Quantifying Benefits of Seismic Retrofitting Gravity Columns Using CFRP Jackets Based on Nonlinear Modeling Parameters per ACI 369.1

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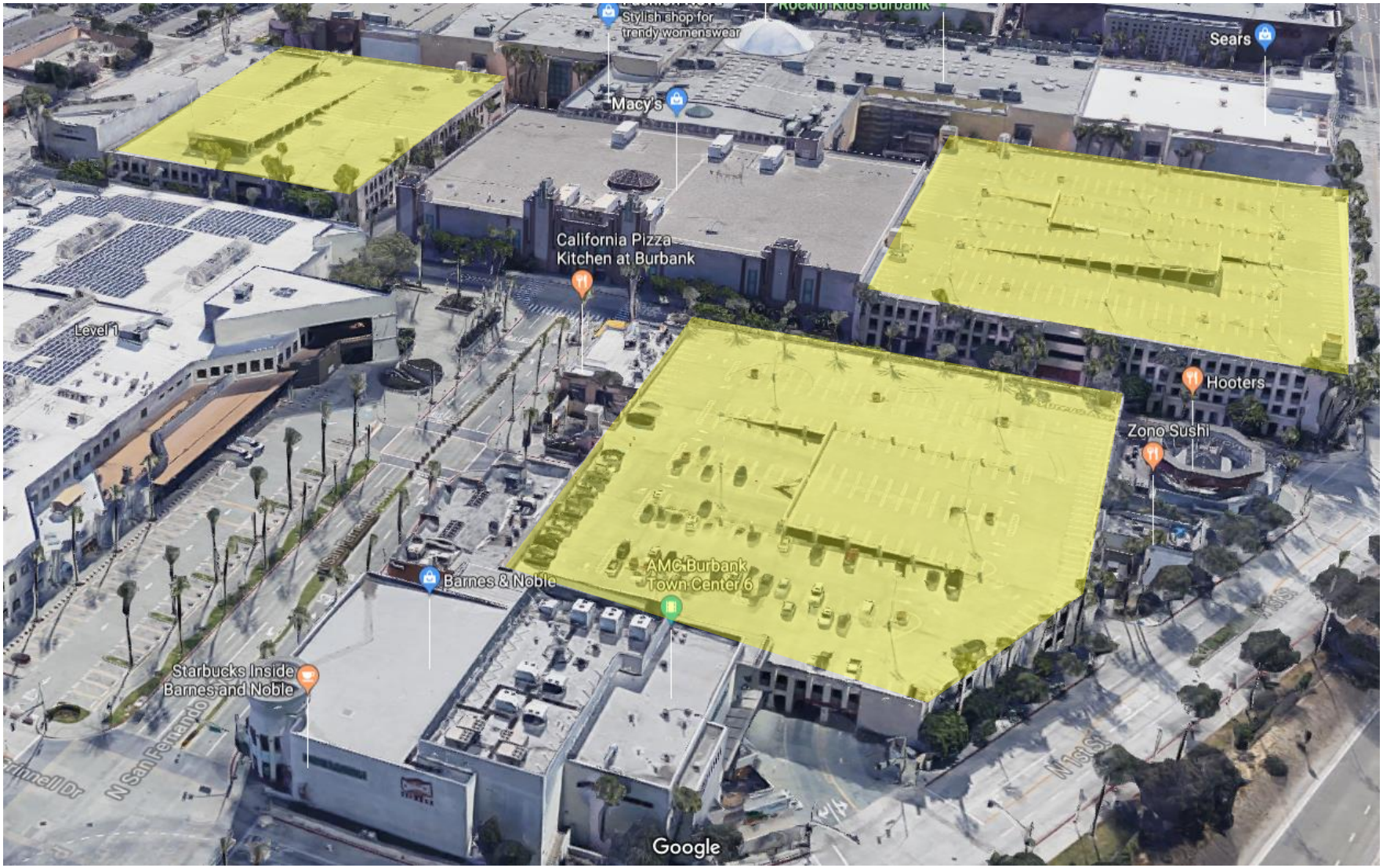
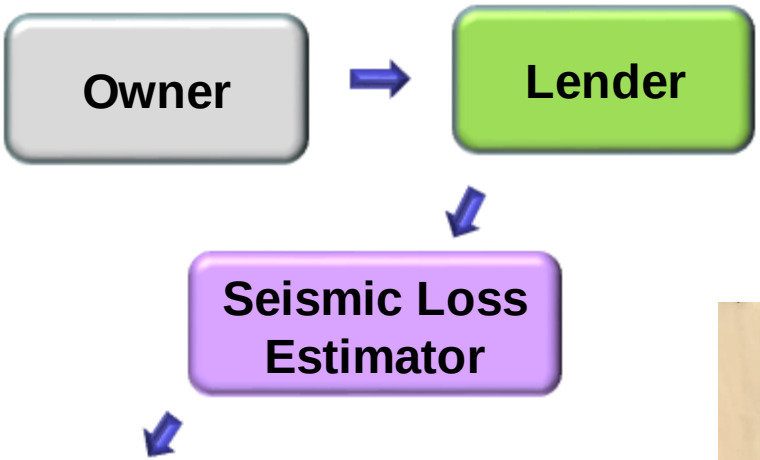
Outline

- Background
- State of Practice
- ACI 369
- Case Study
- Conclusions

Background


Stylish shop for trendy womenswear
Macy's
Sears
California Pizza Kitchen at Burbank
Level 1
Hooters
Zono Sushi
Barnes & Noble
AMC Burbank Town Center 6
Starbucks Inside Barnes and Noble
N San Fernando
W Olive Ave
Google

