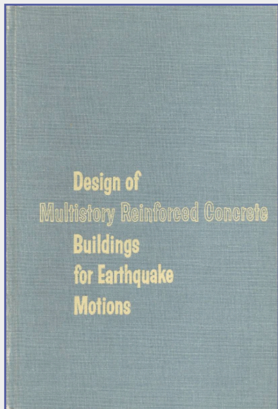
# Current Assessment Approaches




Jack Moehle

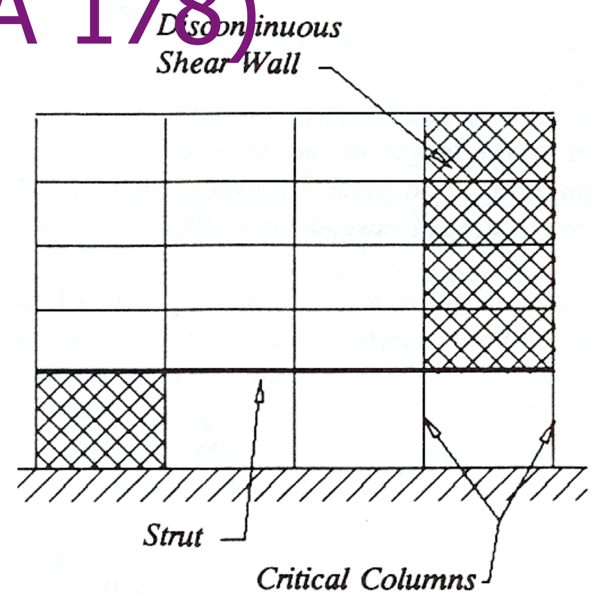
University of California, Berkeley

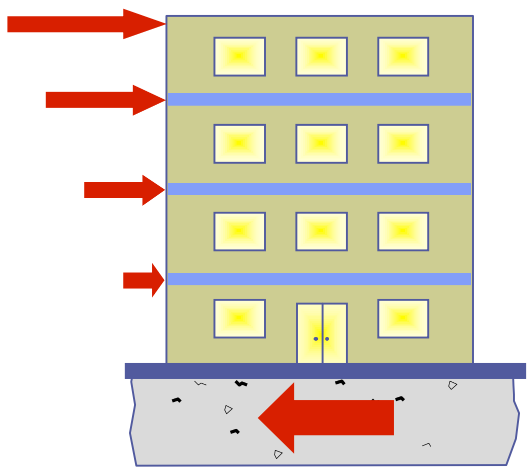
# Outline

- Background
- Early assessment and rehabilitation approaches
- Current assessment and rehabilitation approaches
- Improved simplified analysis methods

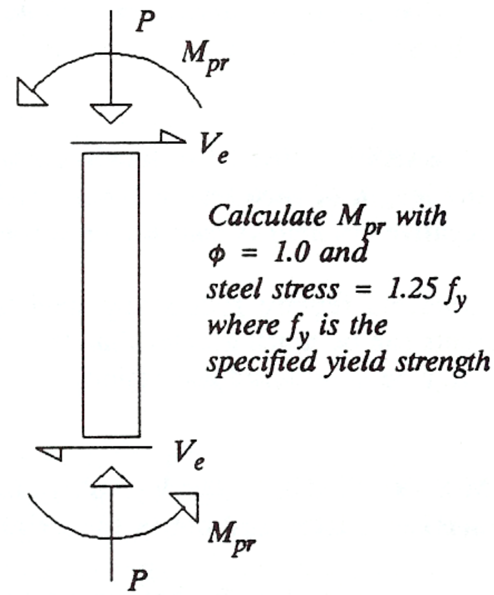
# Seismic assessment/upgrading through mid-1990s (FEMA 178)

- Checklist to identify critical deficiencies
- Minimum strength requirement



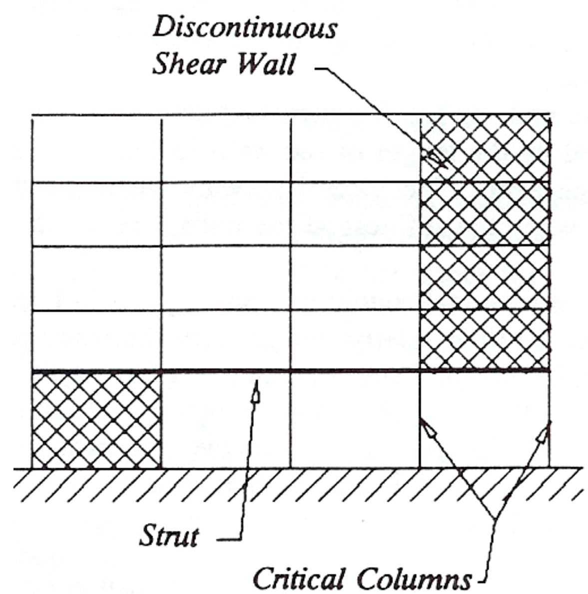



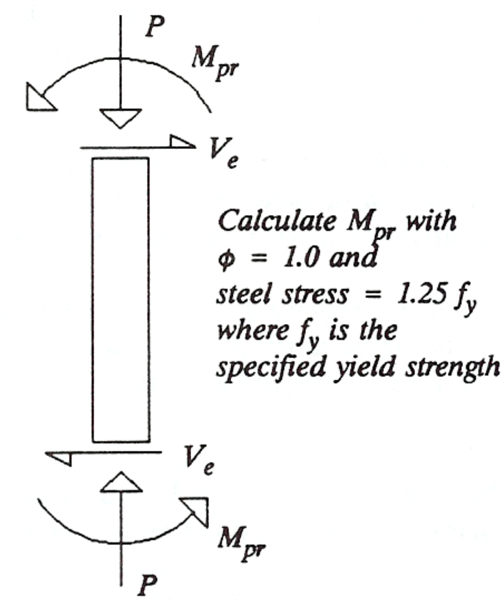
$$V \approx \frac{3}{4}\left(\frac{ZICS}{R}W\right)$$



# Seismic assessment/upgrading since mid-1990s (FEMA 273)

- Checklist to identify critical deficiencies
- Detailed requirements for condition assessment
- Performance approach
  - Performance objectives
  - Seismic hazard characterization
  - Nonlinear, displacement-based analysis
  - Detailed acceptance criteria



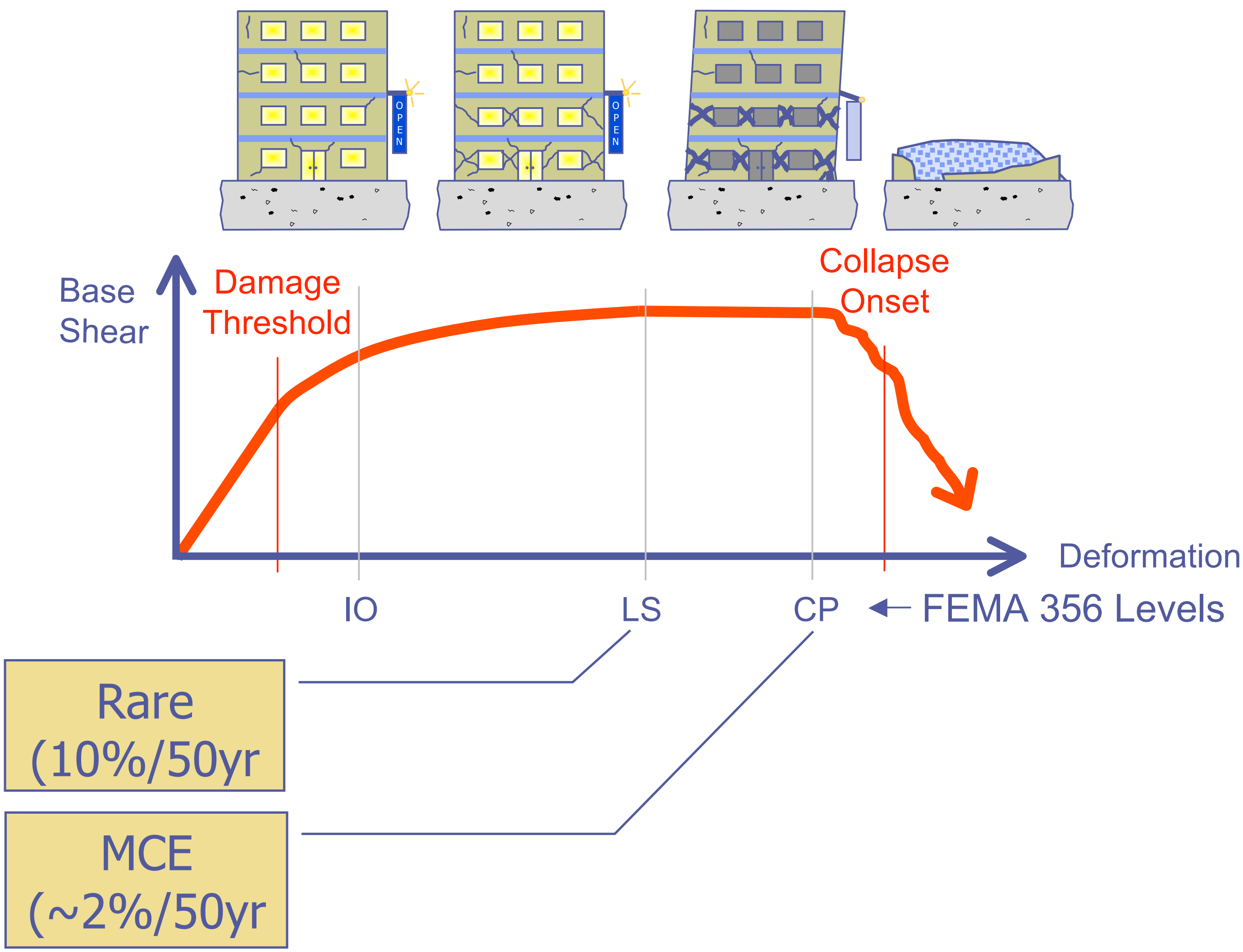
# Performance objectives

**Building Performance Level**

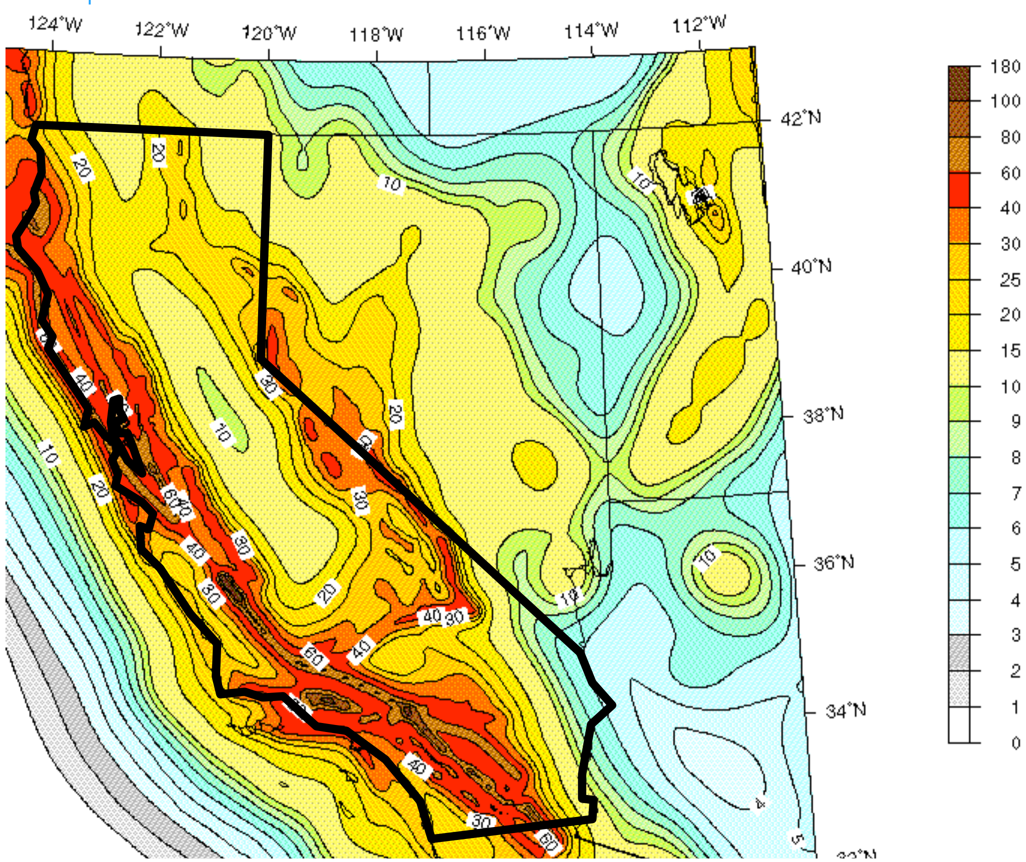
| Design Shaking Level | Operational | Occupiable, Damaged | Life Safe, Major Damage | Near Collapse |
|---|---|---|---|---|
| Frequent (50%/50yr) | a | b | c | d |
| Occasional (20%/50yr | e | f | g | h |
| Rare (~10%/50yr) | i | j | k | l |
| MCE (~2%/50yr) | m | n | o | p |

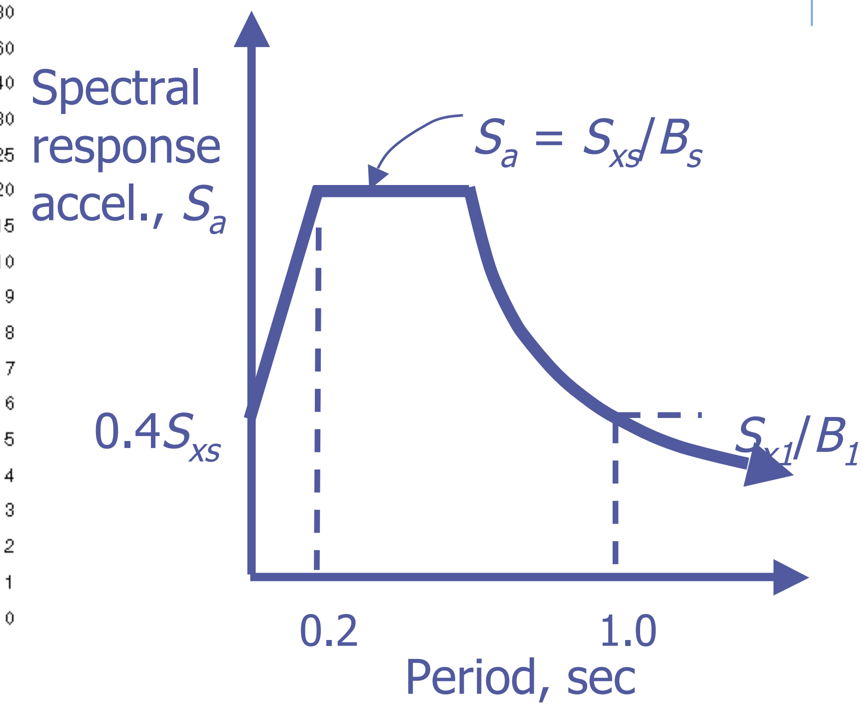
Most commonly selected performance objective

