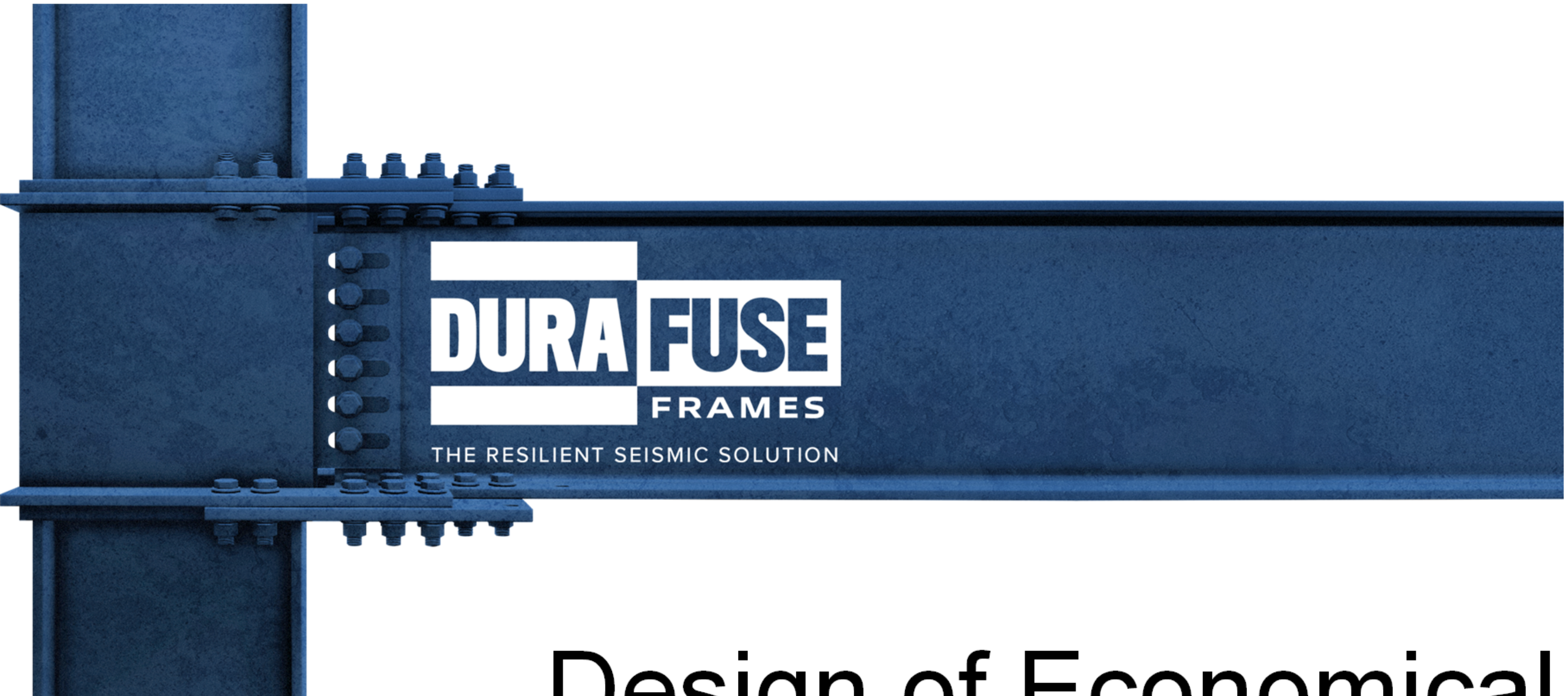
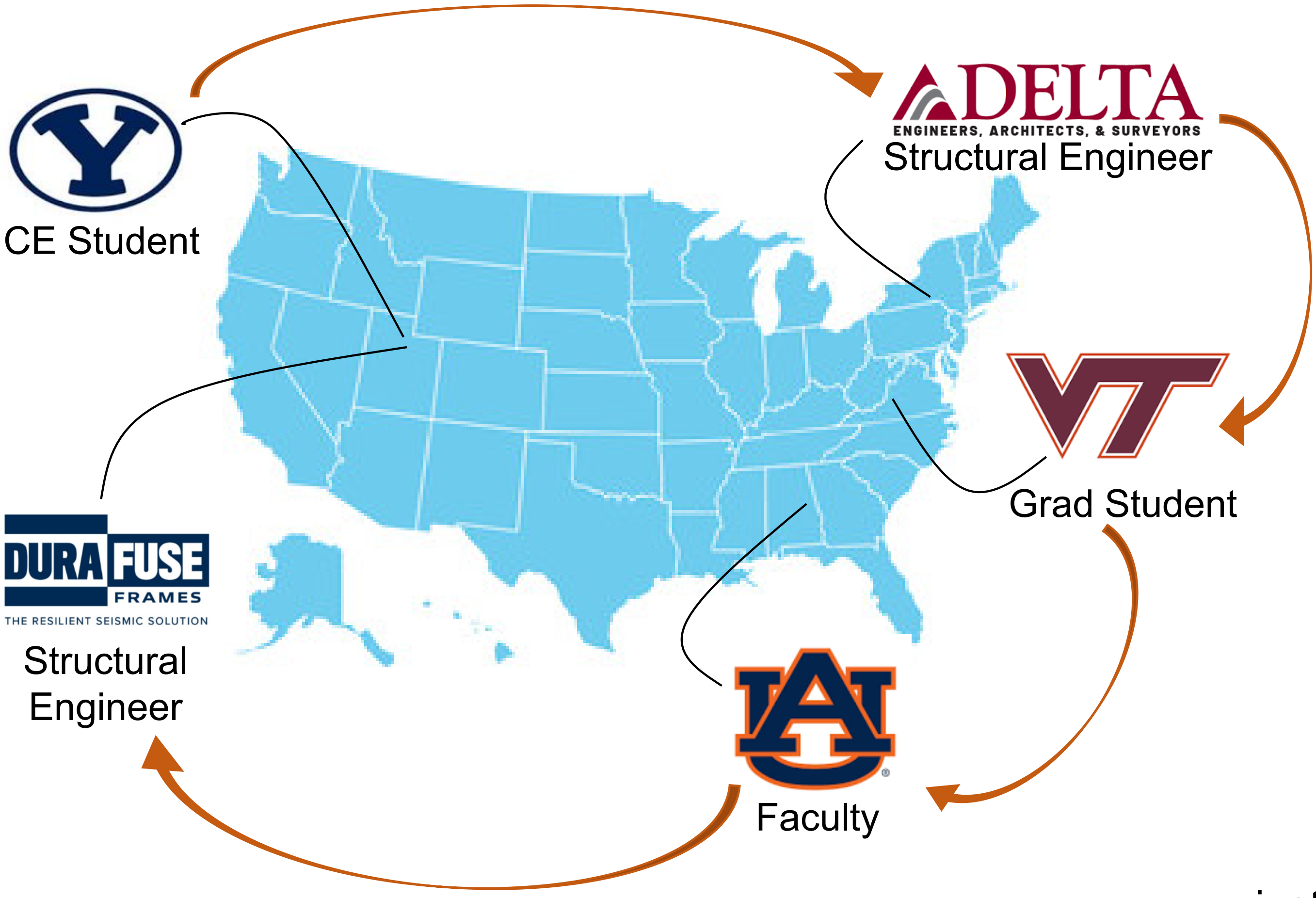


Design of Economical and Resilient Steel Moment Frames

Justin Marshall, PhD, PE
President, DuraFuse Frames
justin.marshall@durafuseframes.com

April 26, 2023 – Structure Magazine Webinar



Justin Marshall, PhD, PE
President
DuraFuse Frames
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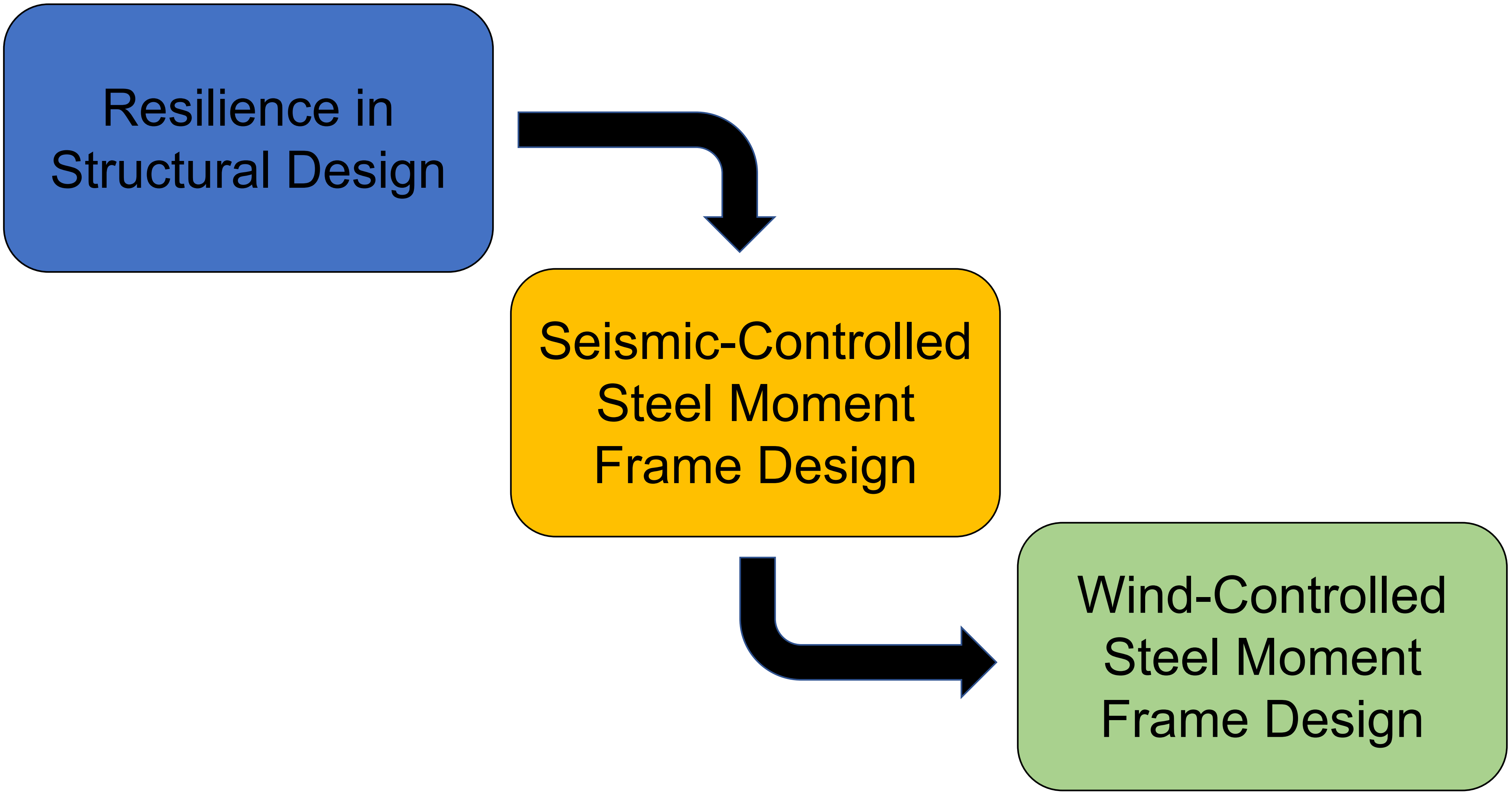
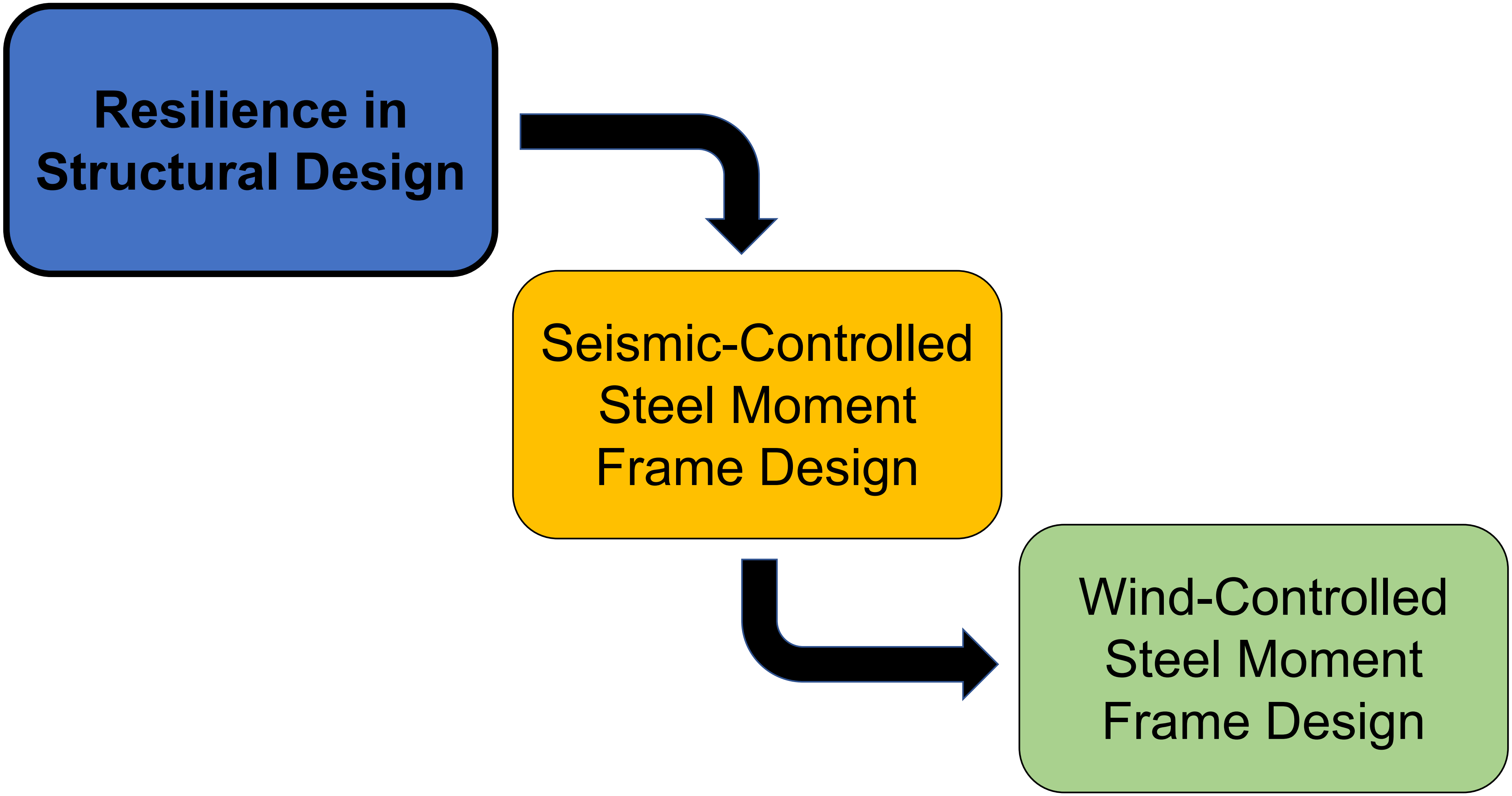
Interests: Mountain Biking, Golf, Volleyball, Being Outdoors