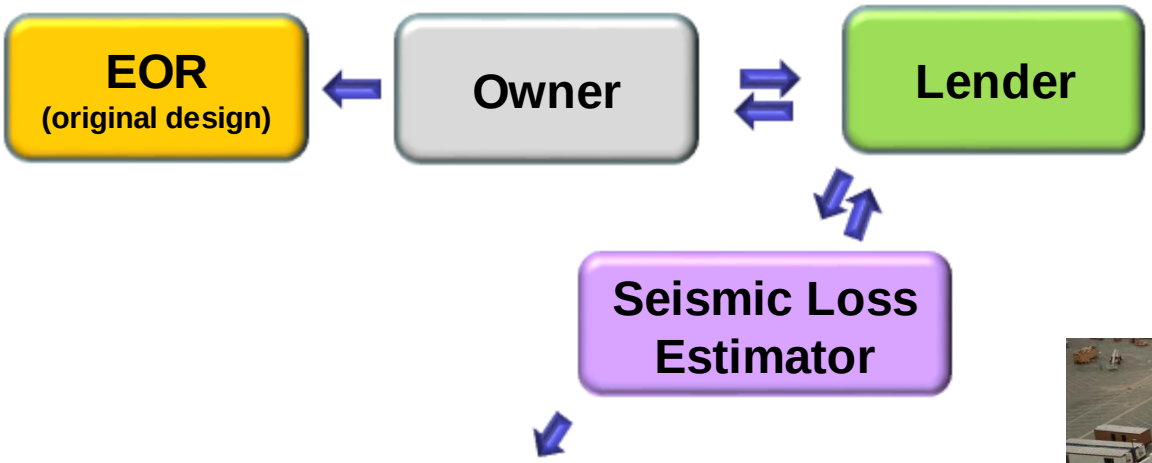
Background



First Look

- RCMRF designed in 1990
- PT slabs, columns with corbels
- Individual footing, no liquefaction
- Partially retrofitted after 1994 EQ
- Probability of collapse per FEMA-P154 is 10% under 2475 RP

Background



CSU Northridge, built in 1991. Photo Credit: Perry C. Riddle, LA Times,

Second Look

- Gravity columns lack confinement, are shear-governed
- Probability of collapse and probable maximum loss (PML) higher than acceptable
- Gravity columns need retrofit

California State University in Northridge, built in 1991. Photo Credit: M. Celebi, U.S. Geological Survey.

Background

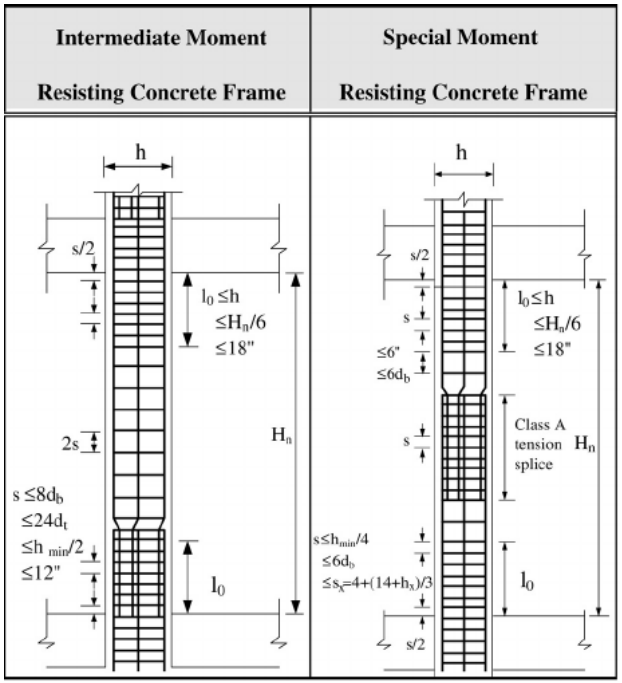
EOR’s Challenge: Limited budget, multiple deficiencies, lack of guideline
Loss estimator's challenge: Quantify the EOR’s solution

1994 Northridge earthquake, Champagne Tower, 16-story residential building, Santa Monica, CA, Typical X-shaped cracking in “short columns”, photo credit: Comartin et al.

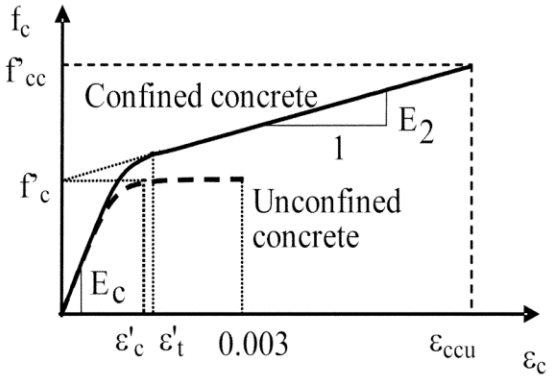
Two instances of column damage at the lap-splice location, 1999 Izmit, Turkey earthquake, photo credit: NISEE

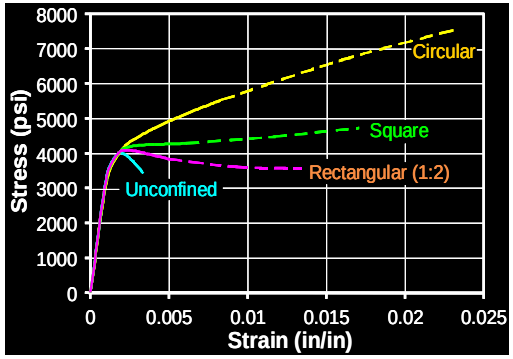
State of Practice

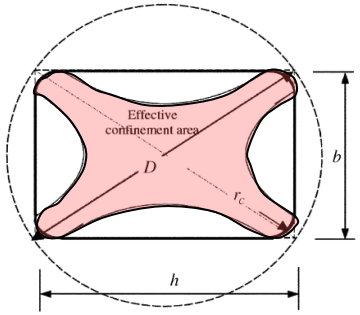
"Vendor/contractor to design FRP to make columns as confined as a column designed per ACI 318."



