Design of Seismic-Resistant Steel Building Structures

Brief Overview

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with the support of the
American Institute of Steel Construction.

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- Earthquake Effects on Structures
- Performance of Steel Buildings in Past Earthquakes
- Importance of Ductility
- Design Earthquake Forces: ASCE-7
- Steel Seismic Load Resisting Systems
- AISC Seismic Provisions

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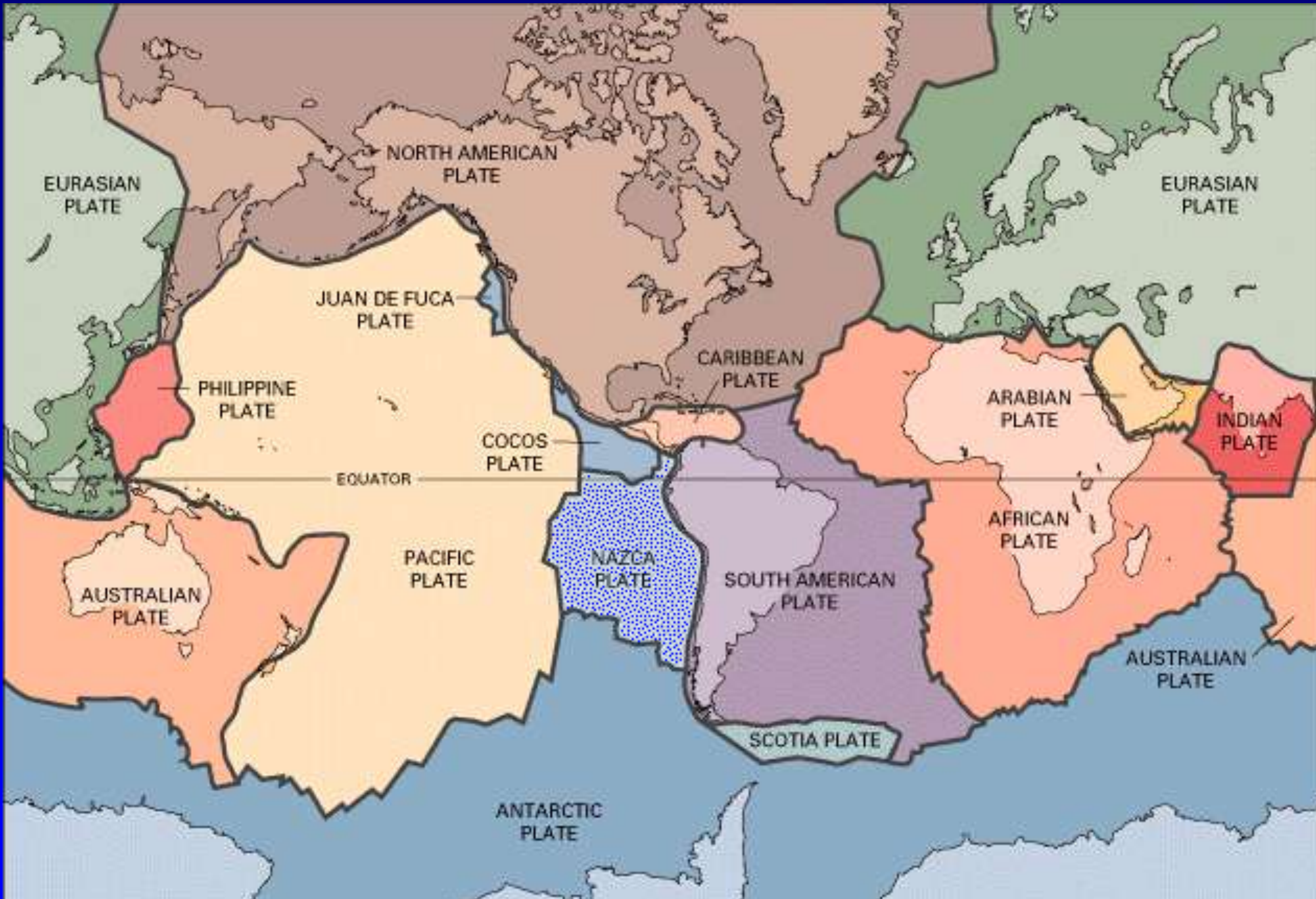
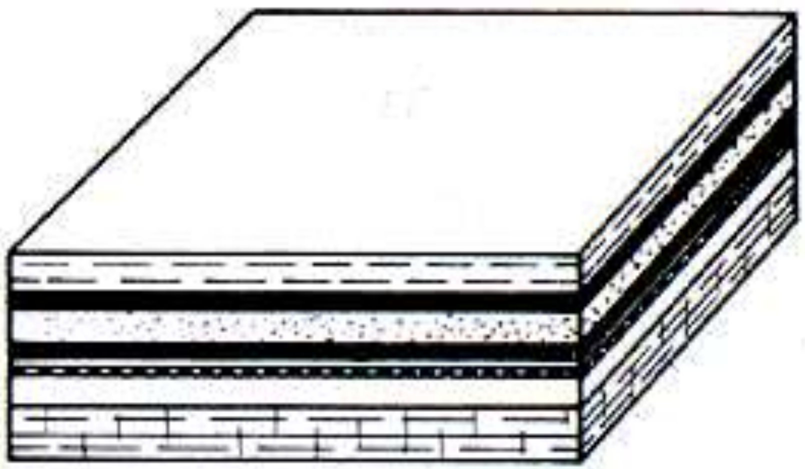
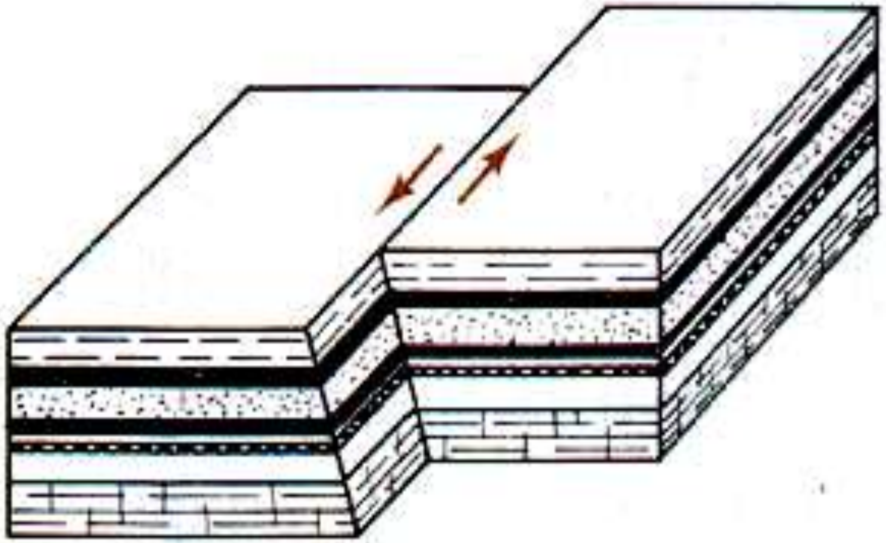
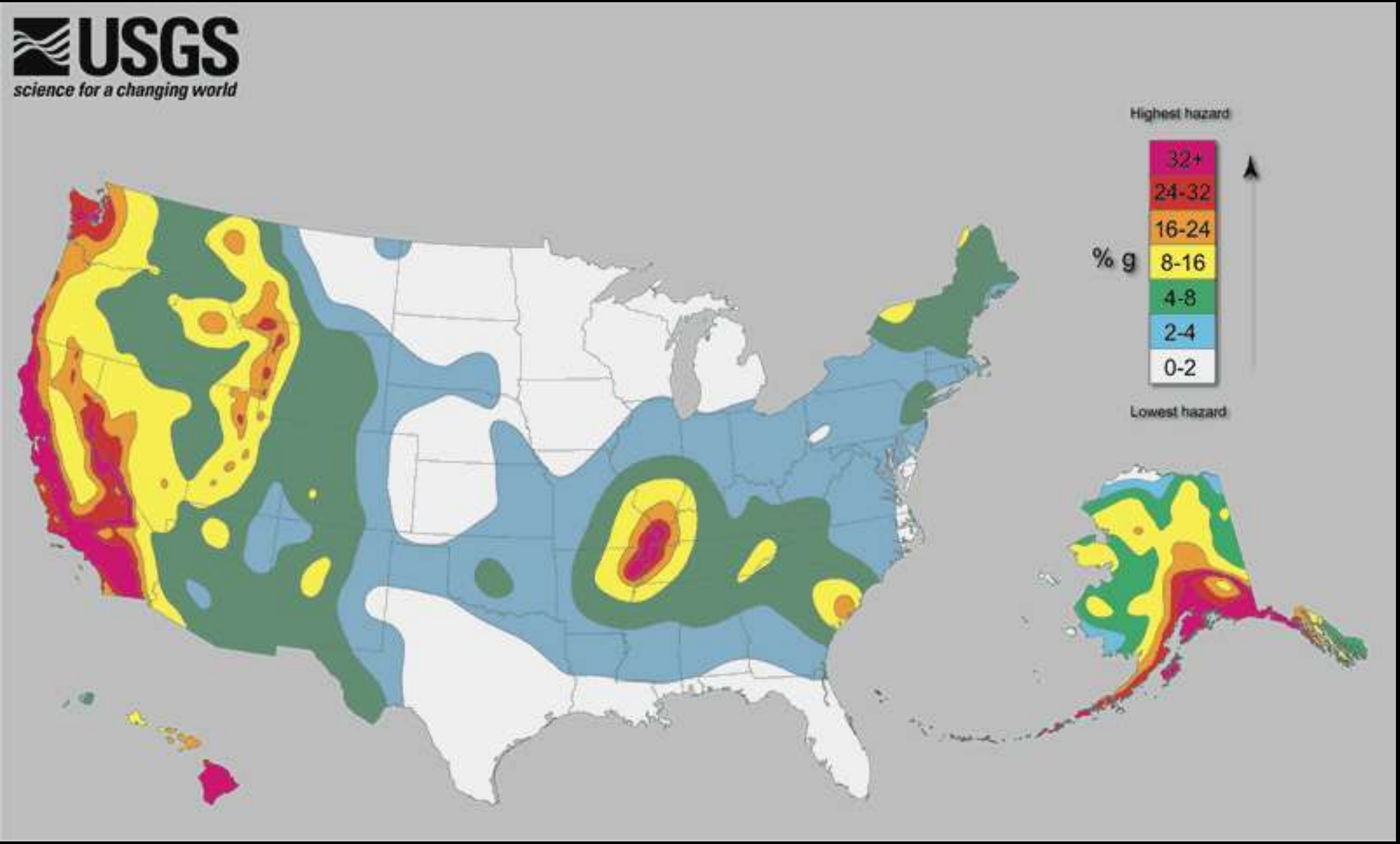
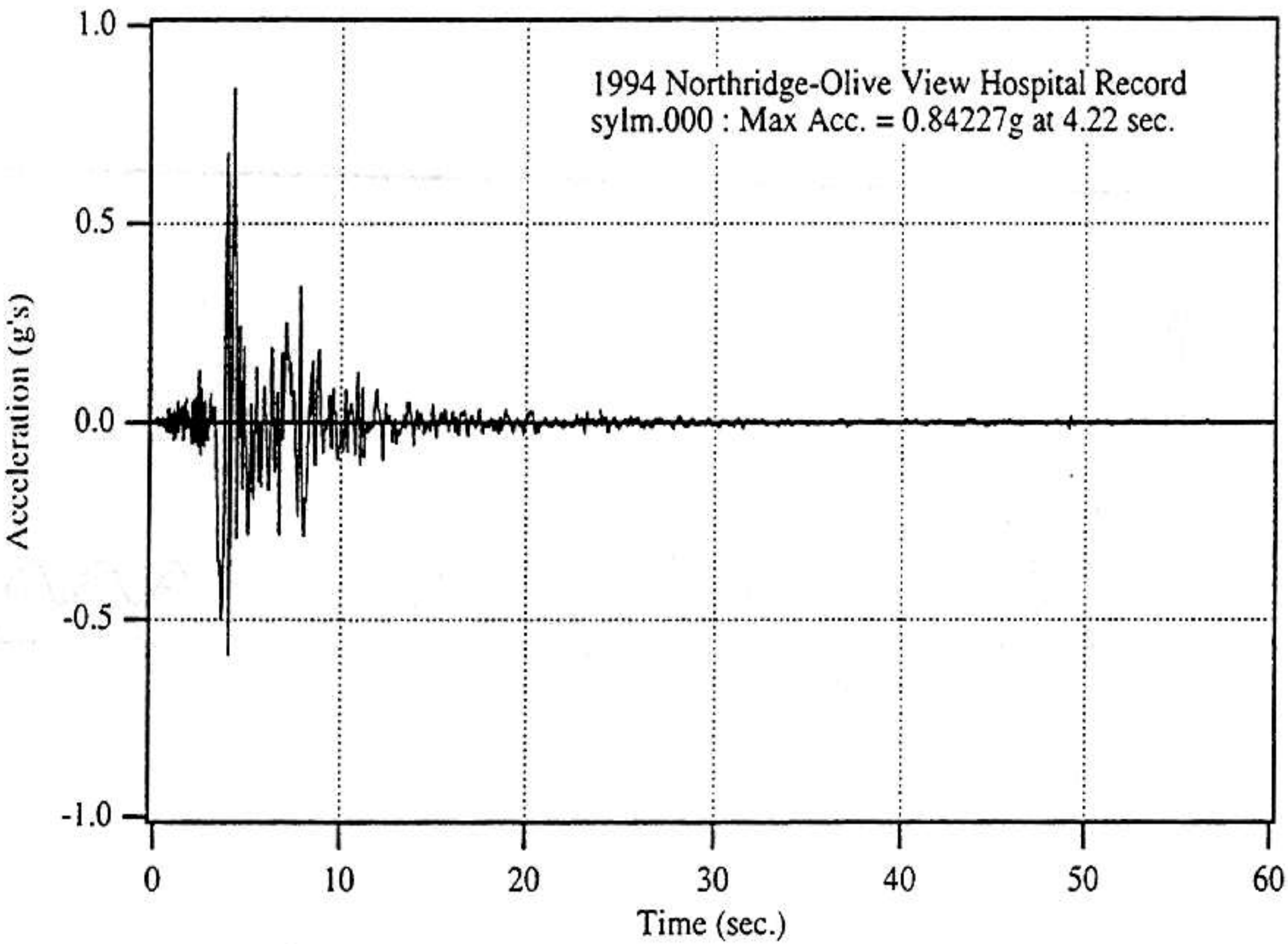

NORTH AMERICAN PLATE
EURASIAN PLATE
EURASIAN PLATE
JUAN DE FUCA PLATE
CARIBBEAN PLATE
PHILIPPINE PLATE
ARABIAN PLATE
INDIAN PLATE
COCOS PLATE
EQUATOR
AFRICAN PLATE
PACIFIC PLATE
NAZCA PLATE
SOUTH AMERICAN PLATE
AUSTRALIAN PLATE
AUSTRALIAN PLATE
SCOTIA PLATE
ANTARCTIC PLATE

