Engineered Solutions
that
Minimize Seismic Damage

Earthquake Protection Systems
California, USA
Continued Functionality
Design Criteria

Limit seismic damage to Architectural, Non-Structural, & Structure to less than 2% of the replacement costs.
Continued Functionality
Design Objectives

Minimize Earthquake Damage

Minimize Economic Losses

Achieve Seismic Resilient Facilities
Seismic Design Options

1) Ductile Structures

2) Stronger Structures

3) Code Compliant Seismic Isolation

4) Continued Functionality Seismic Isolation
The Problem:

Building codes (Conventional & Isolated Structures)

allow seismic damage and some collapses.
Olive View Hospital, California, 1971
Olive View Hospital, California, 1994
No Structural Damage after the Northridge Earthquake.
Non-Structural Damage, 1994 Northridge EQ
Non-Structural Damage, 1994 Northridge EQ
Code Compliant
Seismic Performance Criteria

“Ensure structure safety to protect the lives of persons inside or on the structures.”

“Preventing damage or economic losses is not the intent of the code provisions.”
Learning From Recent Earthquakes

New Zealand and Chile codes require higher seismic design forces than the USA.
A Magnitude 6.3 Earthquake Occurred at Christchurch, New Zealand in 2011

185 People Killed
2 Buildings Collapsed
1200 Buildings Demolished
$30 Billion in Economic Loss
New Zealand 2011
New Zealand 2011
Chile 2010 Earthquake

20 Buildings Collapsed
10,000 Buildings Demolished
$30 Billion Economic Loss
Chile 2010
In societies having modern seismic codes, for every building that collapses, there are over 100 other buildings having no significant structural damage, but they cannot function due to non-structural and content damage.
Worldwide, structures that suffer severe seismic damage do not satisfy owner expectations.
Owners Expectations after an Earthquake.

Facility to Remain Functional to Serve Intended Function

Revenue Source Un-Interrupted
Seismic Isolation Design Options

1) Code Compliant Seismic Isolation

2) Continued Functionality Seismic Isolation
Will code compliant seismically isolated structures satisfy owner expectations?
Trans-European Motorway, Bolu Turkey
New Code Compliant Seismically Isolated Highway
Nearly Collapsed during the 1999 Turkey Earthquake
Trans-European Motorway, Turkey 1999 Earthquake
Bridge Girders Are Not Supported On The Piers
Trans-European Motorway, Lateral Shift Damage, 1999 Turkey
Broken Energy Dissipation Units  Girders Slid Off Bearings
All Energy Dissipation Units Broken
Friction Pendulum Bearings designed and manufactured by EPS, were used to retrofit the damaged viaduct, and for the design and construction of three new Trans-European Motorway viaduct sections.
Seismic isolation is a design approach, not a performance level. The seismic performance results from the design criteria selected.
Continued Functionality
Seismic Design

1) Absorb seismic displacements in bearings
2) Design structures elastically
3) Limit structure drifts
4) Reduce in-structure accelerations
FEMA 58 is a methodology and computer program that calculates expected earthquake damage for buildings.