State of Practice



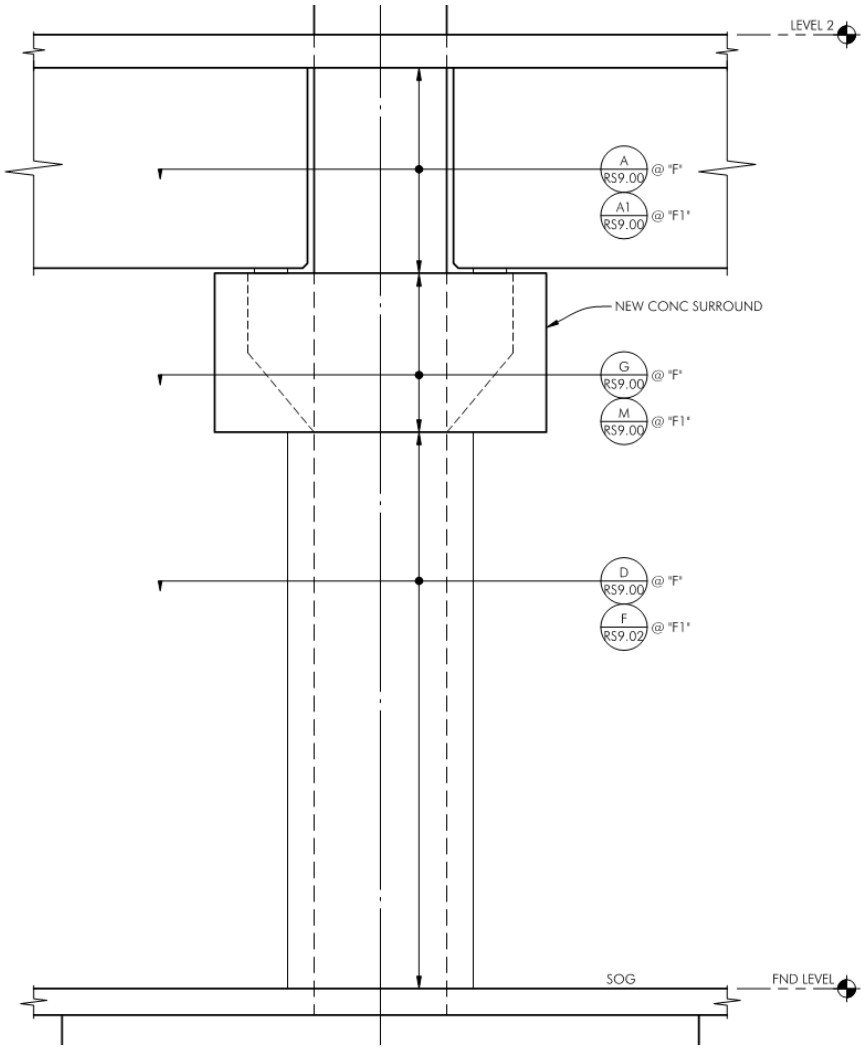


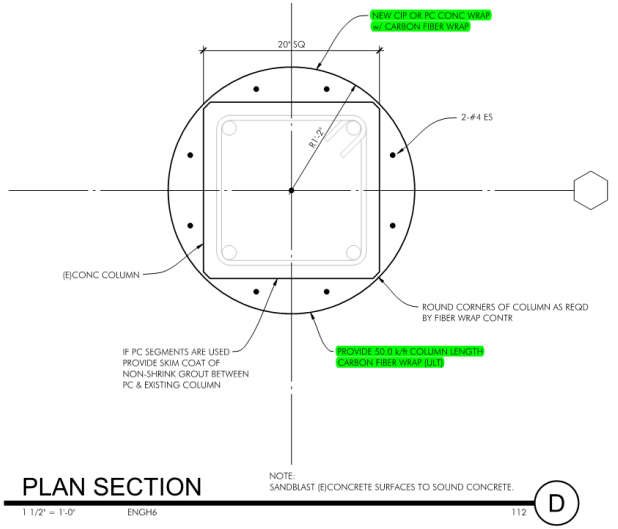


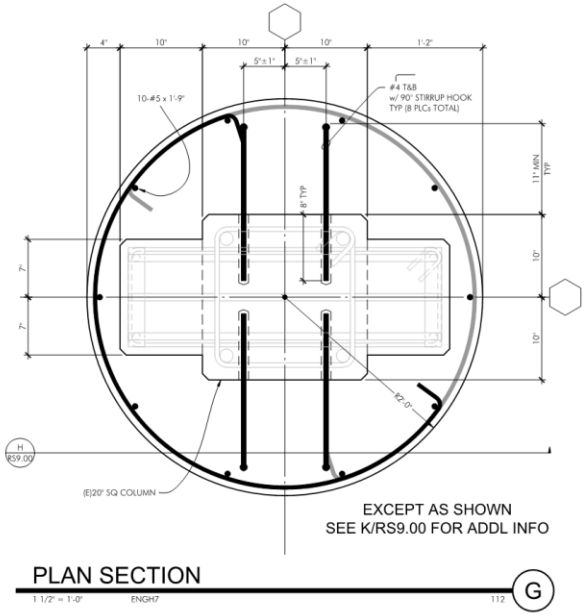
Shape Factor:

$$\kappa_b = \begin{cases} 1 & \text{Circular Column} \\ \dfrac{A_e}{A_c}\left(\dfrac{h}{b}\right)^{0.5} & \text{Non - Circular Column} \end{cases}$$

