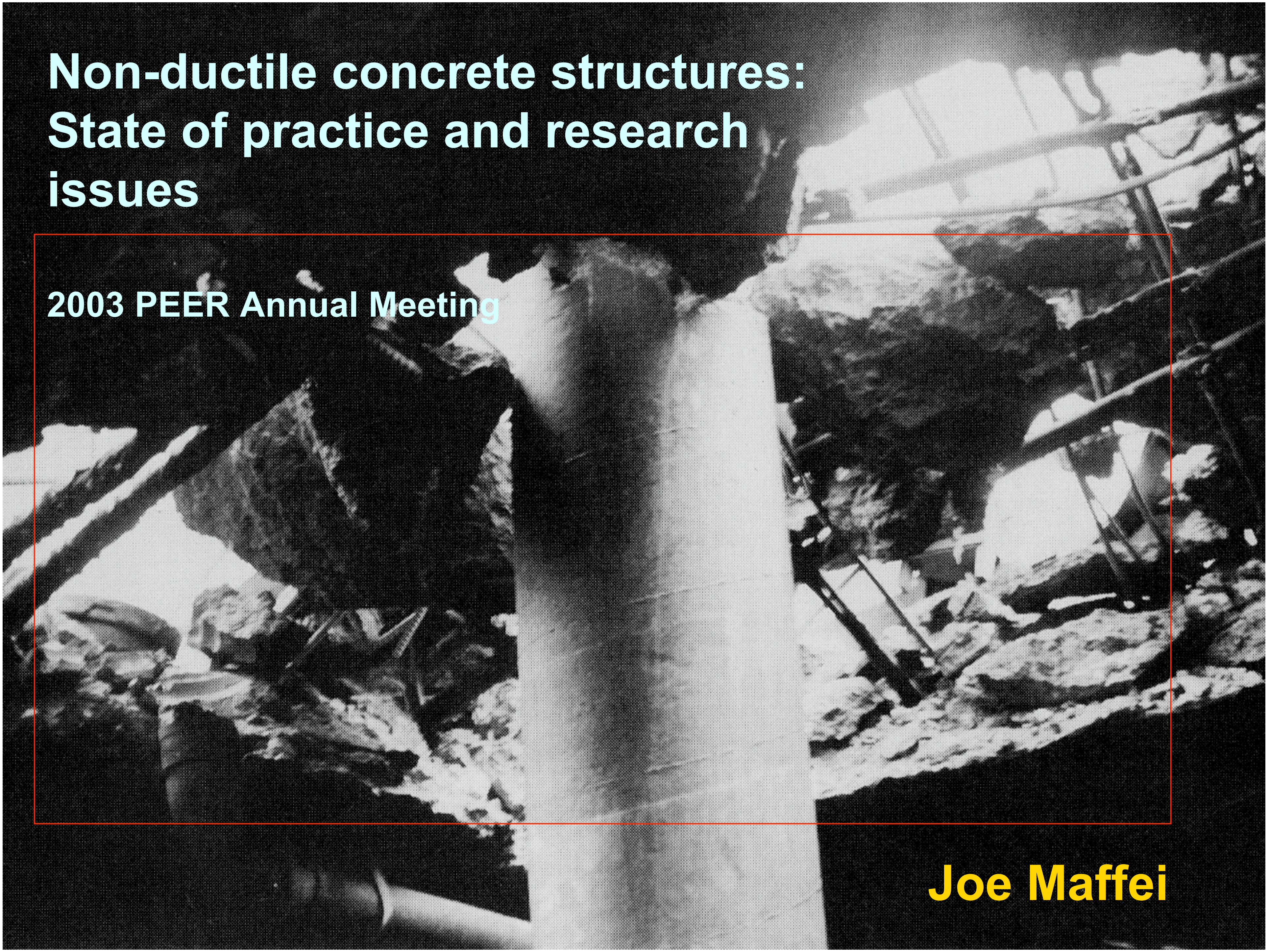
Non-ductile concrete structures: State of practice and research issues

2003 PEER Annual Meeting

Joe Maffei



Overview

- Current state of the practice
- Example projects
- “Compartmentalizing the judgment”
- Research versus development and key issues
- FEMA 306 approach
  – Component type and mechanism
  – Behavior mode
- Recommendations

Q: What is the state of practice for the assessment and retrofit on non-ductile concrete structures?

A: FEMA 356 Guidelines

But for the Savvy engineer it is loosely based on FEMA 356 with plenty of judgment and interpretation

Case Studies of FEMA 273

- **Engineers who followed the Guidelines more closely struggled to find reasonable design solutions.**
- **E.g., 5-story building needing numerous 40-inch thick new exterior concrete walls.**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12-story concrete wall buildings

- Existing concrete walls with boundary ties at 10 in. spacing.
- FEMA 356 would require improving boundary confinement.
- More detailed evaluation, directly using research results and approaches shows that retrofit of boundaries is not needed.

