The ATC 78 Methodology for Evaluation and Mitigation of Non-Ductile Concrete Buildings

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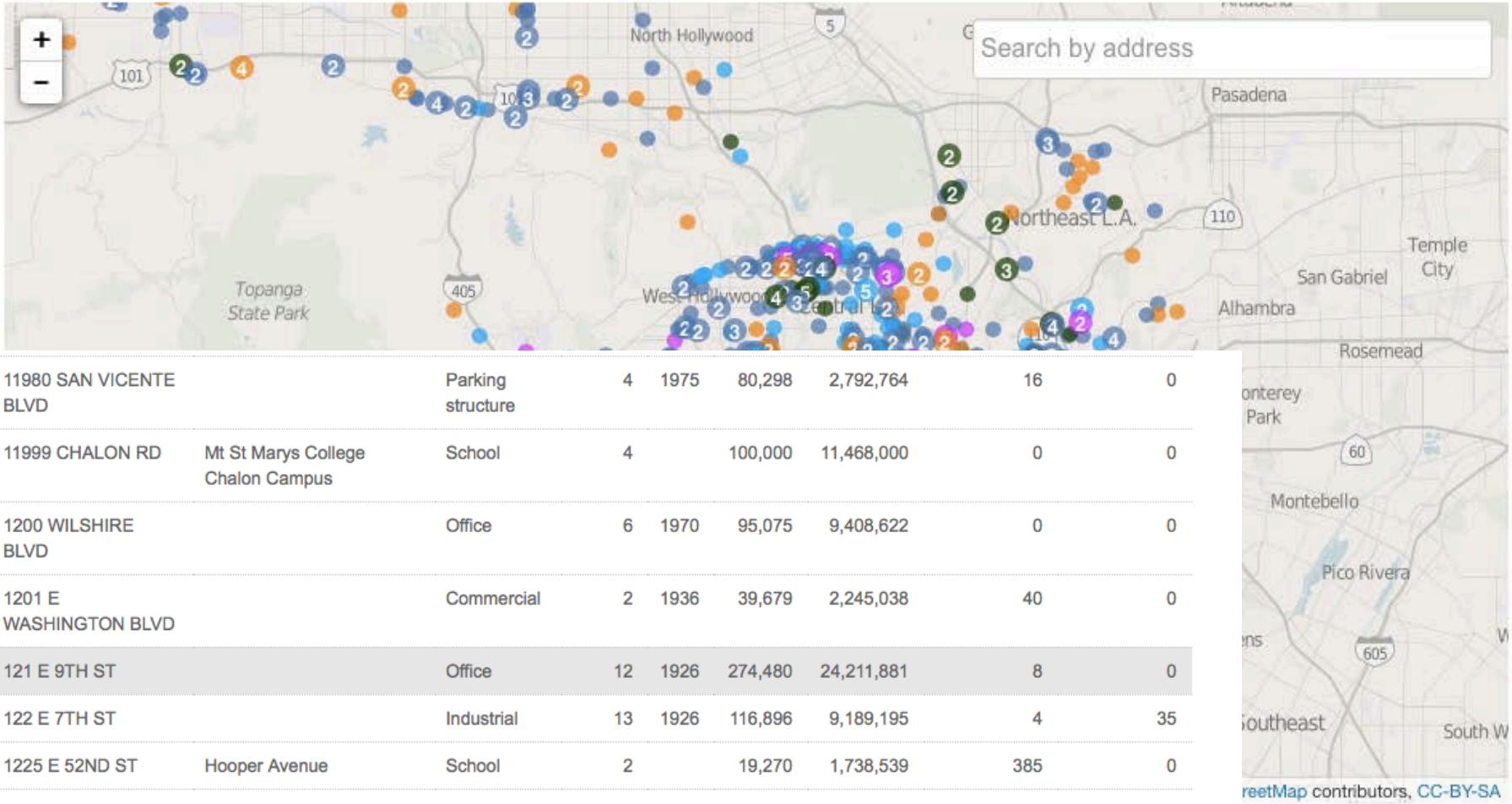
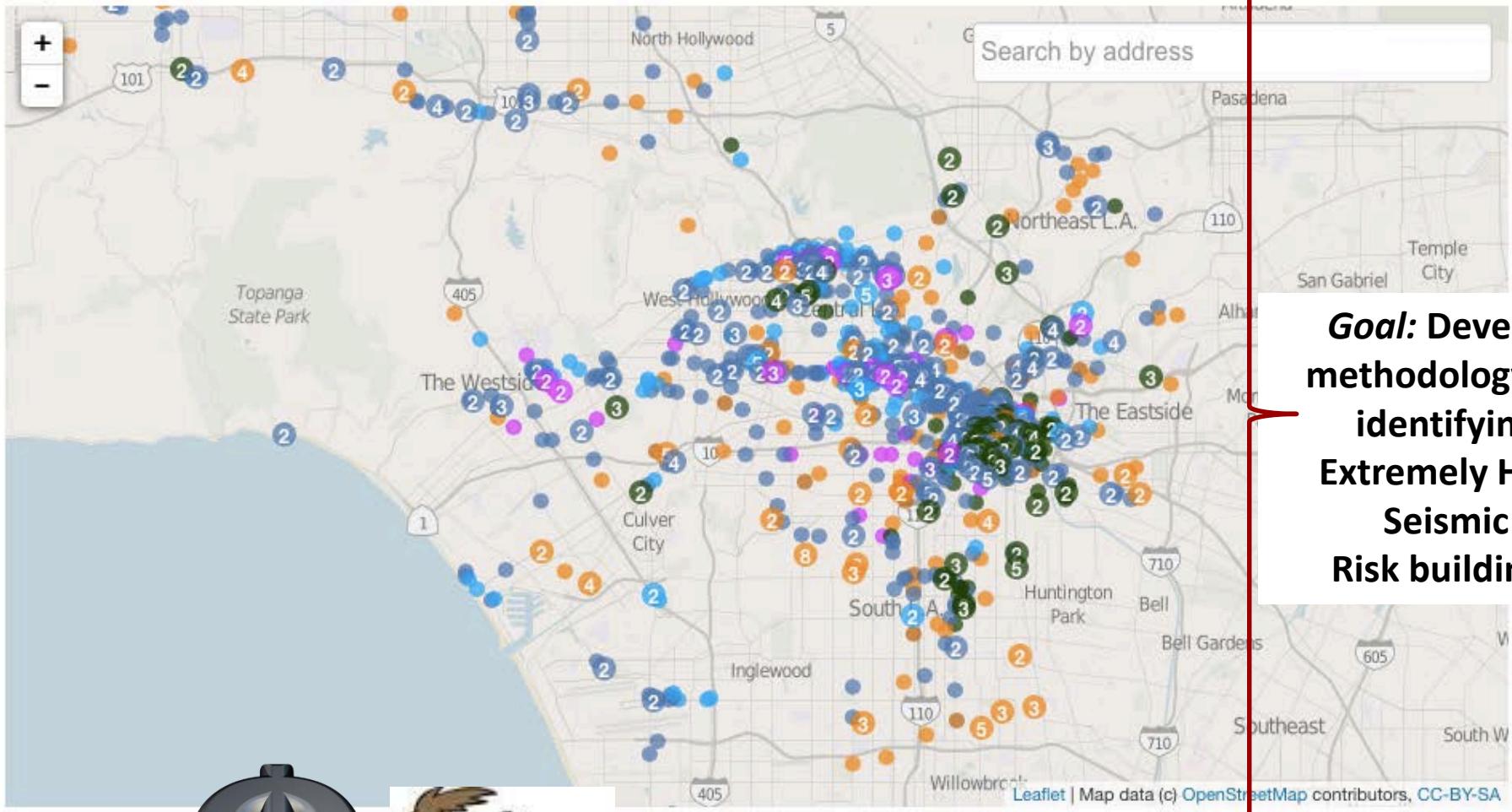
ALL RESIDENTIAL COMMERCIAL INDUSTRIAL GOVERNMENT EDUCATION RELIGIOUS