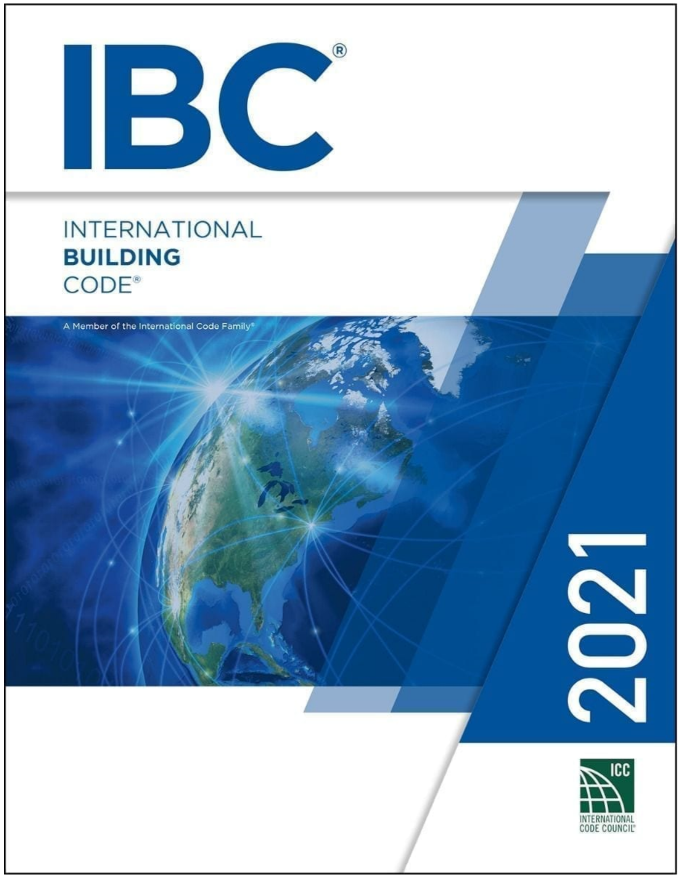
Resilience in Structural Design
Seismic-Controlled Steel Moment Frame Design
Wind-Controlled Steel Moment Frame Design

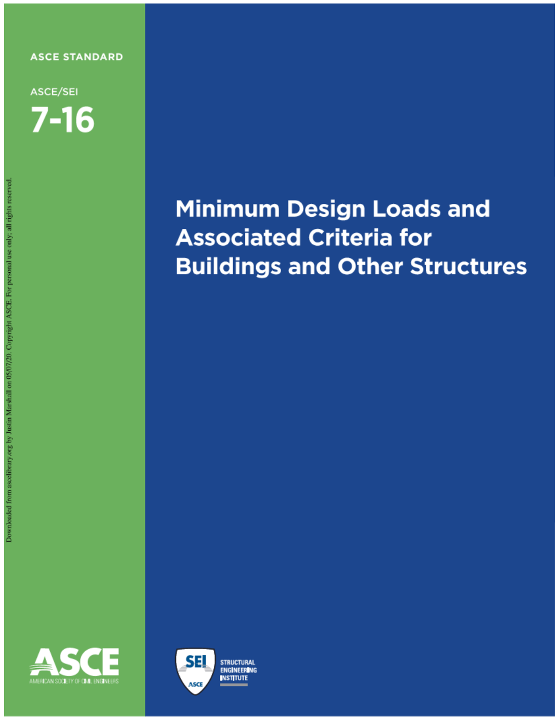

Resilience in Structural Design
Seismic-Controlled Steel Moment Frame Design
Wind-Controlled Steel Moment Frame Design

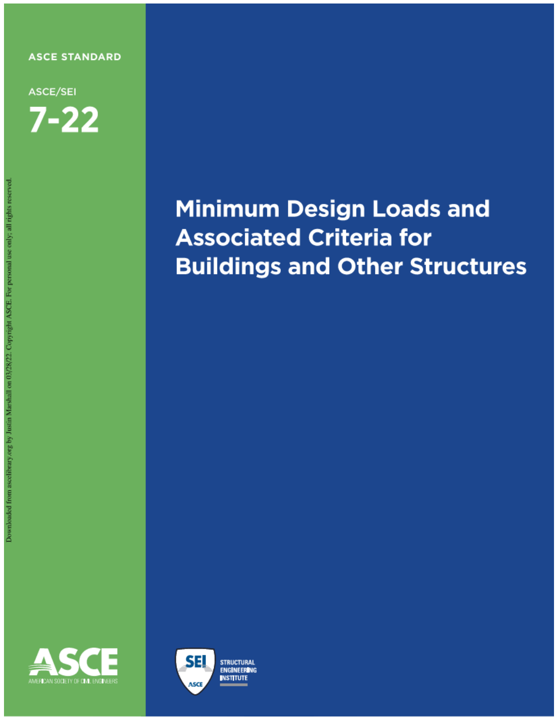
What are the responsibilities of Structural Engineers to our clients and society?

- Design structures that:
  - Meet Life-Safety Provisions (Strength)
  - Meet Occupancy Requirements (Serviceability)
  - Are Economical
  - Sustainably Utilize Resources
  - Contribute to a Resilient Community

Design Codes and Standards







For natural hazards (EQ, Extreme Wind, …) the minimum standard for design is based on **Life Safety**, meaning limiting the probability of disproportionate damage or collapse under a design-level event.

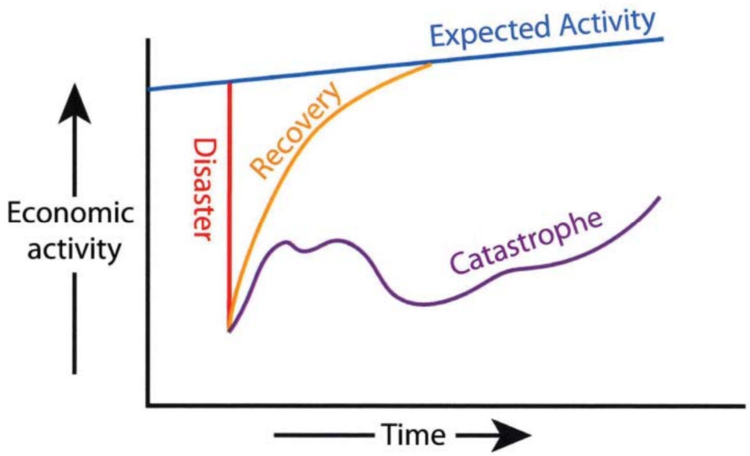
Why does Resilience matter?

"The building did what it was supposed to do," Mr. Devereux says. "But this building is coming down for economic reasons - it was just too expensive to repair."

https://www.nzherald.co.nz/nz/quake-city-landmark-will-soon-be-rubble/LQHGDLBPKJZKUPHQ66PYM5CUIY/

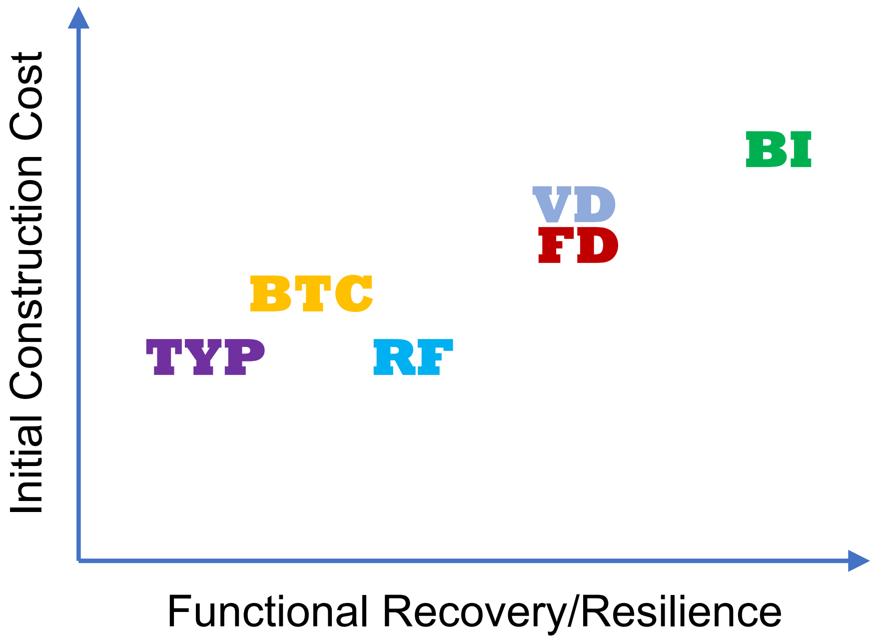
Even if buildings are covered by insurance, it takes years to rebuild a city.