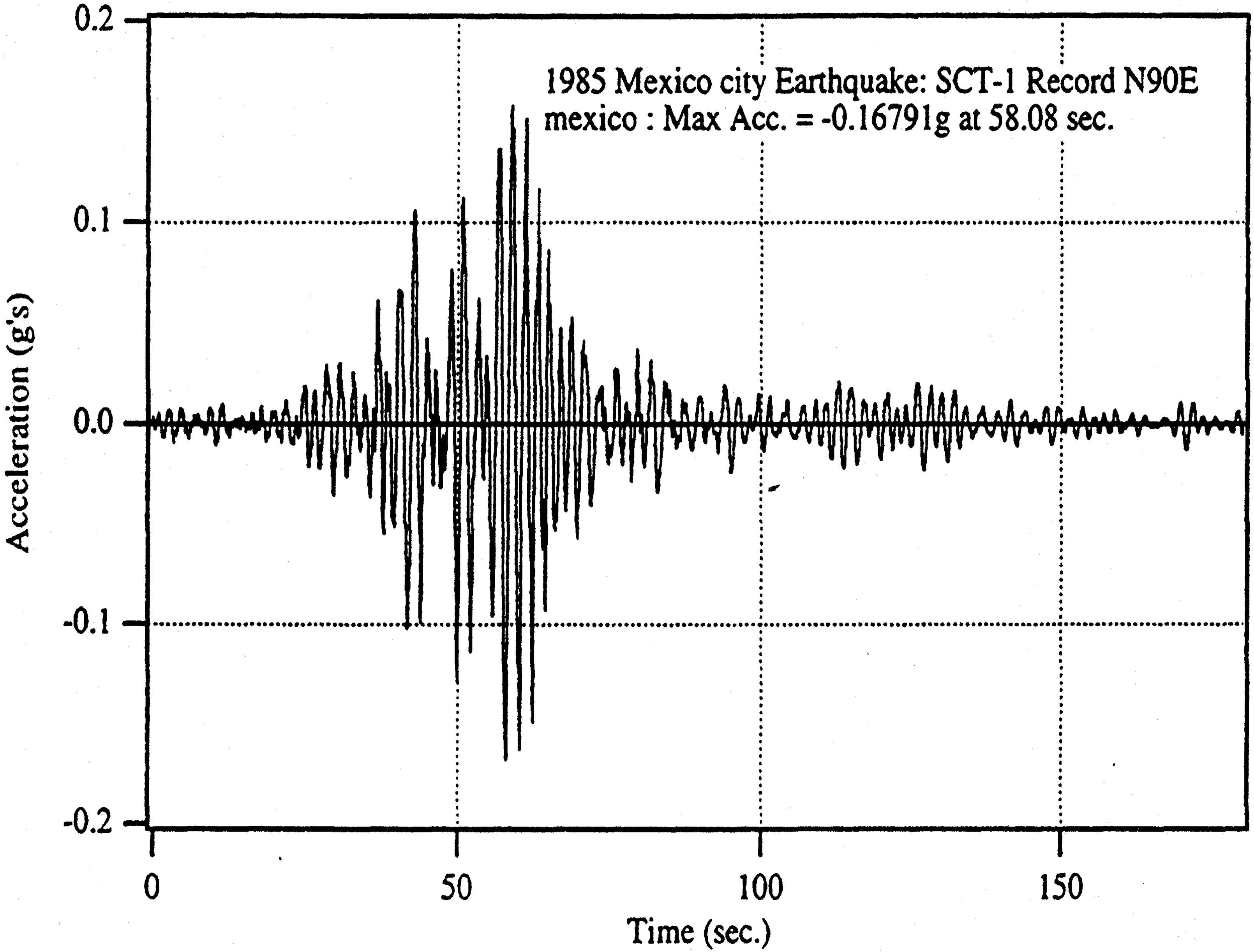


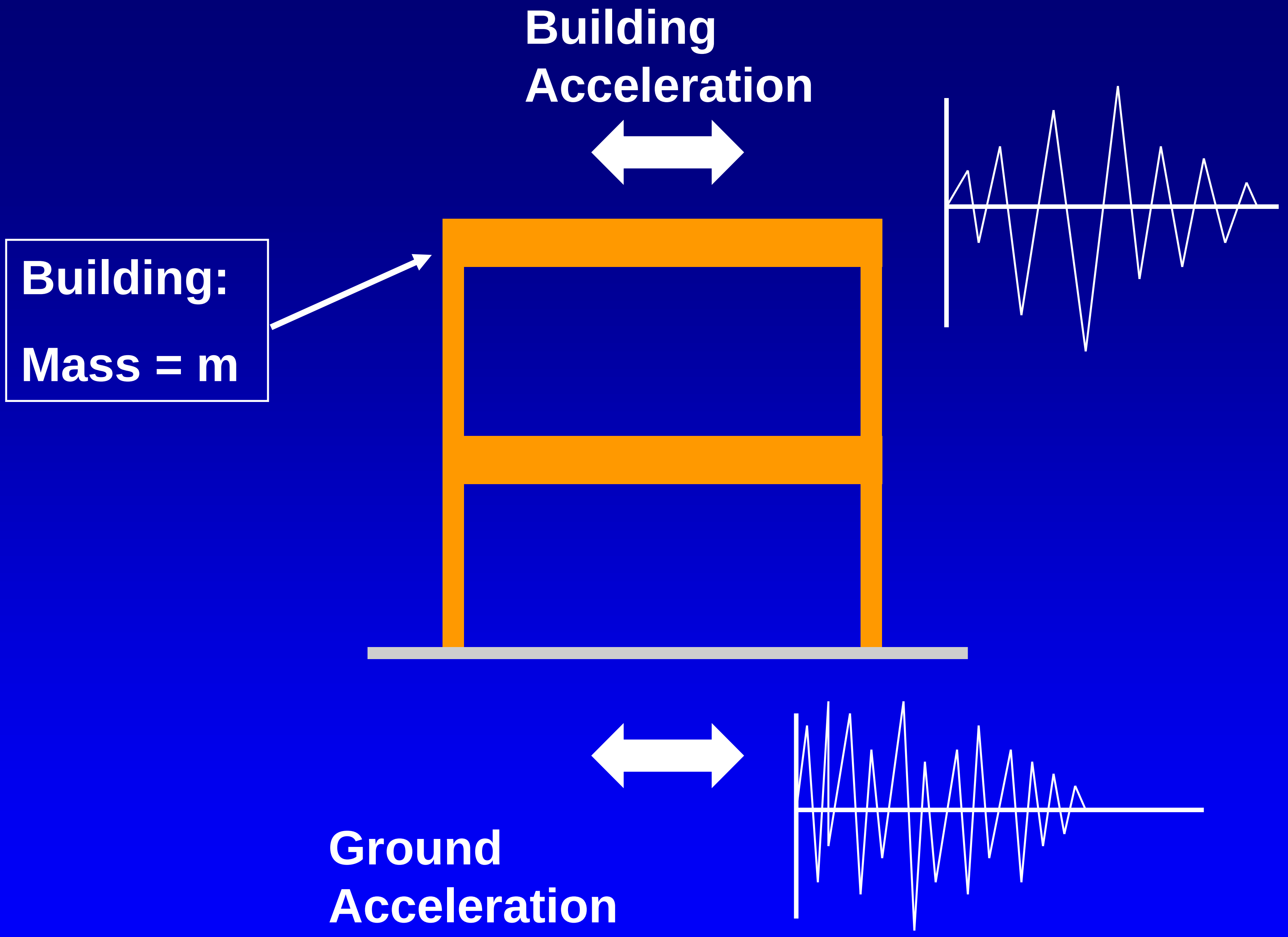


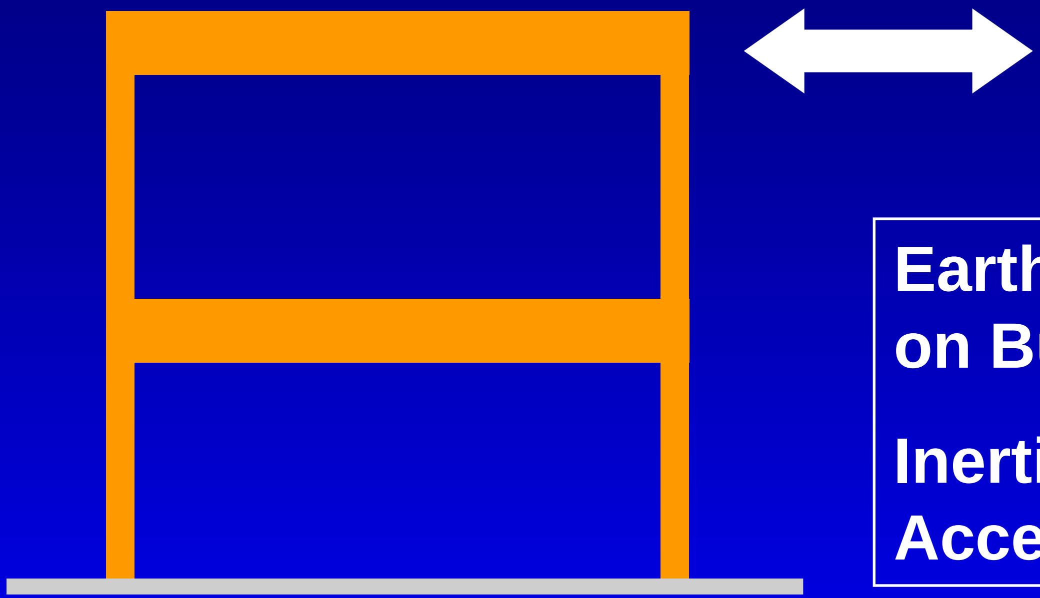

USGS
science for a changing world
Highest hazard
% g
32+
24-32
16-24
8-16
4-8
2-4
0-2
Lowest hazard



1994 Northridge-Olive View Hospital Record
sylm.000 : Max Acc. = 0.84227g at 4.22 sec.
Acceleration (g's)
1.0
0.5
0.0
-0.5
-1.0
0
10
20
30
40
50
60
Time (sec.)


1985 Mexico city Earthquake: SCT-1 Record N90E
mexico : Max Acc. = -0.16791g at 58.08 sec.
0.2
0.1
0.0
-0.1
-0.2
Acceleration (g's)
0
50
100
150
Time (sec.)


Building
Acceleration
Building:
Mass = m
Ground
Acceleration



$F = ma$

Earthquake Forces on Buildings:

Inertia Force Due to Accelerating Mass

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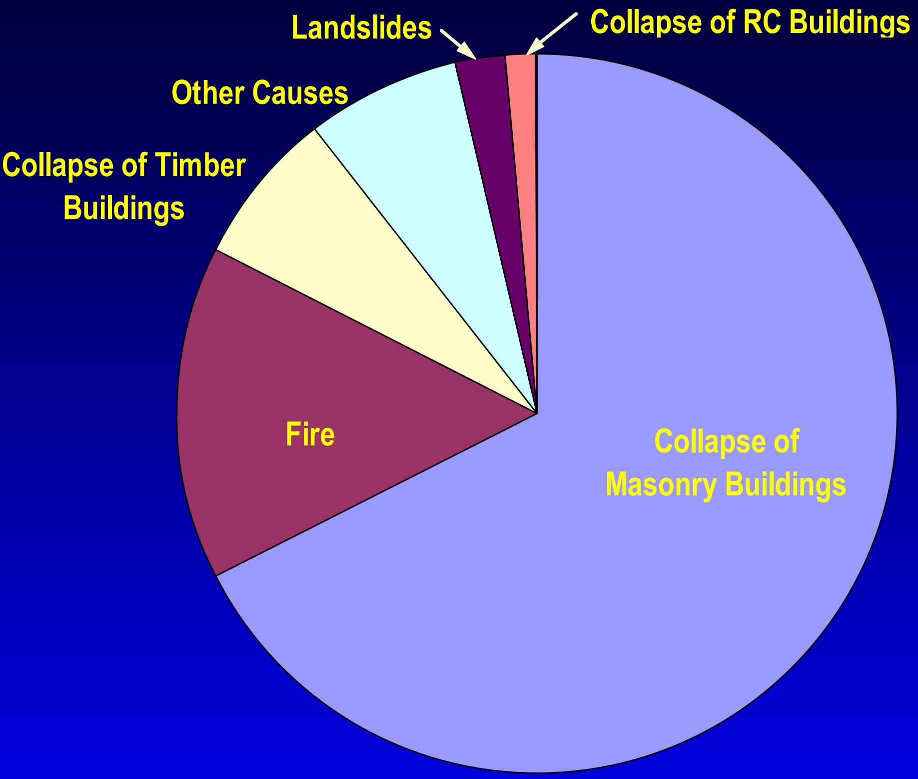
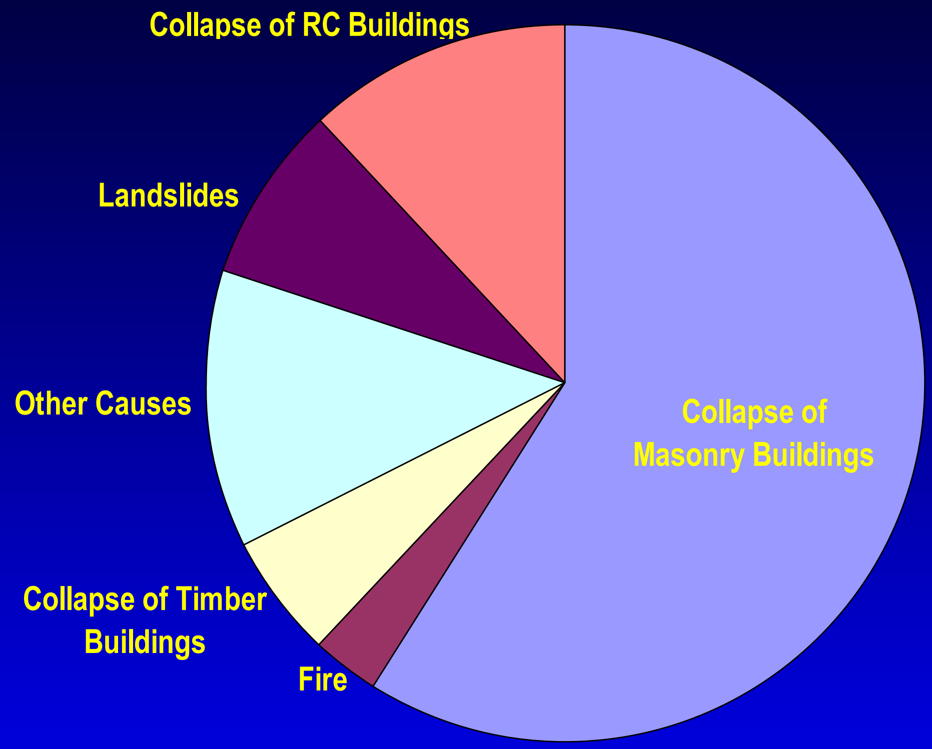




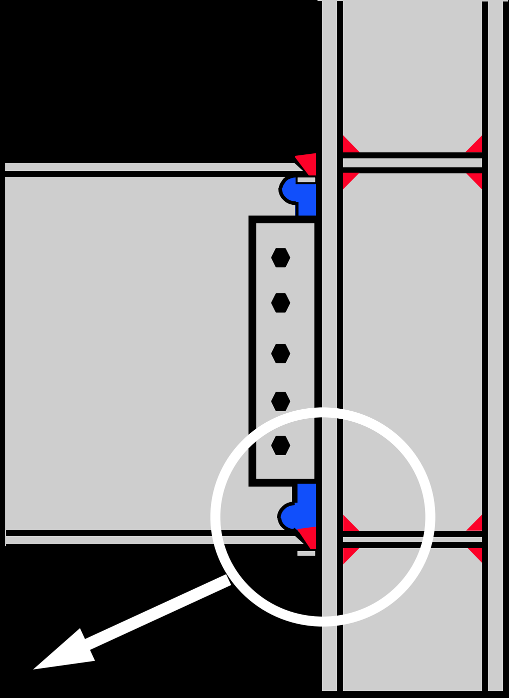
Earthquake Fatalities: 1900 - 1949

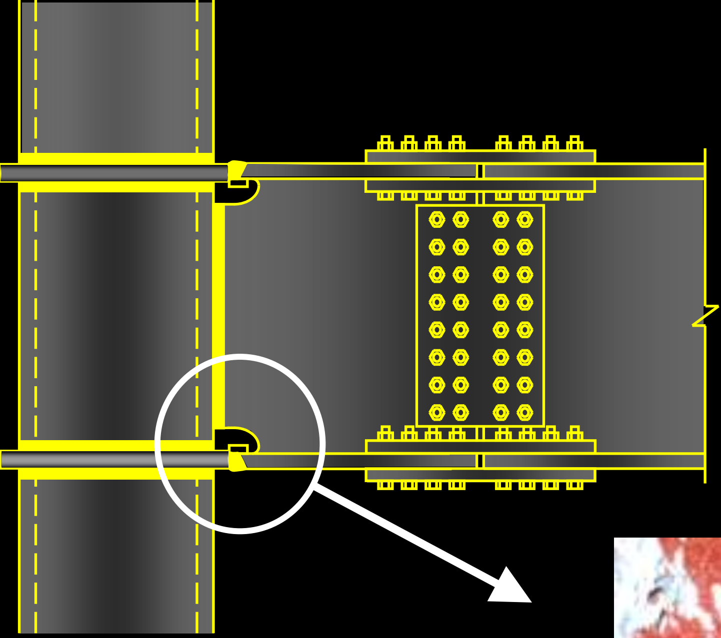
(795,000 Fatalities)

