**
- **Nonlinear Static Procedure**
- **Linear Static Procedure**
- **Foundations and Soil**

Structural Dynamics

- **Equivalent (linear) single degree of freedom oscillator**



$$T = 2\pi\sqrt{\frac{W/g}{K}}$$

Assuming simple harmonic motion, displacement is related to acceleration by

$$S_d = \frac{T^2}{4\pi^2} S_a g$$

Inelastic Response

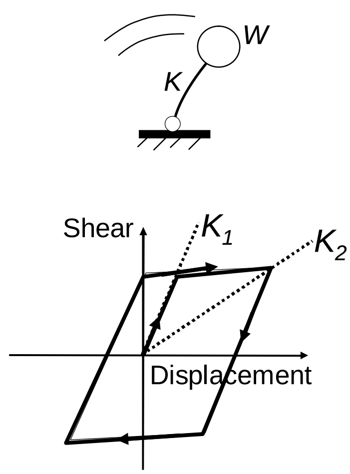
- **Inelastic response …**

<u>reduces stiffness</u>

- increasing effective period of vibration

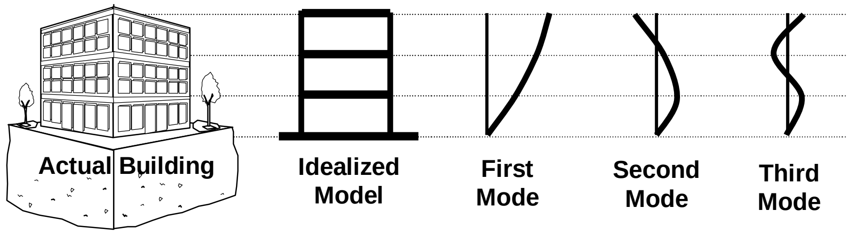
<u>increases energy dissipation</u>

- producing effective damping

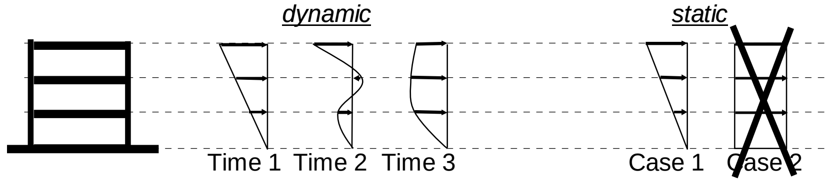


Multi-story Structures

- Can be idealized and analyzed as multi-degree-of-freedom systems



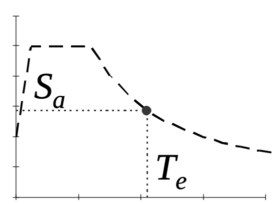
- Actual structures have continually varying inertial loads
- For nonlinear static analysis, the <u>first mode load pattern</u> is sufficient; no bounding analysis is needed [FEMA 440]



Nonlinear Static Procedure (NSP)

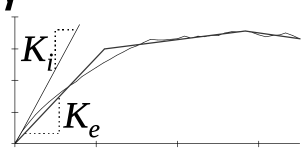
$$\delta_t = C_0 C_1 C_2 \xcancel{C_3} S_a \frac{T_e^2}{4\pi^2} g$$

- S_a is the spectral acceleration at the effective fundamental period of vibration, T_e



- Effective period, T_e, is calculated by

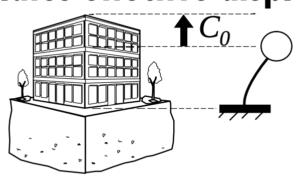
$$T_e = T_i \sqrt{\frac{K_i}{K_e}}$$



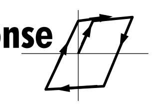
Nonlinear Static Procedure (NSP)

$$\delta_t = C_0 C_1 C_2 \cancel{C_3} S_a \frac{T_e^2}{4\pi^2} g$$

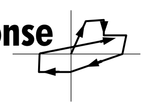
- **C_0 relates effective displacement to that at roof**