11980 SAN VICENTE BLVD		Parking structure	4	1975	80,298	2,792,764	16	0
11999 CHALON RD	Mt St Marys College Chalon Campus	School	4		100,000	11,468,000	0	0
1200 WILSHIRE BLVD		Office	6	1970	95,075	9,408,622	0	0
1201 E WASHINGTON BLVD		Commercial	2	1936	39,679	2,245,038	40	0
121 E 9TH ST		Office	12	1926	274,480	24,211,881	8	0
122 E 7TH ST		Industrial	13	1926	116,896	9,189,195	4	35
1225 E 52ND ST	Hooper Avenue	School	2		19,270	1,738,539	385	0
12326 RIVERSIDE DR		School	2	1964	13,695	1,235,563	274	0
1248 PALMETTO ST		Industrial	1	1970	102,998	7,603,312	5	31
12500 BRADDOCK DR	Marina Del Rey MS	School	1		1,500	169,350	56	0
12540 PIERCE AVE	Maclay, Chas	School	1		26,000	2,345,720	0	0
126 E BLOOM ST	Ann Street	School	1		13,953	1,258,840	279	0

Los Angeles Times, Older Concrete Buildings



Goal: **Develop methodology for identifying Extremely High Seismic Risk buildings**

Cost-Effective

Simple
Repeatable

Avoid excessive conservatism

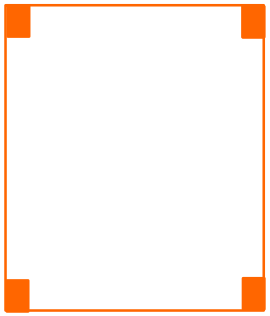
Guiding Principles

- Focused on collapse, taken as loss of gravity support in a story, considering
  - Weak stories
  - Torsion
  - Axial load drift demand and shear capacity of column
  - Punching shear failure of slab-column connections
- Collapse risk evaluated through estimation of median drift demands and capacities, determined without needing a nonlinear model

