Seismic Design of Bridges for Continued Functionality Using Seismic Isolation

Western Bridge Engineers' Seminar
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by

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AASHTO Adopted 2009 Guide Specifications

Proposed

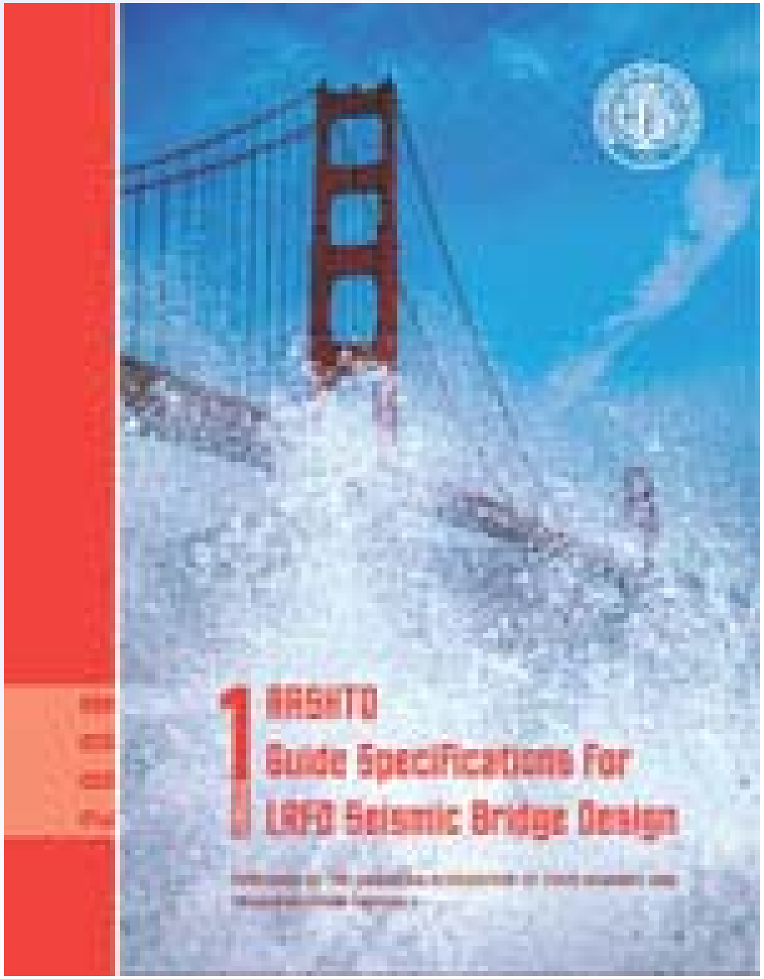
AASHTO Guide Specifications for LRFD Seismic Bridge Design

Subcommittee for Seismic Effects on Bridges
T-3

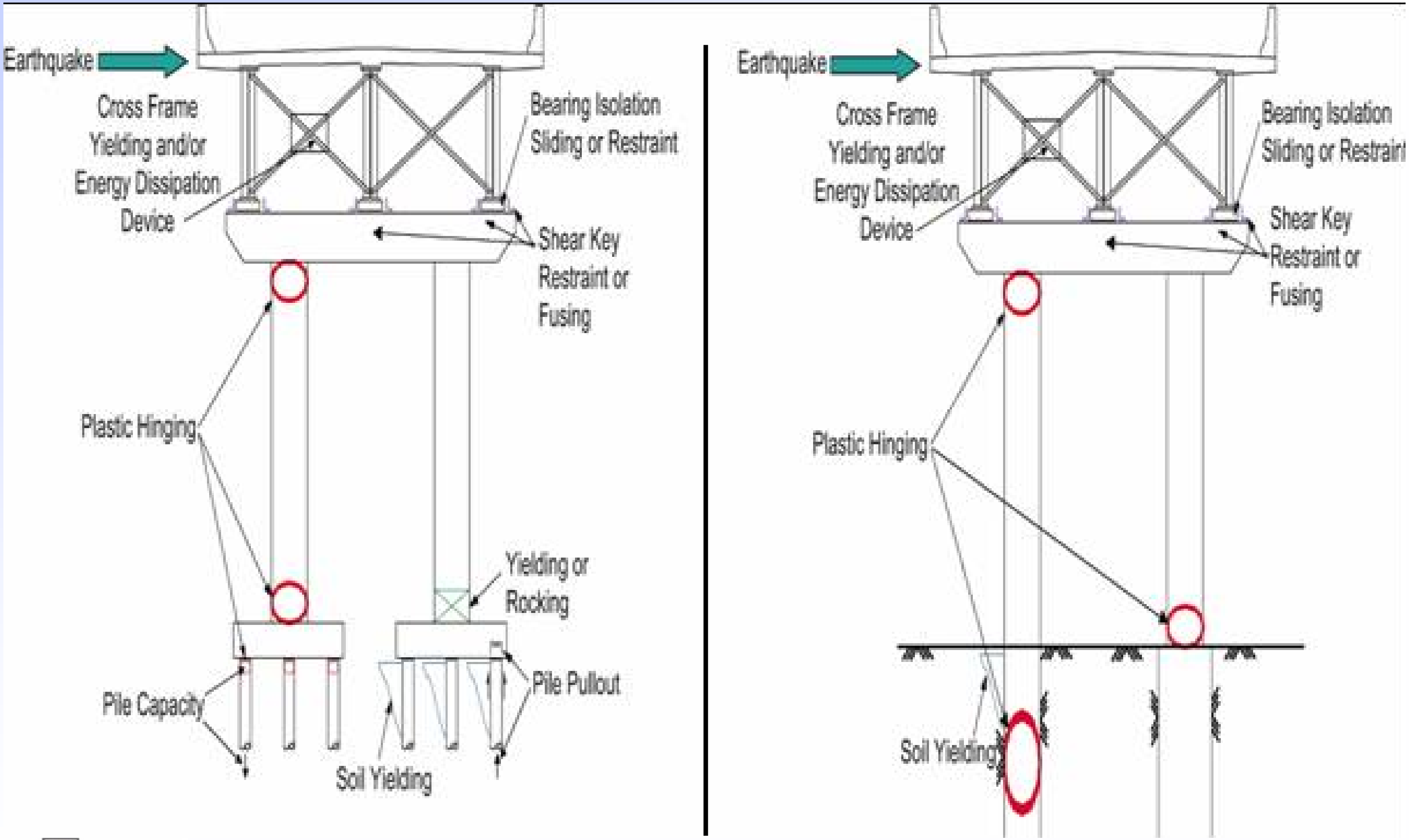
Prepared by:

Roy A. Imbsen
Imbsen Consulting

March 2007



Guidelines(7.1)-General
Seismic Load Path and Affected Components

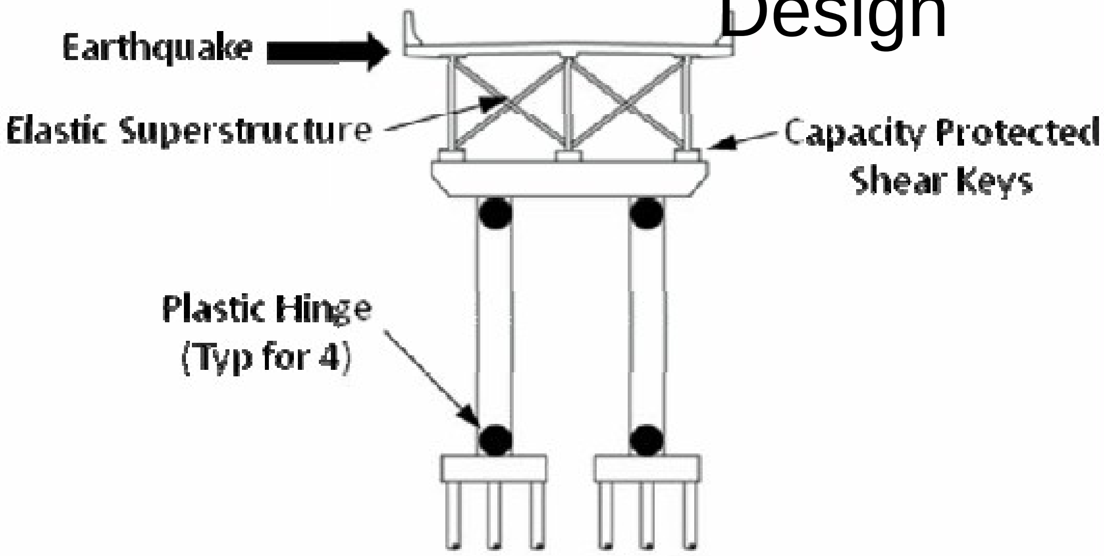


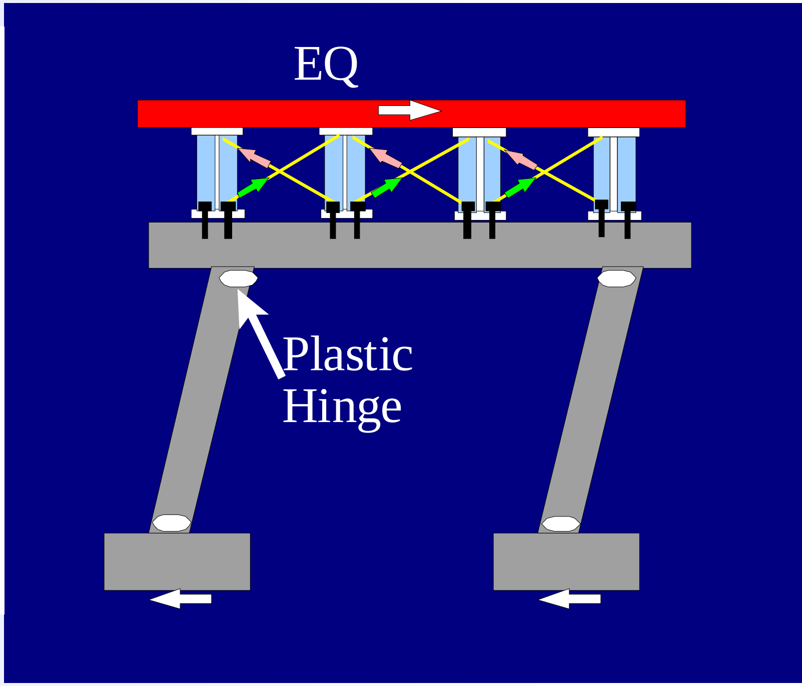
Guidelines(7.2) Performance Criteria

- Type 1 – Design a ductile substructure with an essentially elastic superstructure (i.e., yielding columns)
  - 1 concrete substructure
  - 1* steel substructure
  - 1** concrete filled steel pipe substructure
- Type 2 – Design an essentially elastic substructure with a ductile superstructure (i.e., steel girder bridge with buckling diagonal members in the end diaphragms.
- Type 3 – Design an elastic superstructure and substructure with a fusing (e.g., isolation) mechanism at the interface.