Administrative Building Retrofit

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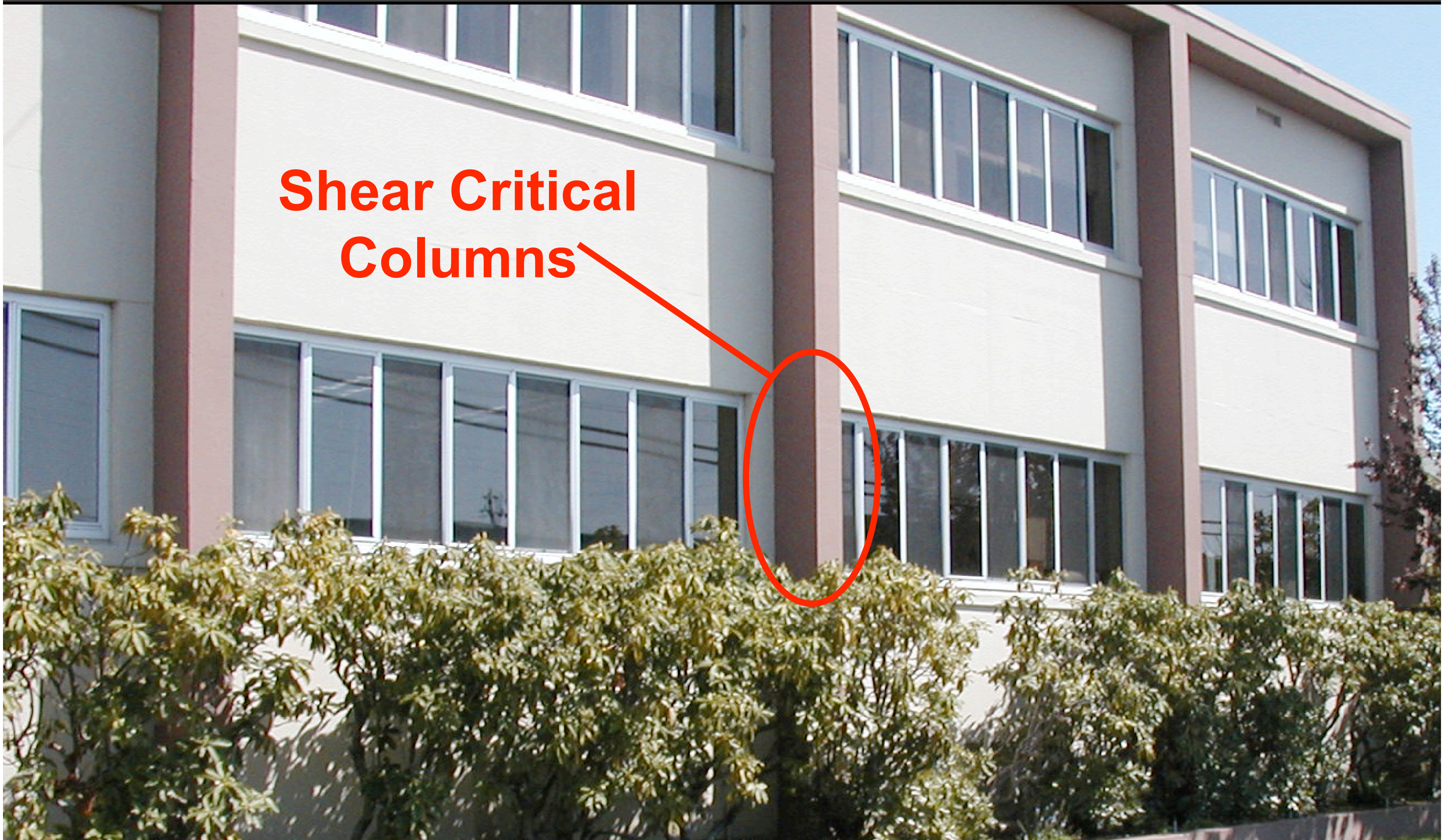
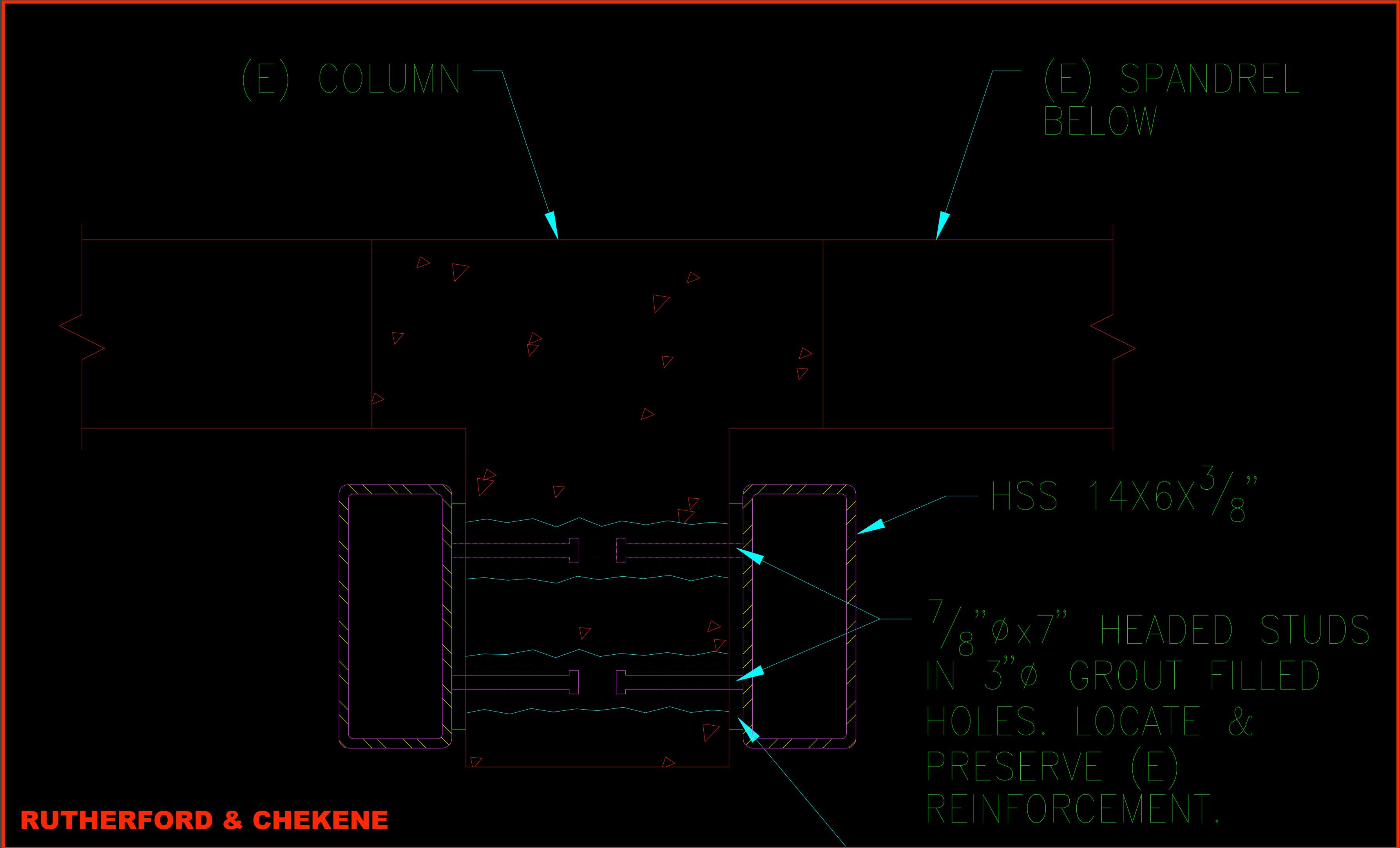
"Gravity" Columns



Acceptance limits for shear-critical columns

- 1% plastic rotation in FEMA 273, revised to 0.3% plastic rotation in FEMA 356 (reason for change not documented).
- Research by Moehle et al.
- But how reliably can we estimate the displacement demand?

Supplemental Support at exterior columns



Wurster Hall
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Steel columns backing up existing precast concrete exterior columns


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Compartmentalizing the research

- Seismic hazard / demand parameters / component capacities / performance levels / Socioeconomic impacts
- In any design process judgment gets applied at some point.
- It can be problematic to apply this judgment to the component results rather than to the final answer

Example design decisions

- Should gravity columns be retrofitted?
- Should wall boundaries be retrofitted?
- In a large building these decisions have million-dollar consequences.

The decision depends on compounded assumptions:

Performance expectation

Acceptability

Local demand (drift or ductility)

Displacement demand

Structure stiffness

Ground motion

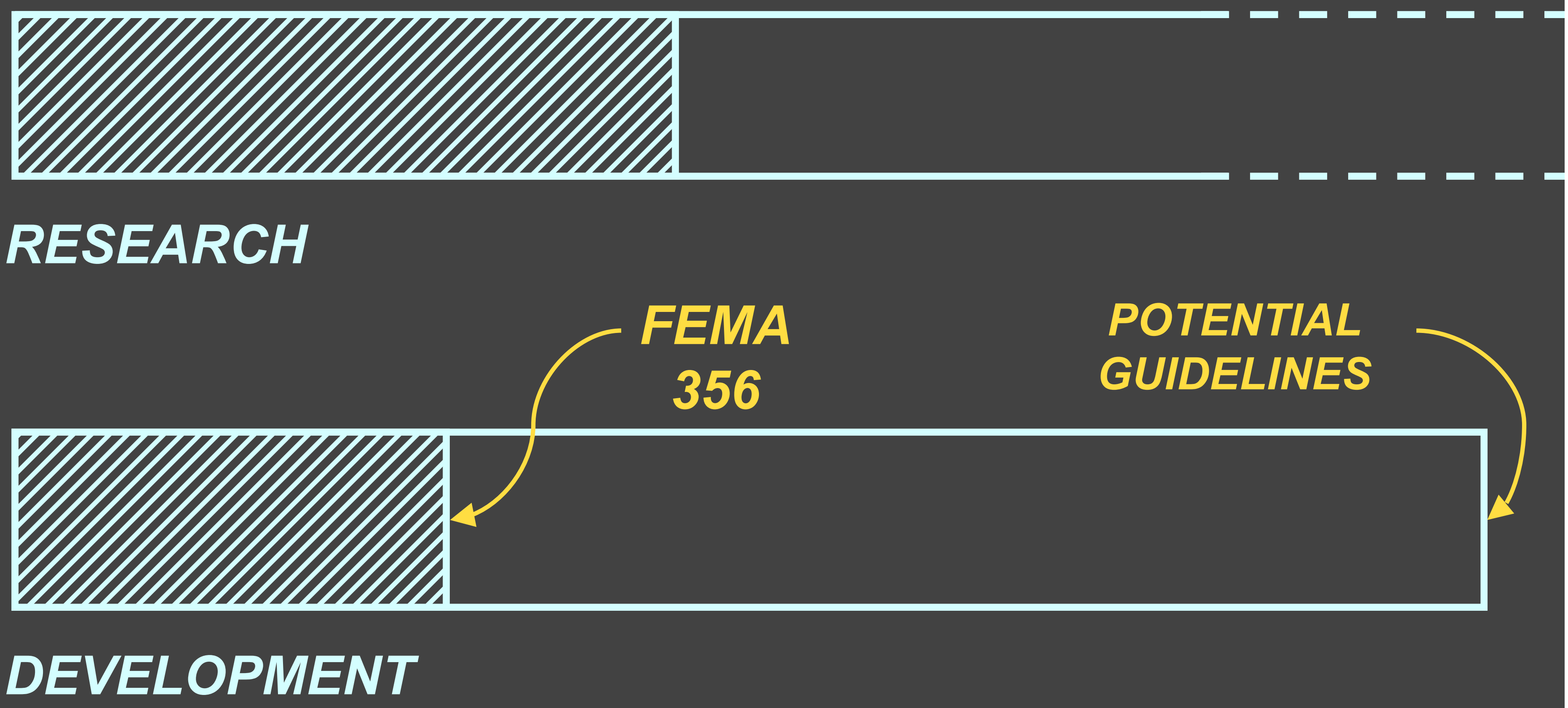
Applying expert judgment to the final result, e.g.:

- Is it right that the wall boundaries in this building, with #3@10” ties, should be retrofitted?
- Do we have enough confidence in our displacement demand and capacity estimates to know that these shear-critical columns can be left un-retrofitted?