# Performance objectives



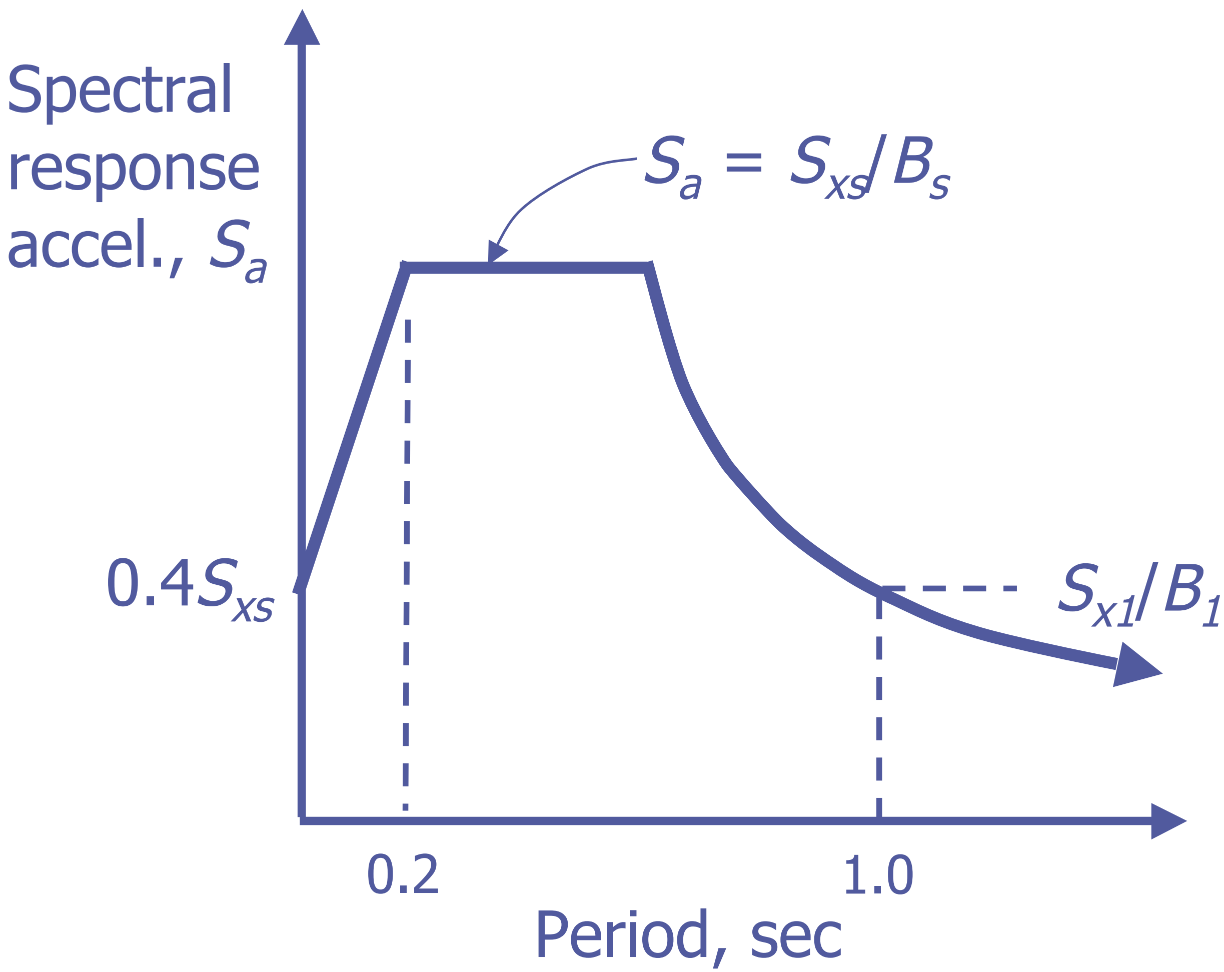
# Seismic hazard



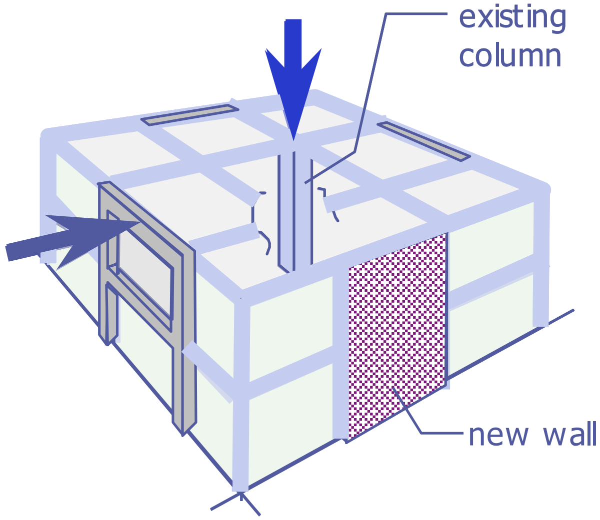



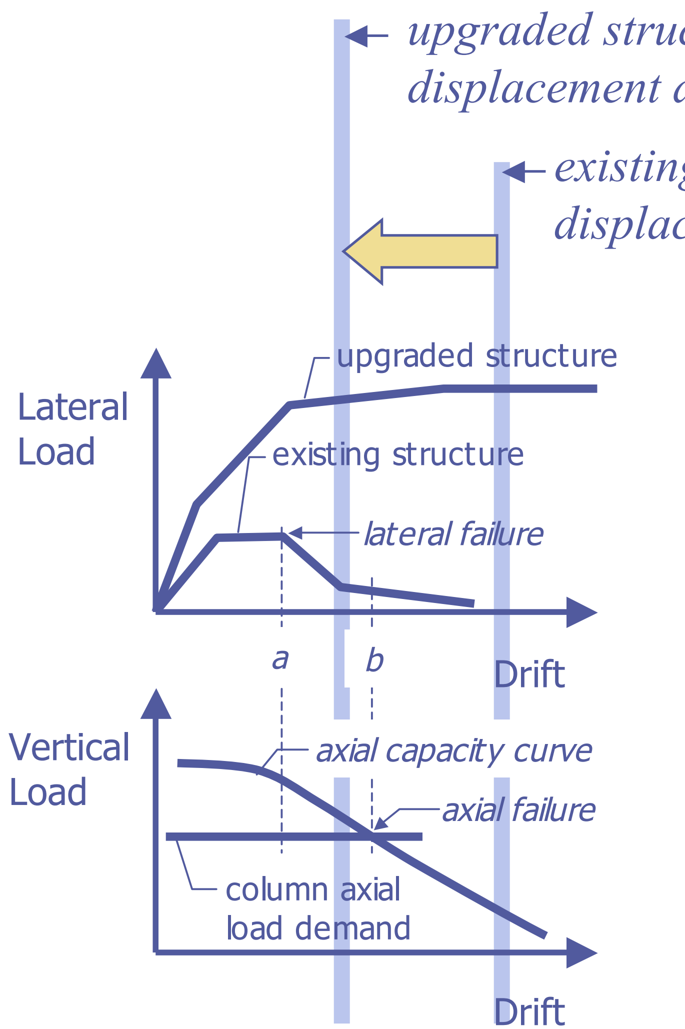
# Design response spectra

*general approach (shown) or site-specific*

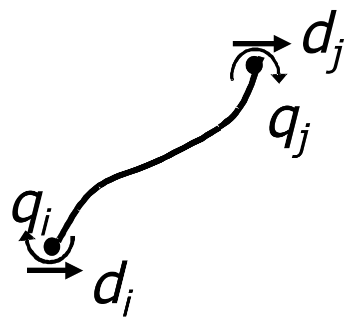


# Nonlinear analysis model/ upgrading concept

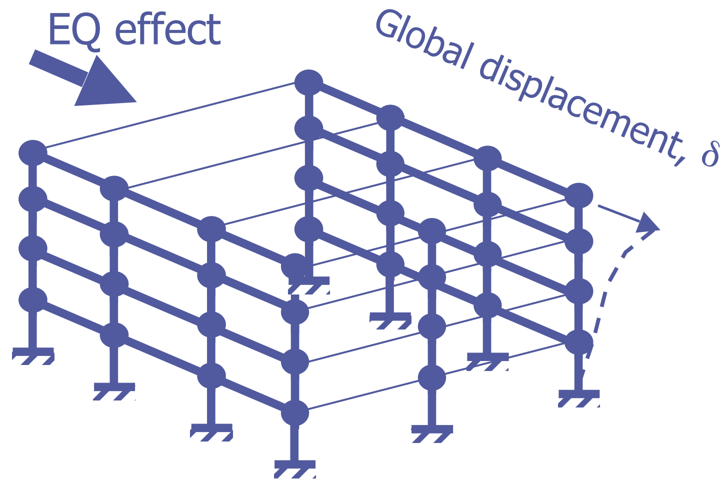


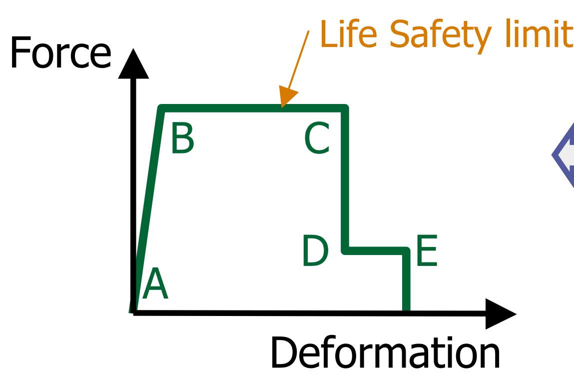

# Modeling, analysis, and acceptance




Component Model




Global Model

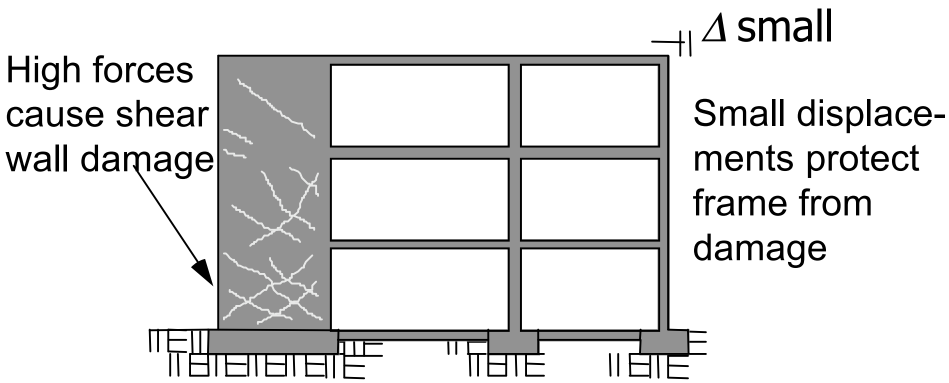



Acceptance Criteria

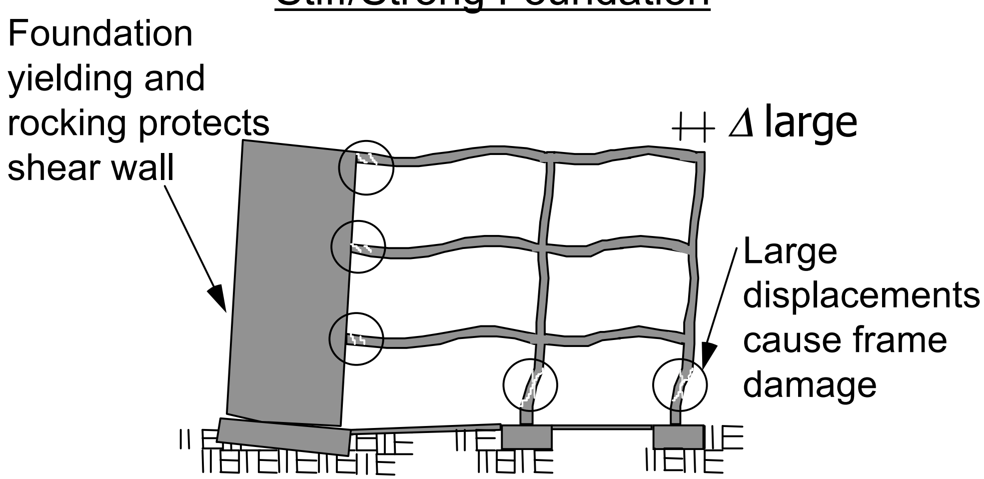
Component Tests

# Foundation modeling

## (a) Foundation deformations




Stiff/Strong Foundation

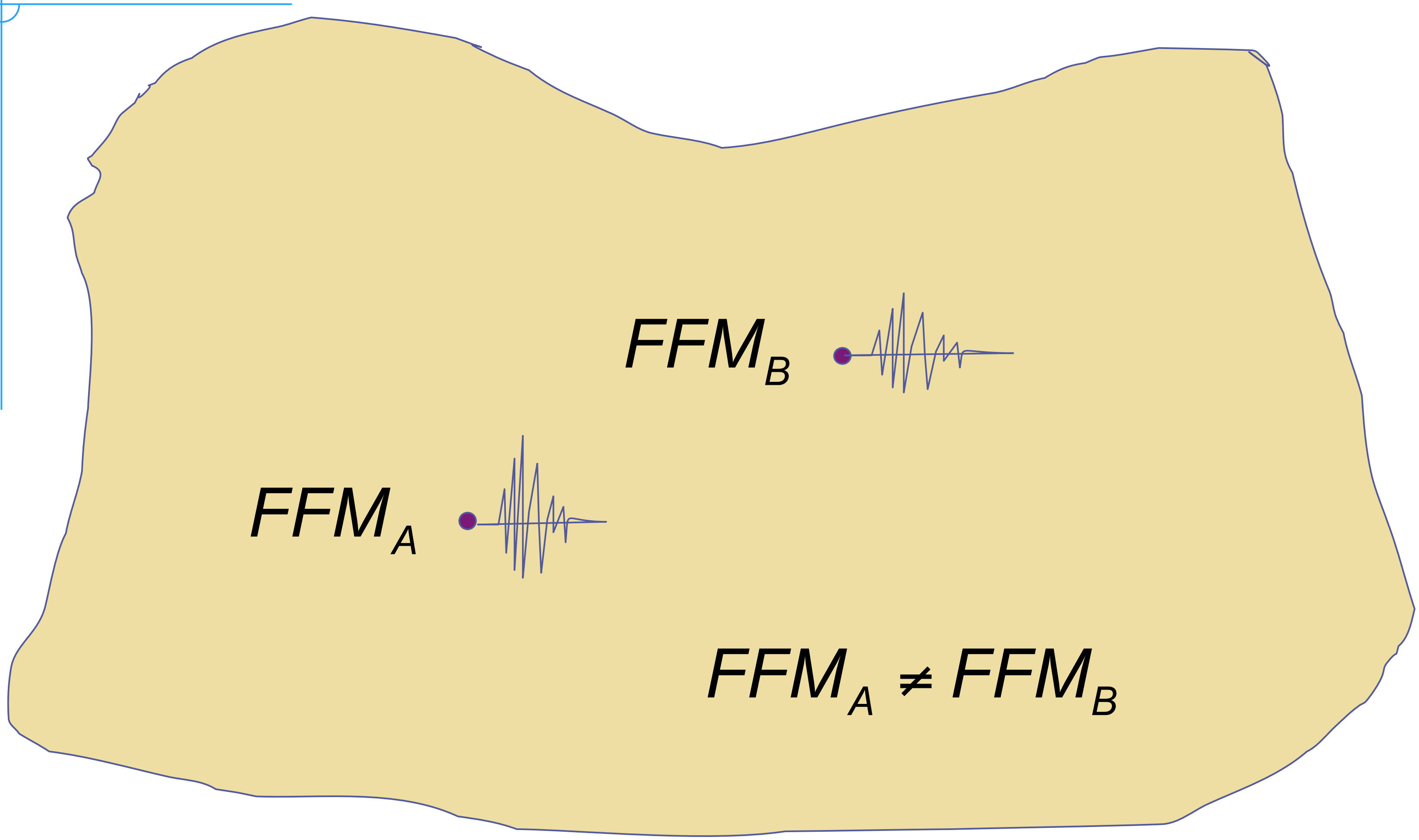



Flexible/Weak Foundation

## (b) Modified input

- "slab" averaging
- embedment
- damping

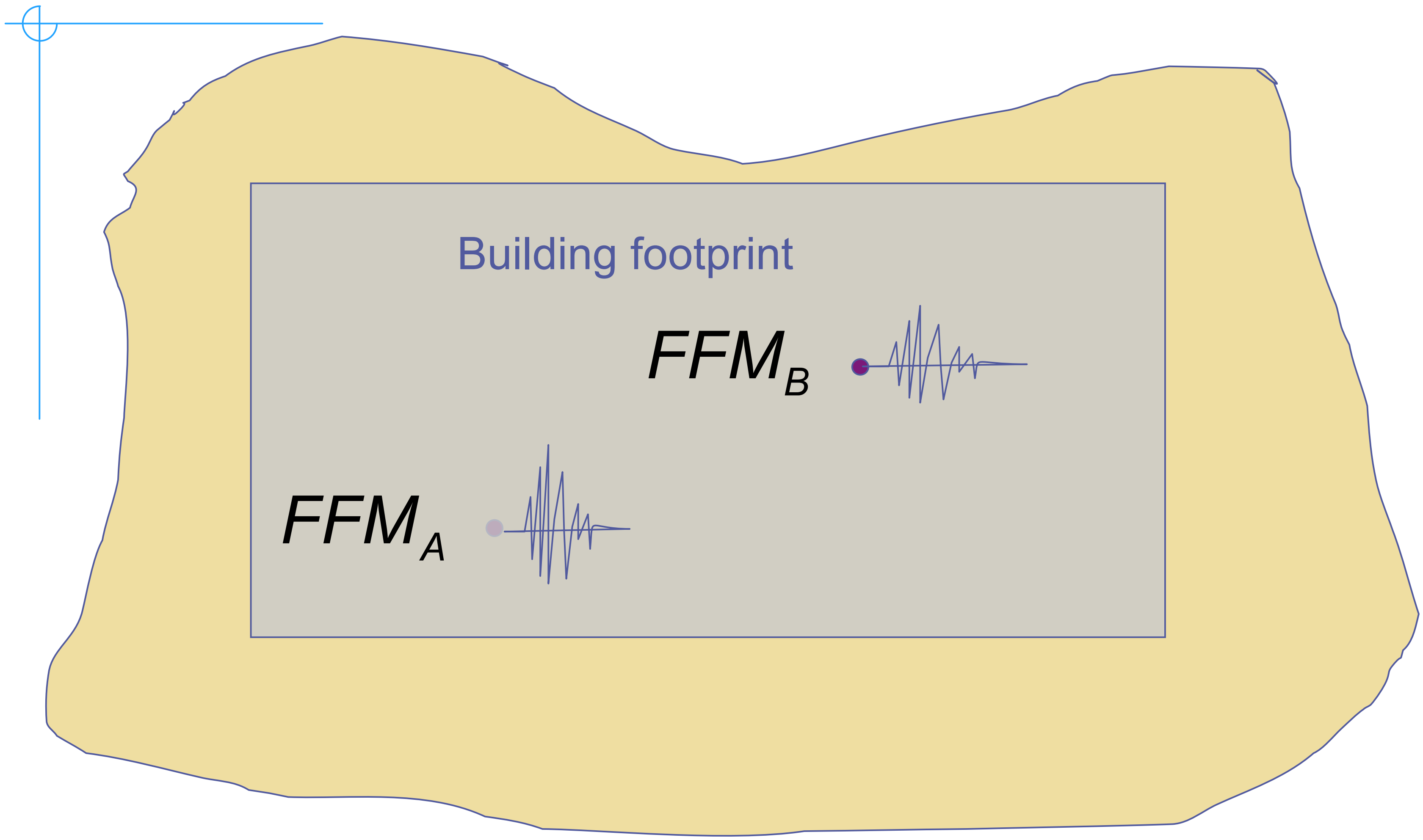
# Free field motion




Site plan

Comartin

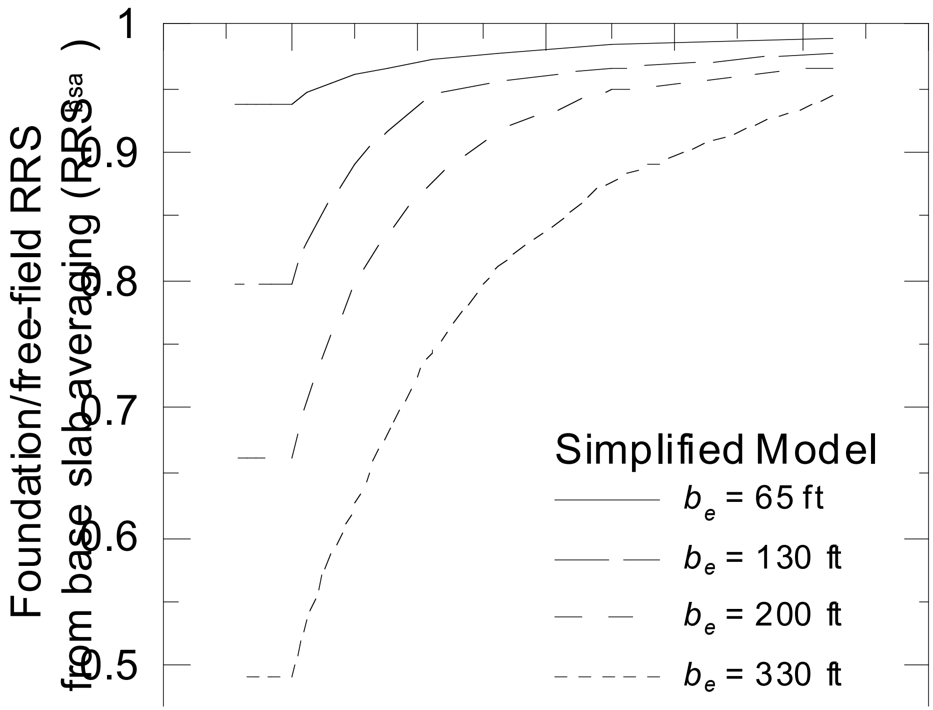
# Foundation input motion




Site plan