Global Design Strategies

Type 1 Design

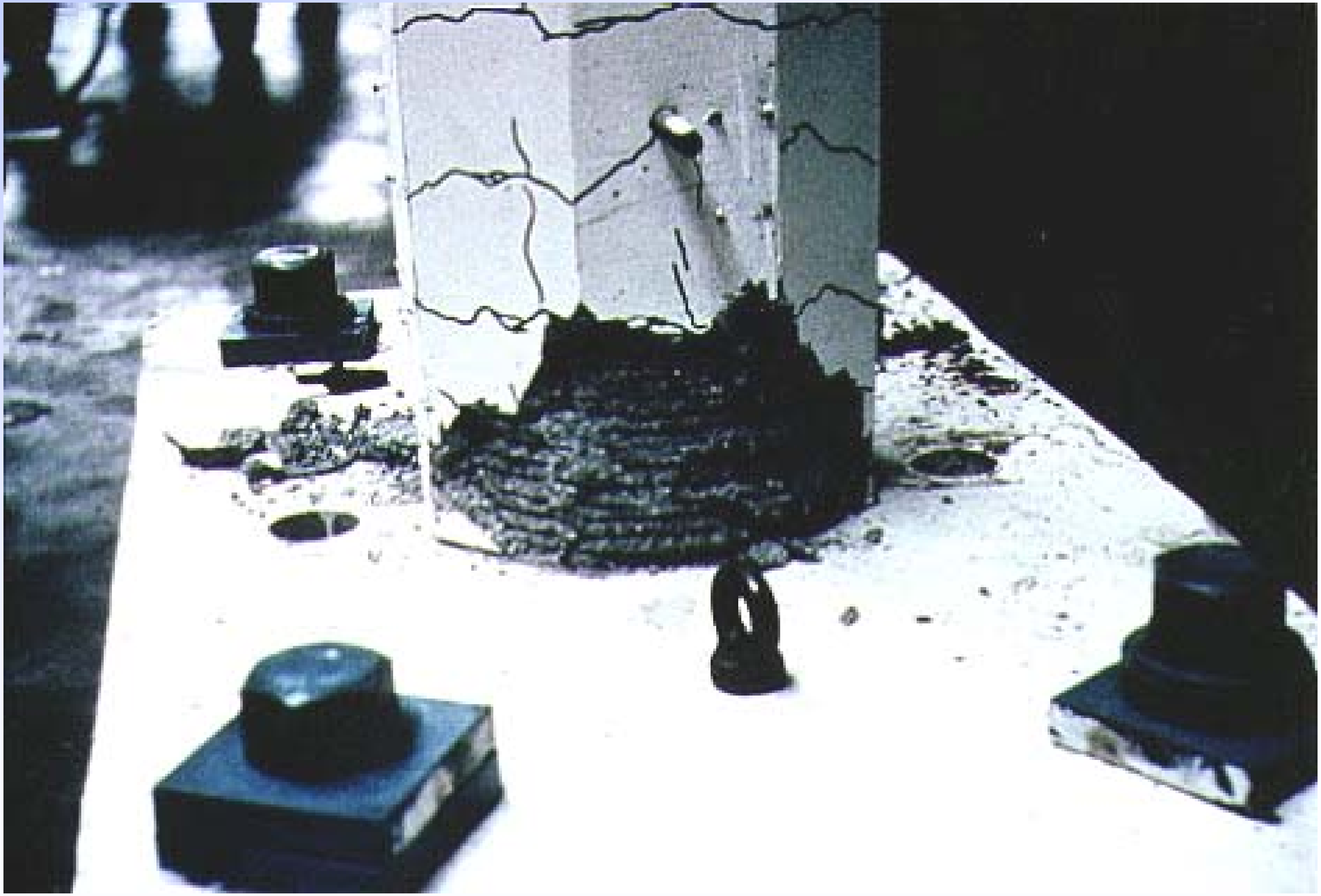




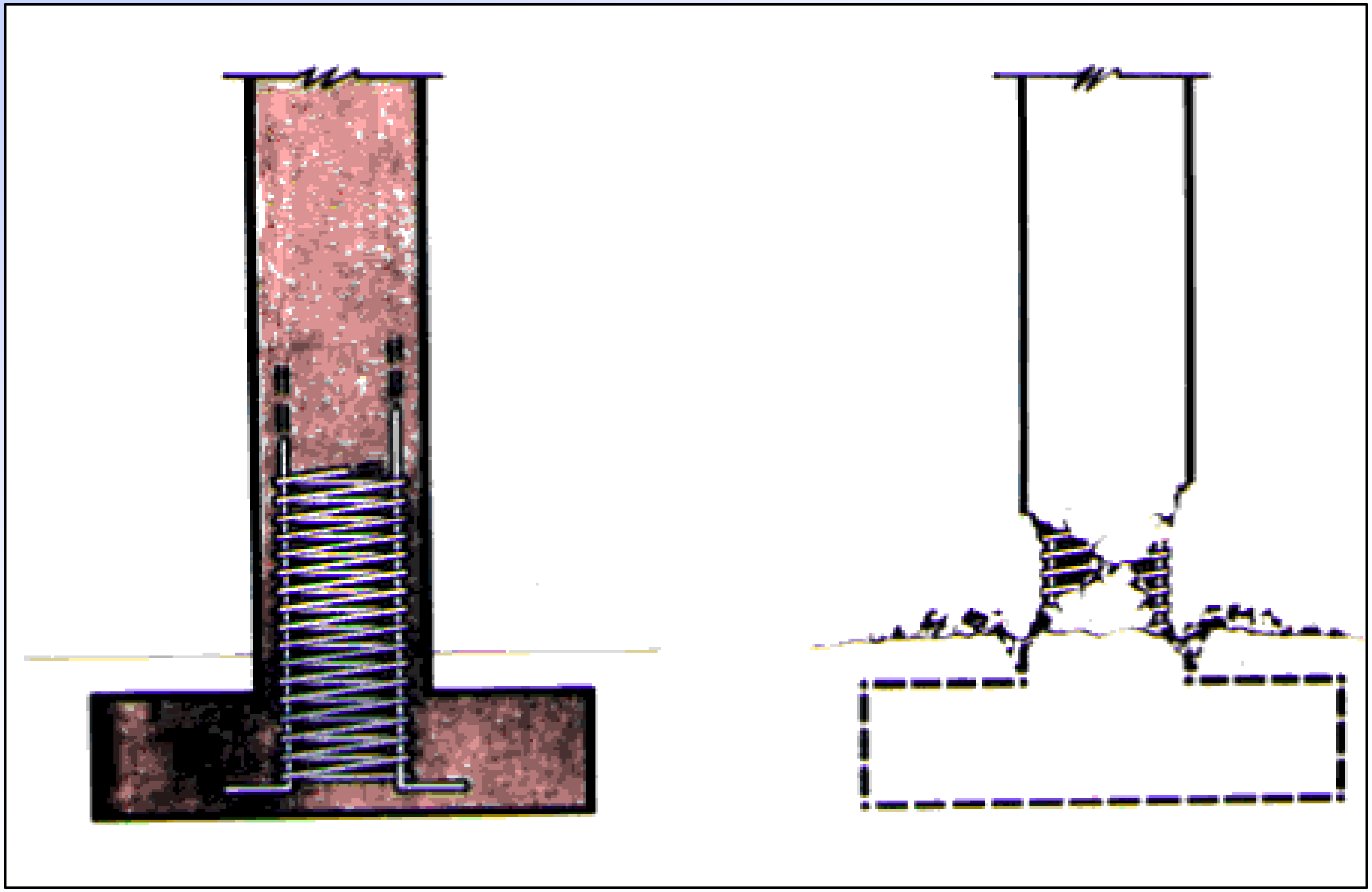
Type 1 - Design a ductile substructure with an essentially elastic superstructure (i.e., yielding columns)

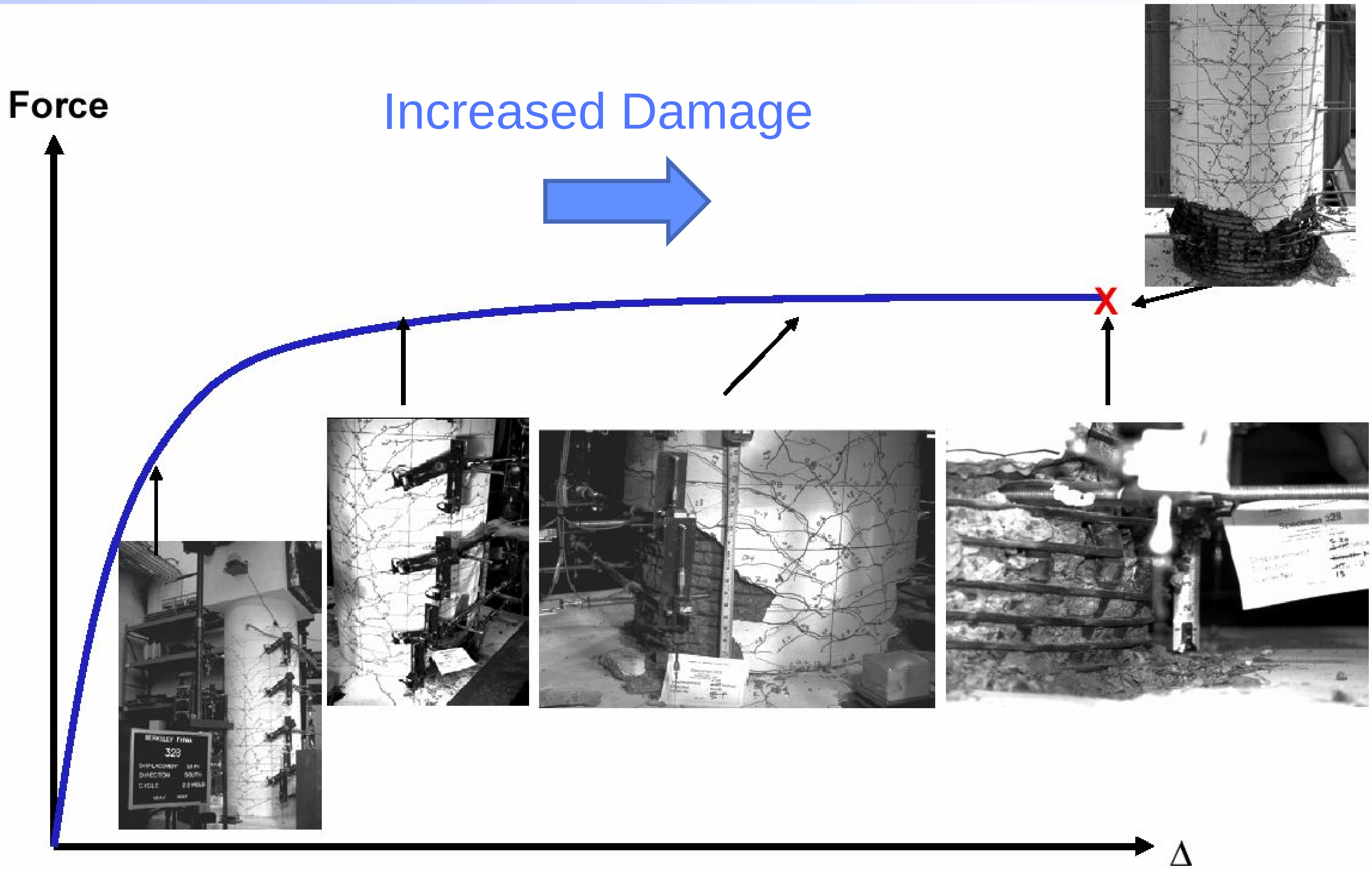
- 1 concrete substructure
- 1* steel substructure
- 1** concrete filled steel pipe substructure