EXISTING CONCRETE BUILDINGS

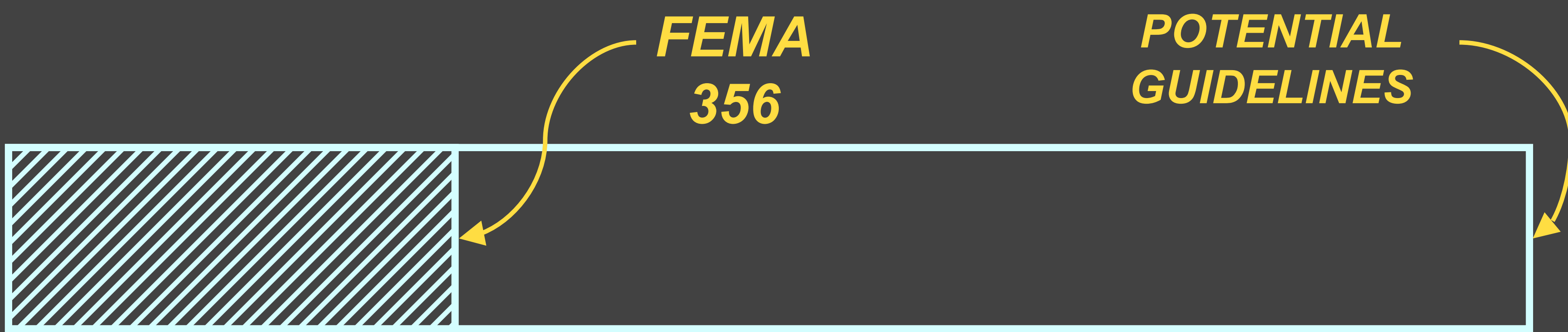
EVALUATION AND RETROFIT GUIDELINES

What needs to be done?



EXISTING CONCRETE BUILDINGS

RECOMMENDED DEVELOPMENT



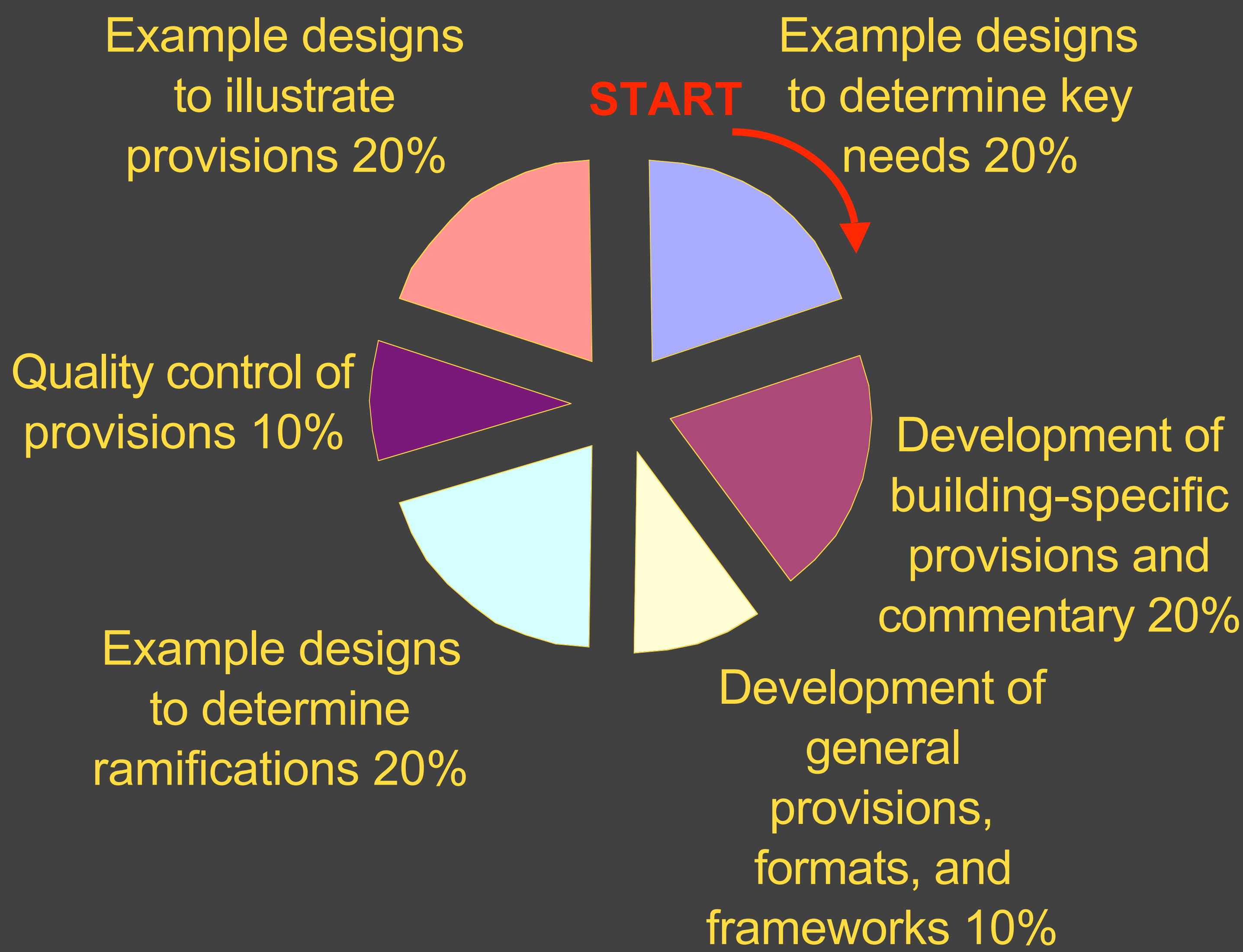
- Tie acceptance limits more explicitly to behavior modes
- Simplify general frameworks
- Improve and clarify evaluation and analysis procedures
- Review research and improve acceptance limits
- Example designs
- Quality control

Two possible approaches for PBD

A reference document with a less prescriptive framework than FEMA 356: Engineer investigates the research herself, with an excellent knowledge of applicable assumptions.

A more specific and vetted FEMA 356, with workable code-language design provisions, commentary, and example applications.

Development of improved guidelines



PEER investigation of key variables and parameters

- E.g., Axial load ratio, load history, concrete strength, story drift, chord rotation.
- Hypotheses of behavior models can help identify what should be a key variable.

FEMA 356 Acceptability Limits

Grouped by:

- **Axial load ratio**
- **Unbalanced reinforcement ratio**
- **Level of shear stress in concrete**
- **Conforming versus nonconforming detailing**

Are we over-frameworkizing the research?

