Viscous Dampers and Replaceable Structural Fuses

Improving Building Performance and Functional Recovery

Justin Marshall, DuraFuse Frames
Nathan Canney, Taylor Devices

Presentation Outline

- How are buildings expected to perform in Earthquakes?
- Replaceable Structural Fuses
- Fluid Viscous Dampers

How are buildings expected to perform in Earthquakes?

BUILDING INNOVATION
Conference

What are the responsibilities of Structural Engineers to society?

Design structures that:

- Meet Life-Safety Provisions
- Meet Occupancy Requirements
- Are Economical
- Sustainably Utilize Resources
- Contribute to a Resilient Community

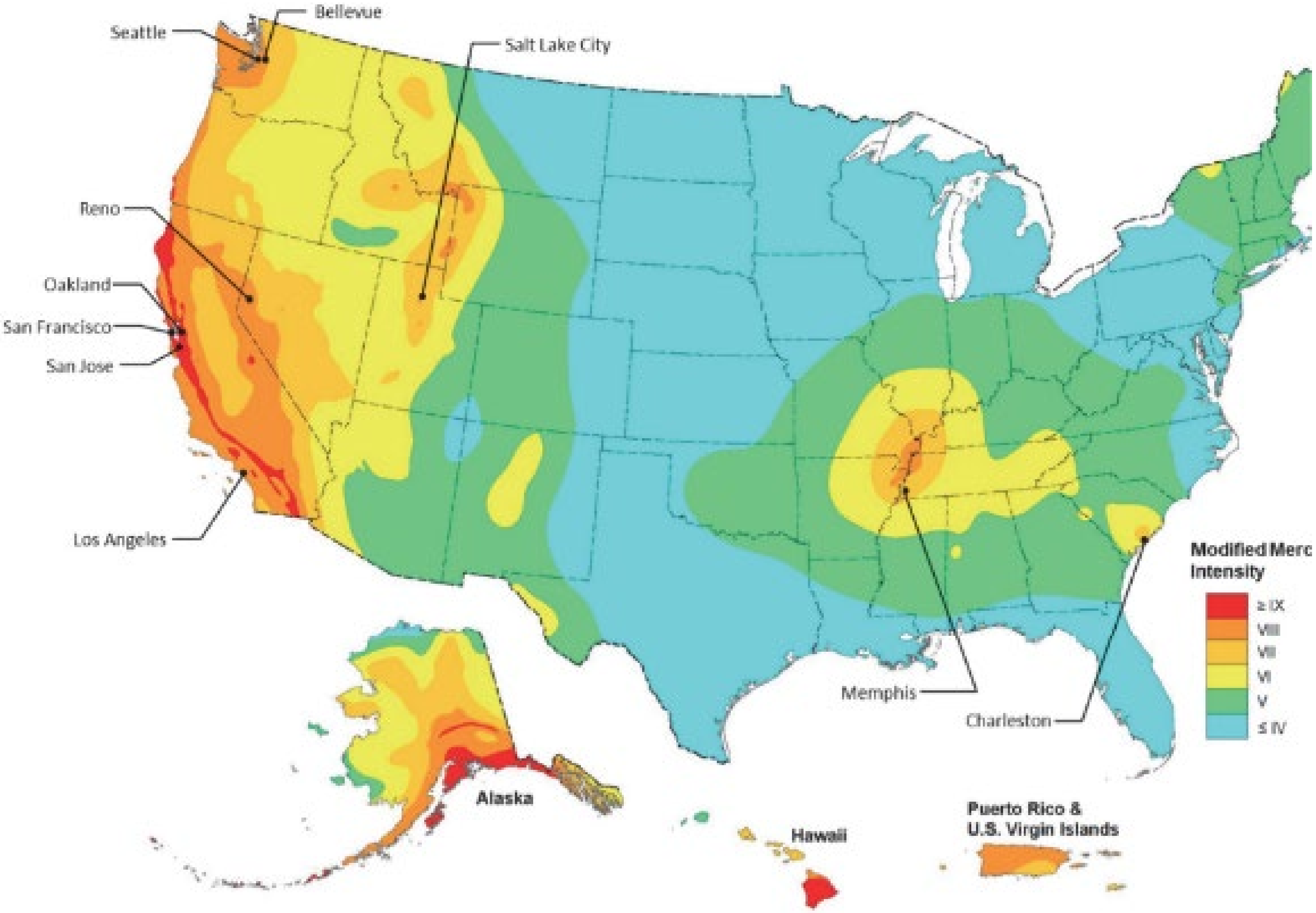
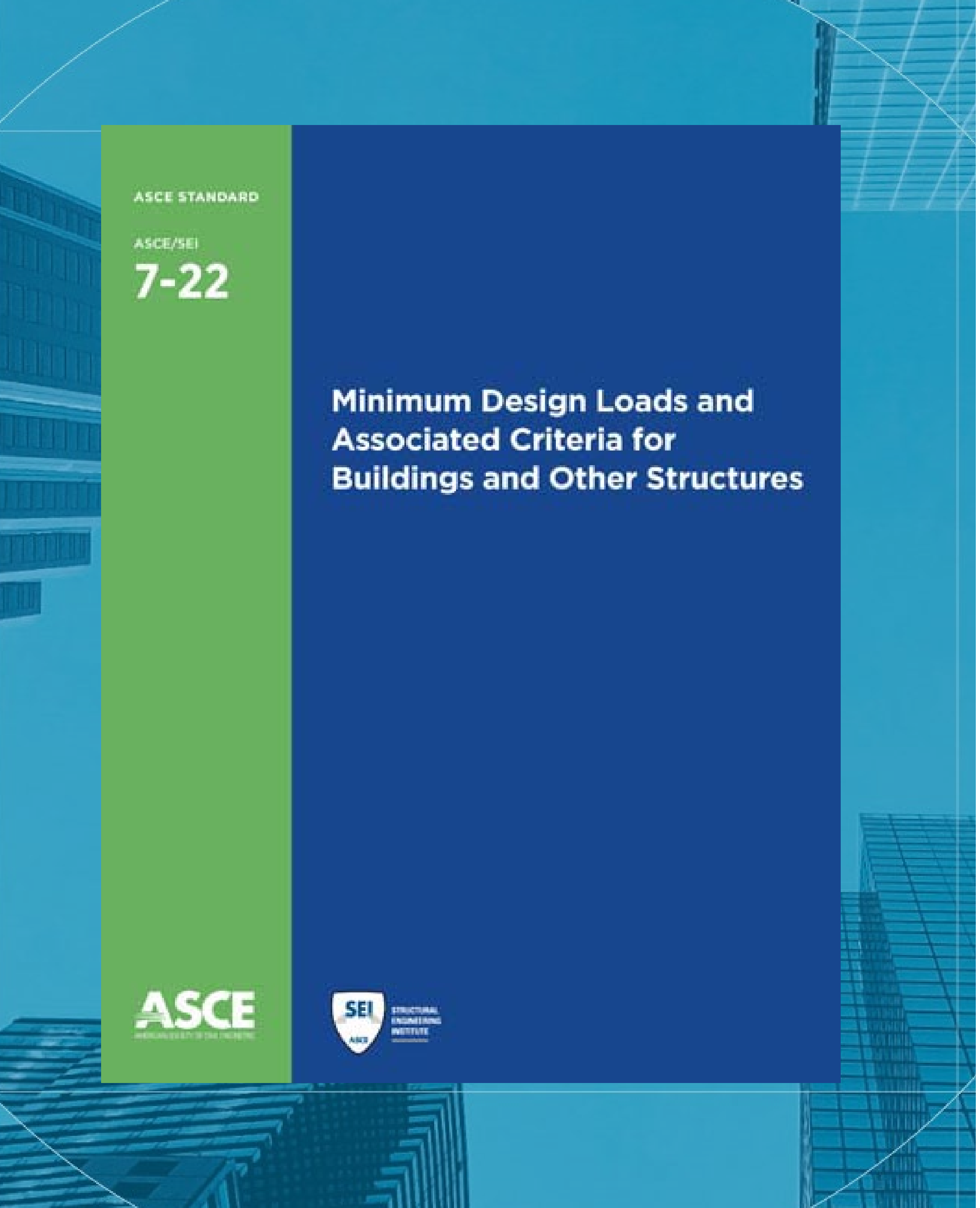


Figure 1-1 **Regions of the United States at risk of significant earthquake shaking (courtesy of N. Luco, USGS).**



C12.1 STRUCTURAL DESIGN BASIS

The performance expectations for structures designed in accordance with this standard are described in Sections C11.1 and C11.5. Structures designed in accordance with the standard are likely to have a low probability of collapse but may suffer serious structural damage if subjected to the risk-targeted maximum considered earthquake (MCE_R) or stronger ground motion.

ASCE 7 seismic design targets

Ductility-Based Life-Safety Design Provisions

DUCTILITY = DAMAGE

Do you know what will happen to your building in the next major earthquake?

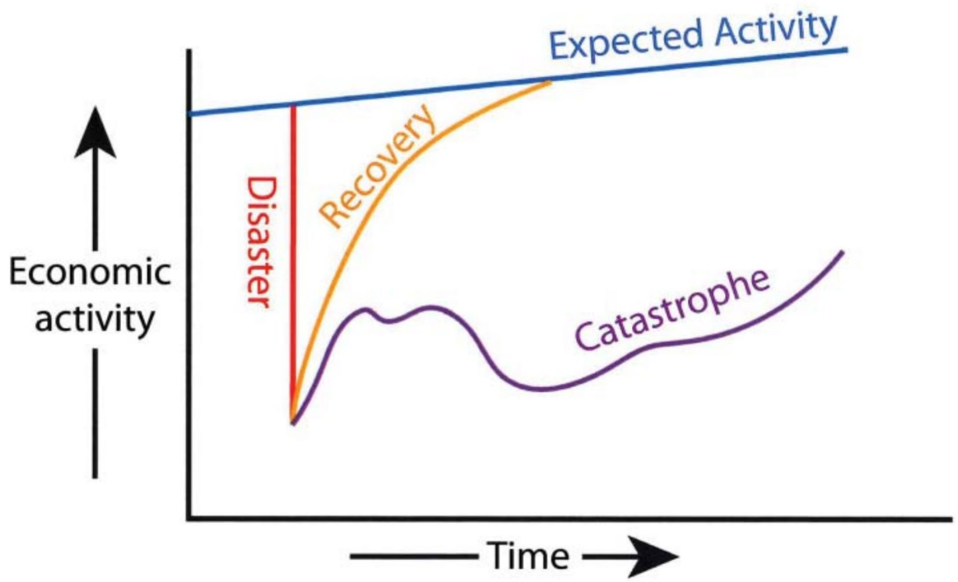
Do you know what will happen to your building in the next major earthquake?

Non-structural Damage – Cladding and Fenestration

Non-structural Damage – Furnishings & Equipment

Non-structural Damage – Ceilings

Resilience Curve



The minimum building code requirements ensure a building has a small chance of collapsing in a design-level earthquake but there will be damage to the structure.

Ref: "Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancy and Functional Recovery Time." FEMA P-2090/NIST SP-1254, January 2021.

- 20% to 40% of modern code conforming buildings would be unfit to occupy
- 15% to 20% of modern code conforming buildings would not be economically repairable
- Older buildings and lifeline infrastructure (bridges, power plants, water, ...) would perform even worse

How do we solve the problem of expected damage to buildings in Earthquakes?

