Improving the earthquake performance of bridges using seismic isolation

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  - Academia
  - DOT practitioners
  - Industry

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- NCHRP 20-7 (262) Review and Update of the AASHTO *Guide Specifications for Seismic Isolation Design*

Outline

- Conventional vs seismic isolation design
- History
- Basic requirements (principles)
- Examples (applications)
- Limitations
- Design of a bridge isolation system
- Additional sources of information
- Design examples
- Q&A

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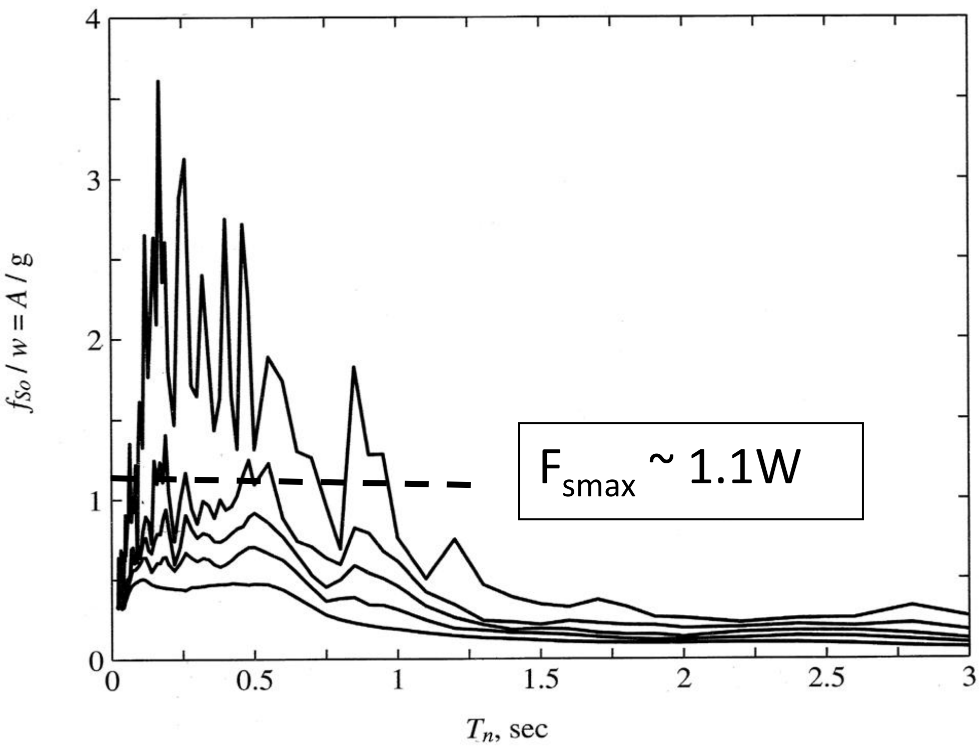
Conventional seismic design

- Fundamental requirement of seismic design:

$$\frac{\text{Capacity}}{\text{Demand}} \geq 1.0$$

Demand

- But demand is excessive



Demand

- Because demand is excessive it is often impractical to provided sufficient capacity to keep structure elastic
- Hence damage is accepted in form of plastic deformation and concrete spalling in ‘hinge zones’

capacity seismic design

Conventional seismic design

- Since yield is permitted:

INCREASE CAPACITY

$$\frac{\text{Deformation Capacity}}{\text{Deformation Demand}} \geq 1.0$$

Conventional seismic design

Deconstruction of Christchurch, 2011-12

Conventional seismic design

Alternative approach

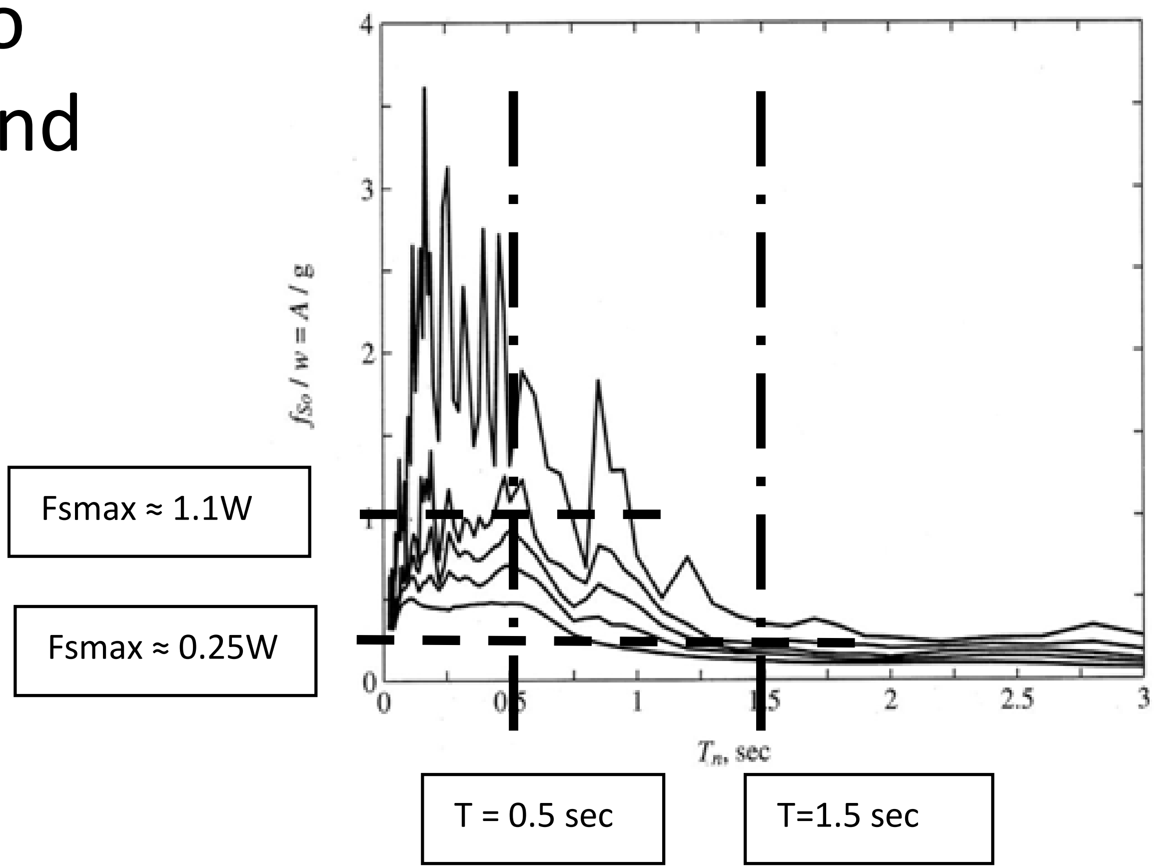
$$\frac{\text{Deformation Capacity}}{\text{Deformation Demand}} \geq 1.0$$

REDUCE
DEMAND

Alternative approach

Alternative approach

- Easiest way to reduce demand is to increase flexibility and lengthen period, T



Alternative approach

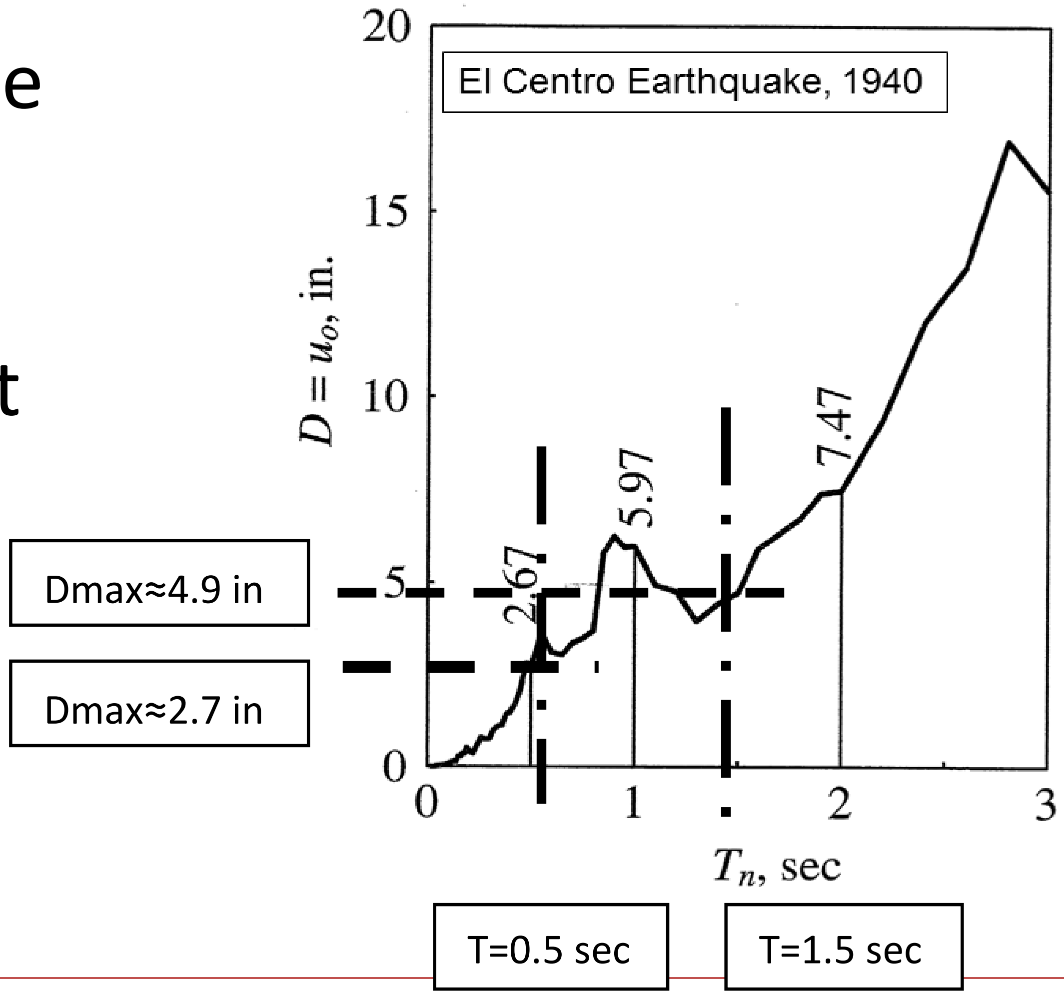
- This approach is essence of **seismic isolation – add flexibility to lengthen period** to give a better ‘ride’

Seismic isolation

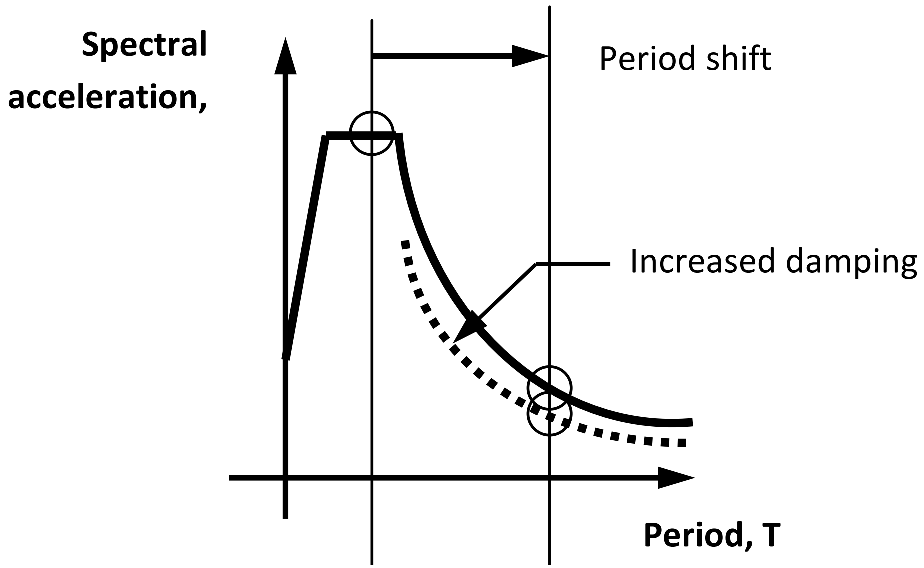
- By lengthening period, substantial reductions in forces (e.g. base shear) are possible and often feasible to keep structure elastic during design earthquake (i.e. no yield)
- Significant reductions in repair costs
- Continuing functionality is achievable
- Applicable to new and existing structures
- Applicable to buildings, bridges, industrial plant…