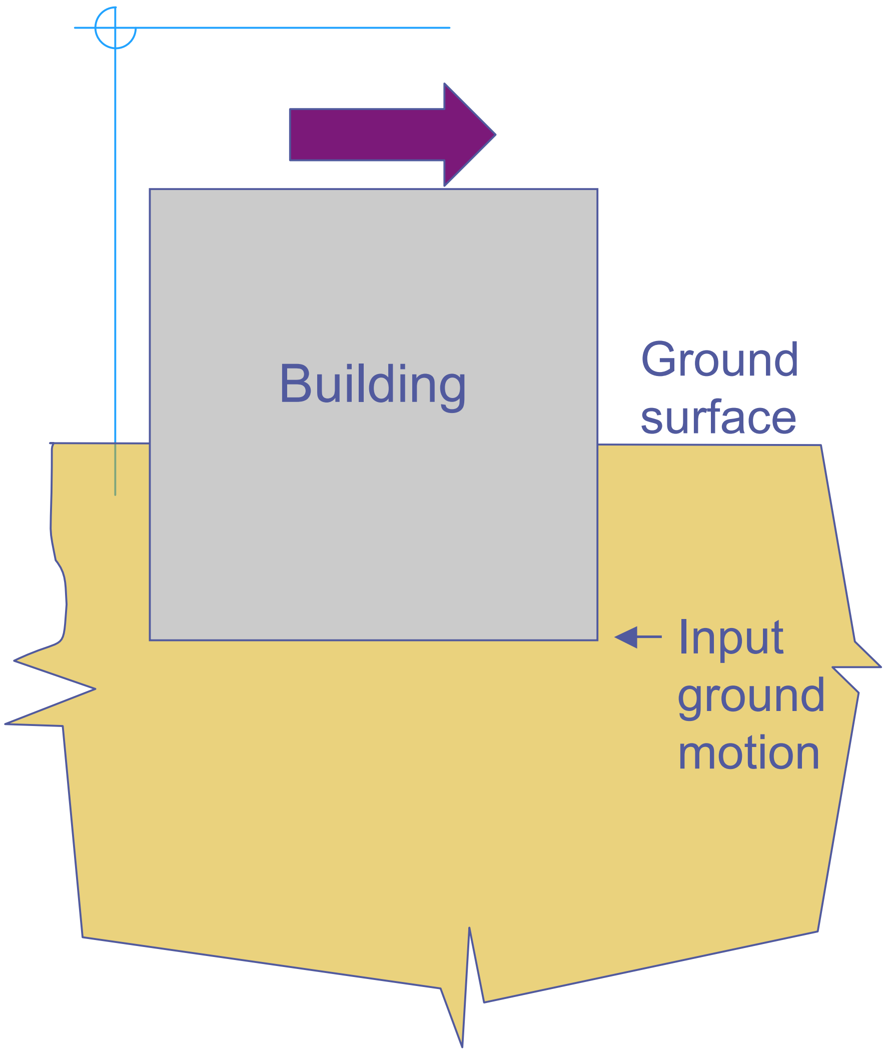
Comartin

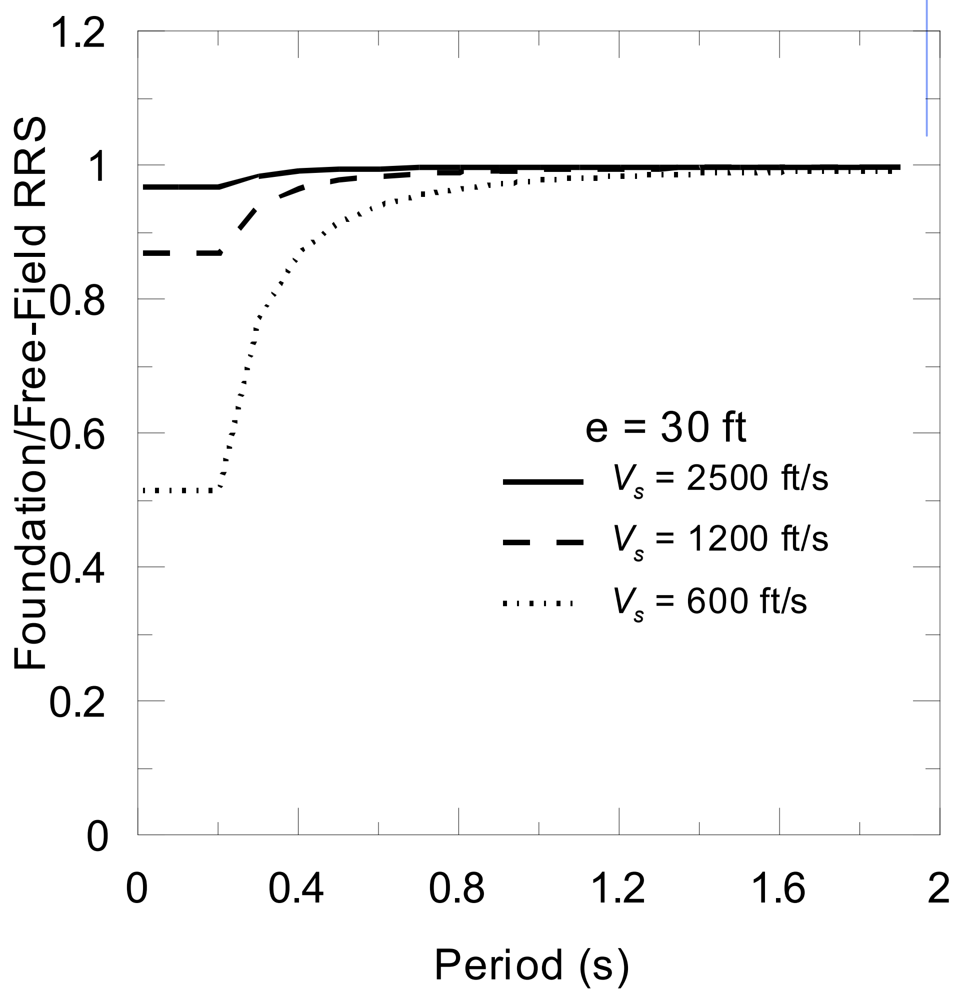
# Slab averaging




FEMA 440

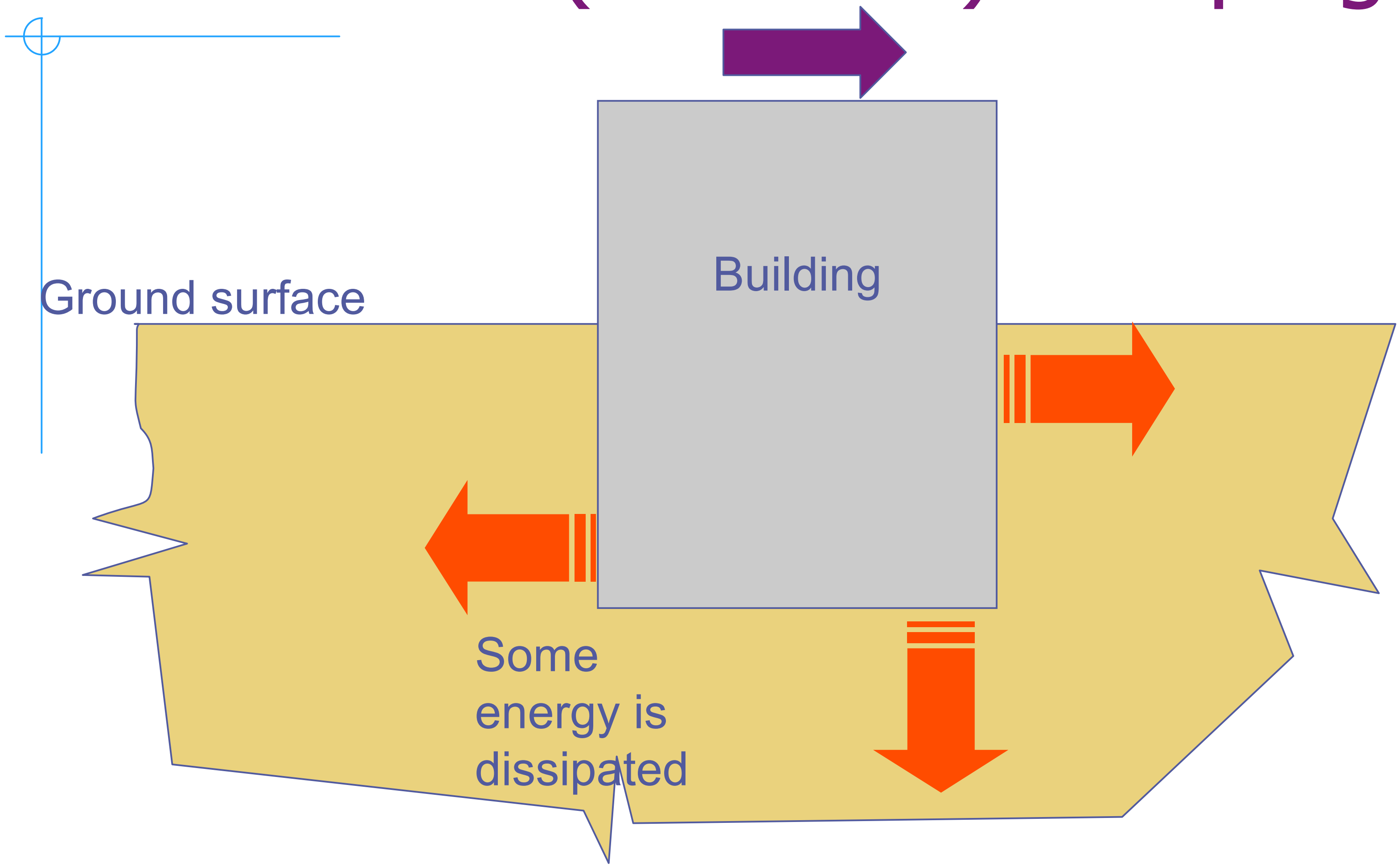
# Embedment effect



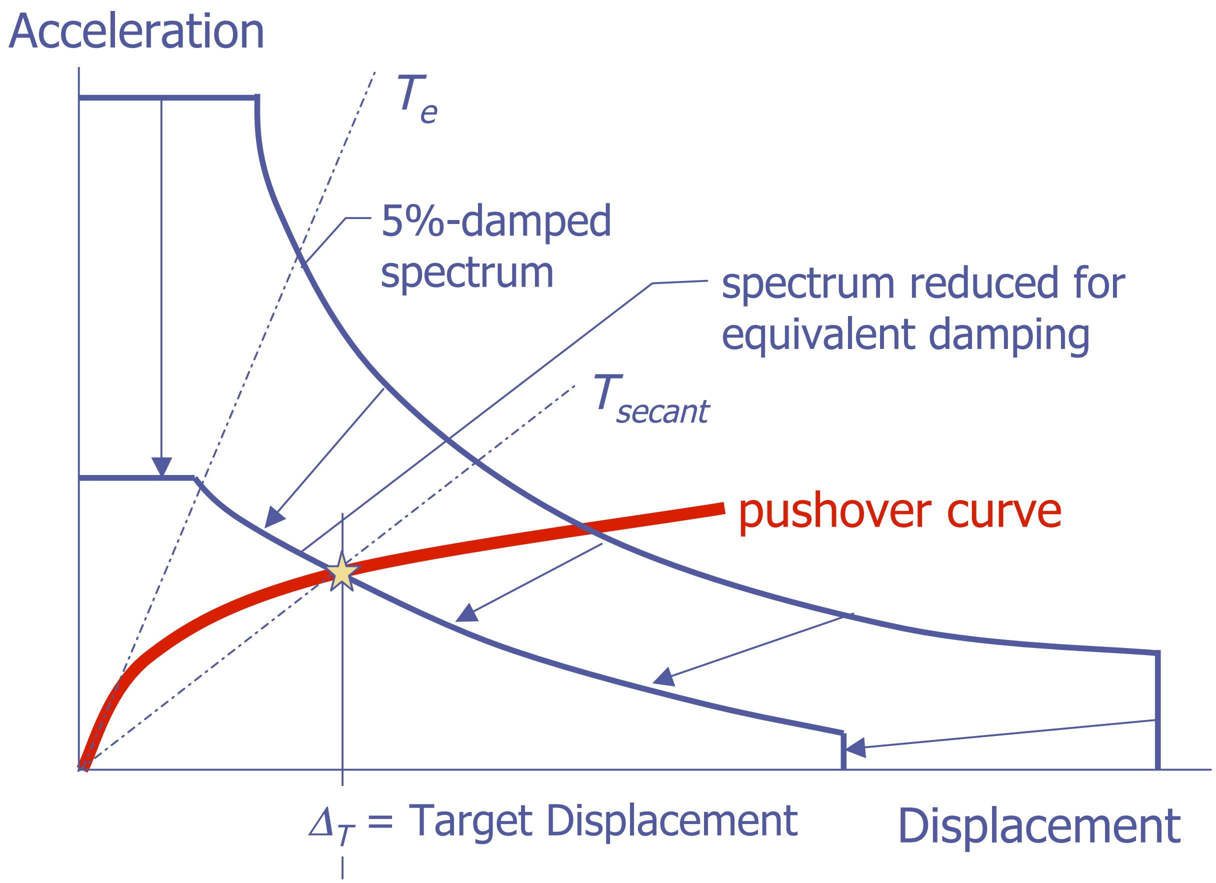

*FEMA 440*

# Foundation (radiation) damping



# Displacement demand – *Equivalent linearization (formerly capacity-spectrum)*

General concept shown below.  See FEMA 440 for details.

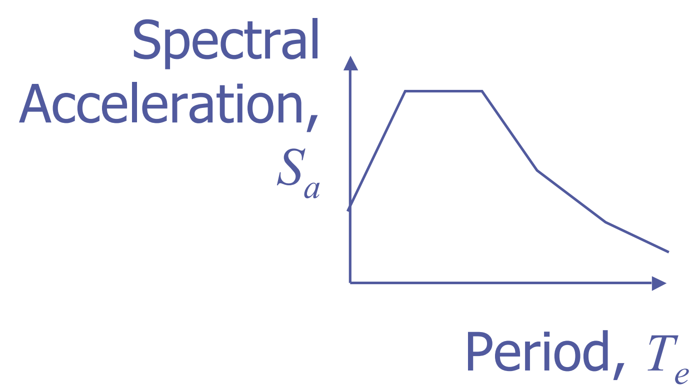


# Displacement demand –

## *Coefficient method*

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

Elastic roof displacement




$C_o$ = converts SDOF spectral displacement to MDOF roof displacement

$C_1$ = amplification for nonlinear response of bilinear system $= 1 + \frac{R-1}{aT^2}$

$C_2$ = amplification for pinched hysteresis, stiffness degradation, and strength deterioration $= 1 + \frac{1}{800}\left(\frac{R-1}{T}\right)^2$

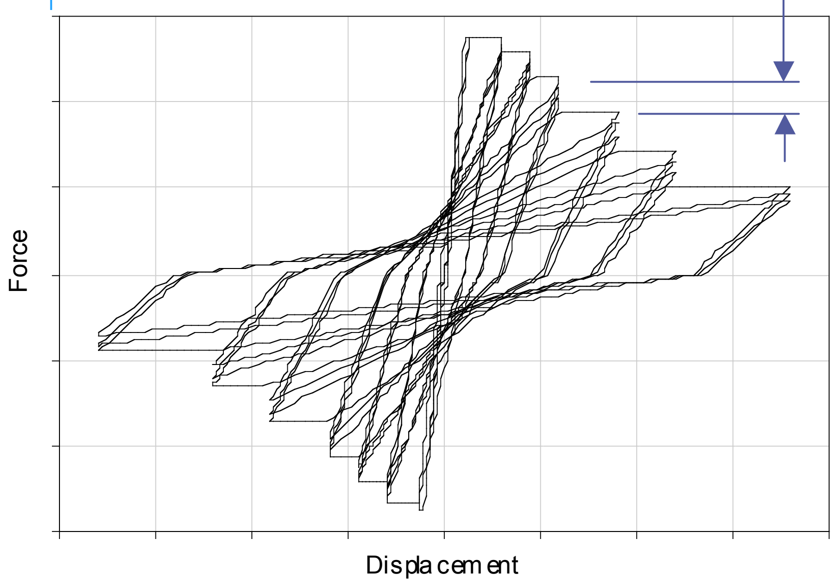
~~$C_3$ = amplification due to dynamic P-Δ effects~~