1. Design buildings to be stronger and stiffer
    - Increases construction cost
    - Structural damage may not be repairable
    - Increased damage to certain non-structural components

2. Design buildings to absorb earthquake energy in replaceable structural fuses and viscous dampers
    - Construction cost is similar
    - Reduced damage to structural and non-structural systems
    - Structural damage is repairable

BUILDING INNOVATION
Conference

Replaceable Structural Fuses:

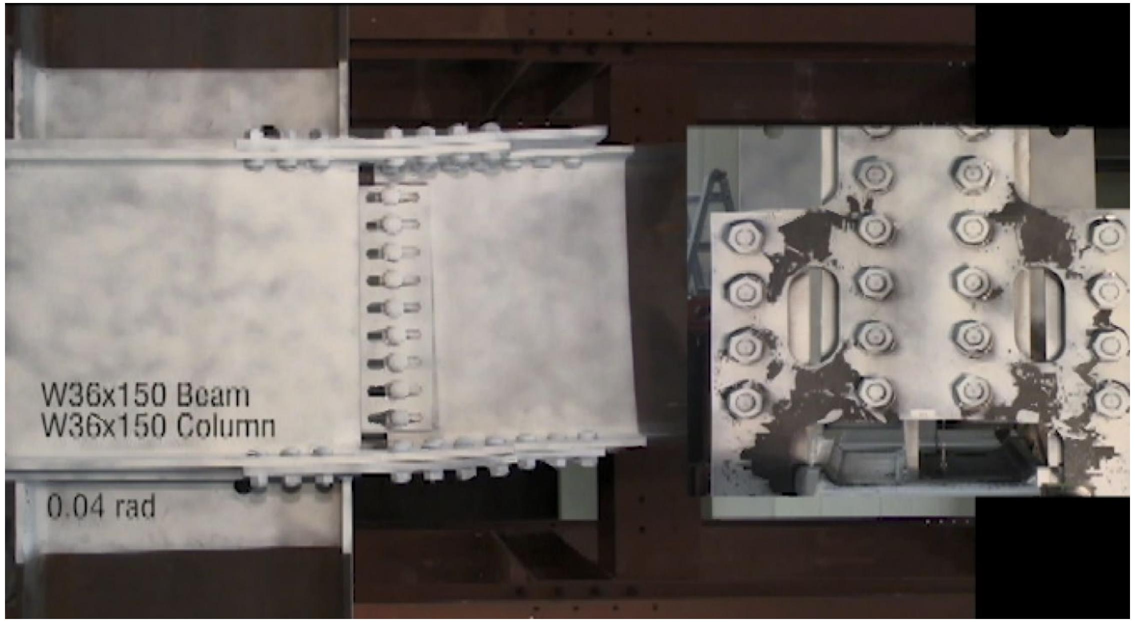
What are they?
How do they improve earthquake response?

What is a replaceable structural fuse?

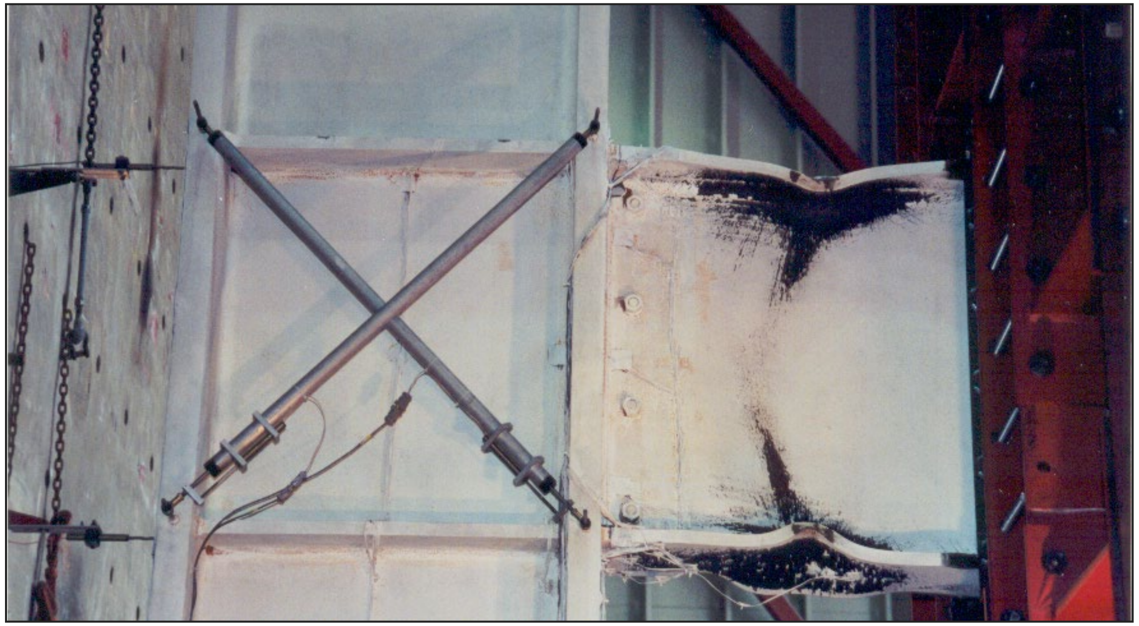
Eccentrically Braced Frame with damage in the Link Beam (Christchurch, NZ 2011)

Steel Moment Connection with Bottom Flange Fuse Plate (2022)

Replacable Fuses in Steel Moment Frames



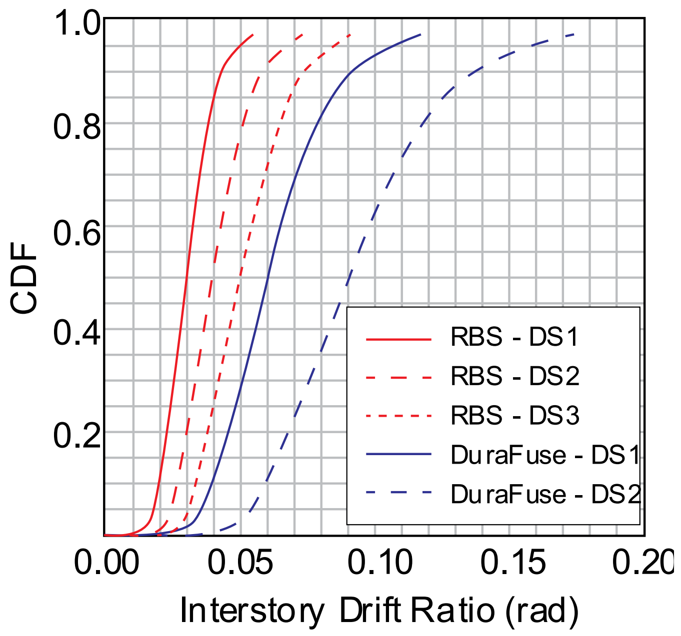
DuraFuse Frames®



Reduced Beam Section (Dogbone)

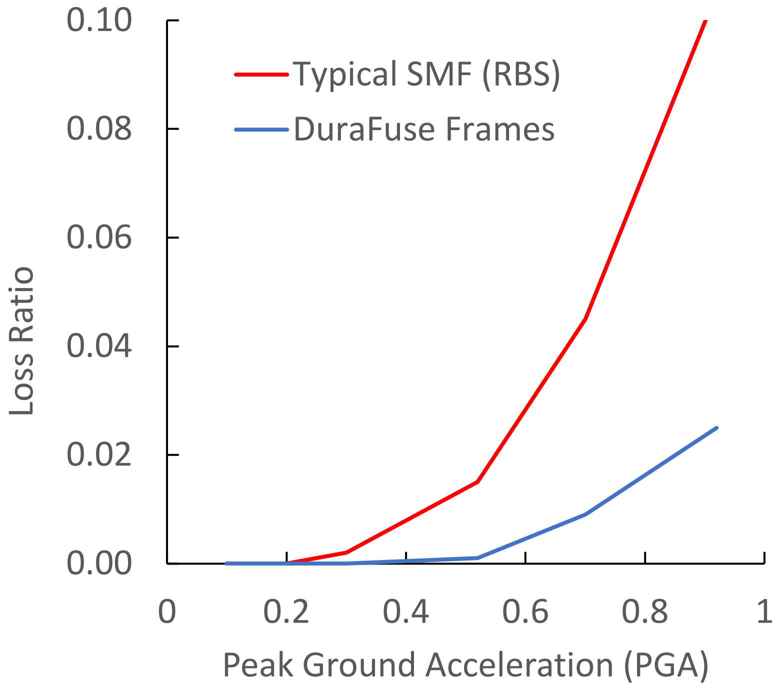
Post-Earthquake Structural Losses

Better Fragility Curves + Lower Connection Repair Cost = Much Lower Structural Losses



RBS= $36,625

DuraFuse= $15,000

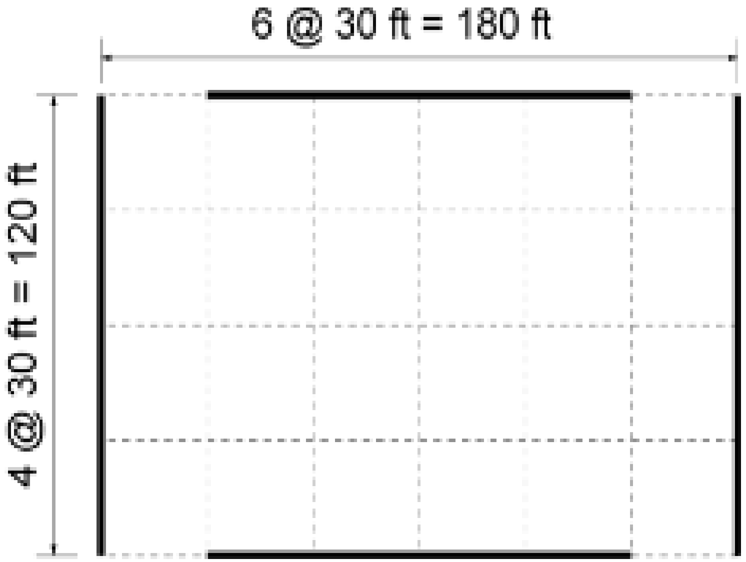


Impact of Repairability on Functional Recovery

Case Study

- Case study of 4-, 6- and 8-story buildings designed as an office building (Risk Category II) and a hospital (Risk Category IV)
- Assess impact of two design strategies:
  - Increase strength and stiffness (current code provisions)
  - Design with replaceable fuse connection
- Each building was analyzed using a suite of earthquake recordings to estimate performance and post-EQ repair costs

Case Study Buildings



Plan View

	Weight (Tons)			
SMF	Col.	Bm.	C.Pl.	Total
4-Story				
RBS II	37.1	48.0	NA	85.0
RBS IV	50.8	70.3	NA	121.1
DFF II	31.8	41.4	8.2	81.3
DFF IV	40.0	57.3	11.0	108.3
6-Story				
RBS II	76.2	87.9	NA	164.1
RBS IV	132.0	169.3	NA	301.3
DFF II	56.0	76.0	14.6	146.5
DFF IV	86.0	153.7	27.4	267.1
8-Story				
RBS II	99.4	112.8	NA	212.1
RBS IV	244.4	216.8	NA	461.2
DFF II	80.8	100.7	17.5	198.9
DFF IV	141.9	220.8	38.5	401.1