- **C_1 is increase for short-period, inelastic response**



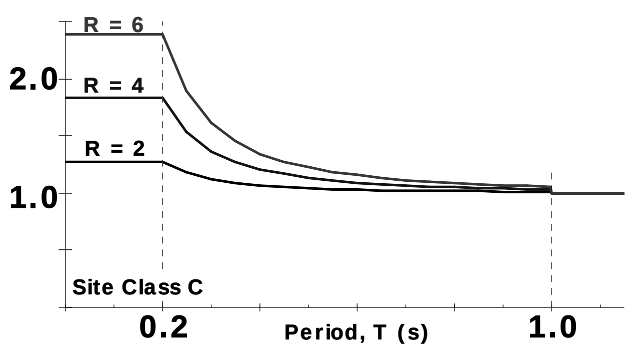
- **C_2 is increase for pinched/degraded response**



NSP: C_1 Coefficient

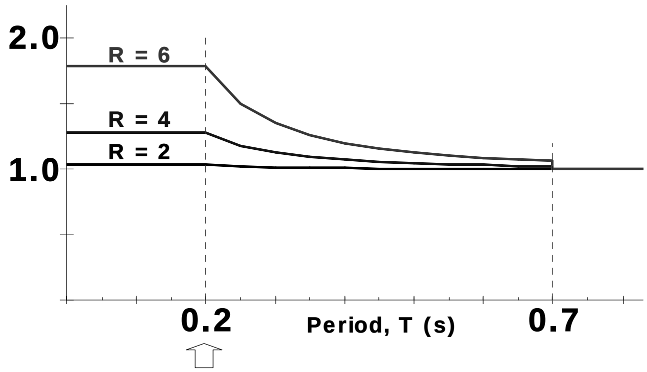
$$C_1 = 1 + \frac{R-1}{\alpha T^2}$$

- α **is for Site Class**
- ***R*** **is the ratio of elastic strength demand to yield strength**



NSP: C_2 Coefficient

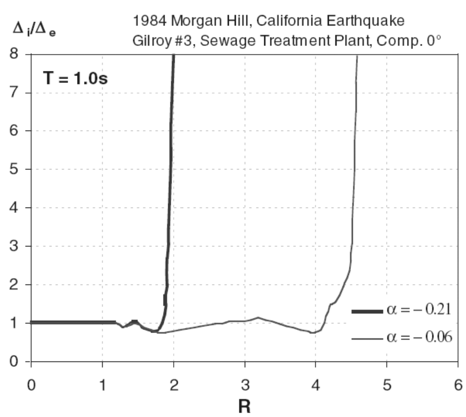
$$C_2 = 1 + \frac{1}{800}\left(\frac{R-1}{T}\right)^2$$



NSP: Dynamic Instability

$$\delta_t = C_0 C_1 C_2 \cancel{C_3} S_a \frac{T_e^2}{4\pi^2} g$$

- Dynamic P-Δ effects do not simply increase roof displacements gradually over a wide range of ductility demand (*R*) as suggested by the C_3 term in FEMA 356
- Instead, systems may become unstable at a distinct ductility demand, approximated by R_{max} in ASCE 41



[from FEMA 440]

Linear Static Procedure (LSP)

$$V = C_1 C_2 C_m S_a W$$

- C_1, C_2, and S_a are the same as for NSP
- C_m is decrease for effective mass in first mode
- W is the seismic weight

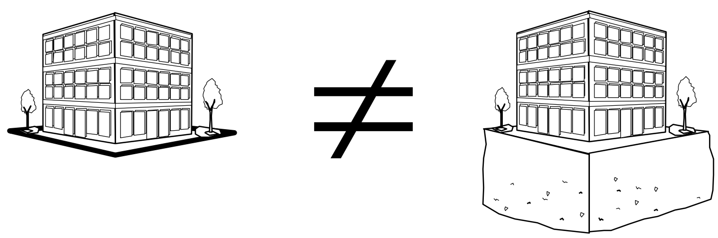
LSP: Calculating *R*

$$R = \frac{DCR_{\max}}{1.5} C_m \geq 1.0$$

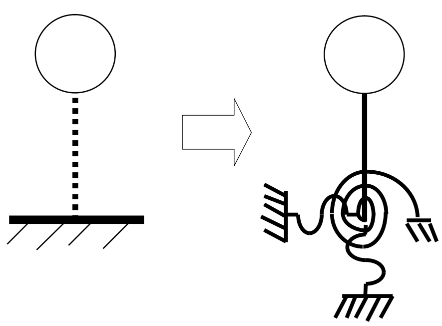
- **Based on a very rough approximation that the elastic base shear capacity is 1.5 times the base shear at first yield**
  - Consistent with Ω_0 = 2.5, ϕ = 0.75, and expected/nominal = 1.25
- **DCR_{max} is the maximum DCR for primary components, computed assuming $C_1 = C_2 = C_m = 1.0$**