Earthquake Fatalities: 1950 - 1990

(583,000 Fatalities)

Causes of Earthquake Fatalities: 1900 to 1990



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Conventional Building Code Philosophy for Earthquake-Resistant Design

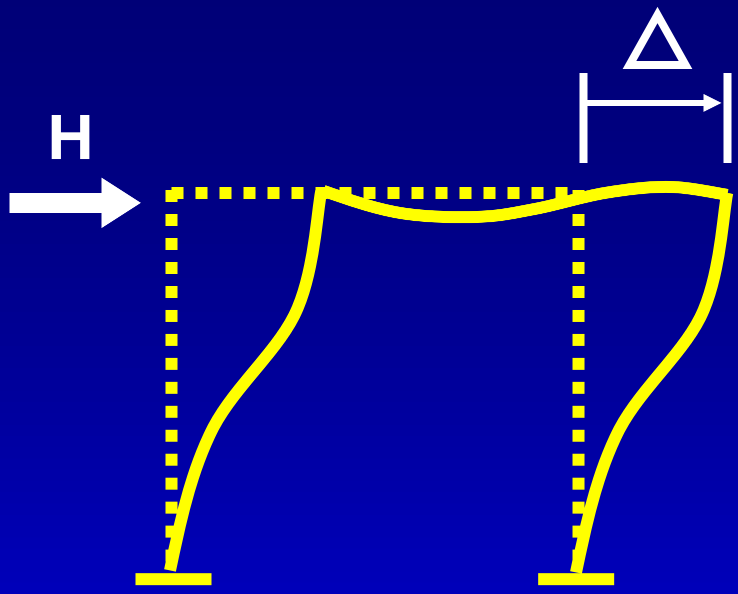
Objective: Prevent collapse in the extreme earthquake likely to occur at a building site.

Objectives are not to:

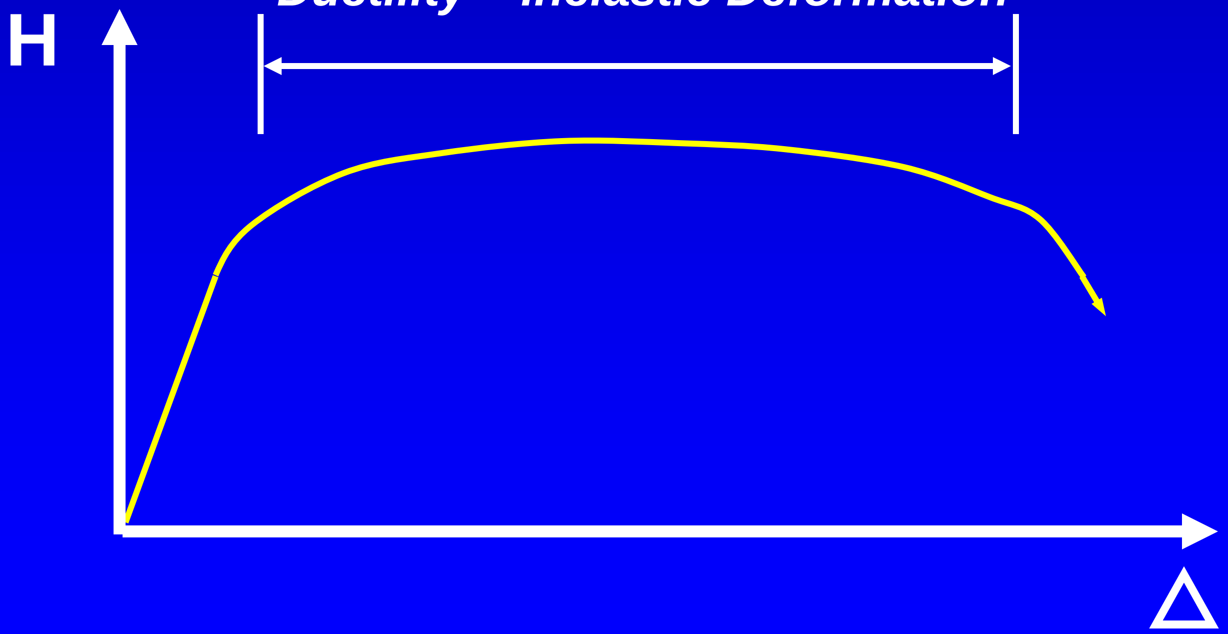
- limit damage
- maintain function
- provide for easy repair

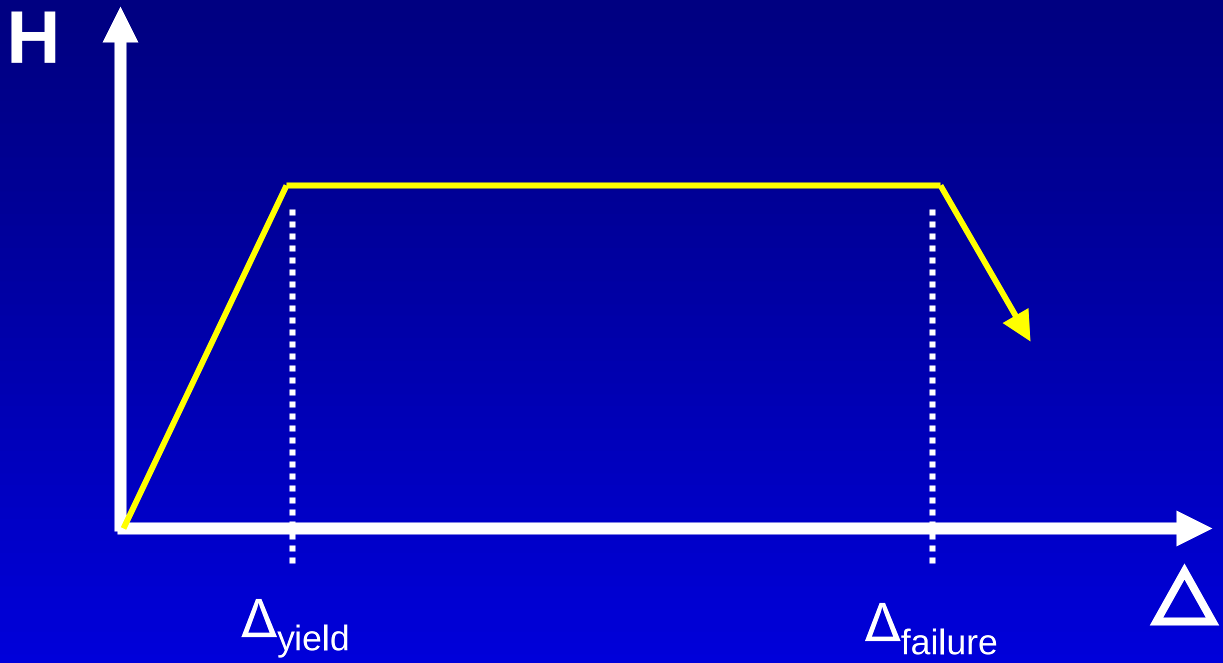
To Survive Strong Earthquake without Collapse:

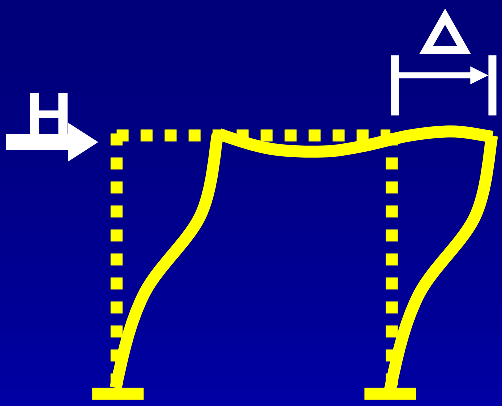
Design for Ductile Behavior



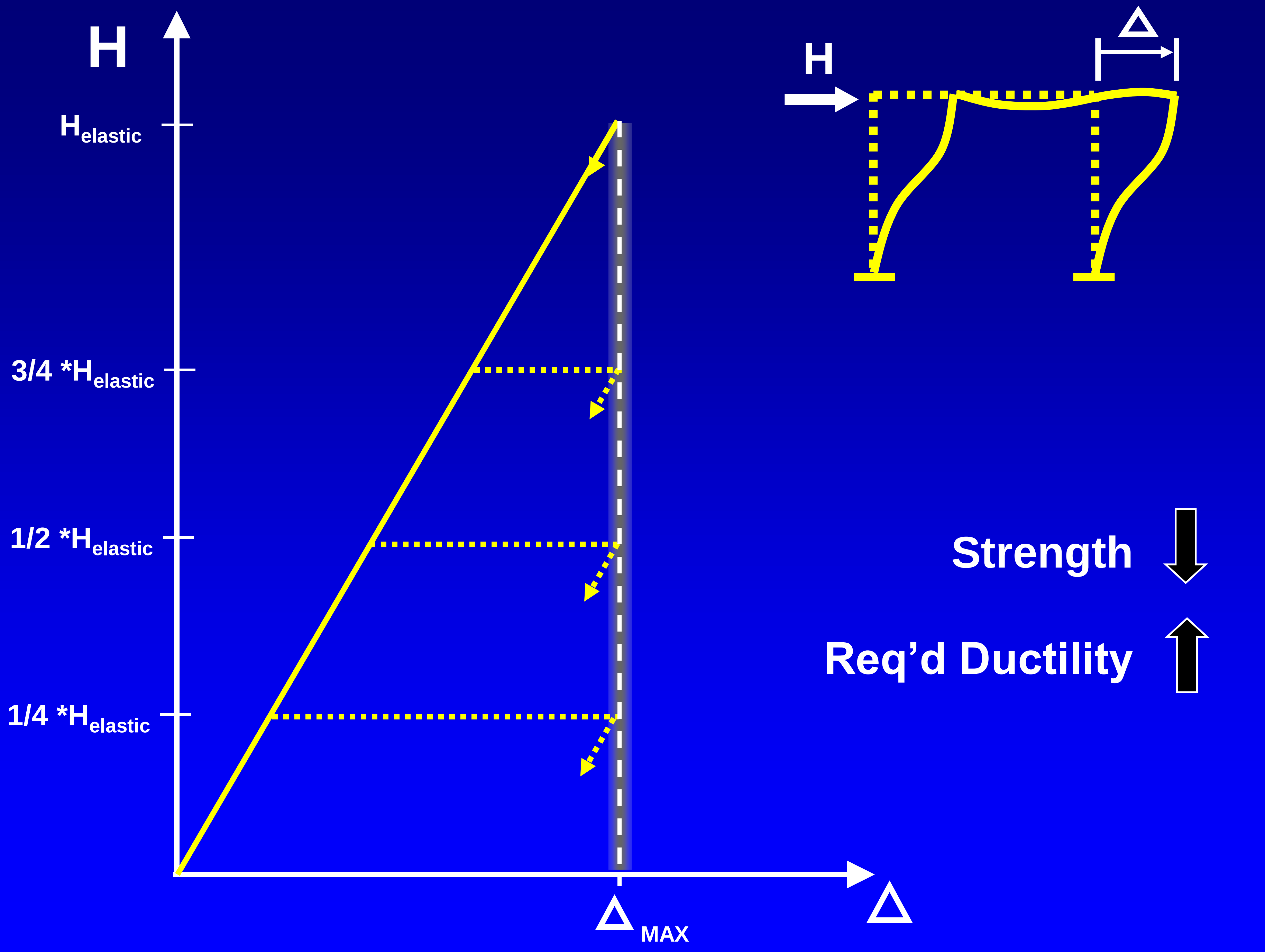
Ductility = Inelastic Deformation







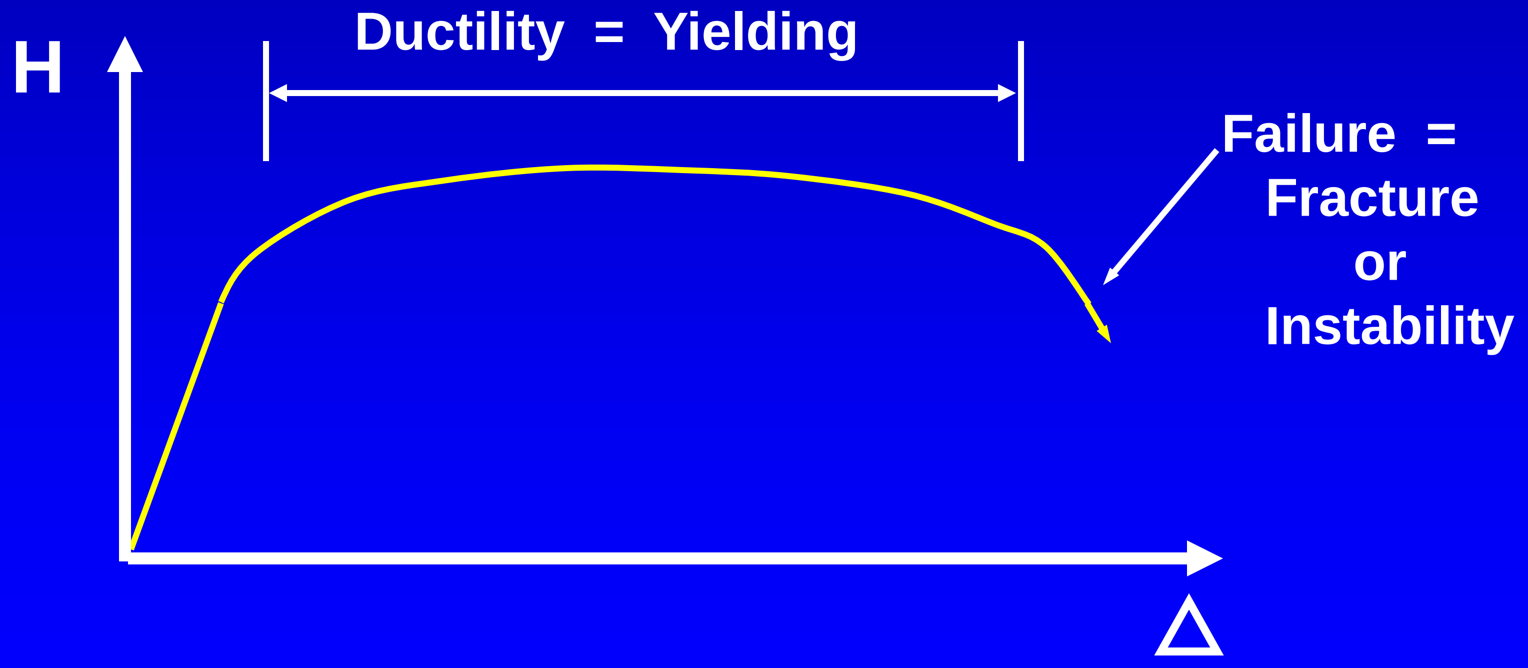
Ductility Factor $\mu = \dfrac{\Delta_{failure}}{\Delta_{yield}}$



H
H elastic
3/4 *H elastic
1/2 *H elastic
1/4 *H elastic
Δ MAX
Δ
H
Δ
Strength
Req'd Ductility

Ductility in Steel Structures: ***Yielding***

Nonductile Failure Modes: ***Fracture or Instability***



Developing Ductile Behavior:

- Choose frame elements ("fuses") that will yield in an earthquake.
- Detail "fuses" to sustain large inelastic deformations prior to the onset of fracture or instability (i.e. , detail fuses for ductility).
- Design all other frame elements to be stronger than the fuses, i.e., design all other frame elements to develop the plastic capacity of the fuses.