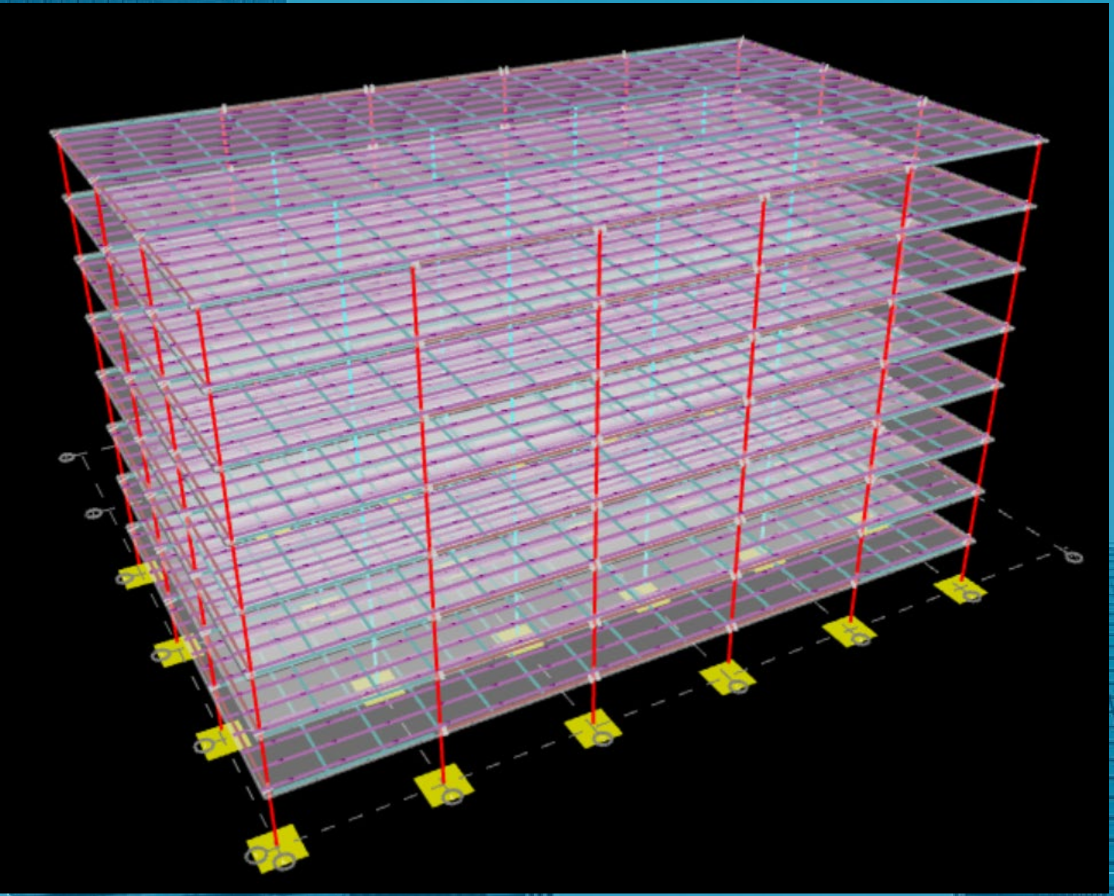
RBS: 1.4
DFF: 1.3

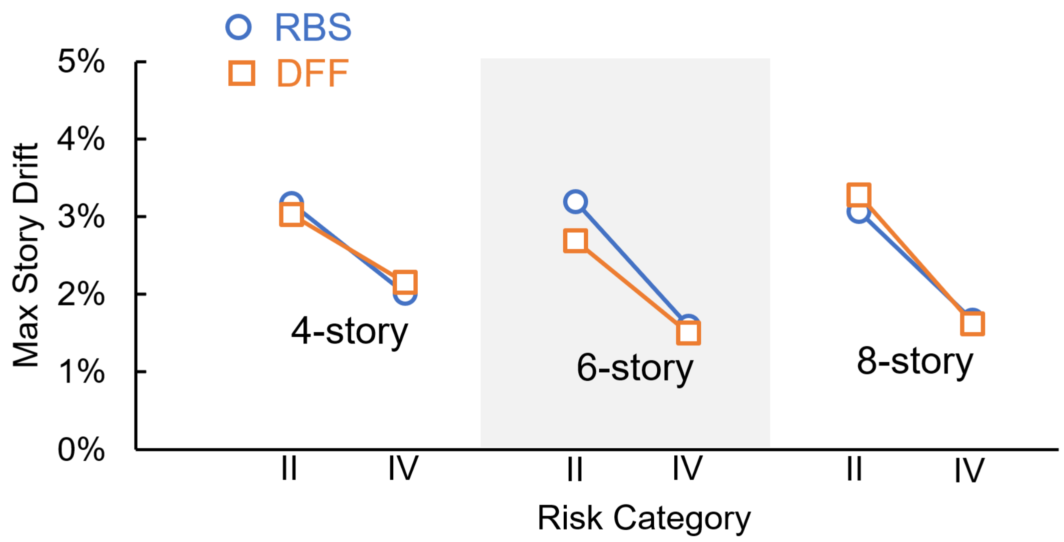
RBS: 1.8
DFF: 1.8

RBS: 2.2
DFF: 2.0

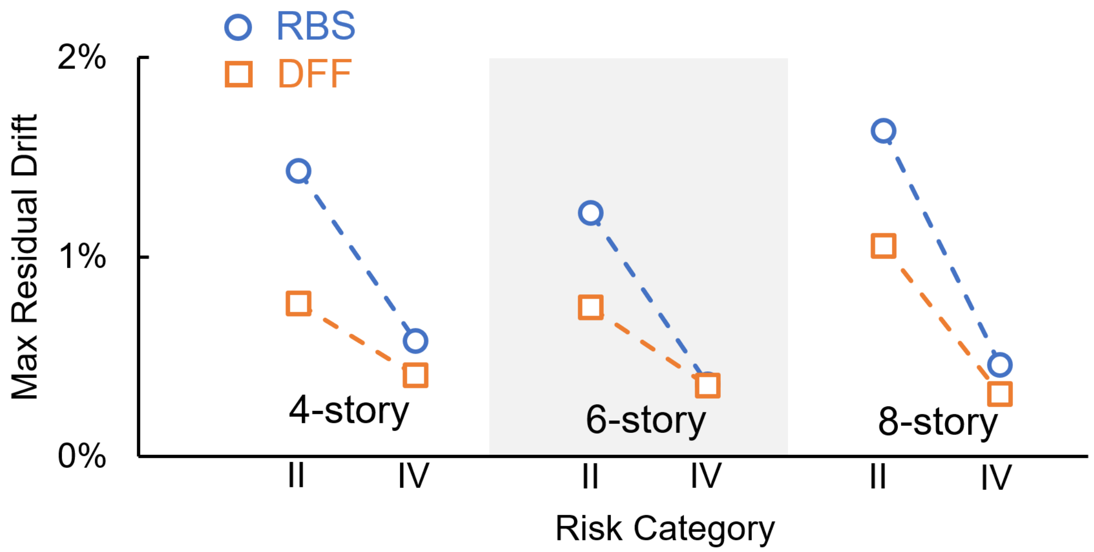
RBS – Reduced Beam Section (Dogbone) Conventional Connection
DFF – DuraFuse Frames Proprietary Replaceable Fuse Connection

