Seismic Isolation and Supplementary Energy Dissipation (dampers) for New Buildings

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BOABC
Promoting Building Safety and Professionalism

Outline

- Fundamentals of these devices
  - What are they? How do they work?
- Overview of provisions in current codes
  - NBC 2015, BCBC 2018 (no changes in NBC 2020, BCBC 2024)
  - Articles 4.1.8.19 through .22
  - Related sections of Commentary J
- General considerations

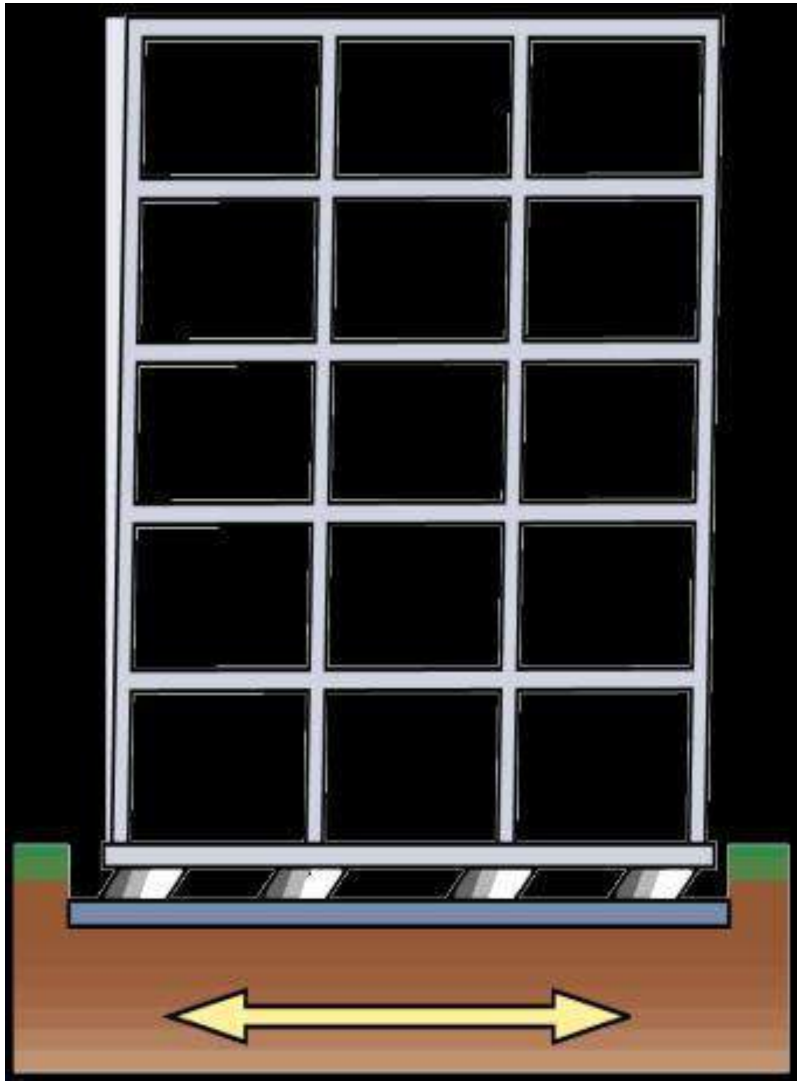
Earthquake Resilience
BC Housing : Learning on Demand (long version, $)
YouTube short videos on each item below

(example #3 - https://www.youtube.com/watch?v=9Iu8JV8s5sc)

1. Understanding code level earthquake design for new buildings
2. Earthquake performance options for new buildings; ‘performance-based’ design
3. Seismic isolation for new buildings
4. Supplementary Energy Dissipation (dampers) for new buildings
5. The cost of improved earthquake performance for new buildings – mini case studies
6. Moving towards post-earthquake habitability in buildings; issues and challenges
7. Considerations regarding seismic upgrading on an existing building
8. Earthquake instrumentation for your building

Seismic Isolation

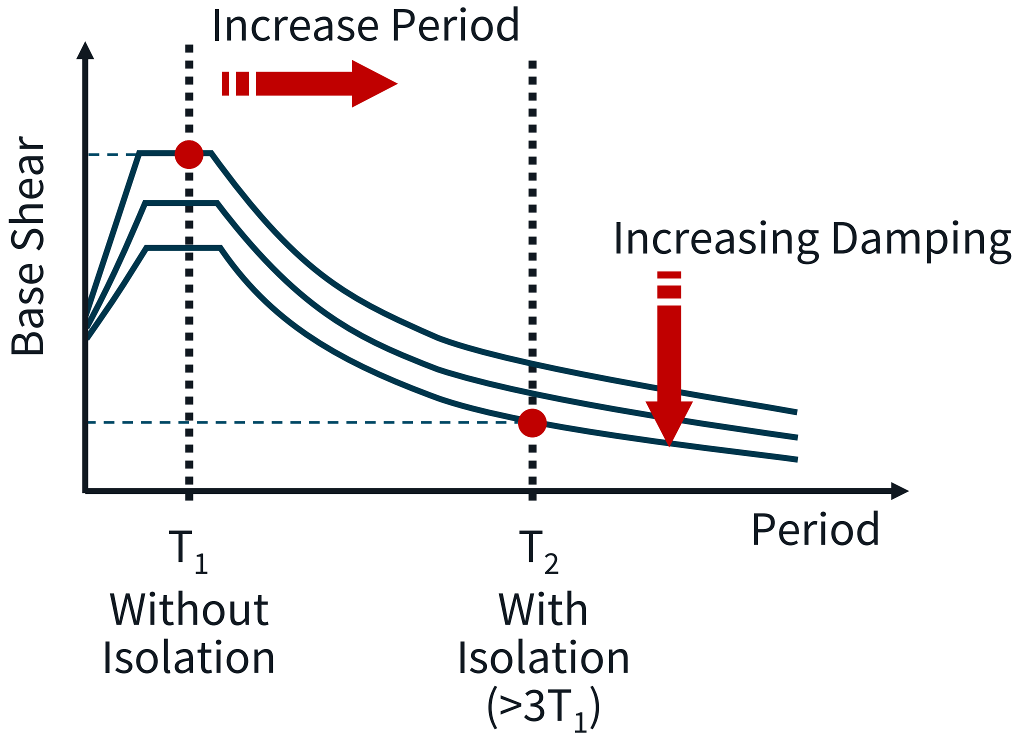
- Isolation bearings near base of the structure, between the foundation and the superstructure
- Lateral shaking forces in building significantly reduced compared to a conventional structure, by ‘decoupling’ the structure from the ground
- Deformation occurs at the isolators to dissipate the earthquake energy; rather than dissipating the earthquake energy by ductility (damage)
- Both the contents and the structure are protected
- In many applications isolators are installed beneath the structure and thus referred to as ‘*base isolation*’