Overview

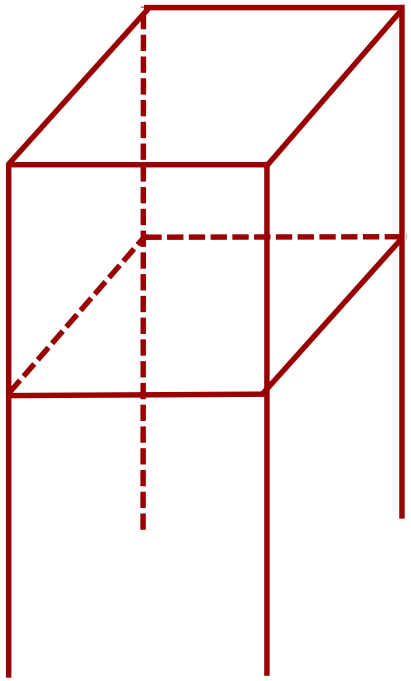
Column Ratings

Column ratings are a function of the drift demand and drift capacity on each column.



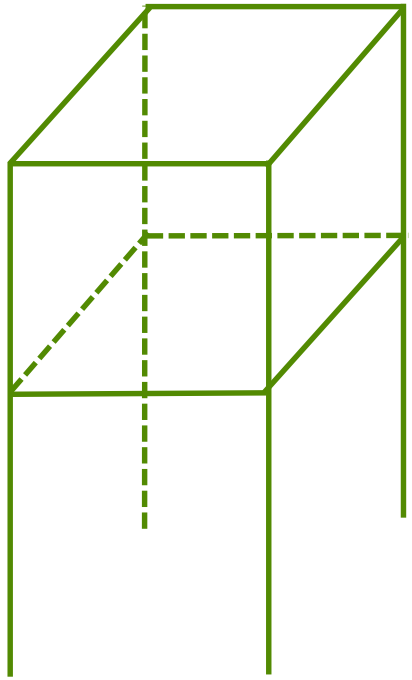
Story rating depends on ratings of individual column and adjacency of poor columns

Story Ratings



Building rating corresponds to worst story rating

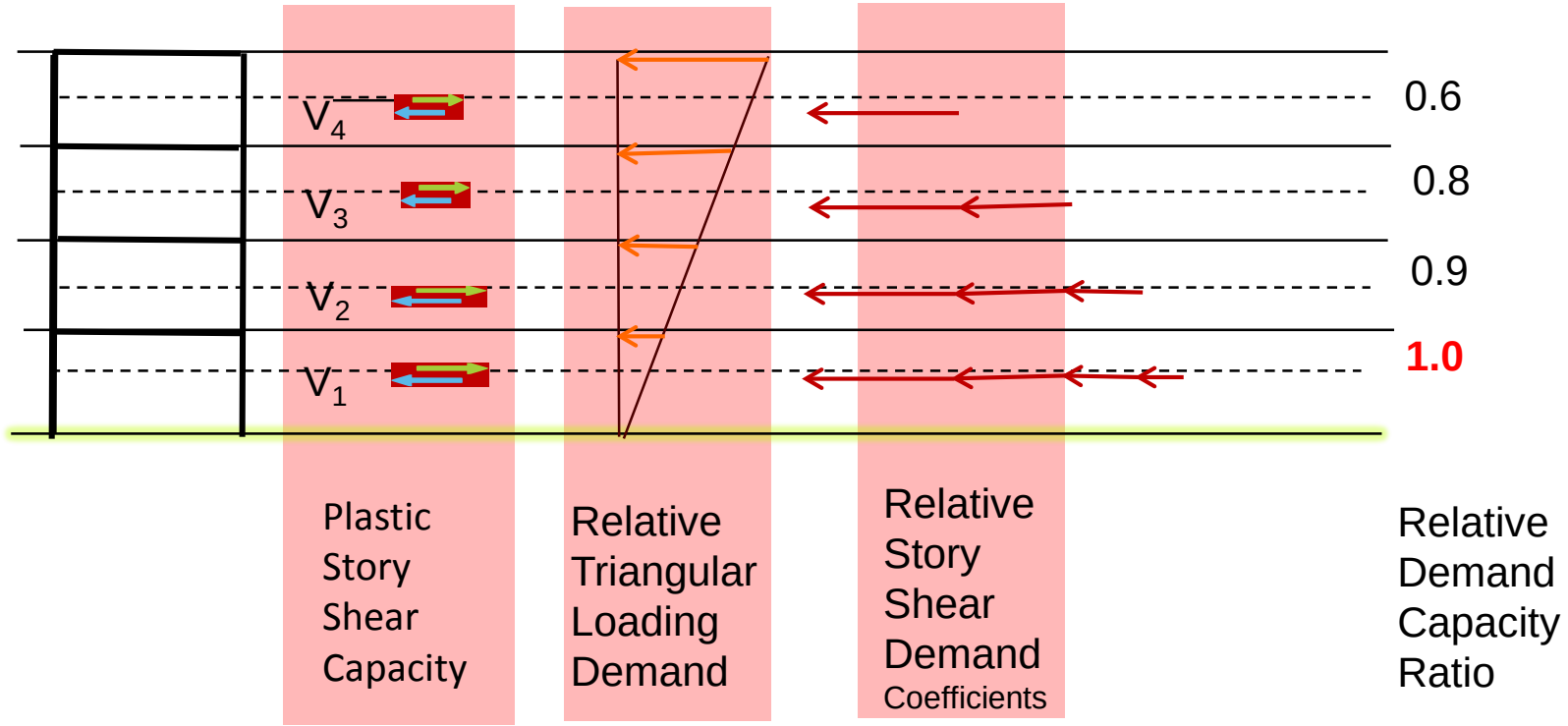
Building Rating



All ratings range from 0 to 1, where a value of 1 indicates a high likelihood of failure for the level of excitation considered.