Resilience curve



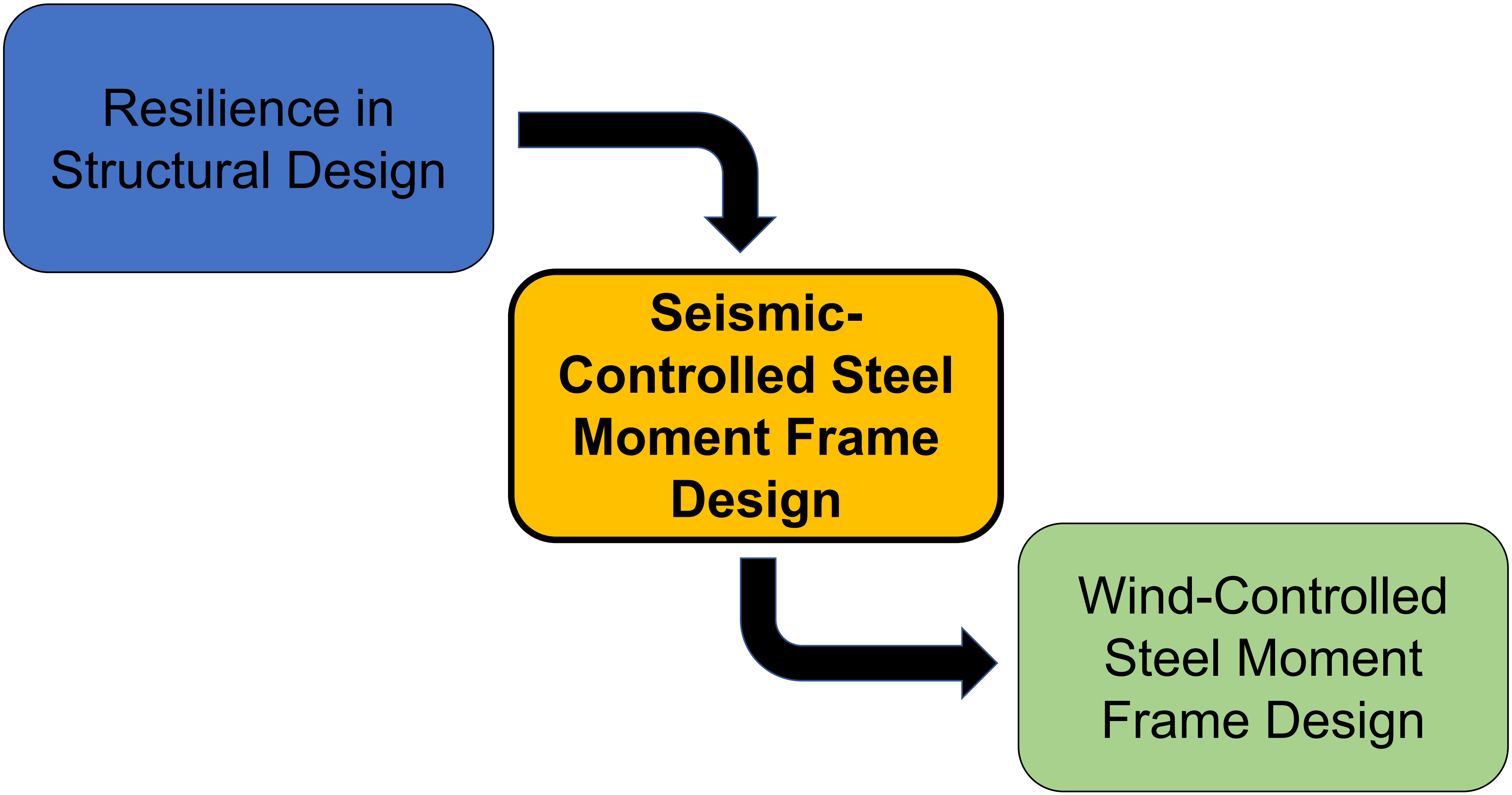

EARTHQUAKE ENGINEERING RESEARCH INSTITUTE
499 14th Street, Suite 220, Oakland, California 94612-1934
Telephone (510) 451-0905 Fax (510) 451-5411 eeri@eeri.org www.eeri.org
a nonprofit corporation
Functional Recovery: A Conceptual Framework with Policy Options
A white paper of the Earthquake Engineering Research Institute
December 6, 2019
Executive Summary
Earthquake-resistant design, especially as required by building codes, has always been primarily about safety. Over the last few years, policymakers and advocates have begun calling for "better than code" seismic design (Federal Register, 2016; San Francisco, 2016; NIST, 2017).
The systems are:
Buildings, new and existing, serving all occupancies and uses
Water and wastewater systems
Energy systems
Communication systems
nehrp
FEMA
National Institute BUILDING SCI
Resource Paper
Resilience-Based Design and the NEHRP Provi
developed by
National Institute of Building Sciences
Building Seismic Safety Council
for
the Federal Emergency Management Agency (FEMA)
2020 NEHRP Recommended Seismic Provisions for New Buildings and Other Structures
FEMA IDIQ Contract HSFE60-15-D-0022
February 2020
ICC INTERNATIONAL CODE COUNCIL
People Helping People Build a Safer World
A National Approach to Seism
Functional Recovery for New
Construction
A roundtable discussion convened by the Internation
Council and California Building Officials
Prepared by: Susan Dowty
Regional Manager, Government Relations, Internationa
PRESENTED BY THE ICC FAMILY OF SOLUTIONS
Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancy and Functional Recovery Time
FEMA P-2090/ NIST SP-1254 / January 2021
FEMA
nehrp
NIST National Institute of Standards and Technology

Spectrum of Resilient Design Options



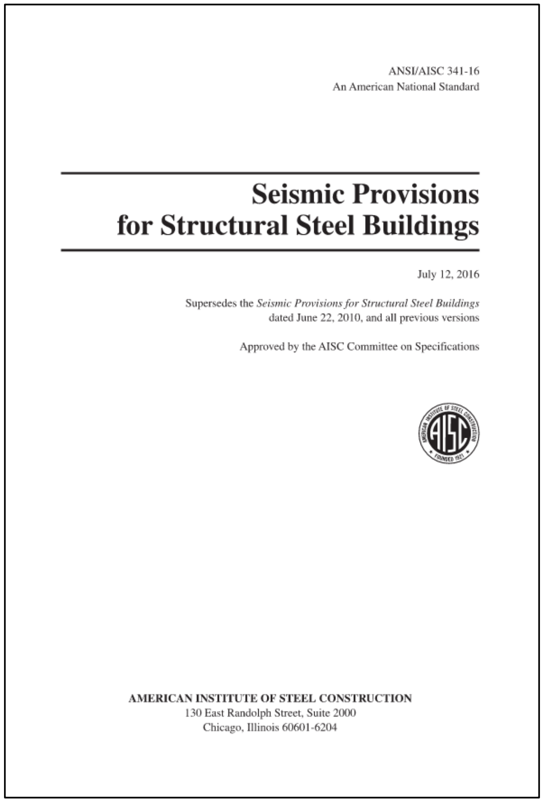
Legend:

- **BI** Seismic or Base Isolation
- **VD** Viscous Dampers
- **FD** Friction Dampers
- **BTC** "Better than Code" Designs
- **RF** Replaceable Fuses
- **TYP** Typical Lateral System


Resilience in Structural Design
Seismic-Controlled Steel Moment Frame Design
Wind-Controlled Steel Moment Frame Design

Seismic-Controlled Design for Steel Moment Frames

- Design is typically controlled by drift limitations (stiffness) as opposed to strength requirements
- For Special or Intermediate Moment Frames, connections must be qualified experimentally
- Numerous detailing requirements impact design and construction


ANSI/AISC 341-16
An American National Standard

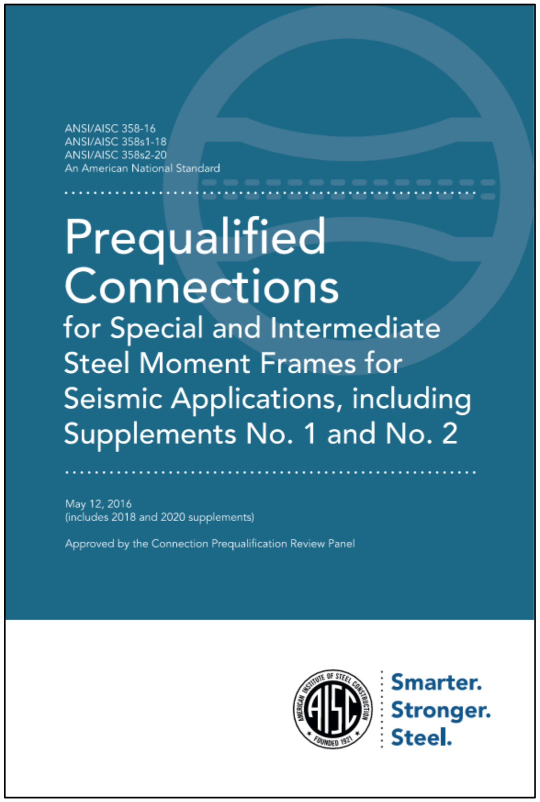
Seismic Provisions
for Structural Steel Buildings

July 12, 2016

Supersedes the *Seismic Provisions for Structural Steel Buildings* dated June 22, 2010, and all previous versions

Approved by the AISC Committee on Specifications

AMERICAN INSTITUTE OF STEEL CONSTRUCTION
130 East Randolph Street, Suite 2000
Chicago, Illinois 60601-6204


ANSI/AISC 358-16
ANSI/AISC 358s1-18
ANSI/AISC 358s2-20
An American National Standard

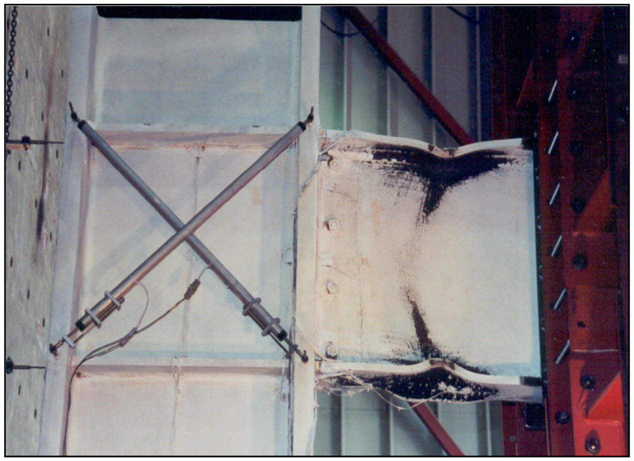
Prequalified Connections
for Special and Intermediate Steel Moment Frames for Seismic Applications, including Supplements No. 1 and No. 2

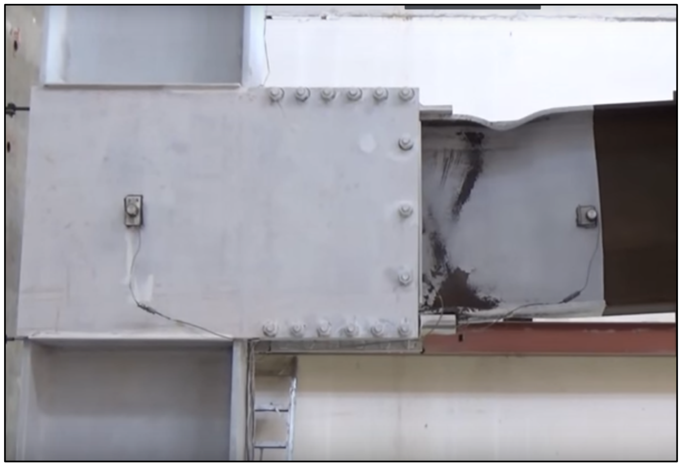
May 12, 2016
(includes 2018 and 2020 supplements)

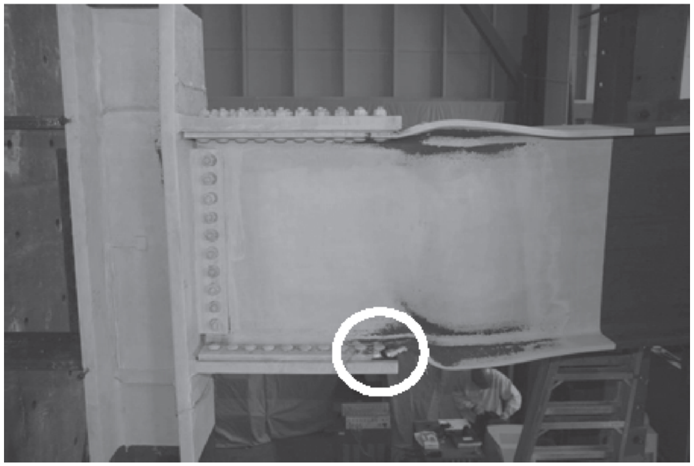
Approved by the Connection Prequalification Review Panel

Smarter.
Stronger.
Steel.