Key Elements of Seismic-Resistant Design

<u>**Required Lateral Strength**</u>

ASCE-7:

Minimum Design Loads for Buildings and Other Structures

<u>**Detailing for Ductility**</u>

AISC:

Seismic Provisions for Structural Steel Buildings

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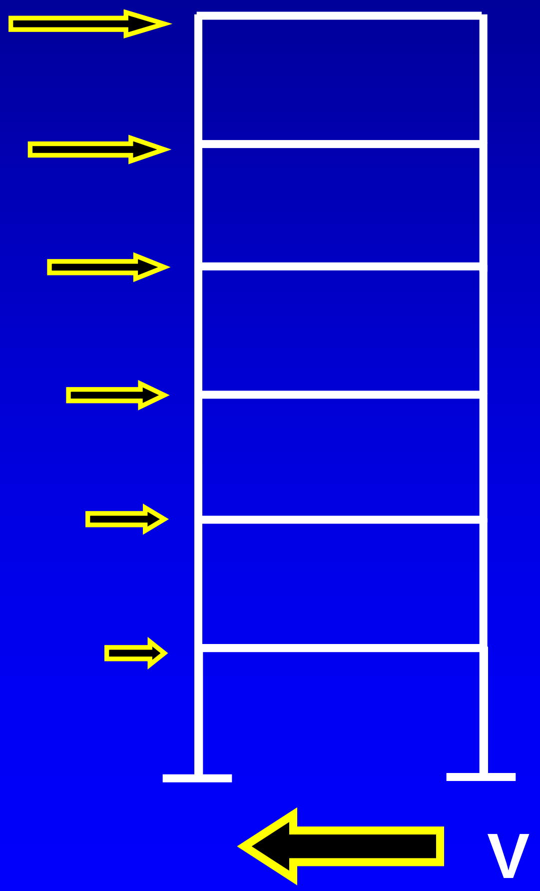
Design EQ Loads – Total Lateral Force per ASCE 7-05:

$$V = C_s W$$

$V =$ total design lateral force or shear at base of structure

$W =$ effective seismic weight of building

$C_S =$ seismic response coefficient



Design EQ Loads – Total Lateral Force per ASCE 7-05:

$$V = C_S W$$

$$C_S = \frac{S_{DS}}{\left(\frac{R}{I}\right)} \leq \begin{cases} \dfrac{S_{D1}}{T\left(\frac{R}{I}\right)} & \text{for } T \leq T_L \\ \dfrac{S_{D1} T_L}{T^2\left(\frac{R}{I}\right)} & \text{for } T > T_L \end{cases}$$

S_{DS} = design spectral acceleration at short periods

S_{D1} = design spectral acceleration at 1-second period

I = importance factor

T = fundamental period of building

T_L = long period transition period

R = response modification coefficient

R factors for Selected Steel Systems (ASCE 7):

SMF	(*Special Moment Resisting Frames*):	R = 8
IMF	(*Intermediate Moment Resisting Frames*):	R = 4.5
OMF	(*Ordinary Moment Resisting Frames*):	R = 3.5
EBF	(*Eccentrically Braced Frames*):	R = 8 or 7
SCBF	(*Special Concentrically Braced Frames*):	R = 6
OCBF	(*Ordinary Concentrically Braced Frames*):	R = 3.25
BRBF	(*Buckling Restrained Braced Frame*):	R = 8 or 7
SPSW	(*Special Plate Shear Walls*):	R = 7

Undetailed Steel Systems in Seismic Design Categories A, B or C (AISC Seismic Provisions not needed) R = 3

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Seismic Load Resisting Systems for Steel Buildings

- Moment Resisting Frames
- Concentrically Braced Frames
- Eccentrically Braced Frames
- Buckling Restrained Braced Frames
- Special Plate Shear Walls

MOMENT RESISTING FRAME (MRF)

Beams and columns with moment resisting connections; resist lateral forces by flexure and shear in beams and columns - i.e. by frame action.

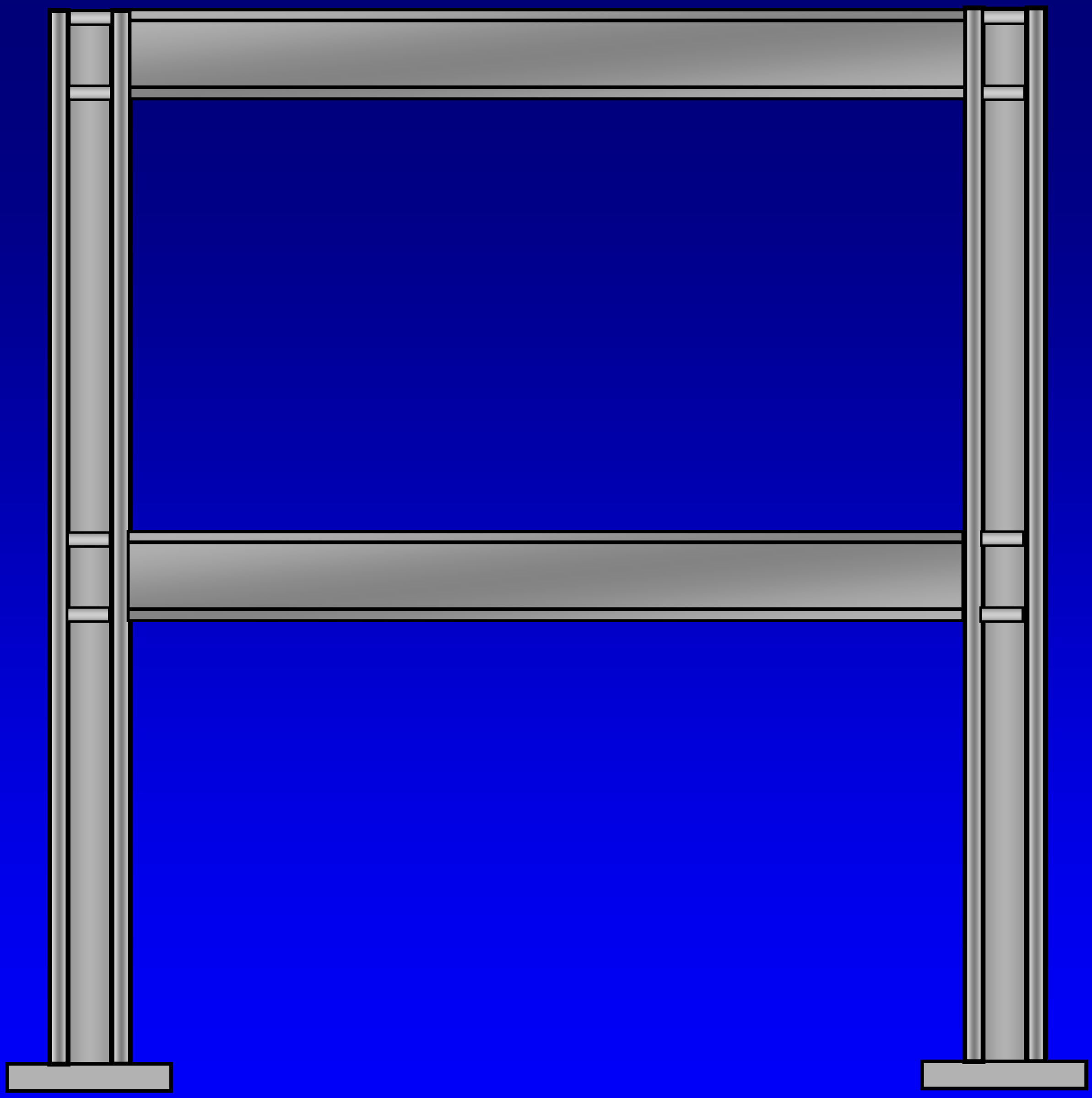
Develop ductility primarily by flexural yielding of the beams:

Advantages

- **Architectural Versatility**
- **High Ductility and Safety**

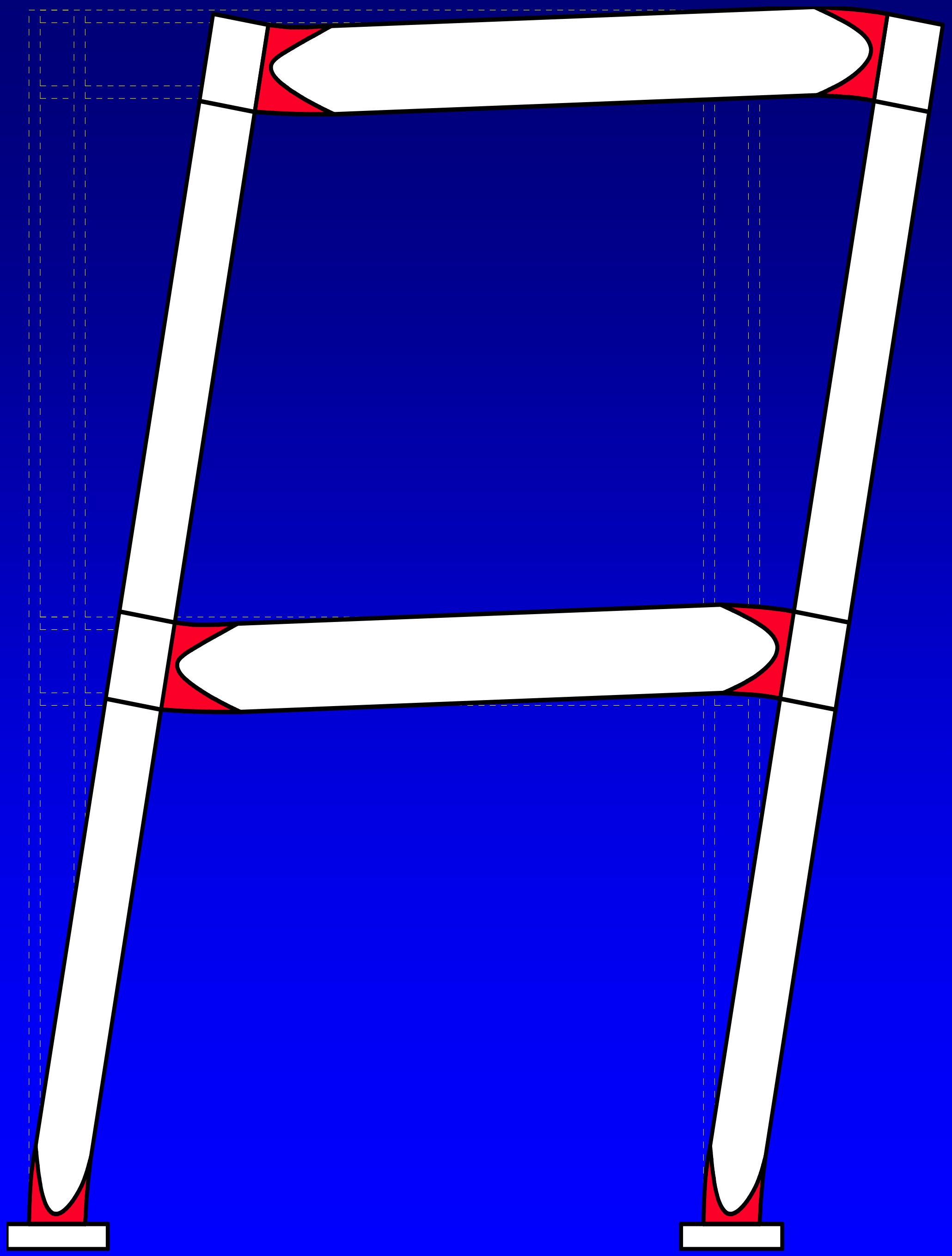
Disadvantages

- **Low Elastic Stiffness**



Moment Resisting Frame

Inelastic Response of a Steel Moment Resisting Frame



Concentrically Braced Frames (CBFs)

Beams, columns and braces arranged to form a vertical **truss**.
Resist lateral earthquake forces by truss action.

Develop ductility through inelastic action in **braces**.

- braces yield in tension
- braces buckle in compression

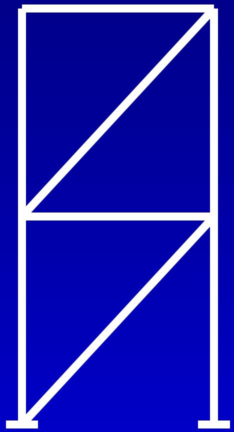
Advantages

- high elastic stiffness

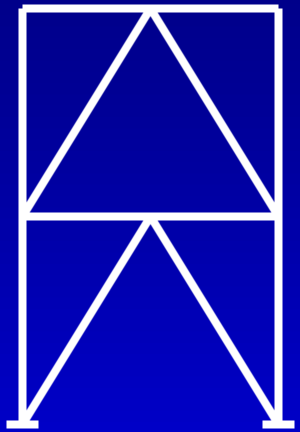
Disadvantages

- less ductile than other systems (SMFs, EBFs, BRBFs)
- reduced architectural versatility