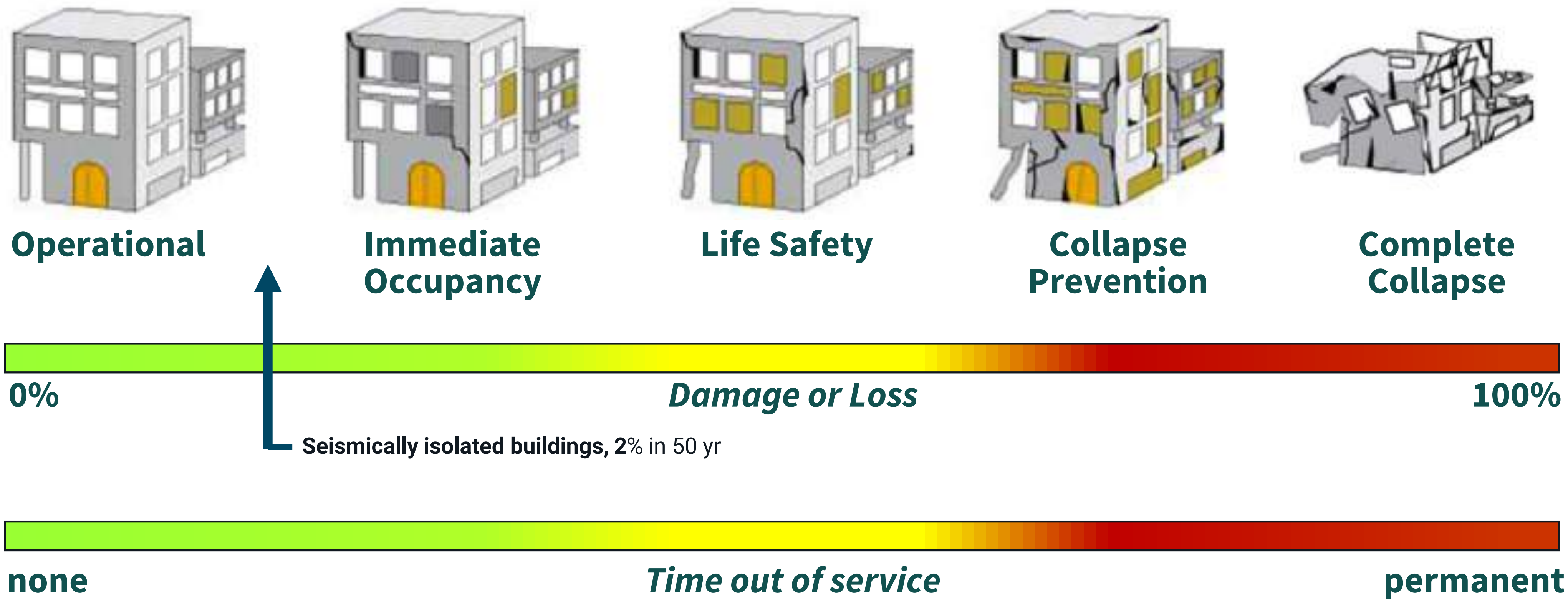
Effect of Seismic Isolation

Design Response Spectrum Perspective

Increase period of vibration of structure, increase damping, to reduce Base Shear



Performance requirement for building with seismic isolation

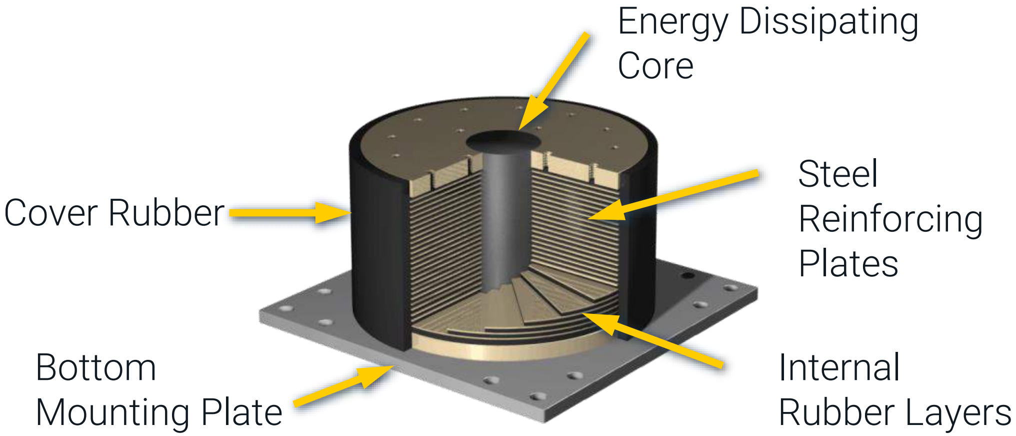


Building figures courtesy of NRC

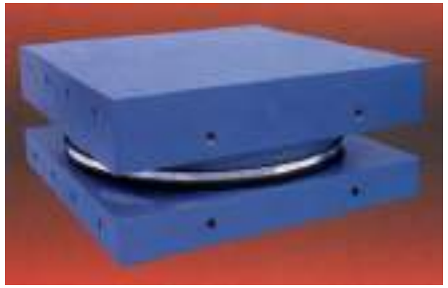
Types of Seismic Isolation Bearings

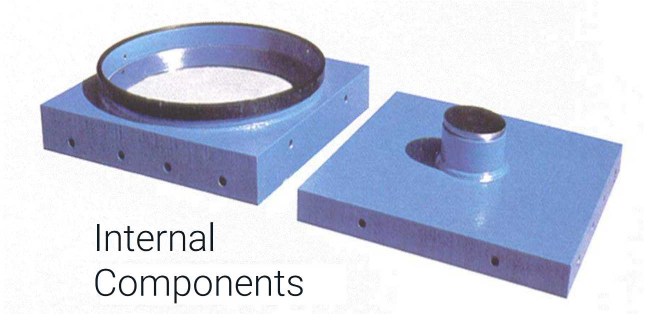
- Elastomeric Bearings
  - Low damping rubber or synthetic rubber
  - High damping rubber
  - Lead rubber
    (low damping rubber with lead core)

- Sliding Bearings
  - Spherical ('friction pendulum')
  - Flat



Lead Rubber Bearing





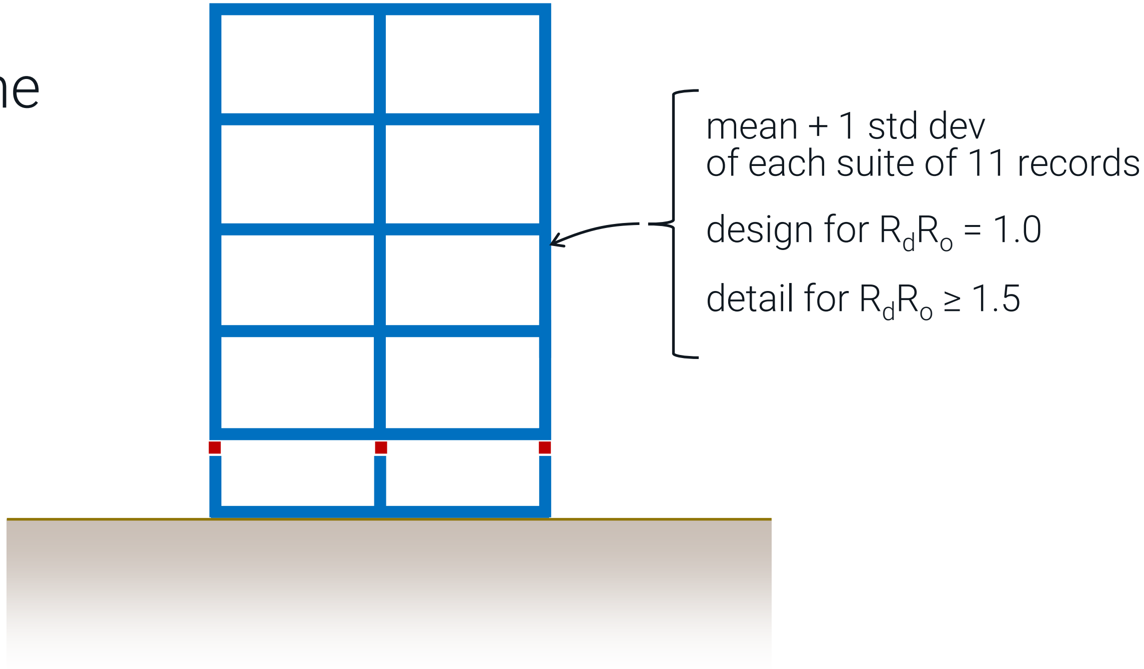
Friction Pendulum Bearing

NBC 2015, BCBC 2018, VBBL 2019 all have provisions for design of new buildings using seismic isolation (as do NBC 2020, BCBC 2024)