Moment Frame Beams Experience Significant Damage in Target Zones – Life Safety

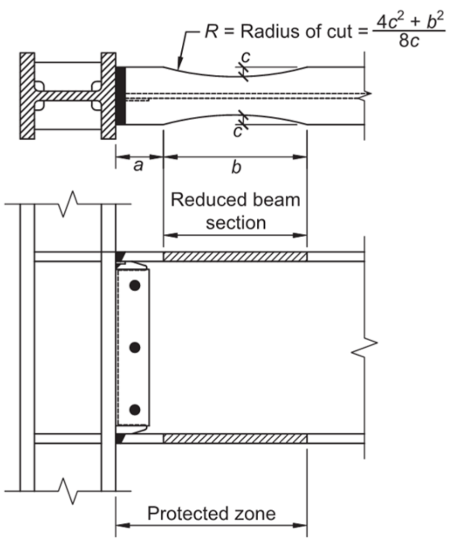




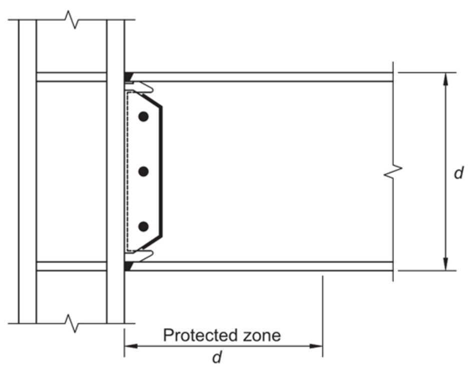


- Beam yielding
- Beam local buckling
- Beam flange and web fracture

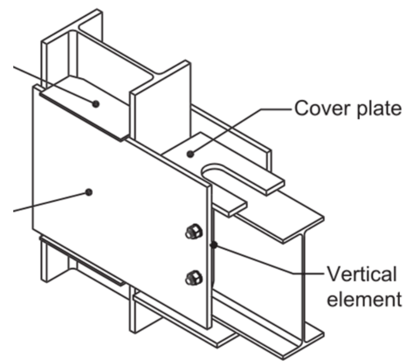
Prequalified Connections (Field Welded)



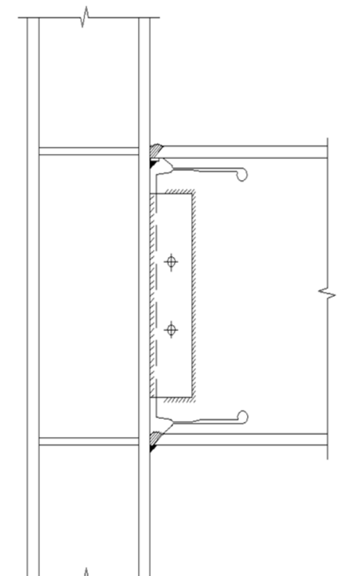
RBS



WUF-W



Welded SidePlate®

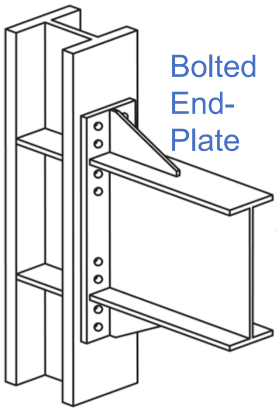


SlottedWeb™

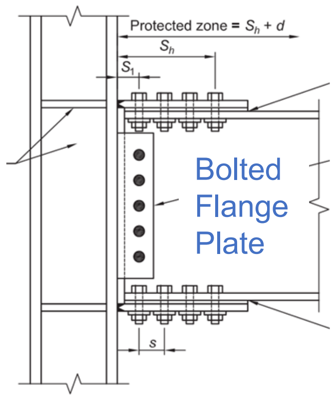
Key: Non-proprietary
Proprietary

Images from AISC 358-16

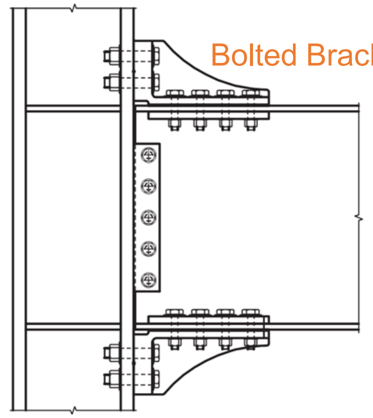
Prequalified (not Field Welded)



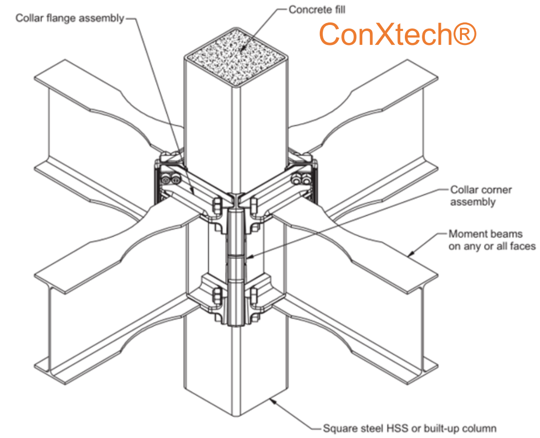
Bolted End-Plate



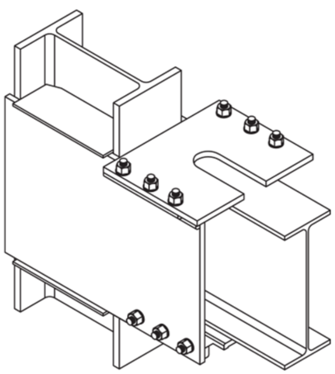
Bolted Flange Plate



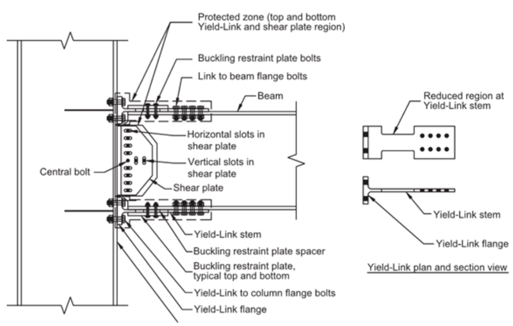
Bolted Bracket



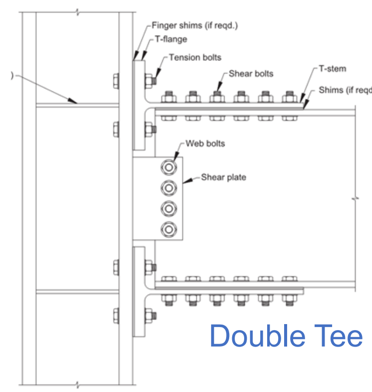
ConXtech®



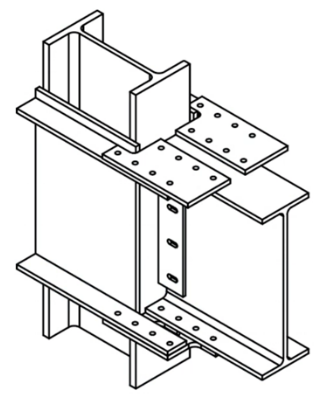
Bolted SidePlate®



Simpson Yield-Link®



Double Tee

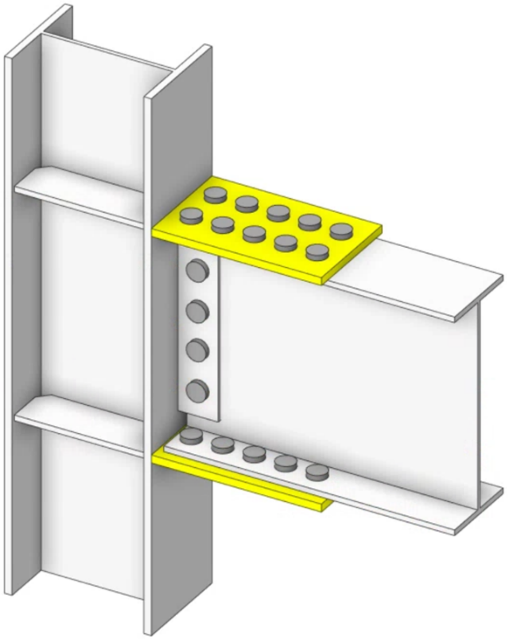


DuraFuse Frames®

Images from AISC 358-16/22

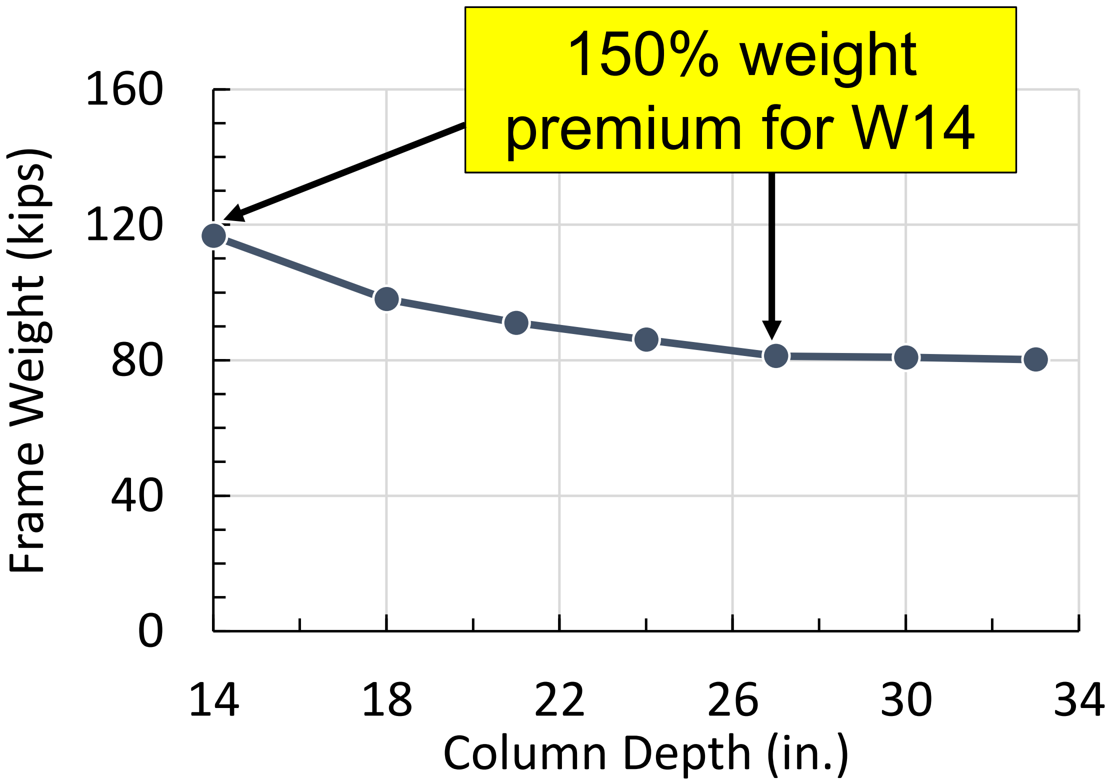
Design and Construction Cost Implications

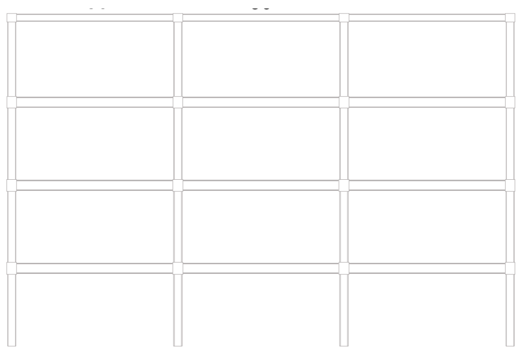
Reduced Beam Section (RBS)
Design: $
Construction: $$$



Bolted Flange Plate (BFP)
Design: $$
Construction: $

Weight Reduction with Deep Columns





Max beam: W36×

McCall and Richards (2022), Using Genetic Algorithms to Optimize Steel Special Moment Frames. 12th NCEE, 27 June – 1 July 2022, Salt Lake City, UT .

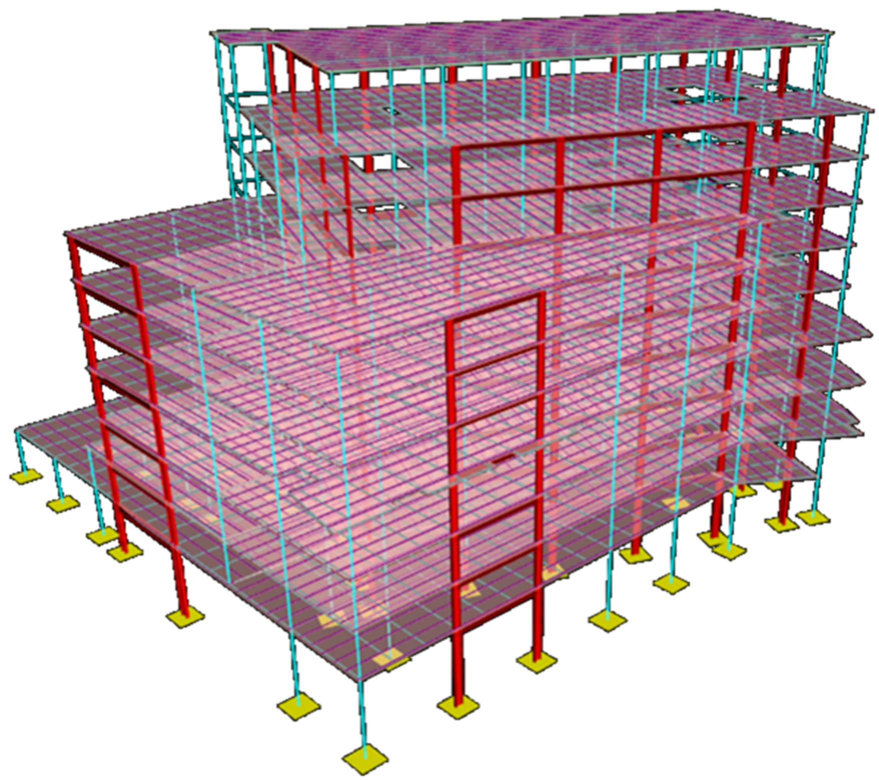
Typical SMF Member Design

Iterative process for design:

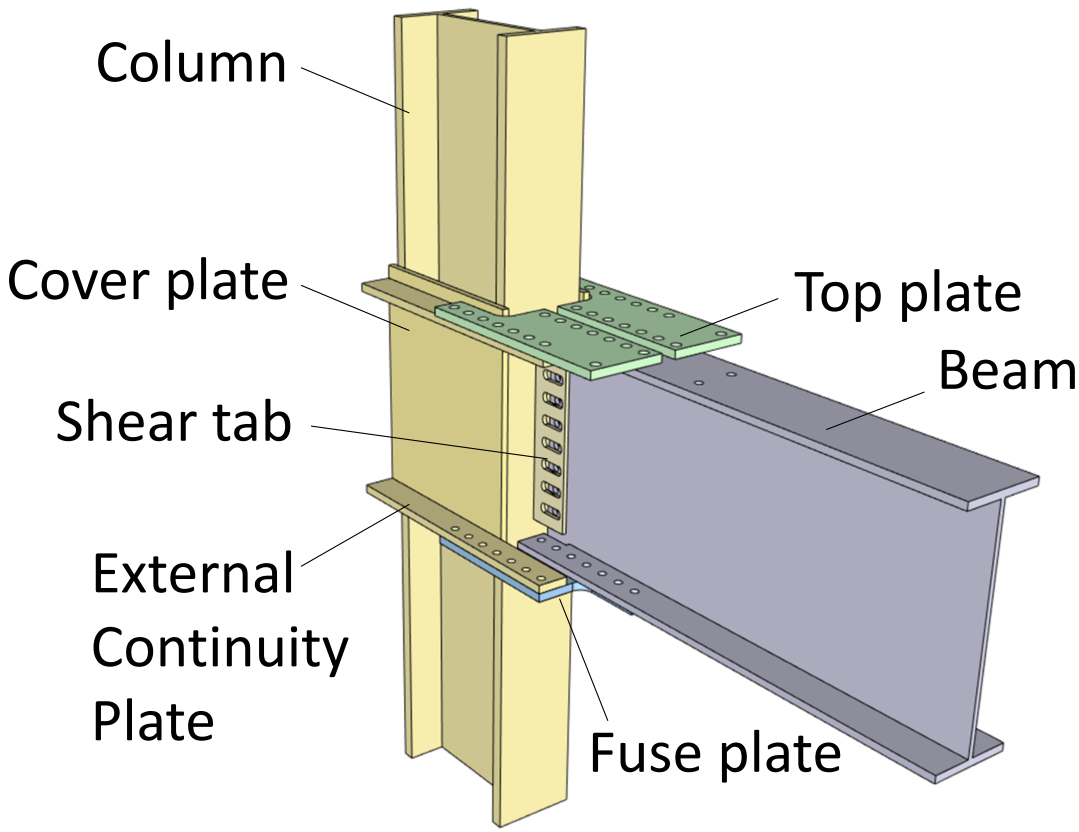
- Pick member sizes
- Check drift
- Check strength
- Check seismic design requirements (e.g. SC-WB)
- Adjust design and repeat

Then:

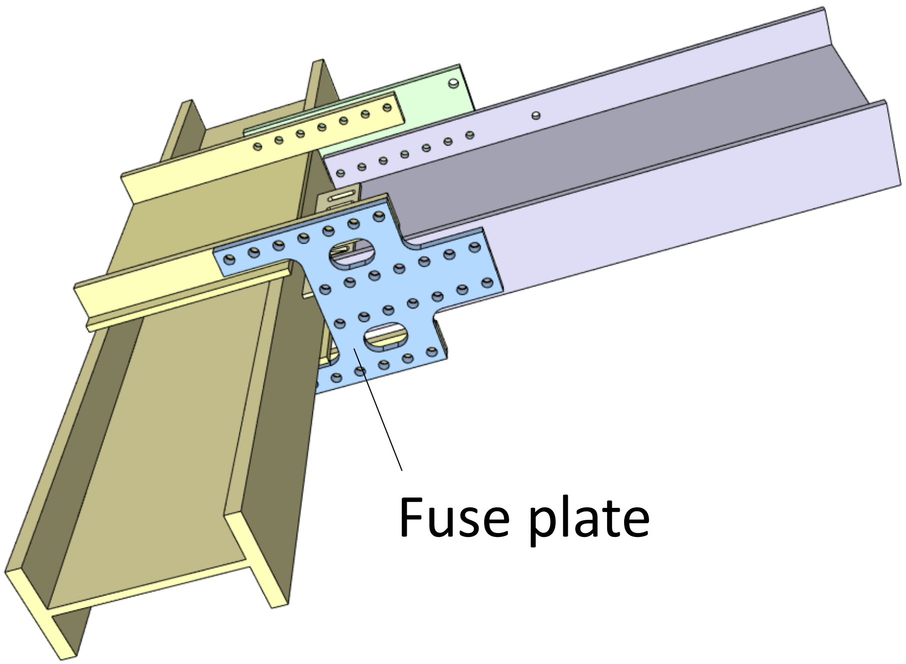
- Design connections and detail for ductility (e.g. lateral bracing, chords, …)

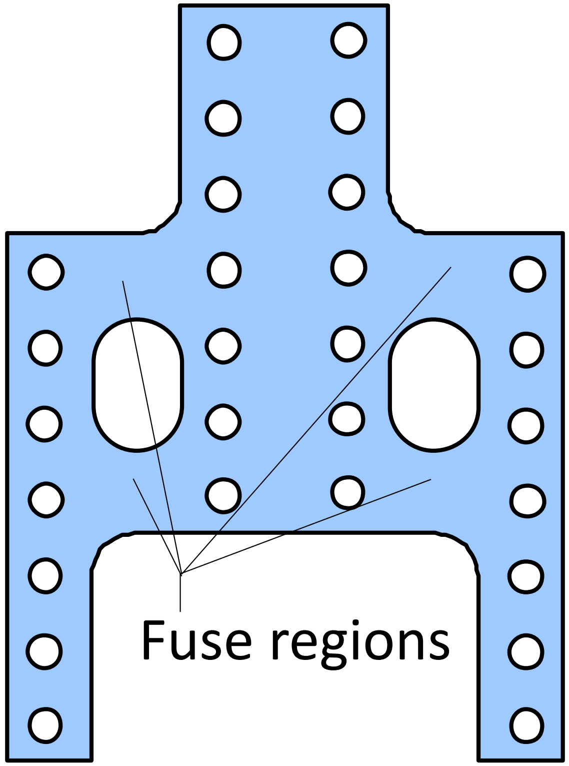


DuraFuse Frames Connection – Field-Bolted Moment Connection with a Replaceable Fuse

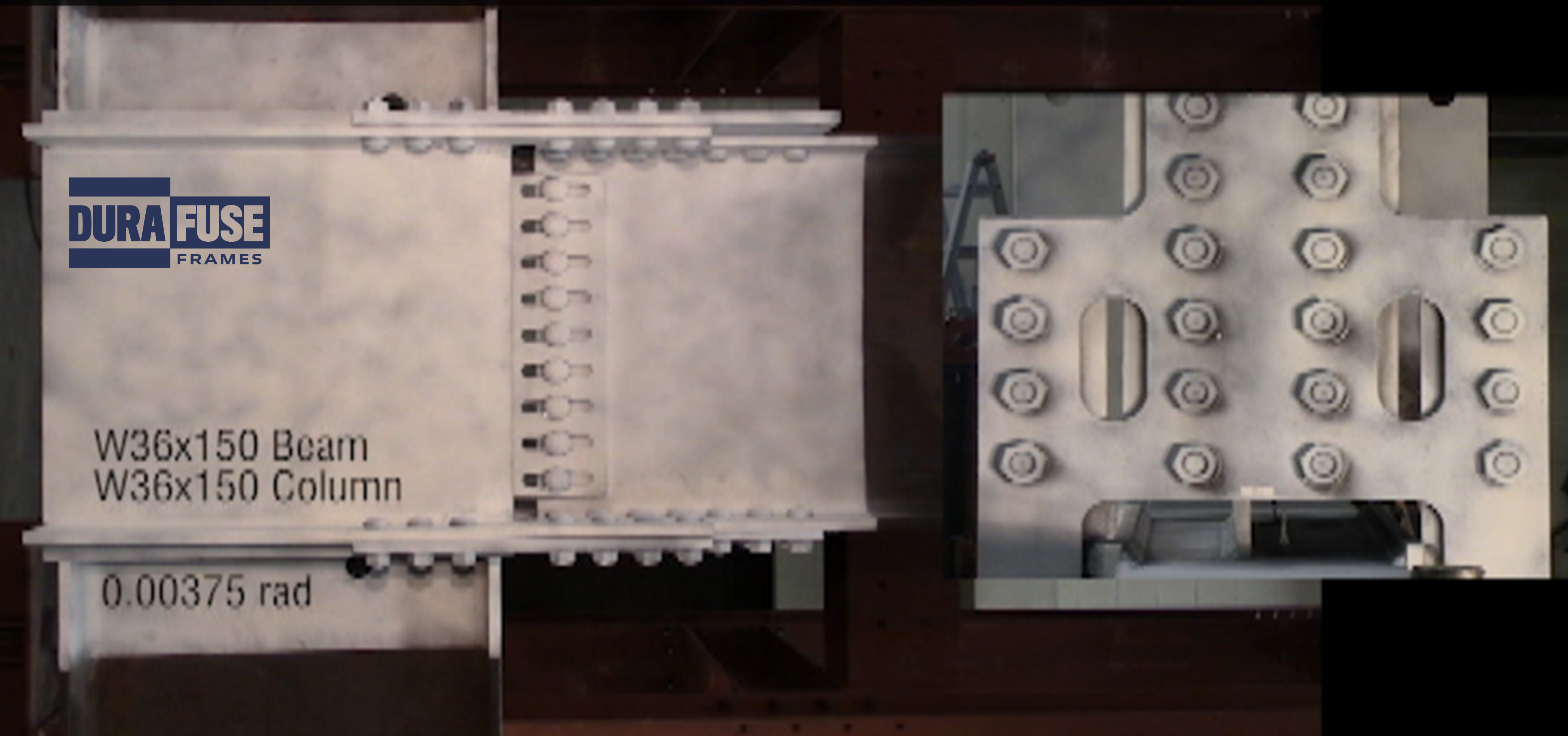


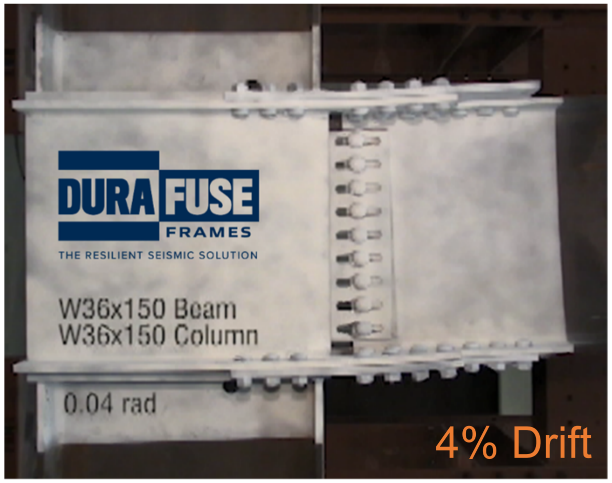
DuraFuse Frames Connection Configuration

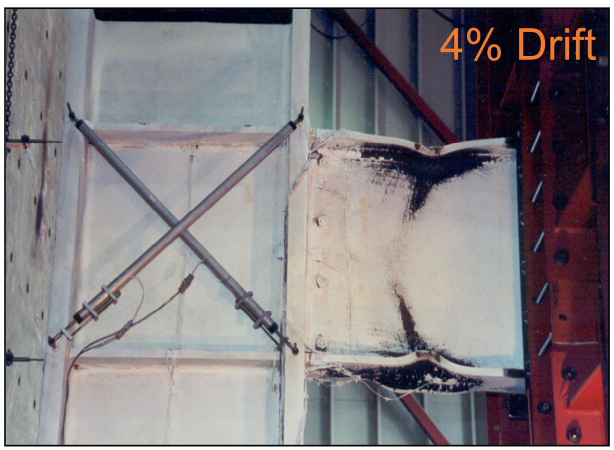




Damage and inelastic deformation is confined to bolted fuse plates.