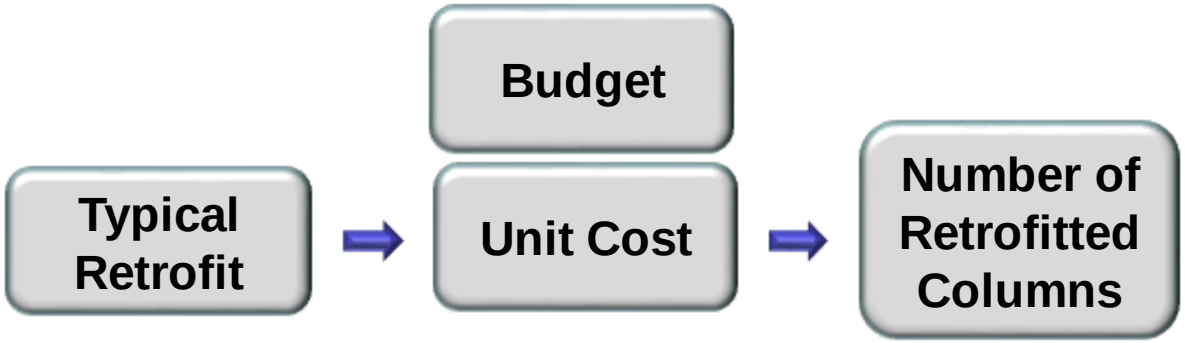
State of Practice







State of Practice



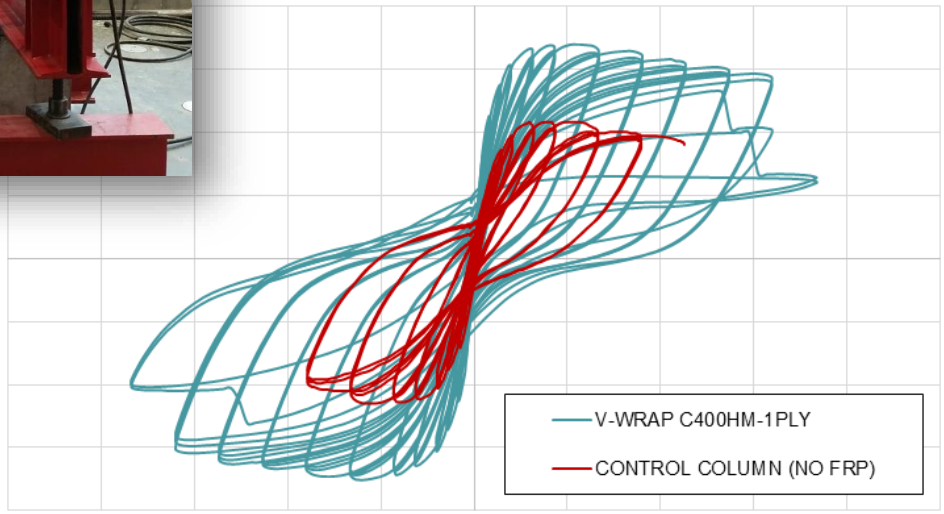
Known

- Several deficient gravity columns
- Some, likely to have highest demand, are retrofitted
- Retrofitted columns likely to perform as well as a new column

Unknown

- Have we targeted the right columns as highest priority?
- What happens with other columns?
- How much probability of collapse has reduced?
- How much estimated loss has reduced?

Missing Piece: Ductility of FRP-Wrapped Column



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Non-linear Modeling Parameters for Jacketed Columns Used in Seismic Rehabilitation of RC Buildings

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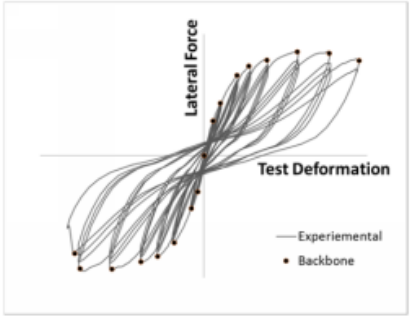
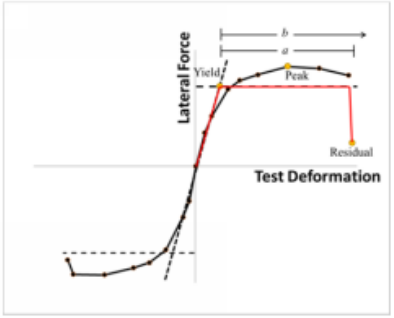
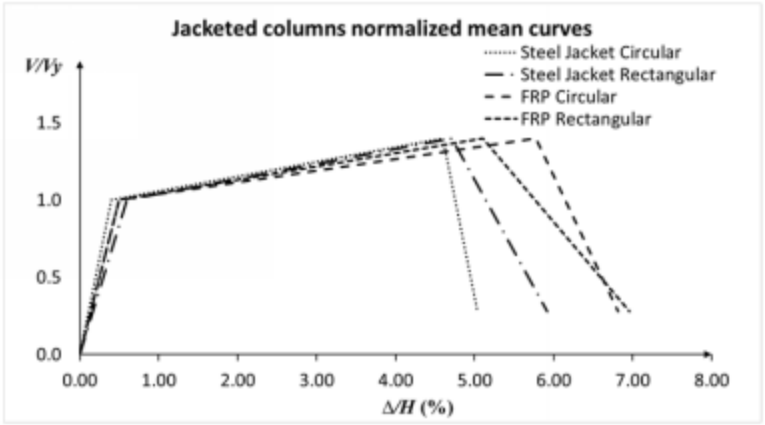
Department of Civil and Environmental Engineering
University of Massachusetts Amherst