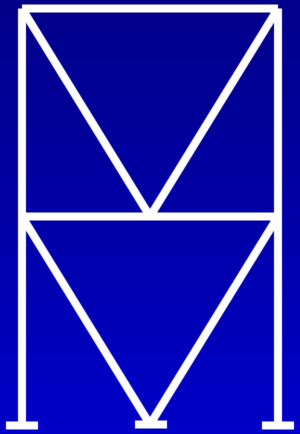
Types of CBFs



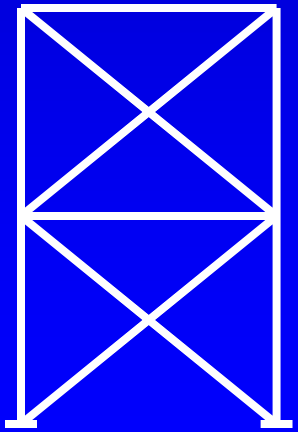
Single Diagonal



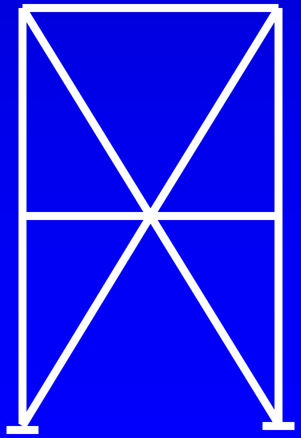
Inverted V- Bracing



V- Bracing



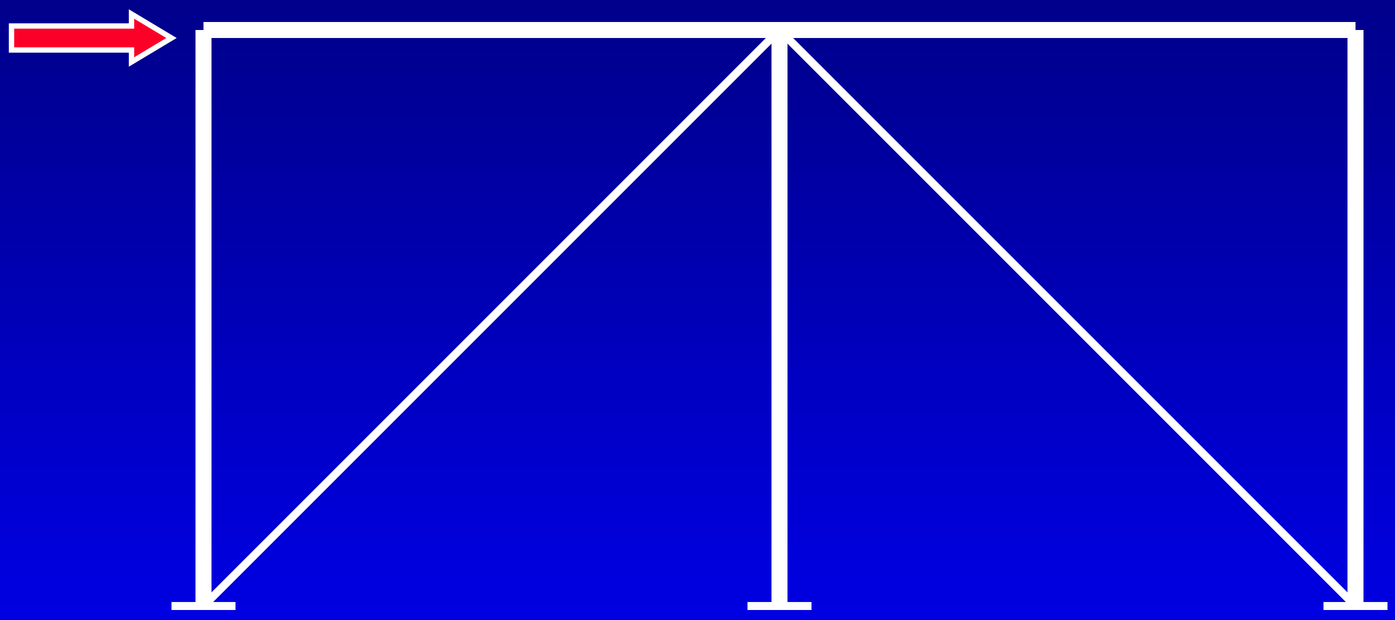
X- Bracing



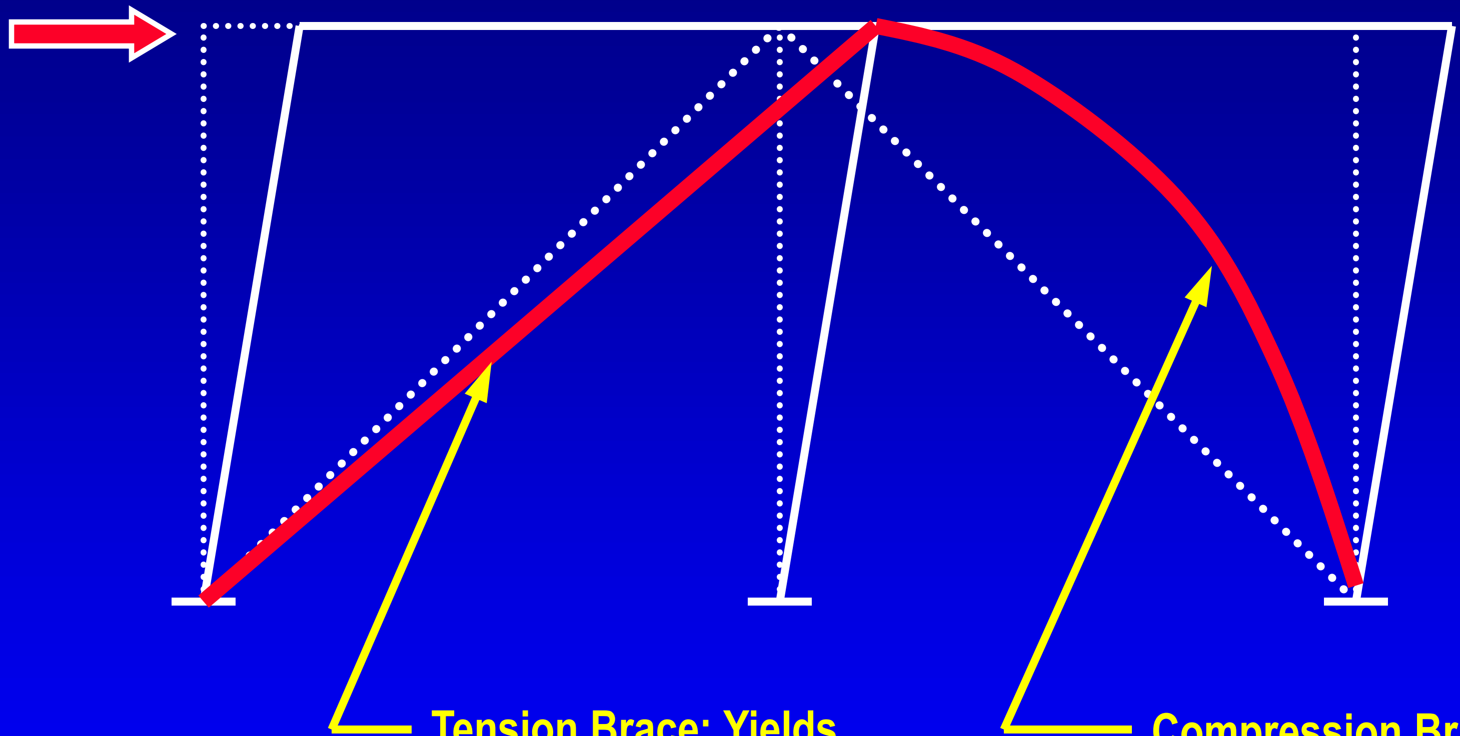
Two Story X- Bracing


SME STEEL
mobile mini

Inelastic Response of CBFs under Earthquake Loading



Inelastic Response of CBFs under Earthquake Loading

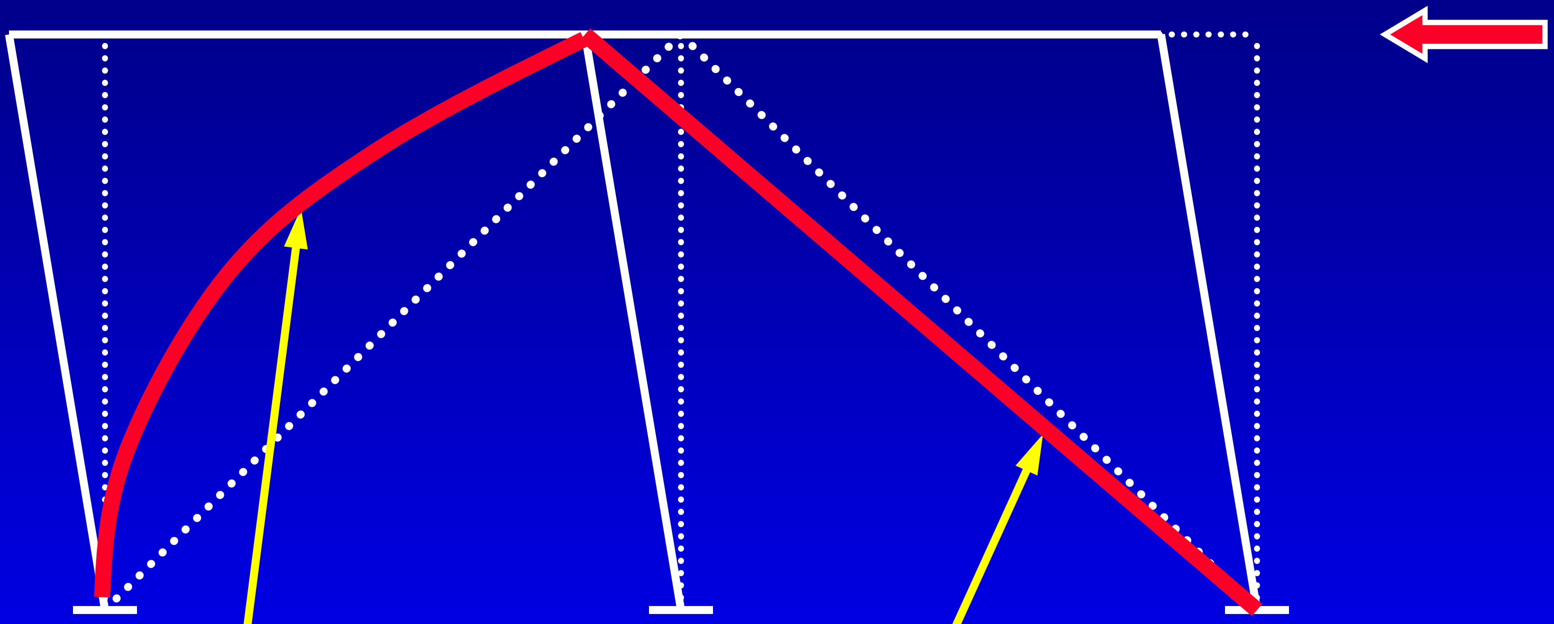


Tension Brace: Yields
(*ductile*)

Compression Brace: Buckles
(*nonductile*)

Columns and beams: remain essentially elastic

Inelastic Response of CBFs under Earthquake Loading



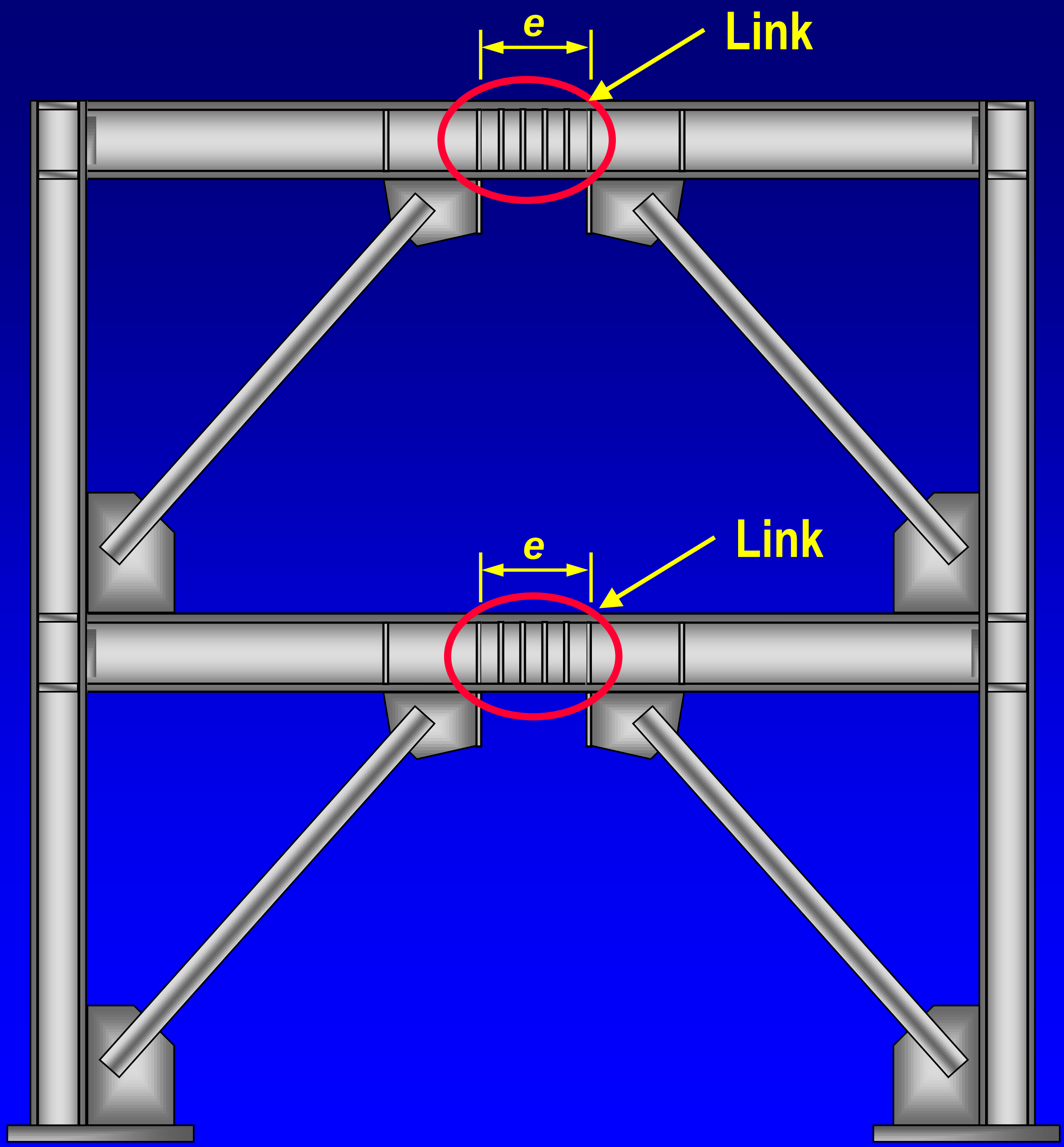
Compression Brace (previously in tension): Buckles (*nonductile*)

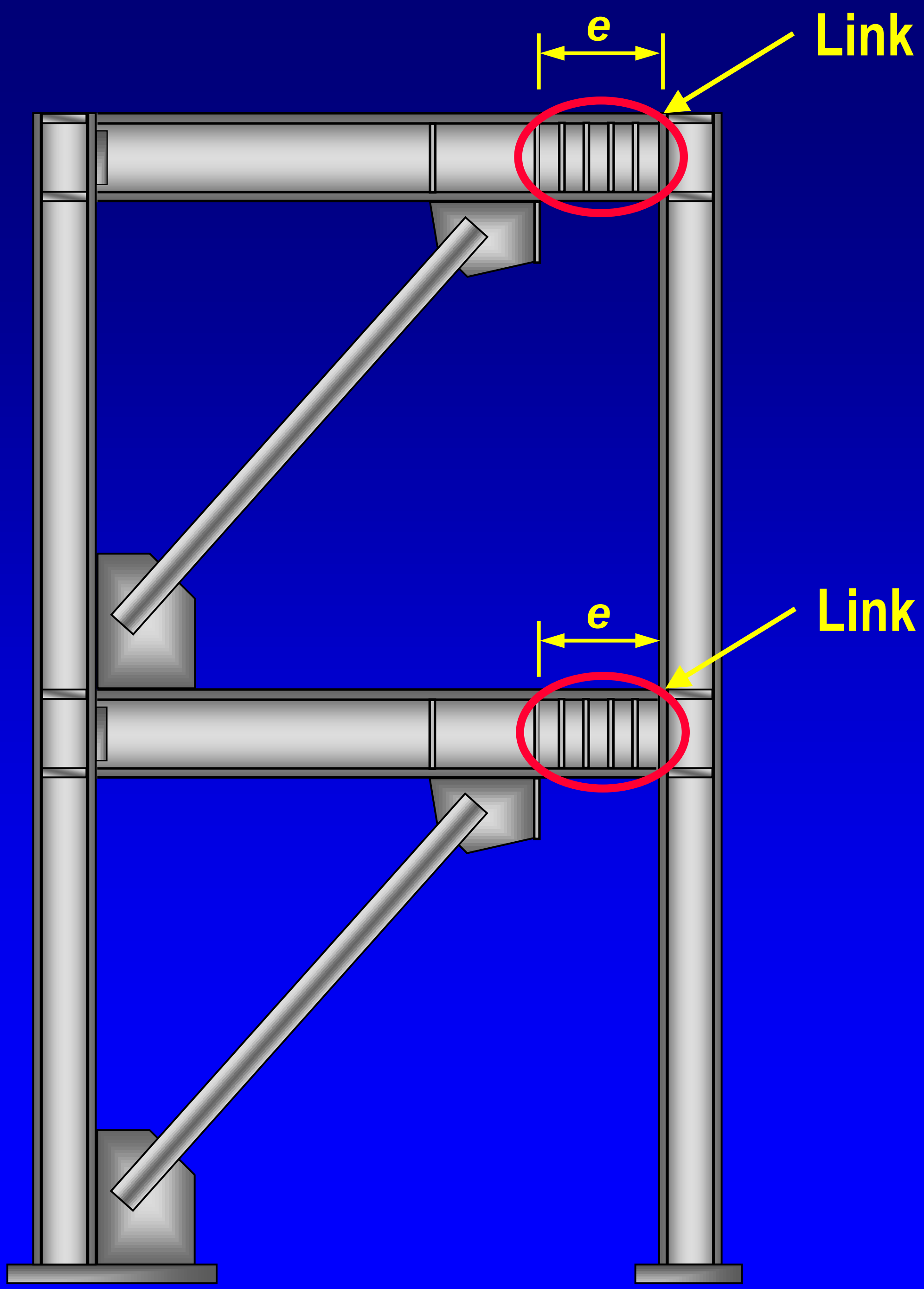
Tension Brace (previously in compression): Yields (*ductile*)

