Post-earthquake safety and quake-resilient communities

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October 2009

RUTHERFORD & CHEKENE

Outline

SPUR's Resilient City Initiative

- Desired performance
- Objectives for new buildings
- Cost of improved performance

Assessment considering post-earthquake safety

- Applications

Conclusions

Resilient City Initiative

Seismic Mitigation Task Force

Overarching Framework – *setting goals*

- Chris Poland - lead author

New Buildings – *building right*

- Joe Maffei - lead author

Existing Buildings – *retrofit only as needed*

- David Bonowitz - lead author

Lifelines – *to support recovery*

- Chris Barkley – lead author

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PLANNING + URBAN RESEARCH
ASSOCIATION

Seismic Mitigation Task Force

Ross Asselstine
David Bonowitz
Laurie Johnson
Jack Moehle
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Chris Poland
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Debra Walker
Jessica Zenk
Chris Barkley
Sarah Karlinksy
Joe Maffei
John Paxton
Jes Penderson
Laura Dwelley-Samant
Tom Tobin
George Williams

Resources:

Kent Ferre   Laurence Kornfield   Hanson Tom

Approach

Desired resilience

↓

Current situation

↓

Needed actions

↑

Obstacles, constraints, costs, benefits, incentives, interrelationships

Desired seismic performance

Transparent Performance Measures for Buildings

Category A *Safe and operational*

Category B *Safe and usable during repair*

Category C *Safe and usable after repair*

Category D *Safe but not repairable*

Category E *Unsafe – partial or complete collapse*


Objectives

Reduce:

Deaths and injuries

Displacement from homes

Displacement of businesses and companies

Repair costs and time

Personal and emotional costs

Loss of architectural heritage

Loss of community and culture

Risks in San Francisco

Fire following earthquake

Existing buildings — High benefit, high cost

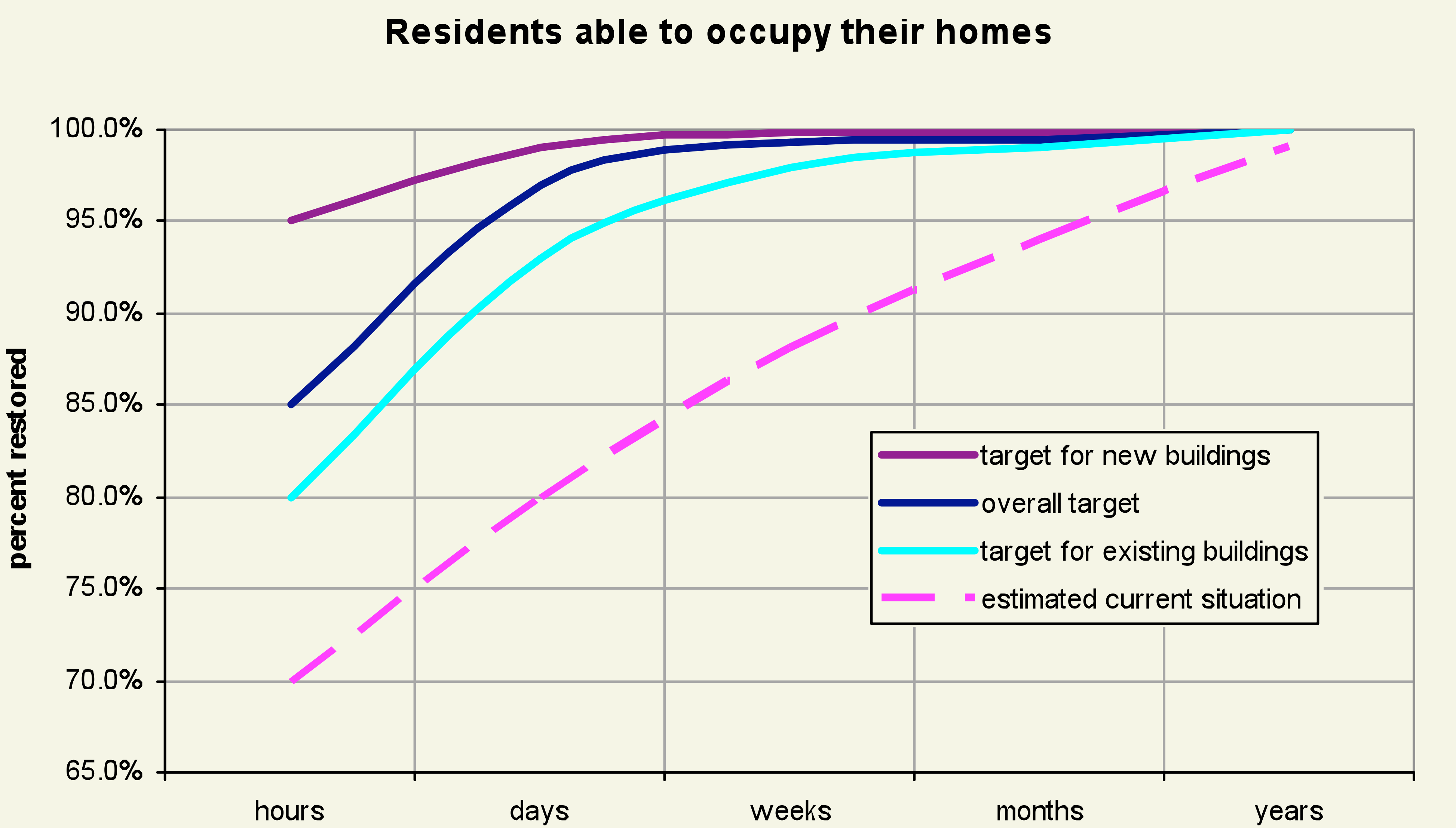
- Non-ductile (pre-1976) concrete buildings
- Soft-story wood-frame buildings (the Marina)
- Unreinforced masonry buildings (Chinatown, SOMA, Montgomery to Battery Sts)
- Older steel frame and brick infill buildings

New Buildings — Moderate benefit, low cost

Nonstructural damage

Objectives for new building construction

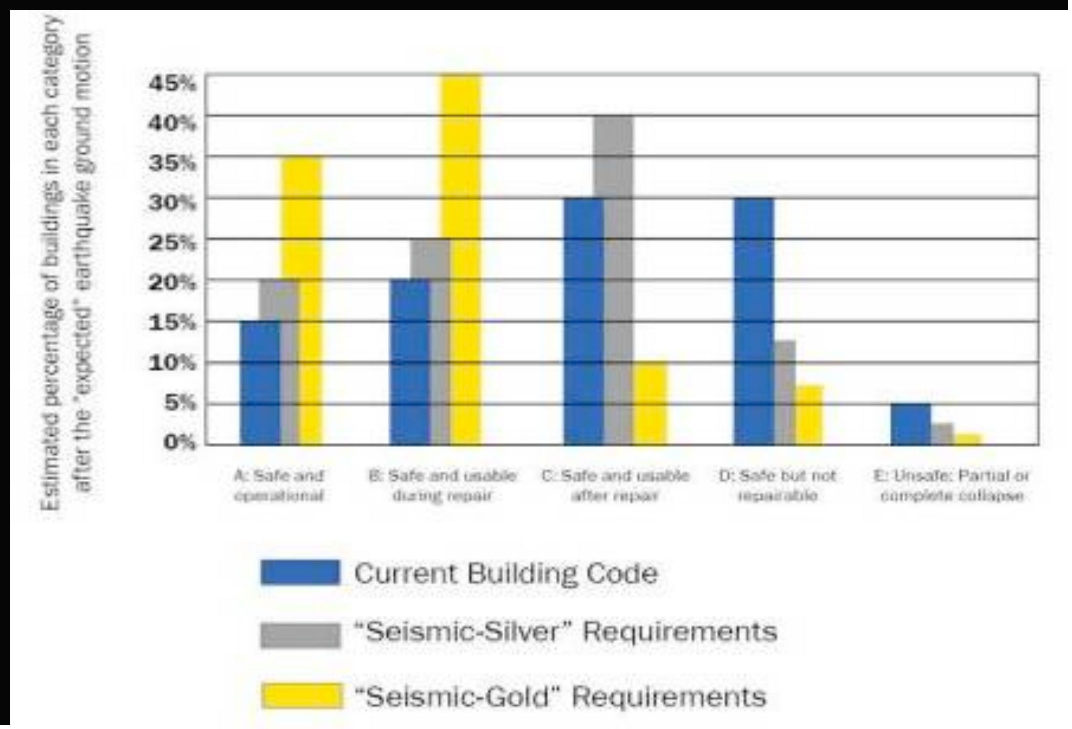
New versus existing buildings



New Buildings

Recommendation (Near Term)

- Declare the expected seismic performance that will be achieved by the current Building Code, and develop code provisions that give options for quantifiably improved seismic performance. Define Seismic Silver and Gold.