Earthquake Performance



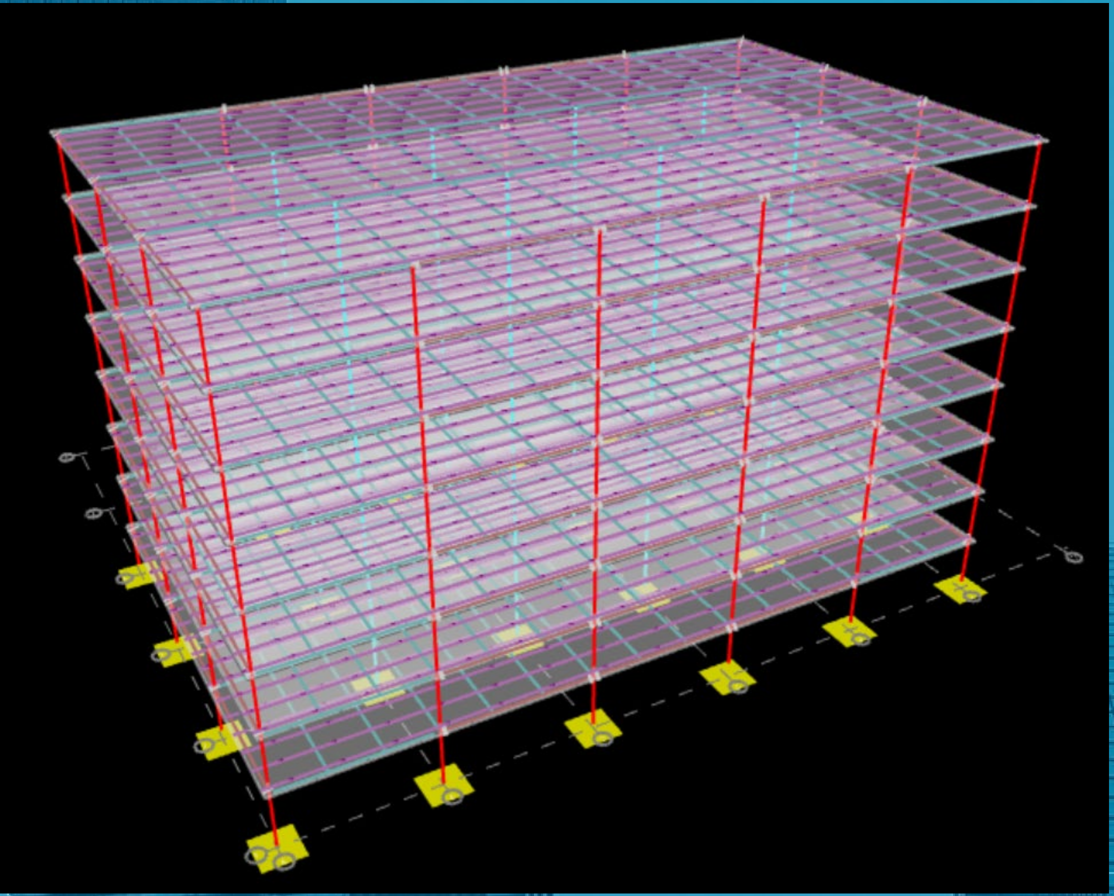


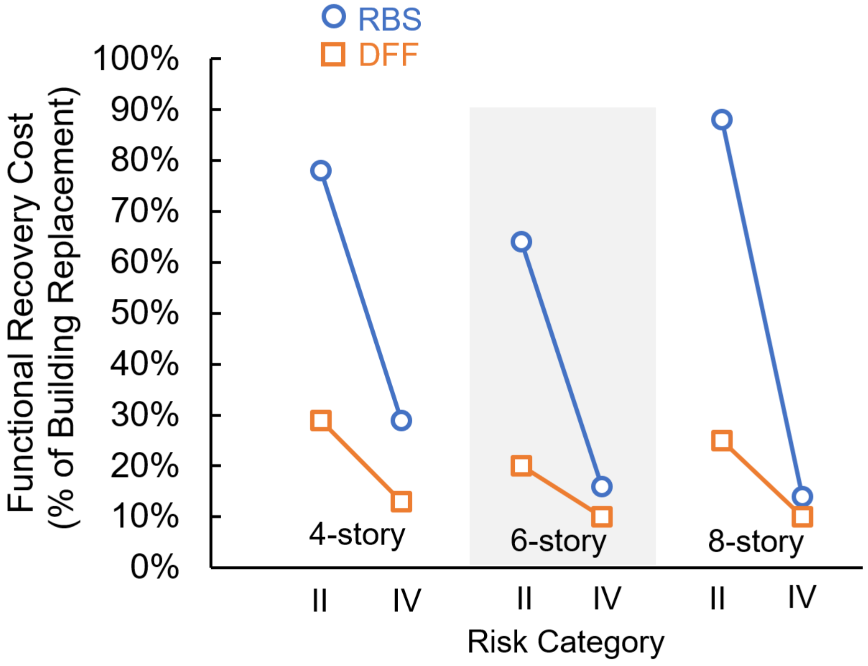
Maximum Story Drift

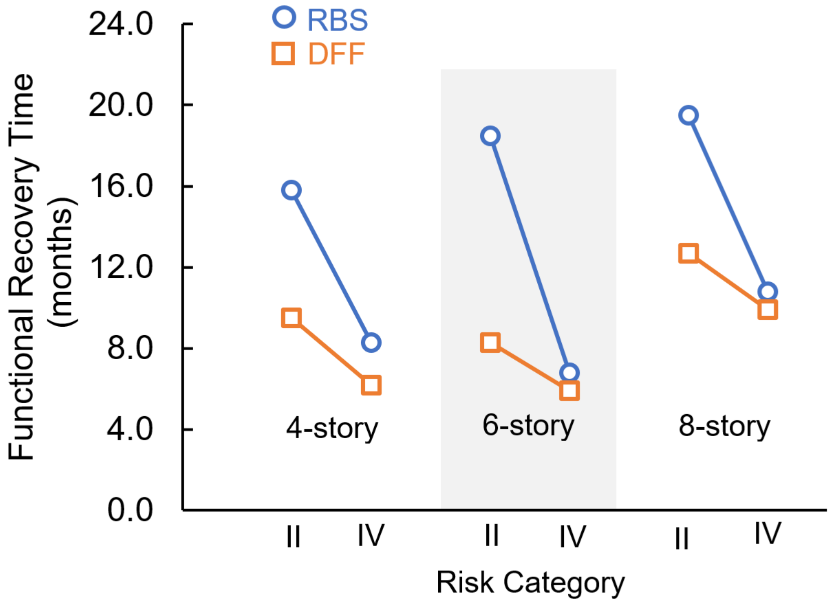


Residual Drift

Post-Earthquake Repair Costs

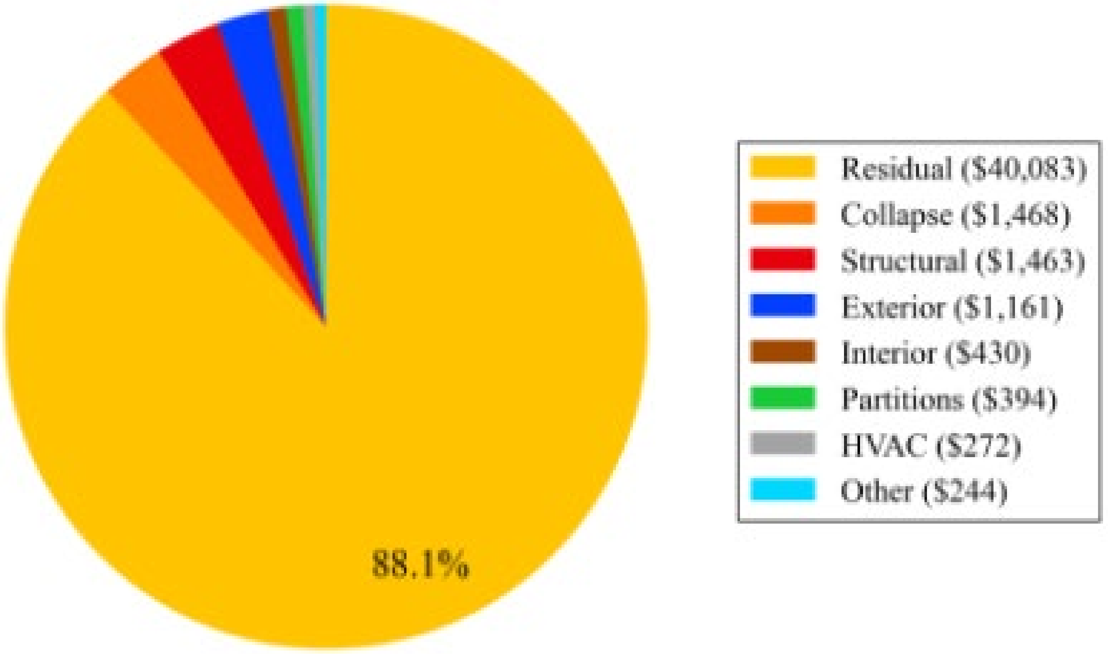




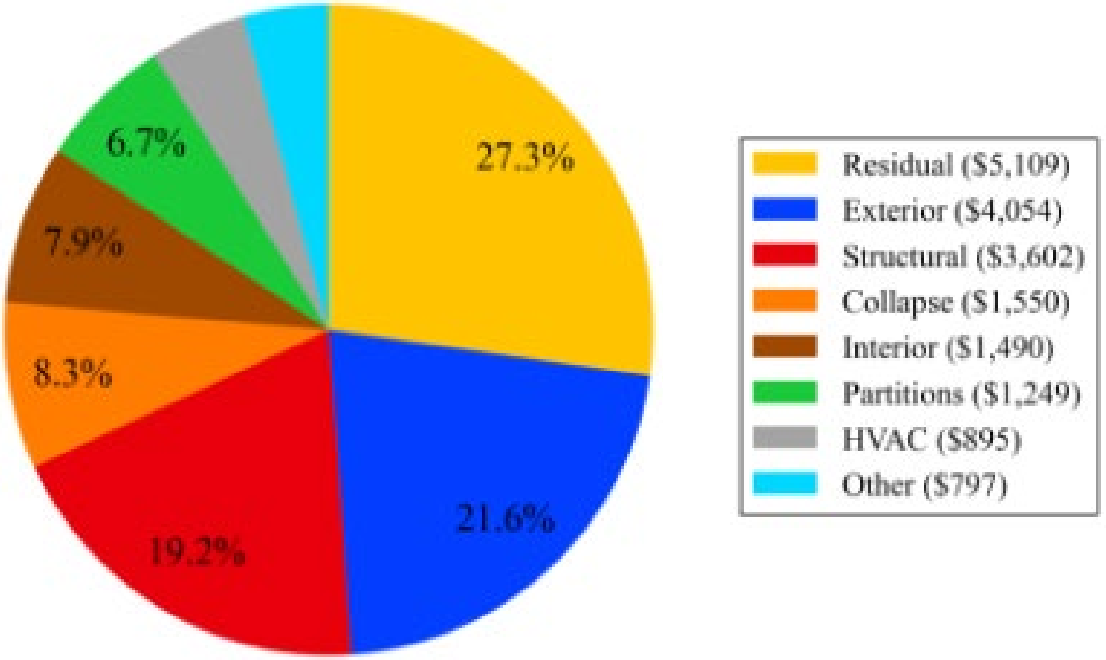


Repair Cost Breakdown (Office Building)

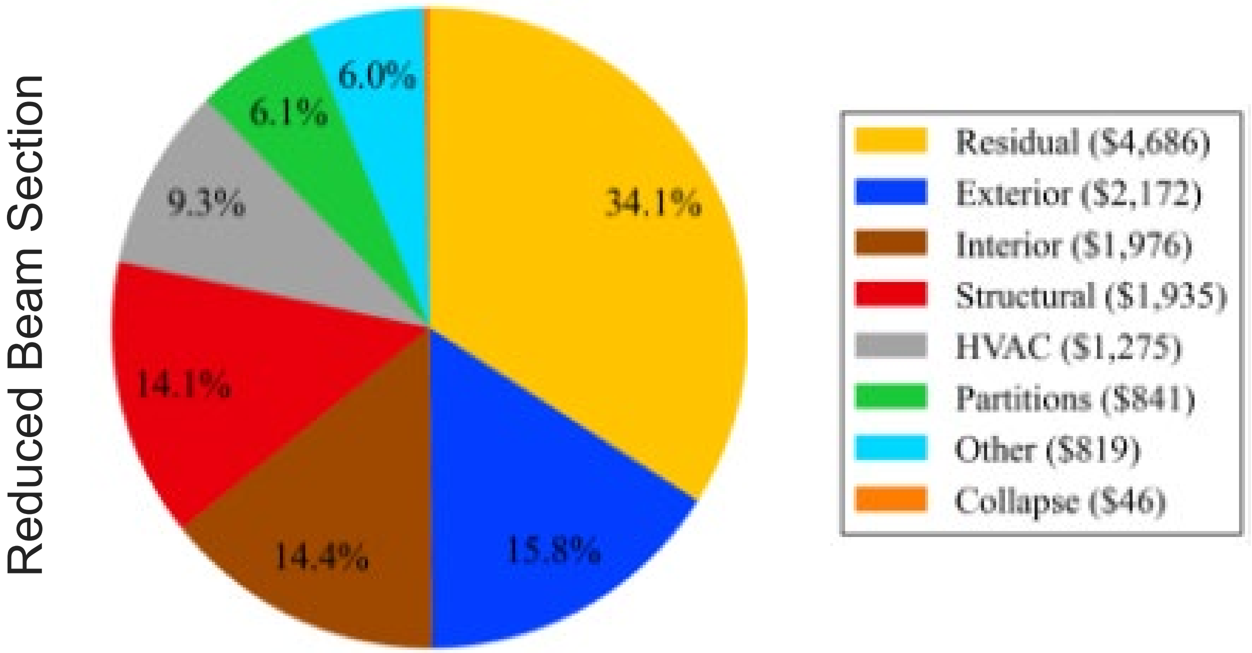
Reduced Beam Section

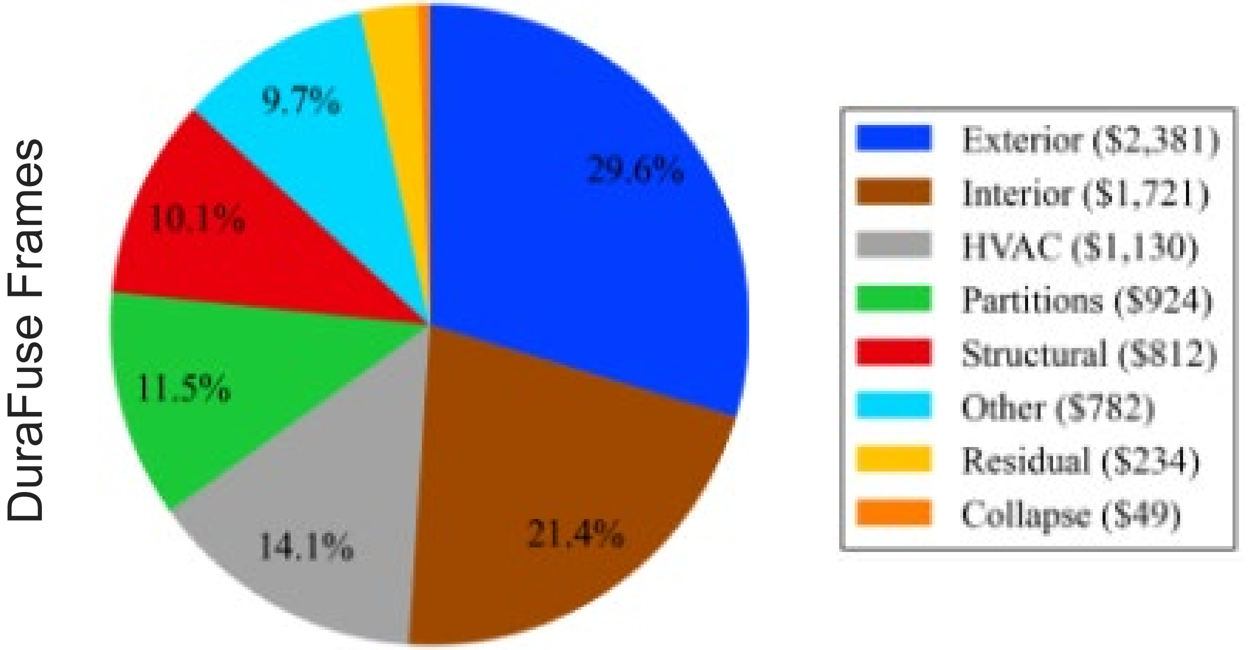


DuraFuse Frames

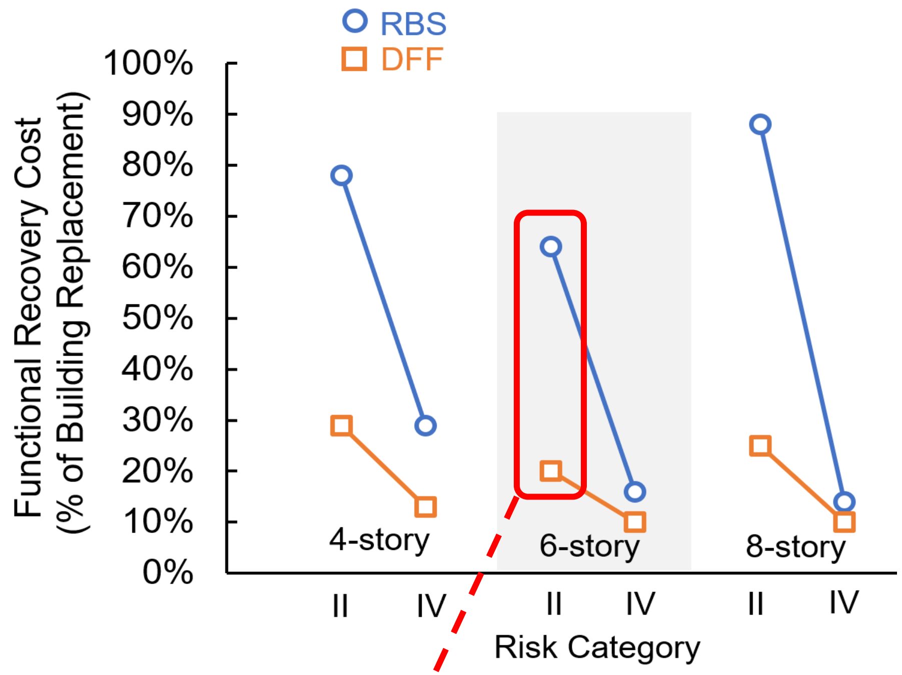


Repair Cost Breakdown (Hospital)



