Seismic Isolation Standard for Continued Functionality

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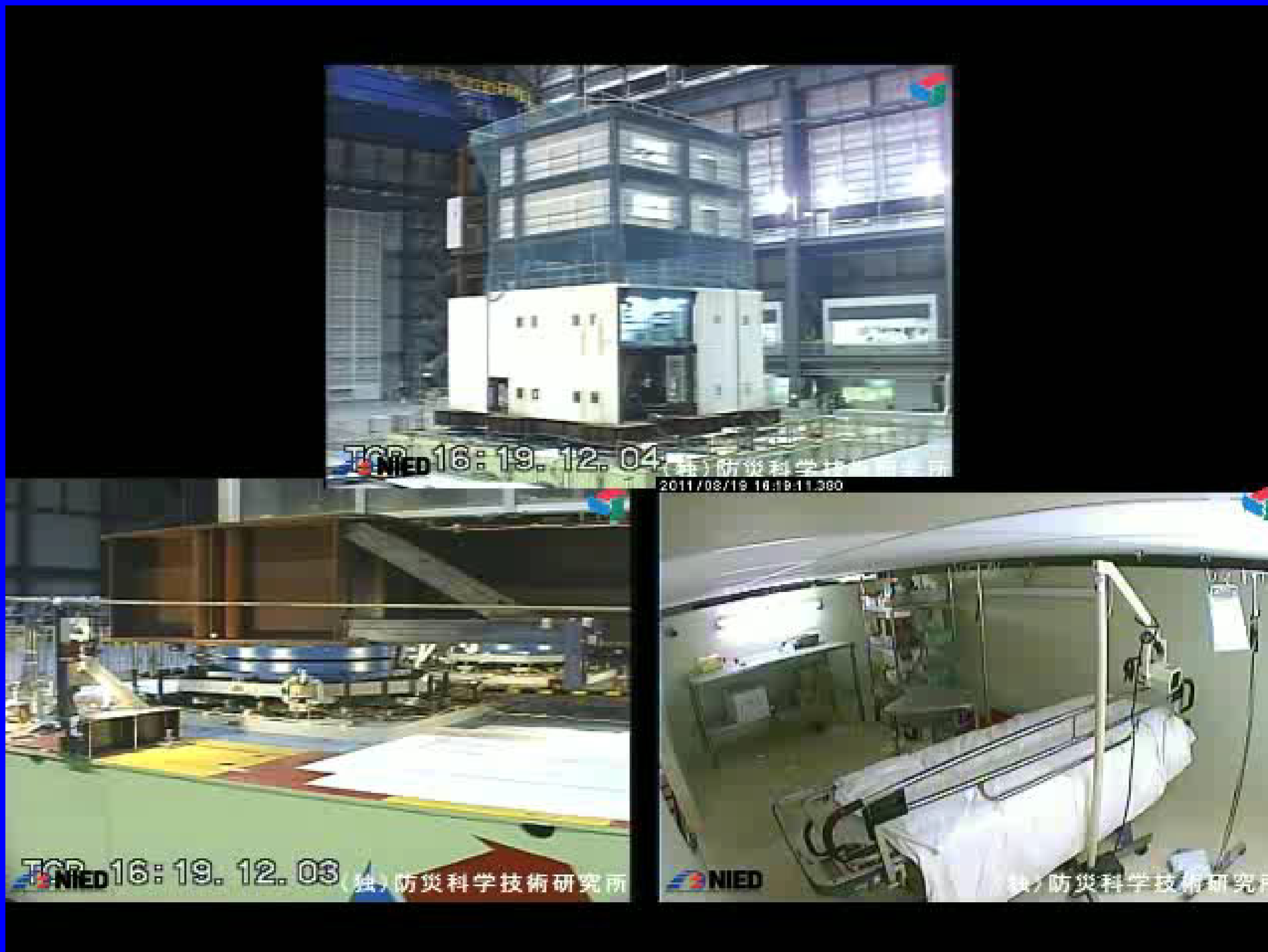
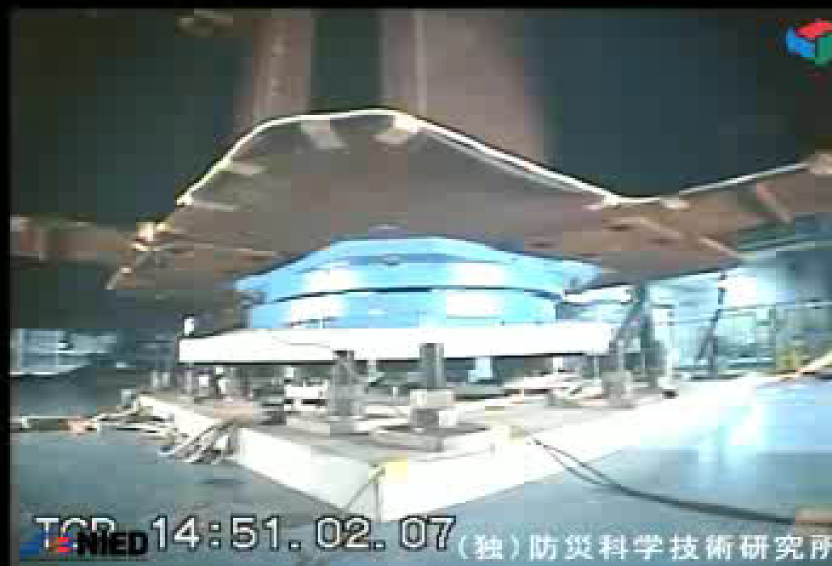
The Seismic Isolation Standard for Continual Functionality specifies criteria for isolator properties that limit seismic damage to less than 2%, 4%, or 8% of facility replacement cost.