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Two options for defining (objective and verifiable) higher standards

1. Develop specific requirements to define *Seismic Silver* and *Seismic Gold* performance.

   + less costly, more appropriate requirements

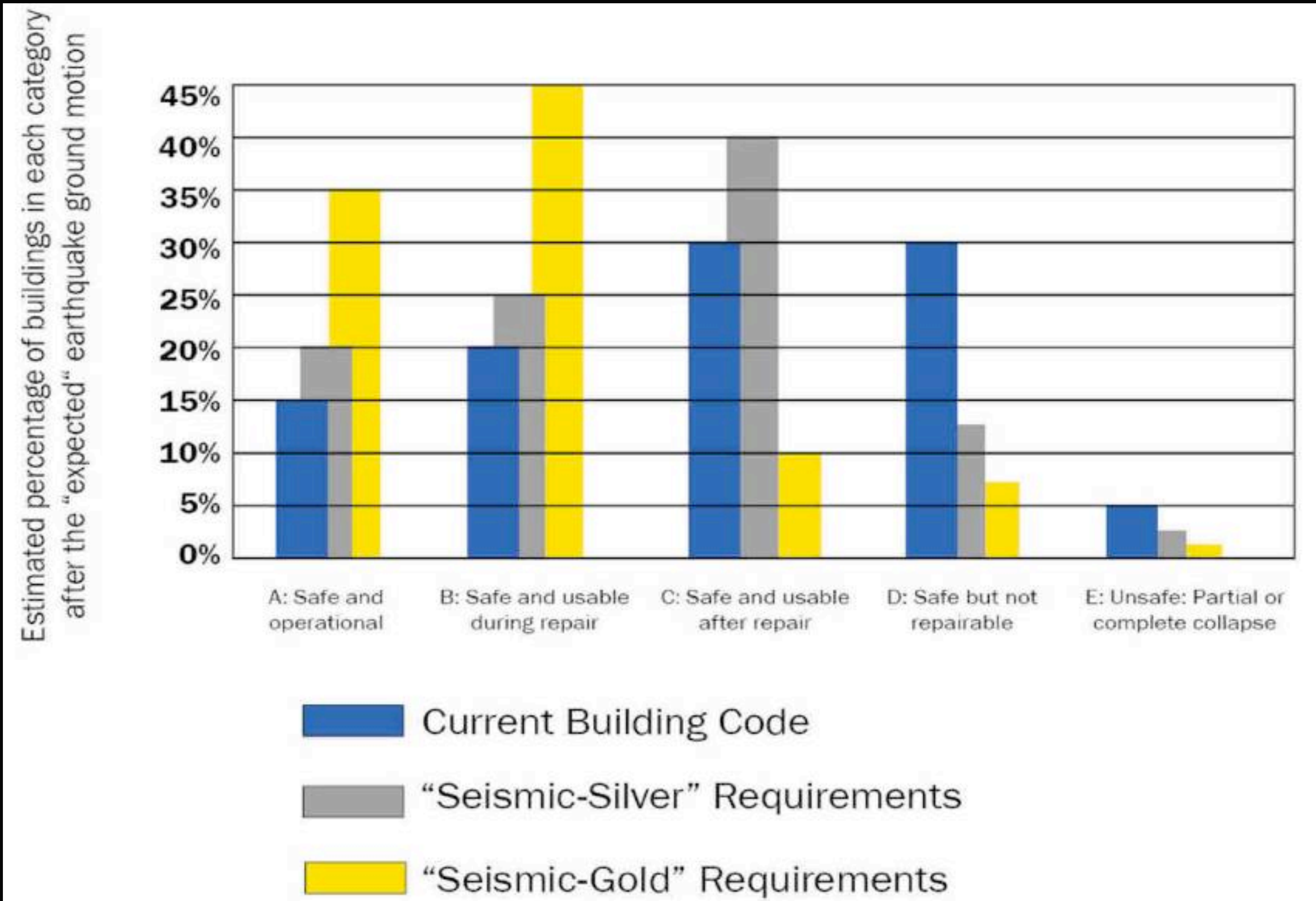
2. Use existing requirements in the code for improved performance.

   + quicker to implement

Occupancy categories in the building code

Cat.	Design factors		
I			Temporary, agricultural, minor storage
II	1.0	1.0	Ordinary buildings
III	1.25	1.5	Assembly, schools, utility buildings, hazardous contents
IV	1.5	2.0	Essential buildings, hospitals, police, fire stations

Policies for Achieving Resilience



Cost of improved performance

We cannot precisely predict seismic performance

Inherent variability of earthquake motions and structural response

Limitations to our knowledge of best methods and assumptions

Construction cost increase

Current code to seismic silver 3%-5%

Current code to seismic gold 7%-11%

Cost feasibility studies

- Five story, 55 ft tall condominium building
- Eight story, 85 ft tall condominium building
- Twenty five story, 240 ft tall office building

Twenty-five-story office building (current code)

Land cost	$78.4M
Hard construction cost	$209.7
Soft costs	$47.4
(Interest, loan fee, lease up, other)	
Government fees	$25.4
(Permit, childcare, jobs-housing linkage, transit impact, school impact)	
10% developer return	$38.8
Total cost	$399.7
Net operating income $38.68/LSF	
Value minus cost	- $11.7

Twenty-five-story office building (3% increase)

3% increase Hard construction cost	$6.3
Increase in total cost	$7.7

3% increase in hard costs ~ 2% increase in overall costs

<u>Value minus cost (if no increase in income)</u>

Current code	- $11.7
3% hard cost increase	- $19.1
7% hard cost increase	- $29.4

New Buildings

Recommendation

- Develop strong incentives that encourage building to higher seismic standards.