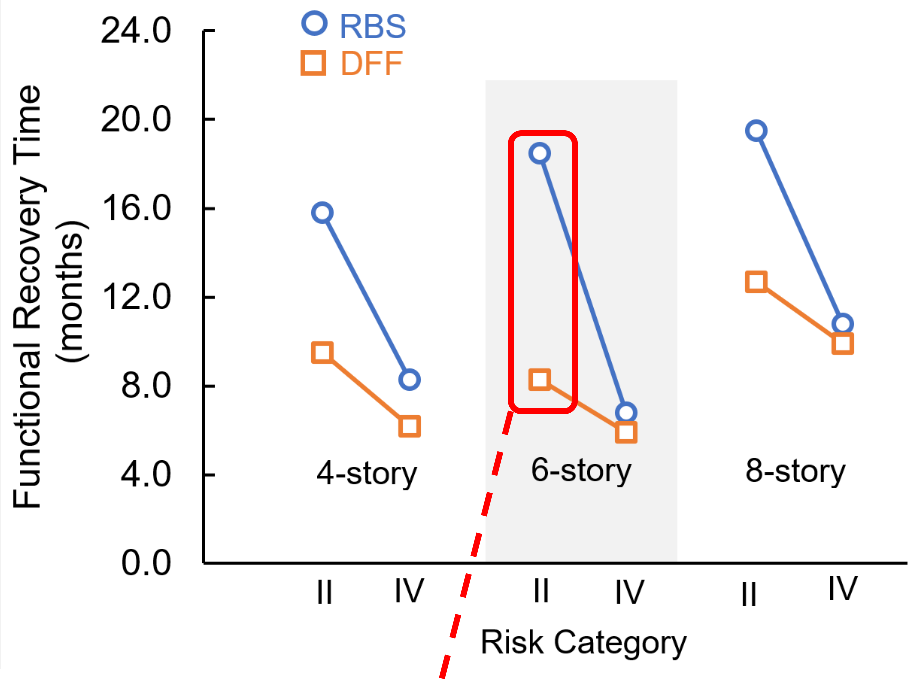


Functional Recovery Cost and Time



	Repair Cost
RBS	$ 19,897,553
DFF	$ 6,217,985

	Total Costs
RBS	$ 26,580,506
DFF	$ 9,123,214



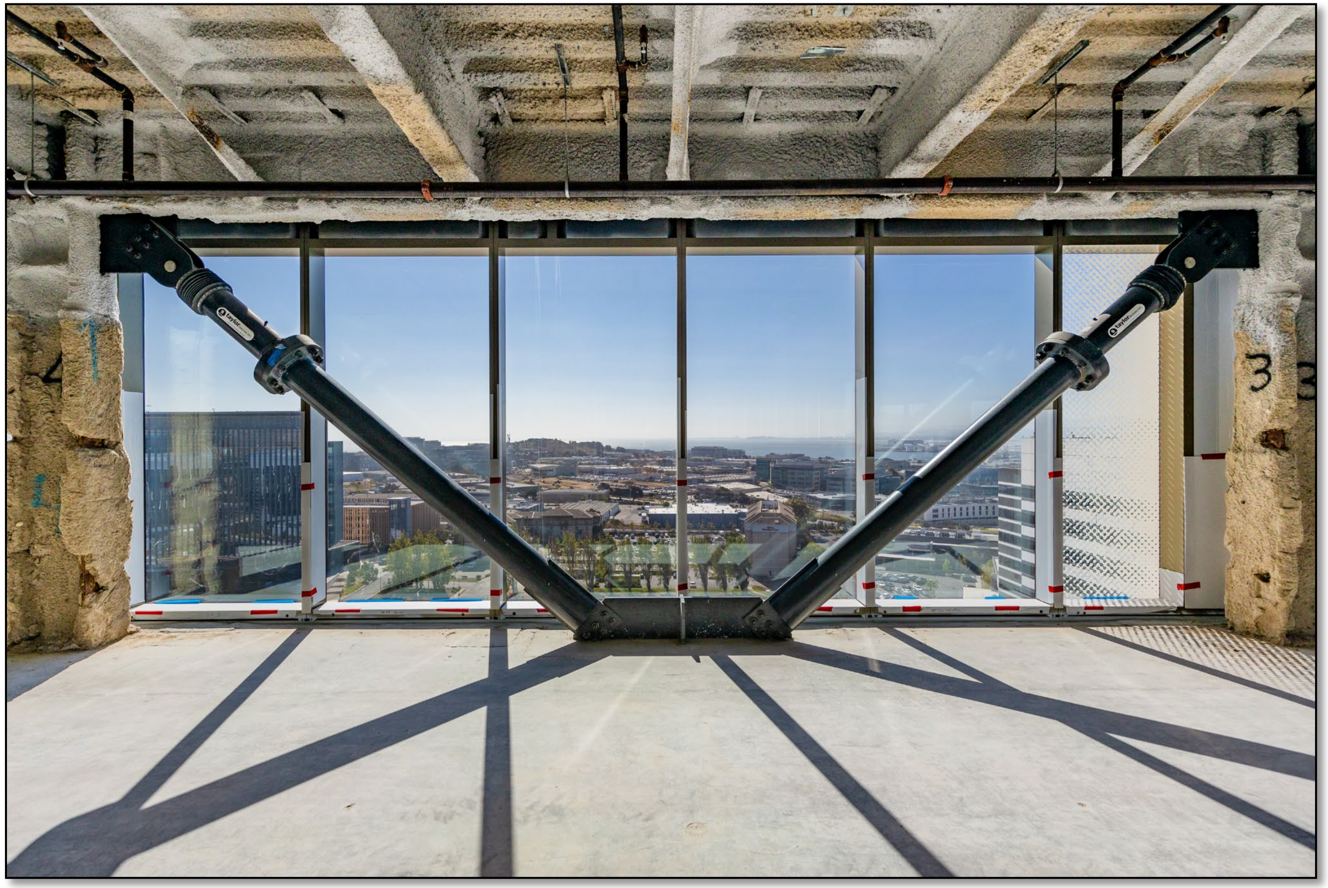
	Downtime Losses
RBS	$ 6,682,954
DFF	$ 2,905,228

BUILDING INNOVATION
Conference

Fluid Viscous Dampers:
What are they?
How do they reduce damage in buildings?

Adding Fluid Viscous Dampers...