New Zealand Small Column Test

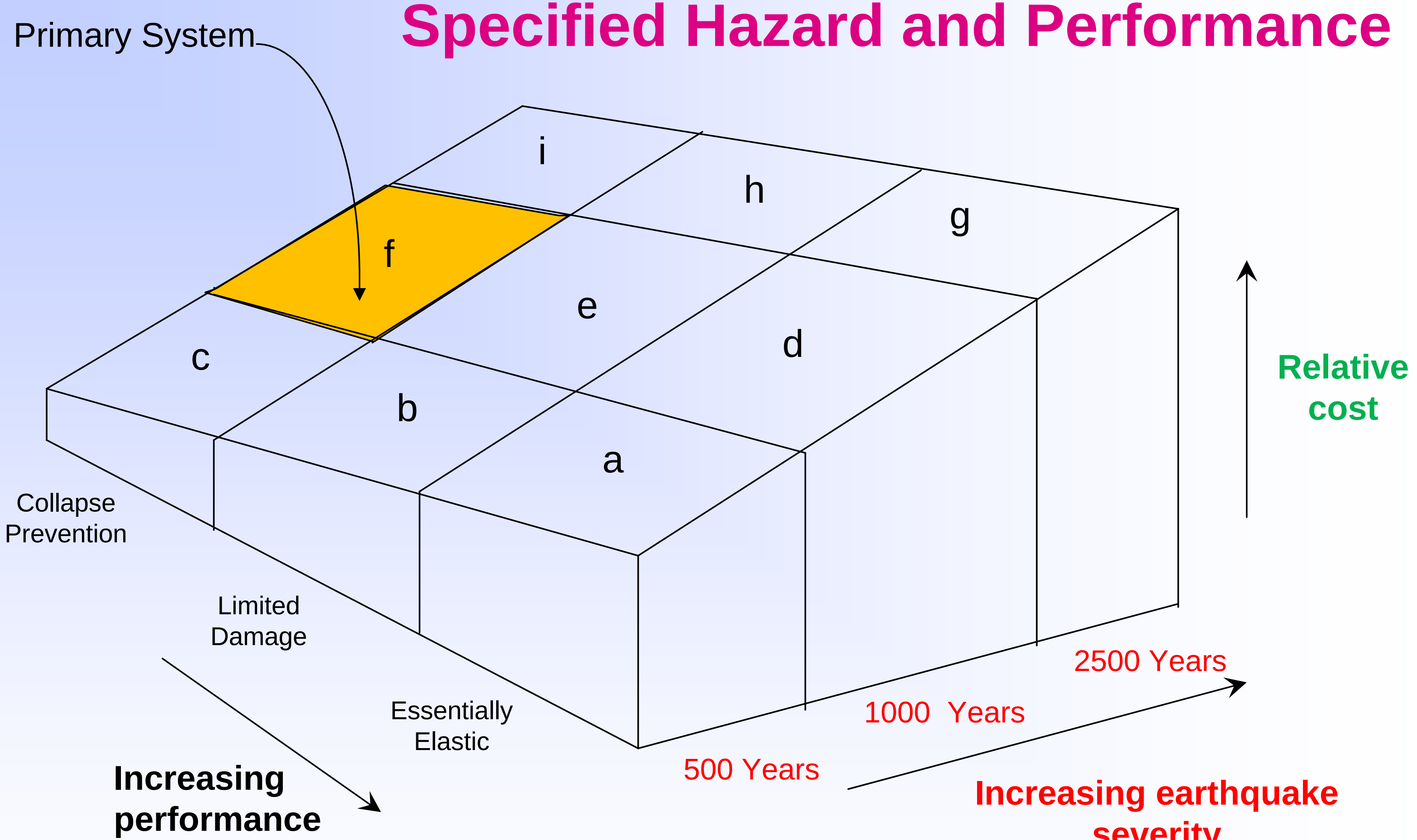


Plastic Hinging of Column
An Affordable Approach




Force
Increased Damage
X
Δ

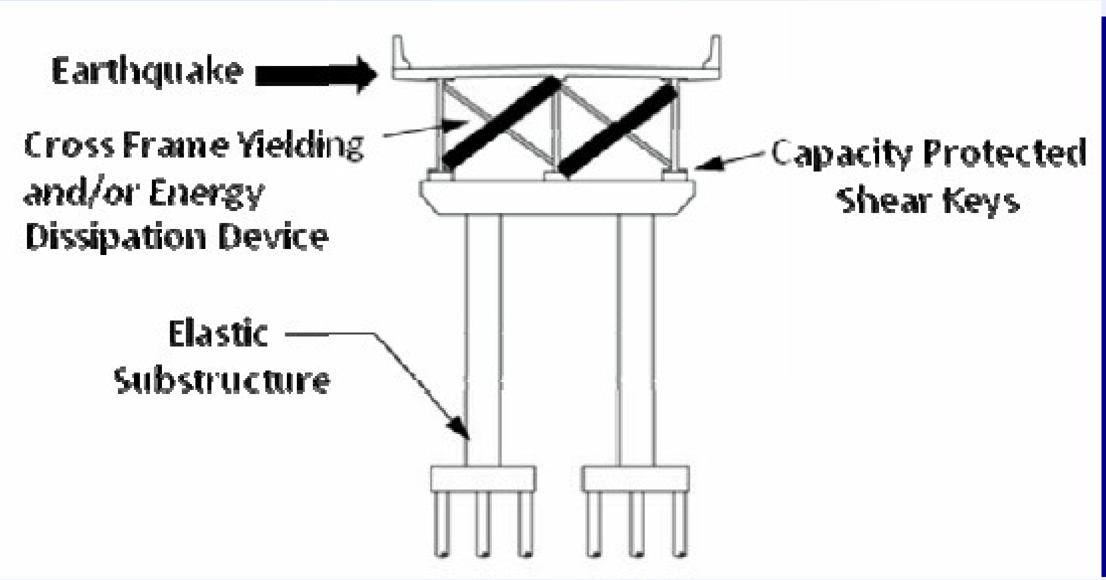
Specified Hazard and Performance

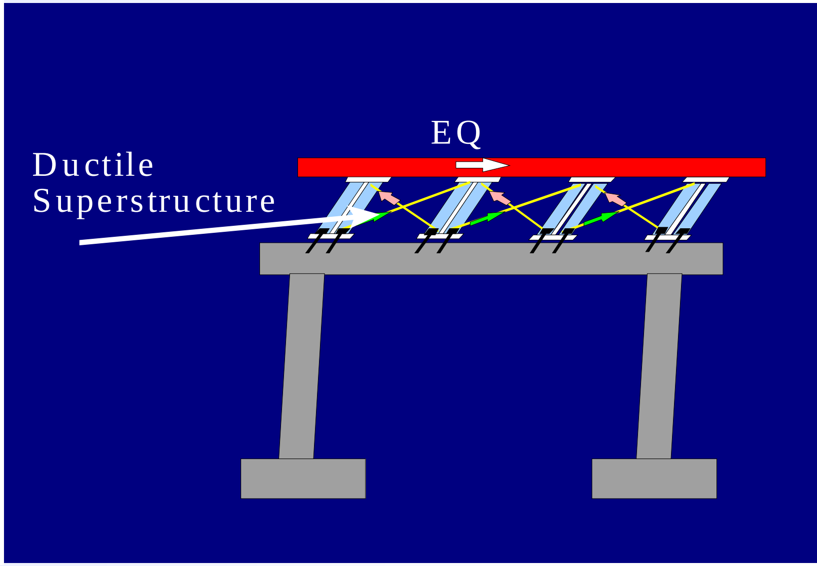


Calibration Objectives

Global Design Strategies

Type 2 Design

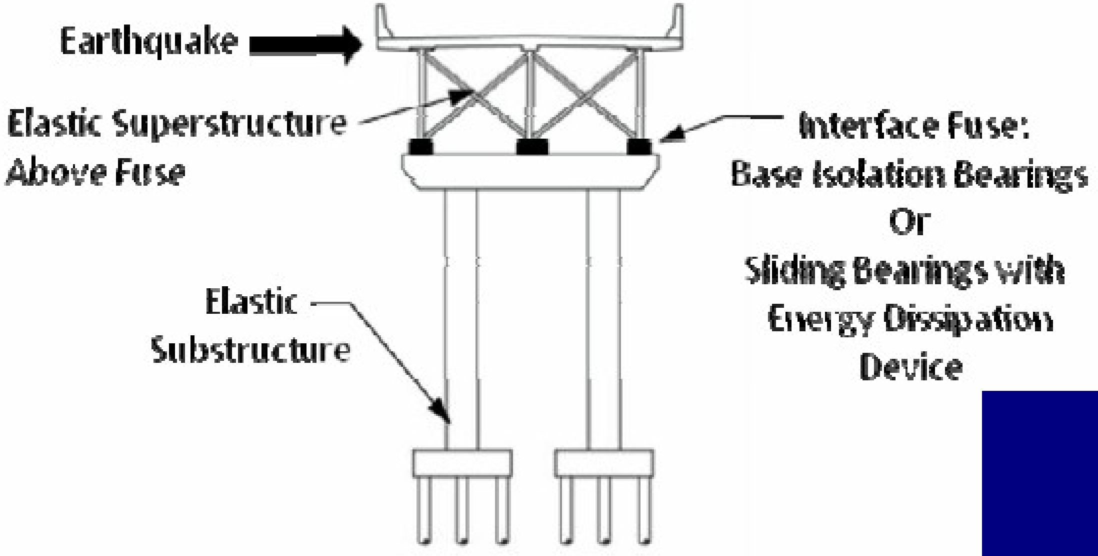




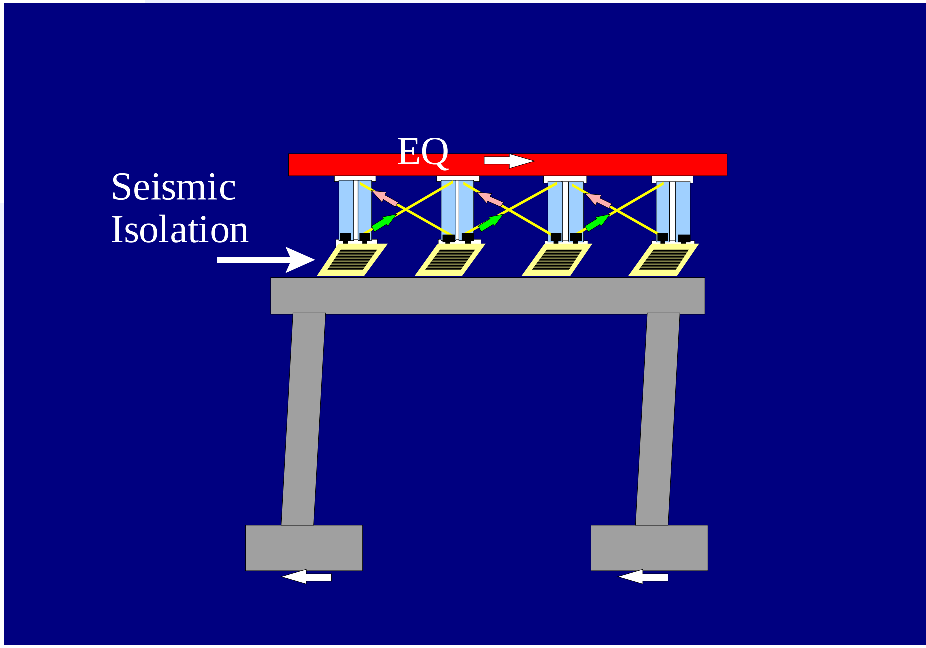
Type 2 - Design an essentially elastic substructure with a ductile superstructure (i.e., steel girder bridge with buckling diagonal members in the end diaphragms.