- 3D Non-linear Dynamic Analysis of the structure is required
- In BC : two suites of 11 earthquake ground motions per suite (x,y,z components of motion)
- The period of the isolated structure > 3x period of fixed base structure
- Isolator units modeled for all expected variations in material properties over the design life of the structure (lower bound and upper bound stiffness properties)
- Prototype testing required of a minimum of two full size specimens of each different isolator (to confirm analyses)
- Production testing of 'representative sample' of isolator units prior to installation (most projects test *every* production isolator before they are shipped to site)

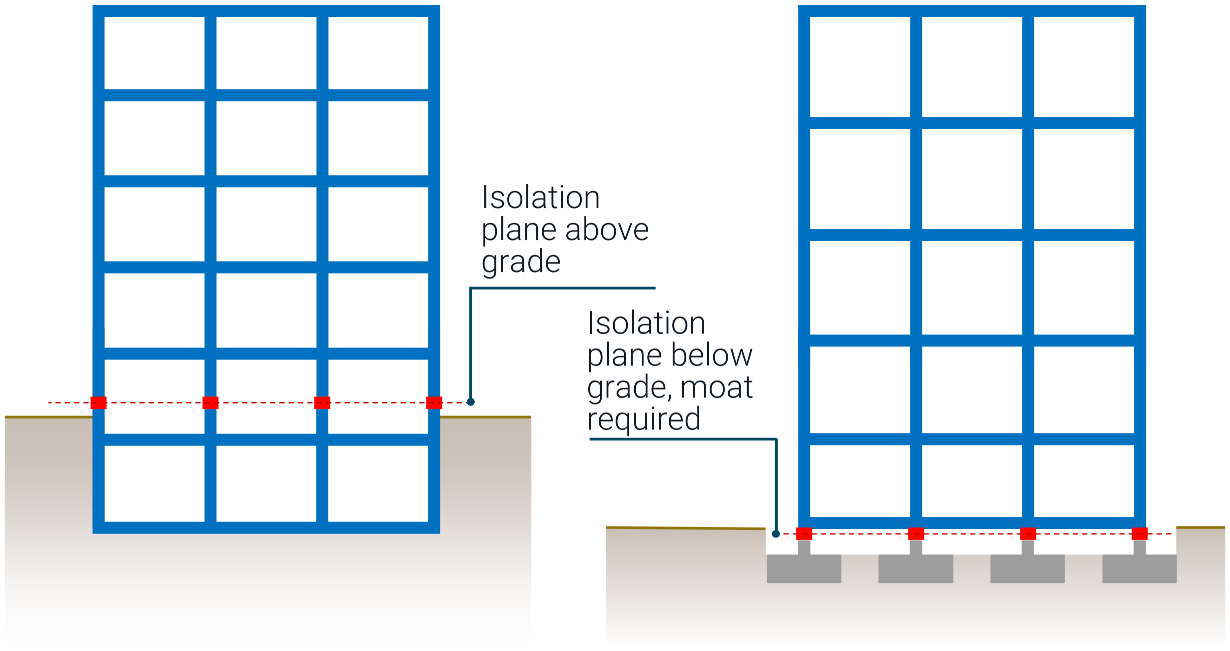
NBC 2015, BCBC 2018, VBBL 2019 all have provisions for design of new buildings using seismic isolation (as do NBC 2020, BCBC 2024)

- Isolators require minimum stiffness requirements for wind load
- All structural components above isolation plane to remain elastic for mean + 1 std deviation of demands for each component (but still have modest ductility detailing)
- All isolators must accommodate a prescribed movement in any direction : mean + 1 std deviation of combined x and y directional movements



General considerations and comments

- Isolation plane can be below grade (moat required) or above grade (no moat)
- Prefer to have no net tension (uplift) at any isolator; buildings with height/width aspect ratio of 6:1 can readily achieve this (however larger aspect ratios are possible)
- The systems described do not reduce the vertical accelerations, only the two horizontal components



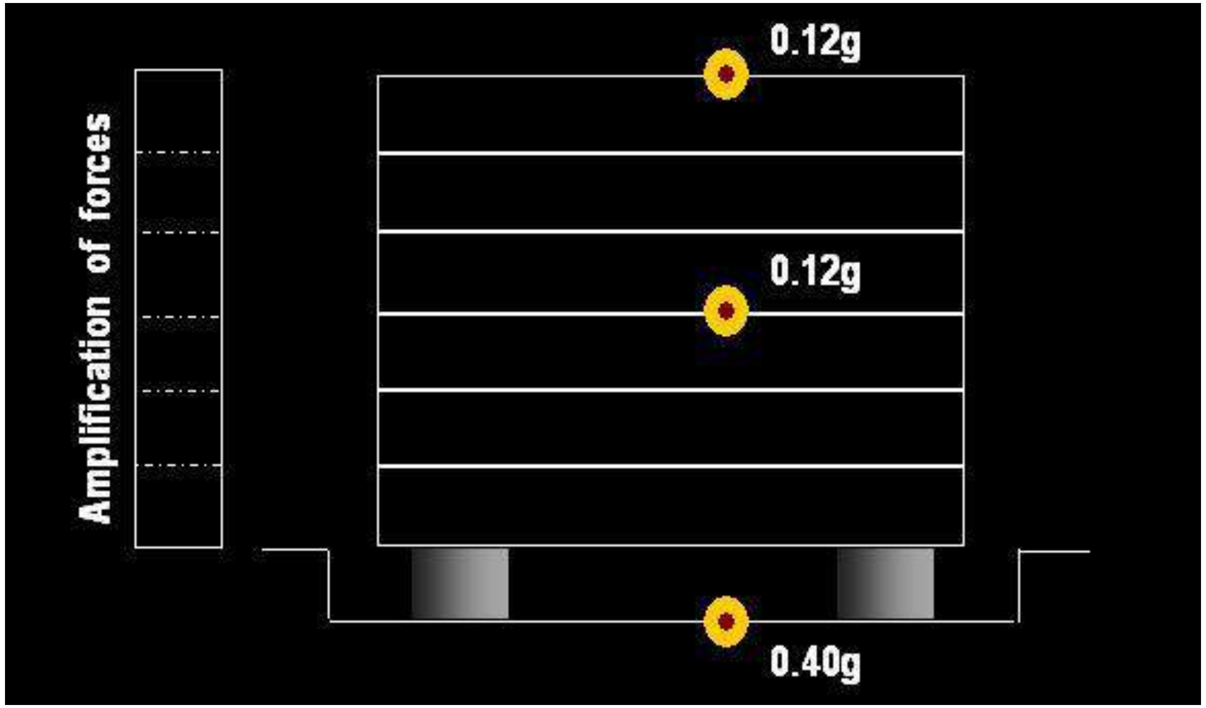
General considerations and comments

- The floor diaphragm above the isolators must be stiff to enable distribution of lateral loads to all isolators
- The structural system above the isolation plane is preferrable to have well distributed seismic force resisting elements, to minimize uplift on the floor diaphragm (core tower not preferred)
- All mechanical, electrical, architectural elements crossing the isolation plane need to be designed to remain functional while accommodating the horizontal movements (in the range of 200 – 500mm in BC)
- Excellent technical assistance available from all vendors
- Usually requires fire protection, same as any gravity load carrying component
- Performance specifications to detail performance requirements, but possible to design in detail to enable bidding from various different vendors and systems