Sydney, Australia
"Living City" Initiative

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Seismic assessment considering post-earthquake occupancy

Advanced Seismic Assessment Method

Developed at Stanford

- Bazzurro, Cornell, Menun, Luco, Motahari
- PEER Lifelines Project

Tested and refined by R&C

- Report for PEER/PG&E
- Building Assessments for PG&E

PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

Advanced Seismic Assessment Guidelines

Paolo Bazzurro
Stanford University
(currently at Air Worldwide Corporation)

and

C. Allin Cornell

Charles Menun

Maziar Motahari

Stanford University

and

Nicolas Luco
Air Worldwide Corporation

Pacific Gas & Electric (PG&E)/PEER Lifelines Program Task 507

PEER 2006/05
SEPT. 2006

PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

Test Applications of Advanced Seismic Assessment Guidelines

Joe Maffei
Karl Telleen
Danya Mohr
William Holmes
Rutherford & Chekene, San Francisco

Yuki Nakayama
Kajima Corporation, Tokyo

PEER Lifelines Program Task 508

PEER 2005/09
AUGUST 2006

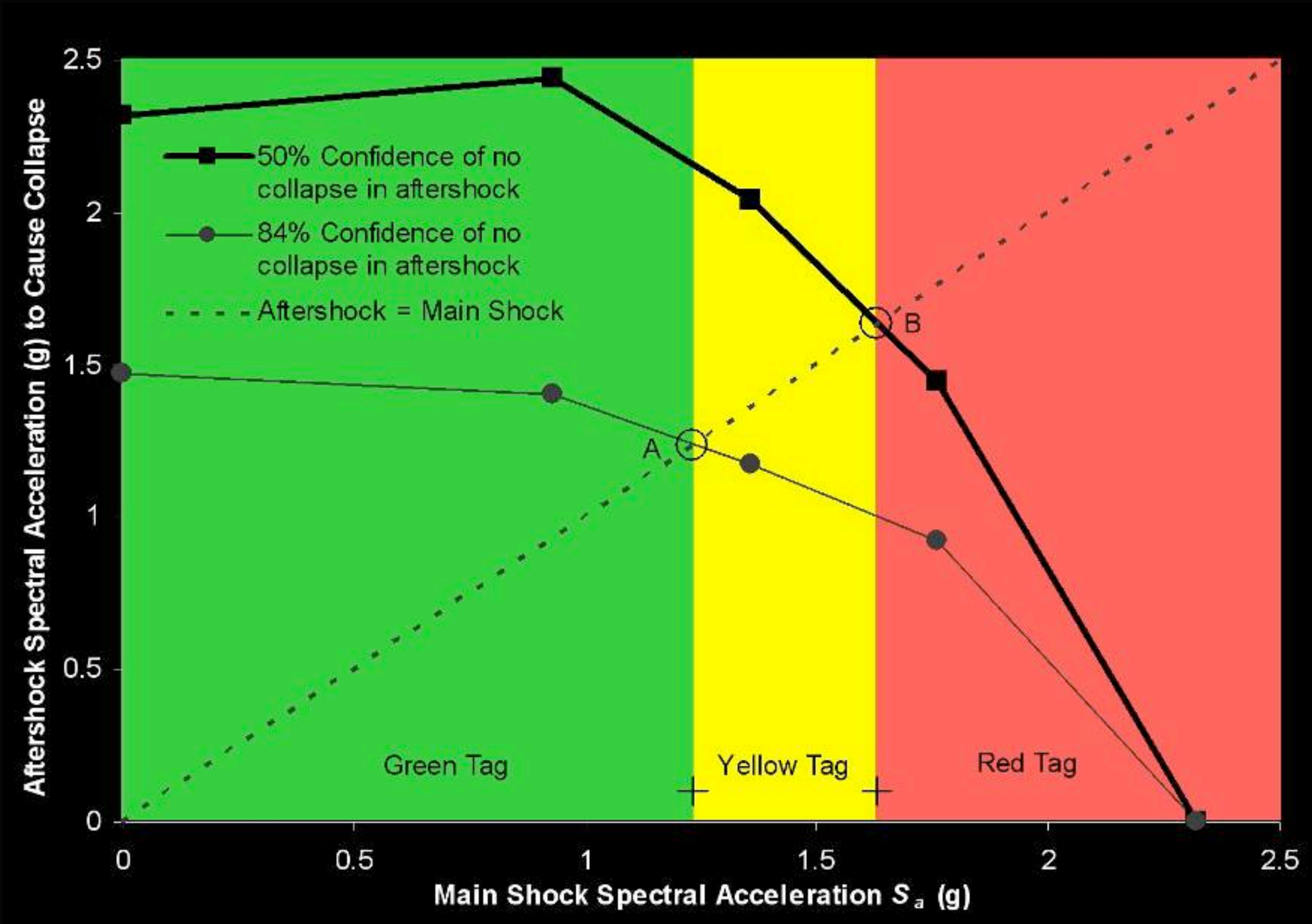
Specific performance goals:

- Will trucks be able to safely exit the garage?
- Will crews be able to safely access switching equipment?

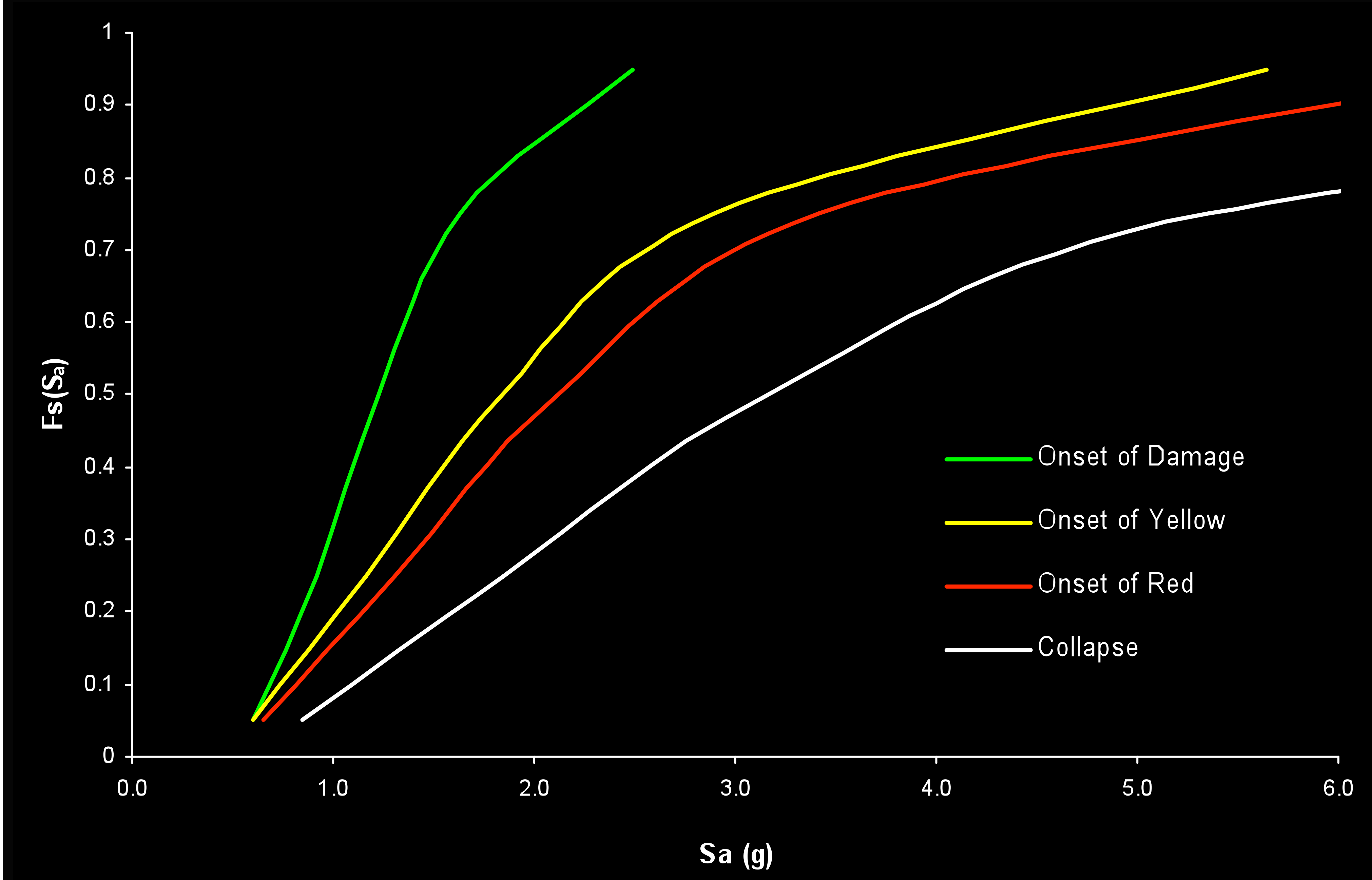
Features of the Method

- Nonlinear analysis of "Intact" and "Damaged" structures
- Emphasis on identifying the governing mechanism of nonlinear response
- Includes the effect of residual drift
- Uses Green, Yellow, and Red Tag performance levels
- Probability-based approach allows inclusion of all levels of seismic hazard