Global Design Strategies

Type 3 Design



Type 3 - Design an elastic superstructure and substructure with a fusing (e.g., isolation) mechanism at the interface.



Current State of Practice for Seismic Design of Bridges

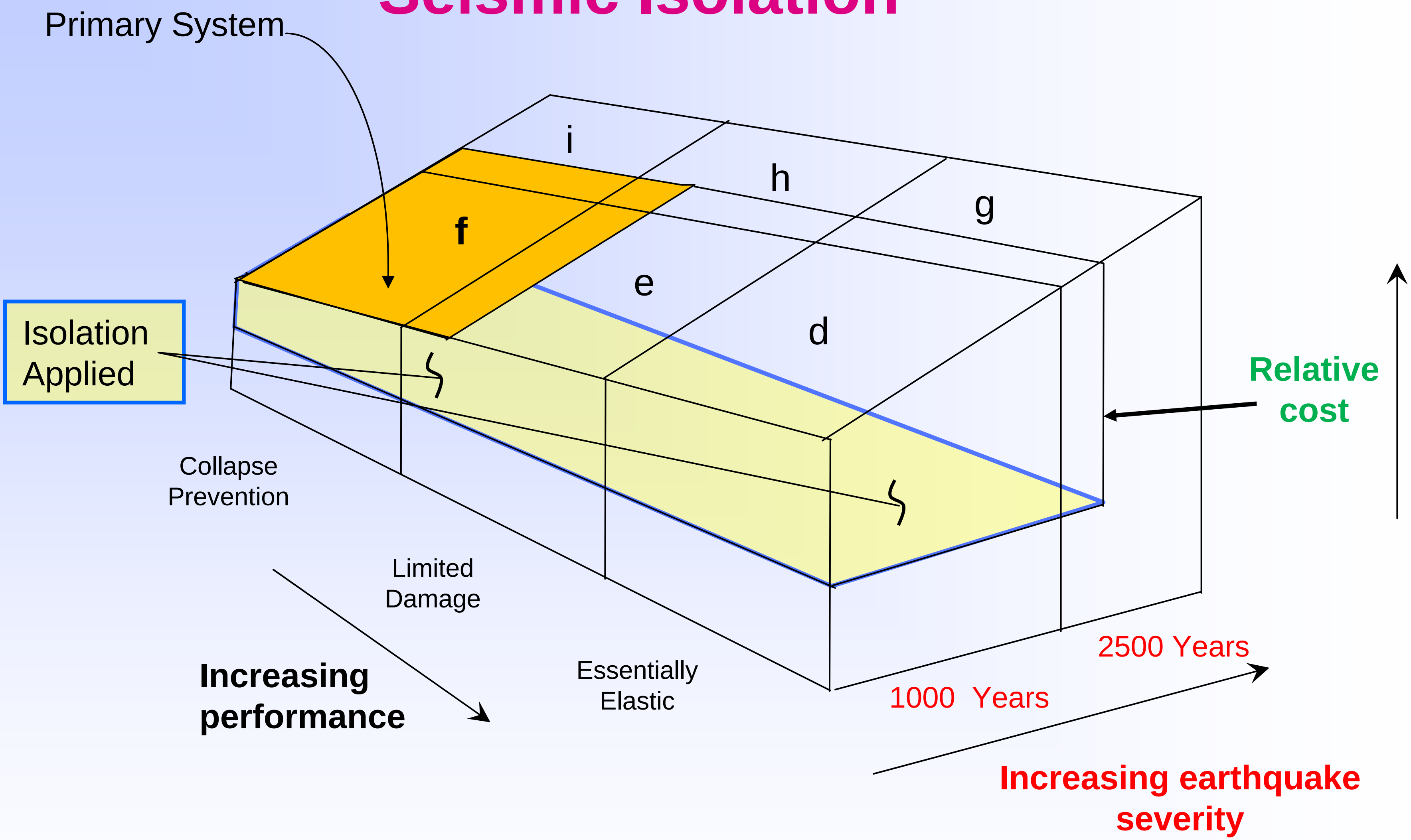
- Ductile based design
- Life Safety (i.e. Collapse Prevention) using ductile design with damage allowed. Continued Functionality is not achieved.
- Non-functional bridges following a major earthquake

Structure Damage Occurs Because

- Seismic codes allow damage for strong earthquakes.
- Severe earthquakes can cause force and displacement demands several times greater than that required by the design criteria.
- When demands exceed the structural design strength, linear elastic dynamic analyses are at best only approximations.
- Large deformations concentrate in the weakest structure members, causing damage, and sometimes collapse.

The Cost To Rebuild After Major Earthquakes is Many Times Greater Than The Costs To Build Before The Earthquake.

Seismic Isolation



Calibration Objectives

How can we have higher Reliability for a Bridge to be Functional for a design life of 75 or 100 Years?

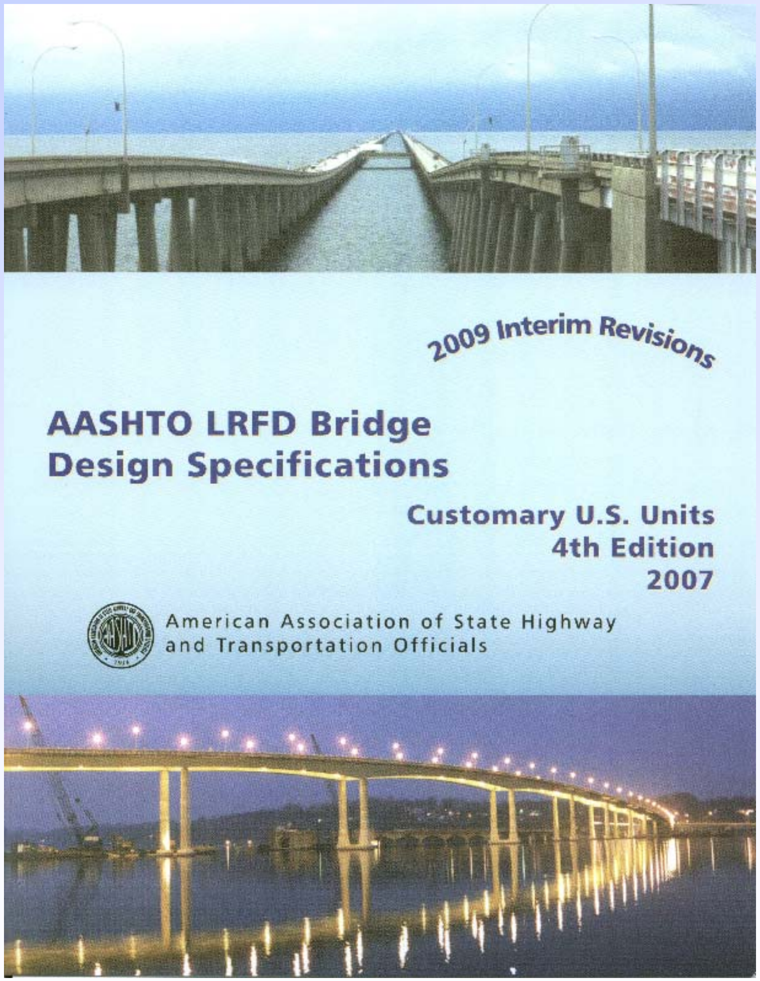
- Responding structure to remain fully elastic (i.e., Reliably Elastic)
- Functional seismic connections and joints

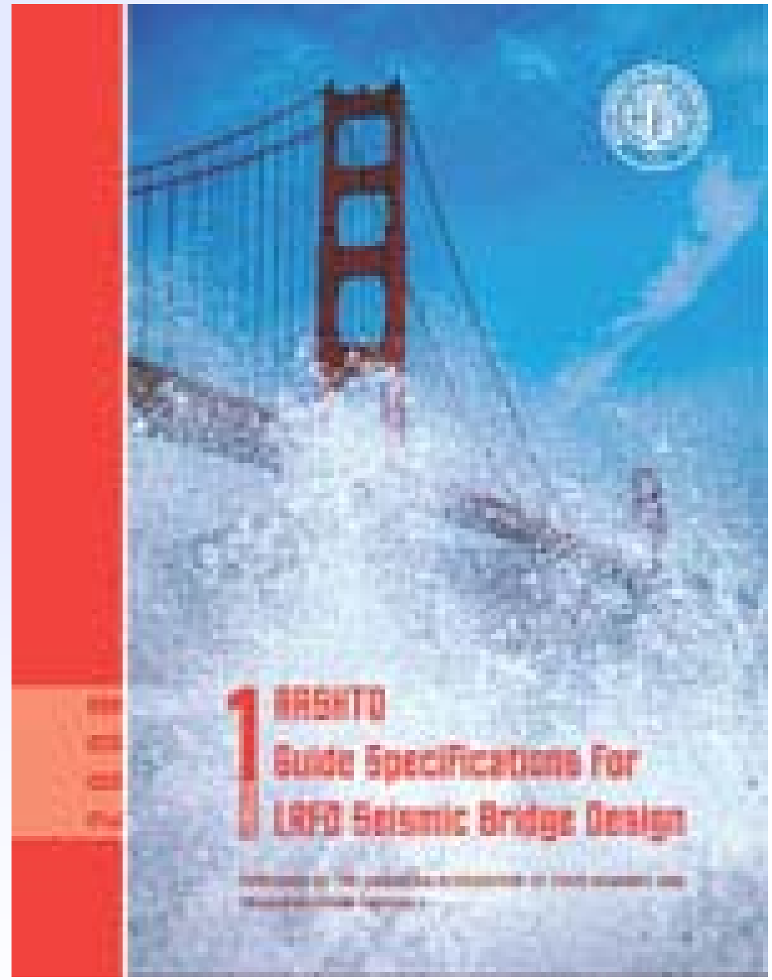
- We now have the technology to design and build a functional bridge at a lower construction cost than designing and building to minimum code requirements