Columns and beams: remain essentially elastic

Eccentrically Braced Frames (EBFs)

- Framing system with beam, columns and braces. At least one end of every brace is connected to isolate a segment of the beam called a *link.*
- Resist lateral load through a combination of frame action and truss action. EBFs can be viewed as a hybrid system between moment frames and concentrically braced frames.
- Develop ductility through inelastic action in the links.
- EBFs can supply high levels of ductility (similar to MRFs), but can also provide high levels of elastic stiffness (similar to CBFs)


e
Link
e
Link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Link
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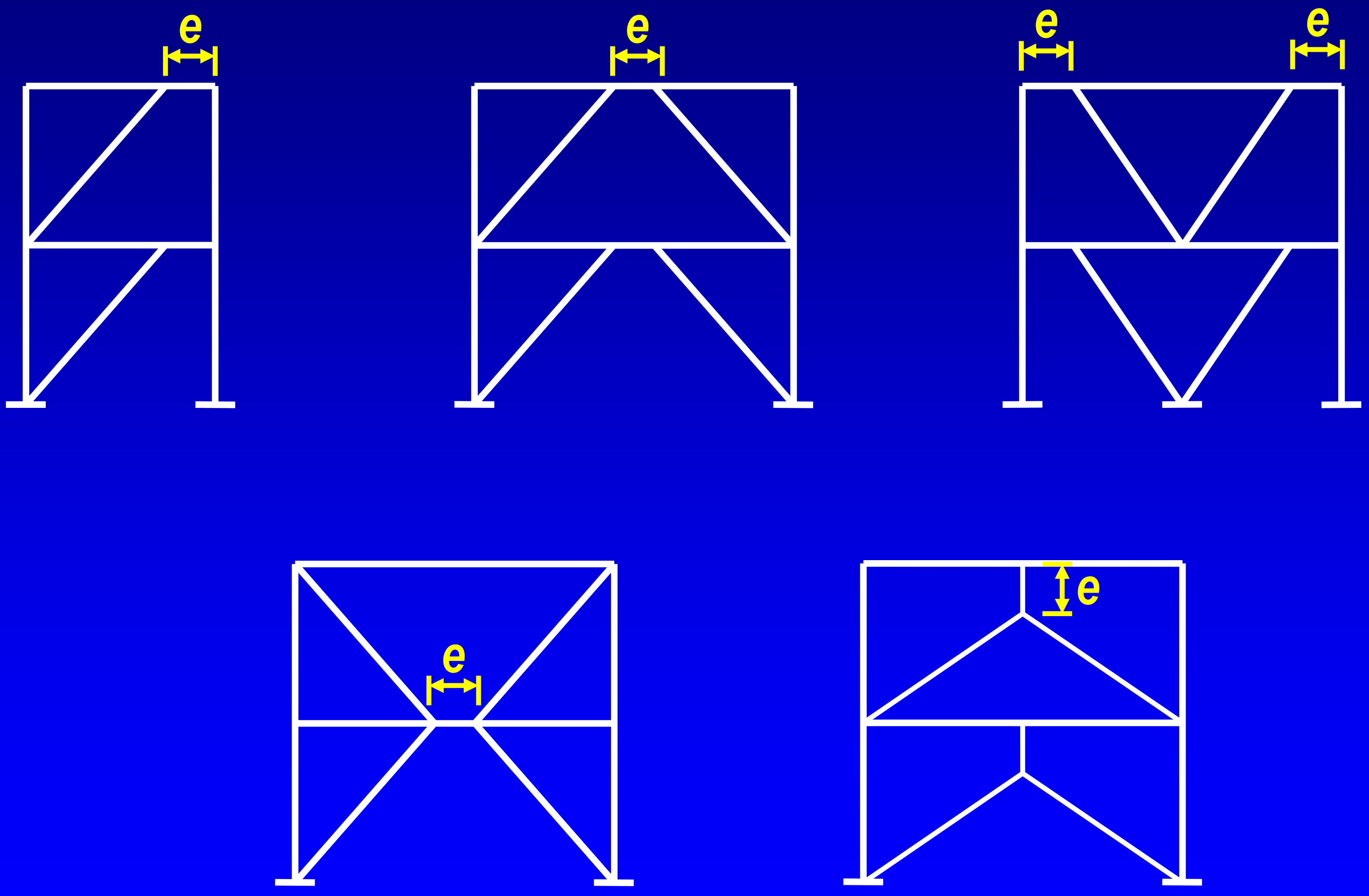
Link