Explicitly considers safety in aftershocks



Gives probabilities of achieving desired performance



Applications

R&C applied the method to a range of building types in PG&E's network:

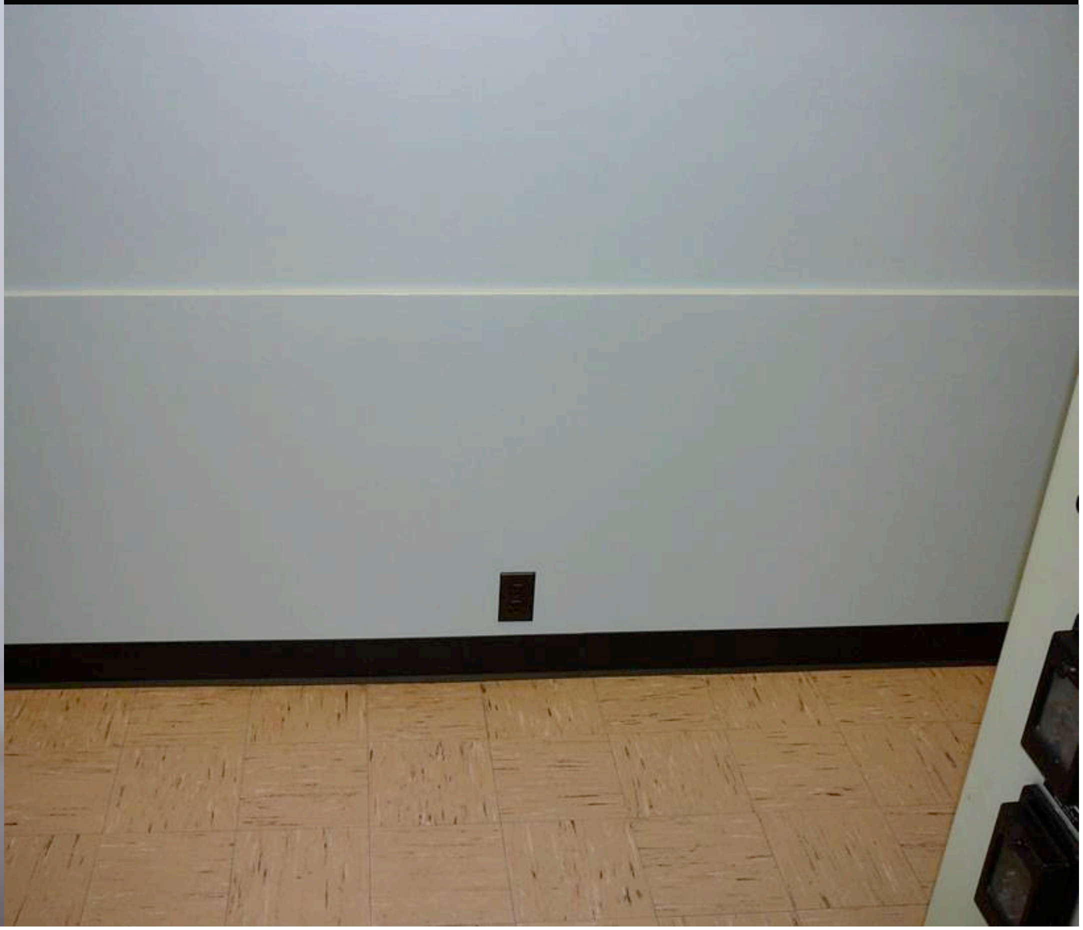
- Electrical substations, office buildings, parking and maintenance facilities
- One to eight stories
- Original construction dates from 1908 – 1990s
- Steel moment frame, concrete wall, concrete wall with steel frame