Objectives for Continued Functionality

- Satisfy Service Load Requirements
- Isolate the Substructure from the Superstructure
- Keep the Substructure Columns Reliably Elastic During an MCE (e.g.1000 year event)
- Precludes the Formation of a Plastic Hinge (i.e. no damage)
- Eliminates the Capacity Protection Required for the Foundation

AASHTO Specifications 2009 and Guide Specifications 2009





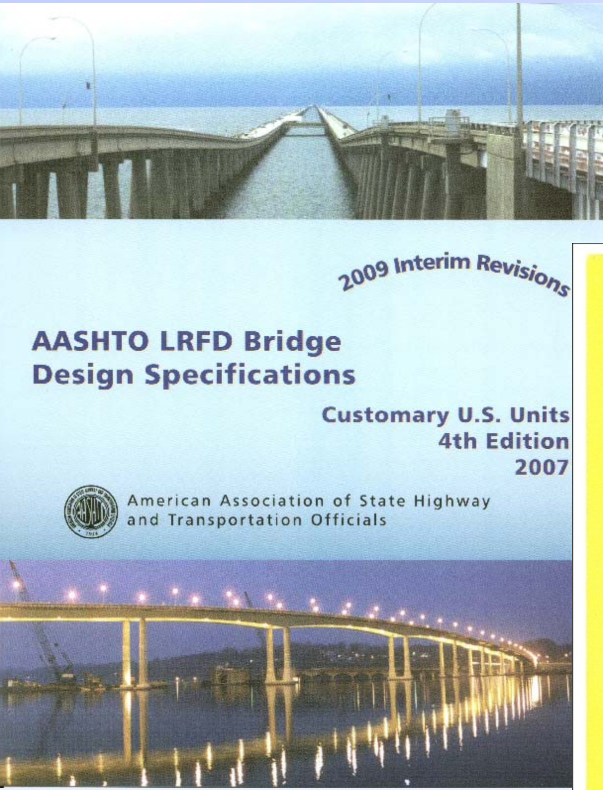
AASHTO LRFD Bridge Design

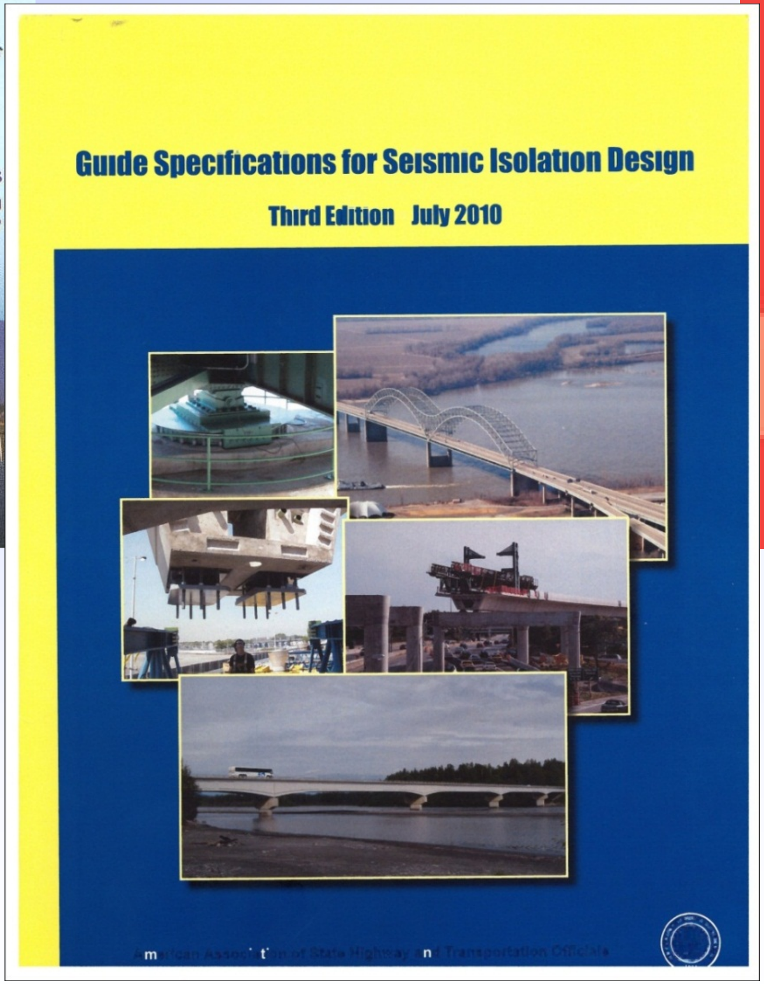
1.3.3 Ductility

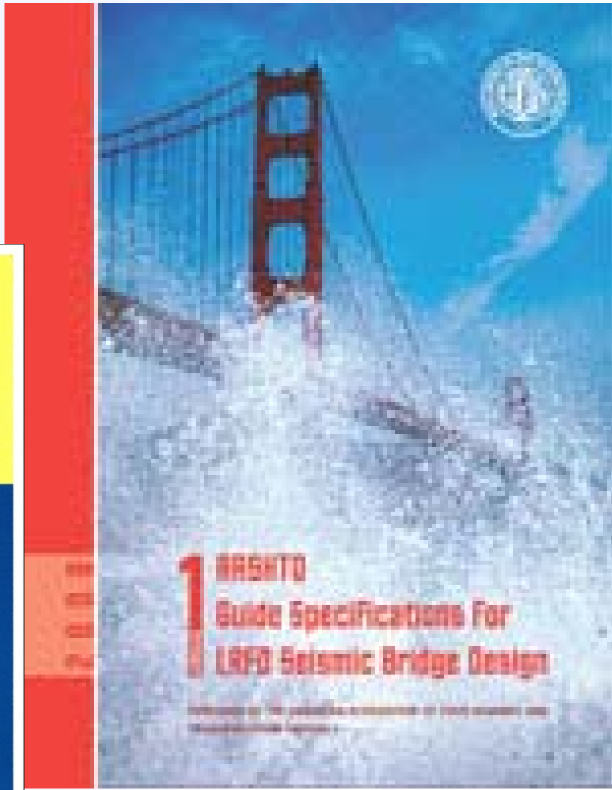
The structural system of a bridge shall be proportioned and detailed to ensure the development of significant and visible inelastic deformations at the strength and extreme event limit states before failure. i.e., Damage

Energy-dissipating devices may be substituted for conventional ductile earthquake resisting systems and the associated methodology addressed in these Specifications or in the *AASHTO Guide Specifications for Seismic Design of Bridges*. i.e., No Damage