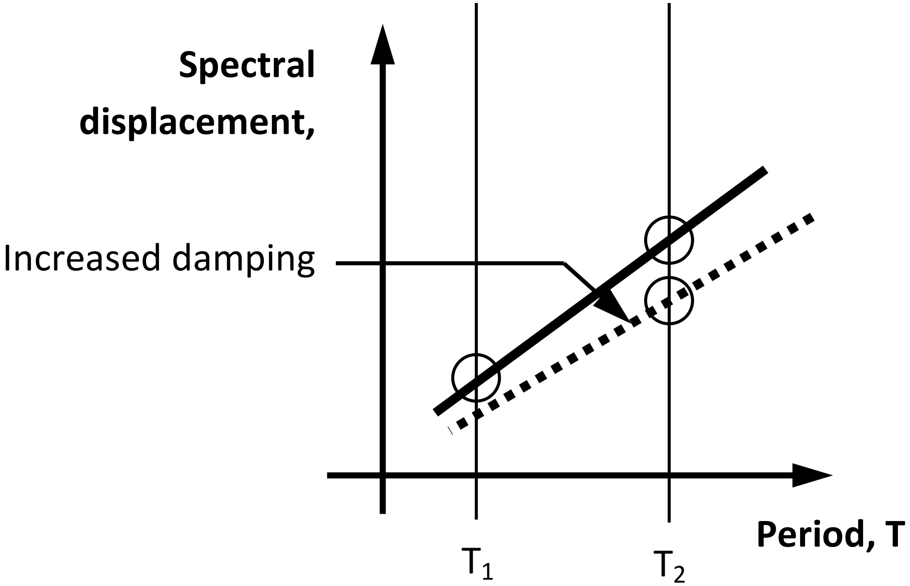
But…

- Increasing the period increases displacement



Force-displacement tradeoff





Force-displacement tradeoff

- Tradeoff between force and displacement is one of the challenging aspects of base isolation
- Additional damping is usually added to limit the increase in displacements
- Note that these ‘larger’ displacements occur mainly in isolator themselves and not in the structure (i.e. columns). Even though the system displacements may be ‘large’, column drift is small

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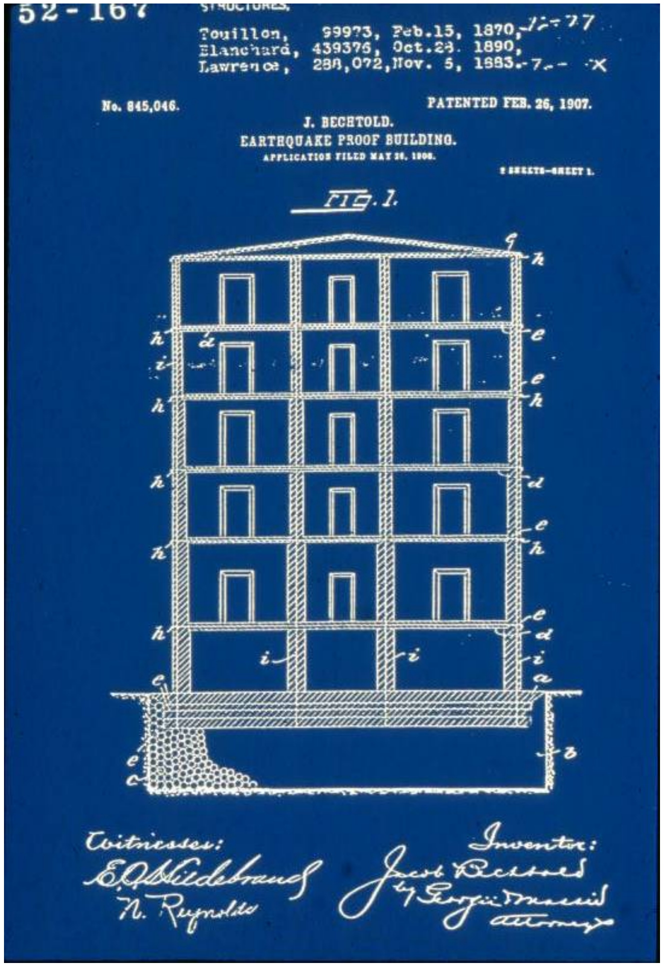
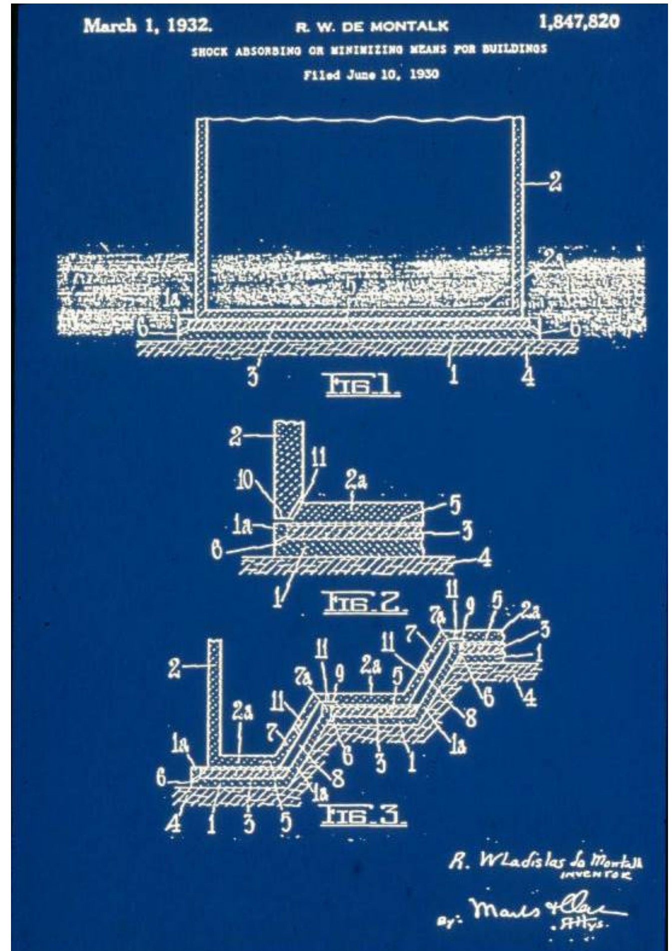
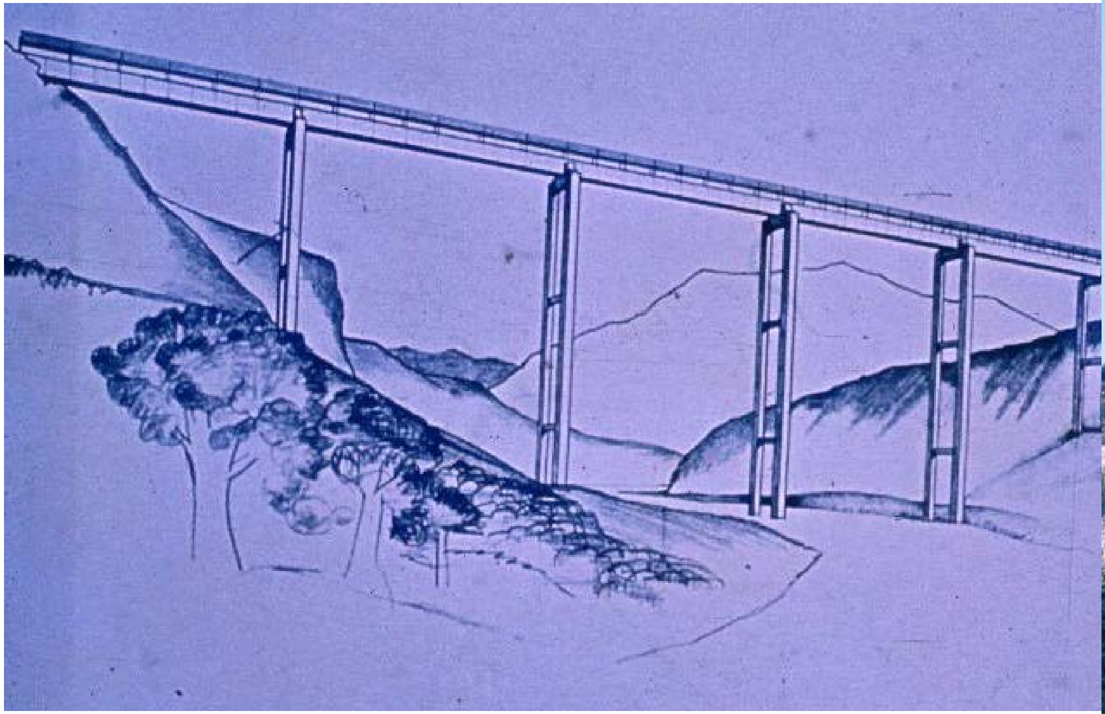
History – The Distant Past





History – So. Rangitikei River Bridge, 1979



World's First Base-Isolated Bridge

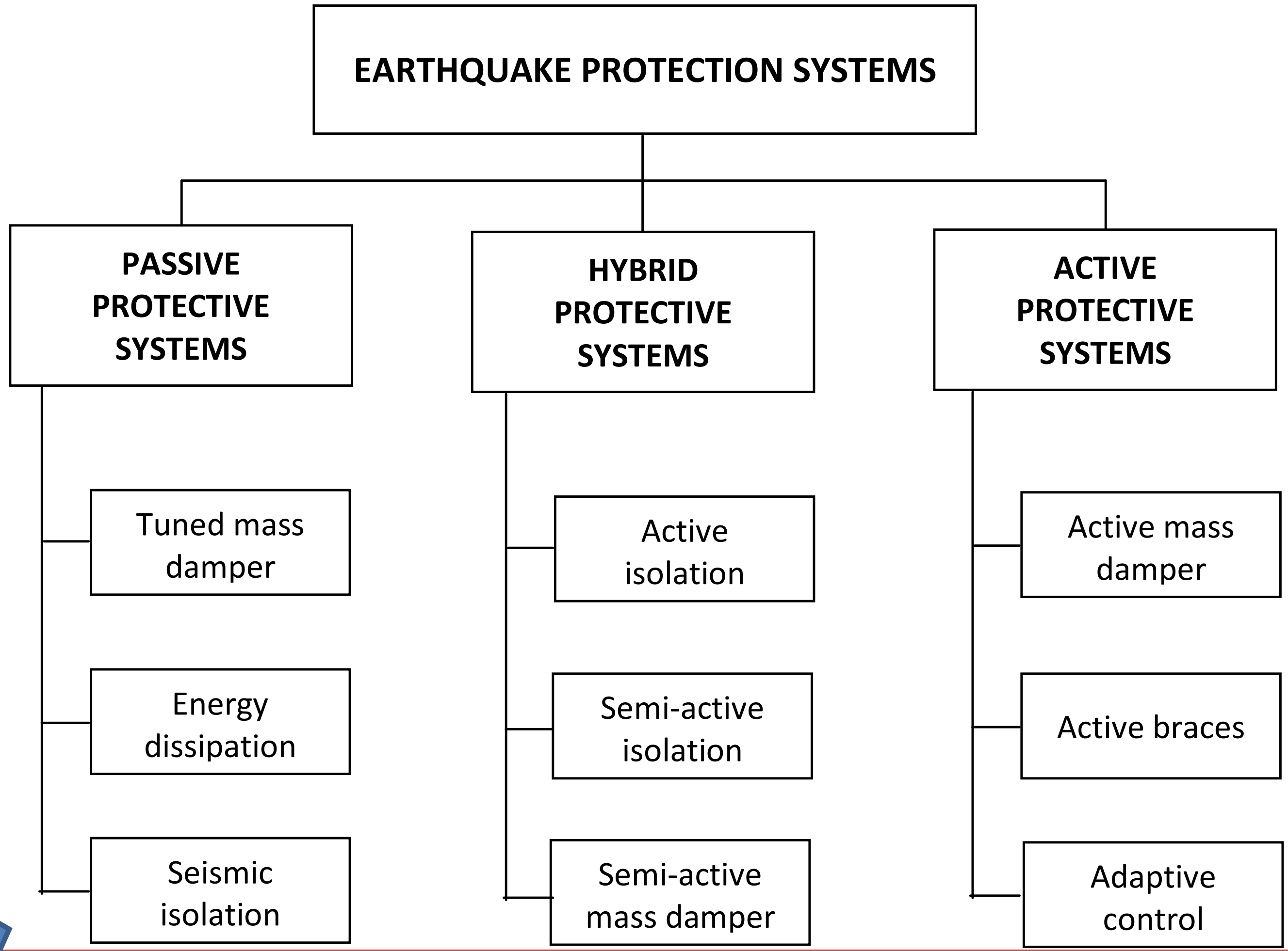
History – William Clayton Building, 1981