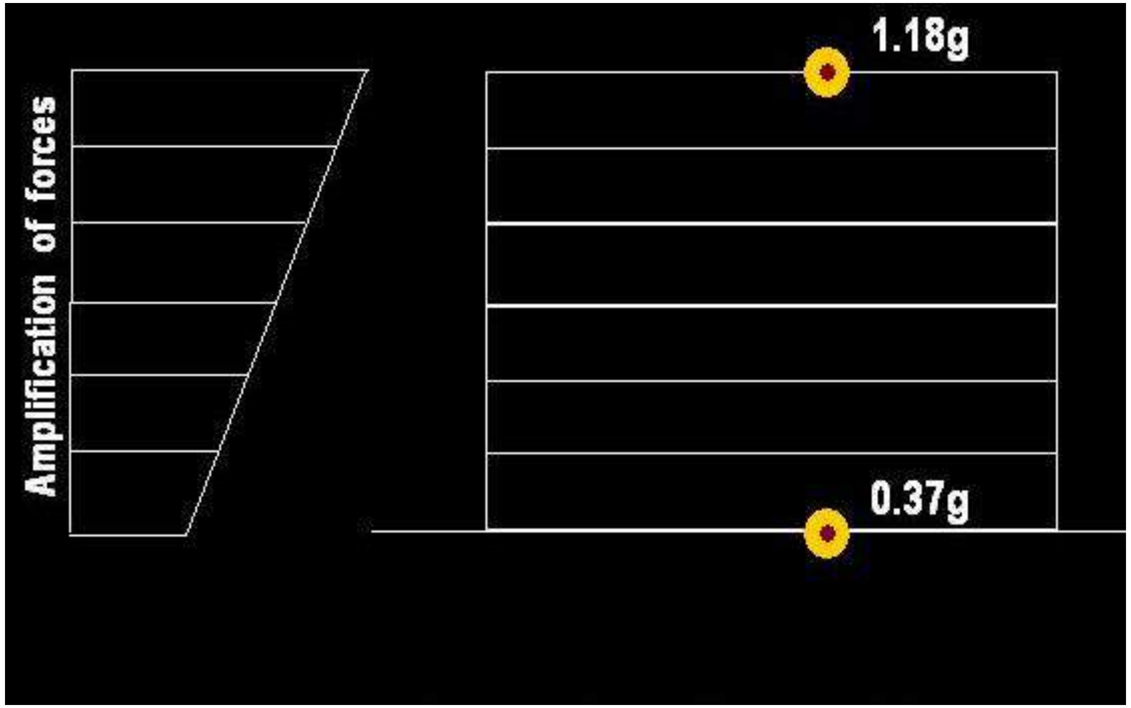
Proven performance in previous earthquakes

Example: West Japan Postal Savings Computer Centre, Kobe

1995 Kobe, Japan Earthquake (M 6.9)



Isolated 6 storey building



Nearby similar 6 storey building

Video of strong shaking conventional building
(not available on pdf file)

Ishinomaki Red Cross Hospital, Japan

Base isolated; Tohoku earthquake 2011, Magnitude 9.0

(actual shaking video on next slide)

Video of very minor shaking on a floor of a base isolated hospital
(not available on pdf file)

Base-Isolated Hospital: Malatya, Turkiye

- 200-bed hospital
- Hospital was operational during and after the EQ
- Hospital did not lose power but has 5 backup generators

Video of testing of isolator, showing deformation (not available on pdf file)

Expected deformation of elastomeric bearing (shown at testing facility)

Base Isolation Projects in at least 15 countries

Hospitals


Arrowhead Medical Center


Yuzawa Hospital


USC University Hospital


Takasu Hospital

Emergency Centers

Kobe North Fire Station

Long Beach 911 Center

Berkeley Public Safety Building, CA

San Diego EOC

Housing

Museums

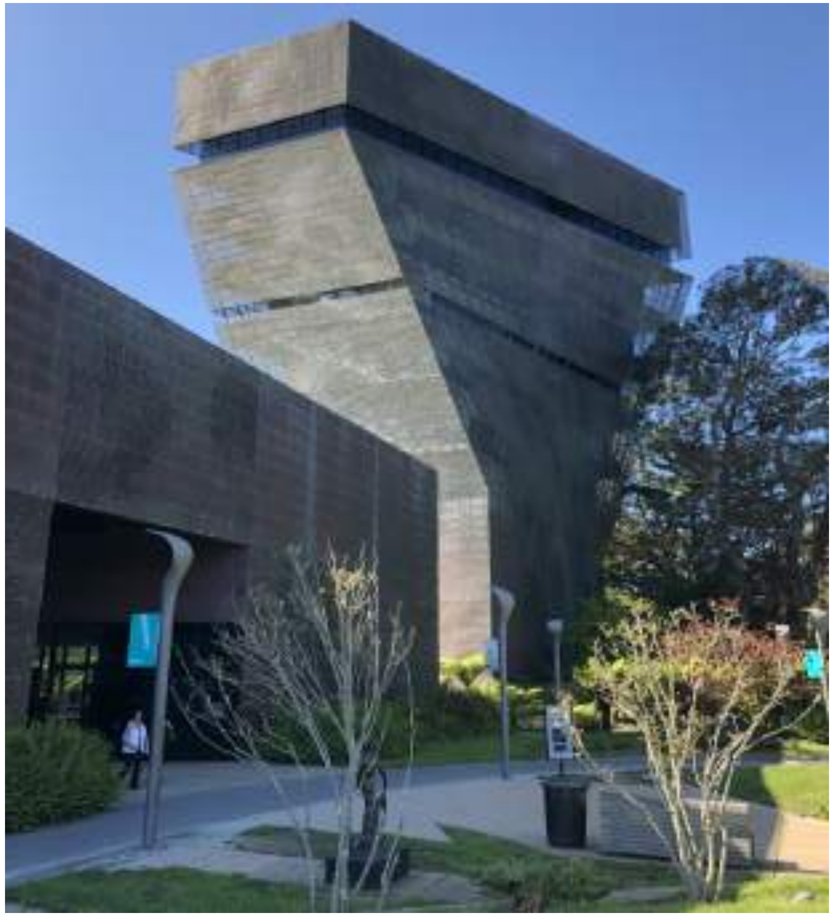
Itsutsubashi

Kamikuzawa

F-museum

De Young Museum – with base isolation

- San Francisco, constructed 2005
- Isolators designed for 26” (660mm) of lateral movement
- Isolation plane below basement level
- Isolation system provides protection to museums’ collections