Story Demand Capacity Ratios

"Simulate" pushover to get story demands and capacities



Period Estimation

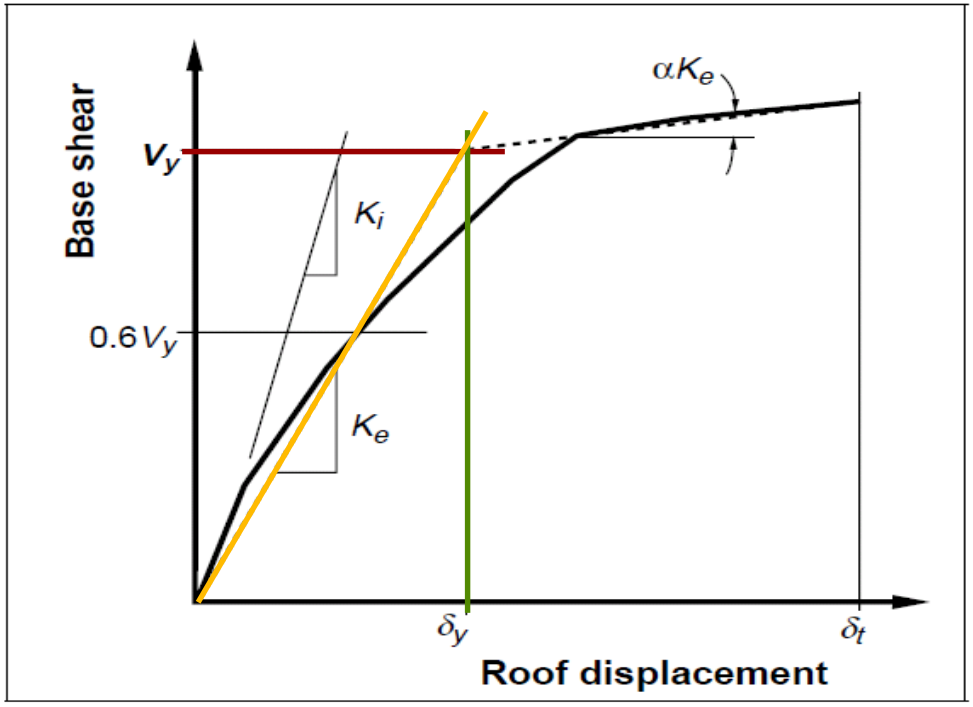
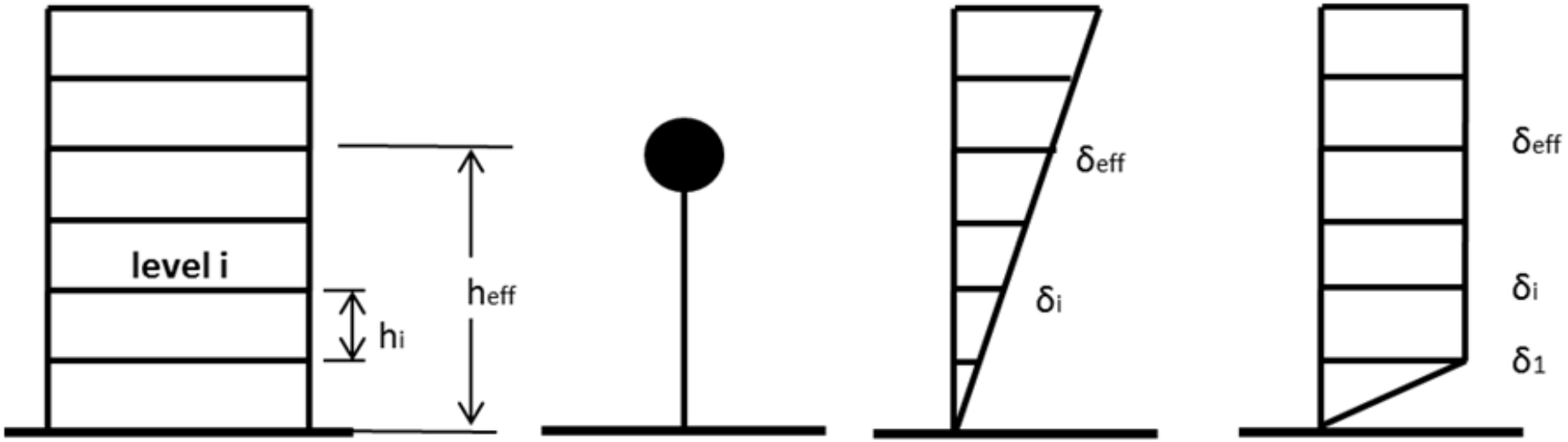