AASHTO Specifications 2009 & 2010





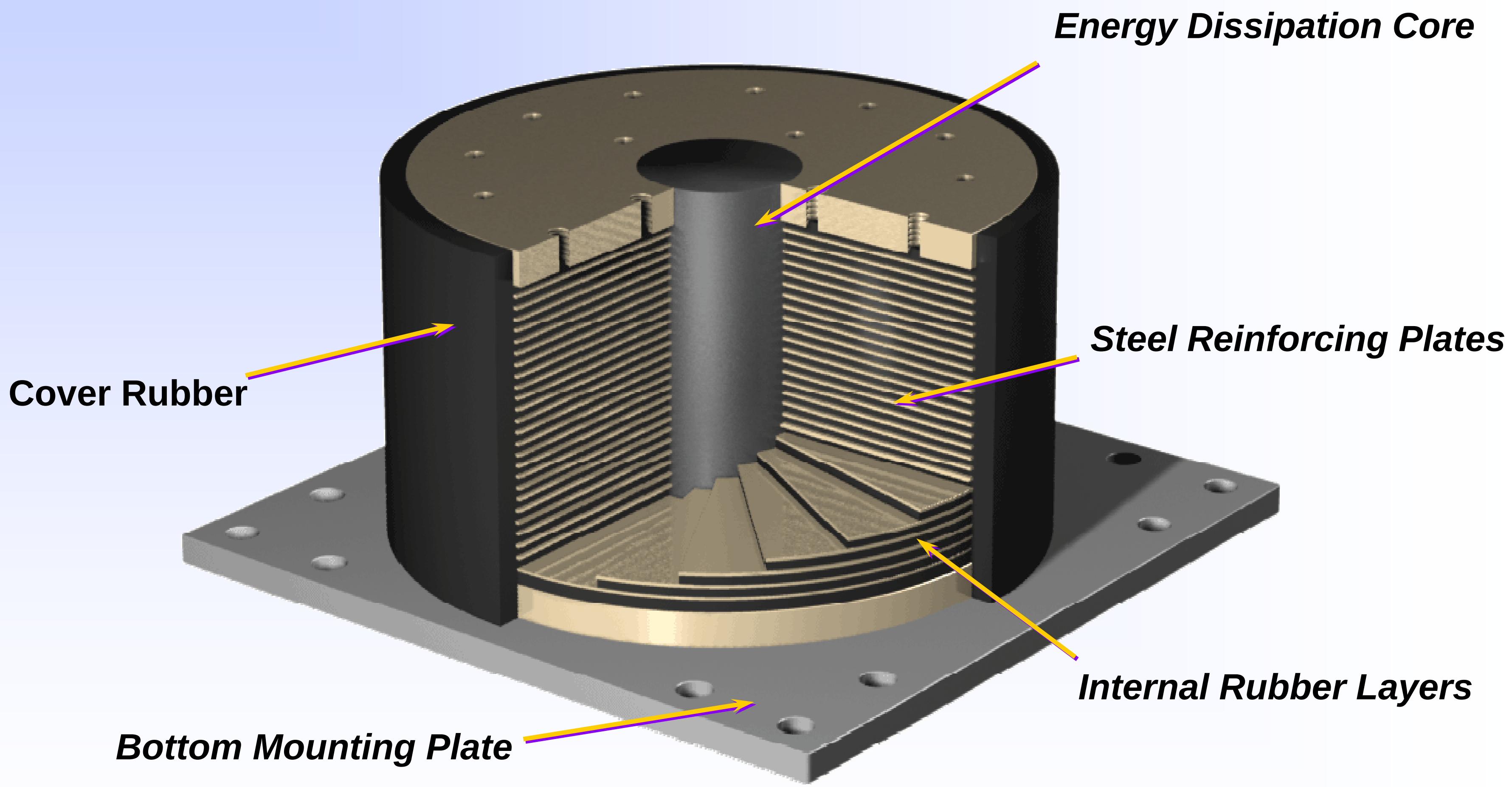


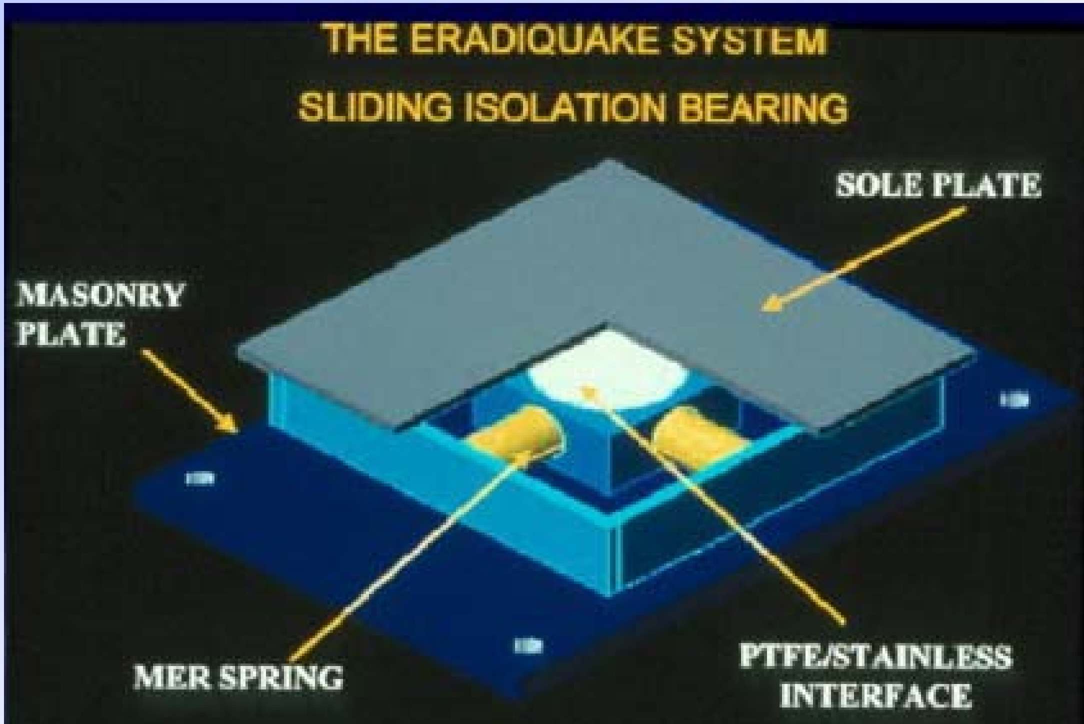
Types of Seismic Isolation Systems Used In USA

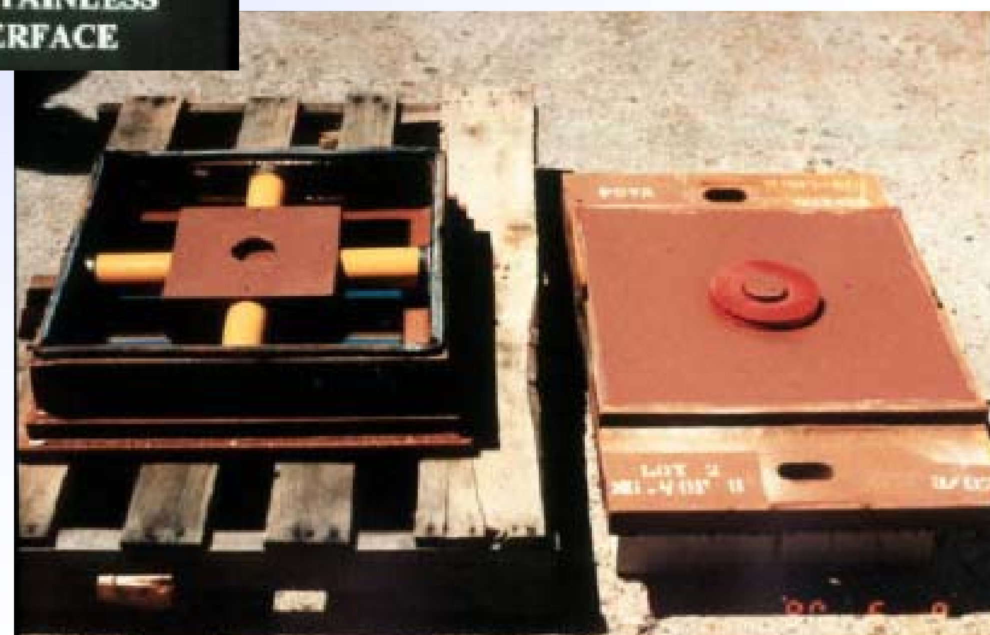
- Lead Core Rubber
  - *Dynamic Isolation Systems, Inc.*
  - *Seismic Energy Products, L.P.*
- EradiQuake
  - *R.J. Watson, Inc.*
- Friction Pendulum
  - *Earthquake Protection Systems, Inc.*

Note: High-Damping Rubber is not used

Lead Rubber Bearing

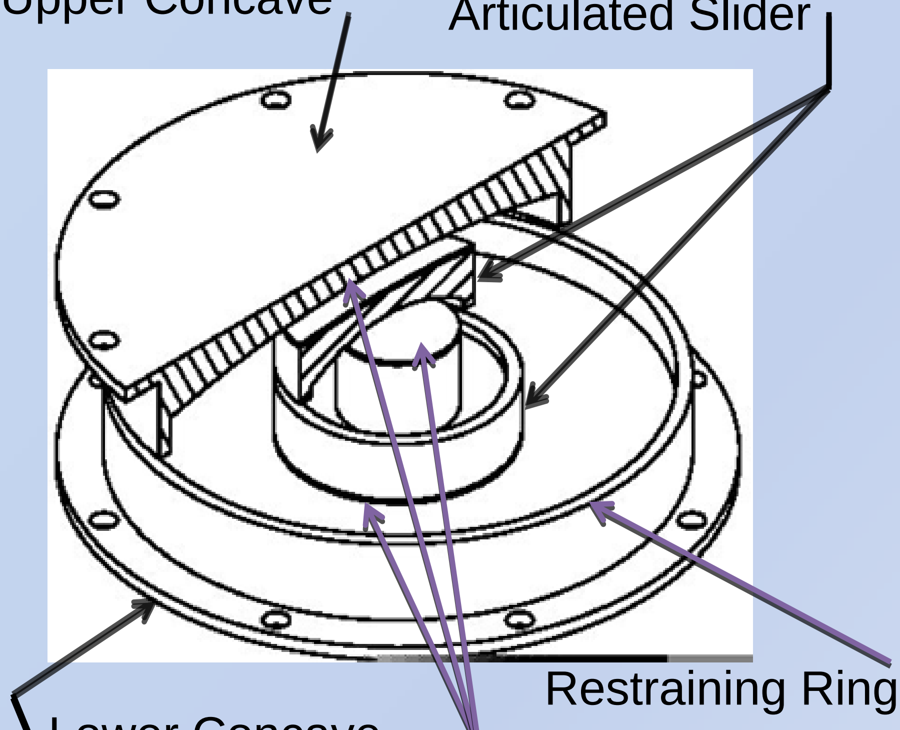



THE ERADIQUAKE SYSTEM
SLIDING ISOLATION BEARING
SOLE PLATE
MASONRY PLATE
MER SPRING
PTFE/STAINLESS INTERFACE



Friction Pendulum Bearings

Triple Pendulum Bearing



Friction Pendulum Bearing

13. Required Tests for Isolation

"All isolation systems shall have there seismic performance verified by Testing"

- ♦ System Characterization
- ♦ Prototype
- ♦ Quality Control

Selection Of An Isolation System

- Service loads and movements
- Axial load, sliding systems have more capacity
- Available height and/or space
- Displacement demands
- Temperatures

California 's High Speed –Rail System

California High-Speed Train Project

FLY CALIFORNIA
Without ever leaving the ground.

TECHNICAL MEMORANDUM

Structure Design Loads
TM 2.3.2

TECHNICAL MEMORANDUM

Interim Seismic Design Criteria
Bridges and Aerial Structures,
Tunnels and Underground Structures,
Passenger Stations and Building Structures
TM 2.10.4

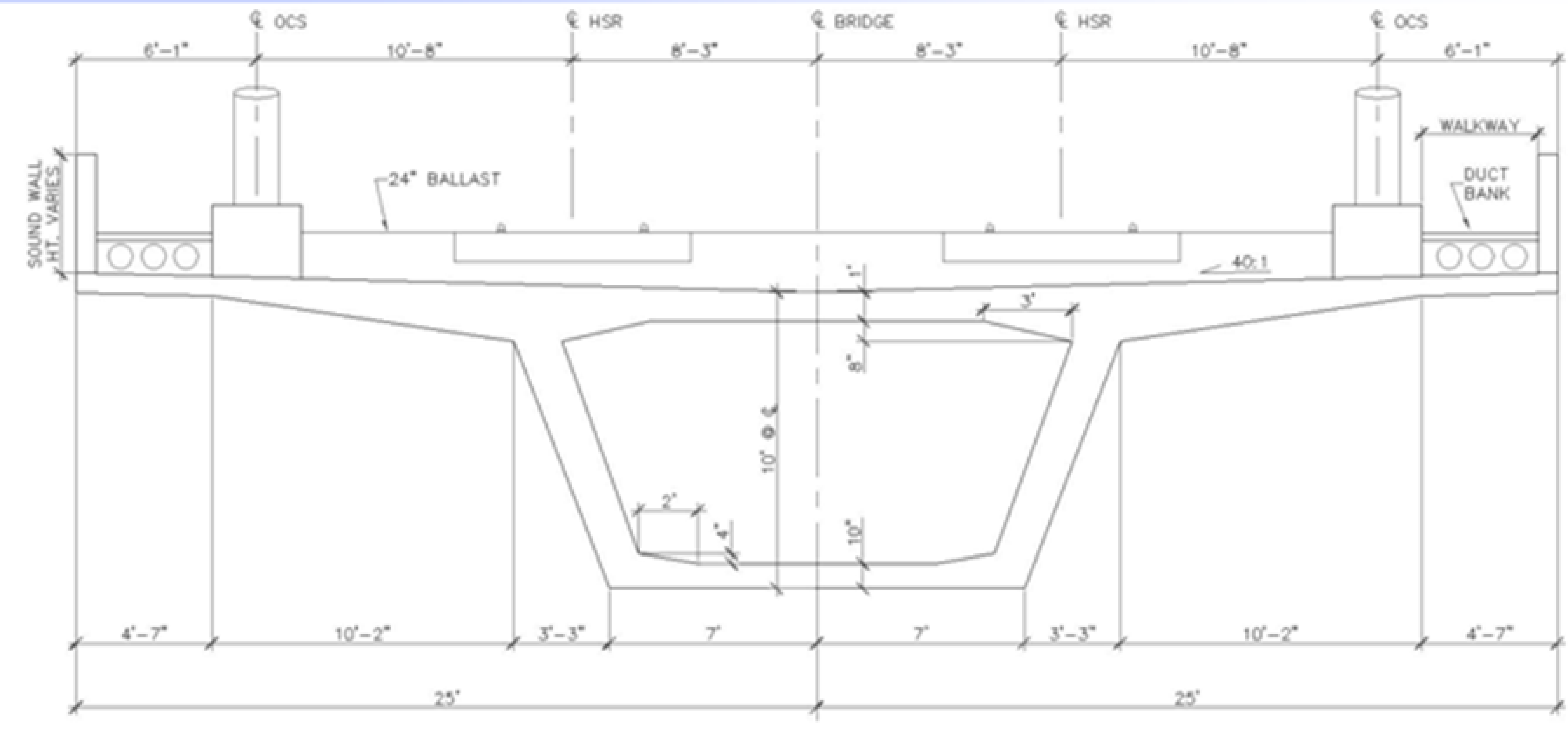
TECHNICAL MEMORANDUM

Track-Structure Interaction
TM 2.10.10

1.2 STATEMENT OF TECHNICAL ISSUE

- The provisions of this Technical Memorandum were developed using a ductility design concept with a plastic hinge forming at the fixed-end support of a column. The performance achieved using this concept is “Life Safety” (i.e. no collapse). Severe damage is permitted to occur in the plastic hinge region as long as structure collapse is prevented.