350 California - San Francisco, CA

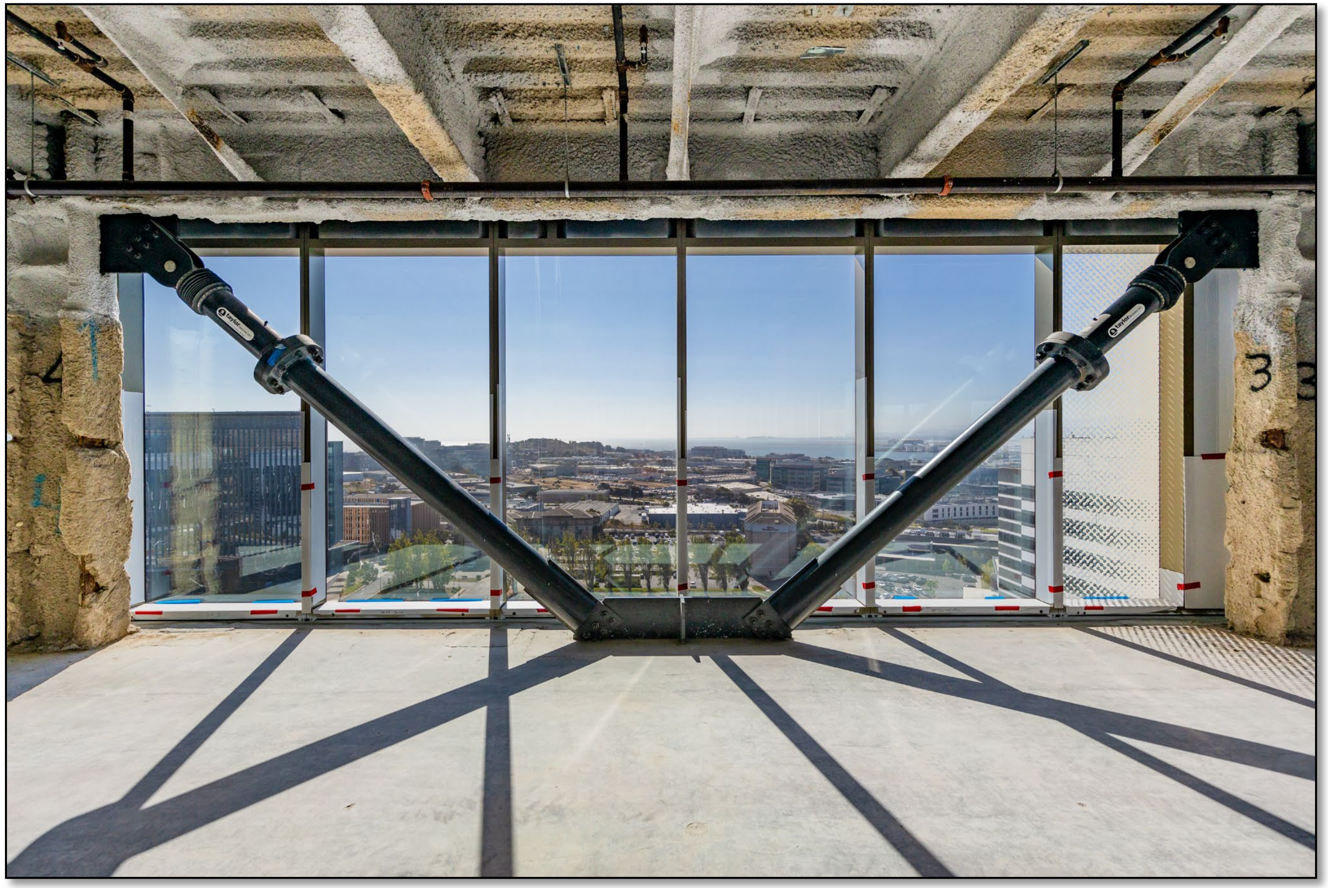


651 Gateway, South San Francisco, CA

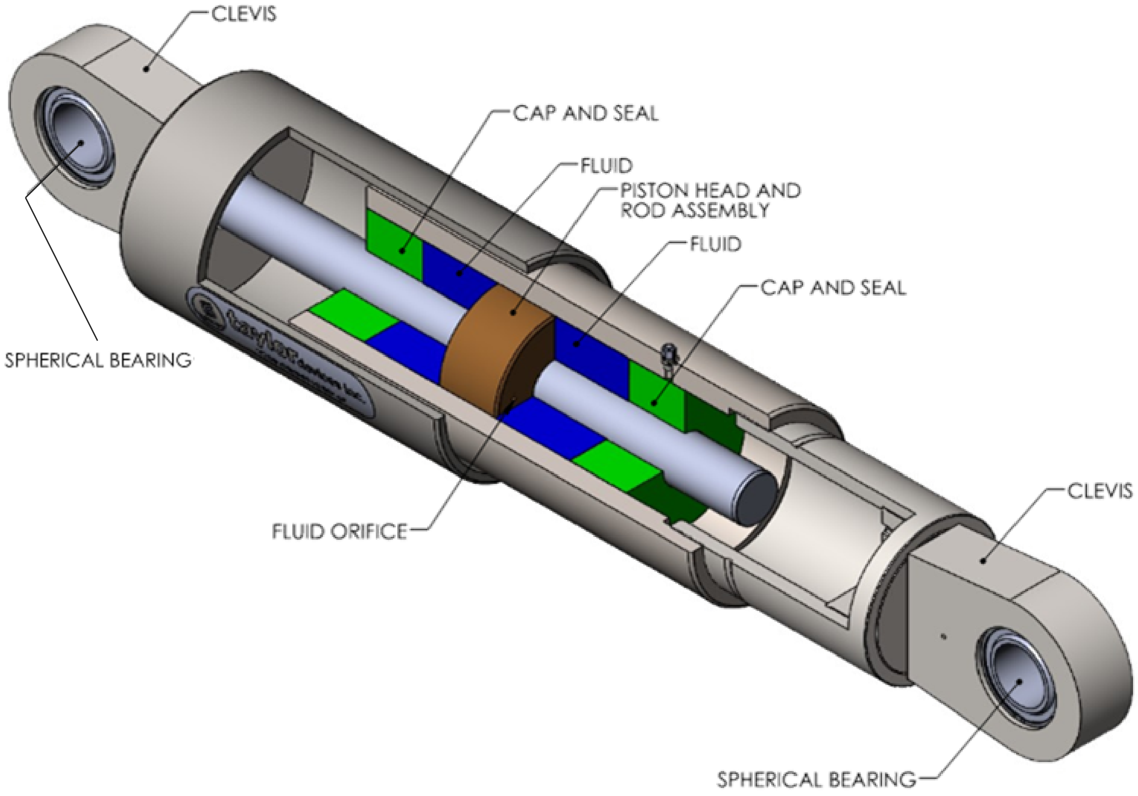
Bayer's Berkeley Campus - Berkeley, CA

181 Fremont,
San Francisco, CA

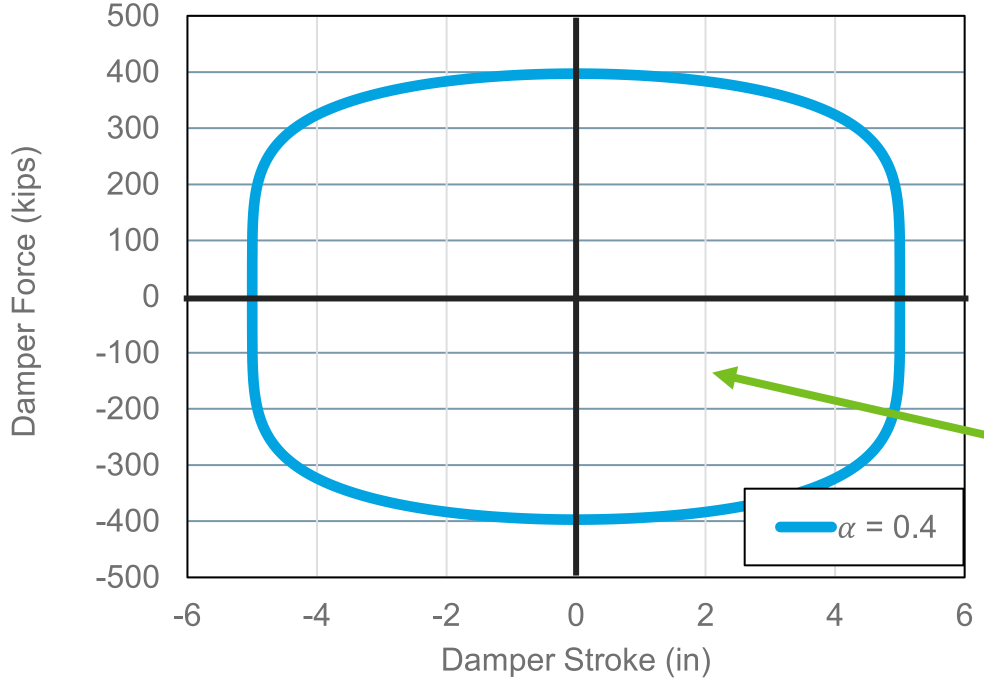
Adding Fluid Viscous Dampers...



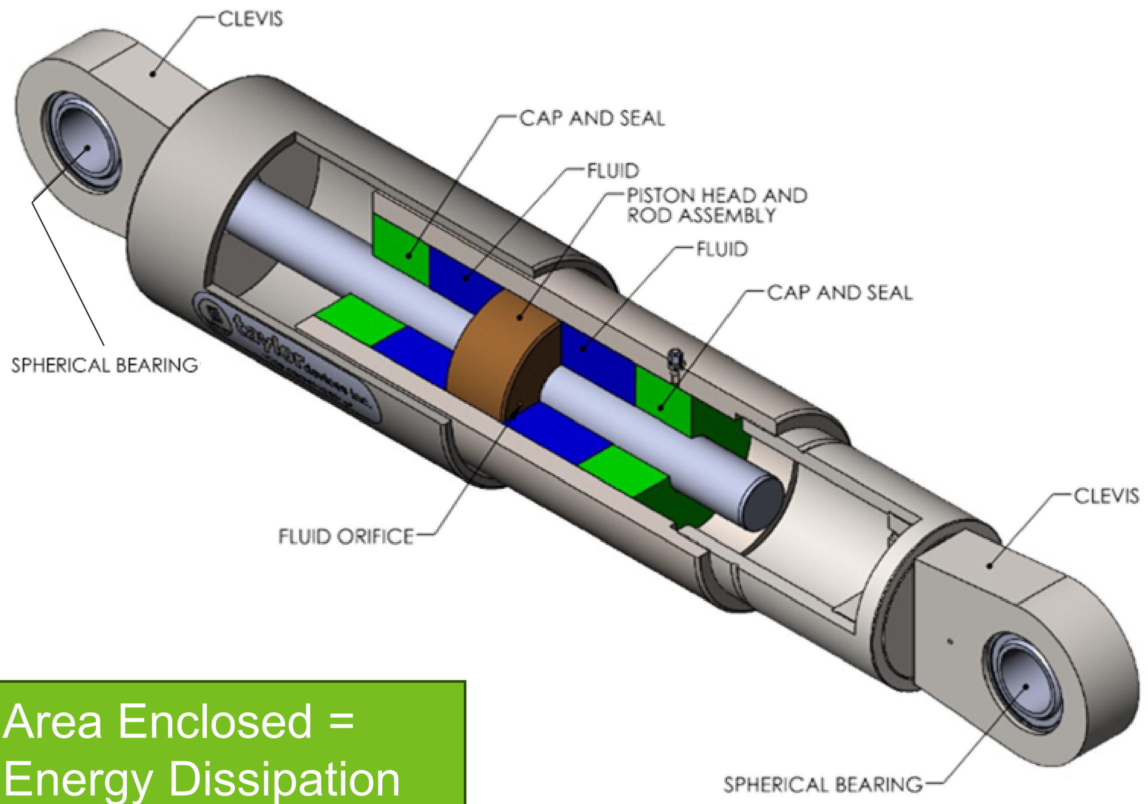
651 Gateway, South San Francisco, CA



Adding Fluid Viscous Dampers...



Area Enclosed =
Energy Dissipation

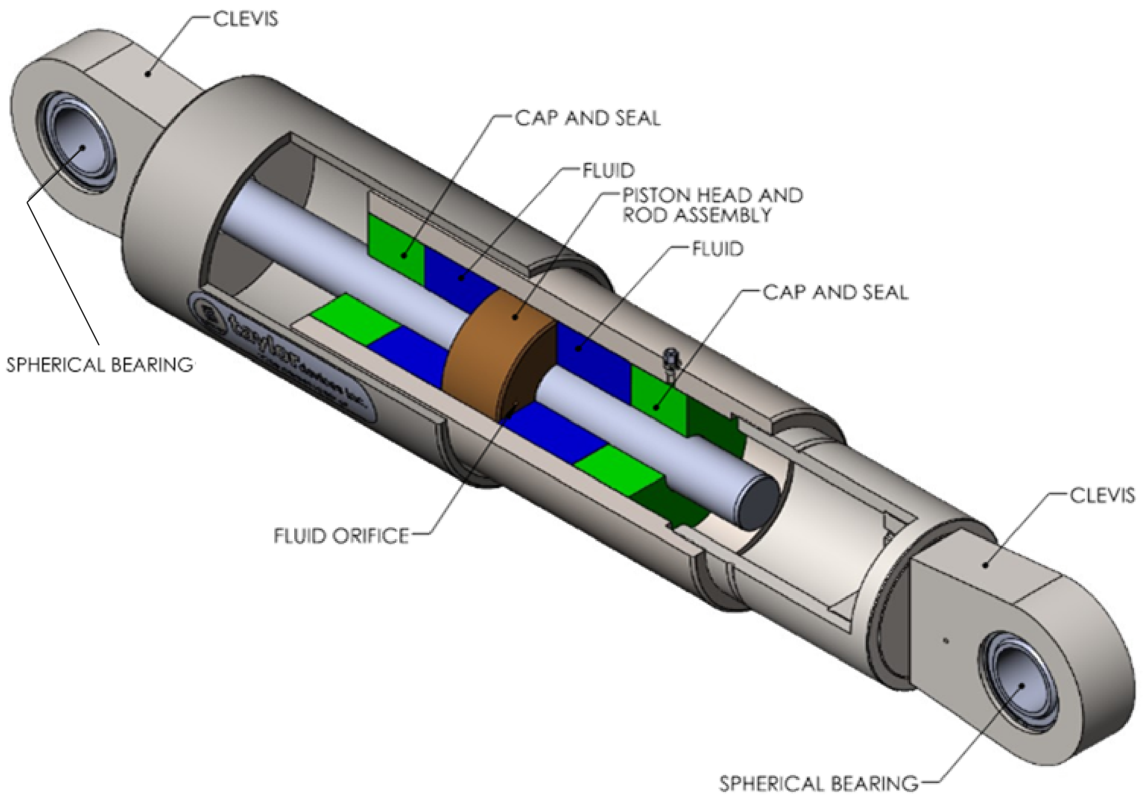


Adding Fluid Viscous Dampers...