Figure 3-1 Calculation of Effective Stiffness, K_e

V_y from plastic story shear capacities

δ_y from assumed structural yield drift

Story Drift Demands



(a) Building Elevation

(b) Equivalent SDOF system

(c) Idealized uniform drift pattern

(d) Idealized weak story drift pattern

$$\delta_i = \alpha_i \beta_{ci} \beta_{si} l_{ui} \left(\frac{\delta_{eff}}{h_{eff}} \right) \leq \delta_{eff}$$

Column Drift Demands

Story drift demands are converted to column drift demands based on two factors

- Torsional amplification of drifts due to inherent and accidental torsion
- Separation of story drifts taken by columns and beams

Column Drift Capacity

Drift capacity represents the drift at which the column of interest will fail axially

Drift capacity computed from empirical relationships depending on reinforcement and axial load

To quantify drift capacity, need to

- Classify column based on failure mode
- Estimate plastic rotation corresponding to axial failure
- Convert plastic rotation to drift

Column Drift Capacity

Column classifications based on failure mode

	Transverse Reinforcement Detail		
Ratio of flexural to shear strengths, V_{pMj}/V_{nj}**	ACI-conforming details with 135° hooks	Closed hoops with 90° hooks	Lap-spliced or any other reinforcement
$(V_{pMj}/V_{nj}) < 0.6$	*i****	*ii*	*ii*
$0.6 \leq (V_{pMj}/V_{nj}) \leq 1.1$	*ii*	*ii*	*iii*
$(V_{pMj}/V_{nj}) > 1.1$	*iii*	*iii*	*iii*

* Adopted from Li et al., 2014

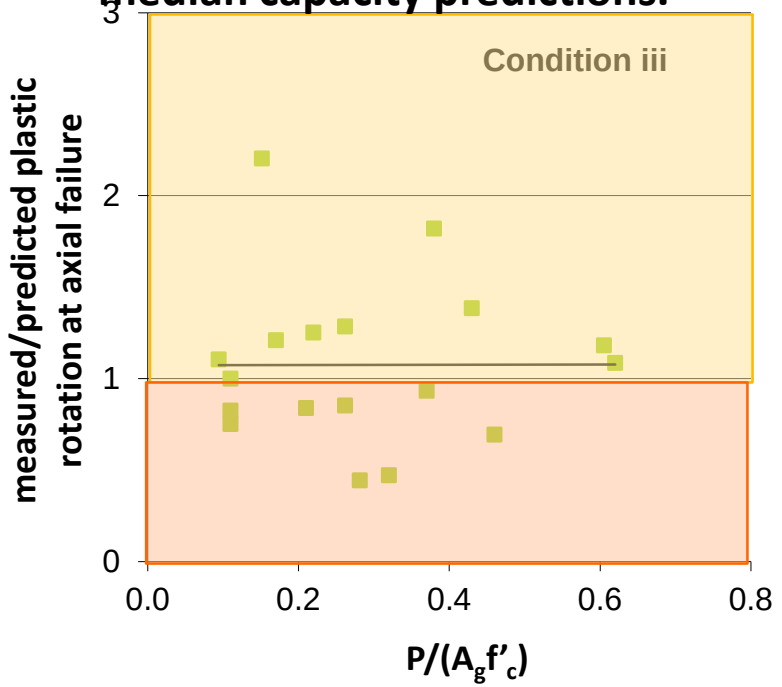
Column Drift Capacity

Column plastic rotation capacity representing axial capacity

Condition	Axial load ratio, $P/A_g f'_{ce}$	Shear reinforcement ratio, $A_v/b_w s$	Plastic Rotation Capacity, θ_c
i	≤ 0.1	≥ 0.006	0.090
	≥ 0.6	≥ 0.006	0.030
	≤ 0.1	= 0.002	0.050
	≥ 0.6	= 0.002	0.018
ii	≤ 0.1	≥ 0.006	0.082
	≥ 0.6	≥ 0.006	0.023
	≤ 0.1	≤ 0.0005	0.025
	≥ 0.6	≤ 0.0005	0.011
iii	≤ 0.1	≥ 0.006	0.075
	≥ 0.6	≥ 0.006	0.020
	≤ 0.1	≤ 0.0005	0.016
	≥ 0.6	≤ 0.0005	0.006

* For axial load and shear reinforcement ratios between the tabulated values, calculate the plastic rotation capacity via linear interpolation.

Tabulated values developed by ATC-78 team from empirical data. Represent median capacity predictions.