The DuraFuse Frames Difference:

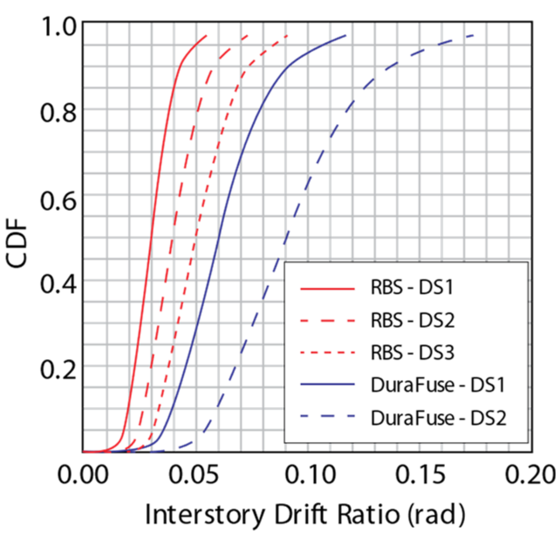
- ❑ **Economy**
  - Reduced lateral system steel weight
  - "Erector-friendly" field-bolted connection
  - Significant reduction in lateral bracing
- ❑ **Performance**
  - Prequalified in AISC 358-22
  - Laboratory and shake-table tested at full-scale
  - Minimized residual drifts
- ❑ **Resilience (through Repairability)**
  - Post-event repair cost and time are reduced by 60% – 70%

Some of the chief benefits include:

- Decreased frame weight (10-15% as compared to non-proprietary connections) – Frame optimization and connection configuration
- Faster construction, erection and fabrication
- Elimination of seismic lateral bracing and beam span-to-depth ratios
- Ability to depart from high-ductility seismic compactness limits
- Significant reduction in protected zone requirements
- Complimentary design assist
- **Outstanding fragility curves leading to unmatched resilience characteristics**

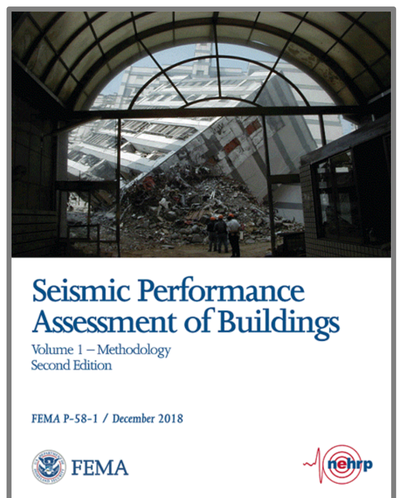
DuraFuse Frames Dramatically Decrease Structural Losses

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

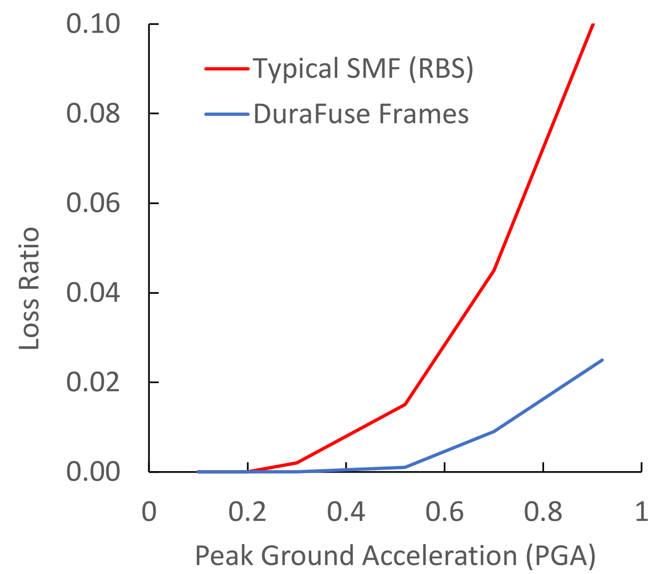


RBS – DS2 = $36,625

DuraFuse – DS2 = $15,000

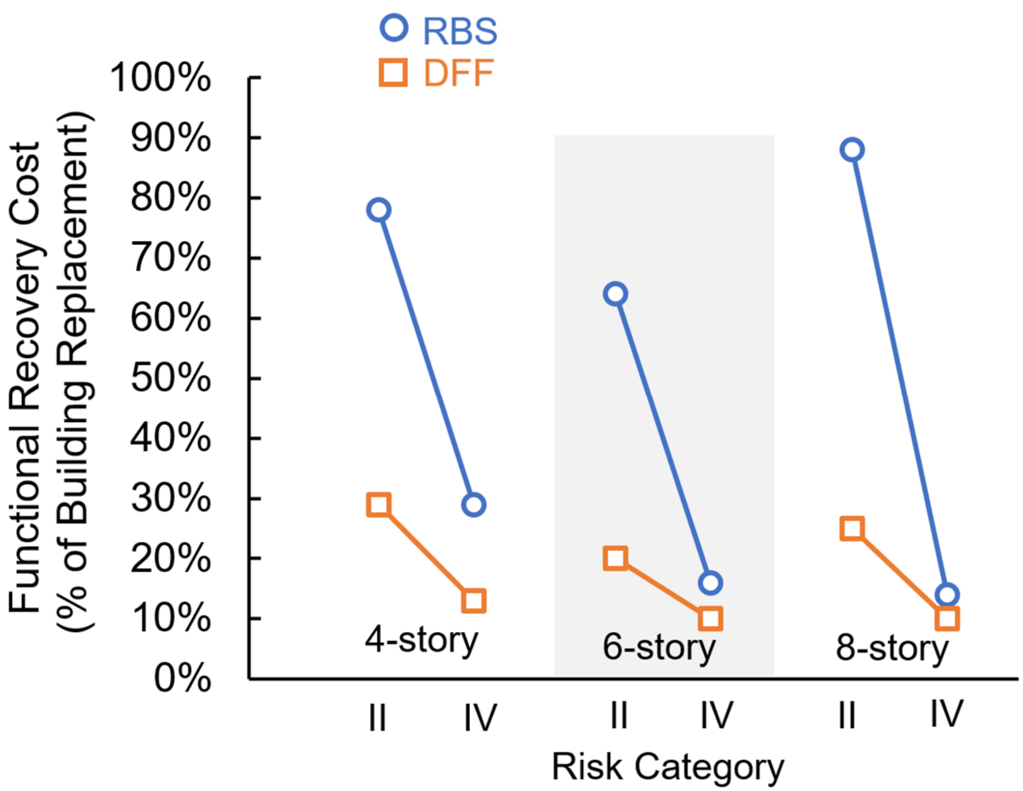


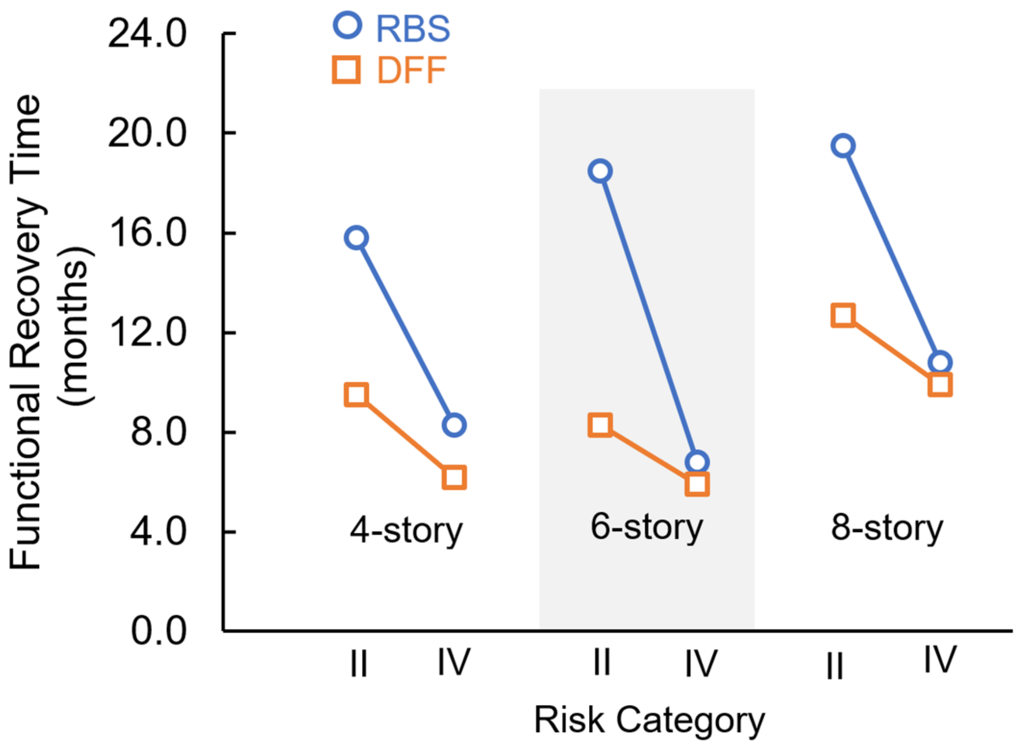
FEMA P58



Haselton Baker Risk Group
SP3 Seismic Performance Prediction Program

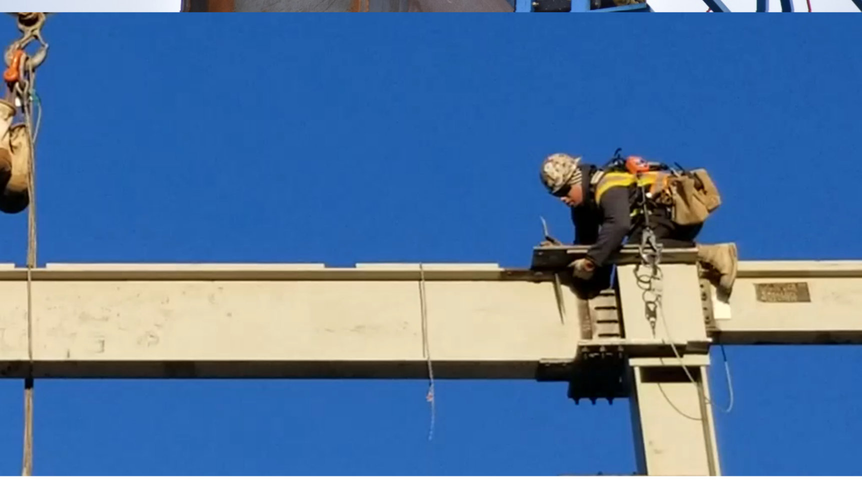
Functional Recovery Costs and Time (Design Earthquake)





Based on FEMA P-58 analysis
using the Nonlinear RHA results.

DuraFuse Frames Accelerate Construction Time

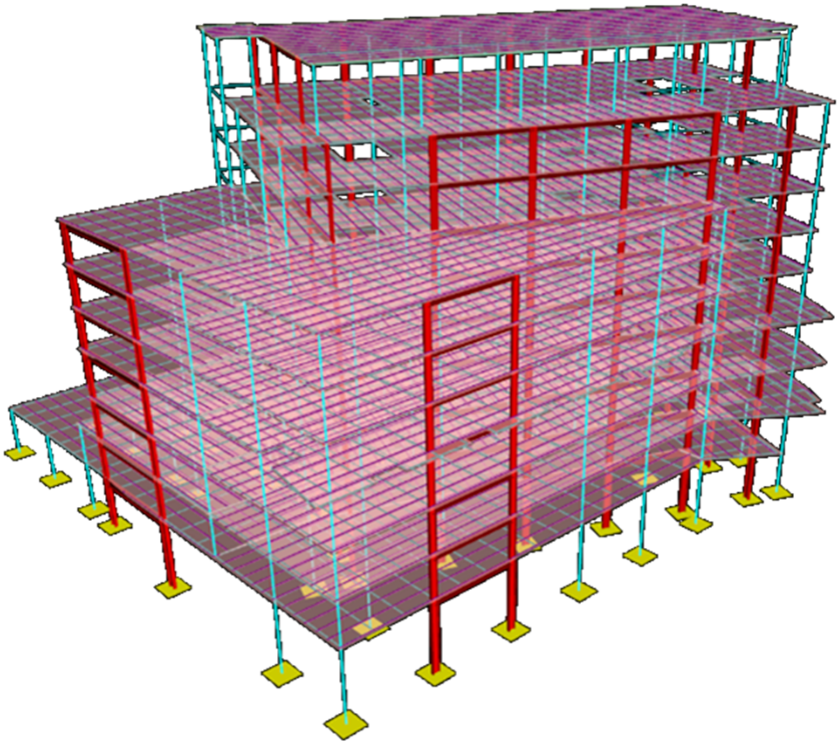


DuraFuse Frames Reduce Overall Frame Weight

- Up to 10% savings in frame weight
- Up to 15% savings in fabricated frame cost (including material and labor)
- Strategic weight optimization for the highest performance & cost benefit by targeting highest-cost items