PG&E Larkin Substation

Supplemental connectors for precast panels

PG&E Larkin Substation

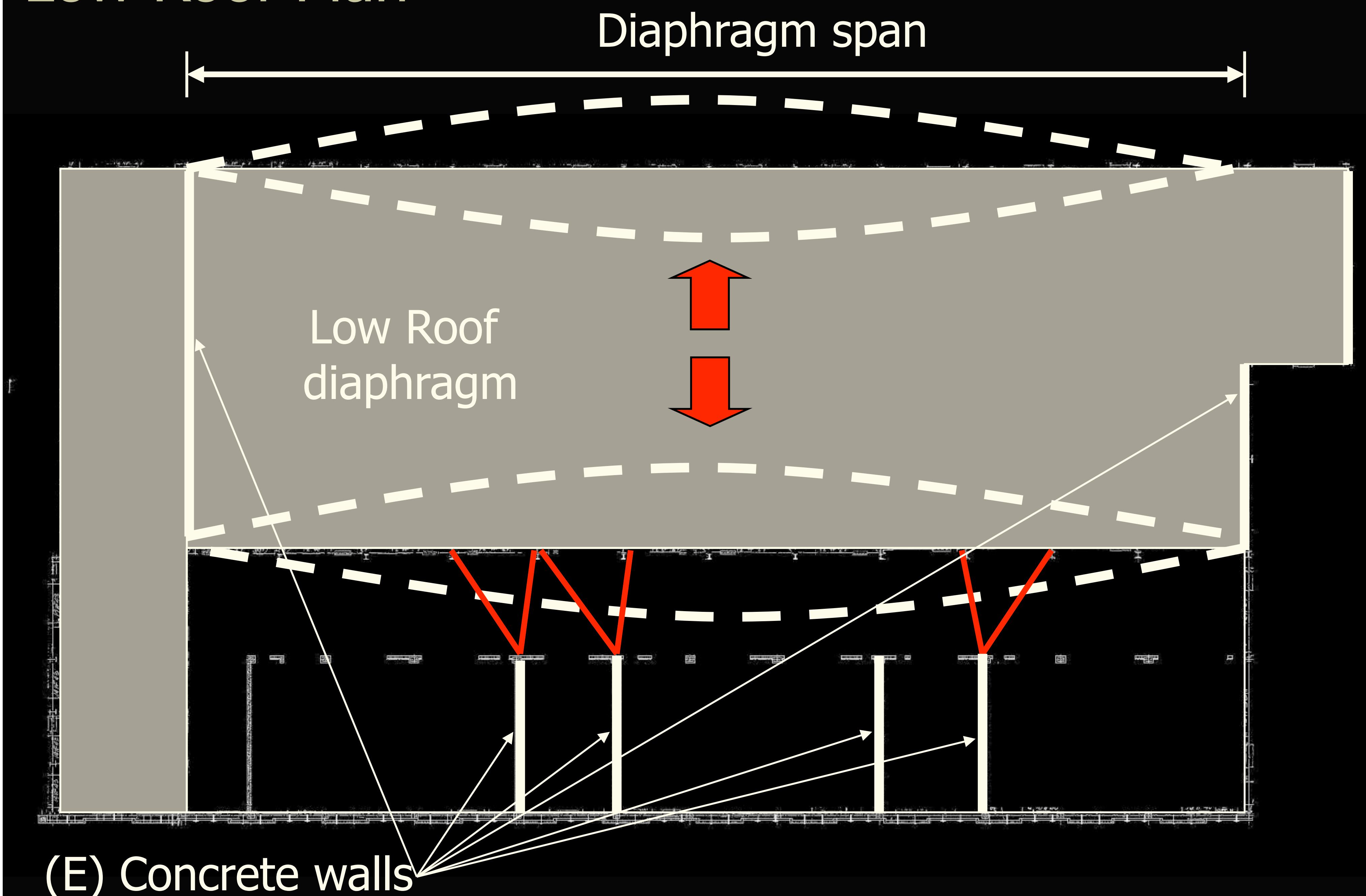
PG&E Larkin Substation



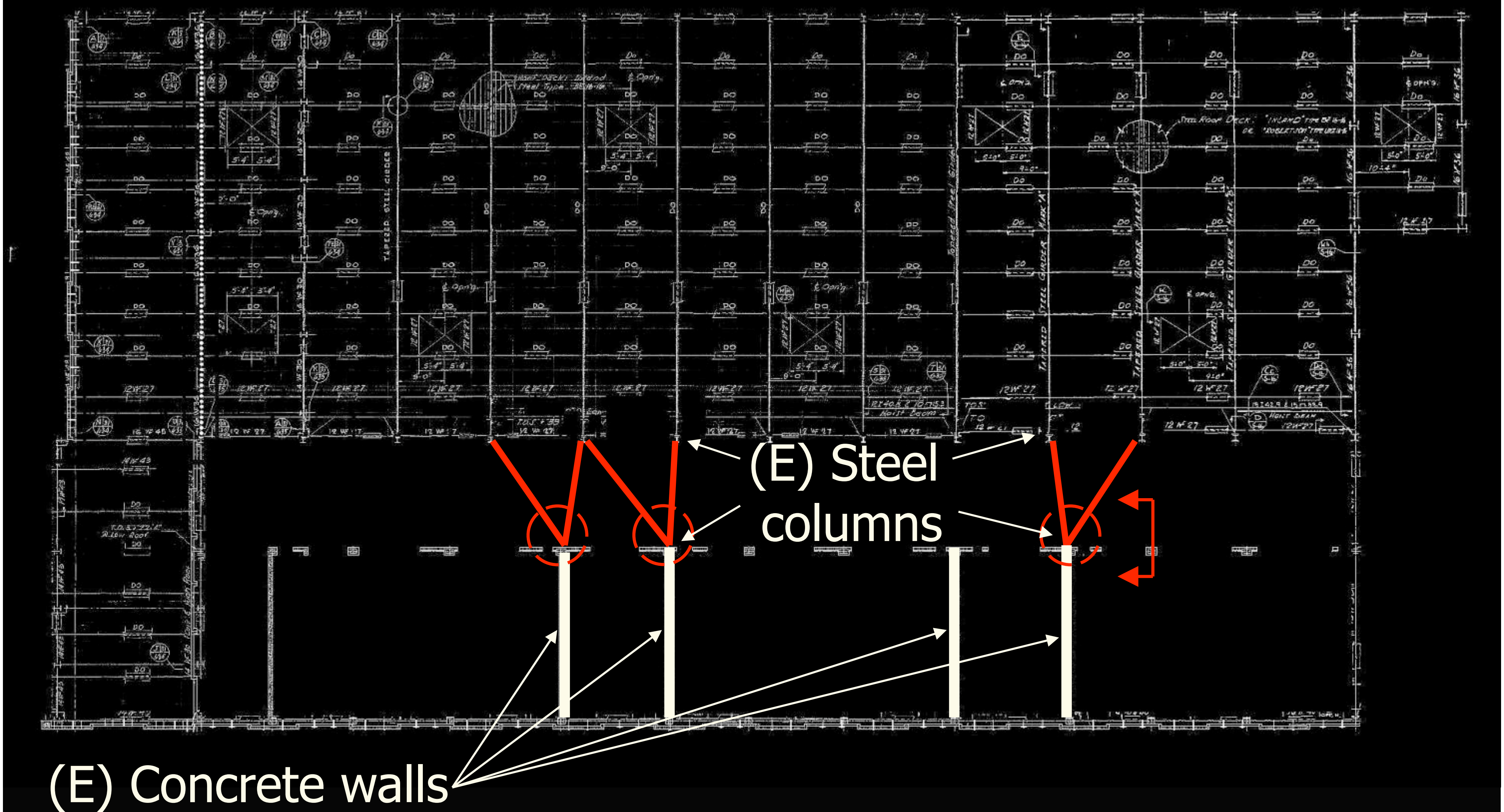
PG&E Larkin Substation

PG&E Larkin Substation

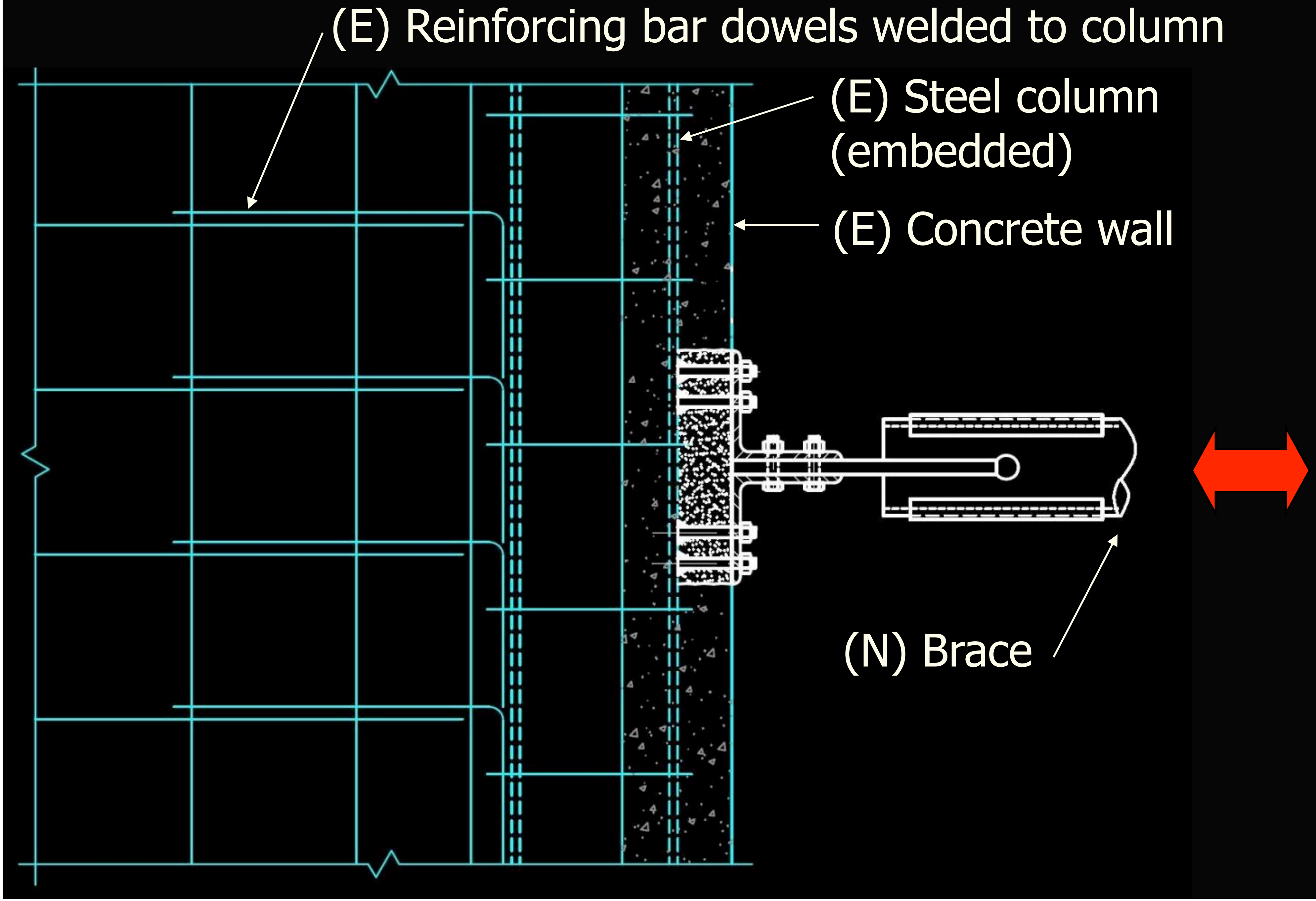