World's First Base-Isolated Building

History - Today

- Today seismic isolation is but one member of a growing family of *earthquake protective systems* that includes:
  - Mechanical energy dissipators
  - Tuned mass dampers
  - Active mass dampers
  - Adaptive control systems
  - Semi-active isolation

History - Today



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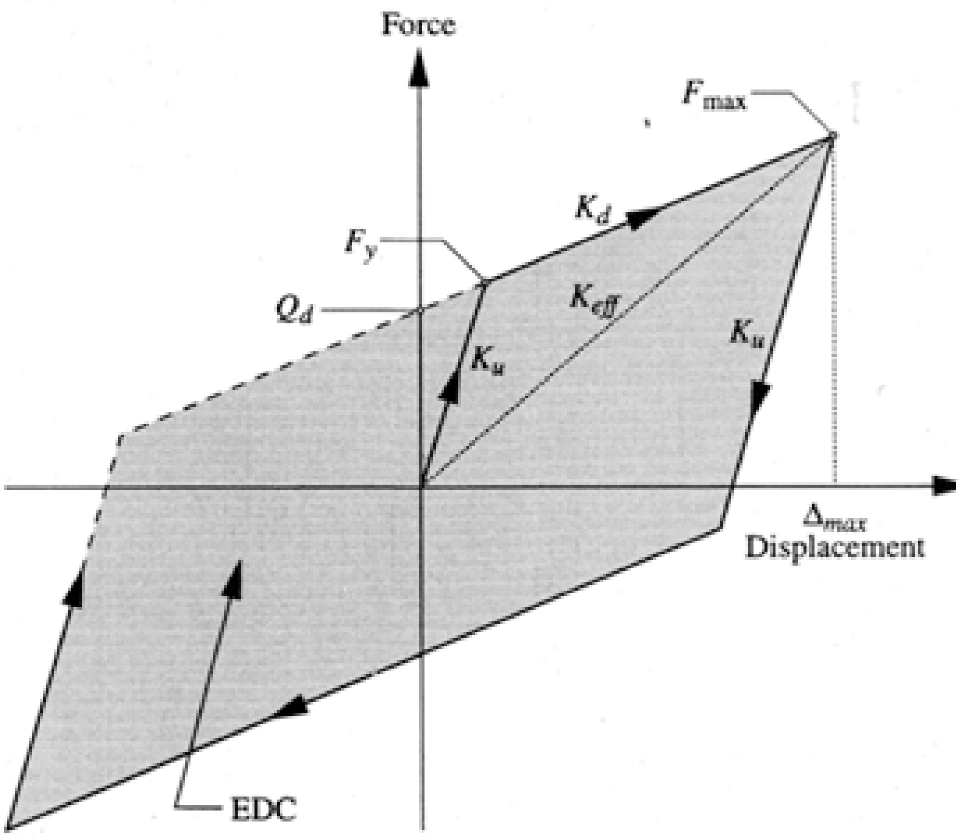
Basic requirements of isolation system

1) Flexible mount to lengthen period of the structural system
2) Damper (energy dissipator) to limit the displacement in the flexible mount
3) Restraint for service loads (wind, braking…)
4) Restoring device to re-centre system following an earthquake

Above requirement- stiff for service loads, flexible for earthquake loads - means that all practical isolation systems are nonlinear.

Basic requirements



Q_d = characteristic strength

F_y = yield strength

F_{max}= maximum isolator force

K_d = post-elastic stiffness

K_u = loading and unloading stiffness

K_{eff} = effective stiffness

Δ_{max} (= u_{max})

= maximum isolator displacement

EDC = area of hysteretic loop

= energy dissipated per cycle.

Basic properties

- Two most important properties are:
  - Q_d: characteristic strength, pseudo yield
  - K_d: second slope, isolator stiffness after 'yield'
  - Q_d and K_d determine effective stiffness (K_{eff}) and energy dissipated per cycle (EDC) for given displacement, Δ_{max}
  - K_{eff} determines effective period T_{eff} and
  - EDC determines equivalent viscous damping ratio, h_{eff}

Basic requirements of isolation system

1) **Flexible mount** to lengthen period of combined structure-isolator system
2) **Damper** (energy dissipator) to control displacement in flexible mount
3) **Restraint** for service loads (wind, braking…)
4) **Restoring device** to re-centre system following earthquake

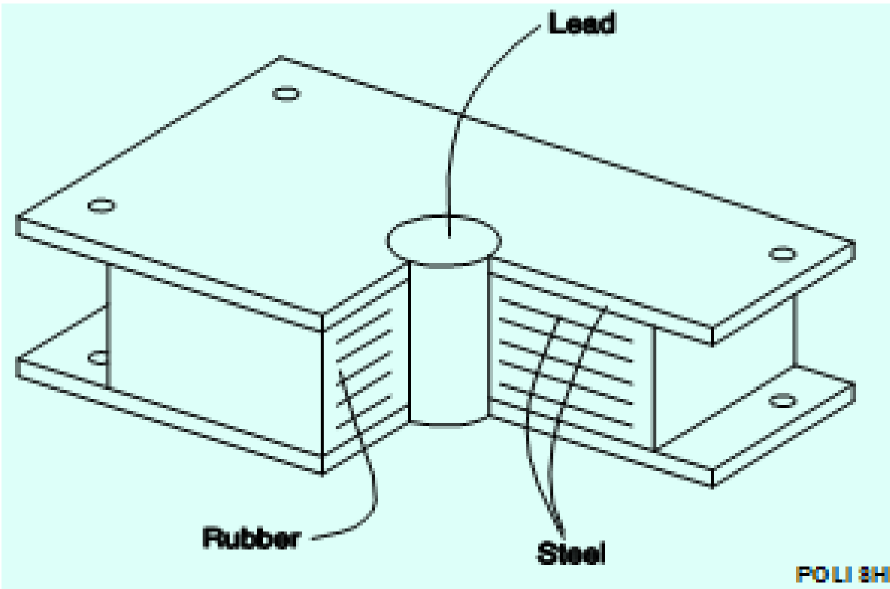
Basic requirements

Requirement	Examples
Flexible mount	Elastomeric bearing (natural or synthetic rubber) Flat or curved sliding surface PTFE and stainless steel)
Damper	Plastic deformation (steel, lead…) Friction Viscosity of fluid High damping rubber compound
Restraint	Mechanical fuse Elastic stiffness of a yielding dissipator Friction (pre-slip)
Restoring device	Elastomeric or metal spring Concave sliding surface

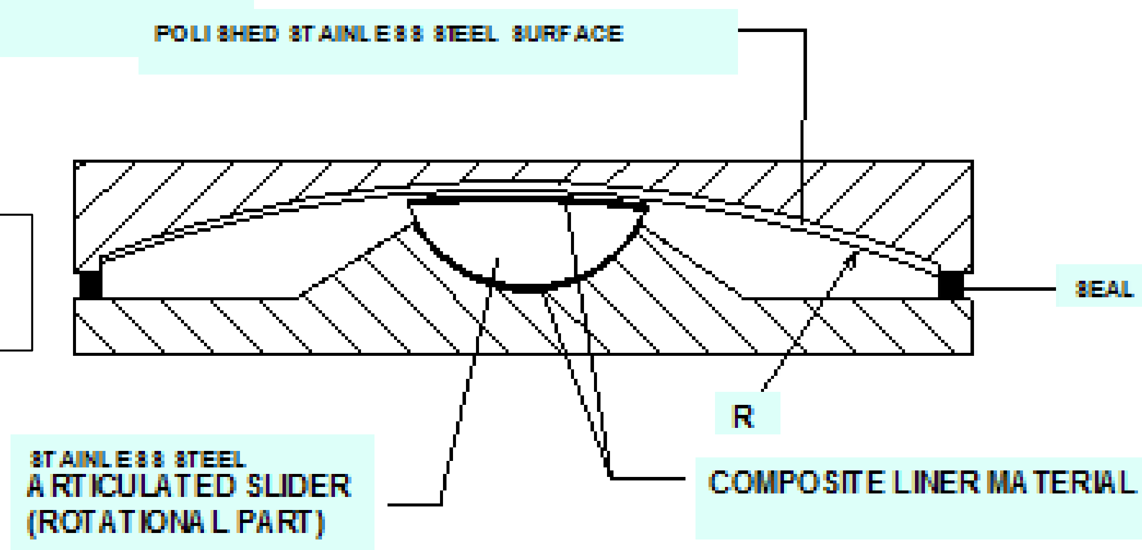
Basic hardware

Isolator Type	Available devices
Elastomeric systems	Lead-rubber bearing (LRB) -standard natural rubber bearing with lead core High damping rubber bearing (HDR) -modified natural rubber bearing with high damping rubber compound
Sliding Systems	Concave friction bearing (CFB) -concave slider using PTFE and stainless steel Flat plate friction bearing (FPB) -flat plate slider using PTFE and stainless steel, and elastomeric springs

Basic hardware

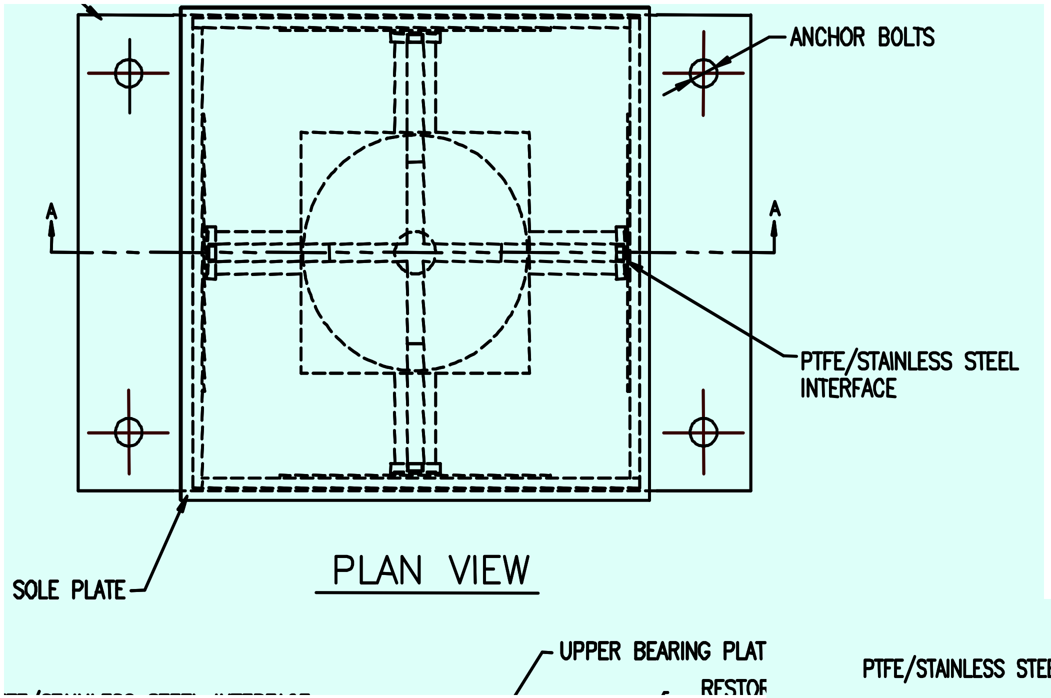


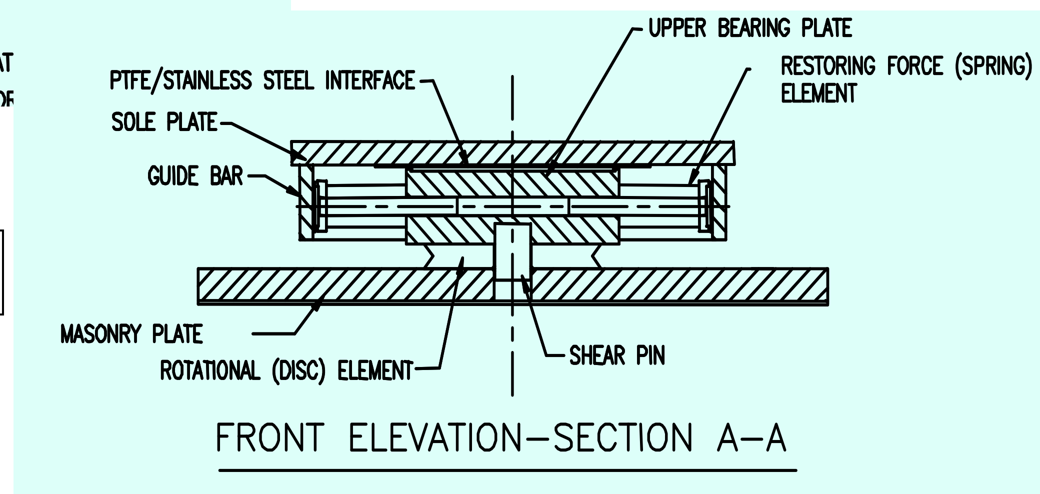
Left: Lead rubber bearing (LRB)



Right: Concave friction bearing
(CFB)

Basic hardware





Flat plate friction bearing (FPB)

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Applications: US 101 Sierra Point, CA

(a) Above: Single column with existing steel bearing before retrofit.