DuraFuse Frames Reduce Beam Lateral Bracing

MOB in high seismic area
9 stories
128 moment frame beams



Other SMF **500+ Lateral brace points**
DuraFuse **144 Lateral brace points**

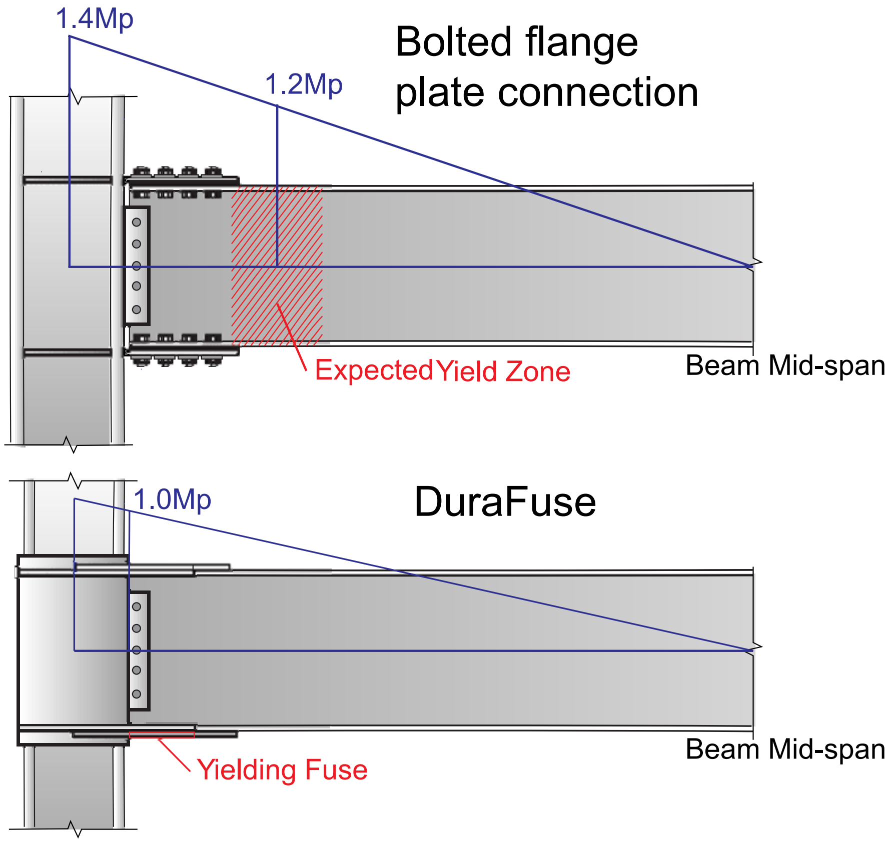
Example

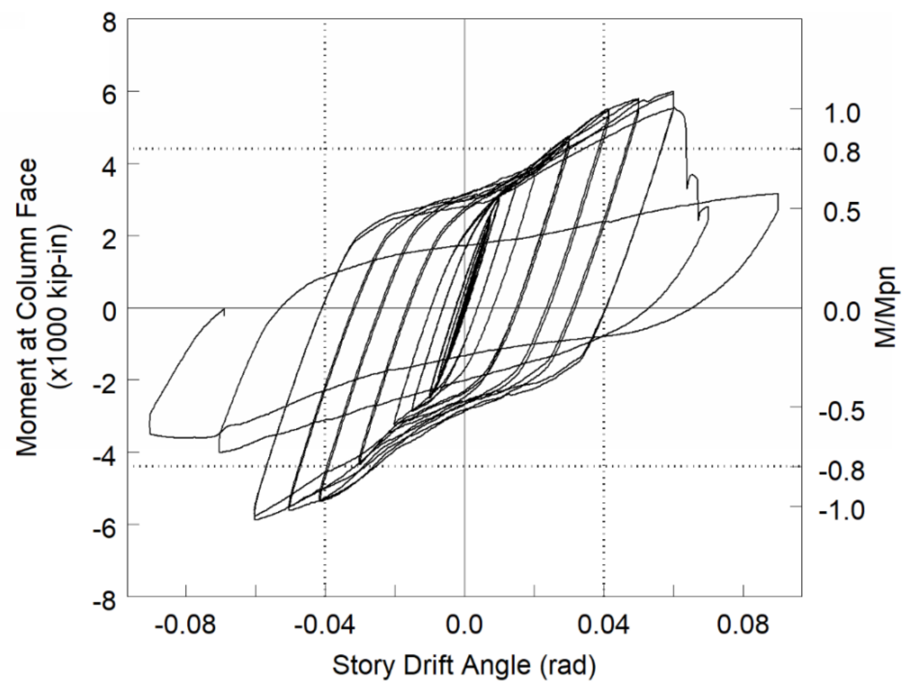
System	Beam	Length (ft)	Braces Req'd
Other SMF	W24x55	30	5
DuraFuse SMF	W21x55	30	1

DuraFuse Frames Eliminates Protected Zones on Beams

Other Connections

Strong-Column Weak-Beam Check



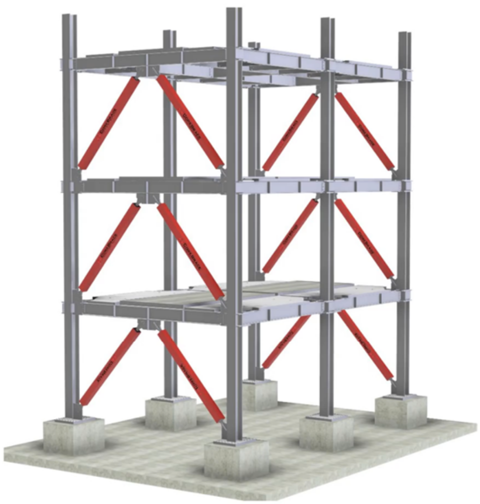


Specimen E1.2: Moment at Column Face

DuraFuse Frames Design Procedure

- 20 Step Process checking all critical limit states
- Results in FR connections where the beams and columns remain essentially elastic
- Maximum probable moment at the face of the column will not exceed M_P of the beam
- Cover plates provide essentially “rigid” panel zone behavior, this assumption is validated
- DuraFuse Engineers design process includes a genetic optimization algorithm to optimize the beams, columns and connections


DURAFUSE
FRAMES
DURAFUSE
FRAMES
Miller
Shake Table Access
Authorized Personnel ONLY!



Modular Testbed Building (MTB²)
NHERI@UC San Diego LHPOST6

Configuration SMF+CB
1994 Northridge Earthquake, Rinaldi Receiving Station
EQ Scale Factor: 1.00X, 1.00Y, 1.00Z
May 16, 2022

NSF

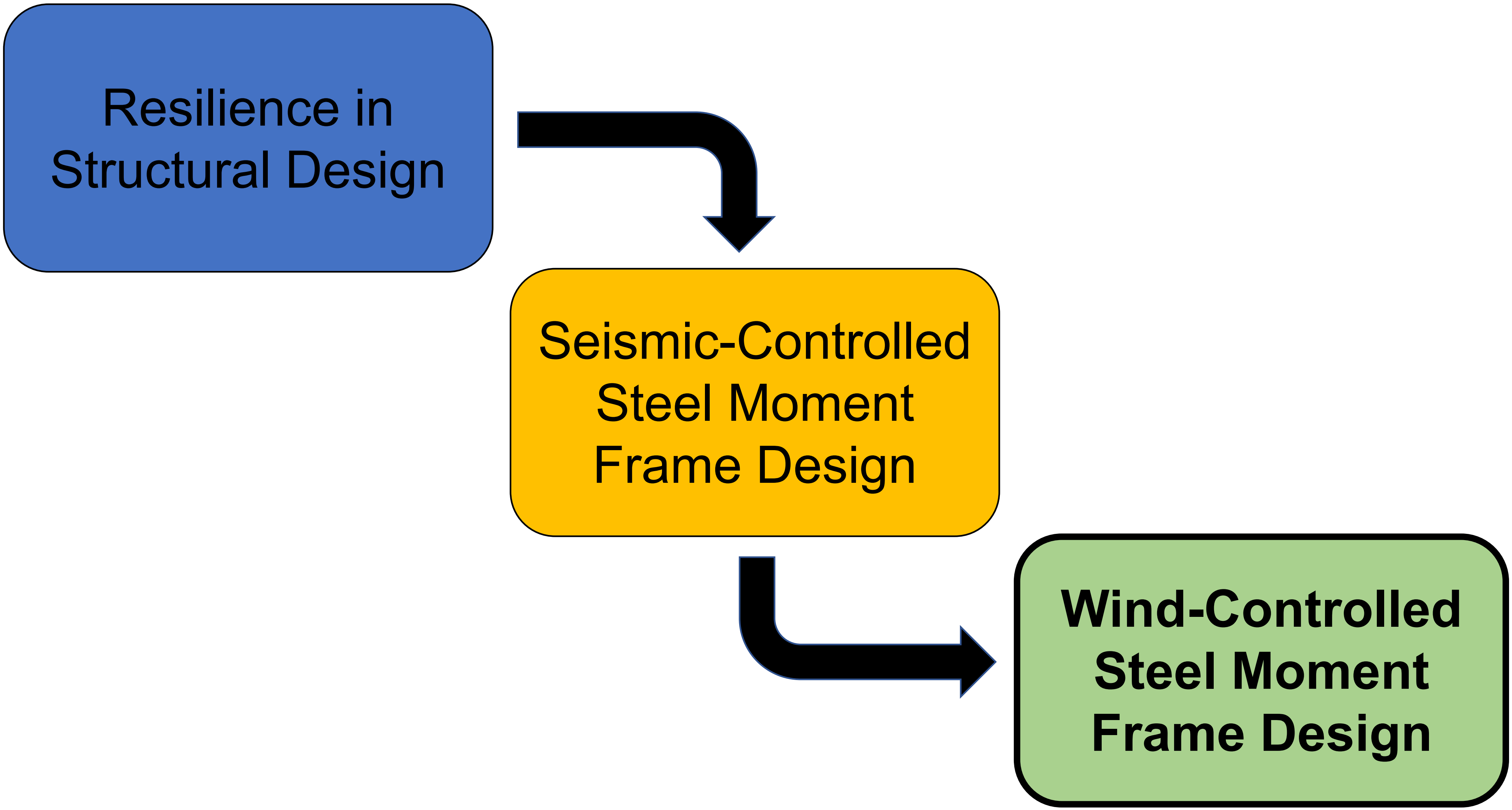
NHERI@ UCSan Diego

UC San Diego
JACOBS SCHOOL OF ENGINEERING
Structural Engineering

THE UNIVERSITY OF UTAH

Preliminary Findings

- Experienced ~2% story Drift
- No beam or column damage
- Good cumulative ductility capacity
- Easy fuse removal


Resilience in Structural Design
Seismic-Controlled Steel Moment Frame Design
Wind-Controlled Steel Moment Frame Design

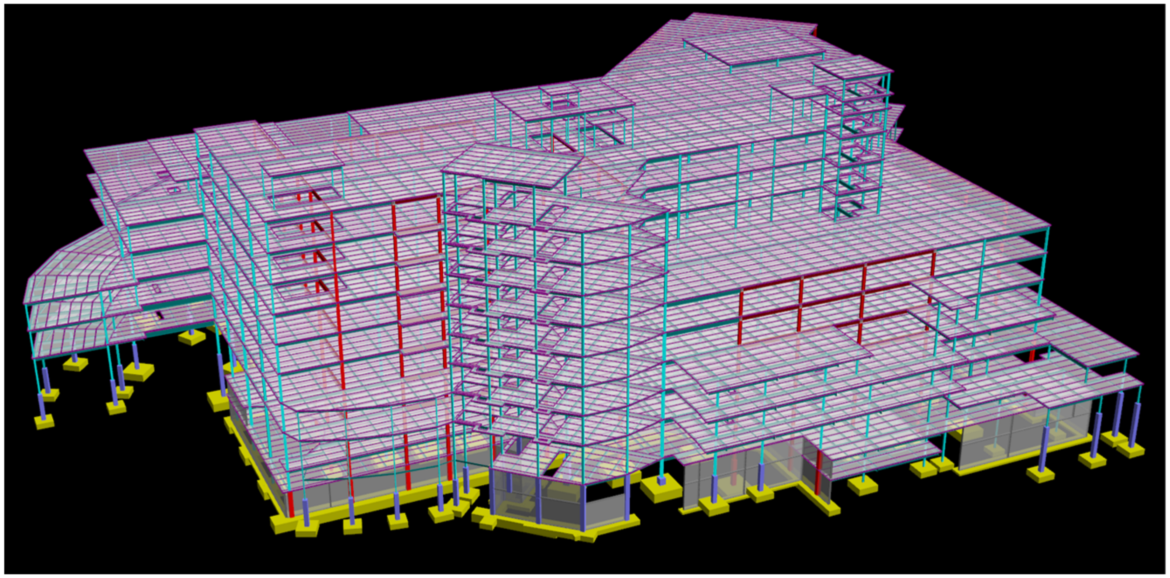
Wind-Controlled Design of Steel Moment Frames

Iterative process for design:

- Pick member sizes
- Check drift
- Check strength
- Adjust design and repeat

Then:

- Design Connections or Delegate Connection Design



Wind-Controlled Design of Steel Moment Frames

Why would you need a proprietary moment connection for wind-controlled design?