Low Roof Plan



Connections to concrete walls



Tension-fusing brace



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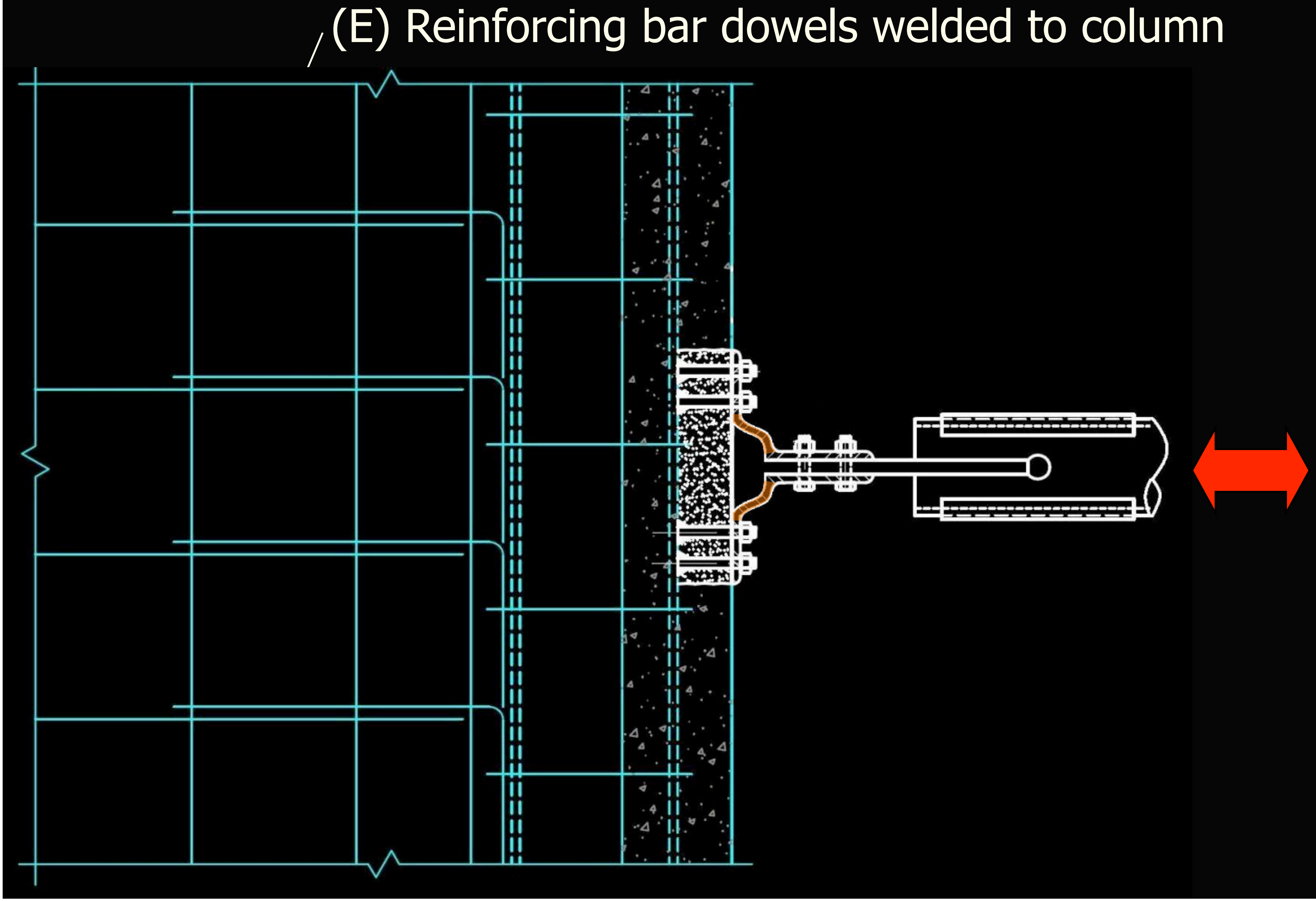
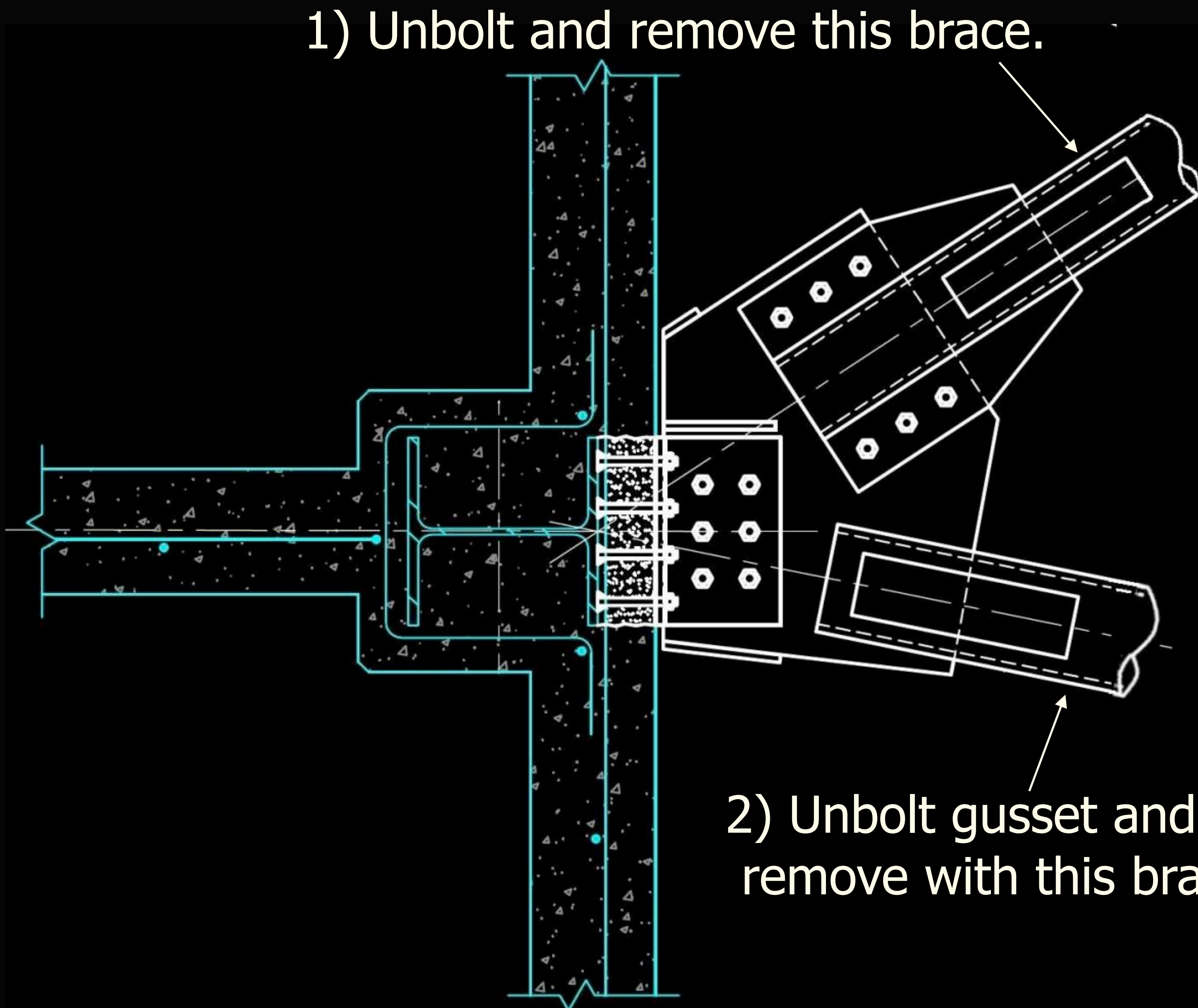
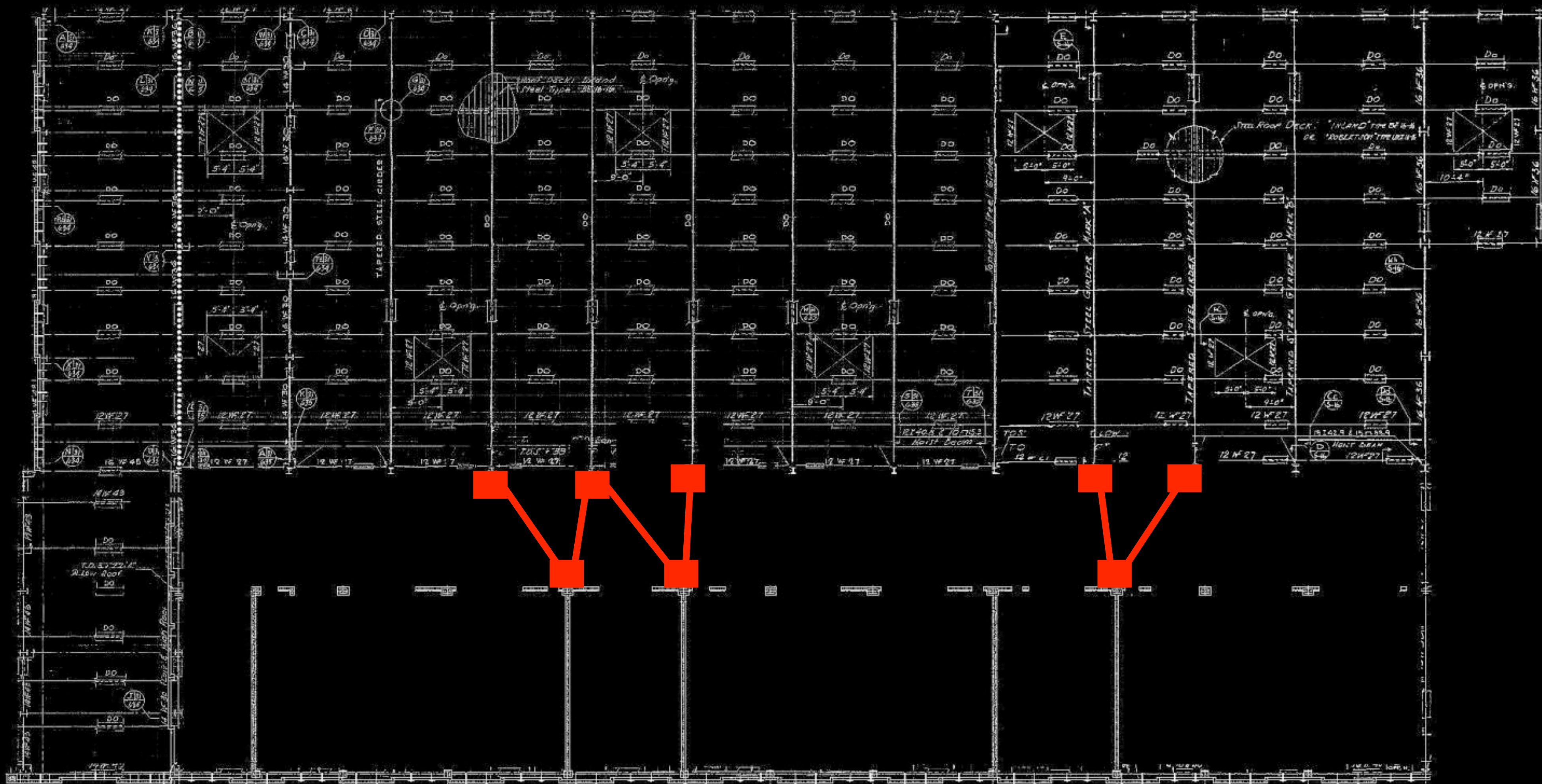