replaced by minimum strength requirement

FEMA 440

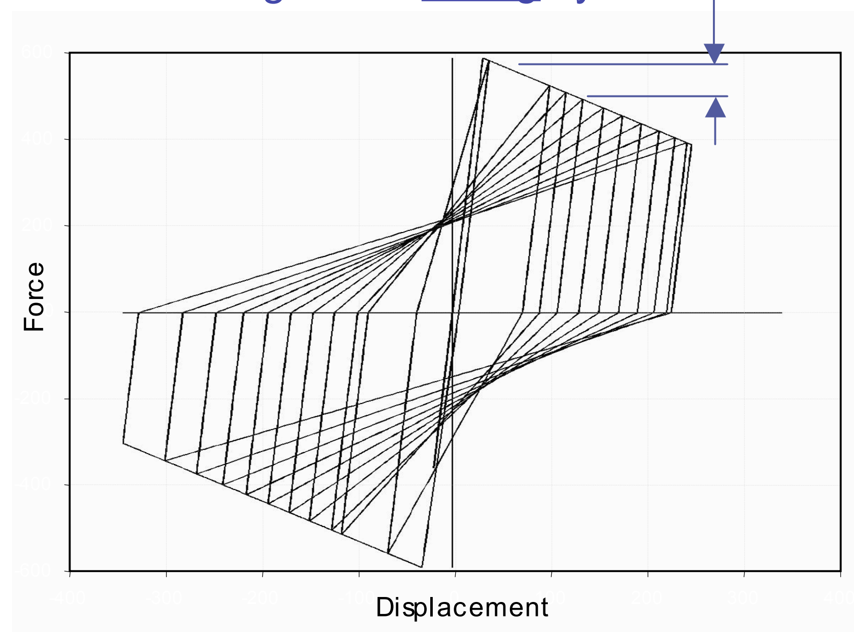
# Two types of strength degradation

Strength loss *between* cycles



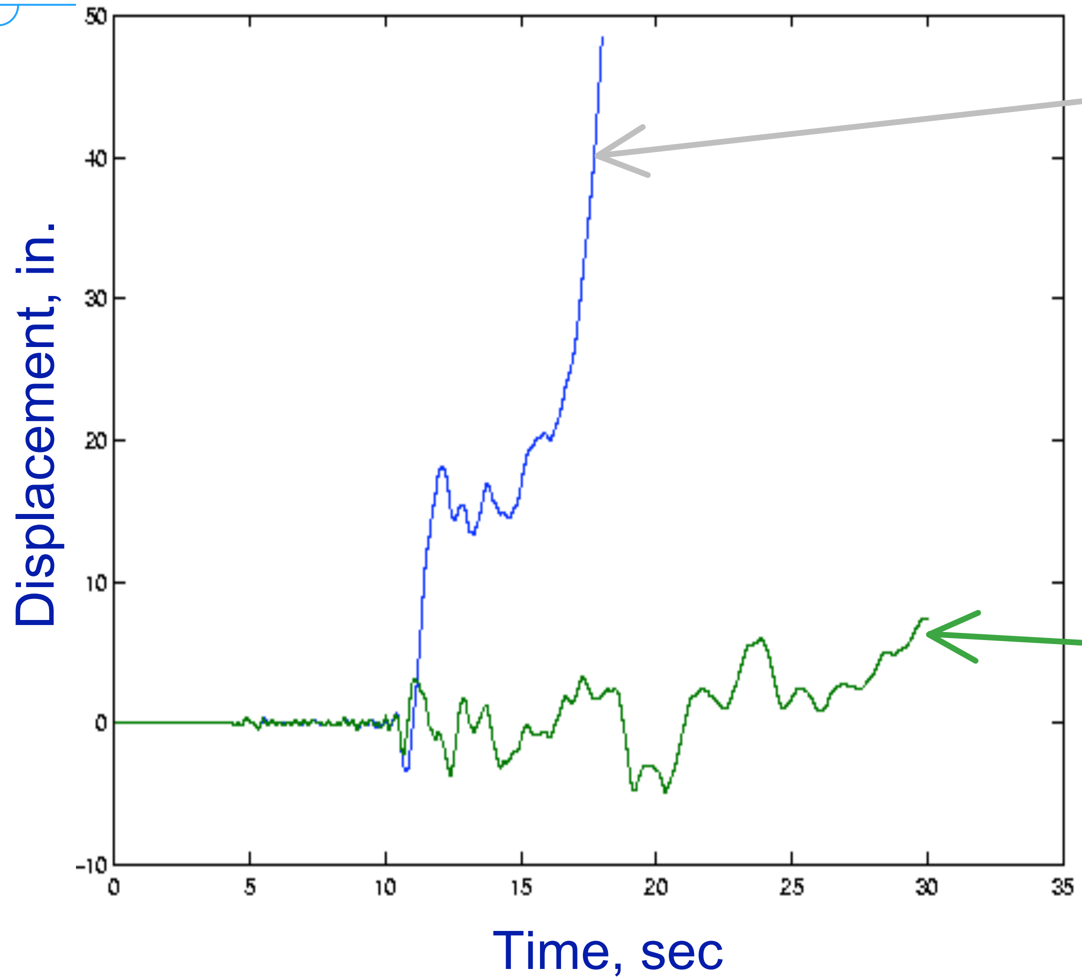

Cyclic strength degradation

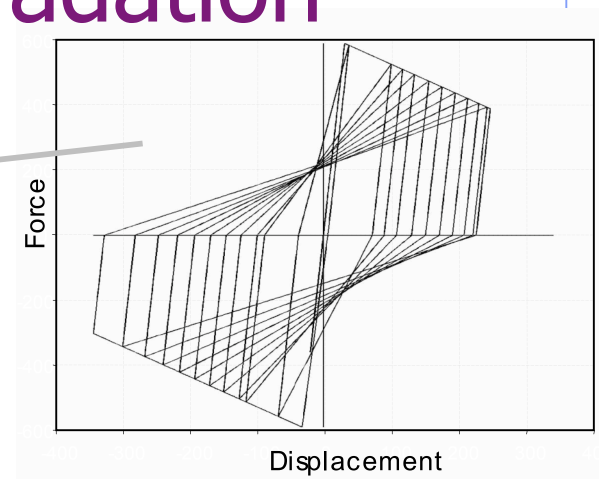
Strength loss *during* cycles

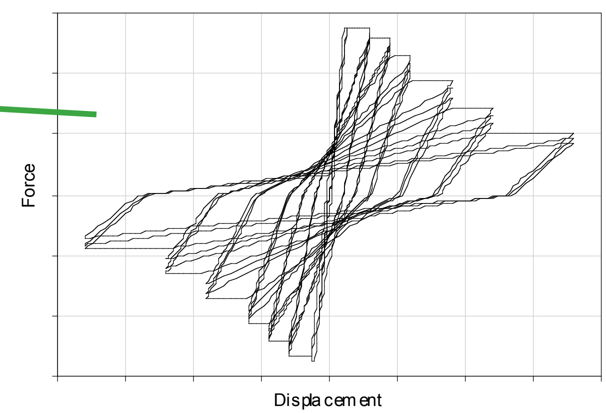



In-cycle strength degradation

# Two types of strength degradation

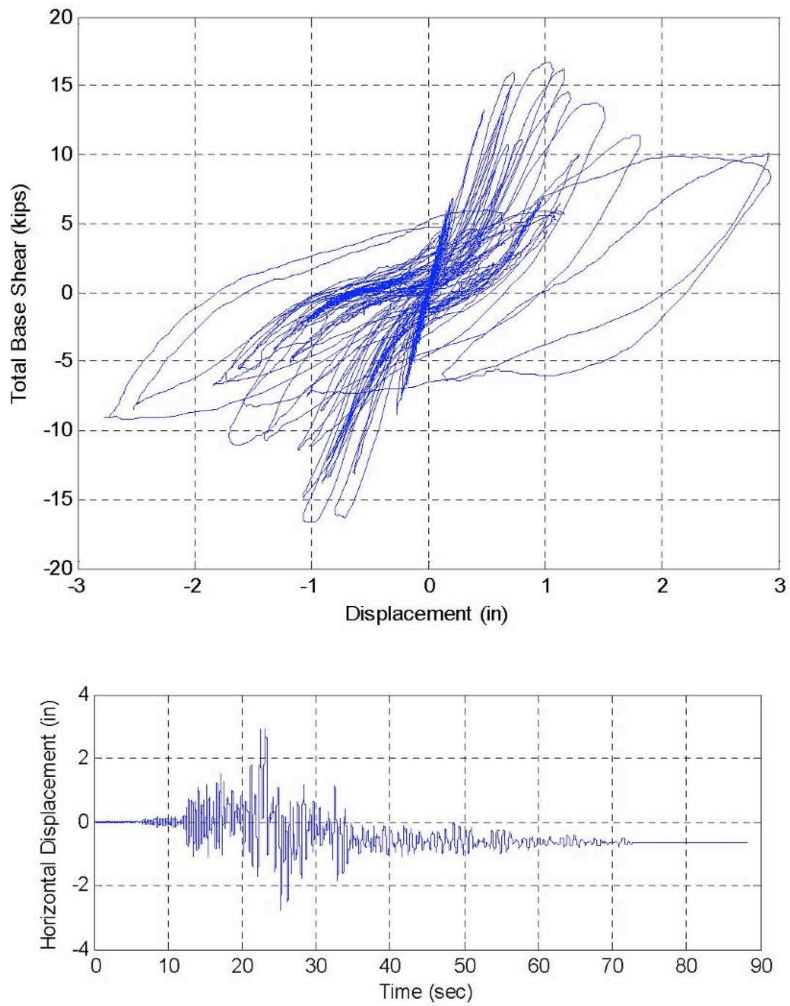