Study of FEMA 356 Acceptability limits

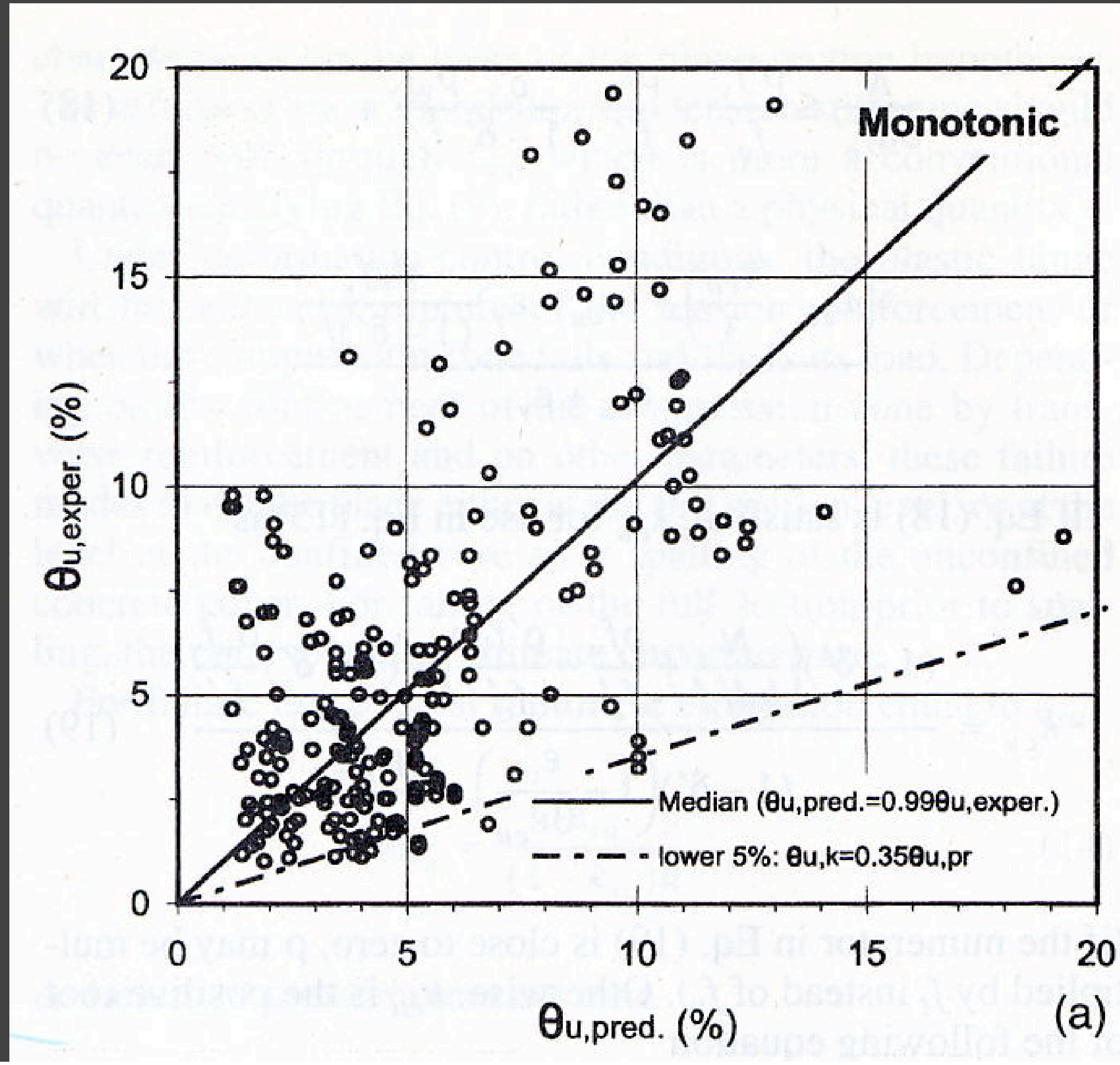
Panagiotakos and Fardis

Table 2—Statistics of ratio of experimental ultimate plastic (chord) rotation θ_{pl} to values suggested by FEMA 273[1] and FEMA 356[3*]

$V/bd\sqrt{f_c'}$, units: lb. in.		$\theta_{pl,exp.}/\theta_{pl,FEMA}$		$\theta_{u,exp.}/\theta_{u,FEMA}$			$\theta_{pl,exp.}/\theta_{pl,FEMA}$		$\theta_{u,exp.}/\theta_{u,FEMA}$			$\theta_{pl,exp.}/\theta_{pl,FEMA}$		$\theta_{u,exp.}/\theta_{u,FEMA}$	
		< 1.00					1.00 to 2.00					>2.00			
$(\rho - \rho')/\rho_{bal}$	n	m	σ	m	σ	n	m	σ	m	σ	n	m	σ	m	σ
Beams with closely spaced stirrups†															
≤ 0	0	—	—	—	—	0	—	—	—	—	0	—	—	—	—
0 to 0.25	42	1.18	0.36	1.28	0.35	11	1.13	046	1.32	0.5	0	—	—	—	—
≥ 0.25	0	—	—	—	—	0	—	—	—	—	0	—	—	—	—
Beams without closely spaced stirrups†															
	0	—	—	—	—	0	—	—	—	—	0	—	—	—	—
$\nu = N/A_g f_c'$															
Columns with closely spaced stirrups†															
≤ 0.1	76	1.43	0.78	1.48	0.70	18	1.07	0.63	1.19	0.55	5	0.78	0.17	1.03	0.13
0.1 to 0.25	172	1.36	0.57	1.55	0.60	16	0.89	0.47	1.05	0.50	0	—	—	—	—
0.25 to 0.4	58	1.2	0.85	1.32	0.78	5	1.12	0.52	1.24	0.43	2	0.09	0.13	0.42	0.05
≥ 0.4	28	1.1	0.85	1.18	0.77	0	—	—	—	—	0	—	—	—	—
Columns with no closely spaced stirrups†															
≤ 0.1	44	2.75	1.33	2.59	1.14	8	2.79	1.72	2.58	1.41	5	2.01	0.54	2.18	0.40
0.1 to 0.25	26	2.13	1.15	2.17	0.98	4	0.93	0.39	1.02	0.39	2	1.92	1.38	1.95	0.99
0.25 to 0.4	21	1.54	1.09	1.77	0.92	1	2.57	—	2.25	—	1	2.56	—	2.25	—
≥ 0.4	12	2.74	1.57	2.38	1.08	0	—	—	—	—	0	—	—	—	—

Ultimate rotation capacity

Panagiotakos and Fardis



FEMA 306 Approach

- Document covers wall buildings.
- Designed for evaluation of earthquake damage.
- Applicable to seismic evaluation
- Emphasizes understanding the mechanism of response and identifying component behavior modes