Triple Pendulum Shake Table Tests
E-Defense NEES TIPS



Triple Pendulum Shake Table Tests
E-Defense NEES TIPS



REDi Rating System: Resilience Based Earthquake Design Initiative

REDi™ Resilience Objectives

Platinum

Downtime:
Immediate Re-Occupancy (Green Tag expected)
and
Functional Recovery < 72 hours

Direct Financial Loss:
Scenario Expected Loss < 2.5%

Occupant Safety:
Physical injury due to failure of building components unlikely

Gold

Downtime:
Immediate Re-Occupancy (Green Tag expected)
and
Functional Recovery < 1 month[1]

Direct Financial Loss:
Scenario Expected Loss < 5%

Occupant Safety:
Physical injury due to failure of building components unlikely

Silver

Downtime:
Re-Occupancy < 6 months (Yellow Tag possible)
and
Functional Recovery < 6 months[1]

Direct Financial Loss:
Scenario Expected Loss < 10%

Occupant Safety:
Physical injury may occur from falling components (but not structural collapse), fatalities are unlikely

The REDi™ roadmap to resilience will allow owners to resume business operations and provide livable conditions quickly after an earthquake.

Building Resilience

Reliable damage-control technologies such as base isolation and energy-dissipating systems have become well established over the past 15 years. At the same time, developments in computer simulation based upon improved knowledge of structural behavior now enable engineers to realistically predict the behavior of buildings. These significant advances make it possible to design resilient buildings that will suffer little damage in major earthquakes, protecting owners' assets in addition to providing life safety.

Above: The San Francisco General Hospital employed base-isolation to protect the structure and non-structural components from suffering damage in a major earthquake. Since the base-isolators reduced the seismic forces, the superstructure utilized less steel tonnage, which more than offset the cost of the base isolators and flexible connections required across the isolation plane.

Ambient Resilience

The lesson from past earthquakes is to be aware of your surroundings and understand external hazards. This is especially true of buildings in dense urban environments, where surrounding structures can collapse or shed debris onto roads or even onto the building. Site access is an important consideration for minimizing downtime.
In addition, other earthquake-induced hazards like tsunamis or liquefaction can have a devastating effect on the time it takes the local community to recover. This could jeopardize the recovery of even the most structurally resilient buildings.

Organizational Resilience

The time to achieve functional recovery is not just the time it takes to complete repairs caused by earthquake damage. Delays due to 'impeding factors' (see box to the right) can contribute a significant amount to the time it takes to recover. In addition, disruption to utilities must be considered to maintain livable conditions and allow business to resume after an earthquake. Pre-earthquake contingency planning is key to reduce these potential risks.

Resilience for sustainability

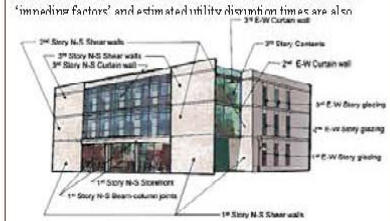
Green-conscious owners have increasingly demanded "net-zero" energy consumption buildings with low embodied carbon. For code-designed buildings in seismically active regions, potential damage from future earthquakes could negatively impact life-cycle costs, negating the benefits of building green. Buildings that achieve a REDi Rating can protect the owner's initial monetary and societal investment by ensuring that the building and its contents are undamaged after an earthquake. LEED has awarded Innovation in Design credits in recognition that enhanced earthquake

Avoid Cliff Edge effects…

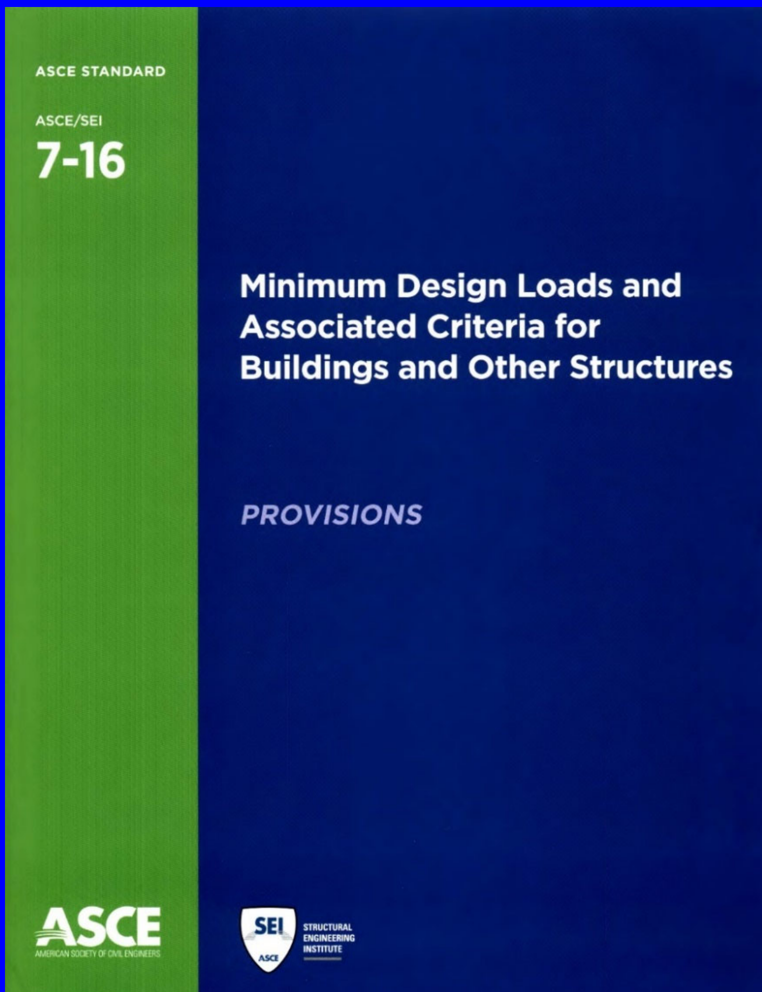
The time to repair a building is essentially proportional to the amount of damage it suffers. If the building suffers little damage, then the repair time may be minimal. But as the damage increases, the time required to achieve functional recovery may increase exponentially. This is due to 'impeding factors' that delay the initiation of repairs. These include the time it takes to complete post-earthquake building inspection, secure financing for repairs, mobilize engineering services, re-design damaged components, obtain permitting, mobilize a contractor and necessary equipment, and for the contractor to order and receive the required components including 'long-lead time' items.