Seismic Isolation Design Study



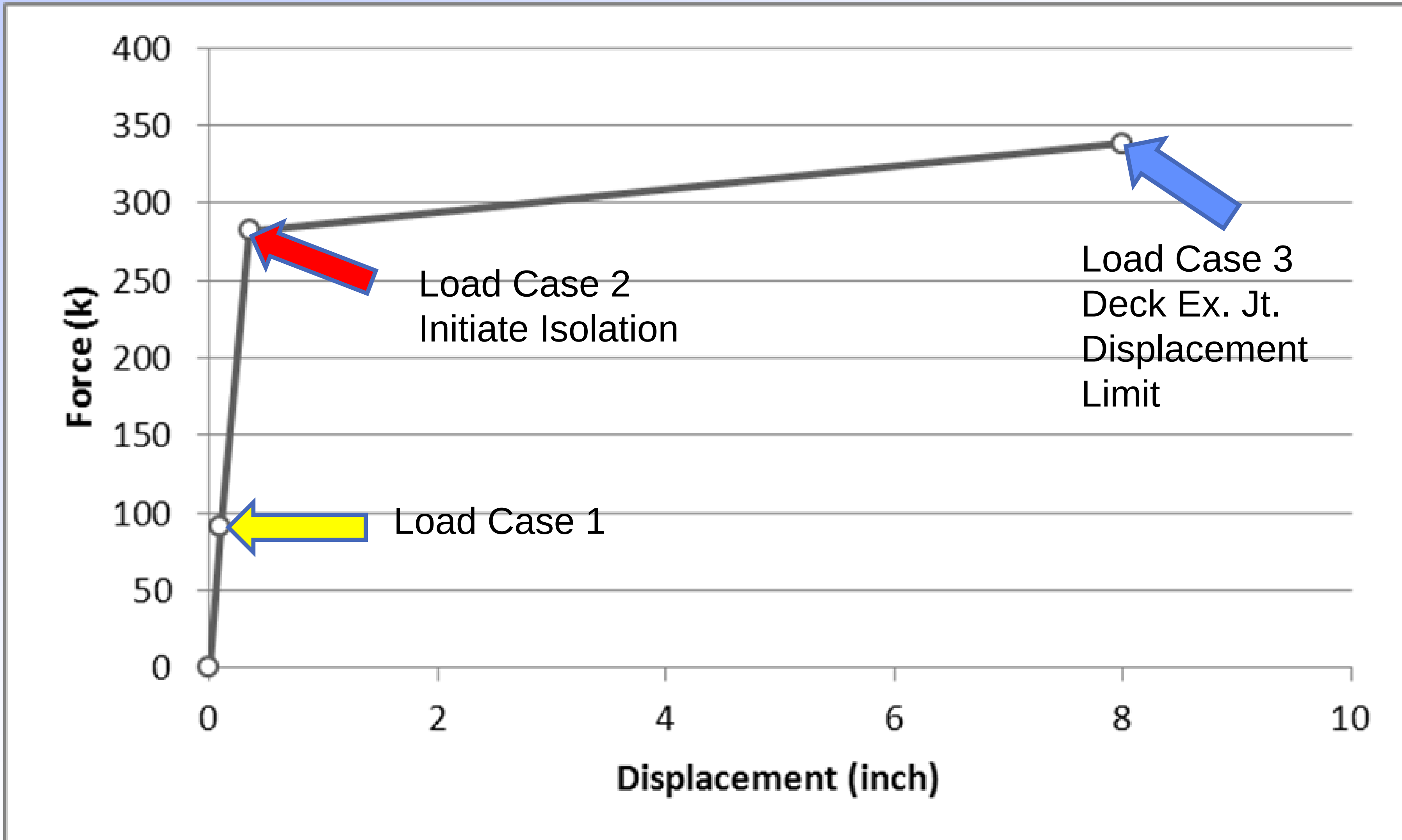
I: vertical impact effect

Load Case Combinations

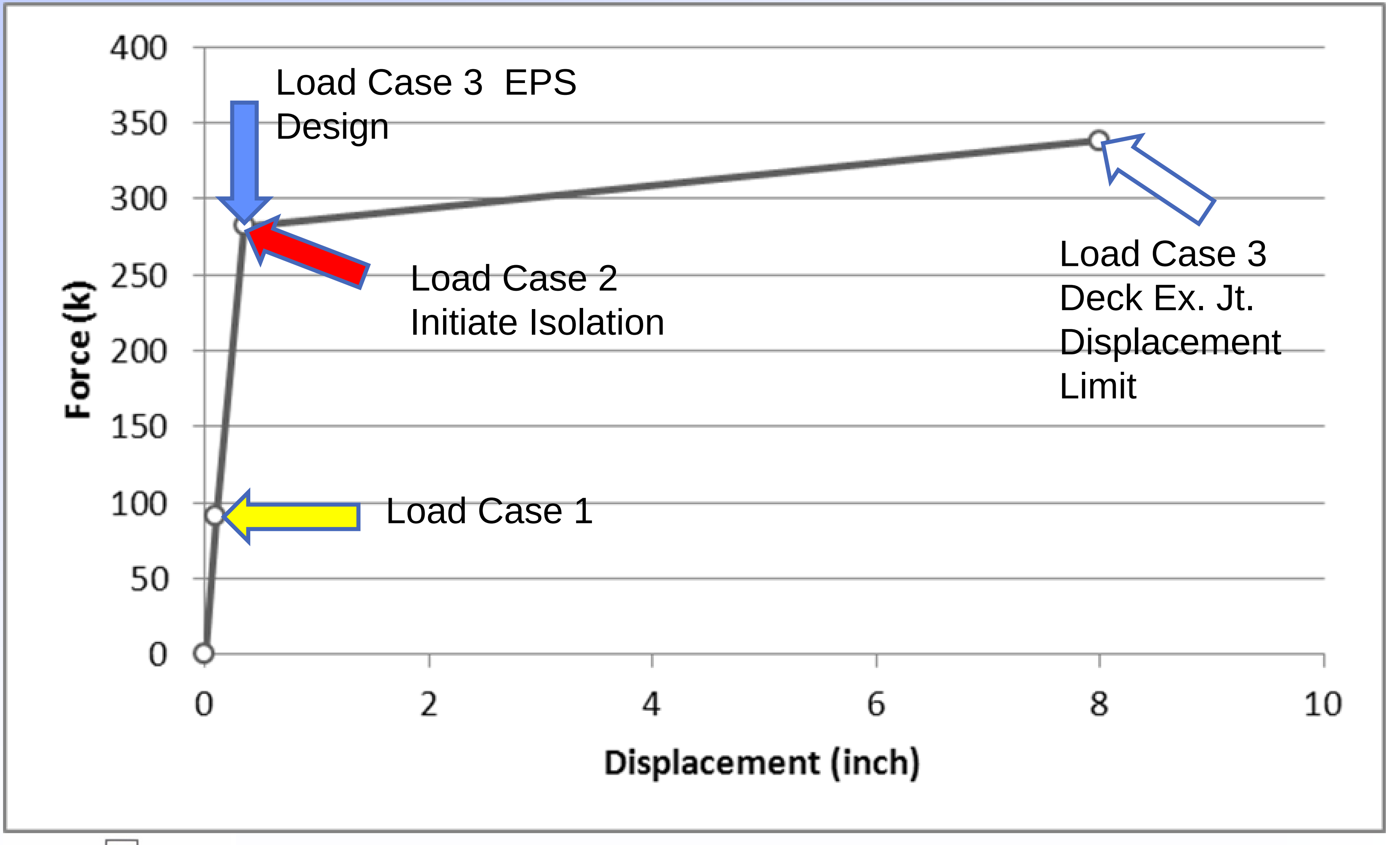
Load Case	Combination
1	DL+(LLRM+I)+LF (two trains)
2	DL+(LLRM + I)+ LF + LDBE (one train)
3	DL + MCE

DL: Dead load of structural components and permanent attachments
LF: Traction or braking force
I: Vertical impact effect
MCE: Maximum Considered Earthquake
LDBE: Lower-Level Design Basis Earthquake
(LLRM + I) multiple tracks of (LLRM + I)

Test-Design Parameters (100 ft. span)



Test-Design Parameters (100 ft. span)



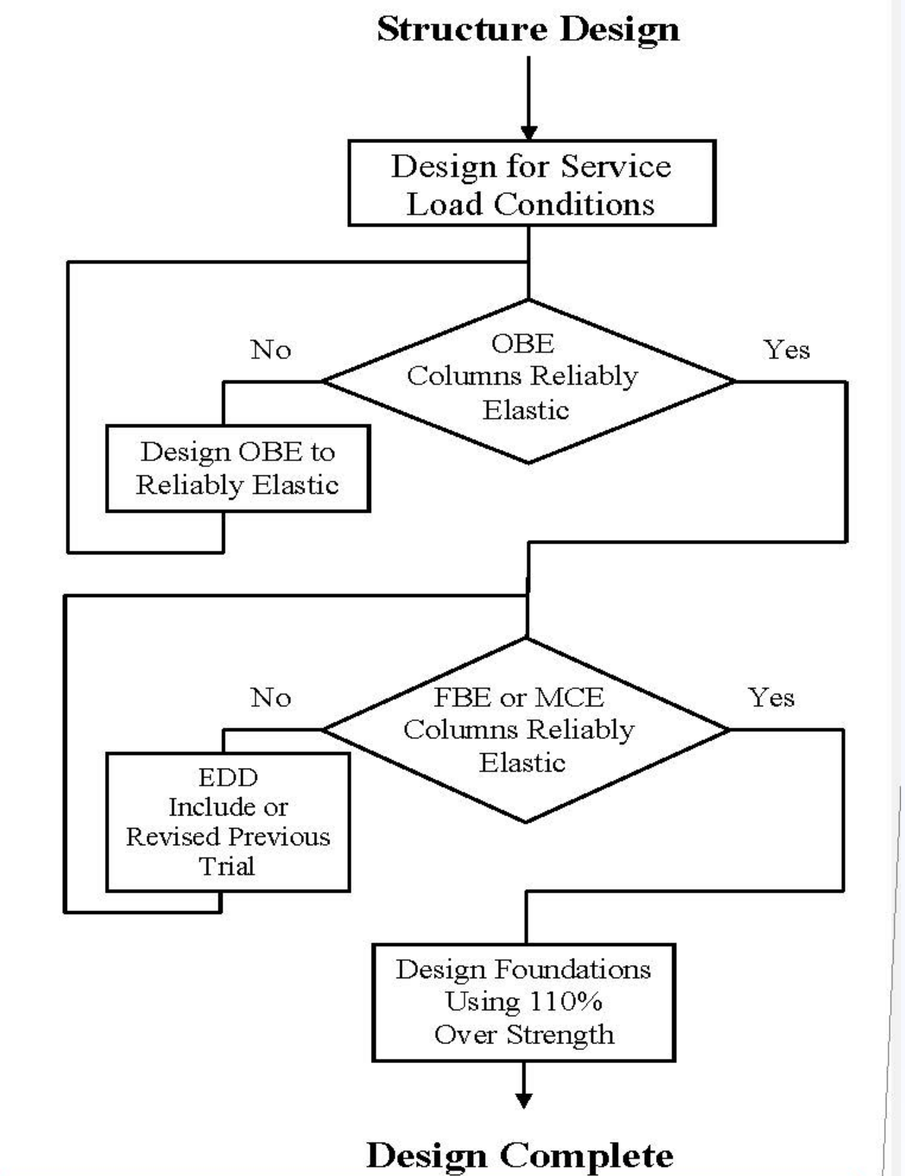


Figure 3.1 Seismic Design Flow Chart for Continued Functionality of Bridges and Aerial Structures