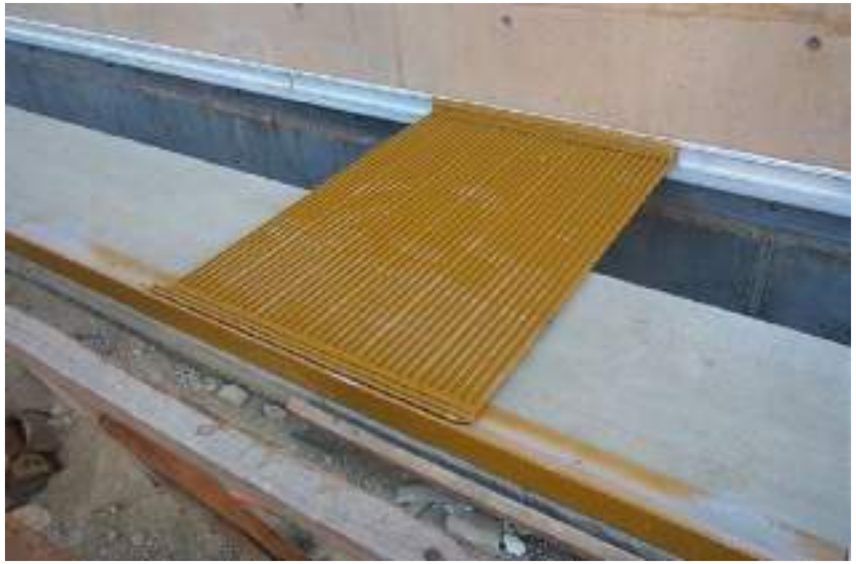
De Young Museum

Elastomeric bearing

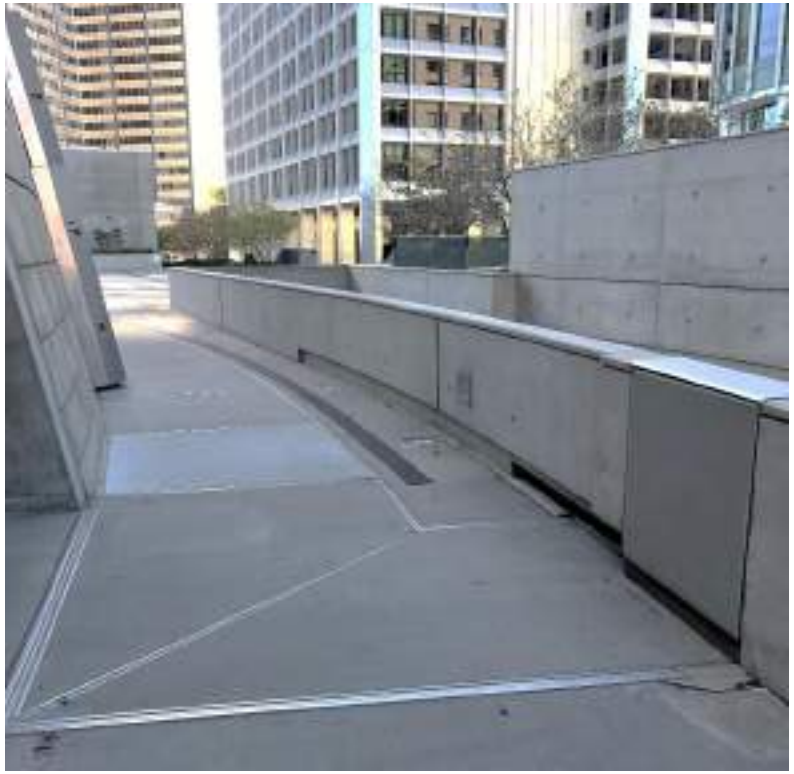

Sliding bearing

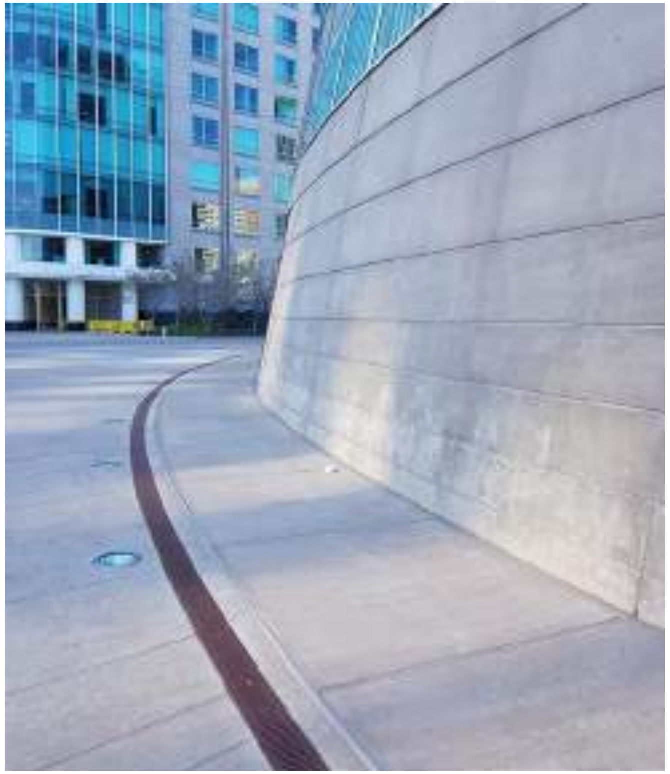

Moat gap below grade

Other examples: Seismic Gap or ‘Moat’