(b) Left: Replacement of existing steel bearing with lead-rubber isolator.

(c) Above: Isolator installation on single column substructures

Applications: I-680 Benicia-Martinez, CA

Applications: JFK Airport Light Rail, NY

Applications: Bolu Viaduct, Turkey

Applications in U.S., Canada, Mexico

State	Number of isolated bridges	Percent of total number of isolated bridges in North America
California	28	13%
New Jersey	23	11%
New York	22	11%
Massachusetts	20	10%
New Hampshire	14	7%
Illinois	14	7%
Total	121	

Applications in U.S., Canada, Mexico

Isolator Type	Applications (Percent of total number of isolated bridges in North America)
Lead-rubber bearing	75%
Flat plate friction bearing	20%
Other: Concave friction bearing, High damping rubber bearing, Natural rubber bearing	5%

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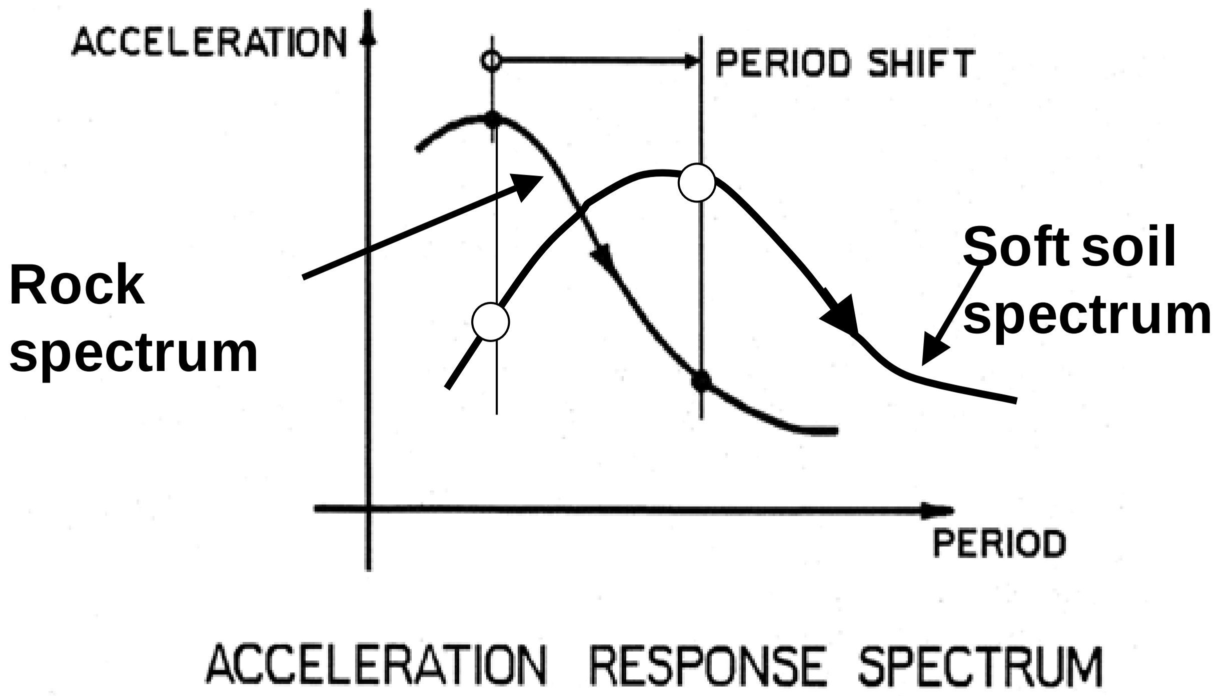
Limitations

- Successful application of isolation is dependent on the shape of the acceleration response spectrum
- Sites not suitable for isolation include those where the spectrum does not decay rapidly with increasing period, such as a soft soil site

Limitations



Limitations

- Other sites where isolation is questionable include near-field sites where long period, high-velocity pulses may be encountered
- Bridges where isolation is questionable include those:
  - with tall piers that have long ‘fixed-base’ periods
  - in high seismic zones on soft sites where superstructure displacements are large and movement joints expensive
- Exceptions exist…

Conversely…

- Bridges most suitable for isolation include those
  - with relatively short ‘fixed-base’ periods (< 1.5 s)
  - on competent soils, and
  - not in near-field.

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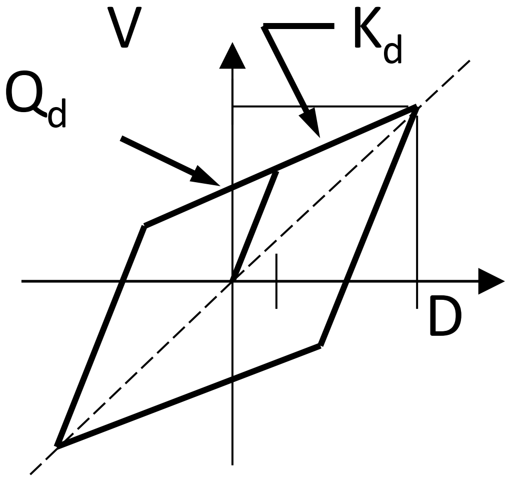
Design of a bridge Isolation system

Three step process:

1. Select required performance criteria
2. Determine properties of the isolation system to achieve required performance (e.g. Q_d and K_d) using one or more methods of analysis
3. Select isolator type and design hardware to achieve required system properties (i.e. Q_d and K_d values) using a rational design procedure



Performance criteria

- Usually set by owner
- Examples include:
  - Not-to-exceed total base shear for Design Earthquake (1,000 yr return period)
  - Elastic columns during Design Earthquake (1,000 yr)
  - Not-to-exceed longitudinal displacement in superstructure during Design Earthquake
  - Essentially elastic behavior for the Maximum Considered Earthquake (MCE, 2,500 yr)
  - Reparable damage in MCE, but not collapse

Analysis methods for isolated bridges

Bridges with nonlinear isolators may be analyzed using linear methods provided equivalent properties are used, such as

- effective stiffness, and
- equivalent viscous damping, based on the hysteretic energy dissipated by the isolators.

Analysis methods for isolated bridges

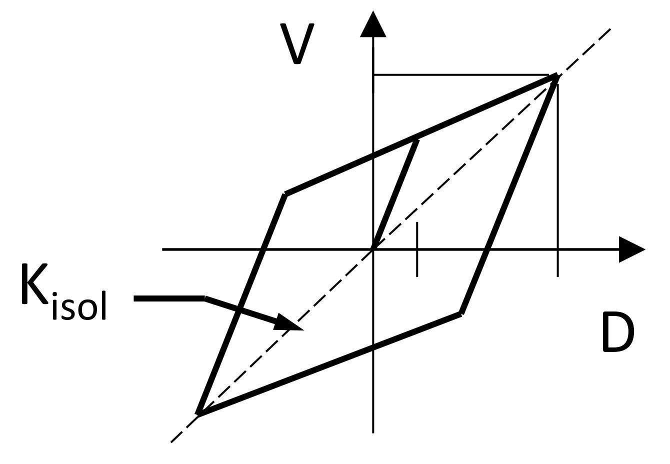
- Uniform Load Method
- Single Mode Spectral Method
- Multimode Spectral Method
- Time History Method

Analysis methods

- ~~Uniform Load~~ Simplified Method
- Single Mode Spectral Method
- Multimode Spectral Method
- Time History Method

Assumptions in Simplified Method

1. Superstructure acts a rigid-diaphragm compared to flexibility of isolators
2. Single displacement describes motion of superstructure, i.e. single degree-of-freedom system
3. Nonlinear properties of isolators may be represented by bilinear loops
4. Bilinear stiffness can be represented by K_{isol}, effective stiffness. Note K_{isol} is dependent on displacement, D



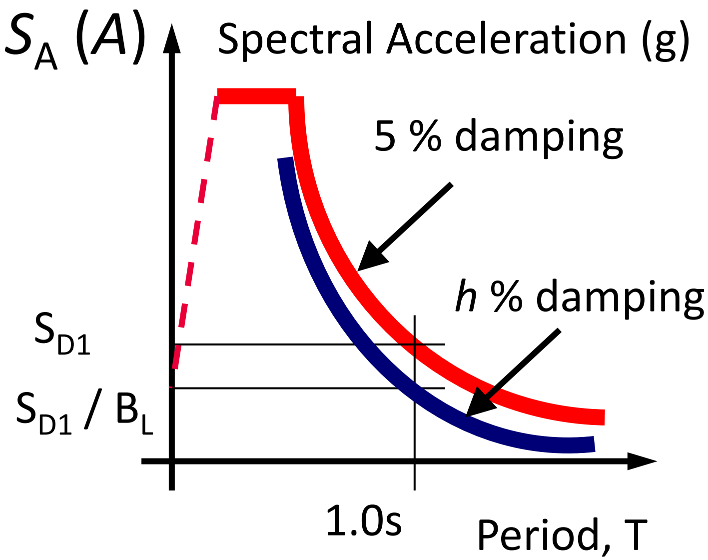
Assumptions in Simplified Method

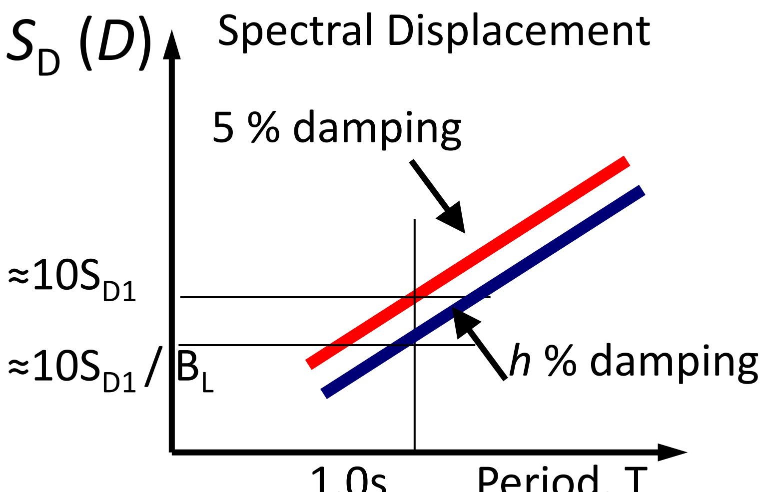
5. Hysteretic energy dissipation may be represented by viscous damping, i.e., work done during plastic deformation can be represented by work done moving viscous fluid through an orifice. Equivalent viscous damping ratio given by

$$h = \frac{2}{\pi} \frac{Q_d}{F_m} \left(1 - \frac{D_y}{D_{isol}}\right)$$

6. Acceleration spectrum is inversely proportional to period (i.e. $S_A = a / T$)

AASHTO Design Response Spectra





AASHTO Spectra (S_A) are for 5% damping on a rock site (Site Class B)

For sites other than rock, the spectra are modified by Site Factors, F_a and F_v

For damping other than 5%, the spectra are modified by a Damping Factor, B_L

$$S_A \equiv A = \frac{F_v S_1}{B_L T} = \frac{S_{D1}}{B_L T}$$

$$S_D \equiv D = \left(\frac{g}{4\pi}\right)^2 \frac{F_v S_1 T}{B_L} = 9.79 \frac{S_{D1} T}{B_L}$$

Assumptions in Simplified Method

7. Acceleration spectra for 5% viscous damping may be scaled for actual damping (*h*) by dividing by a damping coefficient, B_L

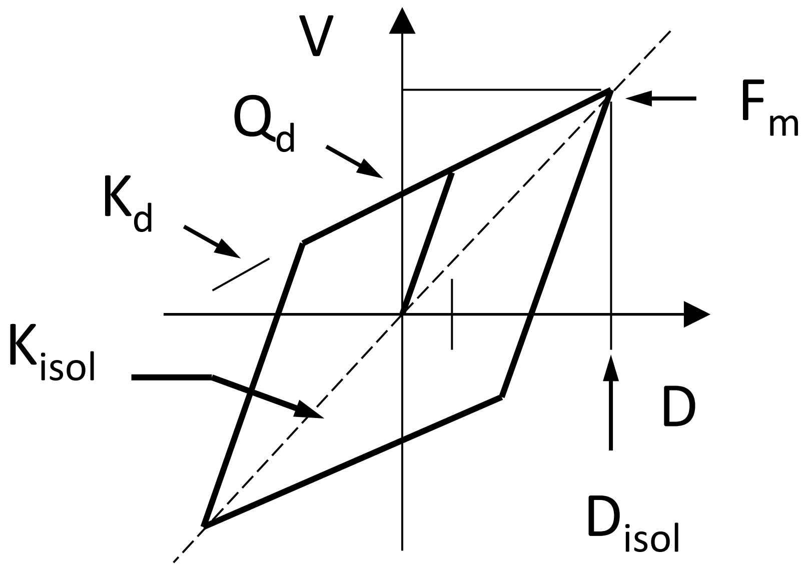
$$B_L = \left(\frac{h}{0.05} \right)^{0.3}$$

B_L is used in long-period range of spectrum. Another factor (B_S) is used in short-period range. Isolated bridges usually fall in long-period range.