Column Rating

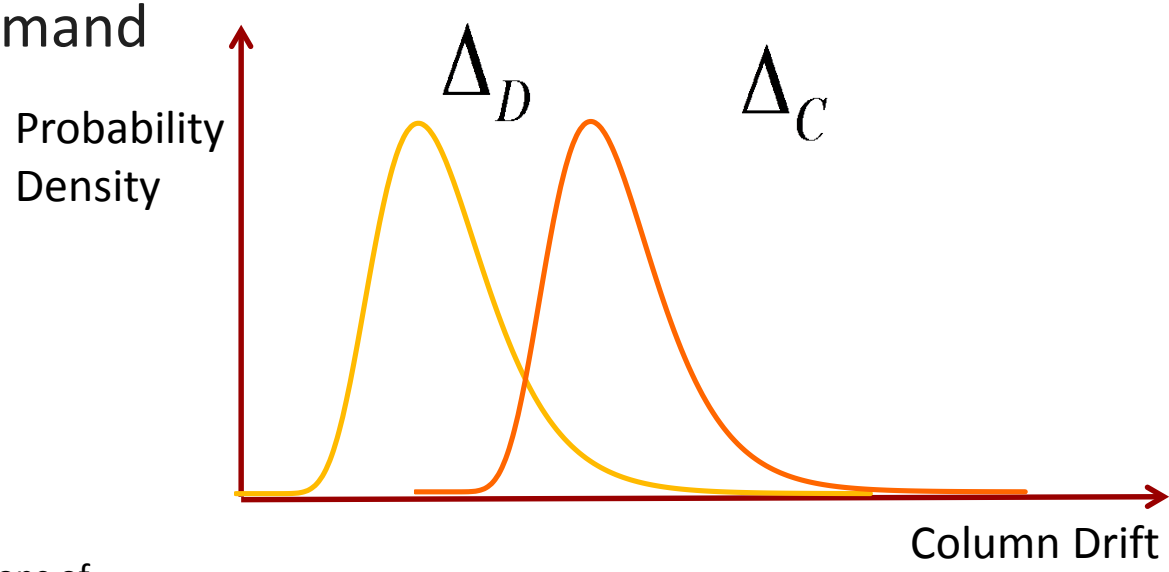
Column rating represents the probability that the drift demand exceeds the drift capacity.

Computed from structural reliability methods where

$$\beta = \frac{\ln(\tilde{\Delta}_C) - \ln(\tilde{\Delta}_D)}{\sqrt{\sigma^2_{\ln,\Delta_C} + \sigma^2_{\ln,\Delta_D}}}$$

Calculations of drift demands and drift capacities

Uncertainties based on test data and structural analysis results, taken as $\sigma_{\ln,\Delta_C} = \sigma_{\ln,\Delta_D} = 0.6$



Column Ratings

Table Used for Determining Column Ratings

Δ_C/Δ_D	Column Rating, CR_j
≥1.75	0.00
1.5	0.02
1.4	0.04
1.3	0.09
1.2	0.17
1.1	0.31
1.05	0.40
1	0.50
0.95	0.61
0.9	0.71
0.85	0.80
0.8	0.88
0.75	0.93
0.7	0.97
0.65	0.99
≤ 0.6	1.00

Higher ratio of capacity vs. demand gives lower CR

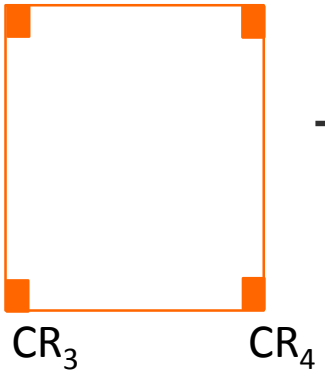
Lower ratio of capacity vs. demand gives higher CR

Other values obtained by linear interpolation

Story Rating

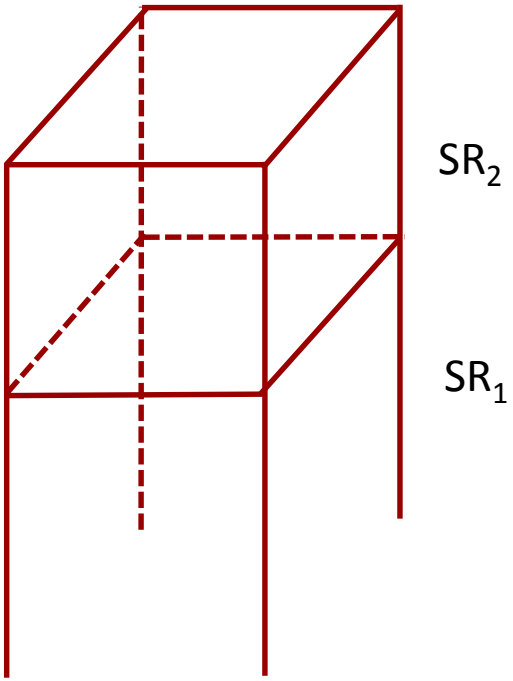
Column Ratings

Column ratings are a function of the drift demand and drift capacity on each column.