What is a Loss Assessment?

We use a FEMA-based tool to quantify earthquake risk in terms of financial losses and time to achieve re-occupancy, functional recovery, or full recovery. The expected earthquake demands on the building from a computer simulation are provided to a BIM-type model which includes the quantity and location of all building components and contents. The consequences of the damage caused by the demands are reported in terms of repair time and direct financial losses due to repairs. Any corresponding 'impeding factors' and estimated utility disruption times are also

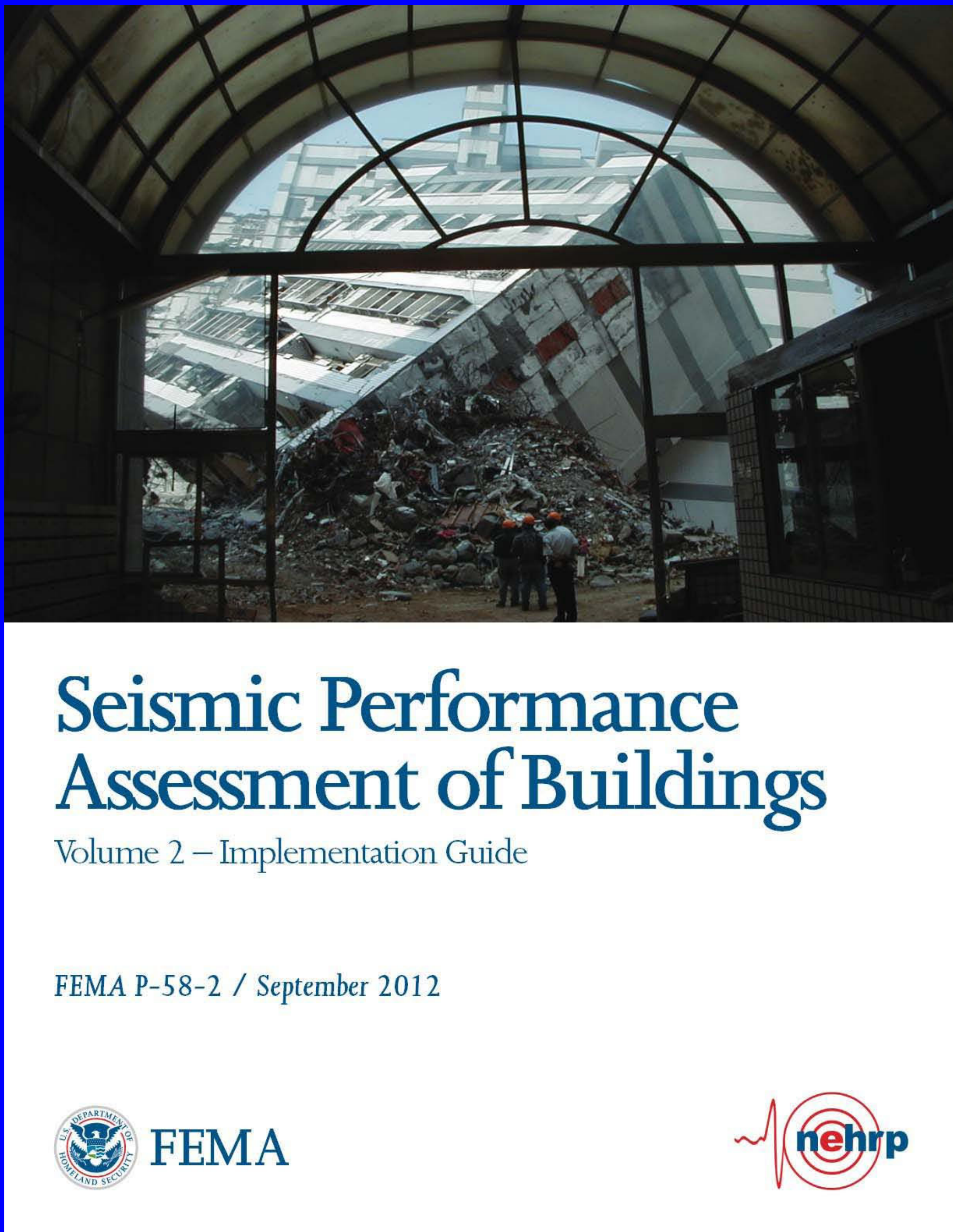


Credit: ARUP Structure Design Consultants



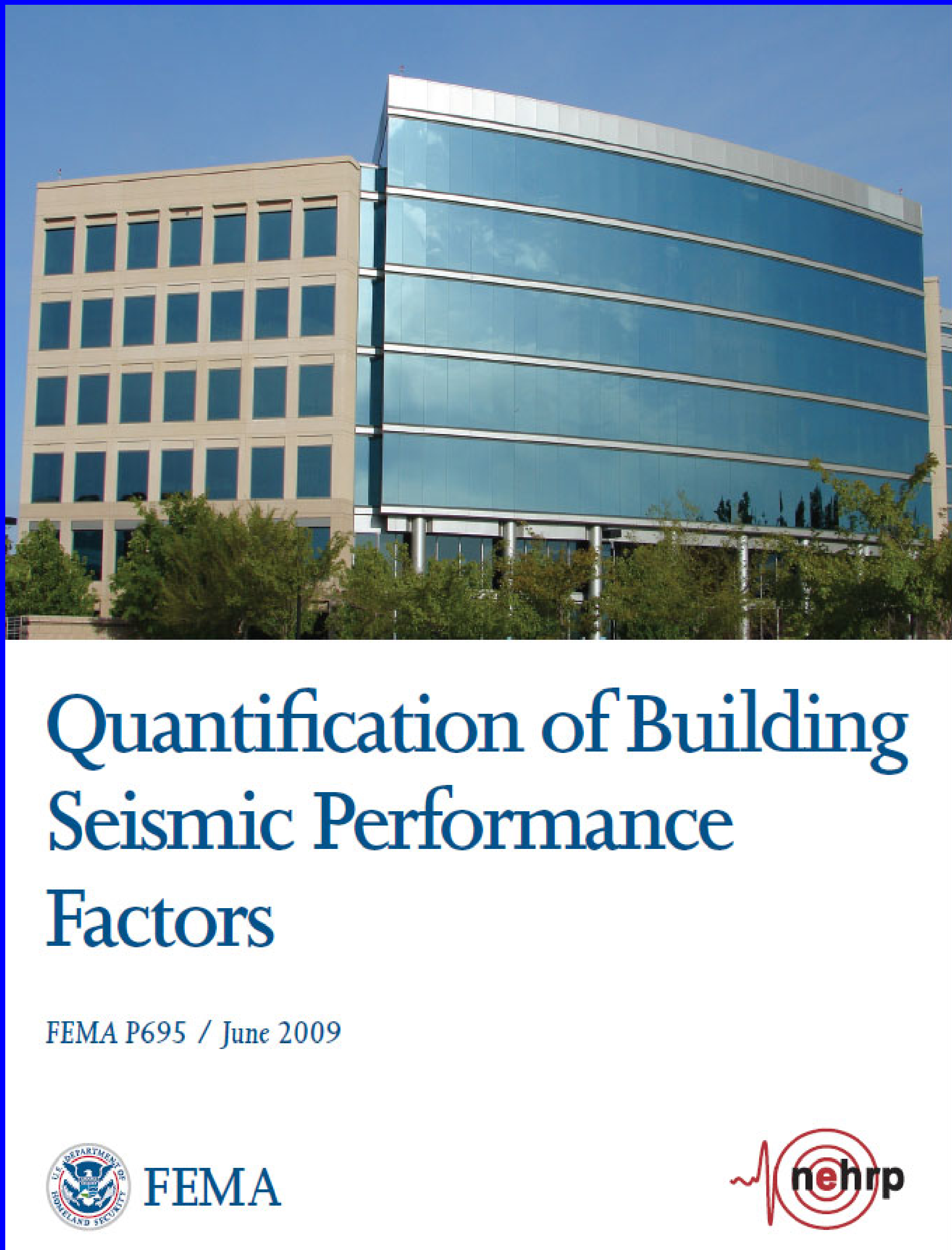
ASCE 7-16

The Seismic Isolation Standard for Continued Functionality is based on ASCE 7 design loads and analysis requirements, and specifies performance criteria for isolator properties that satisfy ASCE 7 Chapter 1 requirements for Functionality after earthquakes.



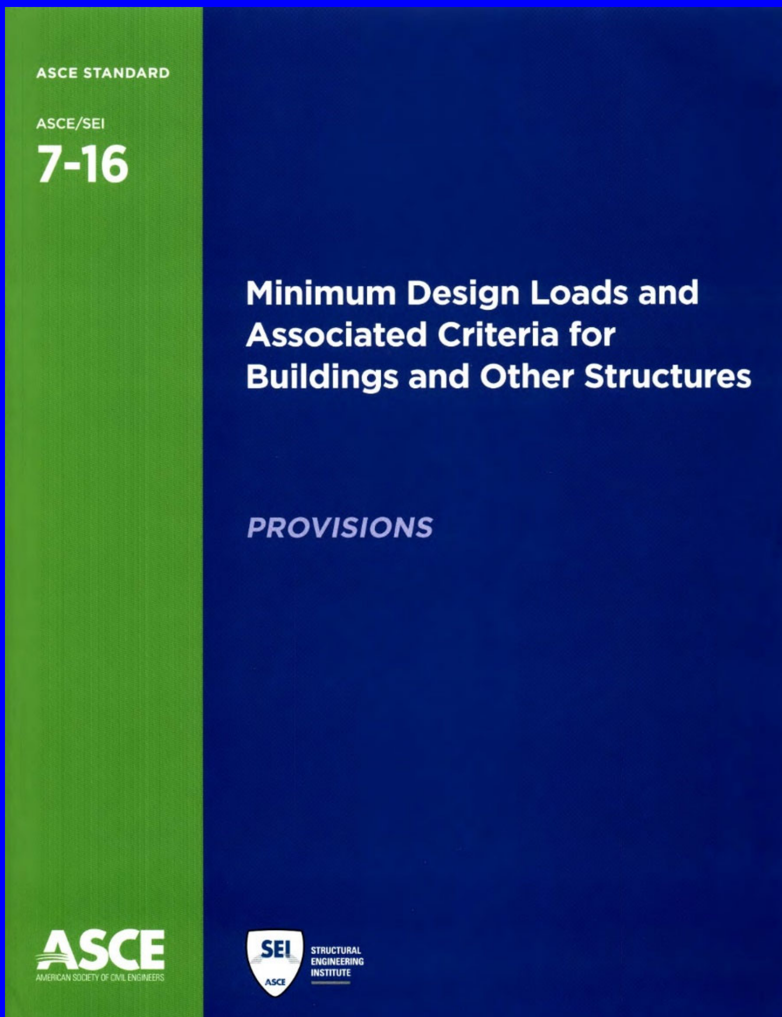
FEMA P58

The Seismic Isolation Standard specifies resiliency criteria that limit seismic damage, using the FEMA 58 methodology to calculate expected seismic damage to buildings.