Simplified Method

Basic steps:

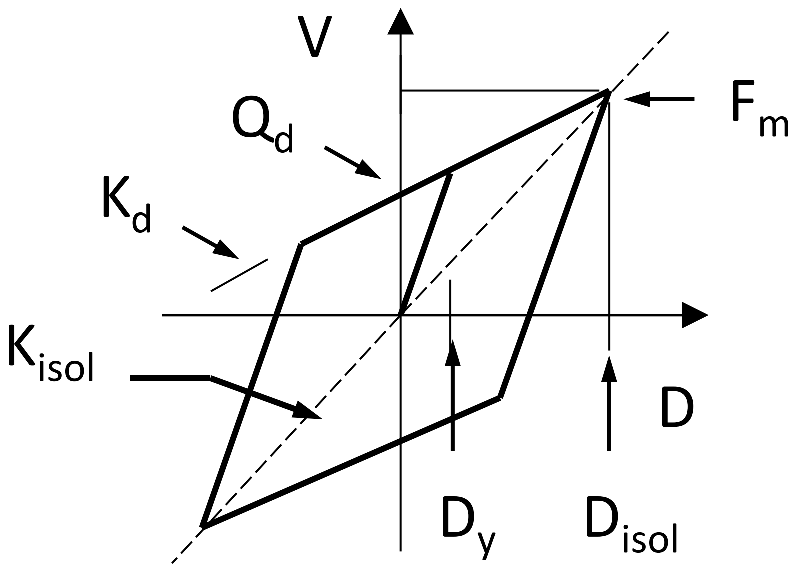
1. Assume value for D_{isol}
2. Calculate effective stiffness, K_{isol}
3. Calculate max. force, F_m
4. Calculate effective period, T_{eff}



$$K_{isol} = \frac{Q_d}{D_{isol}} + K_d \qquad F_m = K_{isol} D_{isol} \qquad T_{eff} = 2\pi \sqrt{\frac{W}{g K_{isol}}}$$

Simplified Method continued

5. Calculate viscous damping ratio, *h*
6. Calculate damping coefficient, B_L
7. Calculate D_{isol}
8. Compare with value for D_{isol} in Step (1). Repeat until convergence.



$$D_{isol} = \frac{g}{4\pi^2}\frac{F_v S_1}{B_L} T_{eff}$$

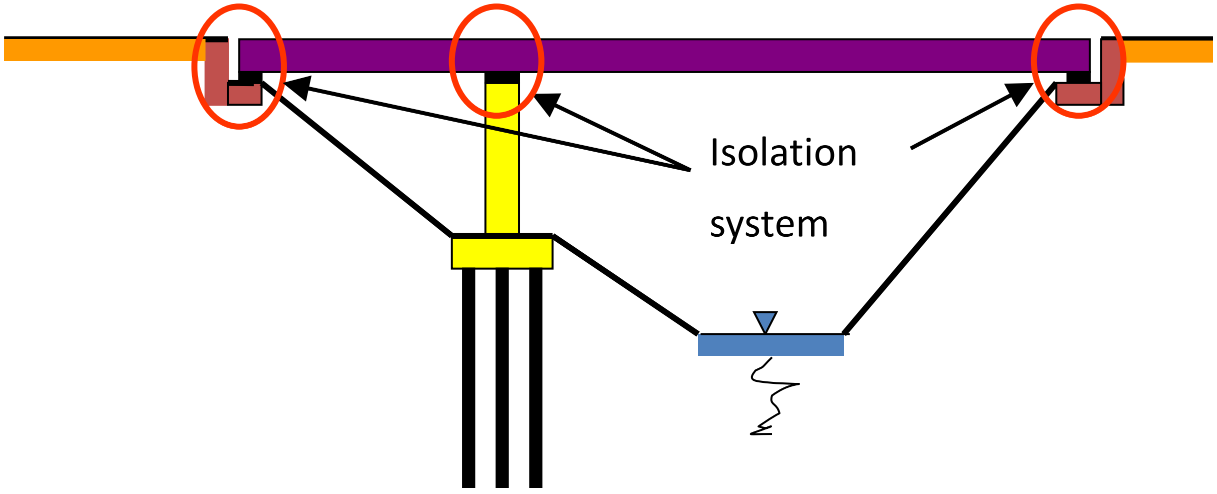
$$h = \frac{2}{\pi}\frac{Q_d}{F_m}\left(1 - \frac{D_y}{D_{isol}}\right)$$

$$B_L = \left(\frac{h}{0.05}\right)^{0.3}$$

$$D_{isol} = 9.79\frac{F_v S_1}{B_L} T_{eff} \ (inches)$$

Example 1: Simplified Method

The superstructure of a 2-span bridge weighs 533 K. It is located on a rock site where S_{D1} = 0.55. The bridge is seismically isolated with 12 isolation bearings at the piers and abutments.



Example 1(a)

(a) If Q_d = 0.075W and K_d = 13.0 K/in (summed over all the isolators), calculate the maximum displacement of the superstructure and the total base shear. Neglect pier flexibility.

Example 1(a) Solution

Solution:

1. <u>Initialize</u>

   1.1 Q_d =0.075 W = 0.075 (533) = 40 K

   1.2 Need initial value D_{isol}

   Take T_{eff} = 1.5 sec,

   5% damping (B_L=1.0) and calculate

   $D = 9.79\ S_{D1}\ T_{eff} / B_L = 9.79\ (0.55)\ 1.5 = 8.08$ in

2. <u>Iterate</u>

   2.1 Set $D_{isol} = D$ and proceed with Steps 1-7

Example 1(a) Solution contd.

Step	Trial 1	Trial 2	Trial n
0. Characteristic strength, Q_d	40.0		
0. Post-elastic stiffness, K_d	13.0		
1. Isolator Displacement, D_{isol}			
2. Effective stiffness, K_{isol}			
3. Max. isolator force, F_m			
4. Effective period, T_{eff}			
5. Viscous damping ratio, h%			
6. Damping coefficient, B_L			
7. Isolator displacement, D_{isol}			

Example 1(a) Solution contd.

Step	Trial 1	Trial 2	Trial n
0. Characteristic strength, Q_d	40.0		
0. Post-elastic stiffness, K_d	13.0		
1. Isolator Displacement, D_{isol}	8.08		
2. Effective stiffness, K_{isol}			
3. Max. isolator force, F_m			
4. Effective period, T_{eff}			
5. Viscous damping ratio, h%			
6. Damping coefficient, B_L			
7. Isolator displacement, D_{isol}			

Example 1(a) Solution contd.

Step	Trial 1	Trial 2	Trial n
0. Characteristic strength, Q_d	40.0		
0. Post-elastic stiffness, K_d	13.0		
1. Isolator Displacement, D_{isol}	8.08		
2. Effective stiffness, K_{isol}	17.95		
3. Max. isolator force, F_m			
4. Effective period, T_{eff}			
5. Viscous damping ratio, h%			
6. Damping coefficient, B_L			
7. Isolator displacement, D_{isol}			

Example 1(a) Solution contd.

Step	Trial 1	Trial 2	Trial n
0. Characteristic strength, Q_d	40.0		
0. Post-elastic stiffness, K_d	13.0		
1. Isolator Displacement, D_{isol}	8.08		
2. Effective stiffness, K_{isol}	17.95		
3. Max. isolator force, F_m	144.9		
4. Effective period, T_{eff}			
5. Viscous damping ratio, h%			
6. Damping coefficient, B_L			
7. Isolator displacement, D_{isol}			

Example 1(a) Solution contd.

Step	Trial 1	Trial 2	Trial n
0. Characteristic strength, Q_d	40.0		
0. Post-elastic stiffness, K_d	13.0		
1. Isolator Displacement, D_{isol}	8.08		
2. Effective stiffness, K_{isol}	17.95		
3. Max. isolator force, F_m	144.9		
4. Effective period, T_{eff}	1.46		
5. Viscous damping ratio, h%			
6. Damping coefficient, B_L			
7. Isolator displacement, D_{isol}			

Example 1(a) Solution contd.

Step	Trial 1	Trial 2	Trial n
0. Characteristic strength, Q_d	40.0		
0. Post-elastic stiffness, K_d	13.0		
1. Isolator Displacement, D_{isol}	8.08		
2. Effective stiffness, K_{isol}	17.95		
3. Max. isolator force, F_m	144.9		
4. Effective period, T_{eff}	1.46		
5. Viscous damping ratio, h%	17.6		
6. Damping coefficient, B_L			
7. Isolator displacement, D_{isol}			

Example 1(a) Solution contd.

Step	Trial 1	Trial 2	Trial n
0. Characteristic strength, Q_d	40.0		
0. Post-elastic stiffness, K_d	13.0		
1. Isolator Displacement, D_{isol}	8.08		
2. Effective stiffness, K_{isol}	17.95		
3. Max. isolator force, F_m	144.9		
4. Effective period, T_{eff}	1.46		
5. Viscous damping ratio, h%	17.6		
6. Damping coefficient, B_L	1.46		
7. Isolator displacement, D_{isol}			

Example 1(a) Solution contd.

Step	Trial 1	Trial 2	Trial n
0. Characteristic strength, Q_d	40.0		
0. Post-elastic stiffness, K_d	13.0		
1. Isolator Displacement, D_{isol}	8.08		
2. Effective stiffness, K_{isol}	17.95		
3. Max. isolator force, F_m	144.9		
4. Effective period, T_{eff}	1.46		
5. Viscous damping ratio, h%	17.6		
6. Damping coefficient, B_L	1.46		
7. Isolator displacement, D_{isol}	6.43		

Example 1(a) Solution contd.

Step	Trial 1	Trial 2	Trial n
0. Characteristic strength, Q_d	40.0	40.0	
0. Post-elastic stiffness, K_d	13.0	13.0	
1. Isolator Displacement, D_{isol}	8.08	6.43	
2. Effective stiffness, K_{isol}	17.95		
3. Max. isolator force, F_m	144.9		
4. Effective period, T_{eff}	1.46		
5. Viscous damping ratio, h%	17.6		
6. Damping coefficient, B_L	1.46		
7. Isolator displacement, D_{isol}	6.43		

Example 1(a) Solution contd.

Step	Trial 1	Trial 2	Trial n
0. Characteristic strength, Q_d	40.0	40.0	40.0
0. Post-elastic stiffness, K_d	13.0	13.0	13.0
1. Isolator Displacement, D_{isol}	8.08	6.43	5.66
2. Effective stiffness, K_{isol}	17.95		20.06
3. Max. isolator force, F_m	144.9		113.6
4. Effective period, T_{eff}	1.46		1.65
5. Viscous damping ratio, h%	17.6		22.4
6. Damping coefficient, B_L	1.46		1.57
7. Isolator displacement, D_{isol}	6.43		5.66

Example 1(a) Solution contd.