		Specimen	Author	V_y (kip)	Δ_y/H (%)	V_{peak}/V_y	Δ_p/H (%)	V_{max}/V_y	Δ_{max}/H (%)	a	b
	All Mean			44.2	0.5	1.4	2.9	0.9	6.9	4.6	6.5

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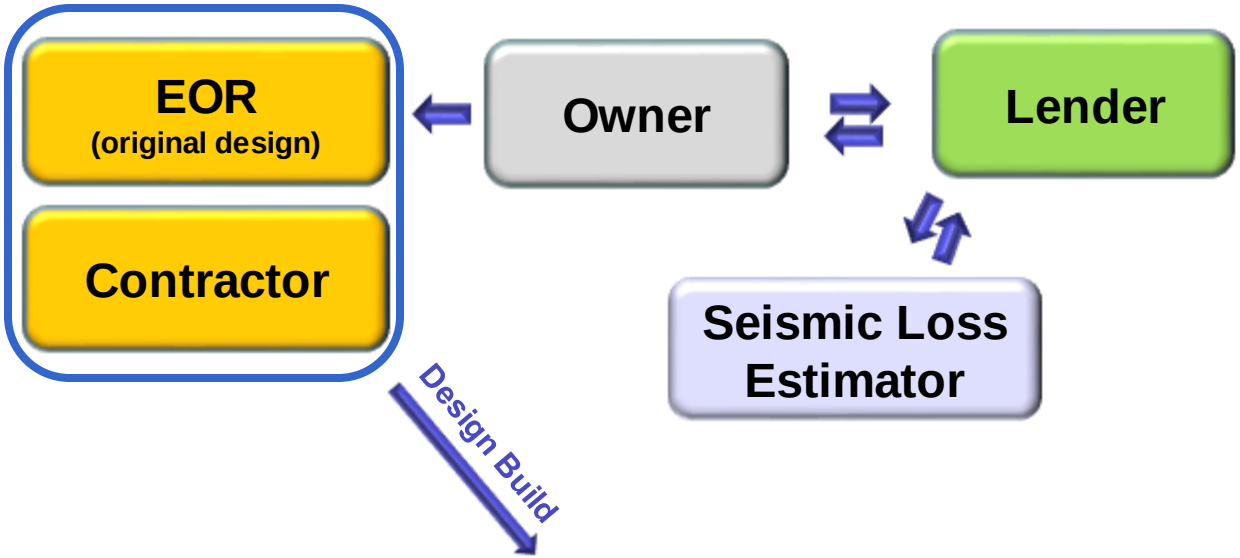
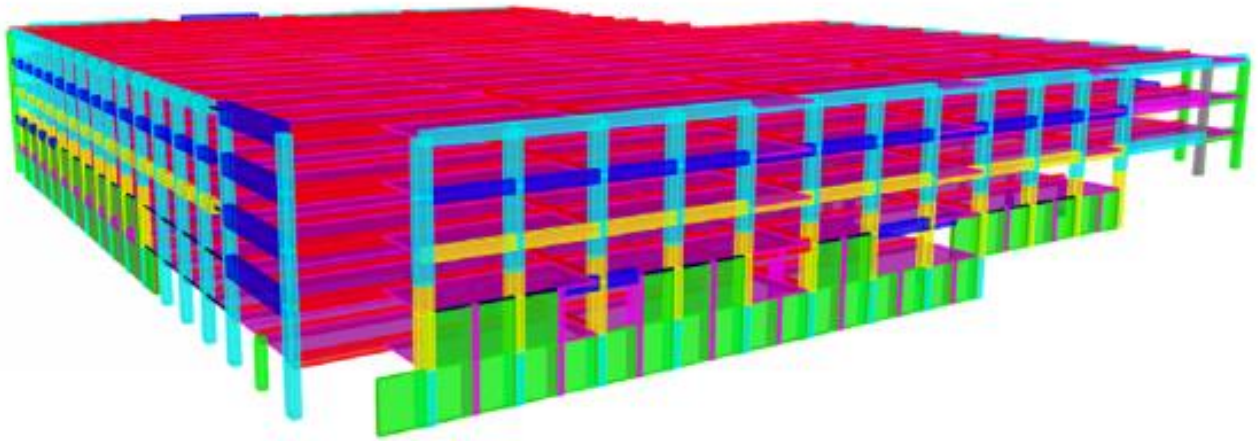

EOR
(original design)
Contractor
Owner
Lender
Seismic Loss
Estimator
Design Build