FEMA P695

The Seismic Isolation Standard specifies the required isolator shear strength and displacement capacity, based on FEMA P695 collapse probability calculations, to satisfy ASCE 7 Target Reliabilities for structural stability.



ASCE 7-16 Chapter 1

requires that isolator design loads be less than the isolator capacities as specified by a materials and fabrication standard for isolators.

An isolator standard must always be specified.

Seismic Isolation Standard for Continued Functionality

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Manufacturer Responsibilities

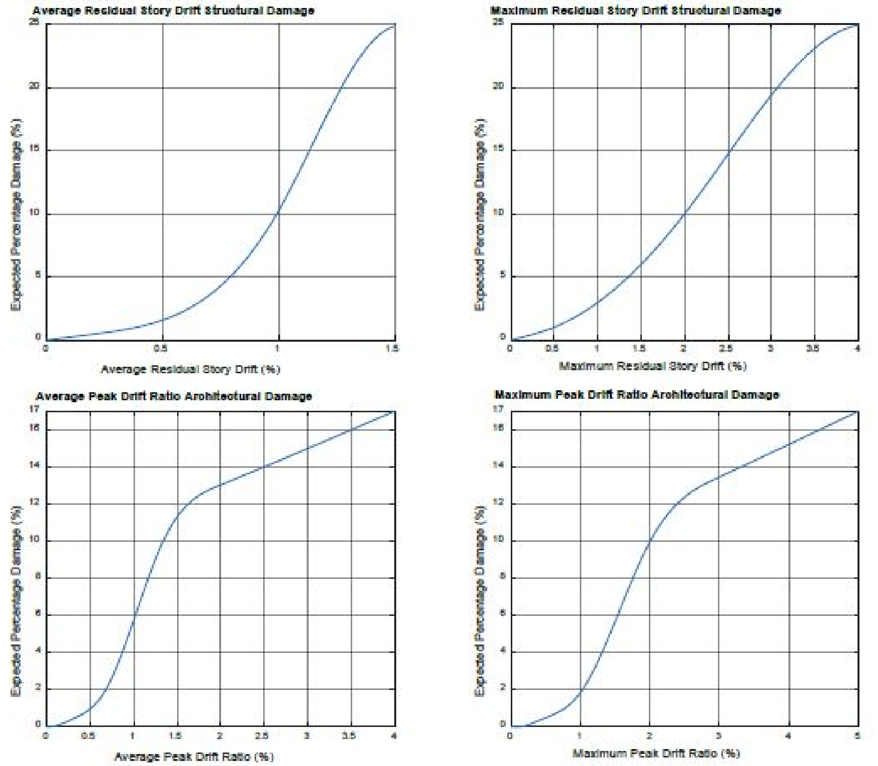
Isolator properties to limit damage

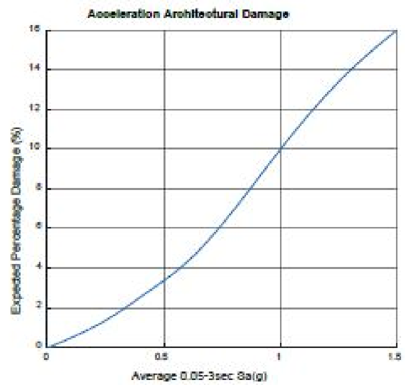
Isolator capacities to satisfy structural safety

Qualification, Capacity, Dynamic Property, and Quality Control tests for isolators.

Structure Design Criteria Applicable Under ASCE 7-16 Base Criteria for the Design Earthquake	Target Limit for Building Architectural & Structural Damage	Average Floor Spectra Acceleration Limit	Average of Peak Story Drifts Limit	Maximum Peak Story Drift Limit	Maximum Peak Residual Story Drift Limit
SISCF Category IV	2%	0.3g	0.20%	0.30%	0.00%
SISCF Category III	4%	0.4g	0.30%	0.45%	0.00%
SISCF Category II	8%	0.6g	0.67%	1.00%	0.00%
Chapter 17 no SISCF	30%	1.0g	1.33%	2.00%	0.00%
Fixed Base DE	60%	1.3g	2.00%	3.00%	2.00%
Fixed Base MCE	100%	1.5g	4.00%	5.00%	4.00%

Table C.3-1 Resiliency Criteria Limits for Structure Design Categories





The suite of relationships presented in this figure are intended to be used to estimate seismic shaking damage as a percentage of construction cost based on various earthquake demand parameters.

Architectural component damage is estimated by summing the contribution from the average spectral acceleration from 0.05-3 sec for all floors, average peak drift ratio for all floors, and the maximum peak drift ratio for any one floor. Structural component damage is estimated by summing the contribution from average residual drift ratio for all floors and maximum residual drift ratio for any one floor.

Figure C.3-2: Building Seismic Shaking Damage Estimate used for selecting Isolator Properties, Structure Type, and Story Stiffness.

Christchurch City Center

Three days after the Magnitude 6.3 Earthquake, 2011

Christchurch City Center

Three years after the Magnitude 6.3 Earthquake, 2011.
70% of buildings demolished. After 5 years, only 15% have been rebuilt. Median loss of property use 15 years.