Step	Trial 1	Trial 2	Trial n
0. Characteristic strength, Q_d	40.0	40.0	40.0
0. Post-elastic stiffness, K_d	13.0	13.0	13.0
1. Isolator Displacement, D_{isol}	8.08	6.43	5.66
2. Effective stiffness, K_{isol}	17.95		20.06
3. Max. isolator force, F_m	144.9		113.6
4. Effective period, T_{eff}	1.46		1.65
5. Viscous damping ratio, h%	17.6		22.4
6. Damping coefficient, B_L	1.46		1.57
7. Isolator displacement, D_{isol}	6.43		5.66

Examples 1(b) and 1(c)

(b) Adjust Q_d in (a) such that the displacement is less than or equal to 5.0 ins. Neglect pier flexibility.

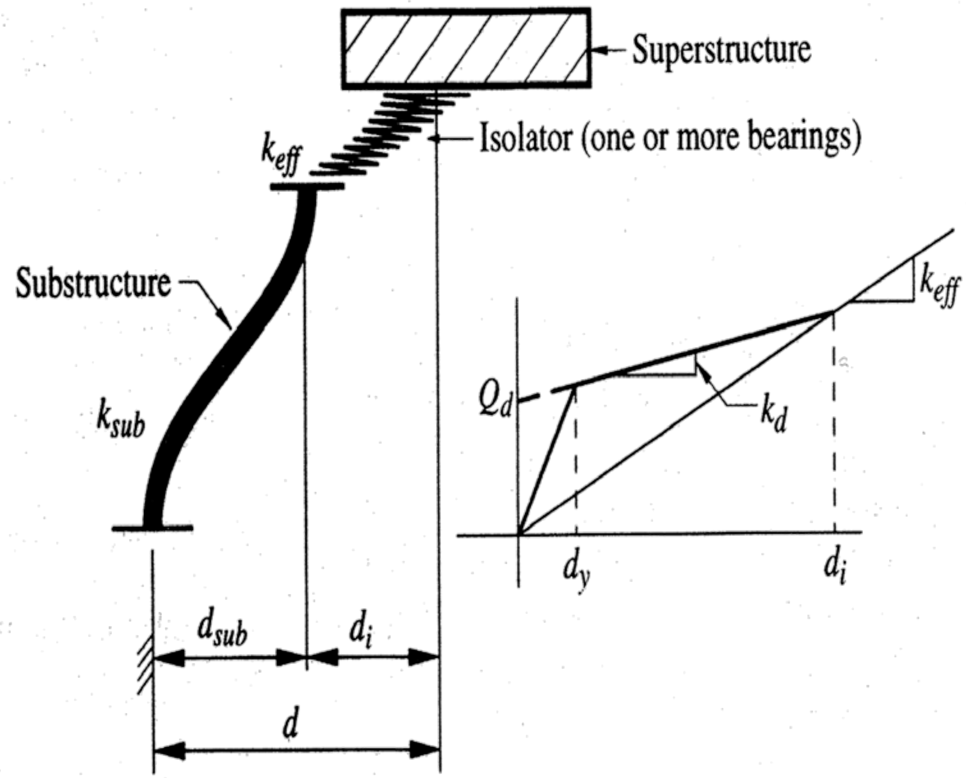
(c) Adjust Q_d and K_d in (a) such that the displacement does not exceed 6.0 ins and the base shear is less than 105 K. Neglect pier flexibility.

Examples 1(a) - (c) Solutions

Step	(a)	(b)	(c)
0. Characteristic strength, Q_d	40.0	49.0	40.0
0. Post-elastic stiffness, K_d	13.0	13.0	10.5
1. Isolator Displacement, D_{isol}	5.66	5.00	5.90
2. Effective stiffness, K_{isol}	20.06	22.75	17.28
3. Max. isolator force, F_m	113.6	113.8	101.9
4. Effective period, T_{eff}	1.65	1.55	1.77
5. Viscous damping ratio, h%	22.4	27.3	25.0
6. Damping coefficient, B_L	1.57	1.66	1.62
7. Isolator displacement, D_{isol}	5.66	5.00	5.90

Simplified Method

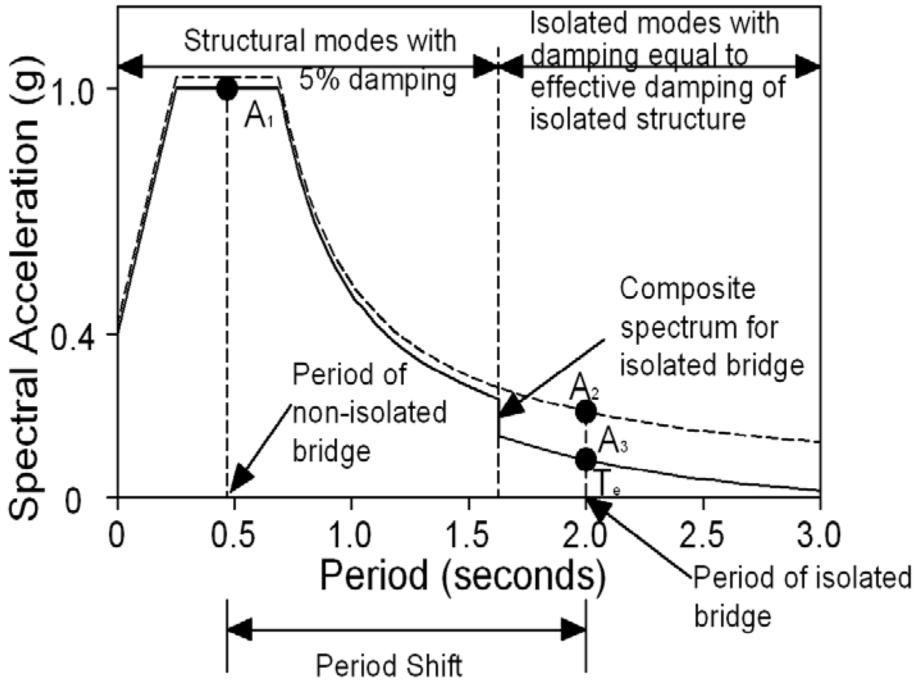
- Basic method assumes near rigid substructures
- Method can be modified to include pier flexibility. See AASHTO *Guide Specification Isolation Design,* 4th Ed., 2014



Multimodal Spectral Method

- Elastic Multimodal Method, developed for conventional bridges, may be used for isolated bridges even though they are nonlinear systems.

  Modeling the nonlinear properties of the isolators is usually done with equivalent linearized springs and the response spectrum is modified for the additional damping in the 'isolated modes'.



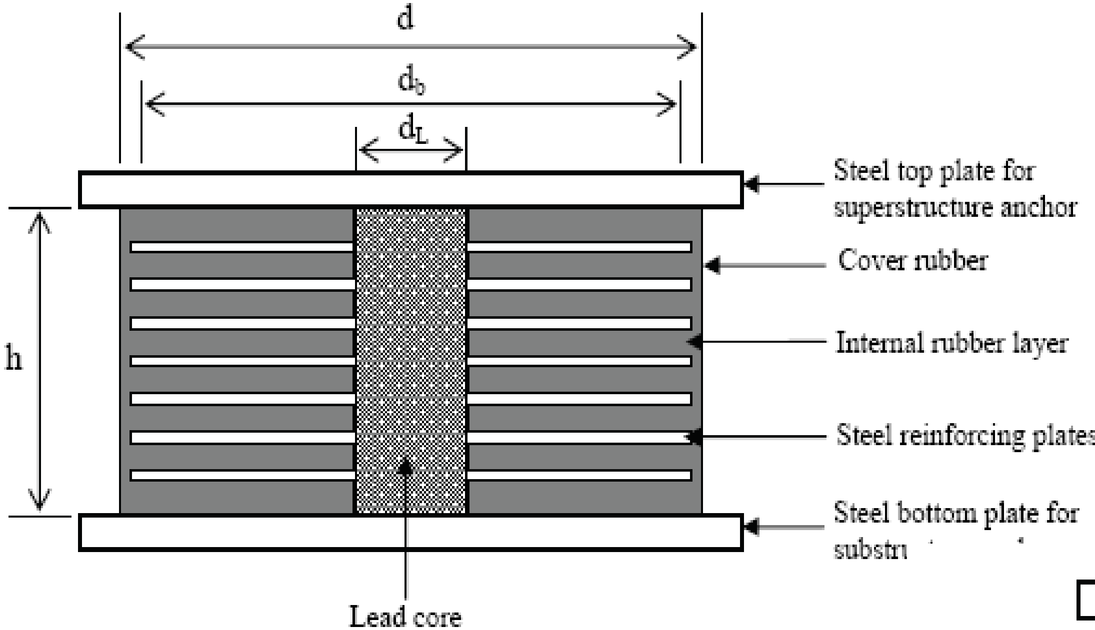
Multimodal Spectral Method

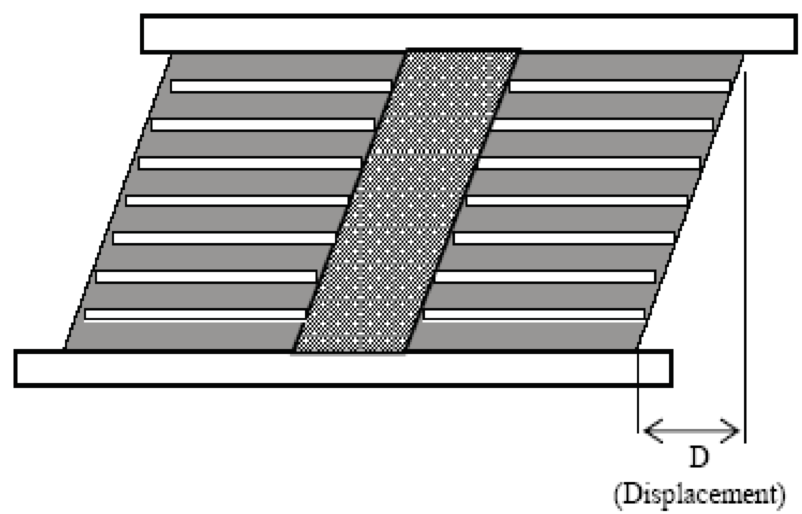
- Method is iterative and a good strategy is to use the Simplified Method of Analysis to obtain starting values for the iteration
- Care is required combining the results of individual modal responses which have different damping ratios. Isolated modes have much higher damping than the structural modes, and the CQC method does not easily accommodate this situation. In this case the SRSS method might be preferred.

Isolator design

- Analysis gives required system properties to meet desired performance (Q_d and K_d)
- Next step is to design an isolation system to have these properties
- Isolators used in bridge design include:
    - Elastomeric bearings with lead cores (Lead-Rubber Bearing, LRB)
    - Curved sliders (Concave Friction Bearing, CFB)
    - Flat plate slider with elastomeric springs (FPS)

Elastomeric isolator design (LRB)





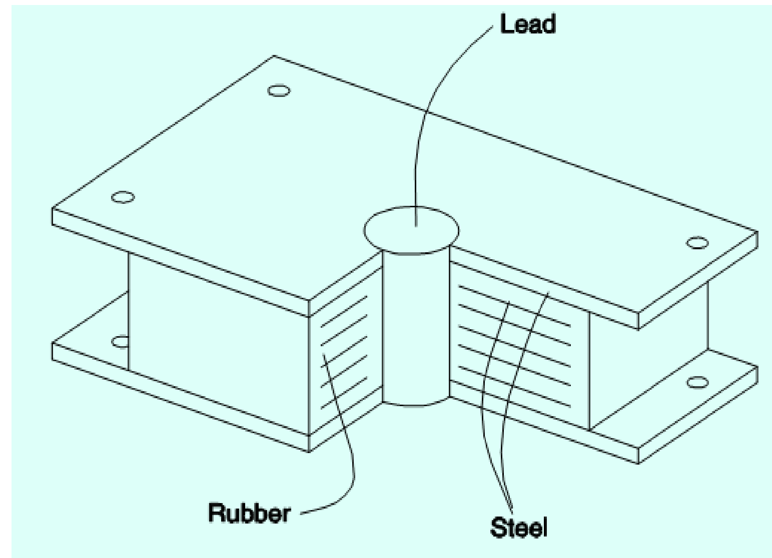
Lead-rubber design (LRB)

- $Q_d = 0.9\ d^2$ (K)

where
d = diameter of lead core (in)

- $K_d = G\ A_r / T_r$

where
G = shear modulus of elastomer
= 0.1 Ksi, say
A_r = bonded area of elastomer
T_r = total thickness of elastomer



- Shear strain in elastomer, $\gamma = D_{isol} / T_r$

Example 1(a): Lead-rubber design (LRB)

From Example 1(a):

- W=533 K and Number of isolators = 12
- Total Q_d = 40.0 K   (Q_d / isolator = 3.33 K)
- Total K_d = 13 K/in   (K_d / isolator = 1.08 K/in)
- Maximum displacement = 5.66 in
- Axial load / isolator = 533/12 = 44.42 K

Design:

Diameter of lead core = $\sqrt{(Q_d/0.9)}$ = $\sqrt{(3.33/0.9)}$ = **1.92 ins**

Assume circular bearing and allowable stress of 800 psi.