- Reduces Story Drift
- Reduces Floor Accelerations
- Reduces Damage to Structural and Nonstructural Systems

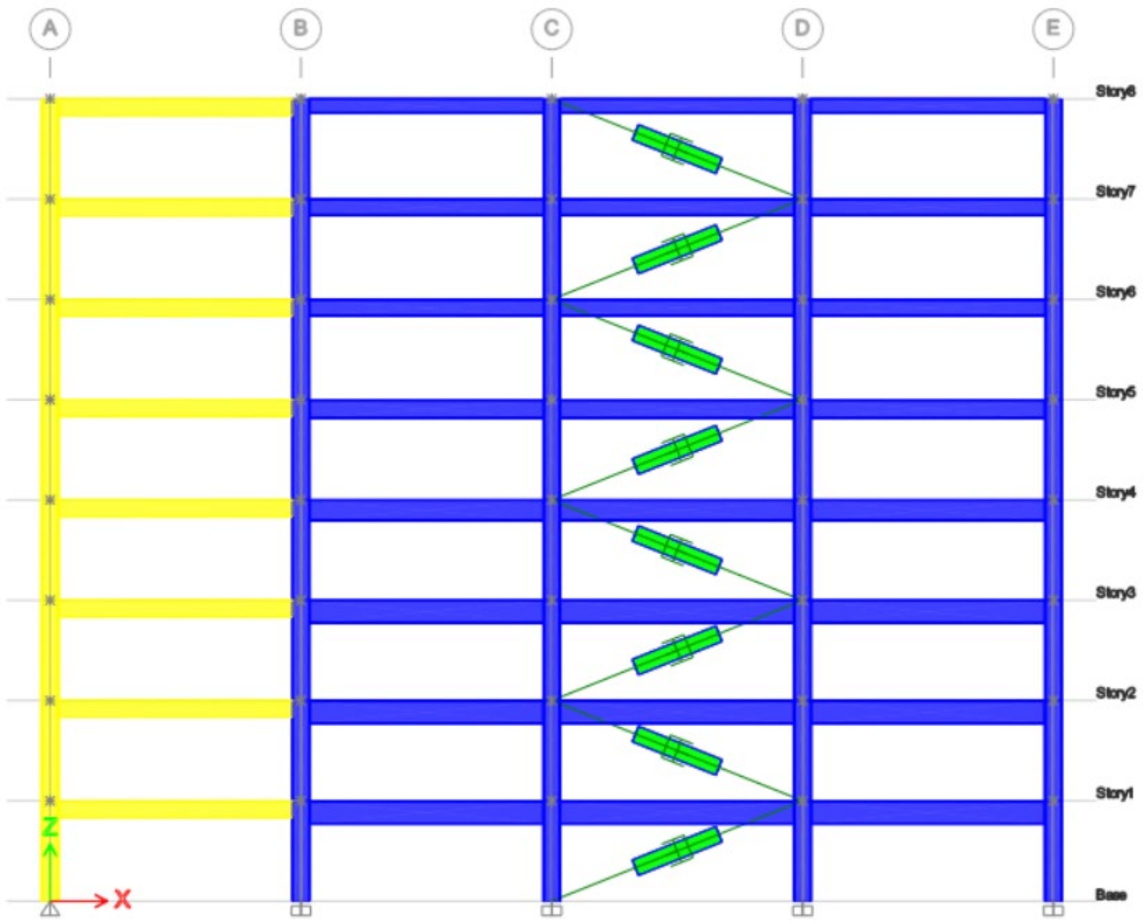
=

Increased Resiliency!!



DuraFuse + Fluid Viscous Dampers (FVDs)

8-Story Risk Category IV Case Study



DuraFuse + FVDs – Case Study

Design Approach:

- Redesign Moment Frame for 75% of ELF Base shear (maximum allowed reduction by the code)
- Ignore Drift in Moment Frame base design
- Control Drift with Dampers using Nonlinear Response History Analysis – Average of 11 Ground Motions

Natural History Museum Commons - Los Angeles, CA

DuraFuse + FVDs – Reduced Steel

	Column Weight (tons)	Beam Weight (tons)	Connection Weight (tons)	Total (tons)
Original Design	142	221	88	451
Damper Design	108	136	54	299
Comparison	**76%**	**62%**	**62%**	**66%**

300 Lakeside, Oakland, CA

More Usable Space:

Column Depth Reduction

- W27 to W24

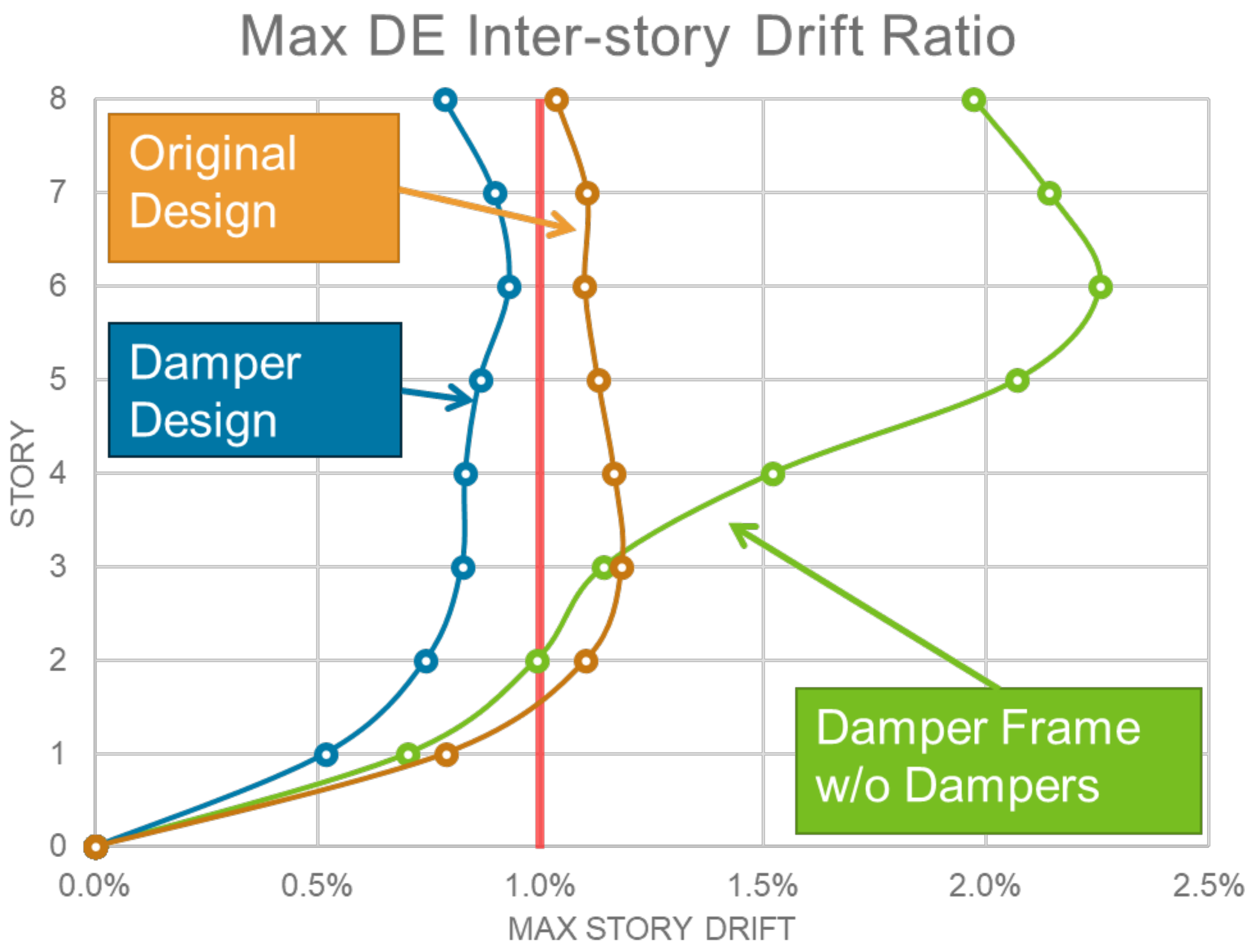
Beam Depth Reduction

- W36 to W33 at bottom
- W36 to W27 at Story 5
- W24 to W21 at Roof

DuraFuse + FVDs – Equivalent Drift

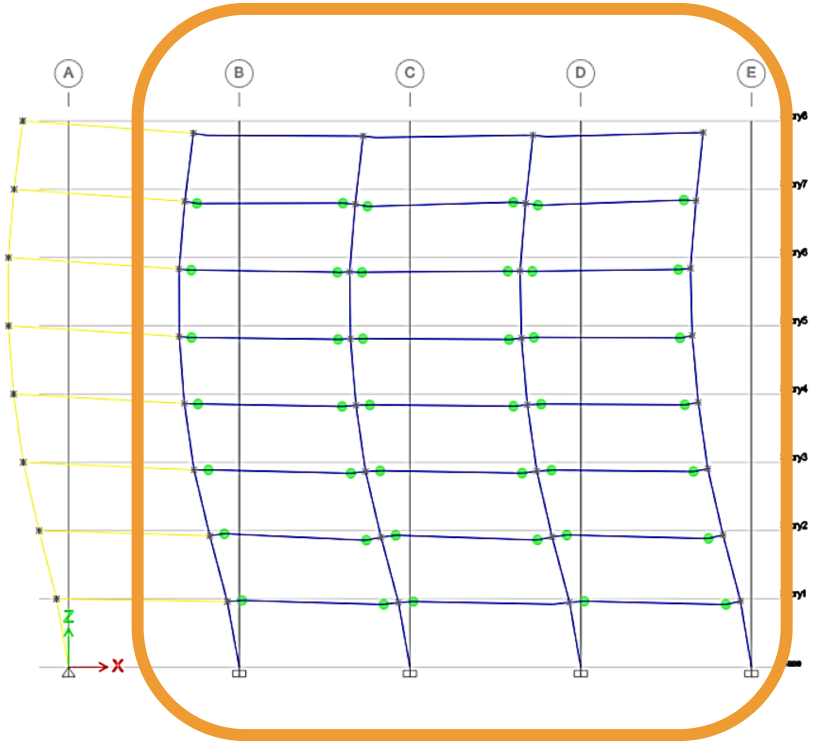
- Both designs targeted 1% drift for the DE level event
- Damper properties selected to control drift