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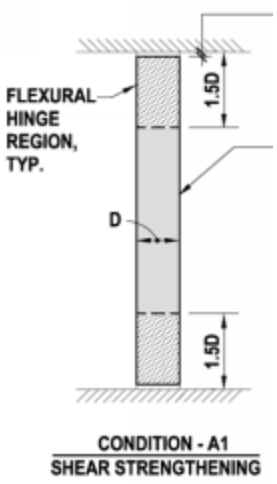
- Columns with multiple deficiencies



Diagrams taken from FEMA-547

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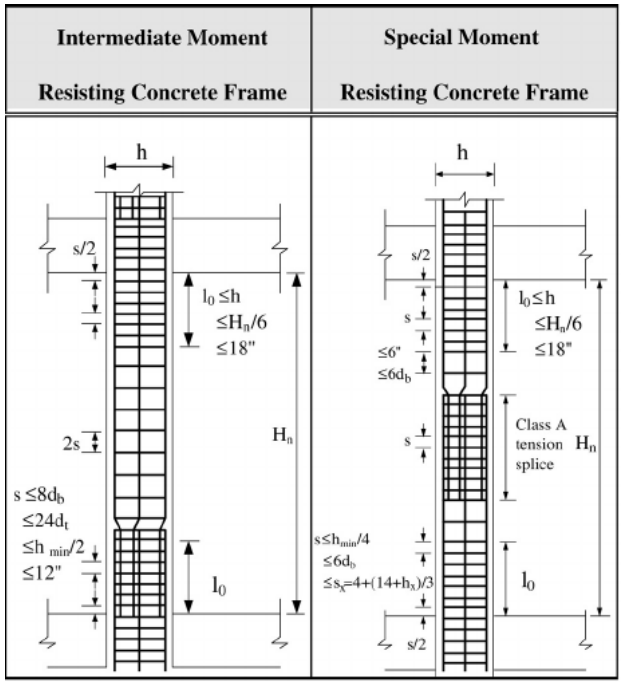
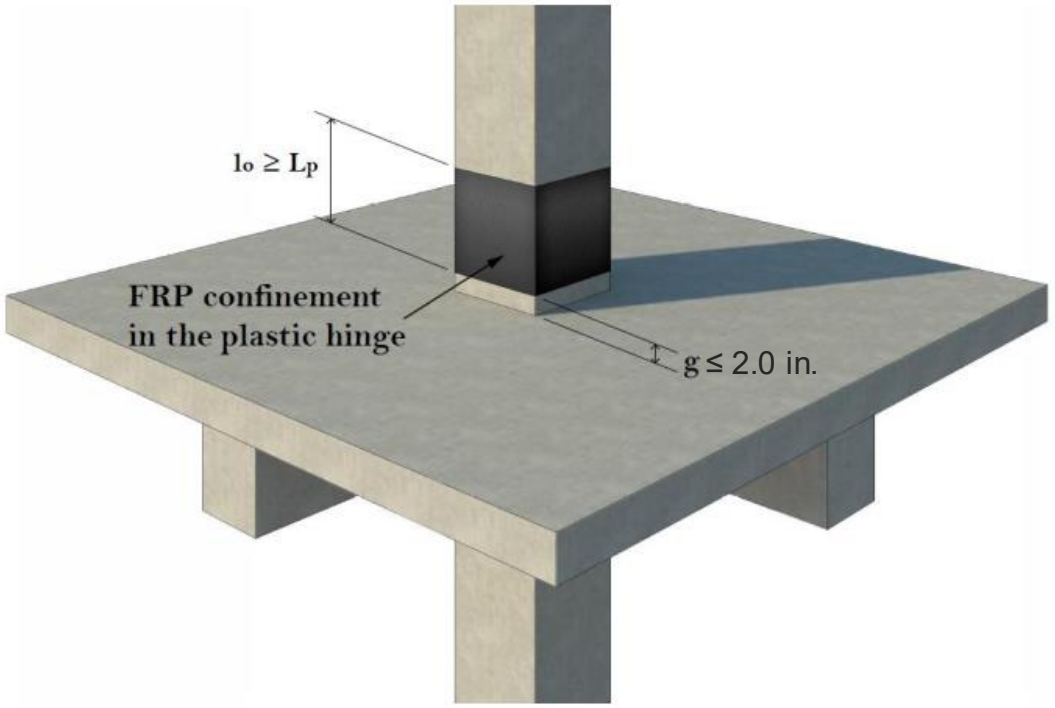




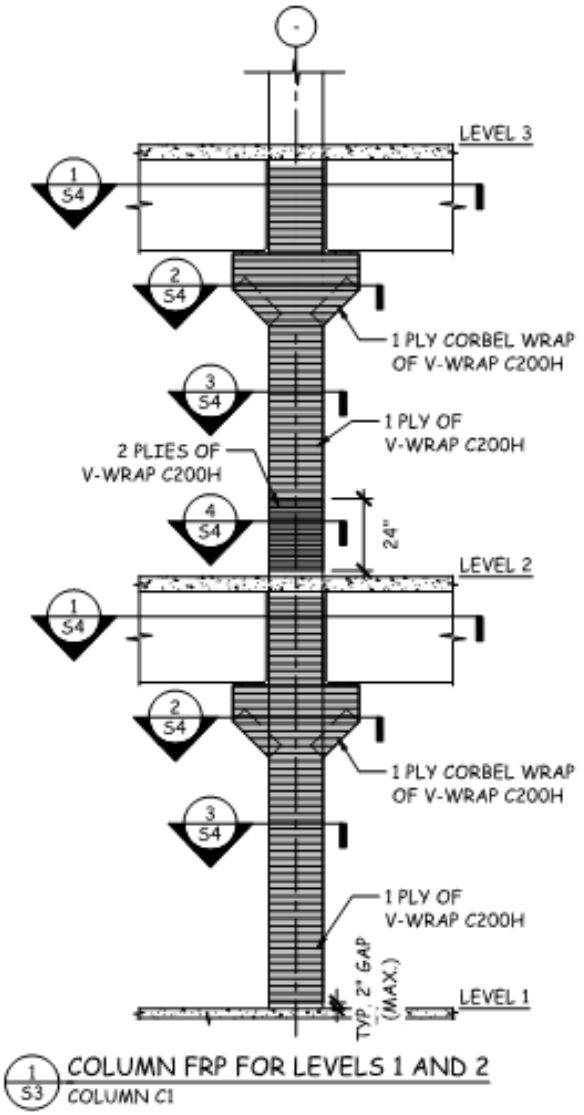
$$L_p = g + 0.0003 f_y d_{bl} \quad (d_{bl} \text{in } in. \text{ and } f_y \text{in } psi)$$