EXIT

Removable (bolted) connections



Removable (bolted) connections



Conclusions

Conclusions

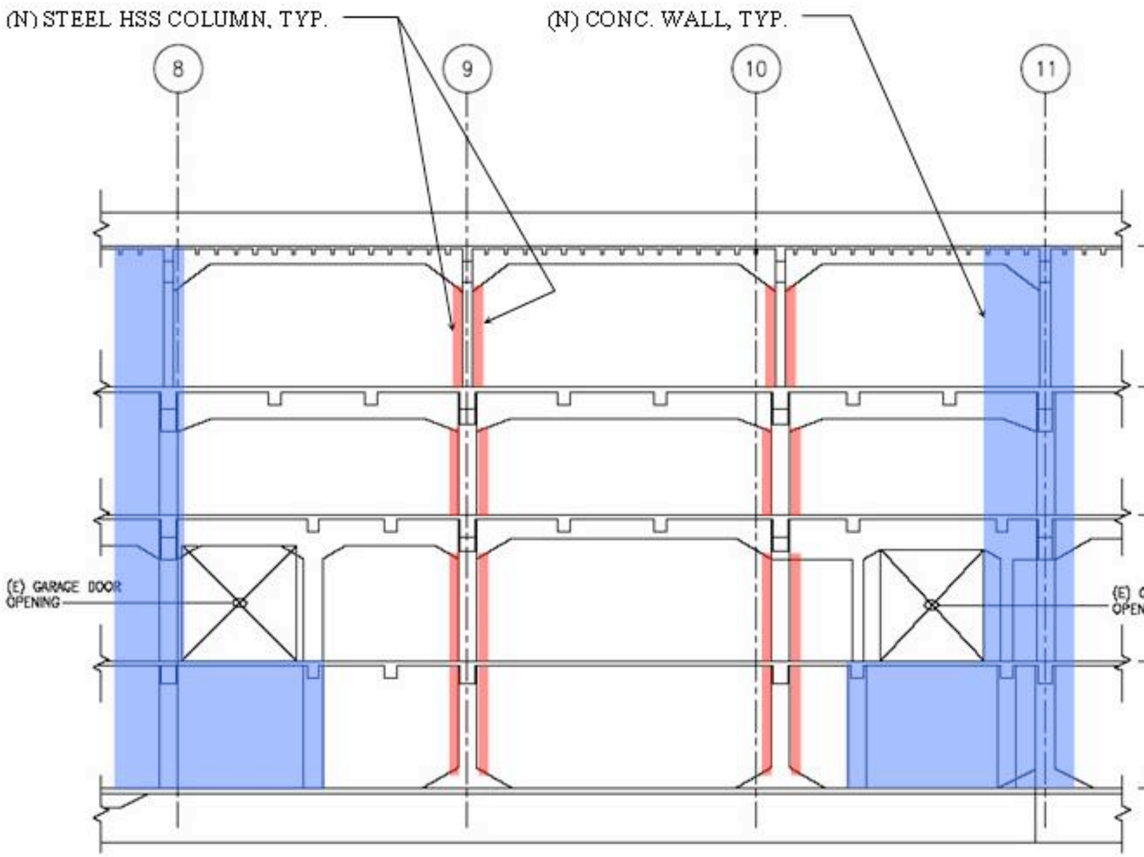
The default level of seismic performance provided by the building code may not be sufficient to make our cities resilient in the face of earthquakes.