FEMA 58 is the result of 20 years of Federal Funding.
The world’s largest corporations rely on EPS Engineered Seismic Solutions.
Apple Headquarters, 400,000 Square Meters
Exxon Offshore Platform, Russia
Texas Instruments Manufacturing Facility
150,000 Square Meters
Shell Offshore Platform, Russia
Over 50 National, State, and City Governments rely on EPS Engineered Seismic Solutions
Preserving Historic Interior Architecture of US Court
Pasadena City Hall, California
Canadian Government Bridge
State of California Dumbarton Bridge
San Francisco General Hospital
Today 27 Countries rely on EPS Technologies
Trans-European Highway
EPS Seismic Bearings
Turkey High-Speed Railway - EPS Seismic Bearings
Greece High-Speed Railway, EPS Seismic Bearings
Spain High-Speed Railway - EPS Seismic Bearings
Equador Bahia Bridge – EPS Continued Functionality Design
No Damage During April 16, 2016 Mag 7.8 Earthquake
New Zealand Factory
EPS Seismic Bearings
Taiwan Condominiums - EPS Seismic Bearings
Taiwan Performing Arts Center, 
EPS Seismic Bearings
Japan Priceless Artifacts – EPS Seismic Bearings
Hermes Statue : Athens, Greece
US $1.9 Billion Space Shuttle Endeavor
Protected with Multi-Stage Friction Pendulum Bearing
IPCU Okemedani Hospital, 200,000 Square Meters
IPCU Lutfi Kirdar Hospital,
300,000 Square Meters
Adana Hospital, Turkey
550,000 Square Meters
Over 50 Million Square Feet of Buildings, Bridges, and Industrial Facilities rely on EPS Engineered Seismic Solutions
Stanford University Hospital
Mills Peninsula Hospital, California
EPS Seismic Bearings
San Francisco Airport, 1 Million Square Feet
EPS Seismic Bearings
Turkey Government Airport, 2 Million Square Feet, EPS Seismic Bearings
California State Building, San Bernadino
EPS Seismic Bearings
Hayward City Hall, California
EPS Seismic Bearings
Cathedral of Christ the Light, Oakland, California
IPCU Goztepe Hospital
200,000 Square Meters
## FEMA 58 Calculations of Seismic Damage (US $)
for
Goztepe Hospital Using Different Isolation Bearings

<table>
<thead>
<tr>
<th>Probability of Being Exceeded in 50 Years: EQ Recurrence Interval</th>
<th>Triple Pendulum Bearings</th>
<th>Single Pendulum Bearings, Same Building</th>
<th>Code Compliant Bearings, Same Building</th>
<th>Same Building Without Seismic Isolation Bearings</th>
</tr>
</thead>
<tbody>
<tr>
<td>90%: 22 year return</td>
<td>$162,000</td>
<td>$797,000</td>
<td>$2,647,000</td>
<td>$5,782,000</td>
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<tr>
<td>50%: 75 year return</td>
<td>$1,224,000</td>
<td>$3,800,000</td>
<td>$10,193,000</td>
<td>$25,143,000</td>
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<tr>
<td>10%: 475 year return</td>
<td>$3,776,000</td>
<td>$8,832,000</td>
<td>$16,365,000</td>
<td>$166,376,000</td>
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<tr>
<td>2%: 2475 year return</td>
<td>$6,228,000</td>
<td>$10,341,000</td>
<td>$34,970,000</td>
<td>$196,717,000</td>
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</tbody>
</table>
Today Over $100 Billion of Constructed Facilities rely on EPS Engineered Solutions
California State Benicia-Martinez Bridge
California State Antioch Bridge
Mississippi River Bridge
Alaska Bridge
California Bridge
2 Chile Liquid Natural Gas Tanks Undamaged By Magnitude 8.8 Earthquake
2 Mexican Liquid Natural Gas Tanks
2 Peru Liquid Natural Gas Tanks
3 Greece Liquid Natural Gas Tanks
ARCHITECTURAL & MEP ISSUES WITH SEISMIC ISOLATION IMPLEMENTATION
ARCHITECTURAL IMPLICATIONS

• **Location of Isolation Plane:**
  - Above foundation Level
  - At Ground Level (Cost-Effective)

• **Critical Elements**: Stairs, Elevators, Exit Ways, etc.
  - Fully Functional/Operational for Design Basis Earthquake (DBE) and Maximum Credible Earthquake (MCE). Movement +/- 30” to 36”

• **Non-Critical Elements**: Moat & Planter Covers, Wall Joints, etc.
  - Fully Functional/Operational for DBE. Movement +/- 20” to 24”.
  - Repairable Damage for Earthquakes Exceeding DBE.
HINGED MOAT COVER, 1/4" STEEL PLATE

STRUCTURAL PERFORATED SLIP SHEET

MOAT COVER AT LOADING DOCK
FACE OF EXTERIOR WALL, S.A.D.

SUPPORT BEAM BEYOND

3'-6"

2'-10"

2'-0"

VENT GRILL S.A.D.