Story rating depends on ratings of individual column and adjacency of poor columns

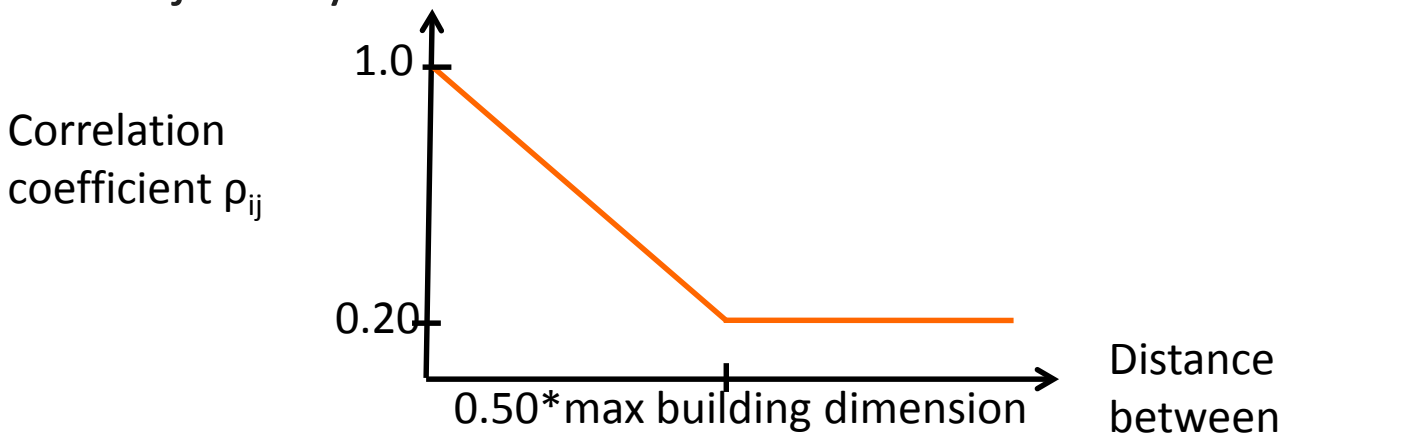
Story Ratings



Story Ratings

Story rating represents the probability of story failure

- Story failure occurs if 25% of columns in a story fail
- Column demand is uncertain, but assumed to be perfectly correlated for all columns in a story
- Column capacity is uncertain, and correlations are assumed to be a function of adjacency



Correlation Model for Column Drift Capacities

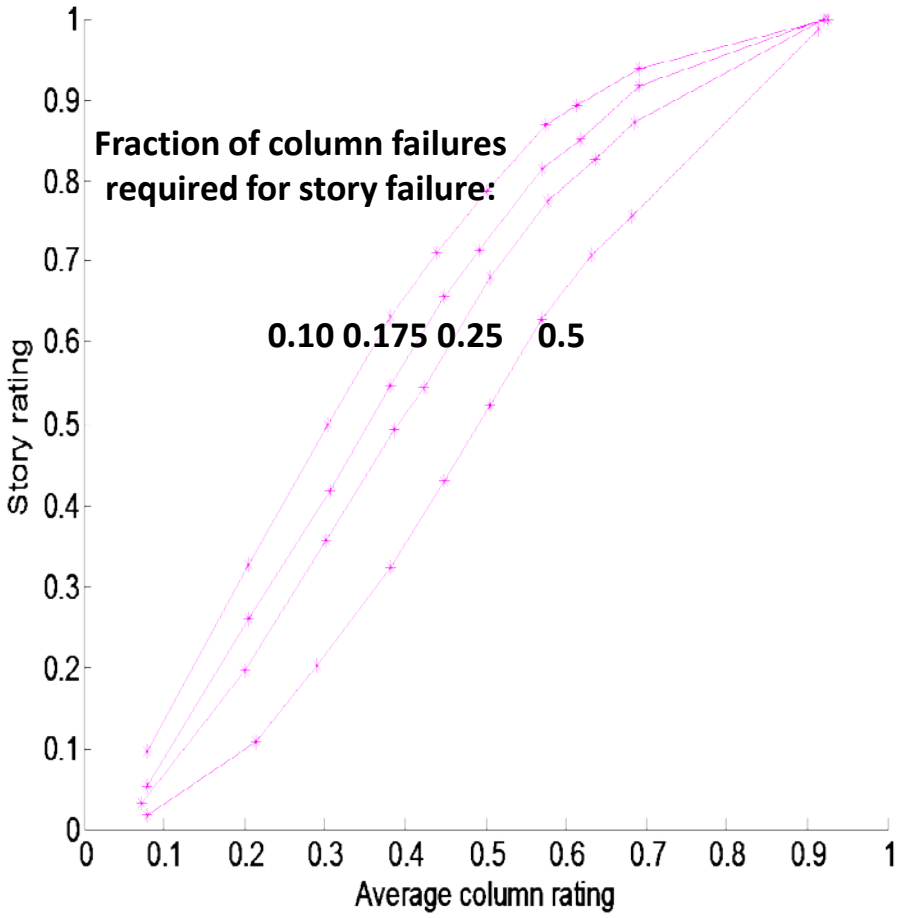
Story Rating

Adjusted Average Column Rating for Story i, $CR_{i,avg}$	Story Rating for Story i, SR_i
$CR_{i,avg}$ <0.06	0.0
0.06 ≤ $CR_{i,avg}$ < 0.16	0.1
0.16 ≤ $CR_{i,avg}$ < 0.23	0.2
0.23 ≤ $CR_{i,avg}$ < 0.29	0.3
0.29 ≤ $CR_{i,avg}$ < 0.36	0.4
0.36 ≤ $CR_{i,avg}$ < 0.42	0.5
0.42 ≤ $CR_{i,avg}$ < 0.50	0.6
0.50 ≤ $CR_{i,avg}$ < 0.58	0.7
0.58 ≤ $CR_{i,avg}$ < 0.68	0.8
0.68 ≤ $CR_{i,avg}$ <0.87	0.9
≥ 0.87	1.0