$$\emptyset_D = \frac{\theta_p}{L_p} + \emptyset_{y,frp} \qquad \emptyset_{y,frp} = \frac{\varepsilon_c}{c_y} \qquad \varepsilon_{ccu} = \emptyset_D c_u \leq 0.01$$

ACI 369

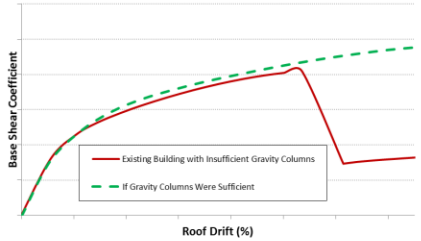
Benefits

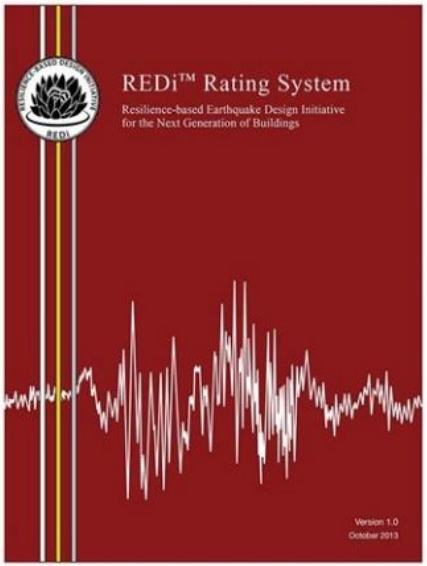
- Found answers to unknowns:
  - . We targeted the right columns
  - . Other columns are fine
  - . Could quantify reduction of probability of collapse and probable loss
- Got rid of enlargement
- Reduced construction cost and length

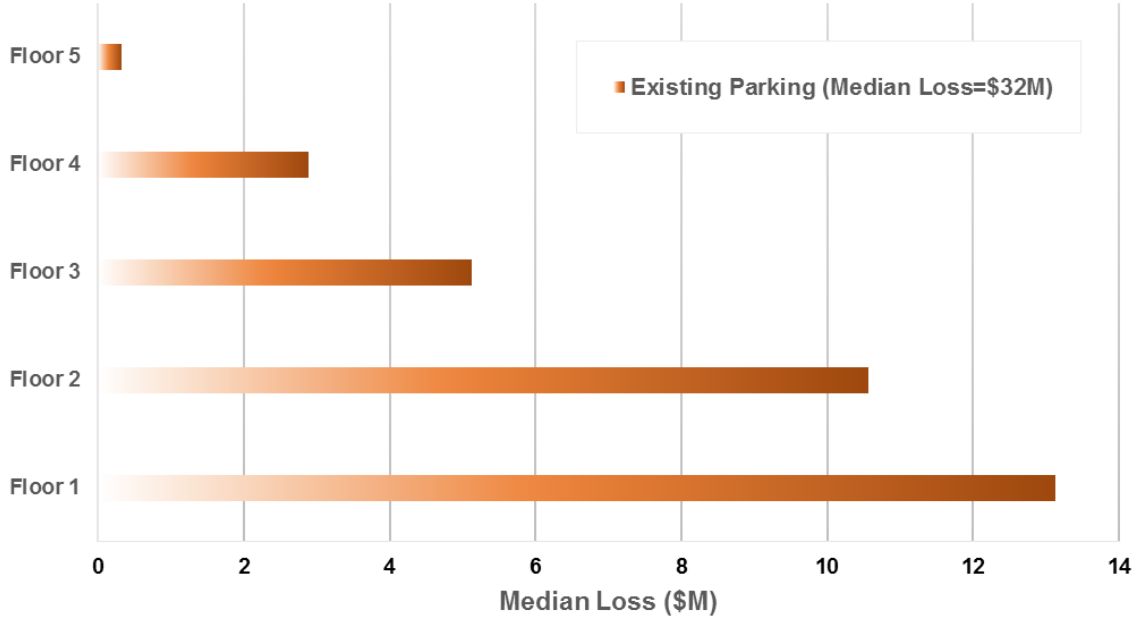


Hypothetical Case Study

- 5-story RCMRF, Los Angeles, 1990
- 100 insufficient gravity columns/floor
- Probability of collapse at DBE level: 20%

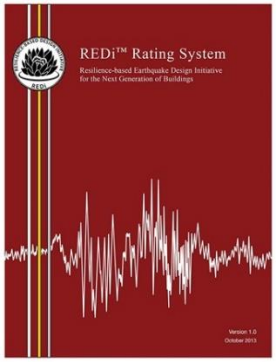






Hypothetical Case Study

- Retrofit 250 columns (100% of first two stories and 50% of third floor)
- $3000 per column for retrofit, $7000 per column for post-EQ damage repair
- Probability of collapse at DBE level < 1%



Conclusions

For ACI 369 Committee:

- Your work is much **needed and impactful** (thank you and keep it up!).