Advanced methods related to post-earthquake resilience are available.

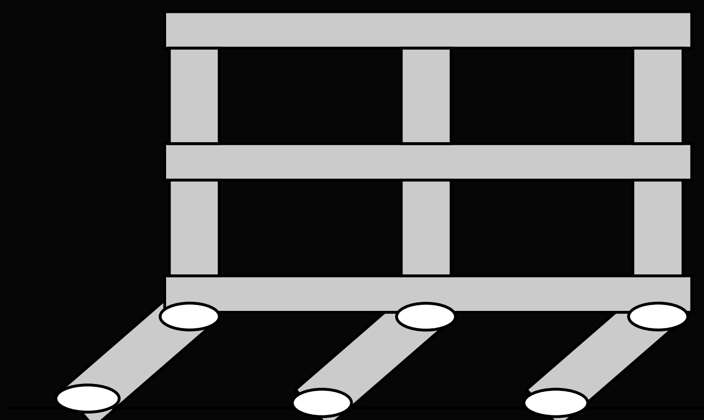
To market or mandate improved performance, criteria (e.g., “seismic silver”) must be objective and verifiable.

[redacted]

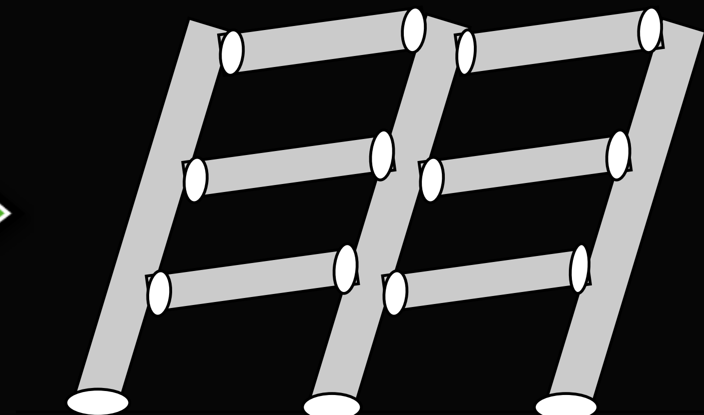
PG&E San Francisco Central Services Garage



PG&E San Francisco Central Services Garage

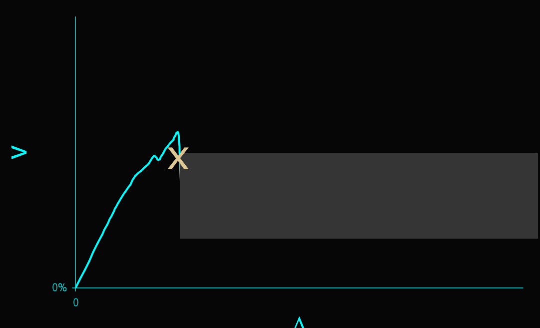


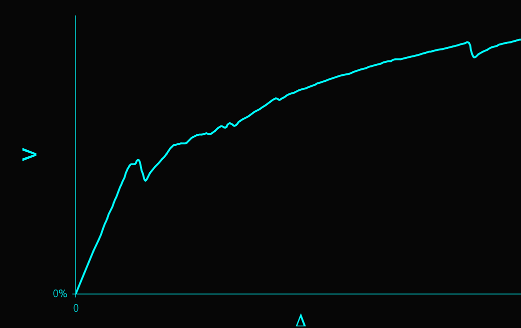
Retrofit



Concentrated Displacement
(Story Mechanism)

Distributed Displacement





Column wrapping with fiber reinforced polymer

PG&E Vaca-Dixon substation

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Buckling-restrained braced frame *to* horizontal plate *to* vertical plate with studs *to* rebar cage *to* dowels to wall and second floor

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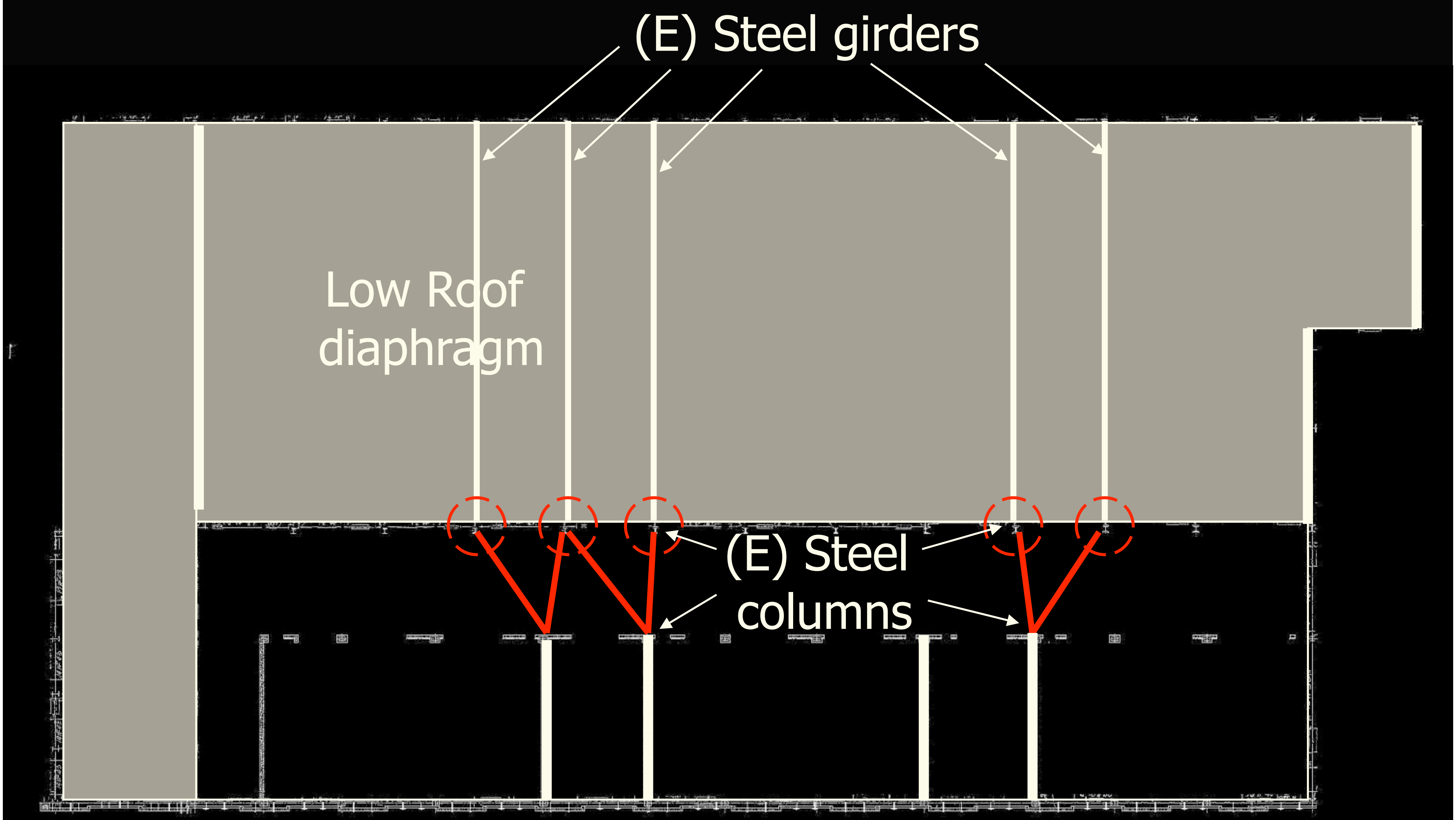
Connections to diaphragm



Connection to (E) steel girder