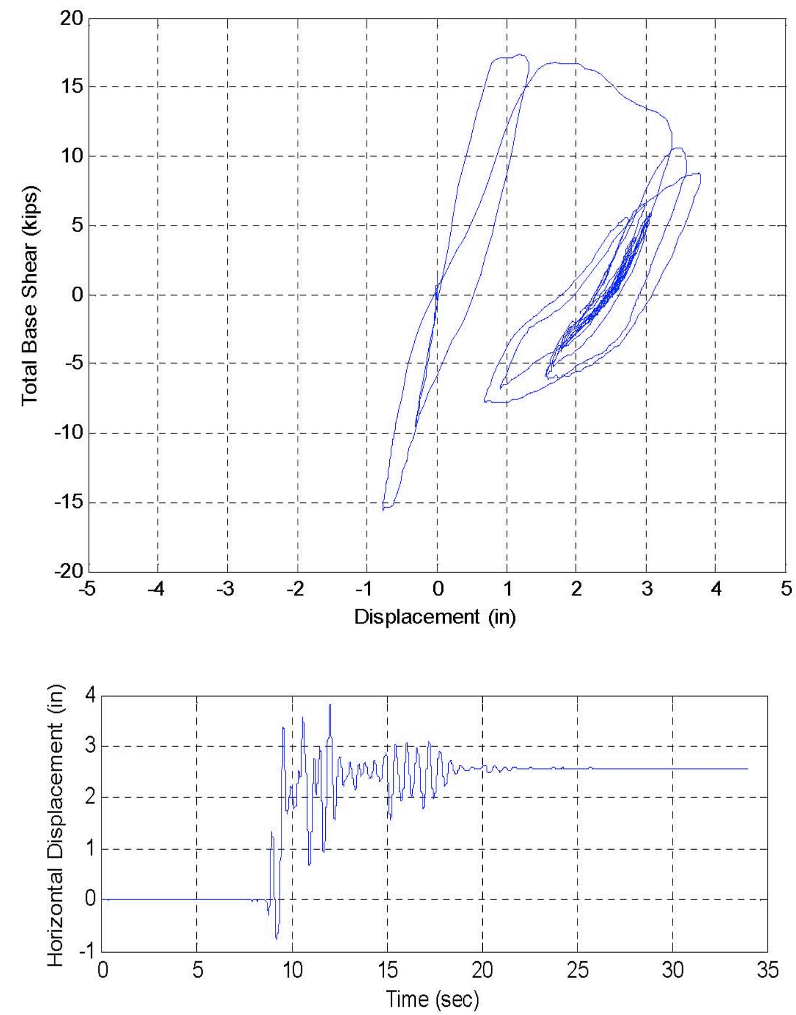




*Michael Scott, PEER, 2003*

# Test observations



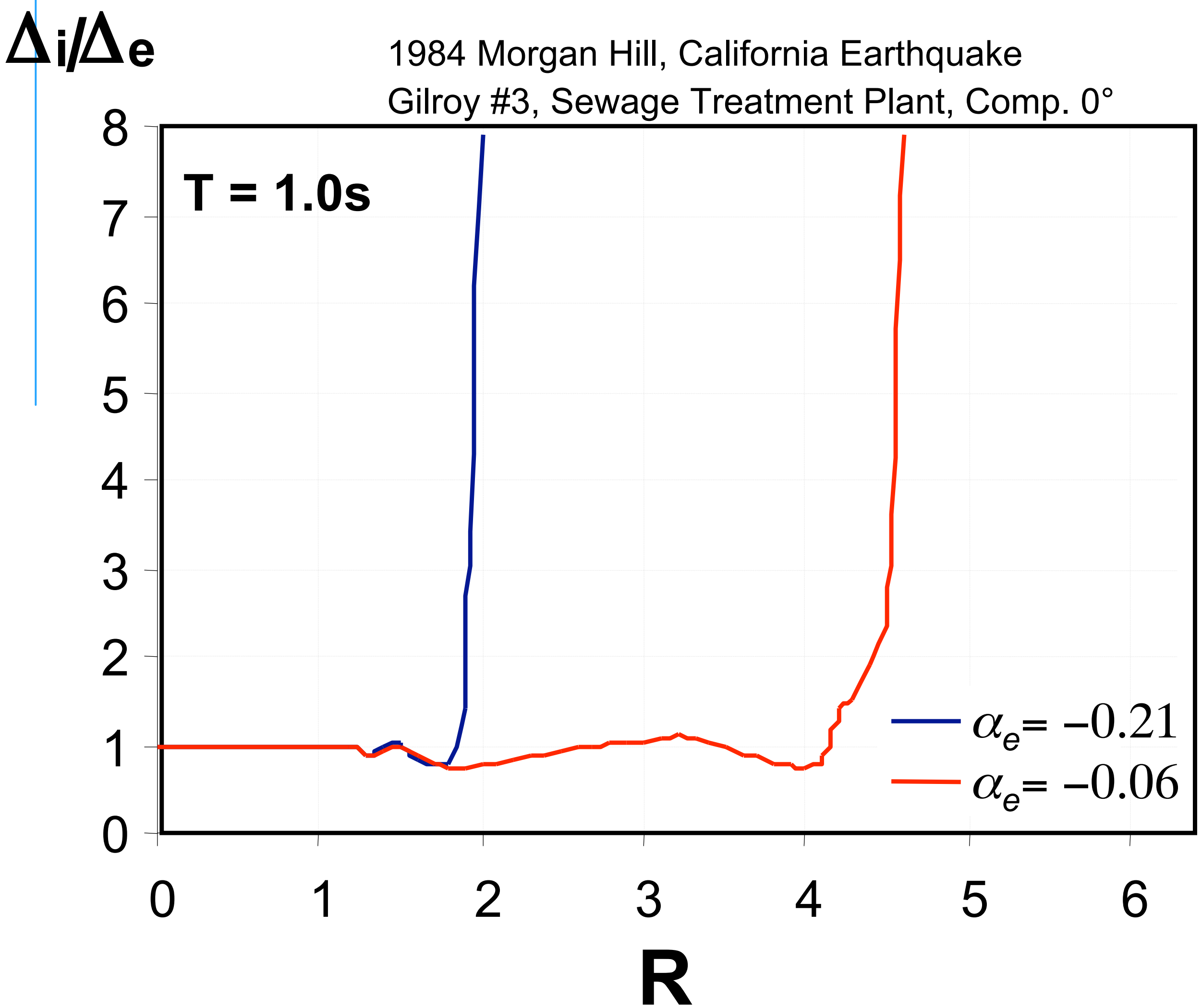

(a) 1985 Chile record

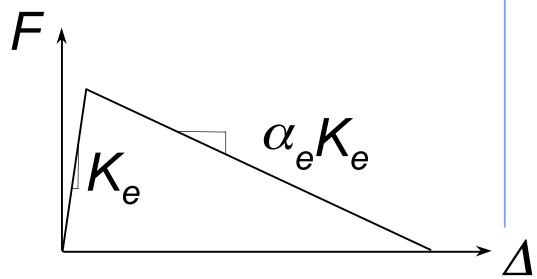



(b) 1995 Kobe record

*Shin, PEER, 2005*

# Strength, strength degradation, and instability

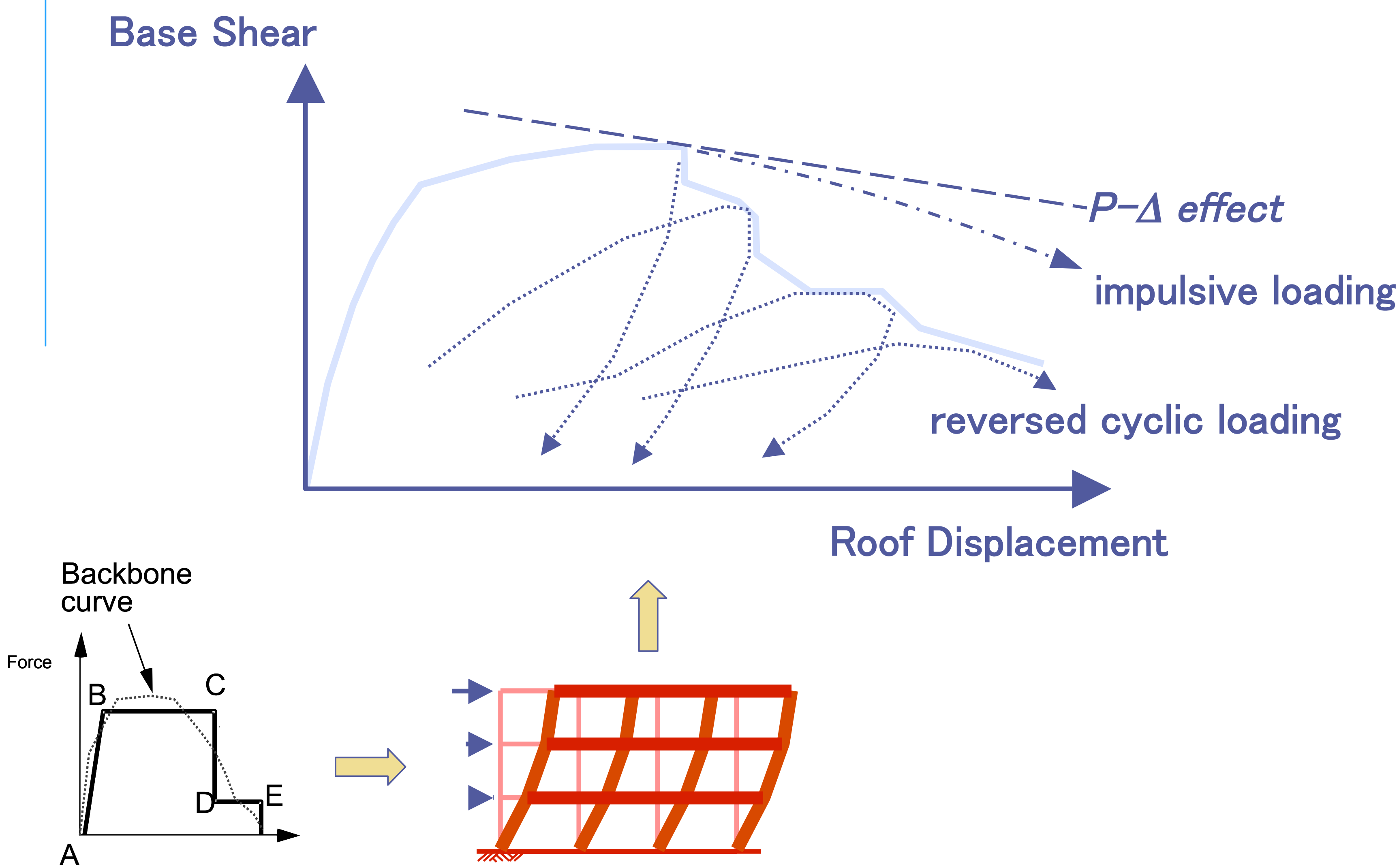


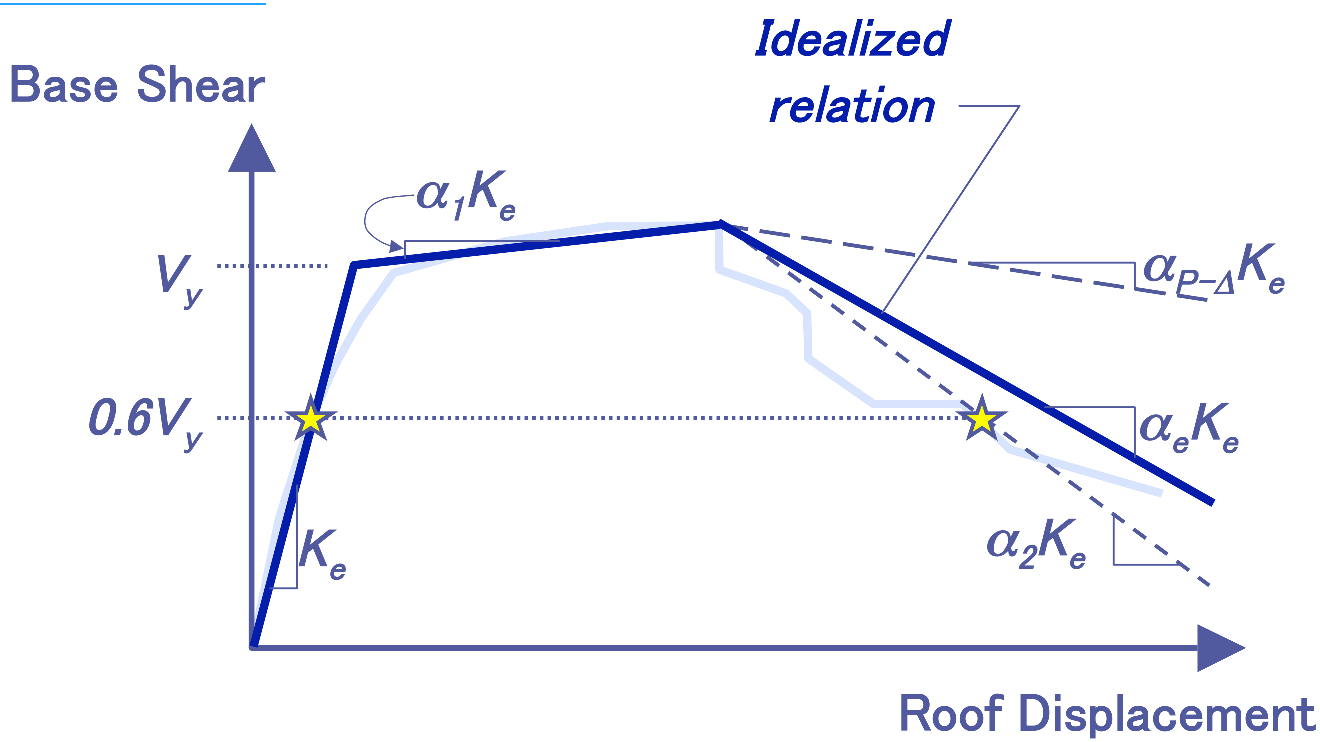

FEMA 440 recommends maximum value for *R* as function of $\alpha_e$.