SEEN COVER AT VENT GRILL

SEE □ FOR INFO. NOT NOTED.
SECTION AT CONCRETE MOAT COVER
Friction Pendulum
Seismic Isolation

Was developed in 1985 by

Earthquake Protection Systems
Original Friction Pendulum Bearing
Original Friction Pendulum Technology
Single Pendulum Bearing

- Stainless Steel Concave Surface
- Housing Plate
- Concave Plate
- Self Lubricating Composite Liner
- Articulating Slider
- Section
Triple Pendulum Seismic Isolation

Was developed in 2006 by

Earthquake Protection Systems
Triple Pendulum Bearing
FRICTION PENDULUM CONCEPT

Period $T = 2\pi \sqrt{R/g}$

Stiffness $K = W/R$

Pendulum Motion

Sliding Pendulum Motion

Single Pendulum Operation

Triple Pendulum™ Operation
TRIPLE PENDULUM BEARING

Main Concave

Slider Concave

Section of Triple Pendulum Bearing
Triple Pendulum and Single Pendulum Sliding Mechanisms
ADVANTAGES OF TRIPLE PENDULUM BEARING
TENSION CAPABLE FRICTION PENDULUM
EPS Manufacturing Facility, California USA

30,000 Square Meter Floor Space

Certified ISO 9001 Quality Control System For Seismic Bearing Design, Manufacture, and Testing

100% Bearing Manufacture and Testing at One Facility
Approved for the Most Critical Applications of Seismic Isolation Worldwide
Triple Pendulum Bearing
CONCAVE OVERLAY MATERIAL

ASTM A240, Type 304 Stainless Steel with polished finish

- Tensile Strength = 415 MPa
- Yield Strength = 275 MPa

Exceptional corrosion and environmental resistance

Large Conacve Thickness = 4.5 mm
COMPOSITE BEARING LINER MATERIAL

The FPB liner is a proprietary composite bearing liner system developed by EPS for use in Seismic Isolation.
EPS Manufacturing Capacity: Over 800 tons per month
Apple Campus Bearings: 700 Large Size Triple Pendulum Bearings

(1.3 m displacement capacity) Manufactured in Six Months
Safe Seismic Isolation Bearing Implementation Requirements

for Satisfying Building Code Basic “Life-Safety” Requirement

(i.e. “Collapse Prevention”)

The fundamental objective of building codes is to prevent collapse of building structures under service and seismic loadings. ASCE 7-10, Section 1.3.1 clearly states, “Building and other structures, and all parts thereof, shall be designed and constructed with adequate strength and stiffness to provide structural stability”. Whether the building is a conventional fixed base structure or an isolated structure this fundamental safety requirement shall be satisfied.

For safe implementation of isolation bearings, EPS recommends that the isolation system have lateral shear capacity greater than:

- Plastic shear capacity of the supported structure, or
- $1.33 \times$ Maximum Considered Earthquake Shear
911 Emergency Communications Center, San Francisco, California

San Francisco’s 911 Emergency Communications center, constructed in 1998, houses the emergency call taking, the combined dispatch of Police, Fire, Emergency Medical and Traffic Control Operations, as well as Emergency Operations Center. As such its continued operation in the aftermath of an earthquake is of critical importance. The seismic performance goals for this project were to have no structural or non-structural damage or functional disruption in the event of a small to moderate earthquake event. Limited damage and minor functional disruption is deemed acceptable during a major event. Base isolation was the best available technology to help achieve these goals, and to achieve an economical solution. The isolation system is installed at the top of the basement level supported on large cantilever concrete columns (Figure 14). This scheme proved to be the most cost effective location for the isolators. The superstructure is a steel structure with conventional braced frames. Figure 15 shows the isolation interface details at building perimeter.