Story Rating

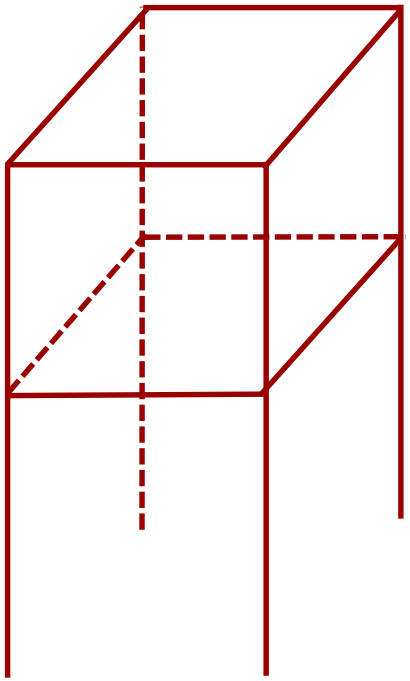
Table development required:

- Monte Carlo simulation: realizations of column demand and capacity were randomly generated
- Simulations accounted for correlation models
- Story failure identified as occurring if more than 25% of the columns failed
- Process repeated to cover range of column ratings



Building Rating

Story Ratings

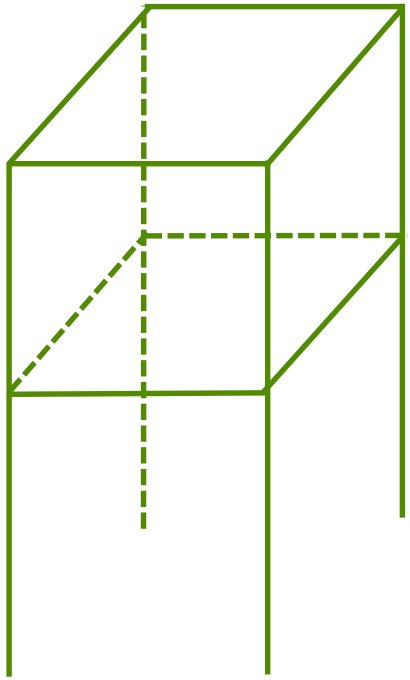


SR_2

SR_1

Building rating corresponds to worst story rating

Building Rating



BR

computed in x and y directions, where higher rating governs

Building ratings can be used to rank buildings. Building rating cut-off will be used to identify *Exceptionally High Seismic Risk Buildings.*

Initial Evaluation Efforts

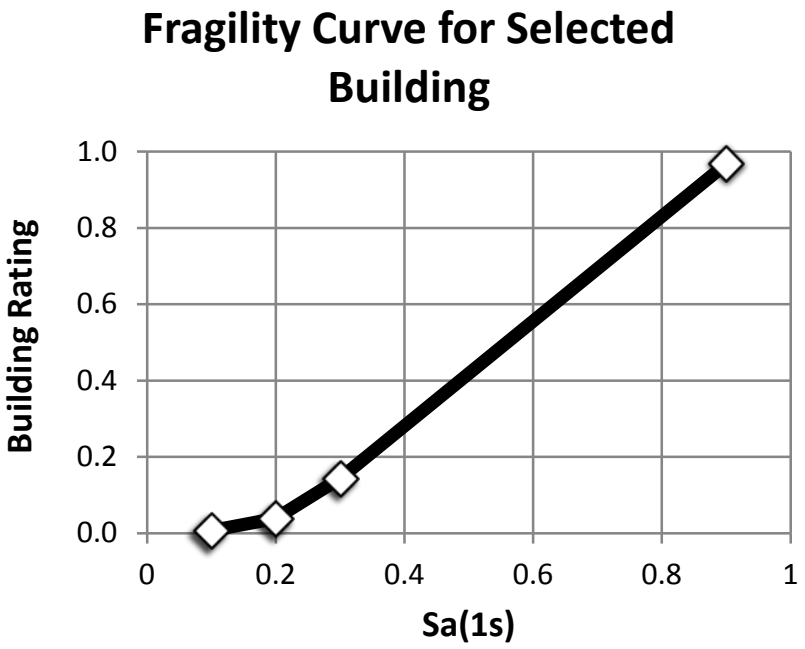
Student Project at University of Colorado

- 9 Buildings
- 9 Teams
  - 2 Students per team
- Weekly submittals
  - Intermediate calculations were checked

Initial Evaluation Efforts

Bldg Rating	Number of Buildings with a Given Rating			
	Sa Level 1	Sa Level 2	Sa Level 3	Sa Level 4
< 0.2	9	8	7	2
0.2 - 0.4	-	1	2	1
0.4 – 0.6	-	-	-	-
0.6 – 0.8	-	-	-	2
> 0.8	-	-	-	4

Lowest Sa → Highest Sa



Next Steps

- Trial evaluation of frame buildings
- Extend procedures to include wall buildings