Replacement Olive Hospital, World’s Strongest Building
1.2g Lateral Shear Capacity, R=1 for MCE

No structural damage during the 1994 magnitude 6.7 earthquake.
Severe architectural damage causes the hospital to be evacuated the day of the earthquake, and remained closed for three months. The hospital could not attend to the people injured by the earthquake.

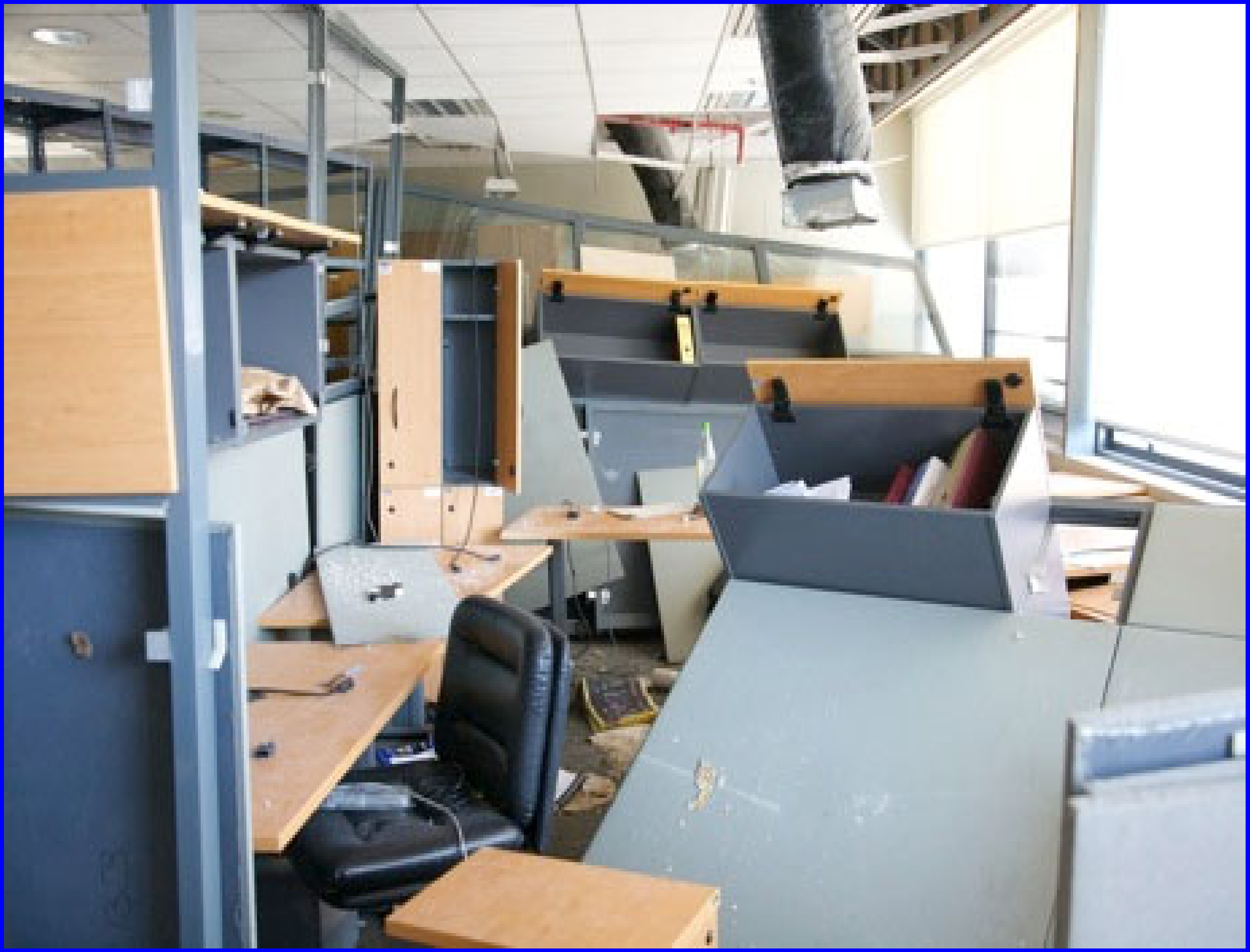
Hospital Closed After Chile Earthquake

Train System Control Center closed after the Chile Earthquake

Court Closed After Chile Earthquake

Commercial Building Closed After Chile Earthquake

Inside Commercial Building



Inside Commercial Building

Inside Commercial Building

Non-Structural Building Damage

Non-Structural Building Damage

Non-Structural Building Damage

Inside Hospital, California

Inside Hospital, California

Indonesia Hospital Patients in Street, 2018

Indonesia Patients on the Street in the Dark, 2018

Indonesia Patients on the Street in the Dark, 2018

Mexico Hospital Patients In Street, 2017

Mexico Hospital Patients In Street, 2017

Mexico Hospital Patients In Street, 2017

Mexico Hospital Patients In Tents, 2017

Mexico Patients on the Street in the Dark, 2017

Hospital de Bahía de Caraques

Evacuated on the day of the earthquake. No hospital care available for those injured in this city. Cost of repair 40%. Loss of use as a municipal building will be 3+ years. Total earthquake loss equal to 56% of original construction cost. Once municipal funds are available, a new hospital will be constructed at a different site. The new hospital will be designed and built for Continued Functionality.