RC2: Weaker
wall pier

RC4: Stronger
spandrel

Wall Shear Failure at First Story

Wall shear failure and story mechanism at 2nd Story

Inelastic displaced shape

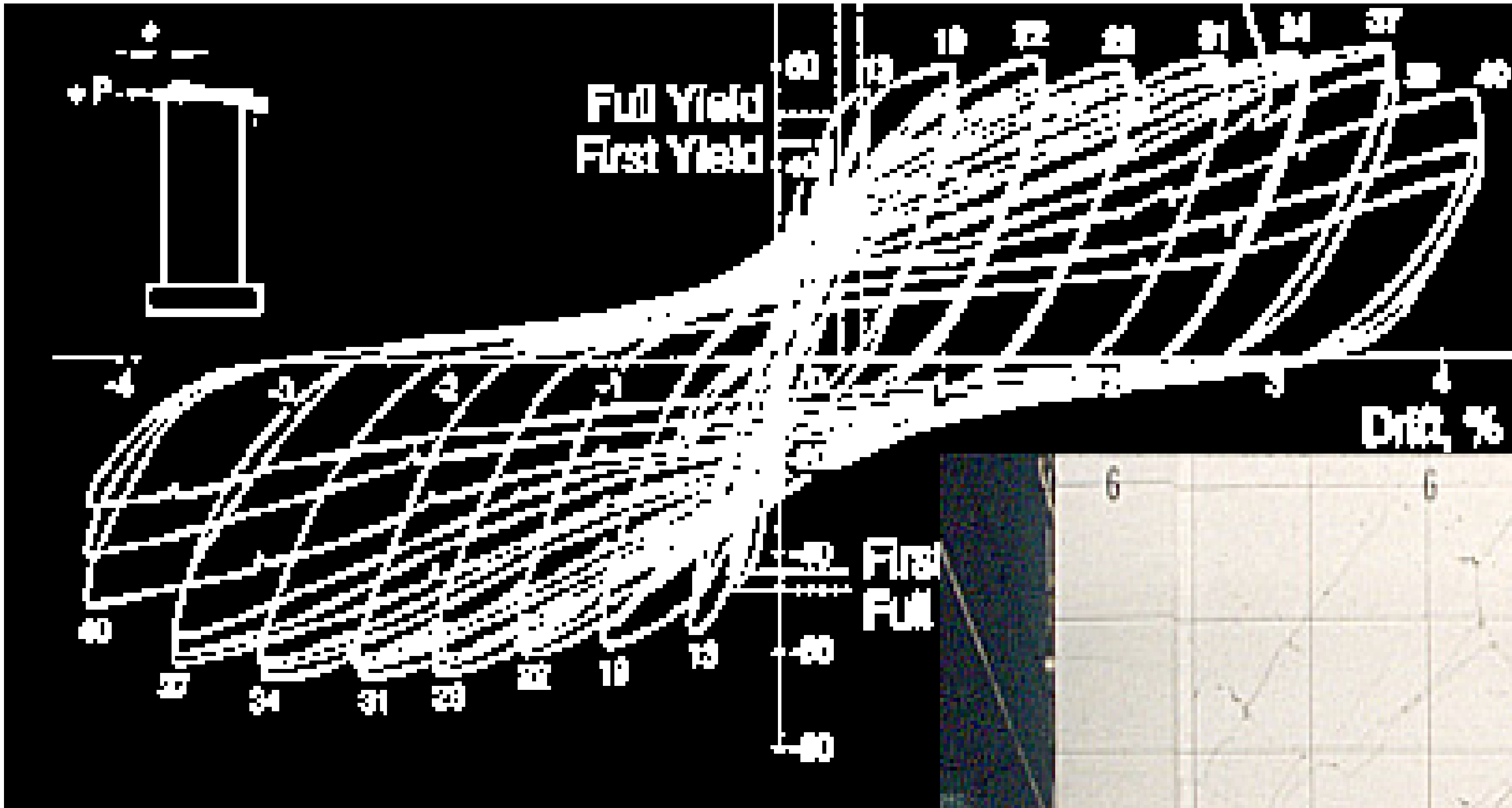
Mechanism of coupling beam failure

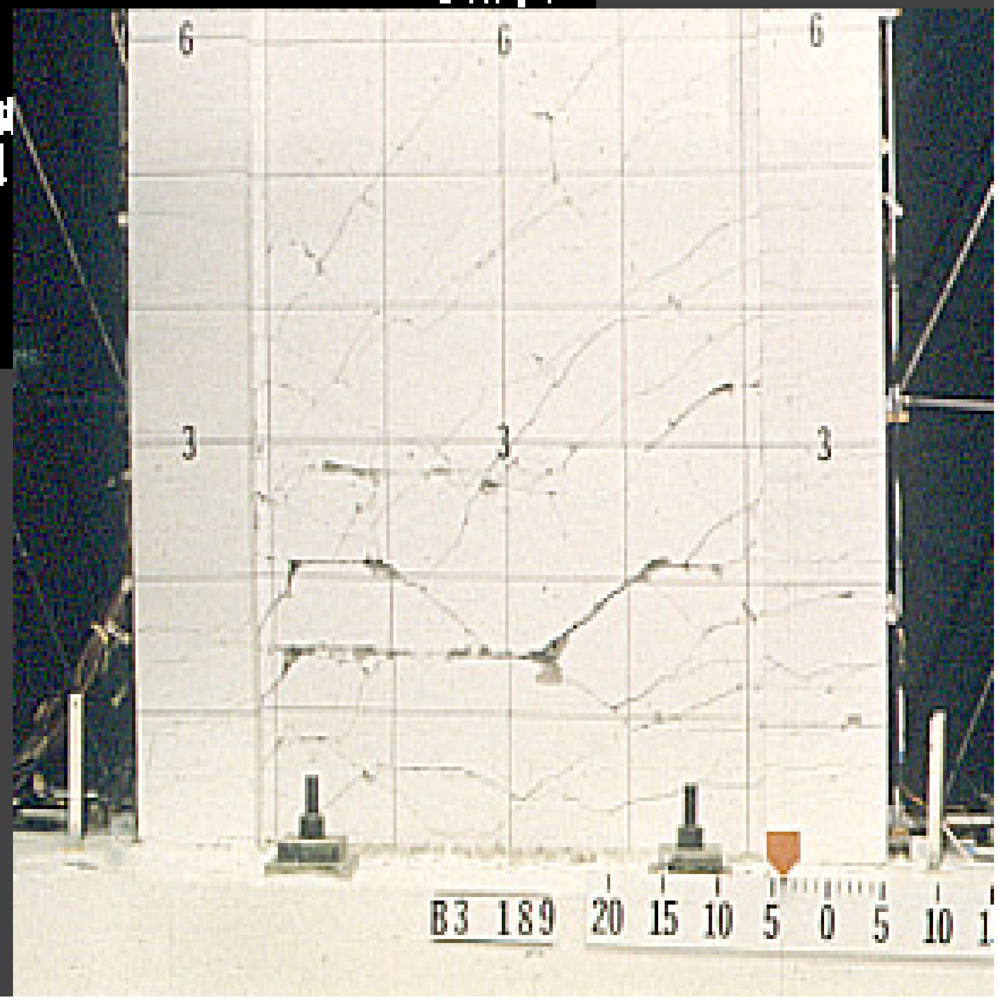
Inelastic displaced shape

Mechanism: Flexural yielding above curtailed reinforcement

Inelastic displaced shape

Behavior Mode	Ductility Capacity
A. Ductile Flexure	High
B. Flexure/Diagonal Tension	Moderate (Varies)
C. Flexure/Diagonal Compression (Web Crushing)	
D. Flexure/Sliding Shear	
E. Flexure/Boundary Zone Compression	
F. Flexure/Lap-Splice Slip	
G. Flexure/Out-of-plane Wall Buckling	