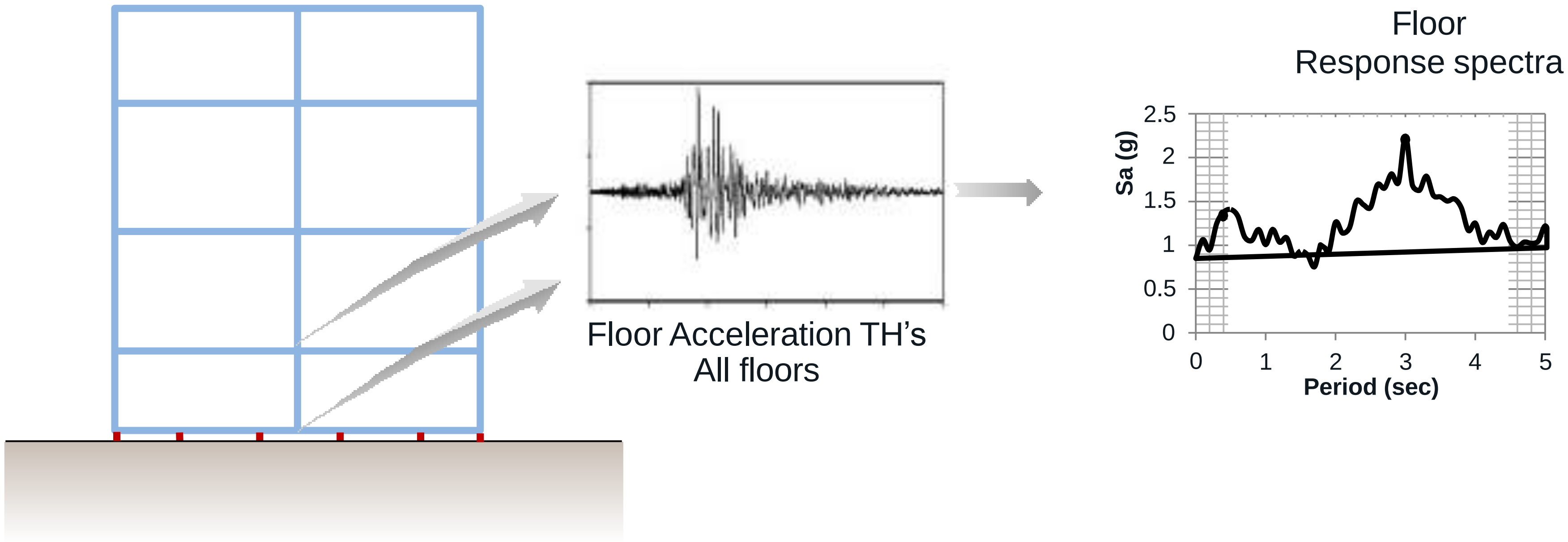
Other examples of moat covers





Moat cover panels

Design of “Parts and Portions” (discussed in Commentary)



Examples of mechanical and electrical services

Articulated mechanical services : white pipes
– arrangement with 3 ball joints

Electrical cables with movement allowance
– slack on tables

Seismic Isolation - Summary

- Design provisions in our current codes
- Proven technology and used in many countries
- Can provide ‘no structural damage’ performance for code level earthquake
- Reduces demand and damage to non-structural components
- Requires 3D non-linear analyses
  - With recommendation of external design review
- Requires attention to details of moat covers, A/M/E services at isolation plane
- Access for inspection and replacement of all devices, is suggested

Design Review

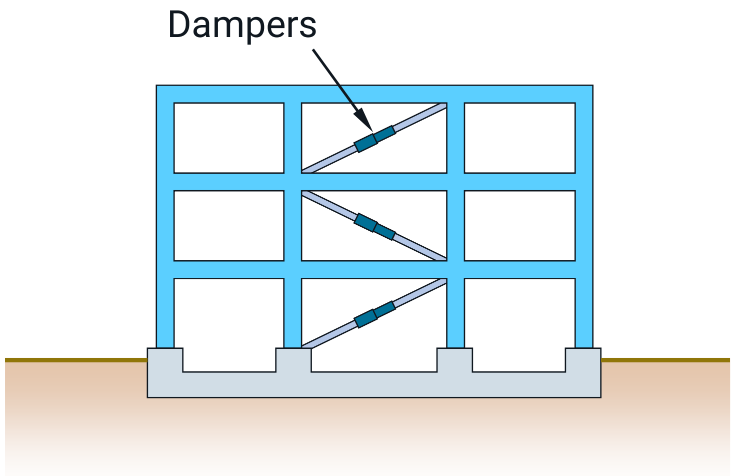
NBC Commentary

It is strongly recommended that a design review of the seismically isolated structure and its isolation system be carried out by an independent team of professional engineers and geoscientists team including persons licensed and experienced in seismic analysis methods and the theory and application of seismic isolation. The design review shall include, but not be limited, to the following:

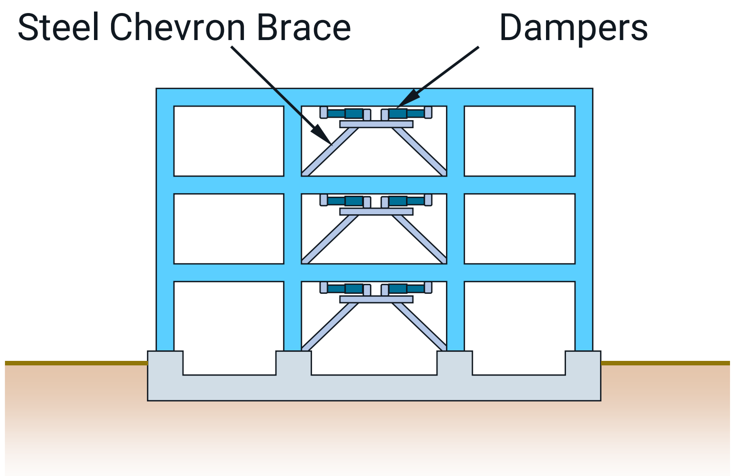
- site specific spectra,
- ground motion time histories,
- modeling and analyses
- testing program and results, and
- final design of all structural framing elements and isolation system components

Supplemental Energy Dissipation (SED) or dampers

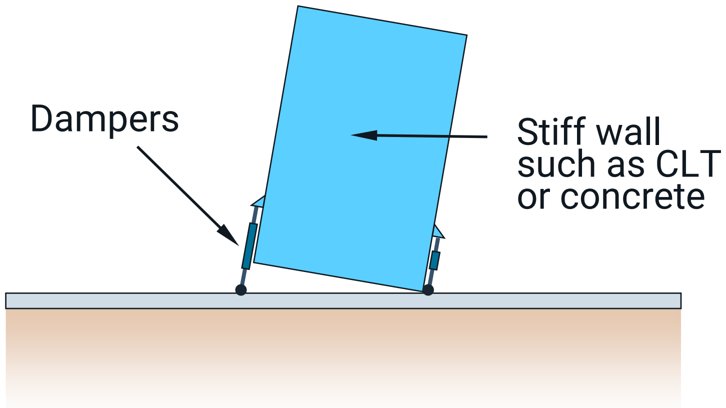
- Large variety of SED devices readily available



Diagonal Bracing with Dampers



Dampers in Chevron Braces



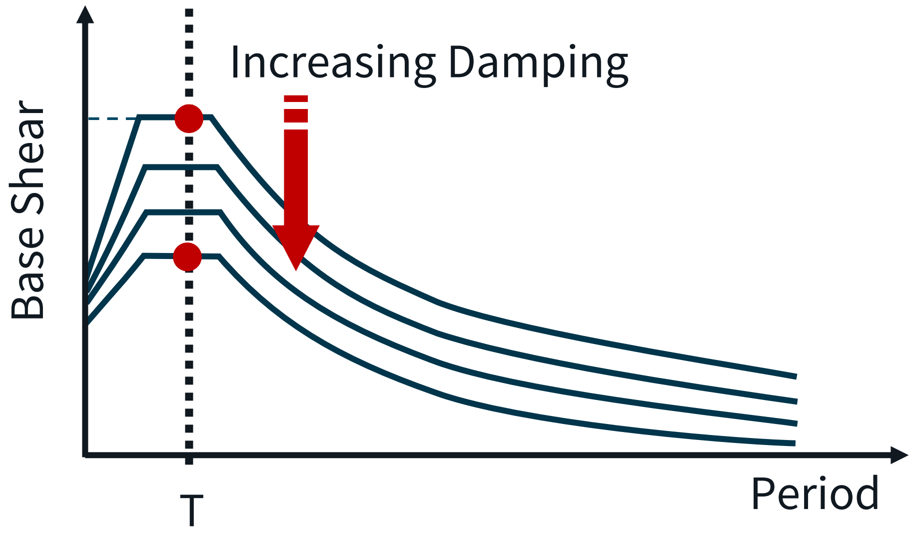
Rocking Wall

Effect of Supplemental Energy Dissipation (damping)