1.2 STATEMENT OF TECHNICAL ISSUE

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1.2 STATEMENT OF TECHNICAL ISSUE

- For elevated structures supporting non-redundant high-speed rail systems higher performance levels having minimum or no damage with Continued Functionality is expected and can be achieved. This is particularly important requirement for the CHSRS to satisfy the expectations of the user community and to satisfy revenue generation commitments.

California High-Speed Train Project

TECHNICAL MEMORANDUM

Seismic Design Criteria with Recommended Revisions for Continued Functionality

Structures Supporting High-Speed Trains TM 2.10.4

Prepared by: ______________________ Fletcher Waggoner, PE — 31 May 11 Date

Checked by: ______________________ Vince Jacob, PE — 31 May 11 Date

Approved by: ______________________ Ken Jong, PE, Engineering Manager — 31 May 11 Date

Released by: ______________________ Hans Van Winkle, Program Director — ______ Date

Revision	Date	Description
0	08 June 09	Issued for 15% Design, Initial Release
1	26 May 10	Revision R1, Revised Design Earthquakes
2	31 May 11	Revision R2, Incorporates TAP comments

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California High-Speed Rail Program Management

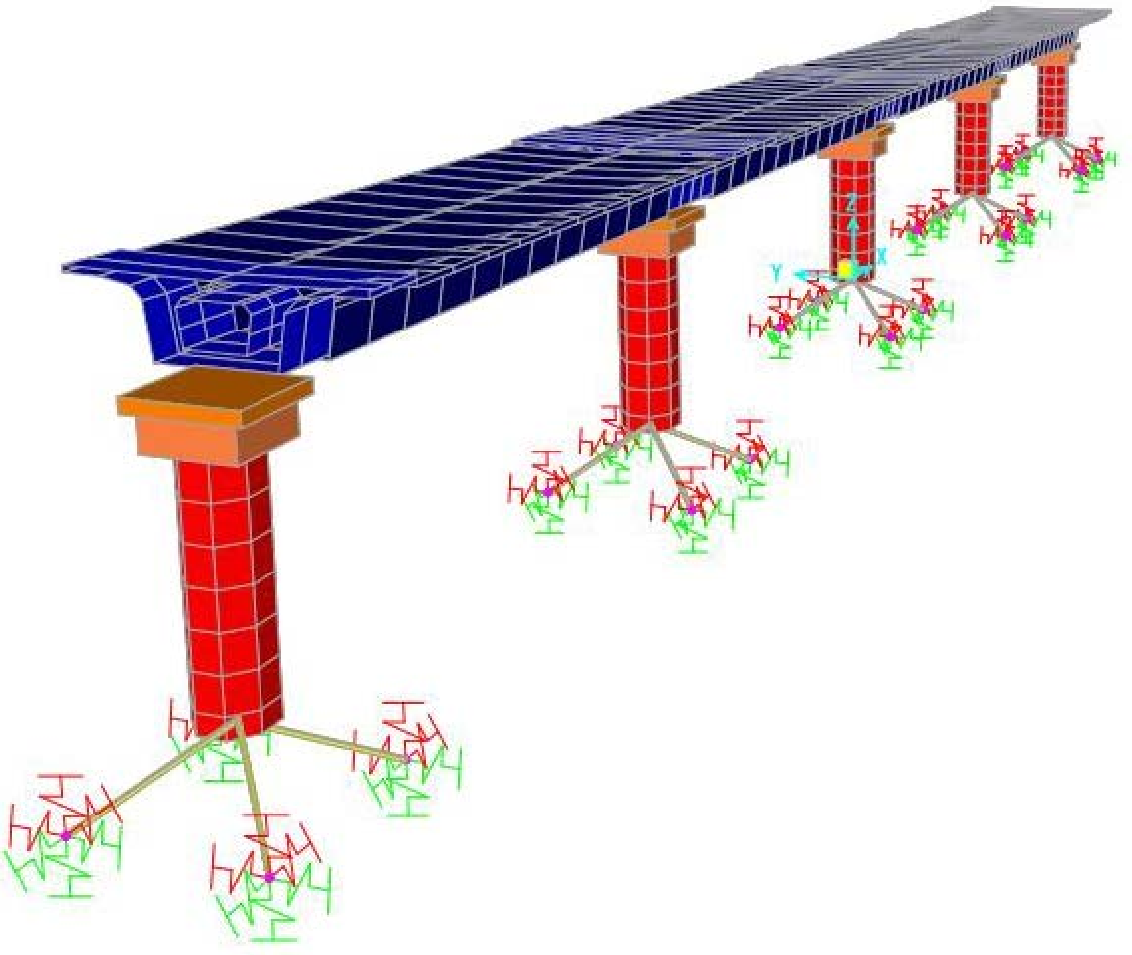

Figure 1: 38' Column Height SAP Model

Objectives

- Satisfy Service Load Requirements
- Isolate the Substructure from the Superstructure
- Keep the Substructure Columns Elastic During an MCE (1000 year event)
- Precludes the Formation of a Plastic Hinge (i.e. no damage)
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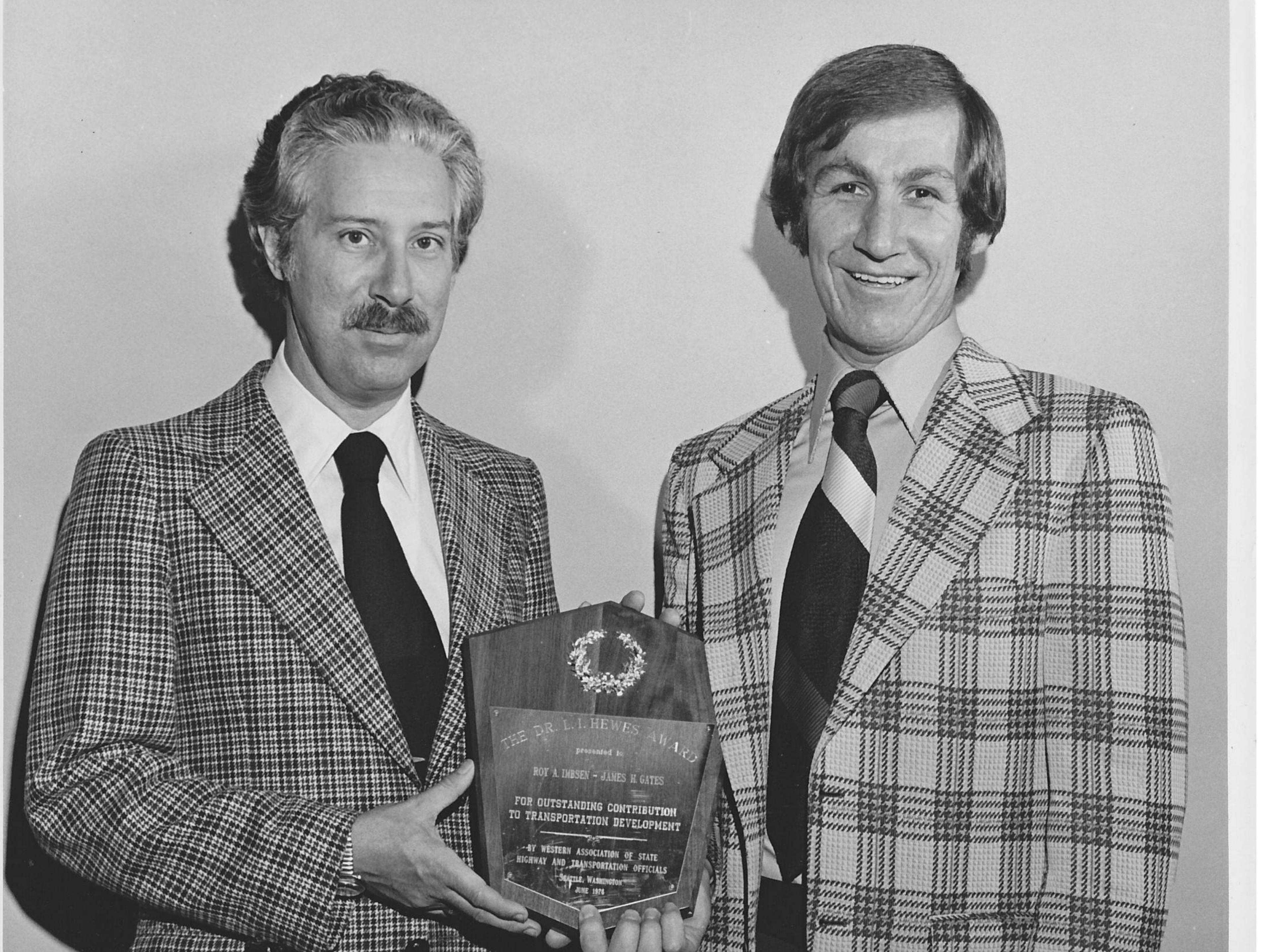
THE DR. L. I. HEWES AWARD
presented to
ROY A. IMBSEN - JAMES H. GATES
FOR OUTSTANDING CONTRIBUTION
TO TRANSPORTATION DEVELOPMENT
BY WESTERN ASSOCIATION OF STATE
HIGHWAY AND TRANSPORTATION OFFICIALS
SEATTLE, WASHINGTON
JUNE 1976

Lets' Take the Next Step
Raise the Bar for Seismic Protection

- Continued Functionality
- Increased Reliability at Lower Construction Costs $$$$
- Increased Performance – No Damage
- Implement Current Technology using Isolation

Thank You

Earthquake

Protection

Systems