*FEMA 440*

# Construction of load-displacement relation



# Construction of load-displacement relation

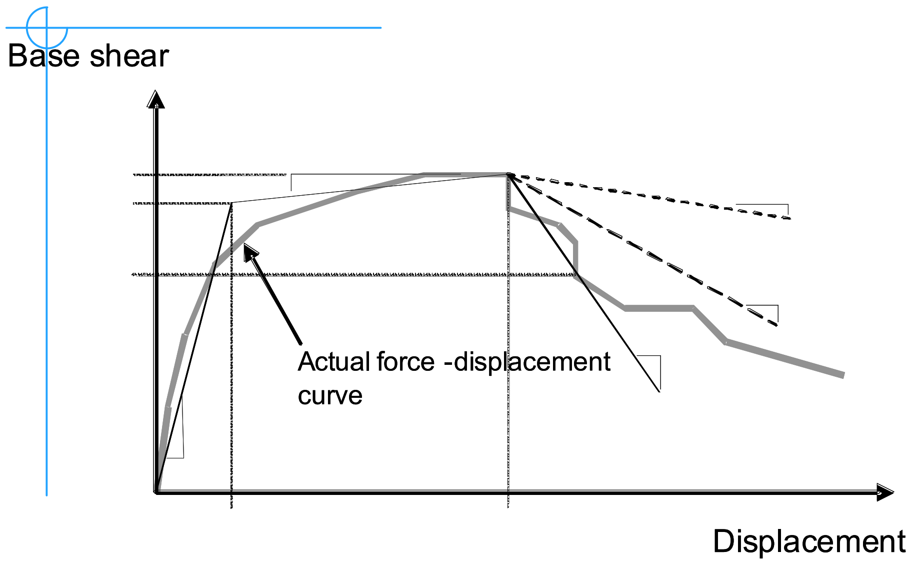



$$\alpha_e = \alpha_{P-\Delta} + \lambda(\alpha_2 - \alpha_{P-\Delta})$$

$\lambda$ = 0.8 for near–field motions
= 0.2 otherwise

*FEMA 440*

# Minimum strength



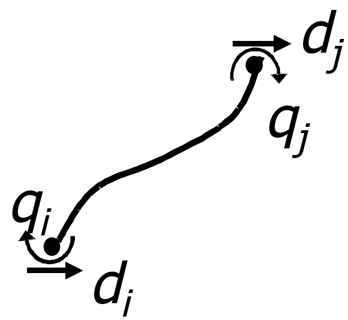

$$\alpha_e = \alpha_{P-\Delta} + \lambda(\alpha_2 - \alpha_{P-\Delta})$$

$$R_{\max} = \frac{\Delta_d}{\Delta_y} + \frac{|\alpha_e|^{-t}}{4}$$

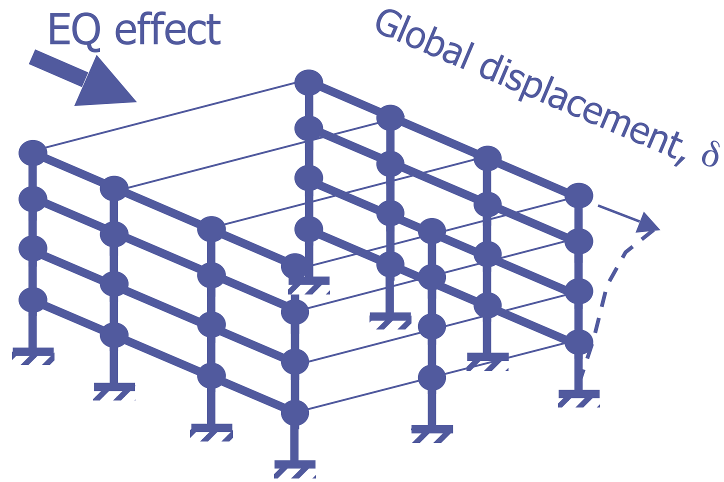
$$t = 1 + 0.15 \ln T$$

FEMA 440

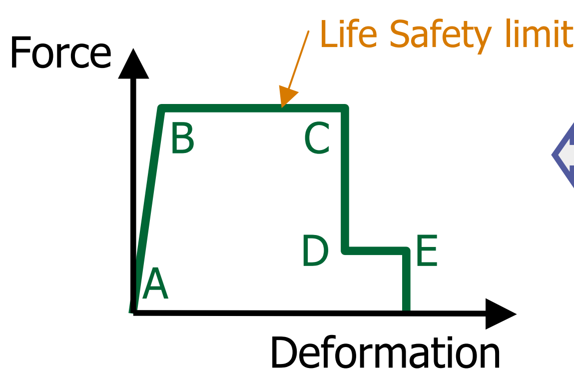
# Modeling, analysis, and acceptance




Component Model




Global Model




Acceptance Criteria

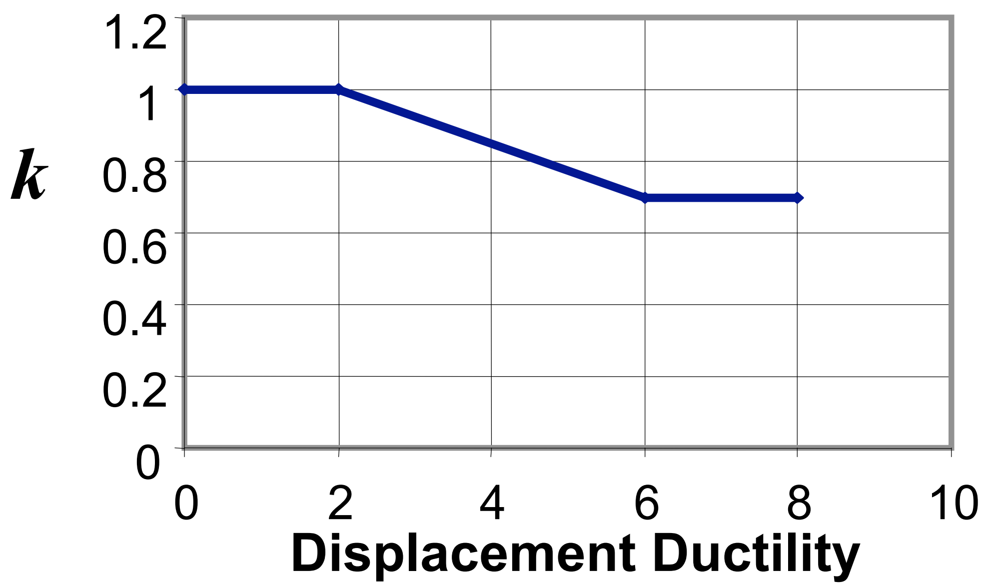
Component Tests

# Component strength
## *(example, column shear strength)*

$$V_n = V_c + V_s$$

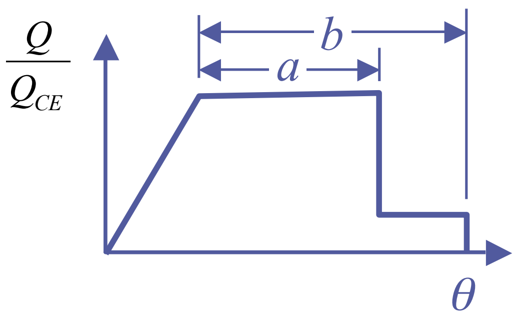
$$V_c = k\left(\frac{1}{M/Vd}\right)\left(6\sqrt{f_c'}\sqrt{1+\frac{P}{6\sqrt{f_c'}A_g}}\right)0.8A_g$$

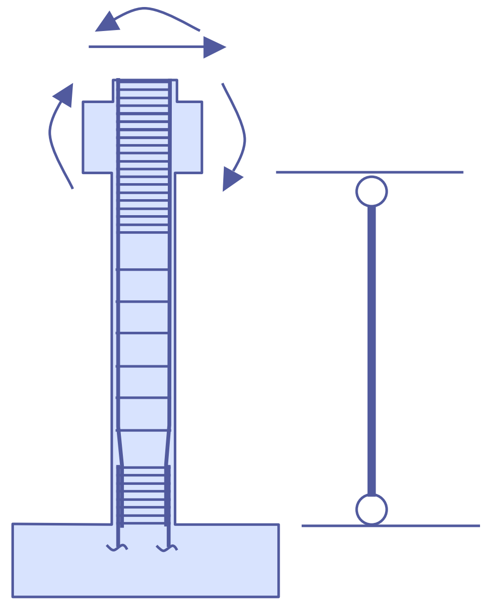
$$V_s = k\frac{A_{sw}f_yd}{s}$$




FEMA 356

# Component deformation capacity
*(example, columns controlled by flexure)*

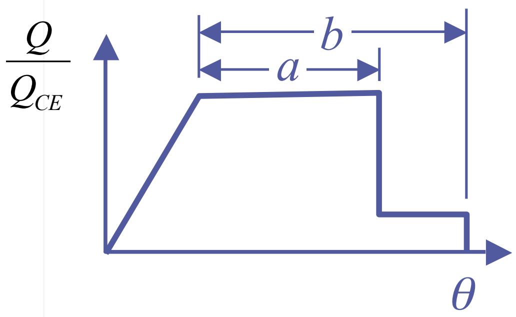


FEMA 356

# Component deformation capacity
## *(example, columns controlled by flexure)*

**Table 6-8 Modeling Parameters and Numerical Acceptance Criteria for Nonlinear Procedures—Reinforced Concrete Columns**

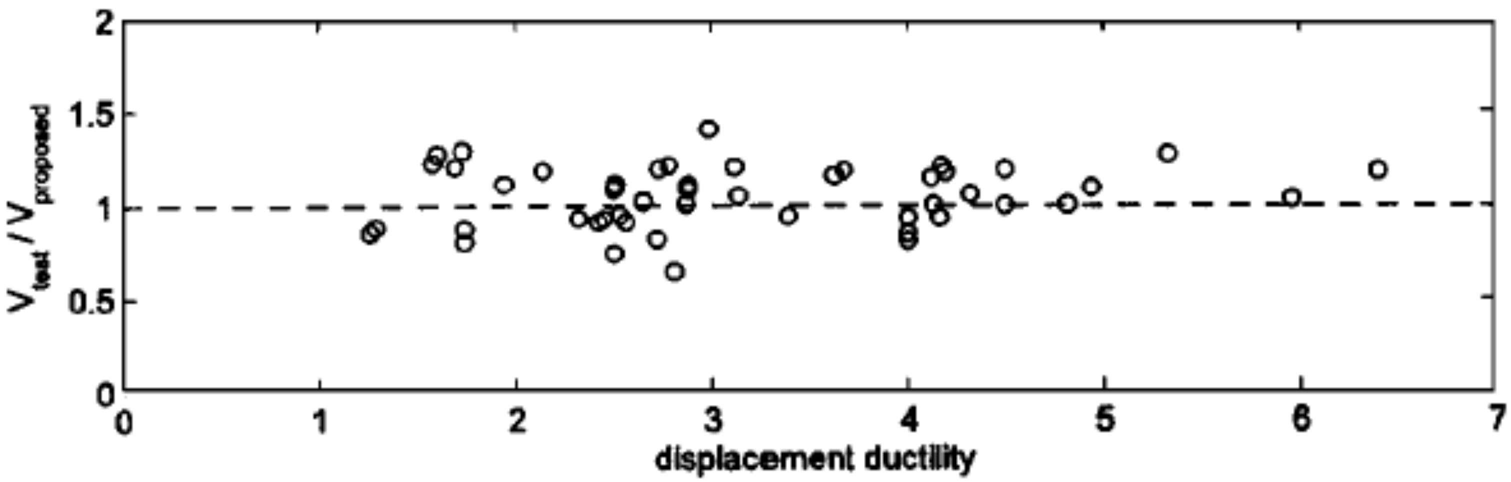


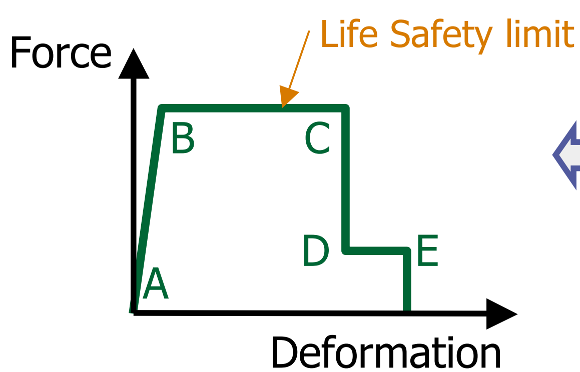

| Conditions | | | Modeling Parameters[4]: Plastic Rotation Angle, radians | | Modeling Parameters[4]: Residual Strength Ratio | Acceptance Criteria[4]: Plastic Rotation Angle, radians — Performance Level | Component Type: Primary | | Component Type: Secondary | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | a | b | c | IO | LS | CP | LS | CP |
| i. Columns controlled by flexure[1] | | | | | | | | | | |
| $\frac{P}{A_g f'_c}$ | Trans. Reinf.[2] | $\frac{V}{b_w d \sqrt{f'_c}}$ | | | | | | | | |
| $\leq 0.1$ | C | $\leq 3$ | 0.02 | 0.03 | 0.2 | 0.005 | 0.015 | 0.02 | 0.02 | 0.03 |
| $\leq 0.1$ | C | $\geq 6$ | 0.016 | 0.024 | 0.2 | 0.005 | 0.012 | 0.016 | 0.016 | 0.024 |
| $\geq 0.4$ | C | $\leq 3$ | 0.015 | 0.025 | 0.2 | 0.003 | 0.012 | 0.015 | 0.018 | 0.025 |
| $\geq 0.4$ | C | $\geq 6$ | 0.012 | 0.02 | 0.2 | 0.003 | 0.01 | 0.012 | 0.013 | 0.02 |
| $\leq 0.1$ | NC | $\leq 3$ | 0.006 | 0.015 | 0.2 | 0.005 | 0.005 | 0.006 | 0.01 | 0.015 |
| $\leq 0.1$ | NC | $\geq 6$ | 0.005 | 0.012 | 0.2 | 0.005 | 0.004 | 0.005 | 0.008 | 0.012 |
| $\geq 0.4$ | NC | $\leq 3$ | 0.003 | 0.01 | 0.2 | 0.002 | 0.002 | 0.003 | 0.006 | 0.01 |
| $\geq 0.4$ | NC | $\geq 6$ | 0.002 | 0.008 | 0.2 | 0.002 | 0.002 | 0.002 | 0.005 | 0.008 |