Some possible bracing arrangement for EBFS

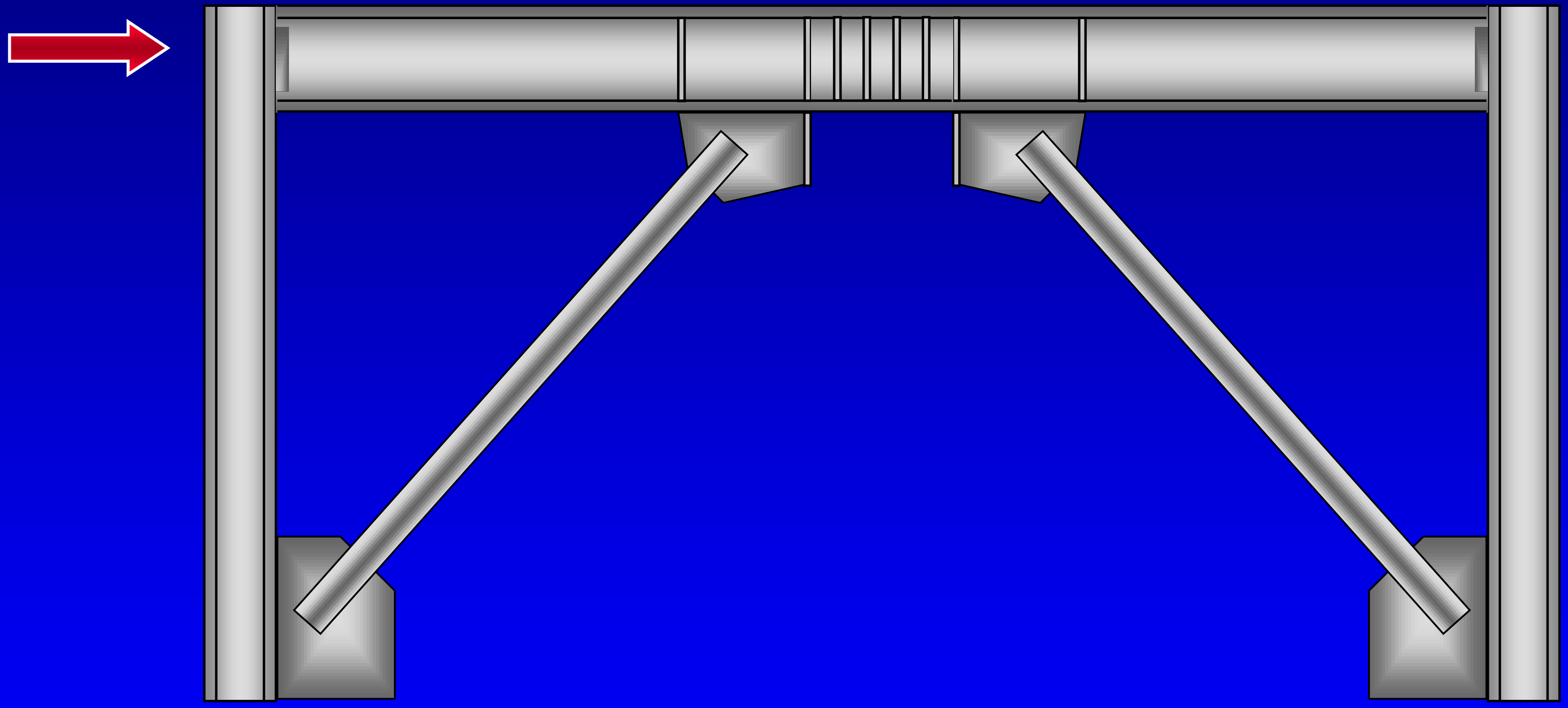


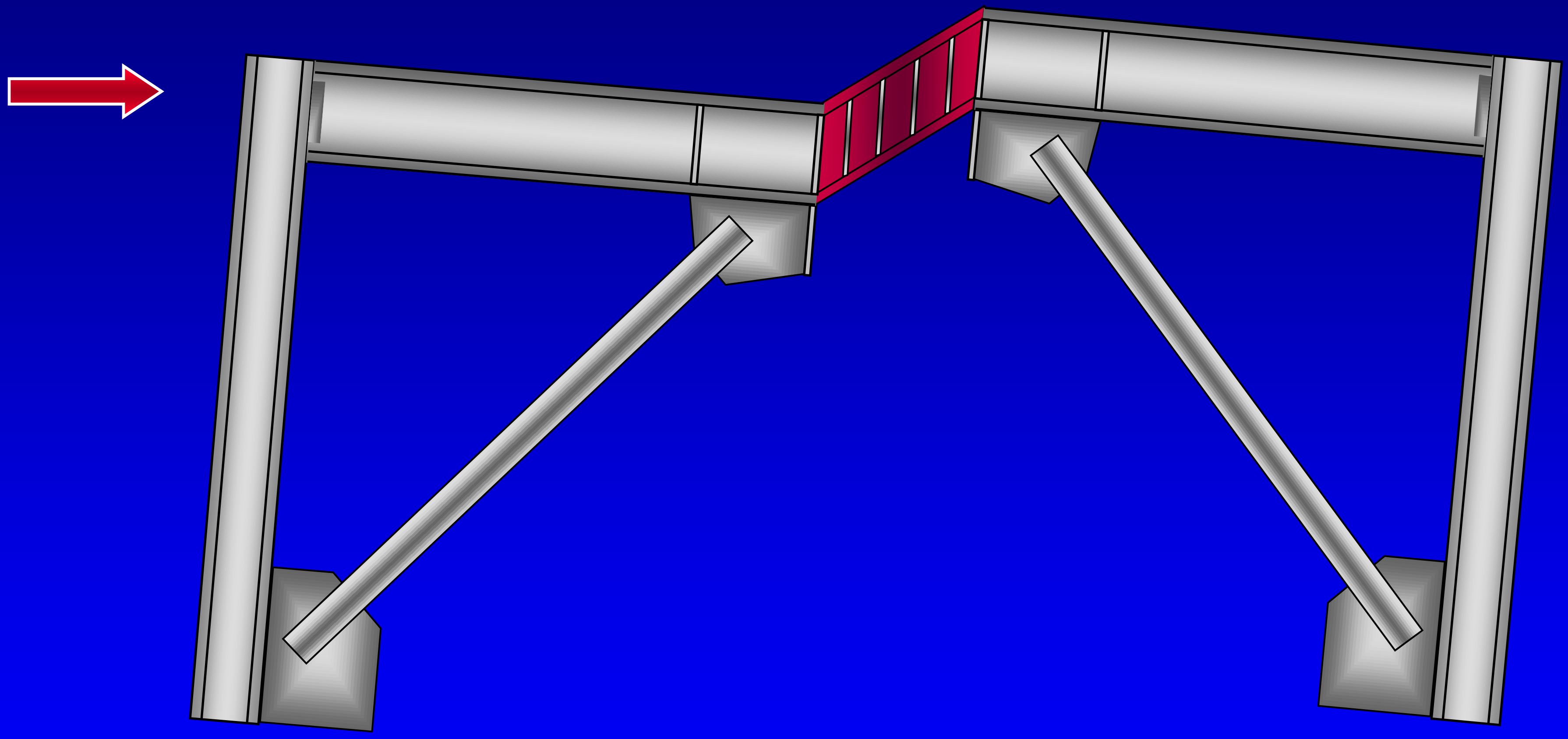

C
BB
BB
65

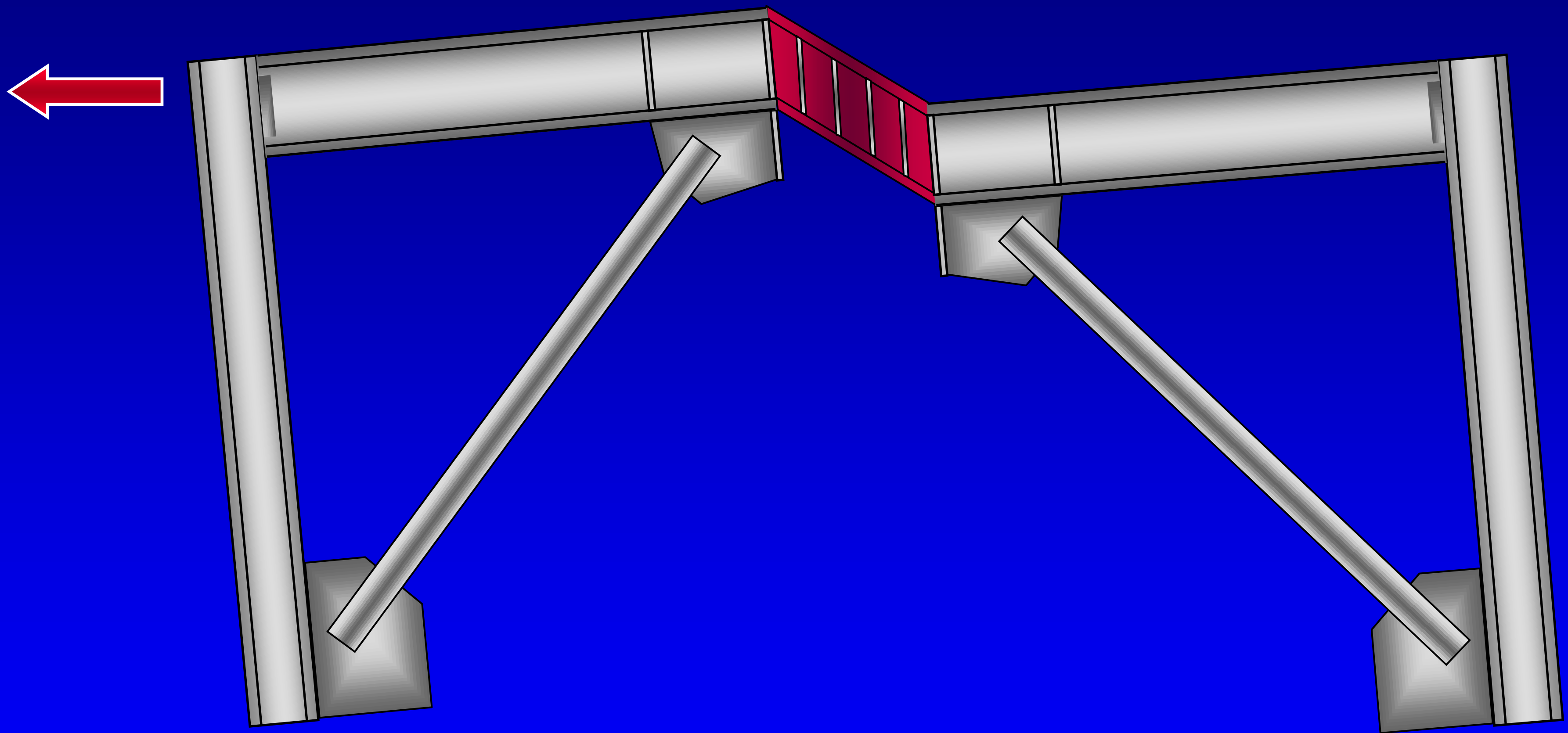

Herrick
KEEP OUT
KEEP OUT


W&W
STEEL
CO
W&W
STEEL
CO

Inelastic Response of EBFs







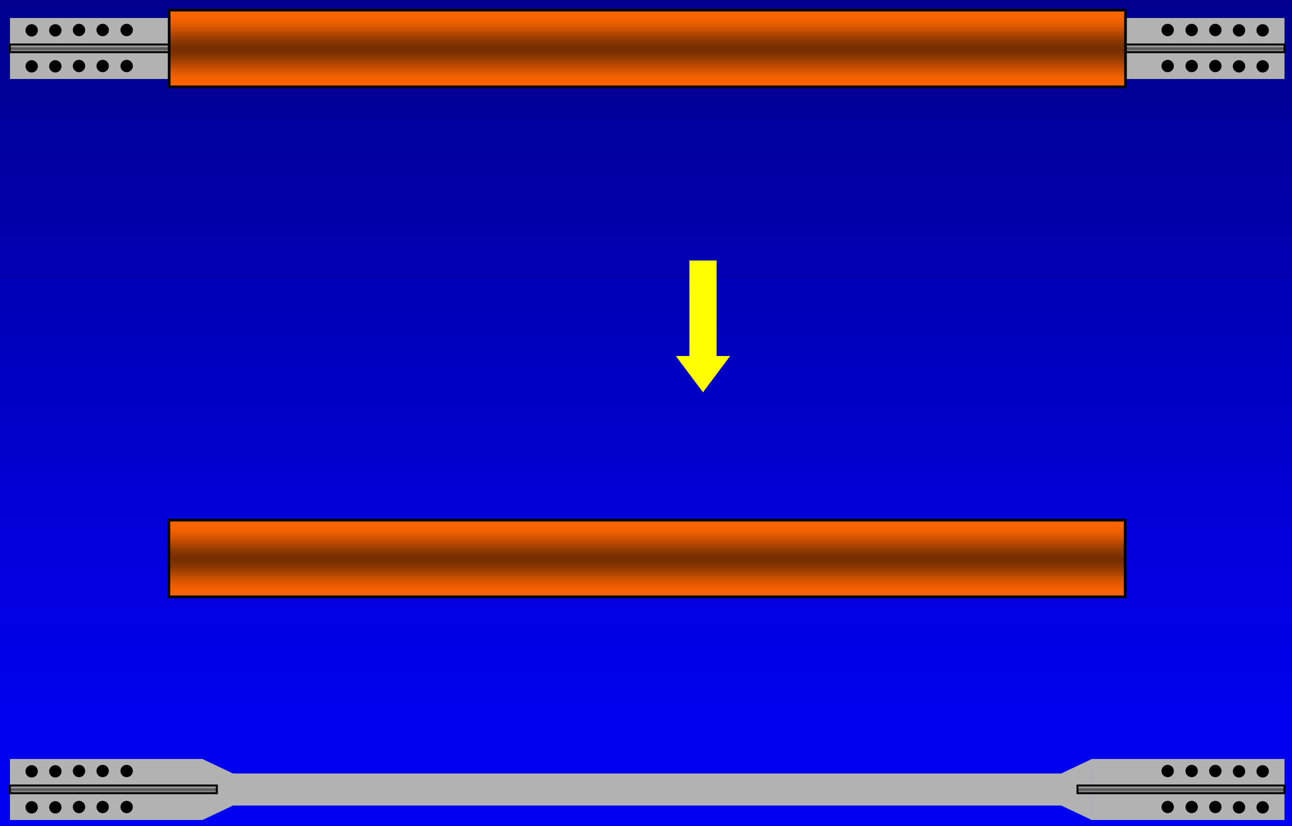
Buckling-Restrained Braced Frames (BRBFs)

- Type of concentrically braced frame.
- Beams, columns and braces arranged to form a vertical **truss**. Resist lateral earthquake forces by truss action.
- Special type of brace members used: ***Buckling-Restrained Braces (BRBs)***. BRBS yield both in tension and compression - *no buckling !!*

- Develop ductility through inelastic action (cyclic tension and compression yielding) in BRBs.

- System combines high stiffness with high ductility.

Buckling-Restrained Brace

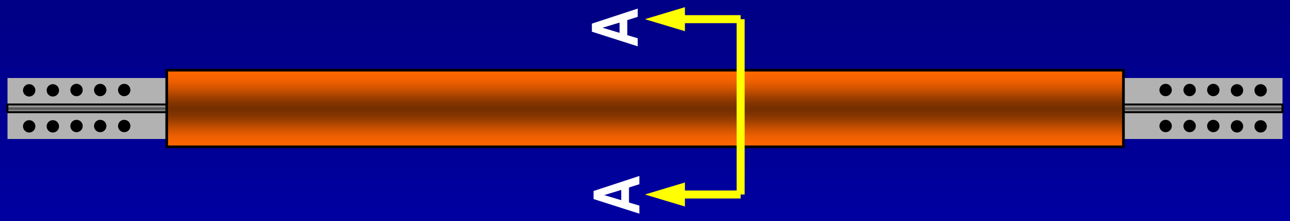


Buckling-Restrained Brace: Steel Core + Casing

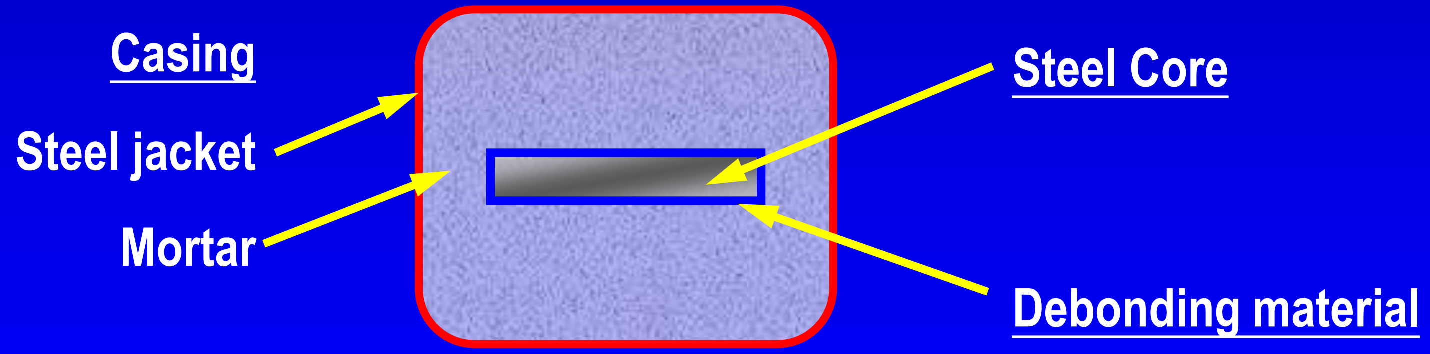
Casing

Steel Core

Buckling-Restrained Brace



Buckling-Restrained Brace:
Steel Core
+
Casing



Section A-A

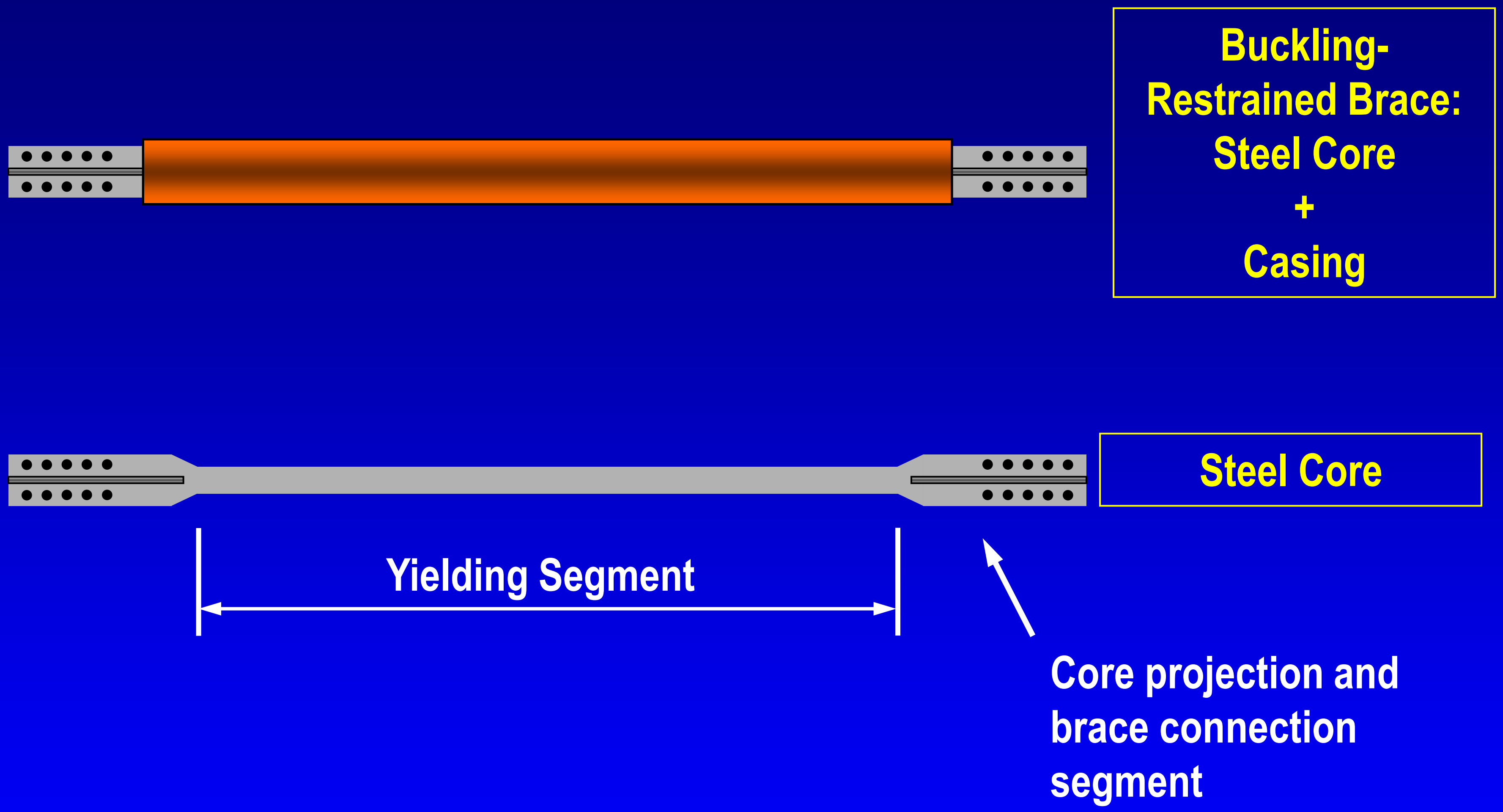
Buckling-Restrained Brace

Steel core resists entire axial force P

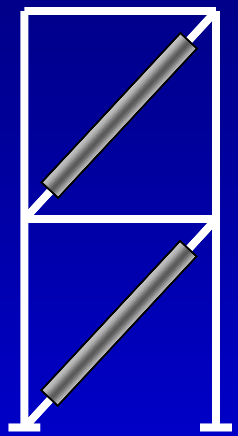
Casing is debonded from steel core

- casing does not resist axial force P
- flexural stiffness of casing restrains buckling of core