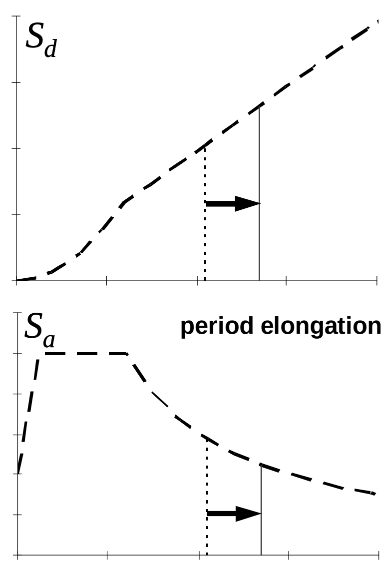
Foundations and Soil

- **Foundation flexibility → period elongation**
  - Reduces force demands
  - Increases displacement demands
- **Soil-structure interaction (SSI)**
  - Reduces spectral demands



Foundation Flexibility



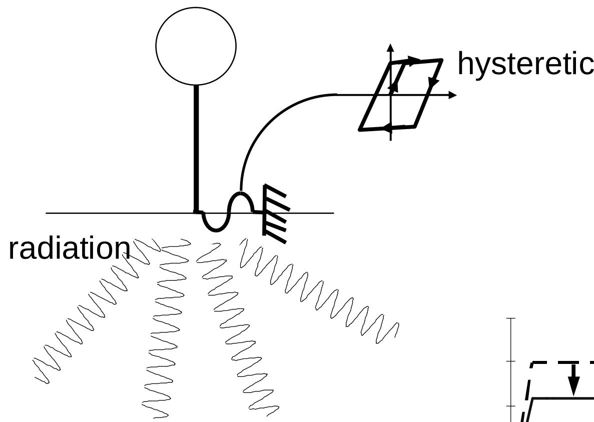


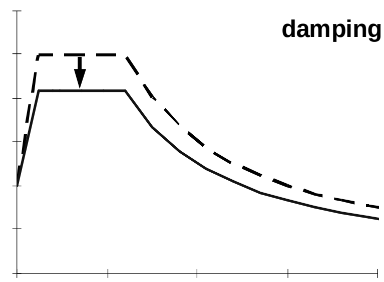
- **Soil "springs" in series**
- **Reduce *K* → increase *T***

$\therefore$

- **Reduce accelerations**
- **Increase displacements**

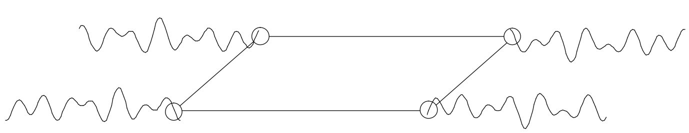
SSI: Foundation Damping

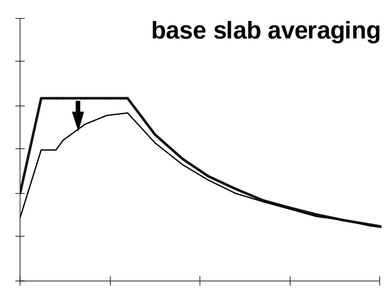




- **Energy dissipated**
- **→ Increases damping**

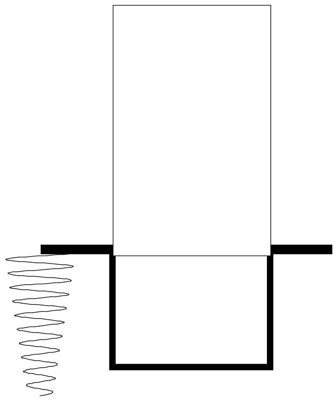
SSI: Base Slab Averaging

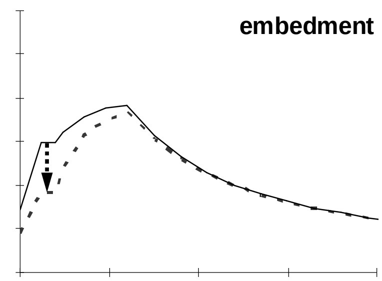




- **Spatial incoherence**
- **Reduces effective "average" accelerations at high frequency (low *T*)**

SSI: Embedment





- Motions smaller at depth
- Vertical incoherence

Summary of Foundation Effects