Then bonded area = 44.42 / 0.8 = 55.52 in^2

and bonded diameter = $\sqrt{(4(55.52)/\pi)}$ = **8.4 in**

Overall diameter = 8.4 + cover layers = 8.4 + 2 (0.5) = **9.4 in**

Example 1(a) continued (LRB)

Design contd:

Thickness of elastomer = GA_r / K_d=0.1(55.52)/1.08 = **5.14 in**

Number of ½ inch layers = 11

Number of 1/8 inch shims = 10

Number of ½ inch cover plates = 2

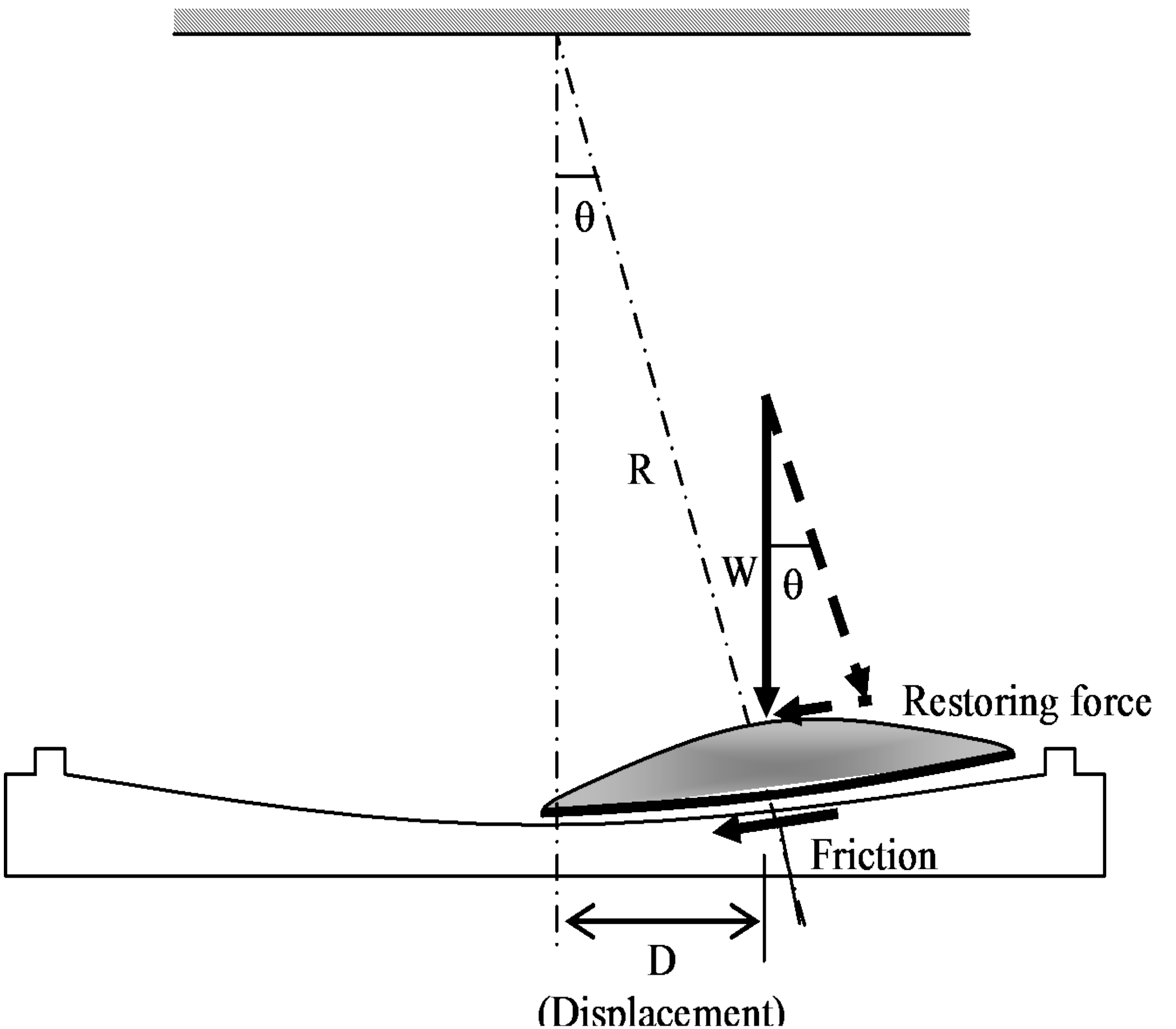
Overall isolator height = 11 x ½ + 10 x 1/8 + 2 x ½ = **7.75 in**

Max. shear strain in elastomer = 5.66/5.5 = **103% ok**.

Solution:

Isolation system is set of 12 x 9.4 inch diam. x 7.75 inch high circular bearings, each with a 1.92 inch diam. lead core.

Concave friction bearings (CFB)



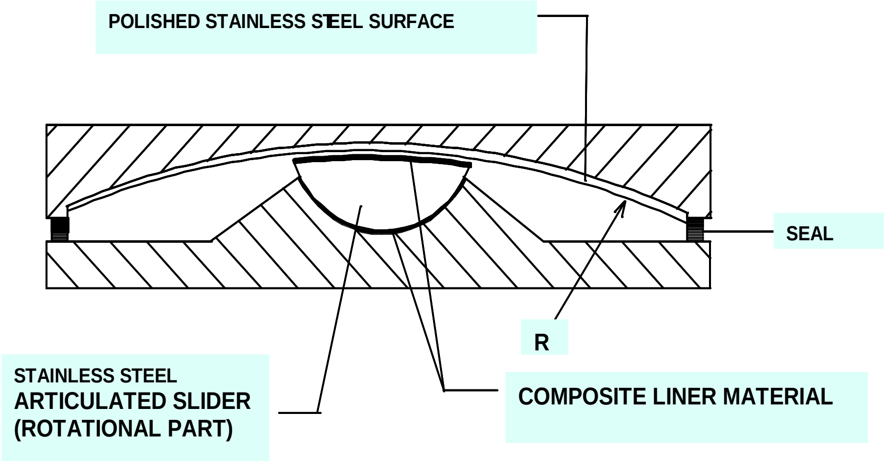
Concave friction bearing design (CFB)

- $Q_d = \mu P$

where:

μ = coefficient of friction

P = weight per isolator



- $K_d = P/R$

where:

R = radius of curvature of slider

- Period when sliding =

$$T_d = 2\pi\sqrt{R/g}$$

Example 1(a): Concave friction bearing CFB)

From Example 1(a):

- W = 533 K and Number of isolators = 12
- Total Q_d = 40.0 K (Q_d / isolator = 3.33 K)
- Total K_d = 13 K/in (K_d / isolator = 1.08 K/in)
- Maximum displacement = 5.66 in
- Axial load / isolator (P) = 533/12 = 44.42 K

Design:

Friction coefficient $\mu = Q_d / P$ = 3.33/44.42 = **0.075**

Radius of curvature, $R = P / K_d$ =44.42/(1.08) = **41.13 in**

Example 1(a) continued (CFB)

Design continued:

- Contact area of slider = *P* / contact pressure
  = P / 3000 psi = 44.42/3.0 = 14.80 in^2
- Diameter of slider = 4.35 in
- Isolator diameter = 2 x max displ. + slider diam. +
  2 x shoulders = 2 x 5.66 + 4.35 + 2.0 = 17.67 (18 ins, say)

Solution:

Isolation system is set of 12 concave friction bearings, 18 in overall diameter, 4.35 in diameter PTFE slider, and 41.13 in radius for stainless steel spherical surface. Probable overall height is about 5 in.

Question

What are the pros and cons of the two design solutions?

Summary of LRB and CFB designs

	Lead-Rubber Bearing (LRB)	Concave Friction Bearing (CFB)
Number of isolators	12	12
External dimensions	9.4 in diam. x 7.75 in height	18 in diam. x 5 in (?) height
Internal dimensions	11 x ½ in layers	radius = 41 in
Other	1.92 in diam. lead core	coefficient of friction = 0.075

Other design issues (all isolators)

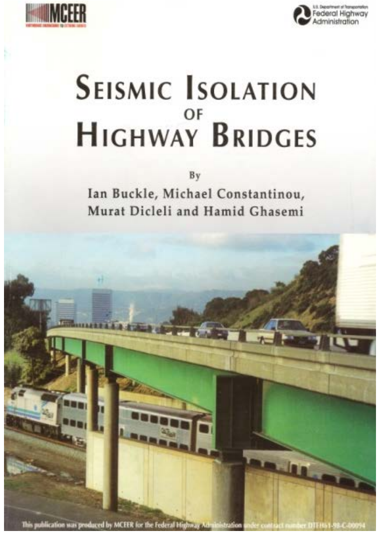
- Restoring force capability
- Clearances (expansion joints, utility crossings…)
- Vertical load capacity and stability at high shear strain
- Uplift restrainers, tensile capacity
- Non-seismic requirements (wind, braking, thermal movements…)
- System Property Modification Factors (λ-factors) for aging, temperature, wear and tear, and contamination
- Testing Requirements: characterization tests; prototype tests; production tests

Outline

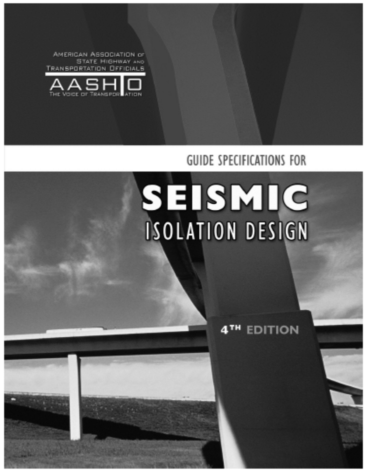
- Conventional vs seismic isolation design
- History
- Basic requirements (principles)
- Examples (applications)
- Limitations
- Design of a bridge isolation system
- Additional sources of information
- Design examples
- Q&A

Sources of information

- FHWA/MCEER 2006, *Seismic Isolation of Highway Bridges*, Special Publication MCEER-06-SP07

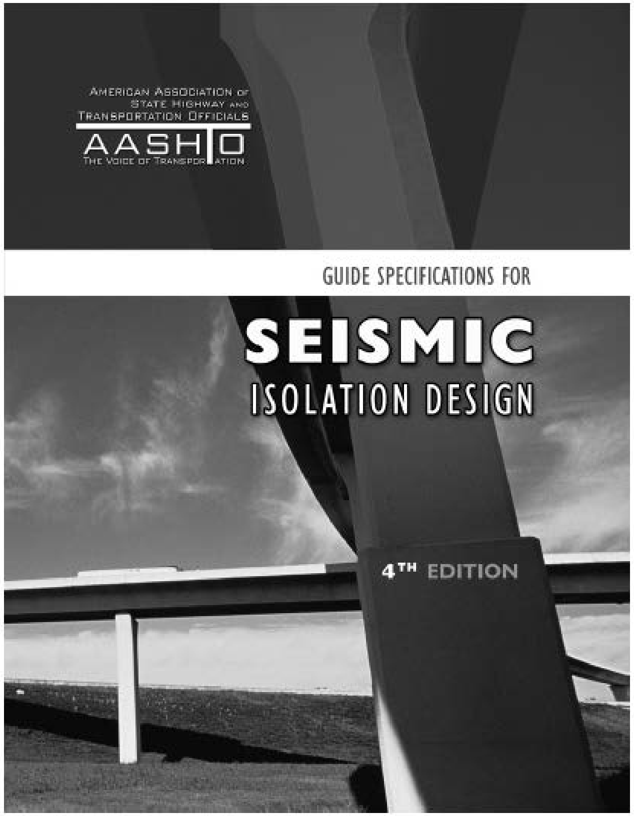


- AASHTO 2014, *Guide Specifications for Seismic Isolation Design,* Fourth Edition



Sources of information

- Fourth Edition of AASHTO *Guide Specification for Seismic Isolation Desig*n published 2014 has design examples in new Appendix B.