*FEMA 356*

# Some shortcomings

*insufficient data, deterministic procedures*



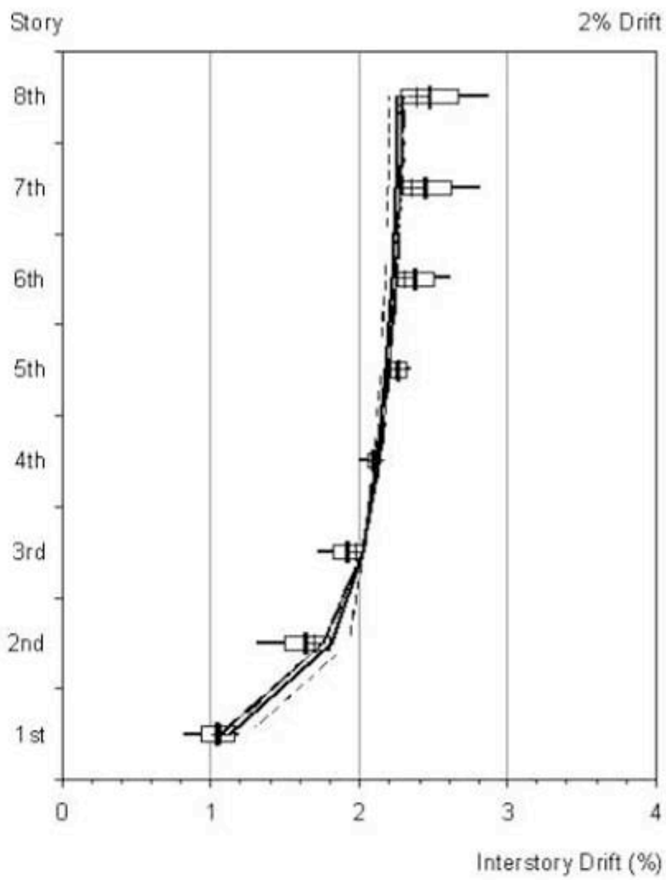

Sezen, 2004

Acceptance Criteria

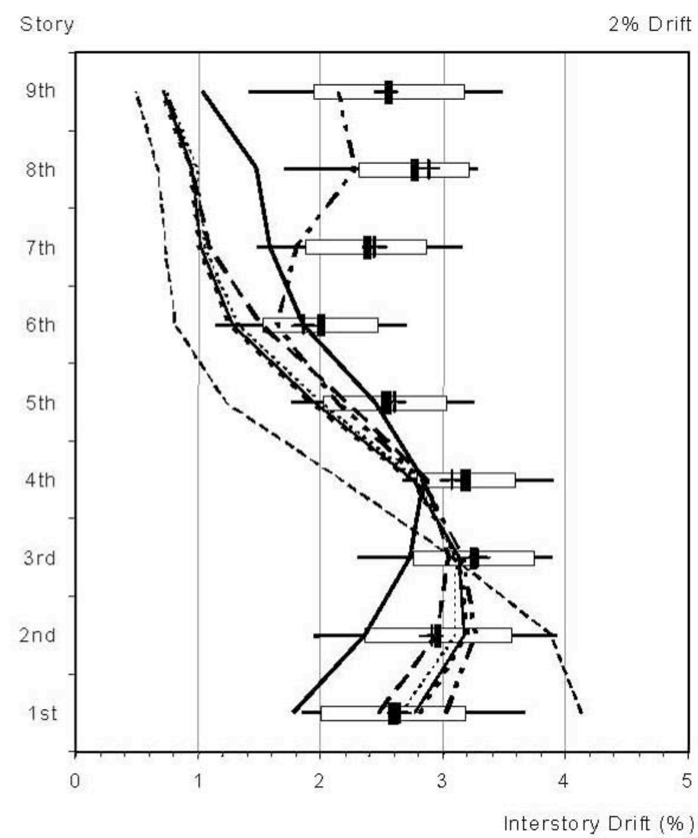
Component Tests

# Some shortcomings

## *static versus dynamic response*




8-story wall—2 %



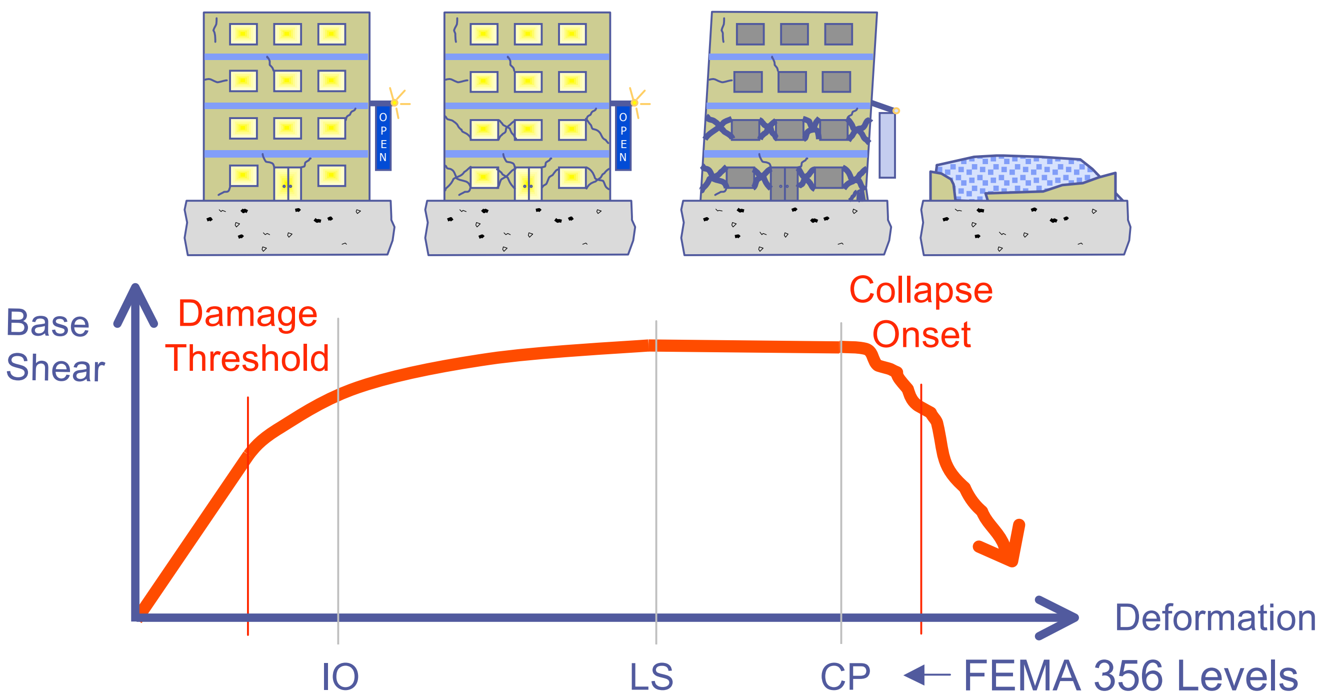

9-story frame —2 %

Mean
Min – Max
+/-SD
+ Median
First Mode
Inverted Triangular
Rectangular
Code
Adaptive
SRSS
Multimode

*FEMA 440*

# Some shortcomings

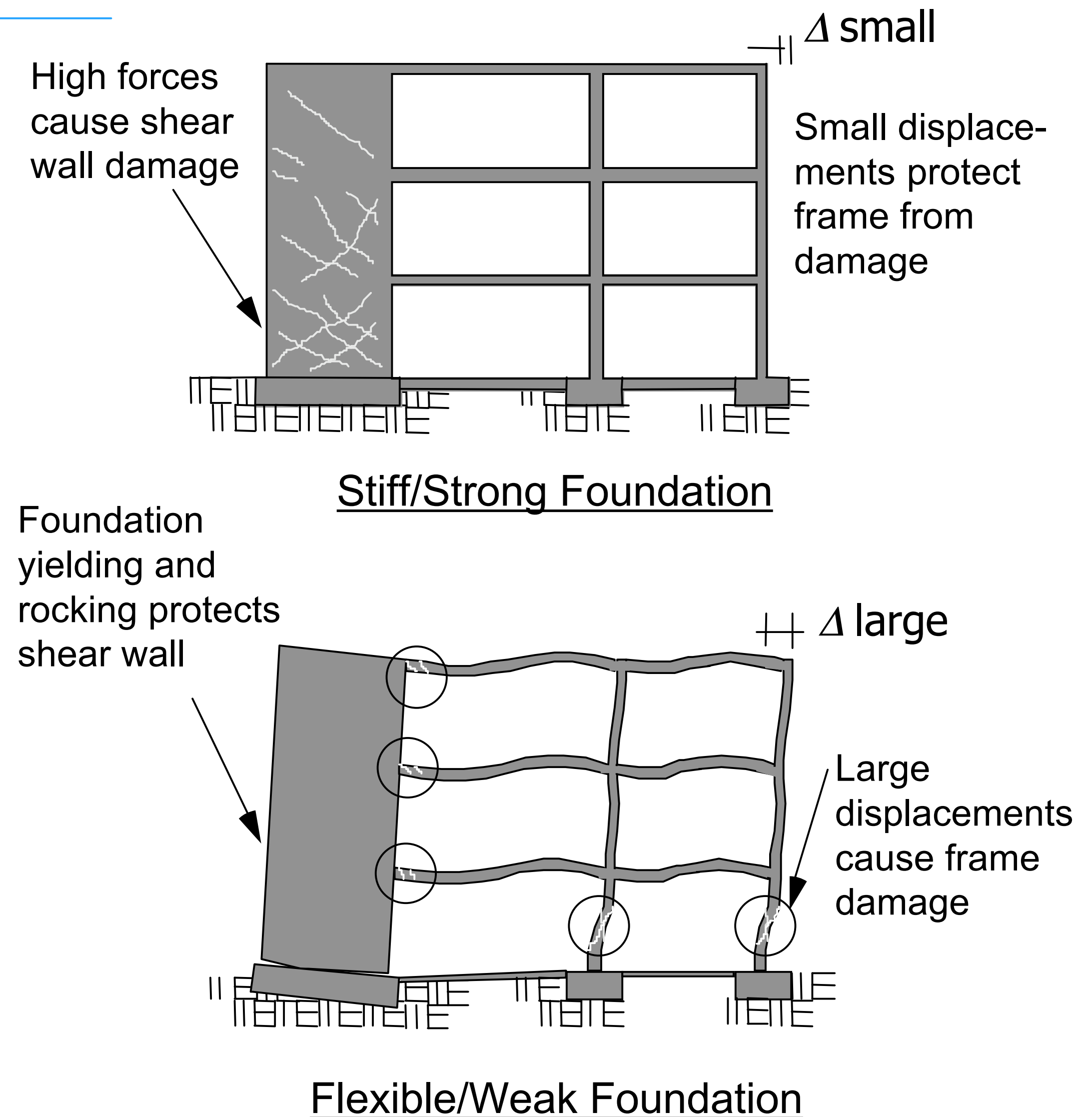
*- Component-based*




When the first component gets to LS performance level, the whole building is defined to be at that level.

# Some shortcomings

## *results can be sensitive to assumptions*

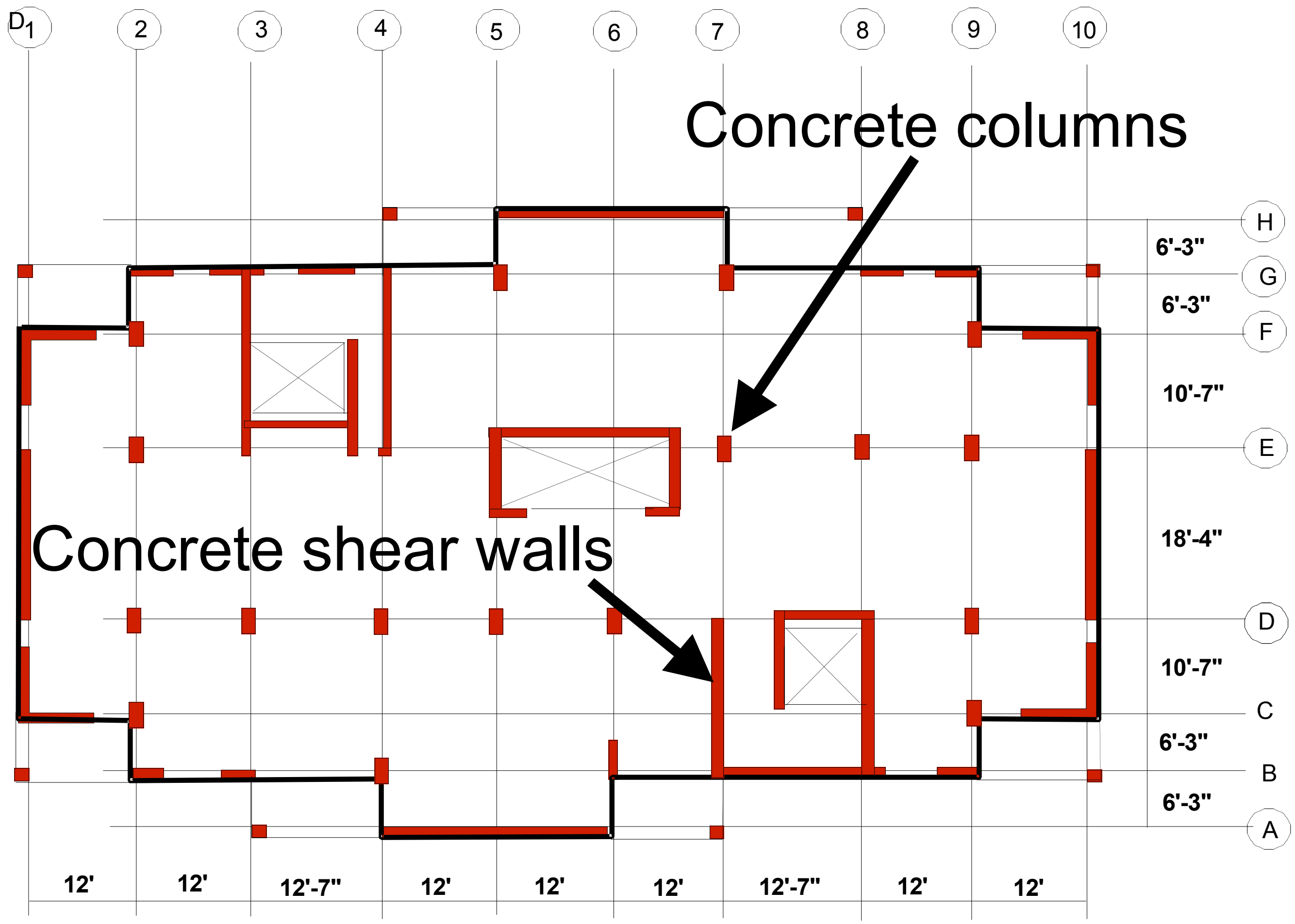



*ATC 40*

# Example:  Escondido Village Midrises

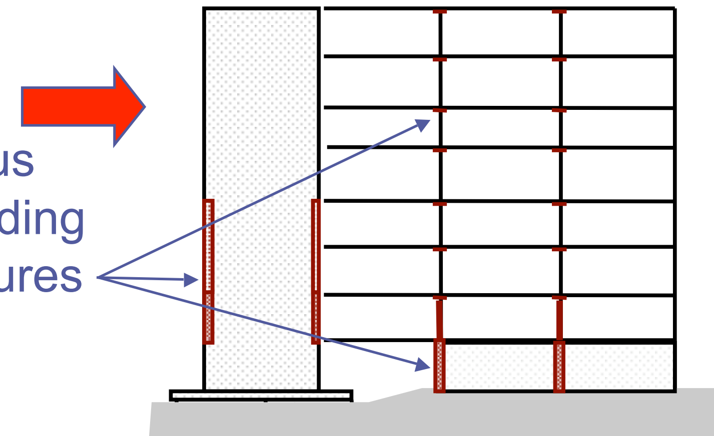
- 1961-64 construction
- 8 stories tall
- Vertical system
  - columns
  - bearing walls
- Lateral system
  - walls controlled by flexure
- Foundation
  - spread footings
- Deficiencies
  - shear-critical columns
  - inadequate boundary steel in walls
  - punching at slab-column connection