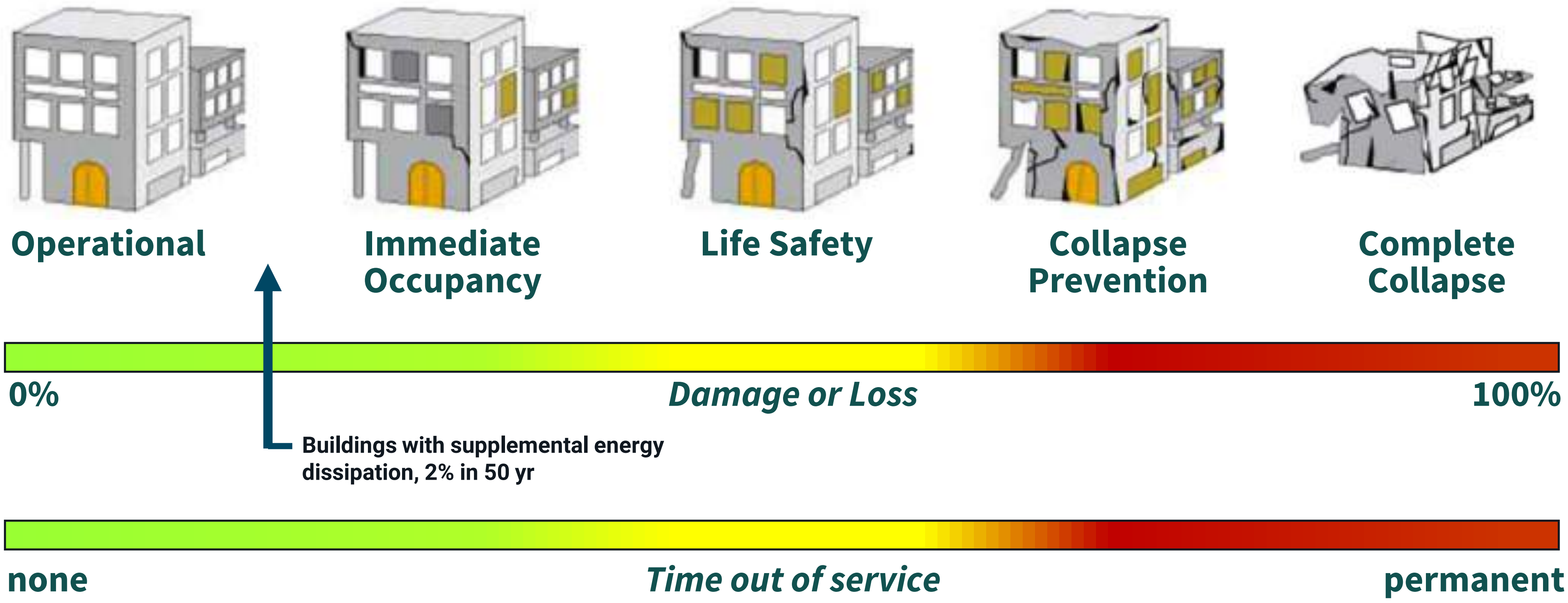
Design Response Spectrum Perspective

Increased damping reduces the Base Shear

From 5% for most buildings to over 30%



Performance target for buildings with SED: no structural damage



Building figures courtesy of NRC

Types of dampers and some vendors

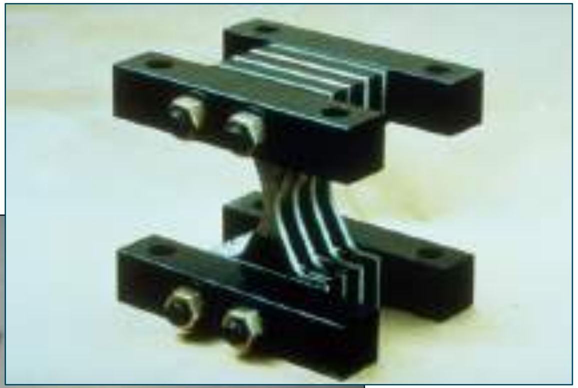
Types of dampers	**Vendors**
• Fluid viscous	Taylor Devices
• Viscous wall	Dynamic Isolation Systems
• Viscoelastic	Kinetica
• Friction	Tectonus, QuakeTek
• Metallic	Castconnex