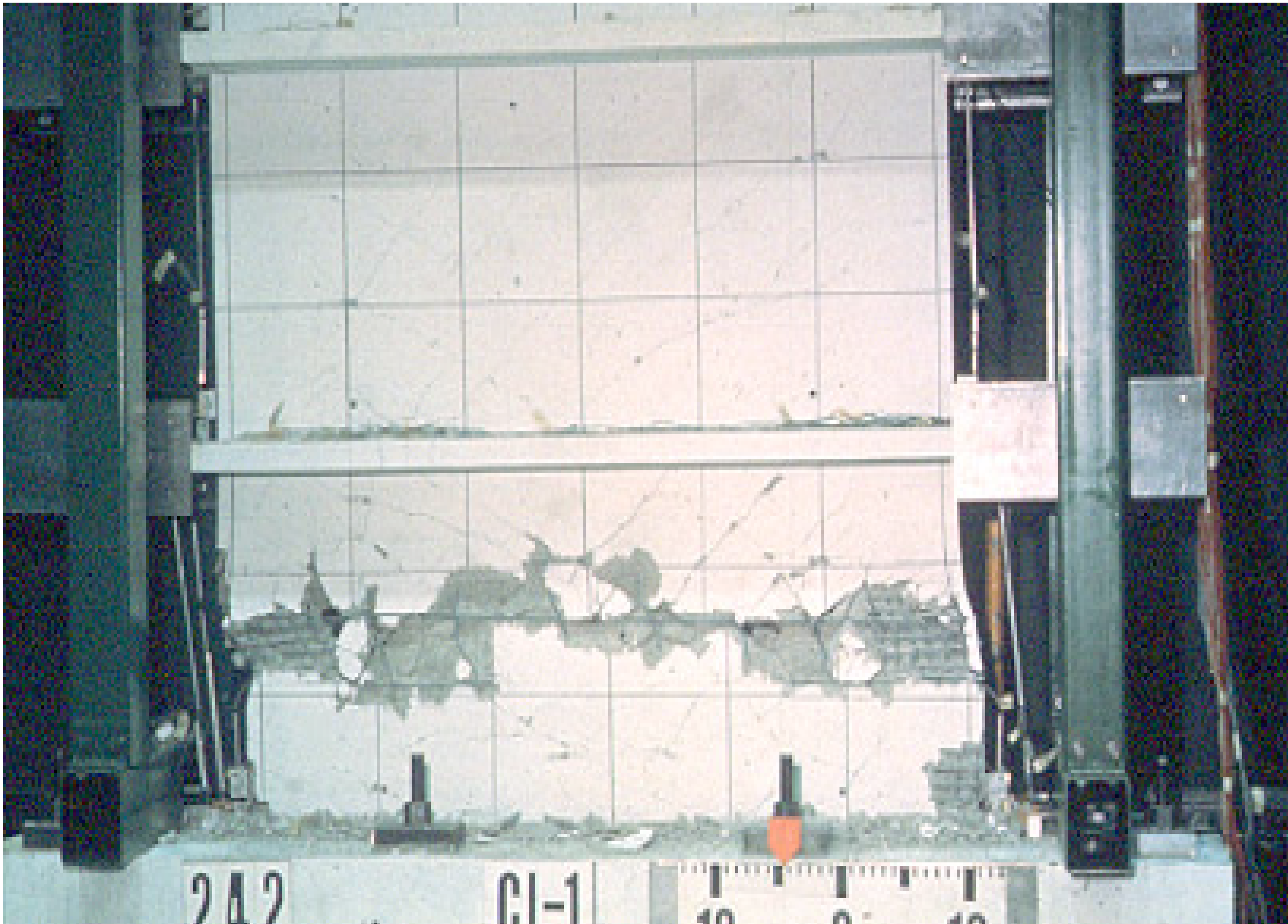
RC1A: Flexure-Governed Wall

Component Type RC1: Isolated Wall

Behavior Mode B: Flexure/ Diagonal Tension

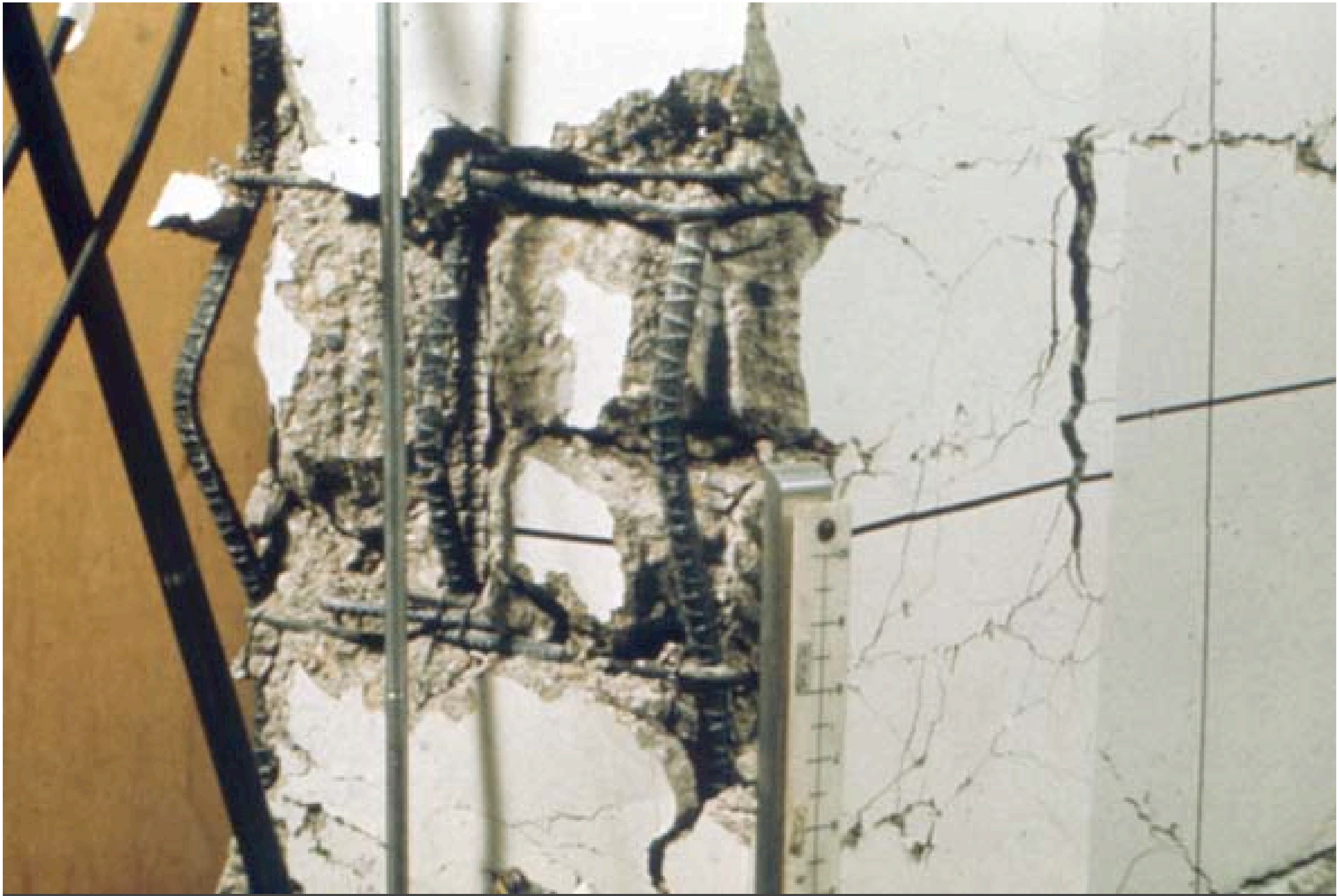
Component Type RC1: Isolated Wall

Behavior Mode D: Flexure/ Sliding Shear

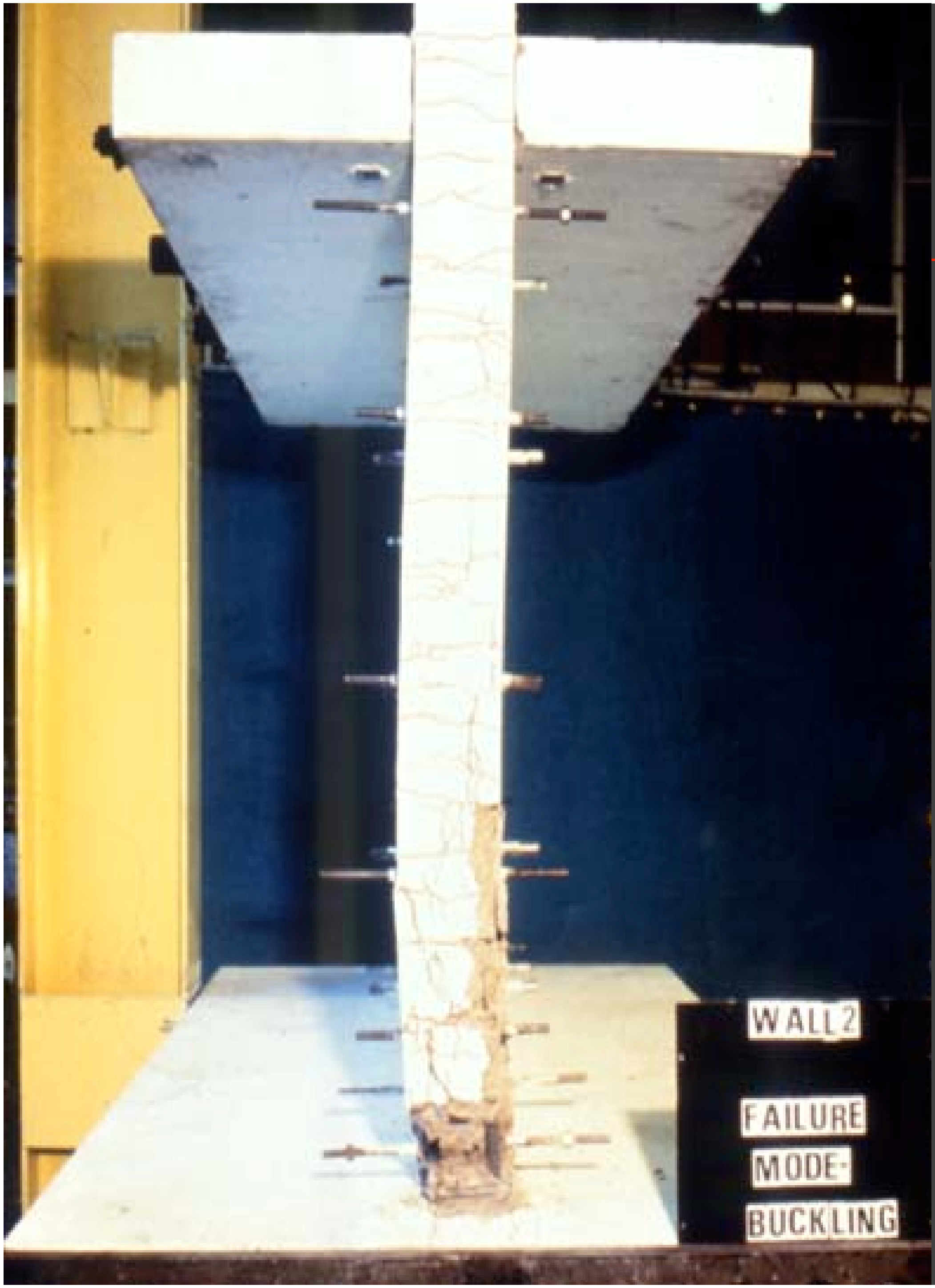


RC1D: Sliding shear failure

Buckled wall reinforcement -- RC1E

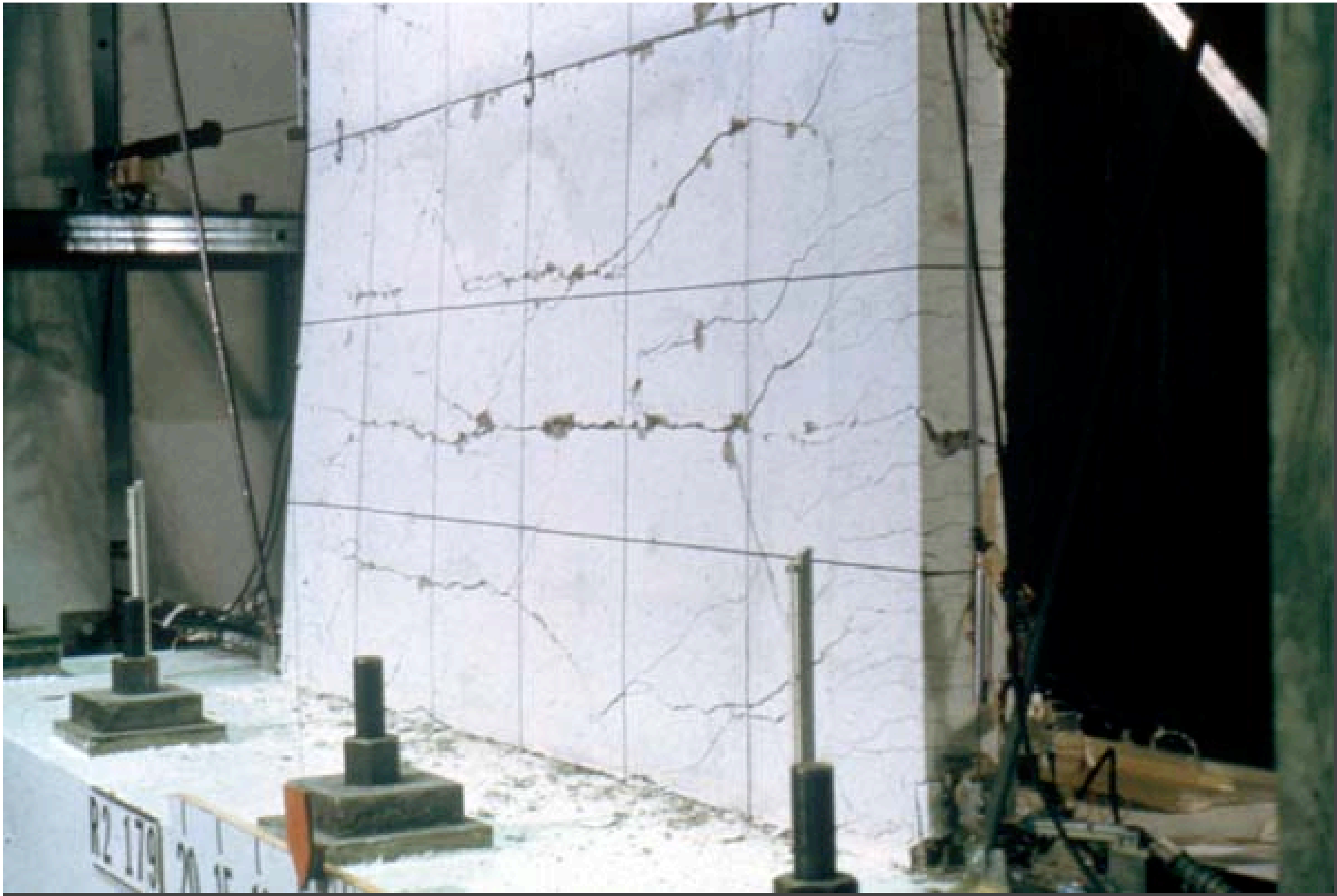


Buckled wall reinforcement -- RC1E