Artise, Bellevue, WA



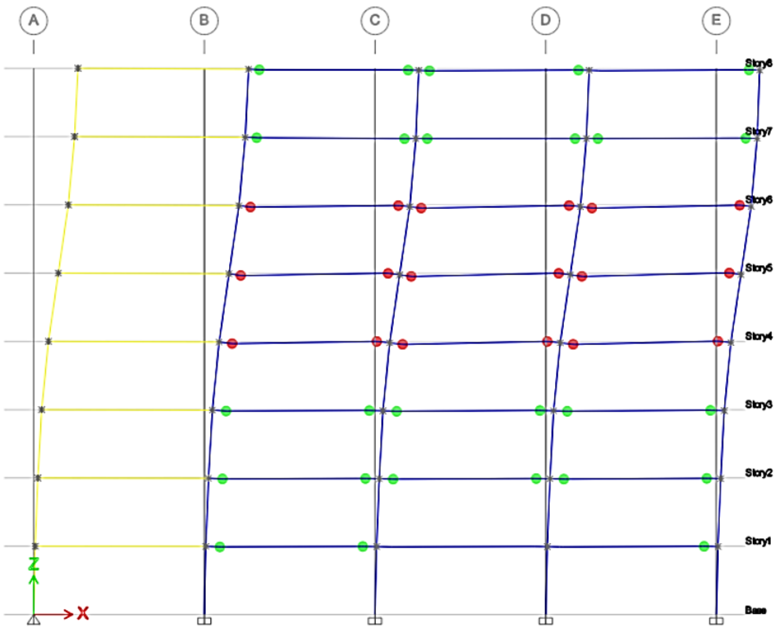
DuraFuse + FVDs – Reduced Damage
@ DE

Original Design

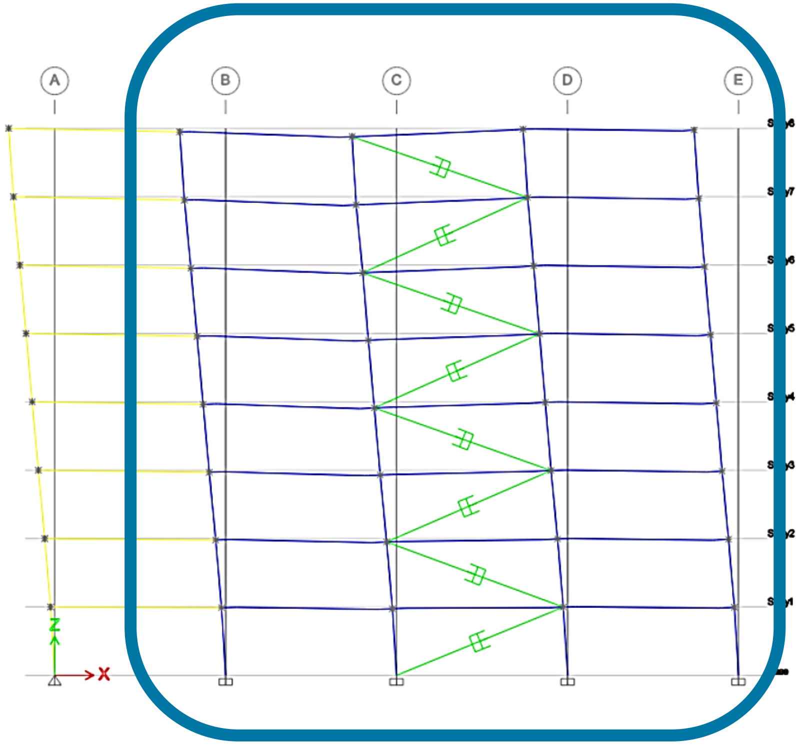


Distributed Yielding Throughout Building

Damper Frame w/o Dampers



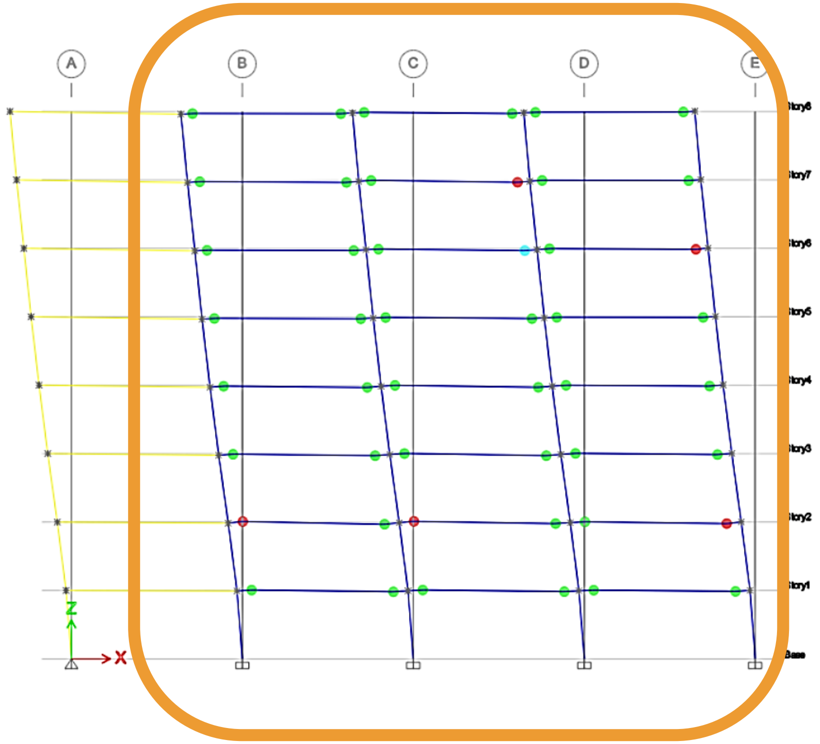
Damper Design



No Yielding

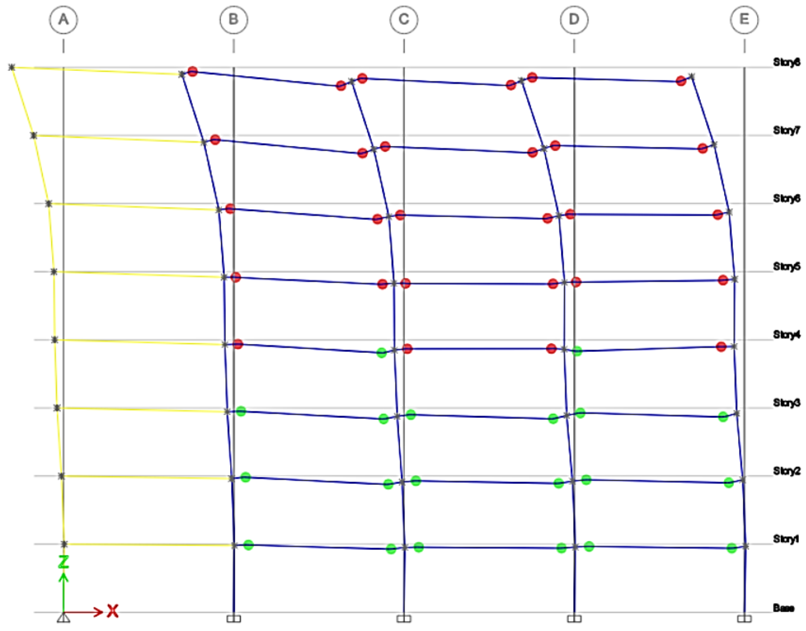
DuraFuse + FVDs – Reduced Damage
@ MCE

Original Design

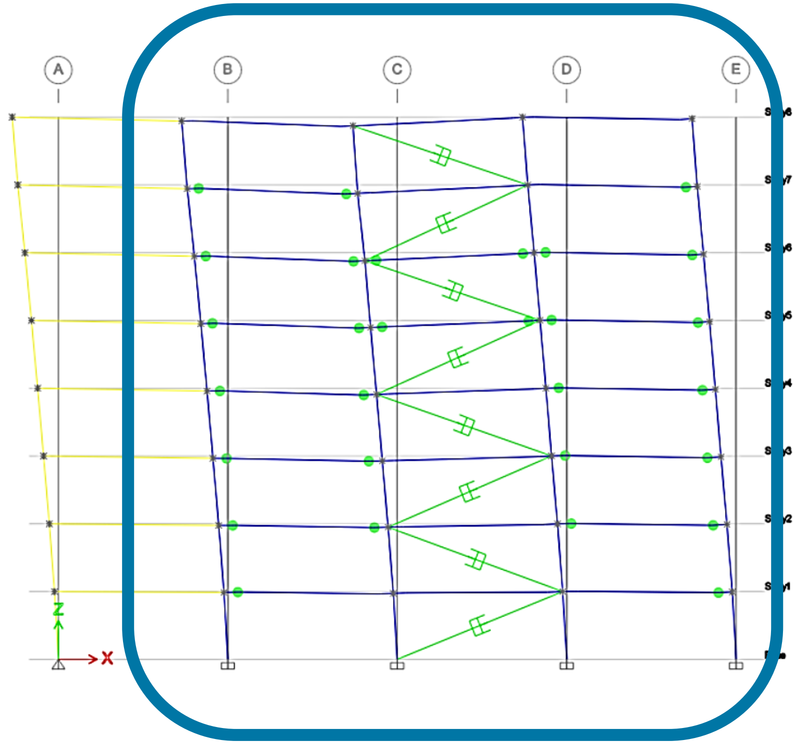


Some Fuses with Advanced Yielding

Damper Frame w/o Dampers



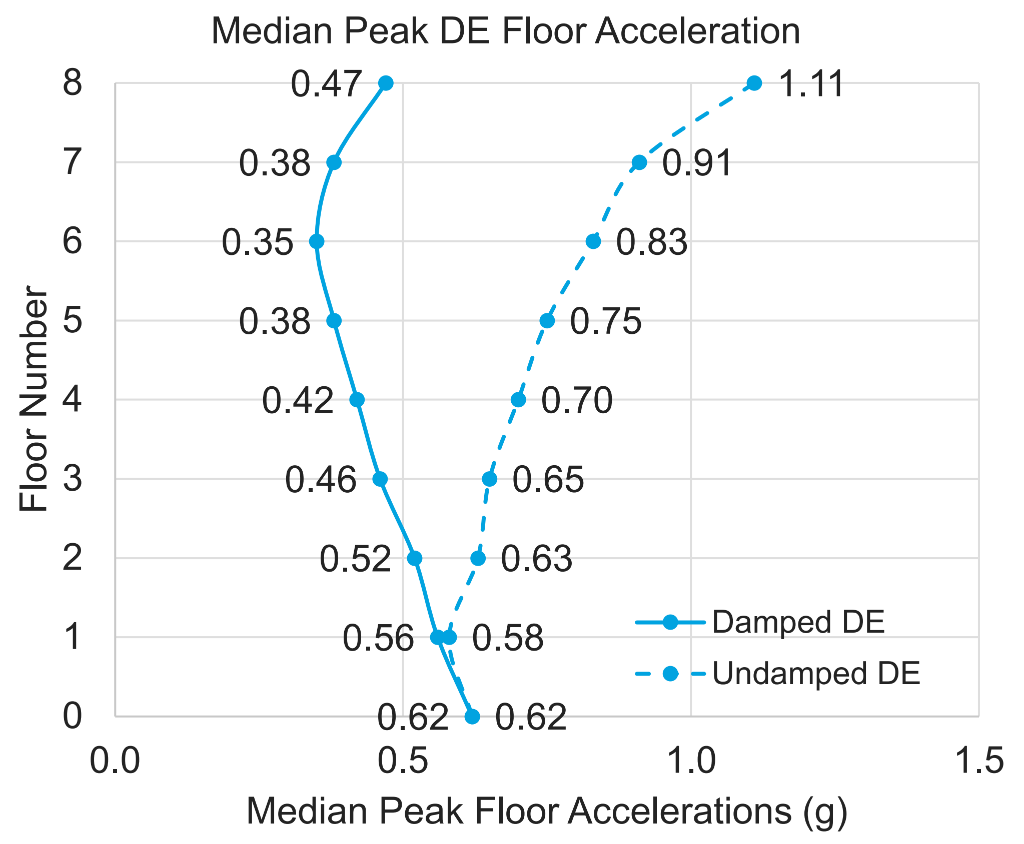
Damper Design



Some Distributed Yielding

DuraFuse + FVDs – Improved Resiliency

Reduced Floor Accelerations @ DE



Reduced Downtimes @ DE

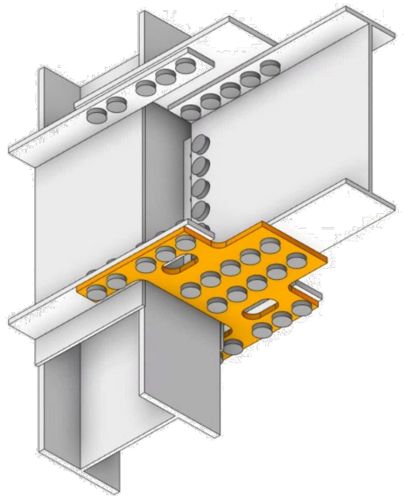
System	Median Days to Re-Occupancy	Median Days to Functional Recovery
Original Design	123	267
Damped Design	55	219

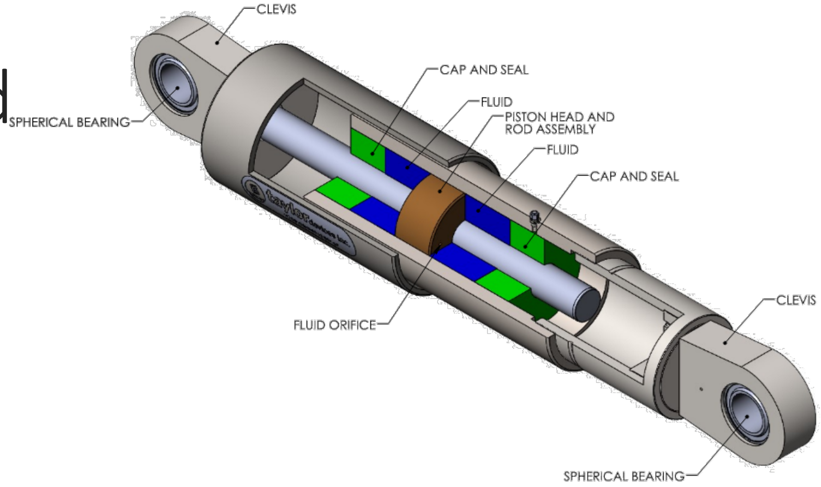
Reduced Repair Costs @ DE

Original Design: 2.9% of total bldg. cost
Damped Design: 1.3% of total bldg. cost

Conclusions

- Improving earthquake performance and resilience of buildings can be accomplished without increasing construction cost
- Repairable Prequalified Connections with replaceable fuses provide both Life Safety and enhanced Functional Recovery
- Adding Supplemental Damping to a prequalified steel moment frame improves performance and Functional Recovery





Thank You

Justin Marshall, justin.marshall@durafuseframes.com

Nathan Canney, nathancanney@taylordevices.com