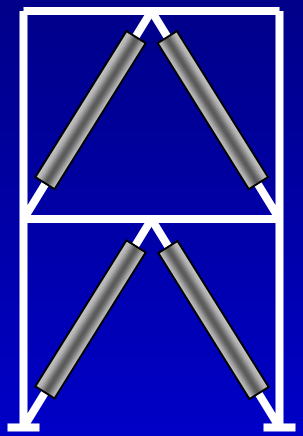
Buckling-Restrained Brace



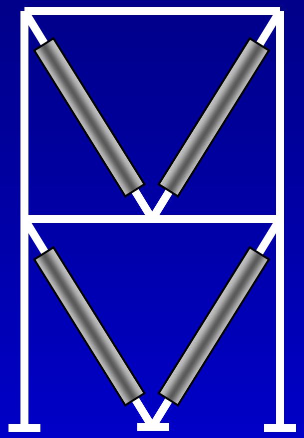
Bracing Configurations for BRBFs



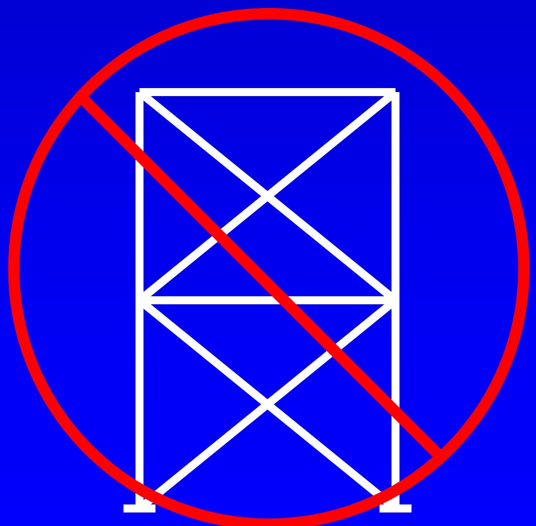
Single Diagonal



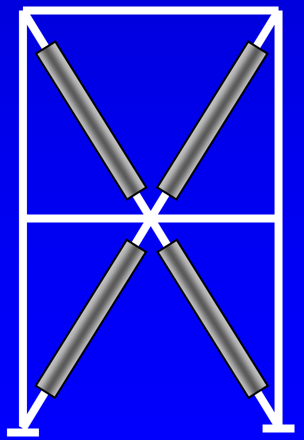
Inverted V- Bracing



V- Bracing



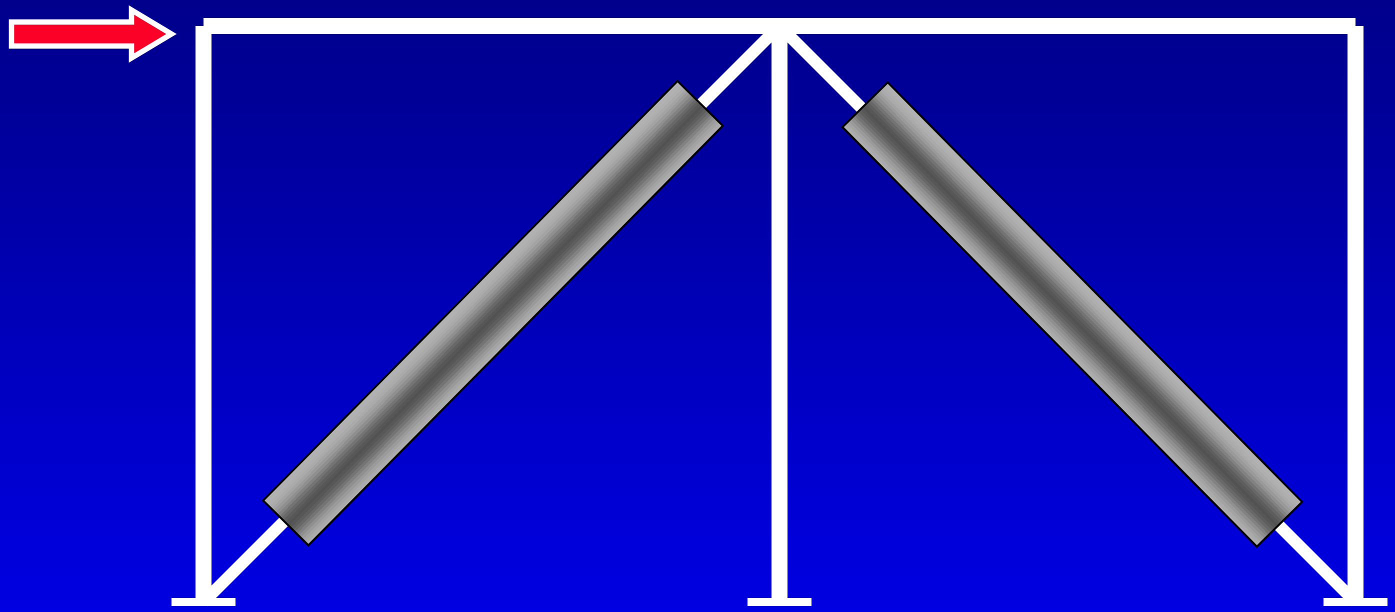
X- Bracing

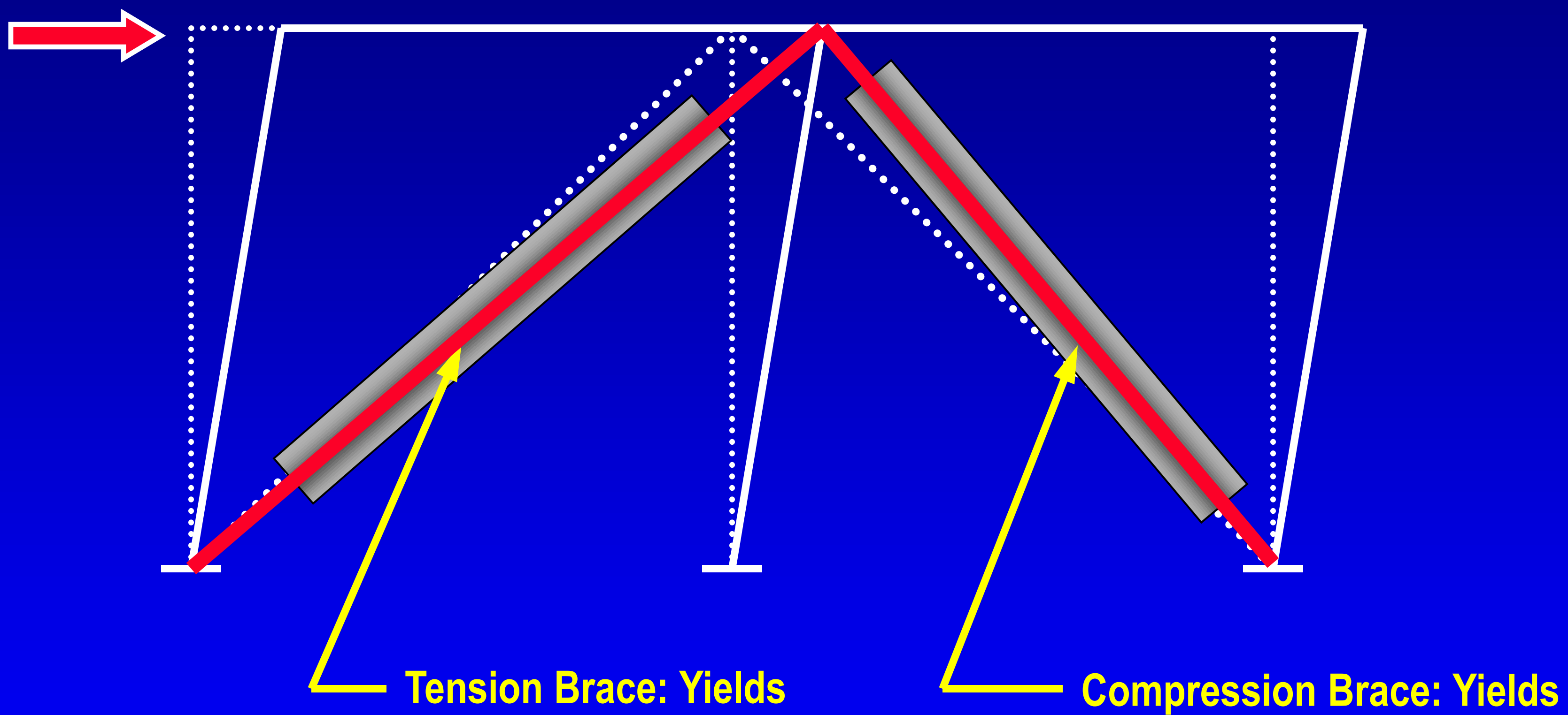


Two Story X- Bracing

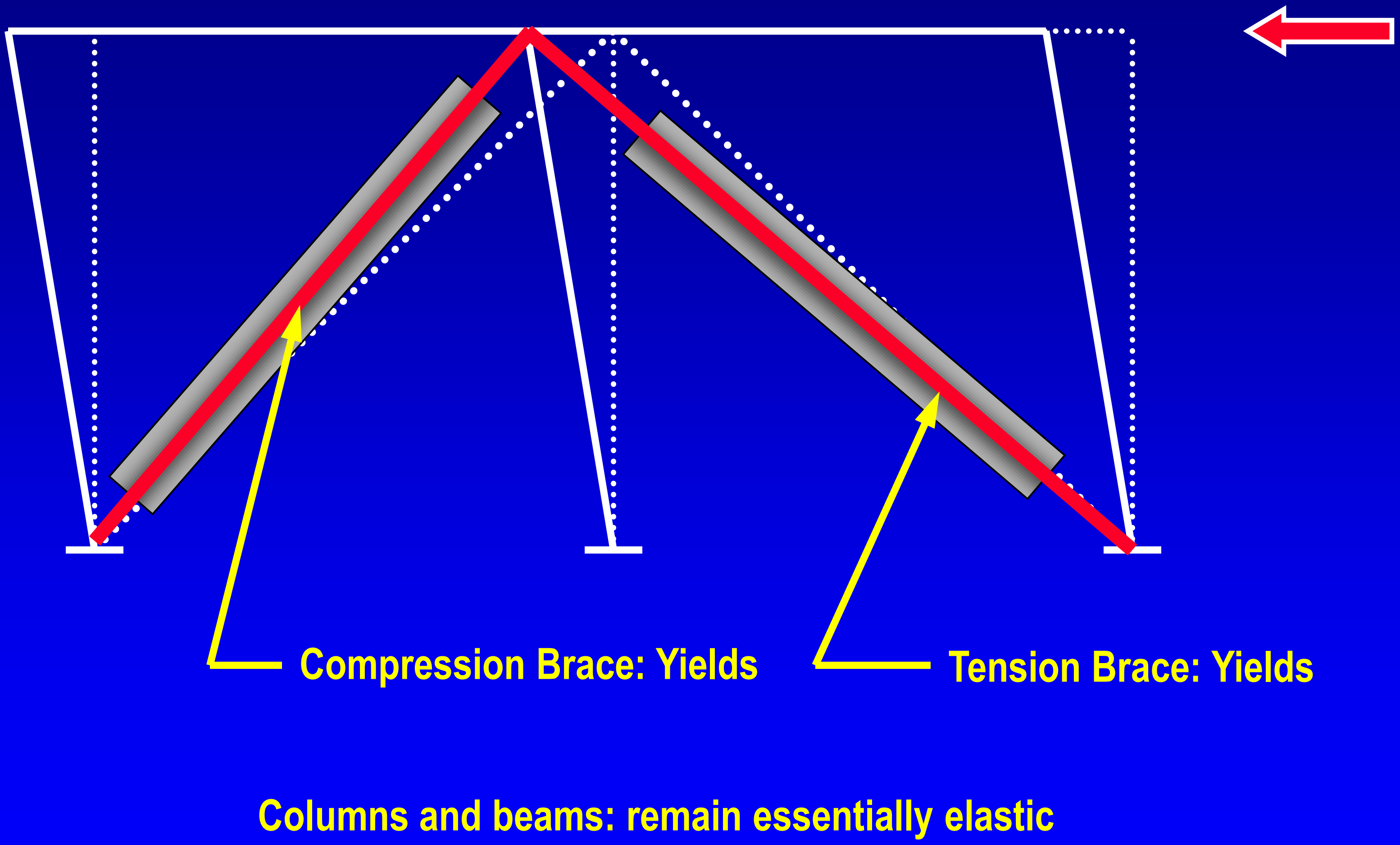

Herrick
Herrick

Inelastic Response of BRBFs under Earthquake Loading





Columns and beams: remain essentially elastic


Compression Brace: Yields
Tension Brace: Yields
Columns and beams: remain essentially elastic

Special Plate Shear Walls (SPSW)

- Assemblage of consisting of rigid frame, infilled with thin steel plates.
- Under lateral load, system behaves similar to a plate girder. Wall plate buckles under diagonal compression and forms tension field.
- Develop ductility through tension yielding of wall plate along diagonal tension field.
- System combines high stiffness with high ductility.

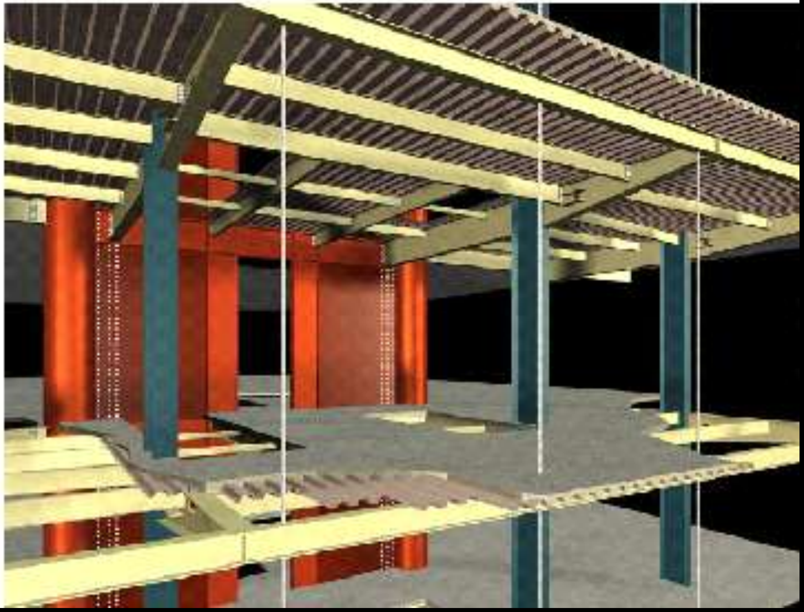
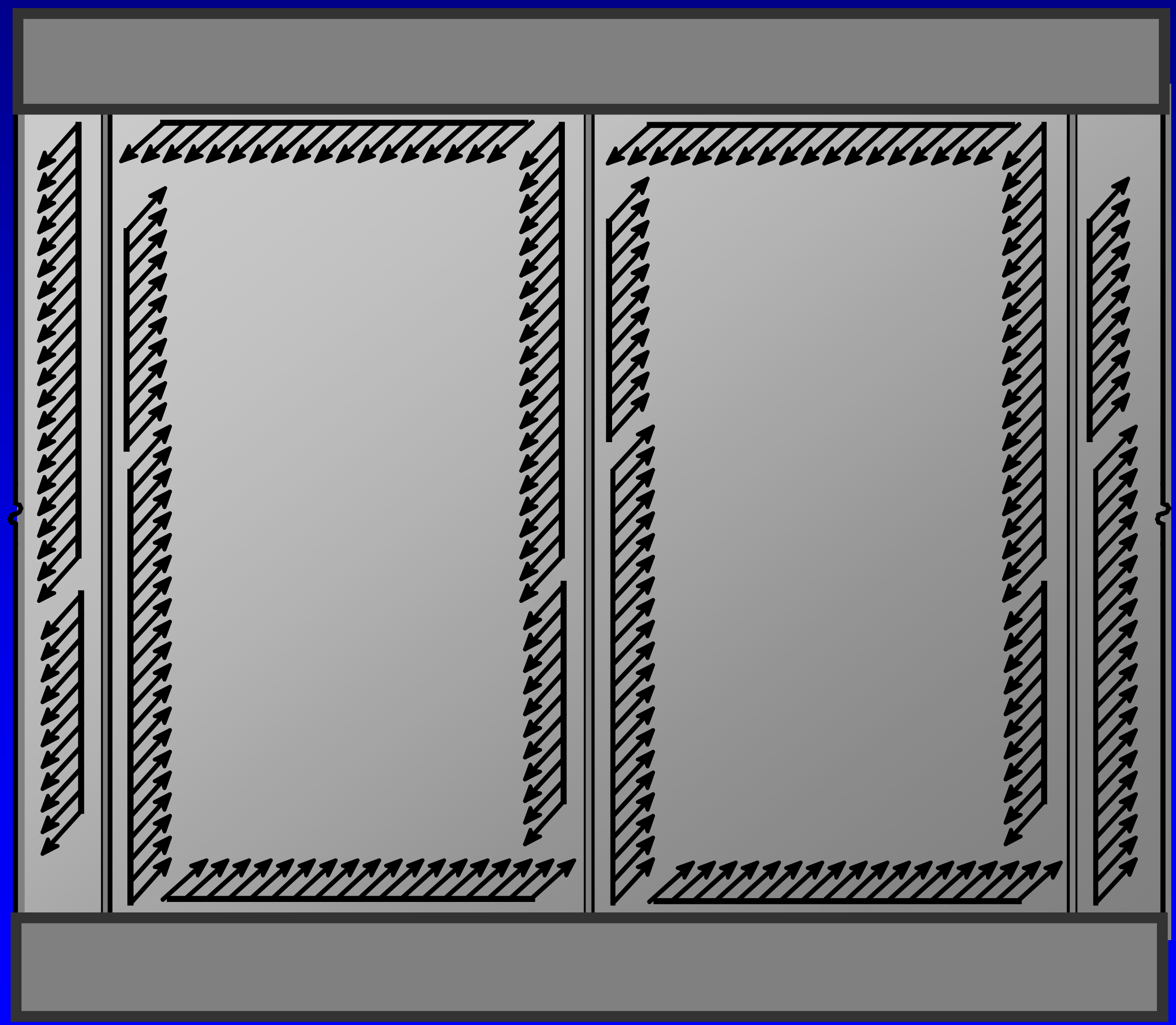
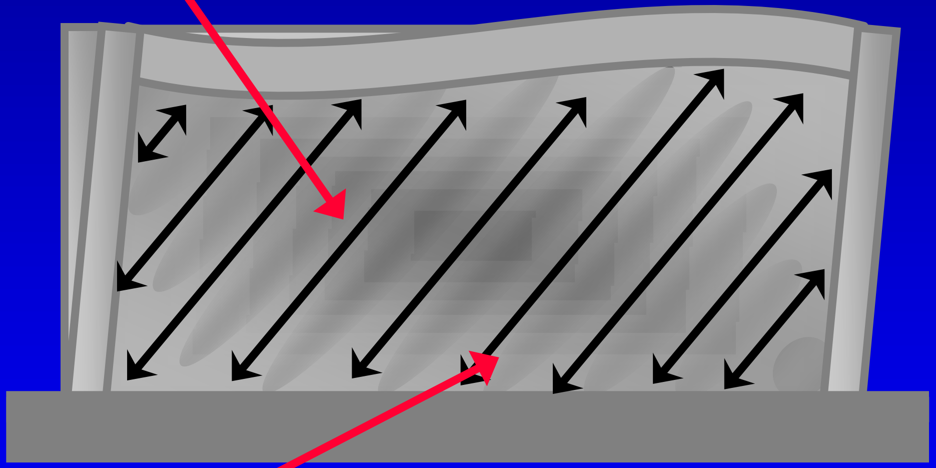


Plate-Girder Analogy



Inelastic Response of a SPSW

Development of
tension diagonals



Shear buckling

Design of Seismic-Resistant Steel Building Structures: A Brief Overview

- Earthquake Effects on Structures
- Performance of Steel Buildings in Past Earthquakes
- Building Code Philosophy for Earthquake-Resistant Design and Importance of Ductility
- Design Earthquake Forces: ASCE-7
- Steel Seismic Load Resisting Systems
- AISC Seismic Provisions

2005 AISC Seismic Provisions

ANSI/AISC 341-05
An American National Standard

Seismic Provisions for Structural Steel Buildings

March 9, 2005

Supersedes the *Seismic Provisions for Structural Steel Buildings* dated May 21, 2002 and all previous versions

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