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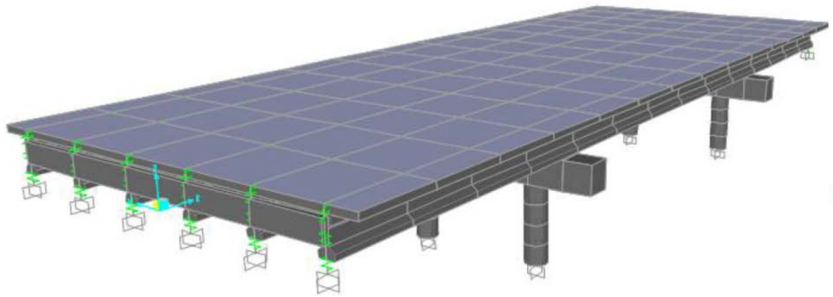
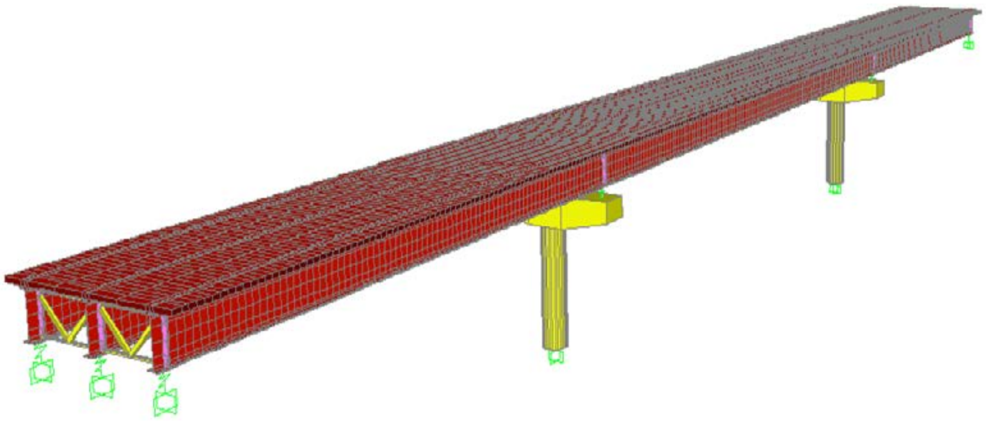
Design examples





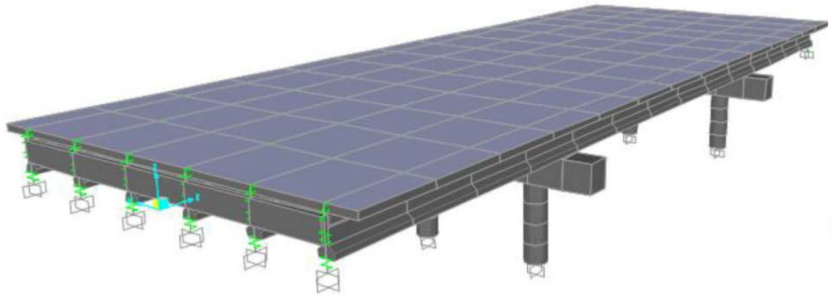
Benchmark Bridge No. 1

- 3-span, 25-50-25 ft
- 6 PC continuous girders
- 3-column piers

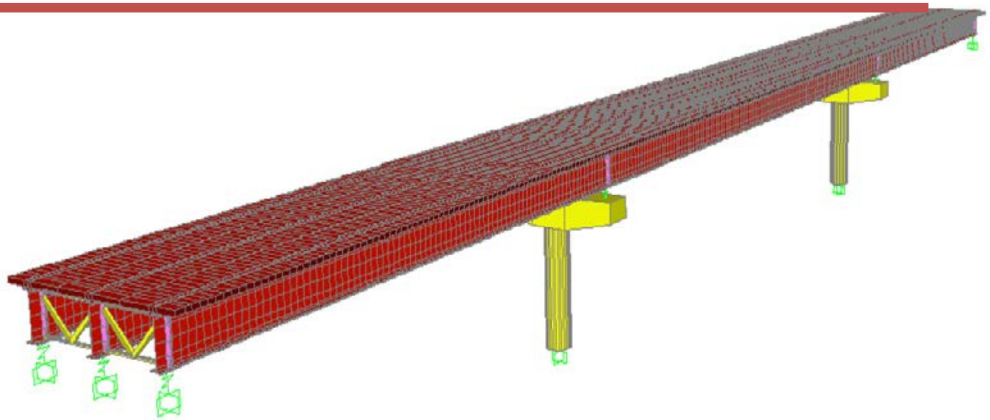
Benchmark Bridge No. 2

- 3-span, 105-152.5-105 ft
- 3 steel plate continuous girders
- Single-column piers

Design examples continued



Benchmark Bridge No. 1



Benchmark Bridge No. 2

7 design examples for each benchmark bridge showing how to design:

- For different hazard levels (S1, Site Class)
- Various types of isolators (LRB, CFB, FPB)
- Bridges with irregular geometry (skew, piers with different height)

Design methodology

Step A. Assemble bridge and site data; determine performance objectives

Step B. Analyze bridge in <u>longitudinal</u> direction (i.e. find Q_d and K_d to achieve required performance using (1) simplified method and (2) multi-modal spectral analysis method)

Step C. Repeat in <u>transverse</u> direction

Step D. Combine results from **B** and **C** (100/30 rule); check performance

Step E. Design isolation hardware to provide required Q_d and K_d

Design example template

Step number / generic instructions

DESIGN PROCEDURE	DESIGN EXAMPLE 1.0 (Benchmark #1)
STEP A: BRIDGE AND SITE DATA	

A1. Bridge Properties
Determine properties of the bridge:
• number of supports, m
• number of girders per support, n
• angle of skew
• weight of superstructure including railings, curbs, barriers and to the permanent loads, W_{SS}
• weight of piers participating with superstructure in dynamic response, W_{PP}
• weight of superstructure, W_j, at each support
• stiffness, $K_{sub,j}$, of each support in both longitudinal and transverse directions of the bridge. The calculation of these quantities requires careful consideration of several factors such as the use of cracked sections when estimating column or wall flexural stiffness, foundation flexibility, and effective column height.
• column shear strength (minimum value). This will usually be derived from the minimum value of the column flexural yield strength, the column height, and whether the column is acting in single or double curvature in the direction under consideration.
• allowable movement at expansion joints
• isolator type if known, otherwise to be determined.
	A1. Bridge Properties, Example 1.0
	• Number of supports, $m = 4$
	  ○ North Abutment ($m = 1$)
	  ○ Pier 1 ($m = 2$)
	  ○ Pier 2 ($m = 3$)
	  ○ South Abutment ($m = 4$)
	• Number of girders per support, $n = 6$
	• Number of columns per support = 3
	• Angle of skew = 0^0
	• Weight of superstructure including permanent loads, $W_{SS} = 650.52$ k
	• Weight of superstructure at each support:
	  ○ $W_1 = 44.95$ k
	  ○ $W_2 = 280.31$ k
	  ○ $W_3 = 280.31$ k
	  ○ $W_4 = 44.95$ k
	• Participating weight of piers, $W_{PP} = 107.16$ k
	• Effective weight (for calculation of period), $W_{eff} = W_{SS} + W_{PP} = 757.68$ k
	• Stiffness of each pier in the longitudinal direction:
	  ○ $K_{sub,pier1,long} = 172.0$ k/in
	  ○ $K_{sub,pier2,long} = 172.0$ k/in
	• Stiffness of each pier in the transverse direction:
	  ○ $K_{sub,pier1,trans} = 687.0$ k/in
	  ○ $K_{sub,pier2,trans} = 687.0$ k/in
	• Minimum column shear strength based on flexural yield capacity of column = 25 k
	• Displacement capacity of expansion joints (longitudinal) = 2.0 in for thermal and other movements.
	• Lead rubber isolators

Step number / calculations for this example

Design example template

e.g. Calculation of Effective Period for Benchmark Bridge No. 1

Step number / generic instructions

Step number / calculations for this example

B1.10 Effective Period and Damping Ratio Calculate the effective period, T_{eff}, and the viscous damping ratio, ξ, of the bridge: Eq. 7.1-5 GSID $\quad T_{eff} = 2\pi\sqrt{\frac{W_{eff}}{gK_{eff}}}$ (B-14) and Eq. 7.1-10 GSID $\quad \xi = \frac{2\sum_j(Q_{d,j}(d_{isol,j} - d_{y,j})}{\pi\sum_j(K_{eff,j}(d_{isol,j} + d_{sub,j})^2}$ (B-15) where $d_{y,j}$ is the yield displacement of the isolator. For friction-based isolators, $d_{y,j} = 0$. For other types of isolators $d_{y,j}$ is usually small compared to $d_{isol,j}$ and has negligible effect on ξ, Hence it is suggested that for the Simplified Method, set $d_{y,j} = 0$ for all isolator	**B1.10 Effective Period and Damping Ratio, Example 1.0** $T_{eff} = 2\pi\sqrt{\frac{W_{eff}}{gK_{eff}}} = 2\pi\sqrt{\frac{757.68}{386.4(31.43)}}$ $= 1.57$ sec and taking $d_{y,j} = 0$: $\xi = \frac{2\sum_j(Q_{d,j}(d_{isol,j} - 0)}{\pi\sum_j(K_{eff,j}(d_{isol,j} + d_{sub,j})^2} = 0.31$

Summary of example designs: Set 1

EXAMPLE SET 1: PC GIRDER BRIDGE (Column yield shear force = 25.0 k)

Ex.	ID	Isolator size including mounting plates (in)	Isolator size without mounting plates (in)	Diam. lead core (in)	Rubber Shear modulus (psi)	Column shear (k)	Super-structure resultant displace-ment (in)
1.0	Benchmark 1	17.00 x 17.00 x 11.50 (H)	13.00 dia. x 10.00(H)	1.61	60	18.03	1.72
1.1	Site Class D	17.25 x 17.25 x 11.875(H)	13.25 dia. x 10.375(H)	1.97	60	25.55*	3.96
1.2	S_1=0.6g	20.25 x 20.25 x 16.75(H)	16.25 dia. x 15.25(H)	1.97	60	29.15*	7.32
1.3	SFB isolator	16.25 x 16.25 x 4.50(H)	12.25 dia. x 4.50(H)	R (in) 39.0	PTFE 15GF	18.03	1.72
1.4	EQS isolator	32.0 x 18.0 x 4.00(H)	18.0 x 18.0 x 4.00(H)	Polyurethane springs 4	 1.25 dia.	18.03	1.72
1.5	H_1=0.5H_2	17.00 x 17.00 x 11.50(H)	13.00 dia. x 10.00(H)	1.61	60	19.56 (P1) 2.56 (P2)	2.32
1.6	45^0 skew	16.00 x 16.00 x 10.00(H)	12.00 dia. x 8.50(H)	1.63	60	28.32*	1.61

Summary of example designs: Set 2

EXAMPLE SET 2: STEEL PLATE GIRDER BRIDGE (Column yield shear force) = 128 k)

Ex.	ID	Isolator size including mounting plates (in)	Isolator size without mounting plates (in)	Diam. lead core (in)	Rubber Shear modulus (psi)	Column shear (k)	Super-structure resultant displace-ment (in)
2.0	Benchmark 2	17.50 x 17.50 x 5.50(H)	13.50 dia. x 4.00(H)	3.49	100	71.74	1.82
2.1	Class D	21.25 x 21.25 x 8.125(H)	17.25 dia. x 6.625(H)	4.13	60	121.0	3.79
2.2	S_1=0.6g	24.0 x 24.0 x 12.625(H)	20.0 dia. x 11.125(H)	4.68	60	175.0*	8.21
2.3	SFB isolator	17.75 x 17.75 x 9.00(H)	13.75 dia. x 7.00(H)	R (in) 27.75	PTFE 25GF	71.74	1.82
2.4	EQS isolator	36.0 x 23.0 6.20(H)	23.0 x 23.0 x 6.20(H)	Polyurethane springs 4	 2.75 dia.	71.74	1.82
2.5	H_1=0.5H_2	17.50 x 17.50 x 5.875(H)	13.50 dia. x 4.375(H)	3.49	100	87.56 (P1) 47.53 (P2)	2.05
2.6	45^0 skew	17.50 x 17.50 x 5.50(H)	13.50 dia. x 4.00(H)	3.49	100	106.8	1.69

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Questions & Answers