Component Type RC1: Isolated Wall

Behavior Mode G: Flexure/ Out-of-plane wall buckling



Out-of-plane wall buckling -- RC1G

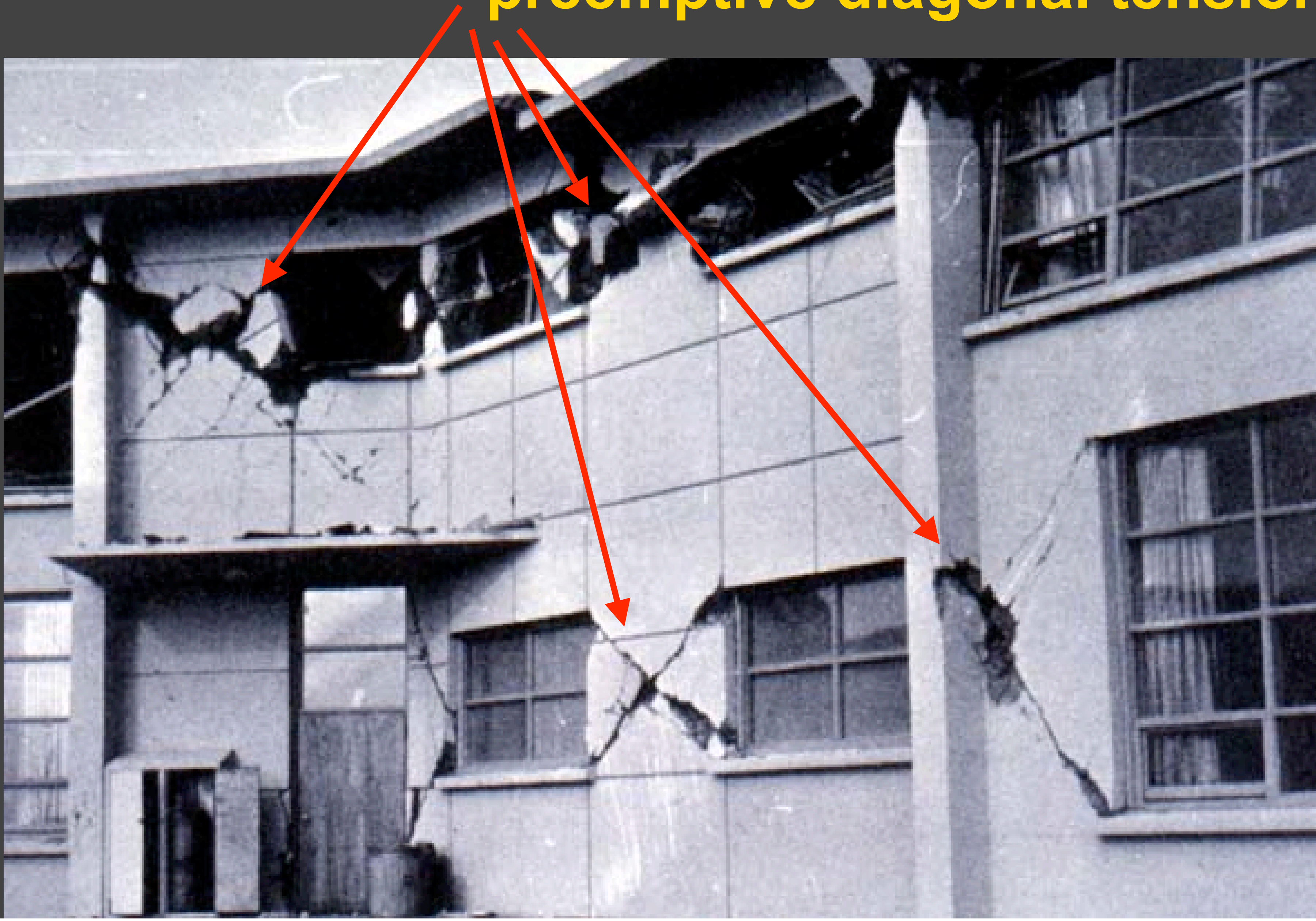
Behavior Mode	Ductility Capacity
H. Preemptive Diagonal Tension I. Preemptive Web Crushing J. Preemptive Sliding Shear K. Preemptive Boundary Zone Compression L. Preemptive Lap-Splice Slip	Low
M. Global Foundation Rocking N. Foundation Rocking of Individual Piers	Moderate to High

Behavior
Mode H:

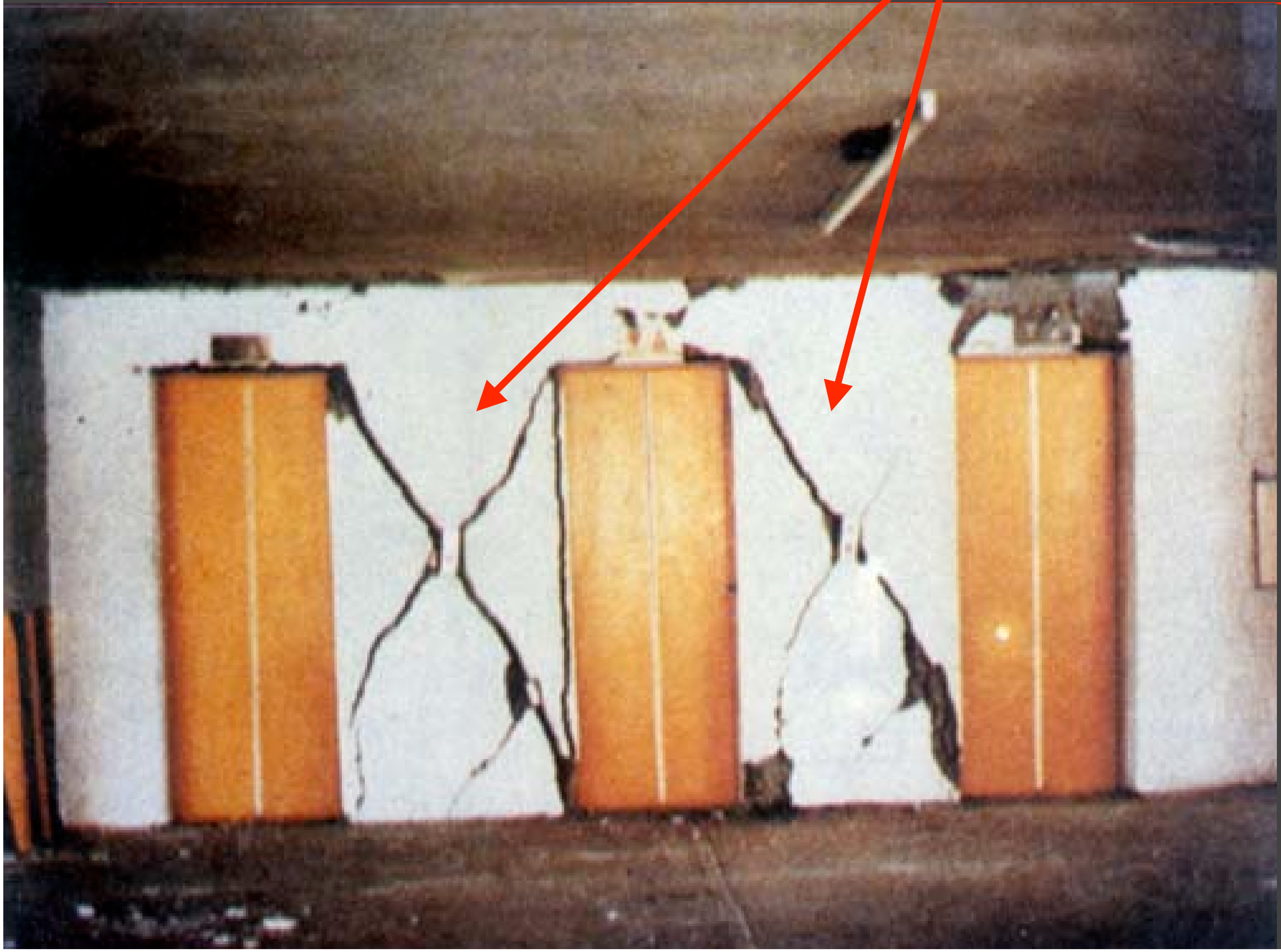
Preemptive
Shear Failure
in Diagonal
Tension

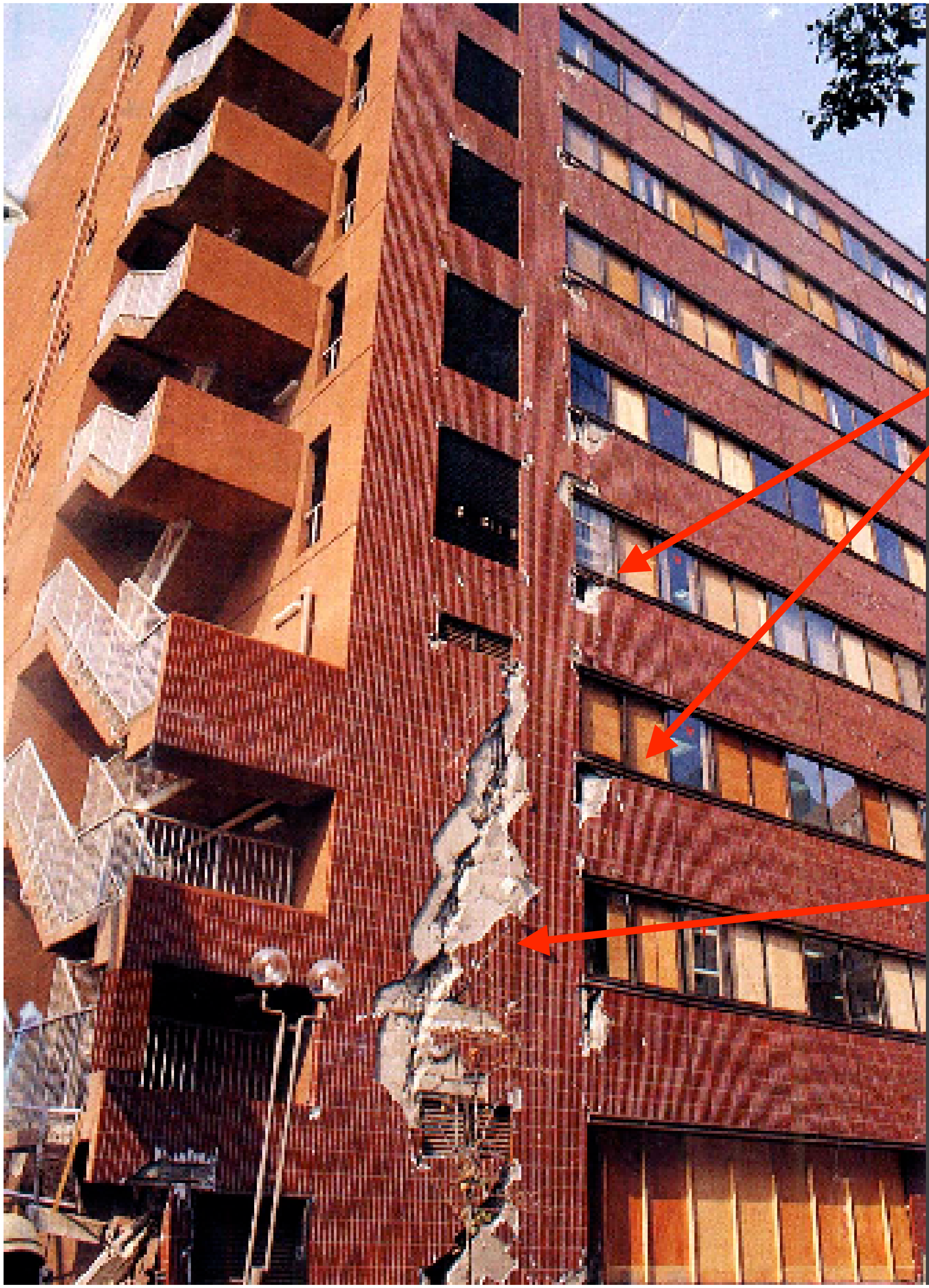
Northridge
1994

RC2H: Weaker wall pier, preemptive diagonal tension



RC2H: Weaker wall pier, preemptive diagonal tension





RC3 Components: Weaker Spandrels

RC1H: Shear Failure in Diagonal Tension

RECOMMENDATIONS

- Take full advantage of research done previously and at non-PEER institutions. Emphasize review of research as well as new research.
- Continue to select and design tests based on actual buildings (to the extent possible) so that overall impacts of findings can be studied.

RECOMMENDATIONS

- Continue to seek and use practitioner input, and coordinate research among institutions.
- Question proposed frameworks if there are potentially better alternatives.