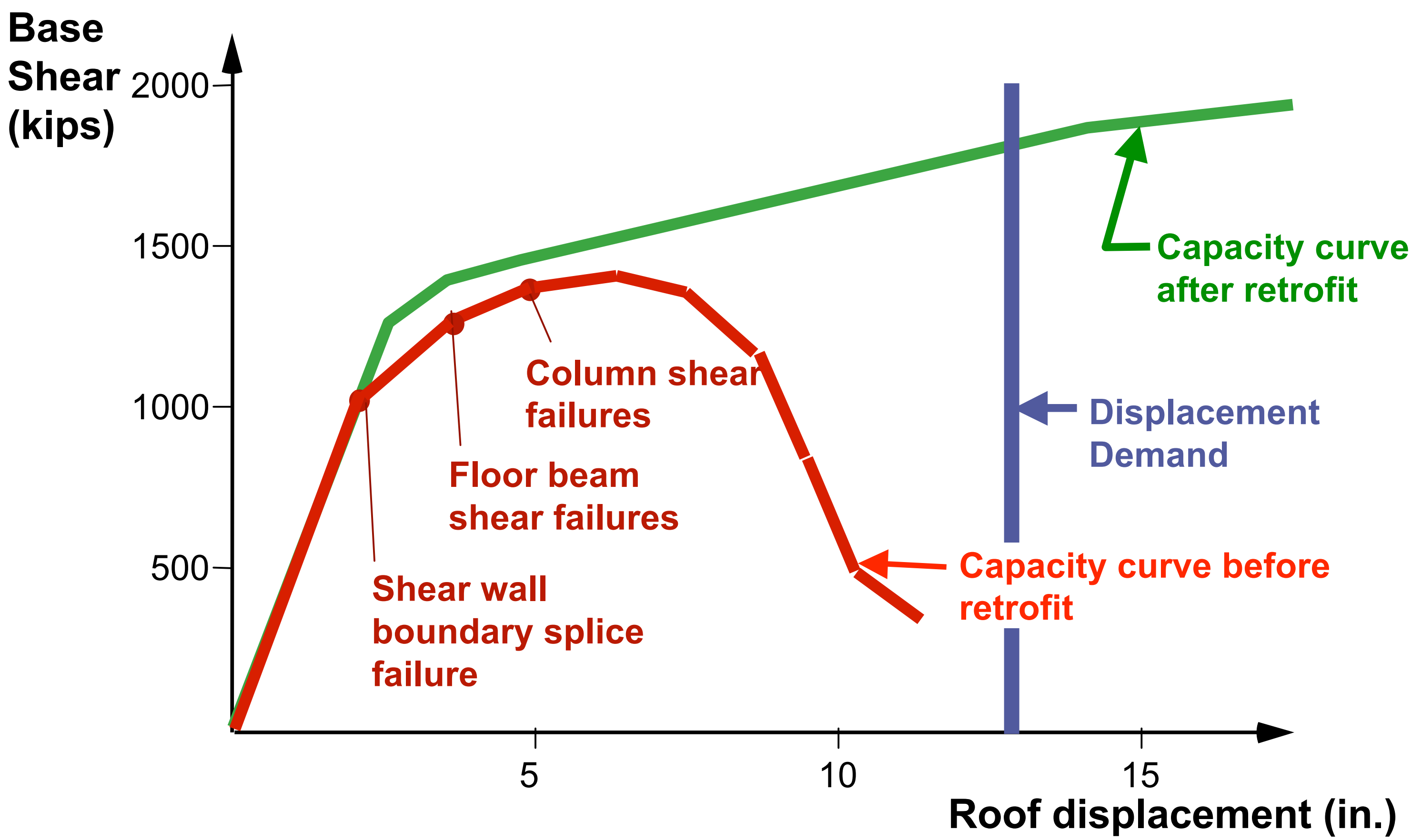
# Typical Floor Plan




*Comartin*

# Structural analysis and retrofit approach

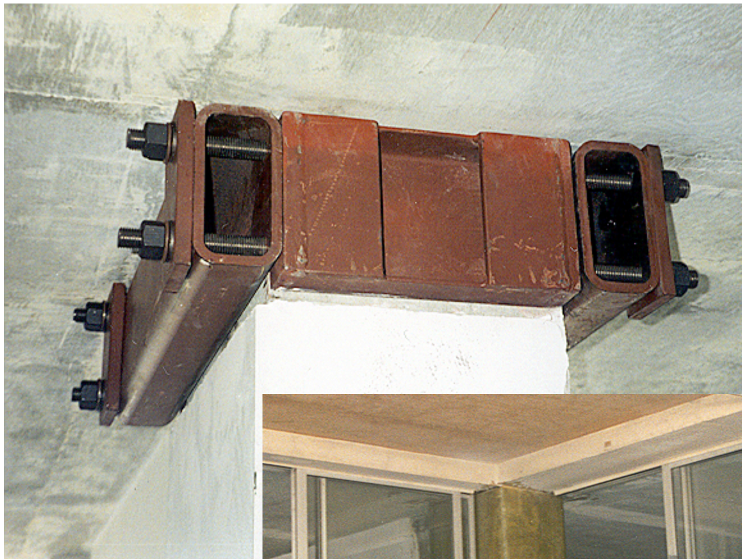


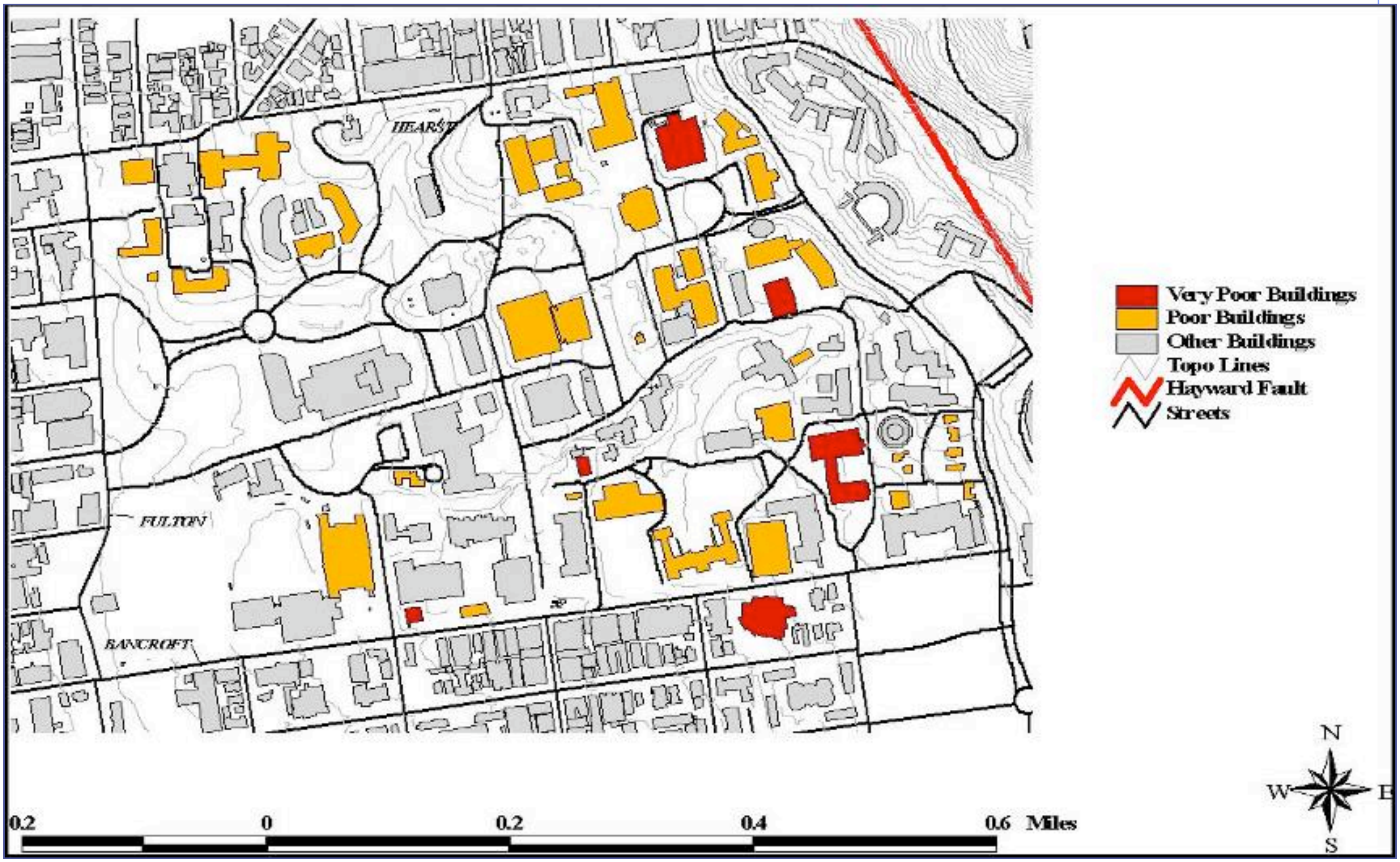

*Comartin*

# Boundary Steel

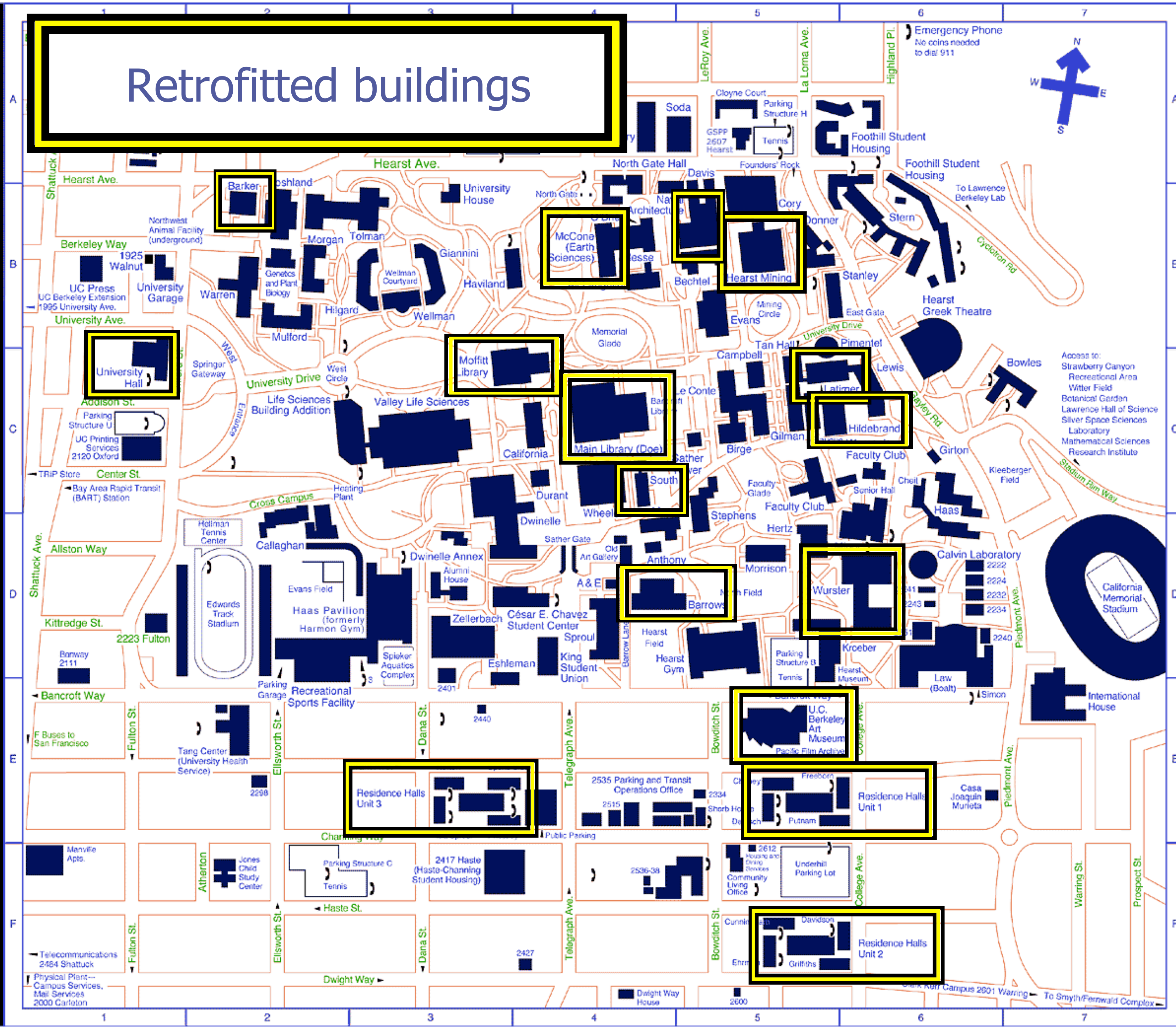
# Column Collars and Fiber Wrap



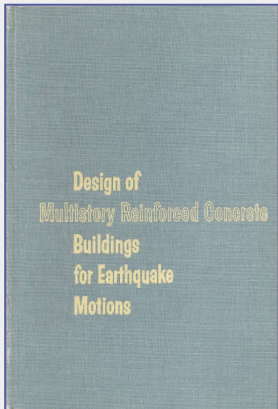
# Older RC building performance ratings - a case study



# Retrofitted buildings



# Current Assessment Approaches

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