- Question:What to pursue? **Perfect tool** that is **used by few** or

Next best practical step useable by many?

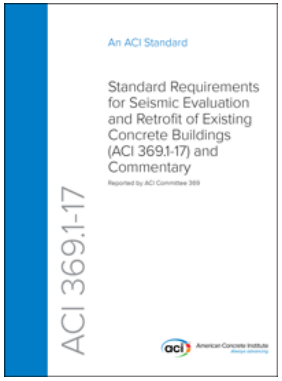
“Genius is making complex ideas simple, not making simple ideas complex.”

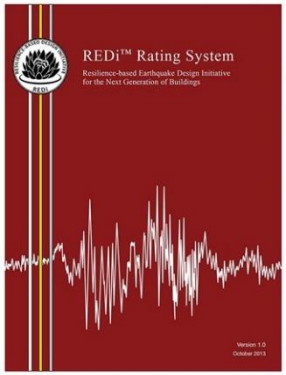
~Albert Einstein

Conclusions

For ACI 369 Audience (Engineers):

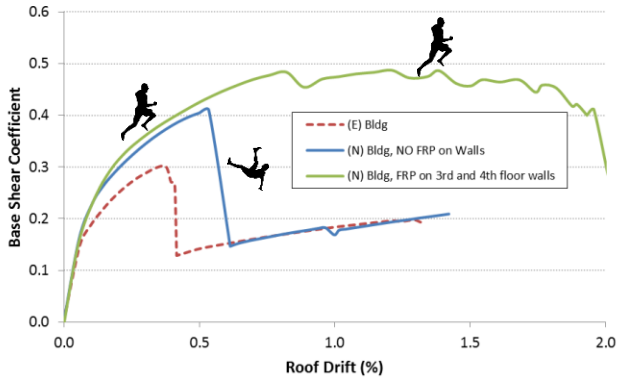
- **Participate**
- **Design-build** can lead to a win-win-win outcome
- **Be on the know**





- **Use** complex tools **mindfully**

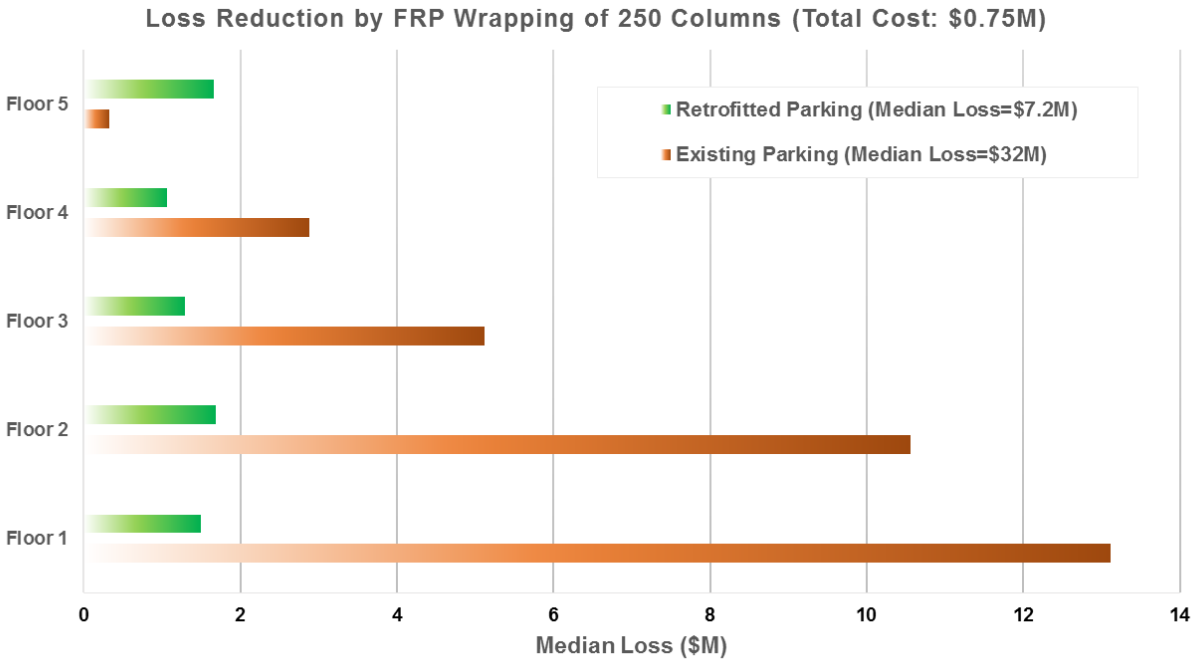
"Most people use statistics like a drunk man uses a lamppost; more for support than illumination"
~ Mark Twain



Conclusions

For All of Us:

- To defeat earthquakes, defeat **normalcy bias**!
- **Preventive retrofit** is much **cheaper than repair.**
- Individual success is impressive, but insufficient for **resilience.**



Credit: Johnny Milano (top), Smiley Pool (bottom)

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Questions

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Thank you!