Some SED devices in buildings

Viscous fluid dampers

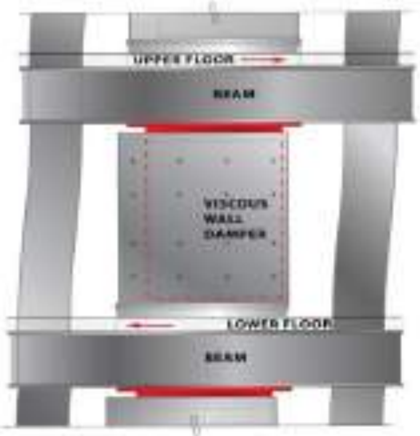
Some SED devices in buildings

Metallic dampers



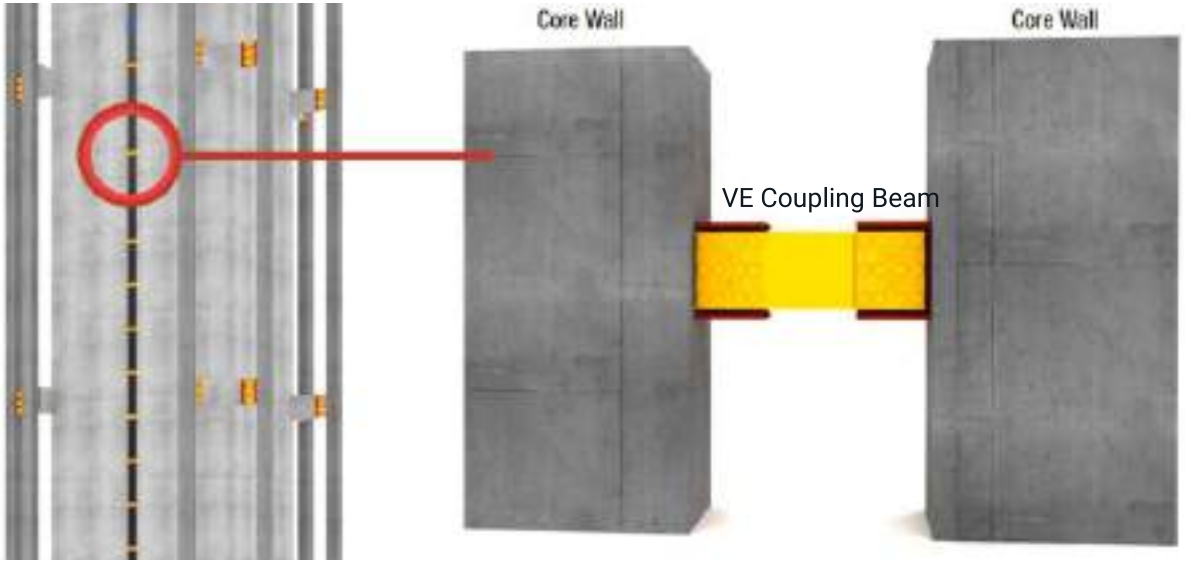
Some SED devices in buildings

Viscoelastic dampers



Some SED devices in buildings

Viscoelastic dampers



Some SED devices in buildings

Friction dampers

Some SED devices in buildings

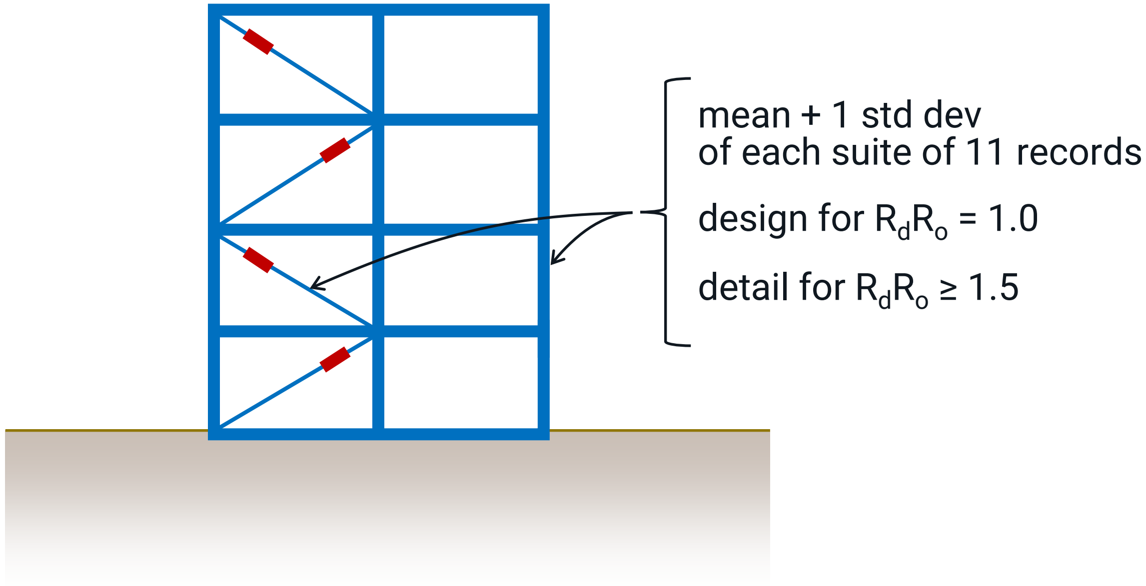
Rocking walls (concrete, CLT)

NBC 2015, BCBC 2018, VBBL 2019 all have provisions for design of new buildings using SED (as do NBC 2020, BCBC 2024)

- 3D Non-linear Dynamic Analysis of the structure required
- B.C. : two suites of 11 earthquake ground motions per suite (x,y,z components of motion)
- SED devices modeled for expected variations in material properties over the design life of the structure (lower bound and upper bound properties)
- Prototype testing required of a minimum of two full size specimens of each different isolator to confirm analyses
- Production testing of 'representative sample' of isolator units prior to installation
- Access for inspection and replacement of all SED devices

NBC 2015 (2020), BCBC 2018, and VBBL 2019 provisions for design of new buildings using SED

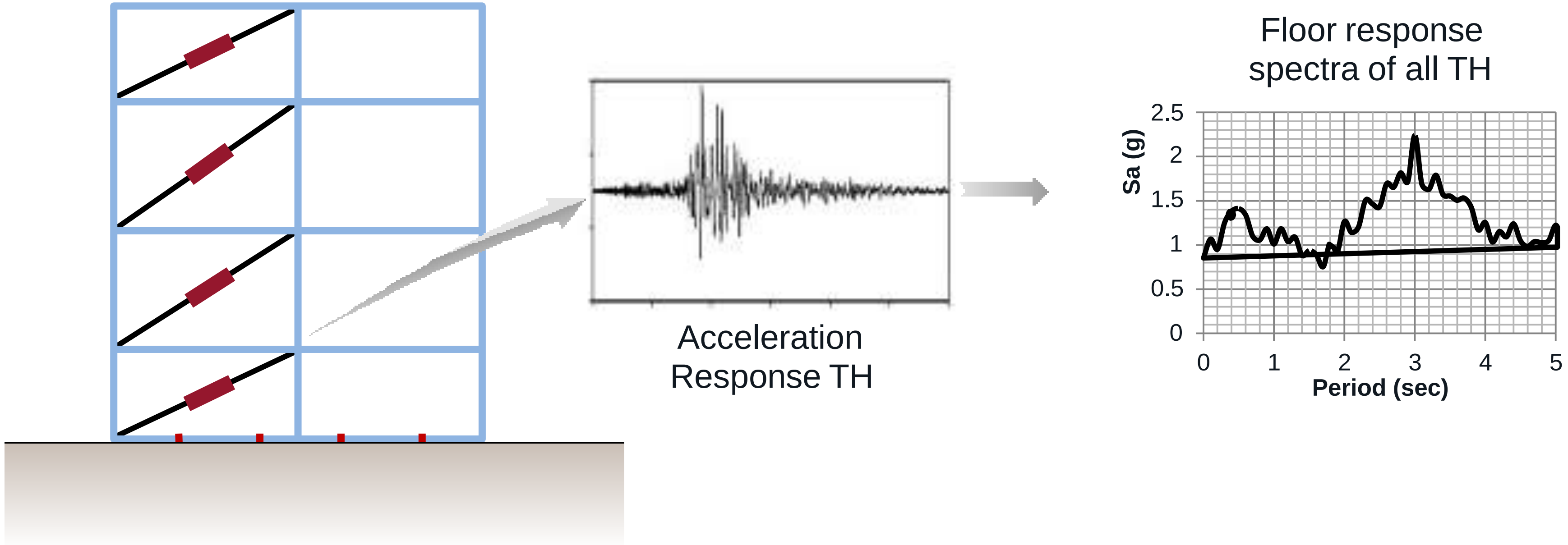
- Wind load: building requires minimum stiffness
- Preferred design: all structural components to remain elastic for mean + 1 std deviation of demands for each component (but still have modest ductility detailing)



General considerations and comments

- Buildings with SED also reduce demand to non-structural components
- Excellent technical assistance available from all vendors
- Considerations for fire protection, to ensure capability to sustain aftershocks, should there be any fire following after the earthquake
- Performance specifications to detail performance requirements, but possible to design in detail to enable bidding from various different vendors and systems

4.1.8.18.(16) “Parts and Portions” (text from NBC 2020)



For structures with supplemental energy dissipation, elements and components of buildings described in Table 4.1.8.18. and their connections to the structure shall be designed for a specified lateral earthquake force, Vp, determined at each floor level as follows: where Ssed = peak spectral acceleration, Sa(T,X), in the period range of T = 0 s to T = 0.5 s determined from the mean 5%-damped floor spectral acceleration values by averaging the individual 5%-damped floor response spectra at the centroid of the floor area at that floor level determined using Non-linear Dynamic Analysis, and I_E, Cp, Ar, Rp, Wp = as defined in Sentence (1). (See Note A-4.1.8.18.(16).)

Supplemental Energy Dissipation - Summary

- Design provisions in current codes
- Proven technology used in many countries; now in some buildings in B.C.
- Can provide ‘no structural damage’ performance for code level earthquake
- Reduces demand and damage to non-structural components (but not as much as BI)
- Requires 3D non-linear analyses
    - With recommendation of external design review
- Requires attention to details to accommodate deformations at locations of SEDs

Thank you!

Questions?

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