Pinas Del Oro Hospital, Ecuador

Loma Linda Hospital, San Bernadino CA

San Francisco General Hospital

Stanford University Hospital

Mills Peninsula Hospital, California

Washington Hospital, California

Basaksehir Hospital Facility, Turkey
1 Million square meters

Adana Hospital, Turkey

550,000 square meters

Lutfi Kirdar Hospital, Turkey
300,000 square meters

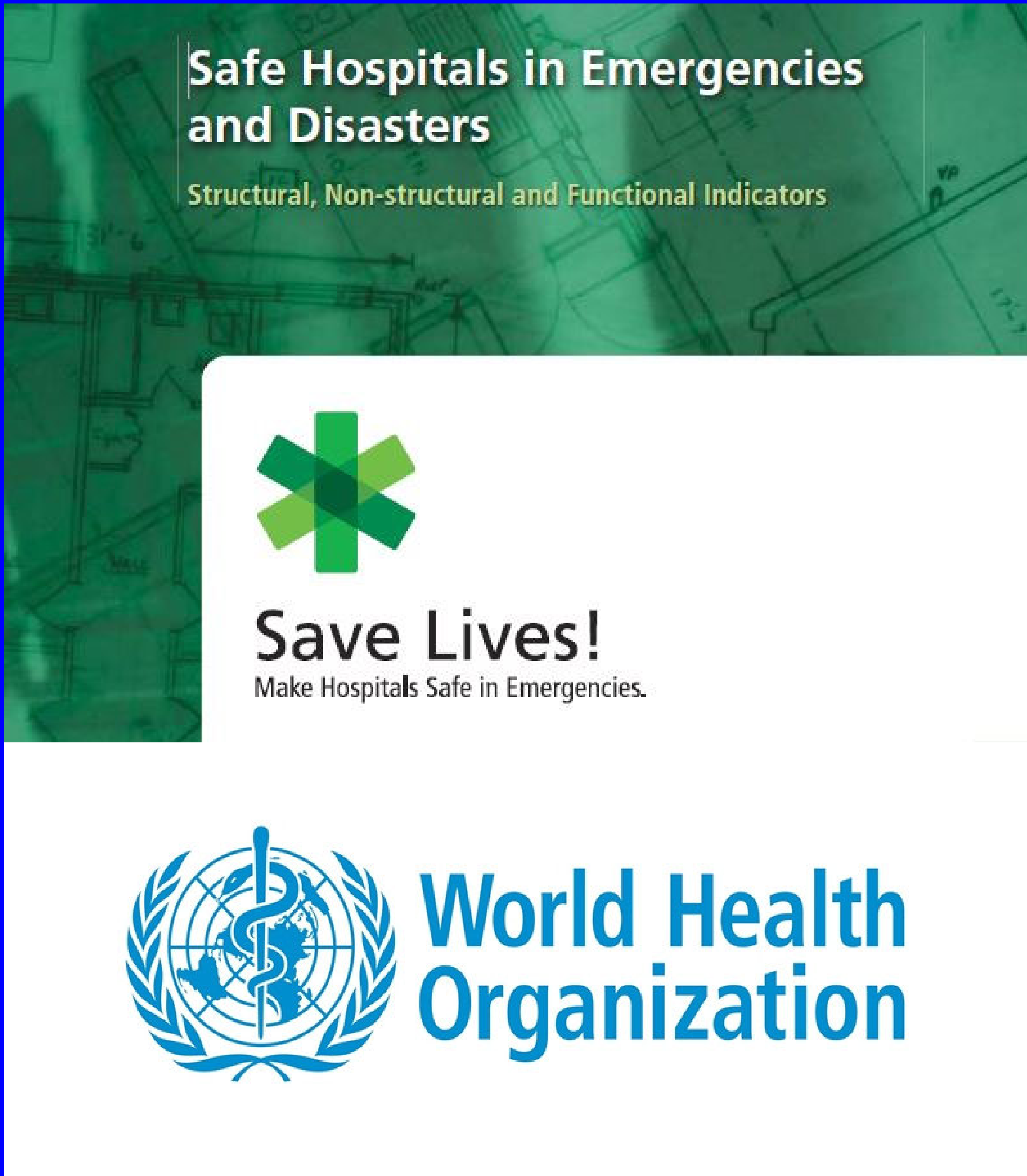
Elazig Hospital, Turkey
250,000 square meters

Goztepe Hospital, Turkey

200,000 square meters

Okemedani Hospital, Turkey

200,000 square meters



The World Health Organization "WHO" Safe Hospitals directive specifies that new hospitals be designed and constructed to maintain maximum functionality after earthquakes.

The governments of 194 countries, including New Zealand, Japan, and the USA, have committed to do their best to comply with this WHO Directive. Structural codes and practices need to be consistent with this commitment to the WHO.

Peru law requires hospitals to be designed to maintain their maximum capacity to function after an earthquake, using seismic isolators.

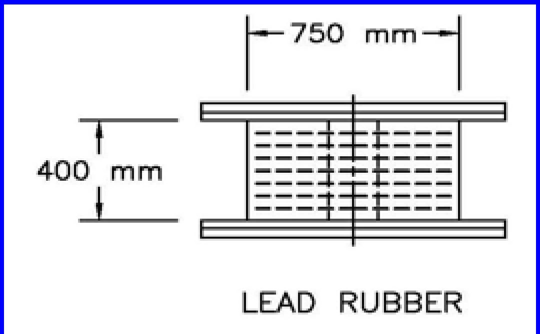
Medicina Deportiva del Callao

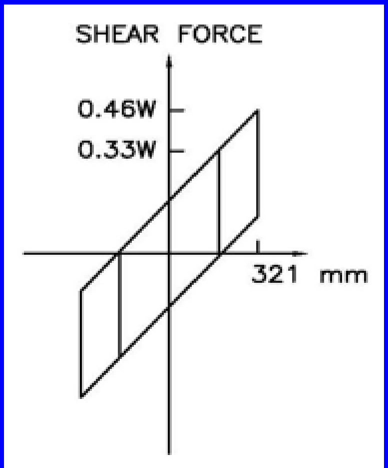
Hospital General de Puno

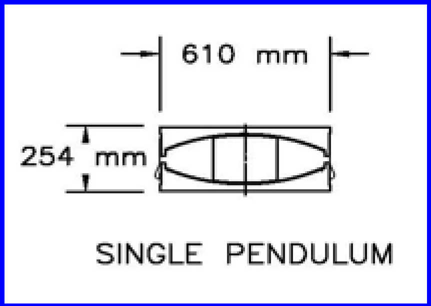
Apple California Corporate Headquarters
400,000 Square Meters, 98% reliability of limiting seismic damage to less than 2%