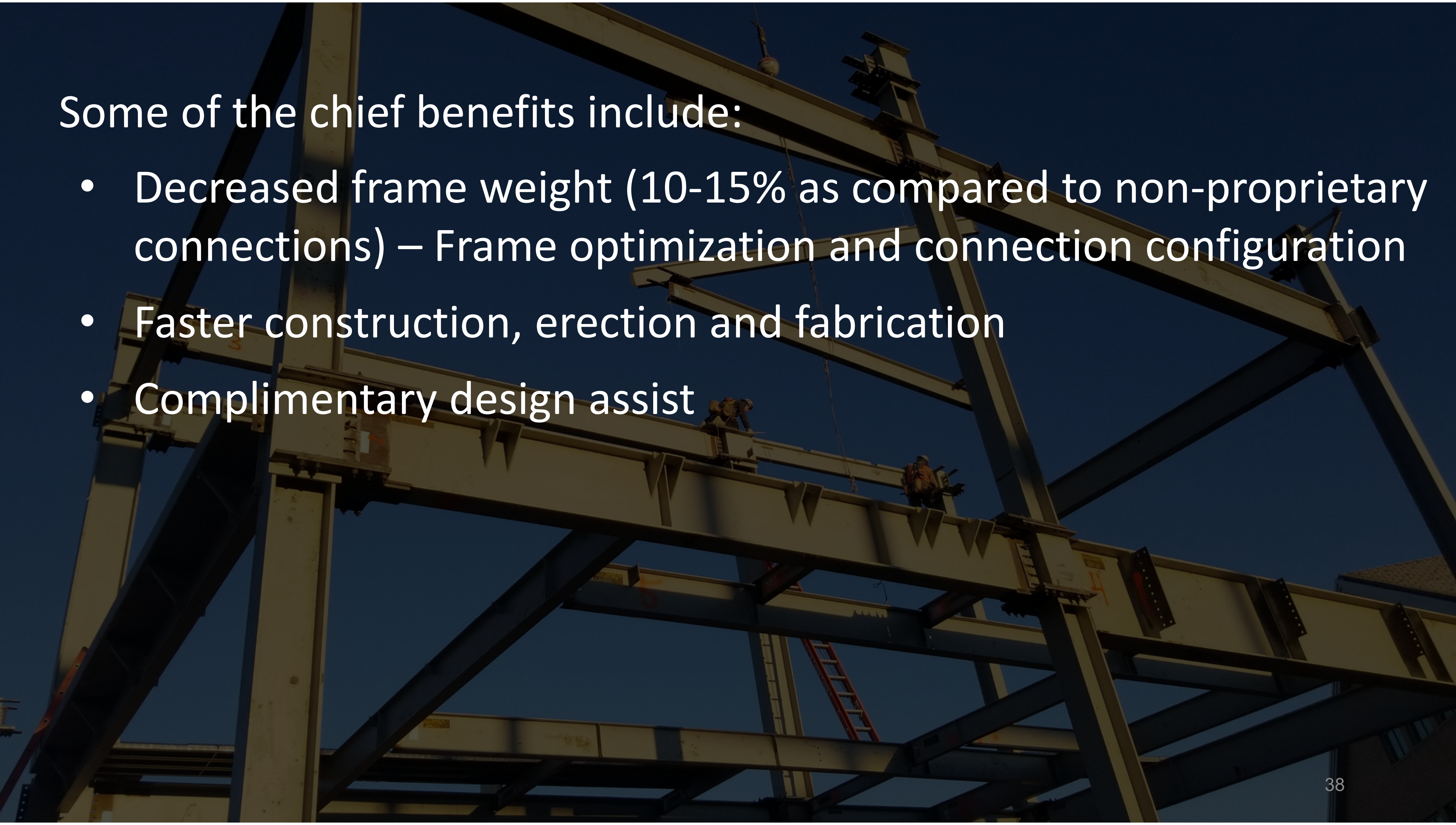
~~Prequalification~~

~~Seismic Resilience~~

Economic Benefits

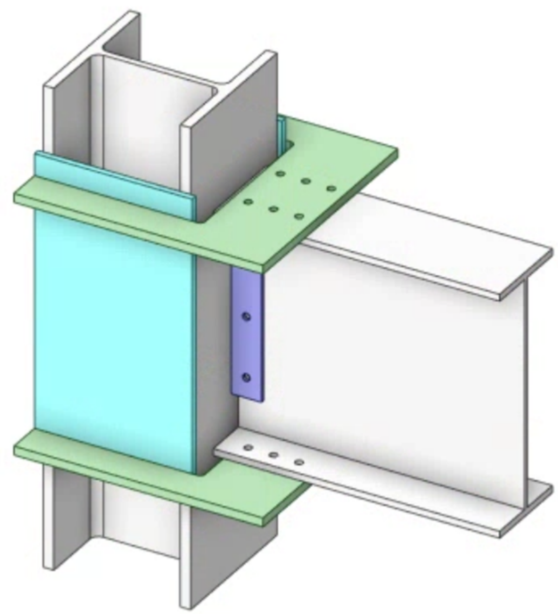
Some of the chief benefits include:

- Decreased frame weight (10-15% as compared to non-proprietary connections) – Frame optimization and connection configuration
- Faster construction, erection and fabrication
- Complimentary design assist



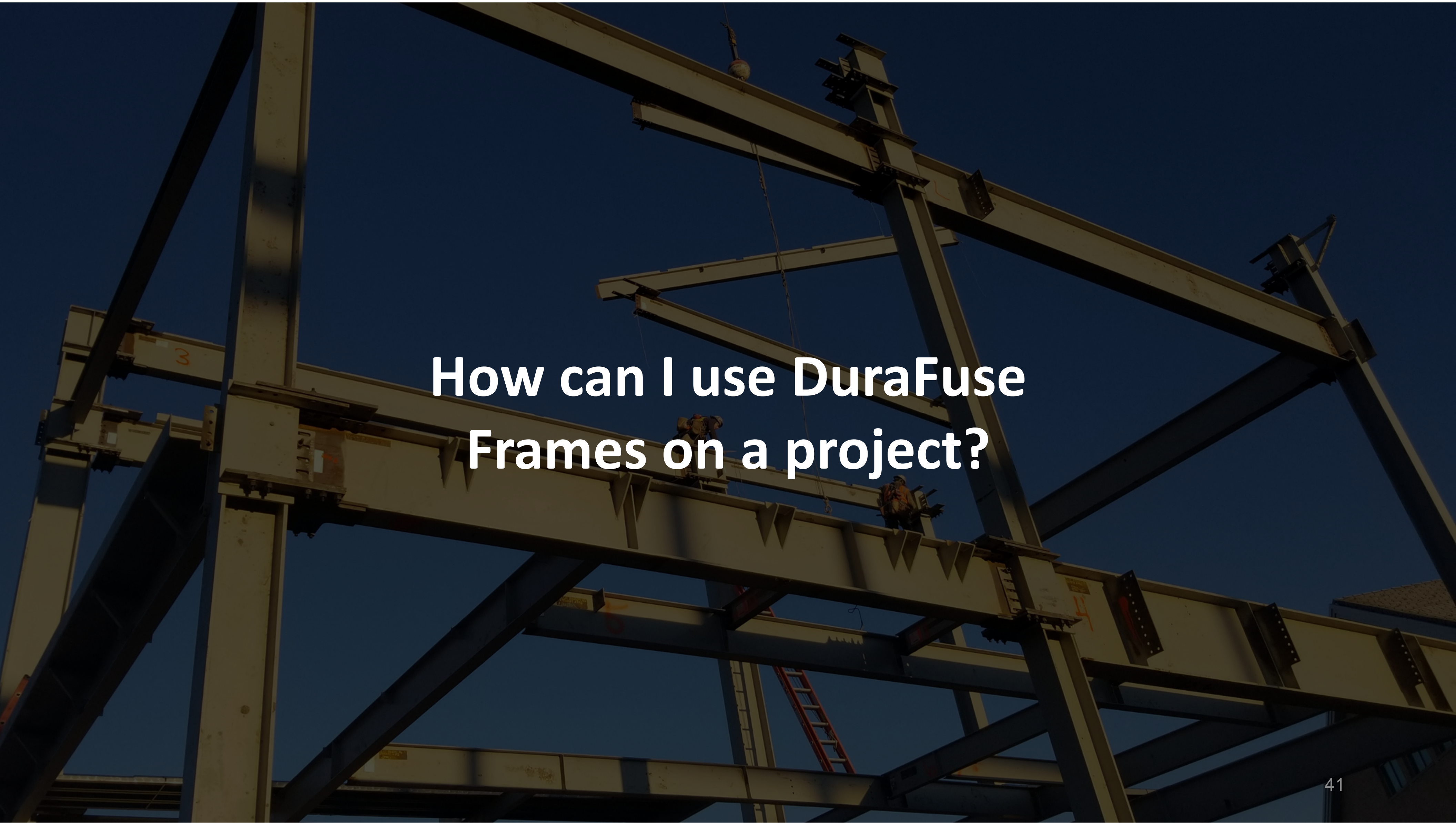
Wind-Controlled Design of Steel Moment Frames

- Optimized design process and connection configuration results in frame weight savings
- Fabrication is simplified compared to other proprietary connections
- Fully field-bolted connection results in quick frame erection
- Complimentary assessment of whether DuraFuse Frames will add value



Case Study – Las Vegas Health Facilities (MOB)

- Three buildings (D, C, and T) in different locations in Las Vegas, NV
- Building frame is nearly identical for all three sites
- The DuraFuse design process assessed the best solution for each building
- Site geotechnical conditions varied causing different designs to be optimal:
  - Building D: Wind Controlled, R=3 Connection in both directions
  - Building C: Seismic Controlled, R=8 Connection in both directions
  - Building T: Seismic and Wind each controlled one direction of the building, both R=3 and R=8 were used



How can I use DuraFuse Frames on a project?

DuraFuse Frames Engineers Optimize the Frame Design

Preliminary Design – We Provide

- Sizing of columns, beams and connections
- Total estimated frame weight (savings)
- Preliminary detail sheets with connection schedules
- License fee (paid by fabricator, only if DuraFuse Frames are used)

- No cost to explore the option

DuraFuse Frames are Designed/Detailed with Typical Software

RAM Structural System

DuraFuse Frames Included in Jun 2020 release

ETABS/SAP

DuraFuse Frames Technical Bulletins provide modeling guidance to represent connections

RISA-3D

DuraFuse Frames Technical Bulletins provide modeling guidance to represent connections

Tekla® Structures

SDS2® A NEMETSCHEK COMPANY

DuraFuse Frames plug-in automatically details connections from schedule information

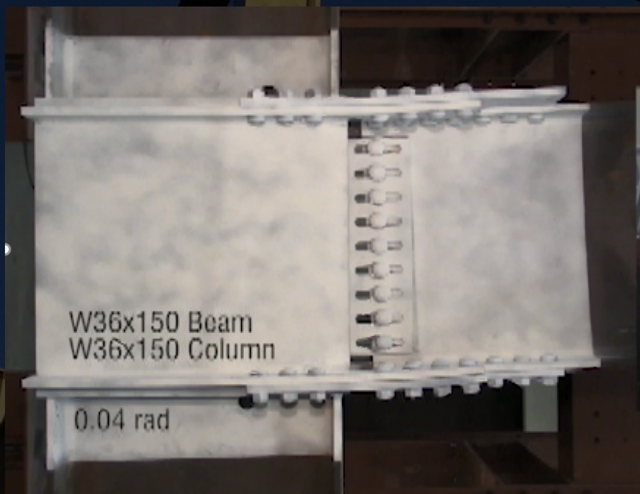
AUTODESK® REVIT®

DuraFuse Frames families provide accurate connection representation in model

DuraFuse is Fabricated by the Project Fabricator

DuraFuse Deliverables
- Stamped connection schedules and details
- Stamped calculations

DuraFuse Fabrication Roles
- Review and approve shop drawings
- Shop visits (as necessary)
- Site visits (as necessary)



The DuraFuse Frames Difference:

- Resilience
- Economy
- Performance

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DURAFUSE FRAMES
THE RESILIENT SEISMIC SOLUTION