The isolators for this Ecuador bridge were designed according to the Continued Functionality criteria in the Isolator Standard. The bridge maintained full functionality during the 2016 magnitude 7.8 earthquake. The isolators experienced seismic loading demand 2 times the code MCE spectra. The Ecuador Army Corps of Engineers reported this bridge maintained functionality during and after the earthquake, with 15,000 vehicles crossing the bridge during the first 24 hours, evacuating the injured persons from the devastated City of Bahia. The Ecuador Army Corps of Engineers has adopted the Seismic Isolation Standard for Continued Functionality as mandatory for all their isolated projects.

Wellington Town Hall Seismic Isolation Retrofit







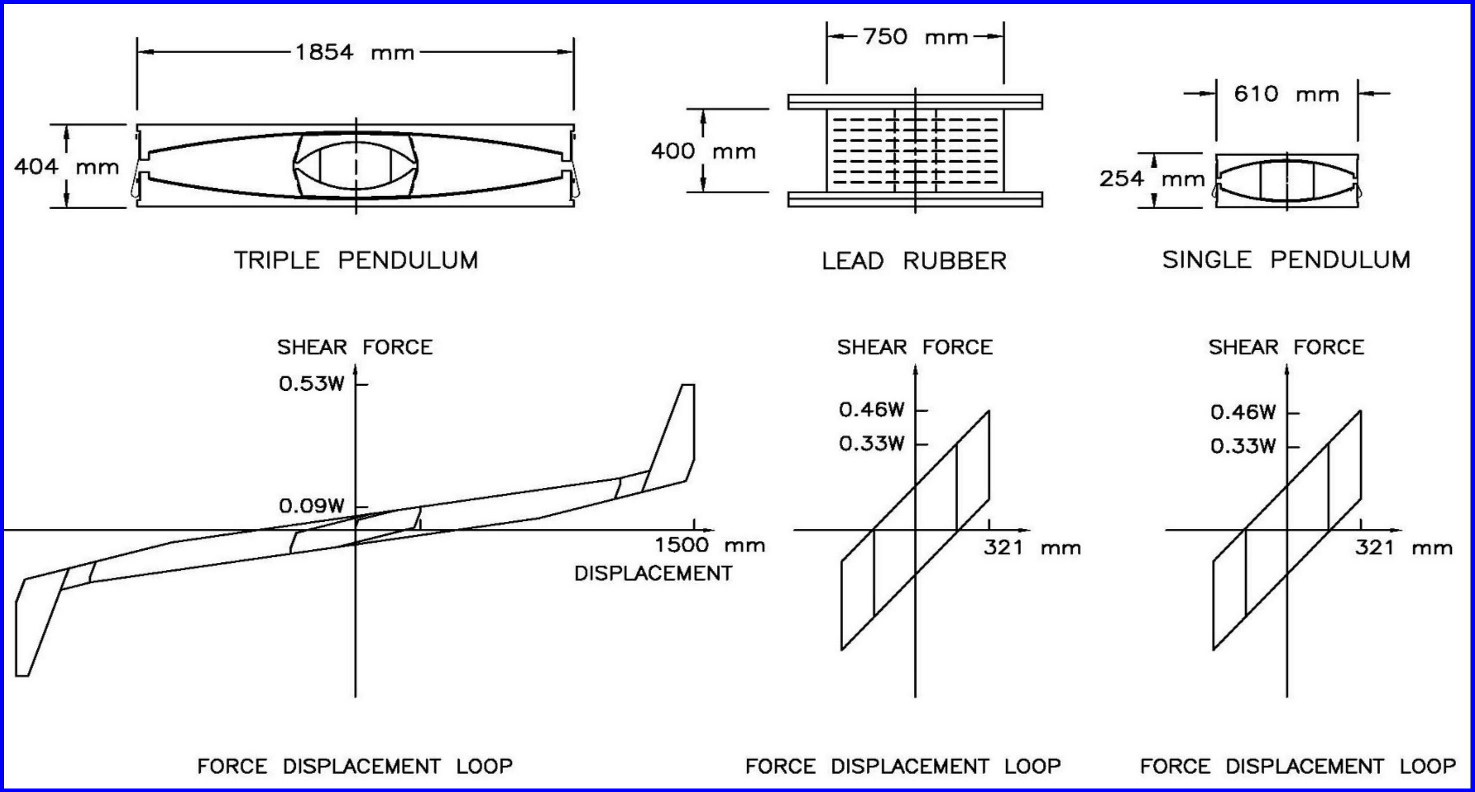
Fletcher Construction paid NZ $ 30 million to repair earthquake damage to the Christchurch Women's Hospital constructed with rigid Lead Rubber Isolators

UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

"Performance Analysis of Base Isolation System"
UC CF 1297: "the lead-rubber isolators did not displace during the earthquakes and the hospital responded essentially as if it was fixed base"

Fletcher
The leading contractor in New Zealand and the South Pacific.

Wellington Children's Hospital Isolator Comparisons



Isolators are Dumb

Engineers need to be smart

The Seismic Isolation Standard
for Continued Functionality
should be specified as the product
standard for all isolators.

Thank You

for helping to build a resilient
and sustainable society.