Fig. 14: 911 Emergency Communications Center
Fig. 15: ECC Isolation Interface
SAFE LEAD-RUBBER BEARING INSTALLATION
ON TOP OF COLUMN

LA-USC Hospital, Los Angeles, CA
(Fail-Safe Back-Up System for Elastomeric Bearings)

St. John’s Hospital, Los Angeles, CA
(Fail-Safe Back-Up System for Elastomeric Bearings)
SAFE SLIDING PENDULUM BEARING INSTALLATION
ON TOP OF COLUMN

SAFE TRIPLE PENDULUM BEARING INSTALLATION
ON TOP OF COLUMN
04-Aug-2014 EPS Bearing Test Report for Stage 6 Radius

Test Date: 8-04-2014; Test Time: 10:14:22.4; Test Data File: 6831STAGESLIP2.18
Bearing Dim.: Rc = 88 Rsc = 16, IDc = 31, ODsc = 18, IDsc = 16.5, ODsi = 12, tsc = 2, hsi = 7 in; Target Frictions: μ1 = 0.02, μ2 = 0.08, μ3 = 0.08
Target Test: 1 Cycle; Vertical Load: 800 kips; Target Cyclic Displacement: 18 in

FORCE-DISPLACEMENT LOOP

Vert Load: 823.2 kips avg, 935.3 kips max, 738.5 kips min; Velocity: 3.4 in/sec max, 1.1 in/sec avg, Shear Load: 578.3 kips max, -523.6 kips min

Data Results

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Disp</th>
<th>EDC</th>
<th>Avg Fric</th>
<th>(H/V)max</th>
<th>(H/V)min</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18.3</td>
<td>7.49</td>
<td>0.1022</td>
<td>0.629</td>
<td>-0.621</td>
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</tbody>
</table>

EPS BEARING WITH SHEAR STRENGTH=0.60W
(BEARING STRONGER THAN STRUCTURE)
Testing of Seismic Isolation Bearings

- Prototype Testing
- Quality Control
Prototype Testing of Isolation Bearings

ASCE 7 Requires Prototype Testing of Full-Scale Bearings during Design Phase (and NOT during Construction)

ASCE 7 Requires Dynamic Prototype Testing

Prototype Tests should include

- Shear Load Capacity Tests
- Vertical Load Capacity Tests
- Uplift Displacement Capacity Tests
Quality Control Testing of Bearings

100% QC Testing VERY IMPORTANT

100% QC Testing Required by AASHTO & ASCE 7-16

When Testing is Required for 100% of Column Materials (Steel or Concrete), then Why Isolation Bearings which support Column Loads are Either Not Tested or Tested to Certain Percentage (20%)?
EPS Prototype Testing

Dynamic Prototype Testing at Design Phase

Rated Capacity Tests

Uplift Capacity Tests
EPS Quality Control Testing

100% of Production Bearings QC Tested Dynamically
EPS Large Scale Dynamic Test Machine
Bearing: FPT15663/20-16/14-8  Prototype Bearing Test: A63.1.v2400
Real Time Variable Displacement Property Test - P3

| Avg. Vert. Load (kips) | 2583 | 11530 kn |
| Max. Vert. Load (kips) | 3114 | 13900 kn |
| Min. Vert. Load (kips) | 1699 | 7585 kn |
| Peak Velocity (in/sec) | 50.6 | 1285 mm/s |

<table>
<thead>
<tr>
<th>Cycle</th>
<th>D (in.)</th>
<th>EDC(W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>39.0</td>
<td>4.841</td>
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<tr>
<td>2nd</td>
<td>27.0</td>
<td>2.706</td>
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<tr>
<td>3rd</td>
<td>15.0</td>
<td>1.322</td>
</tr>
<tr>
<td>4th</td>
<td>2.5</td>
<td>0.102</td>
</tr>
</tbody>
</table>

Friction Values
- Measured: 0.01 0.02 0.05
- Measured: 0.005 0.01 2.5
- Measured: 0.094 0.00717 0.333
EPS Dynamic Quality Control Test, Triple Pendulum Bearing
30 Years of USA Extensive University Research Testing and Investigations at:

University of California Berkeley, Earthquake Engineering Research Center

State University Of New York, National Center for Earthquake Engineering Research

University of California San Diego, CALTRANS Seismic Response Modification Device Testing Facility
Single Wythe
M-8
5-Story Full-Scale Building Isolated with 9 Full-Scale Triple Pendulum Bearings with 1 m Displacement Capacity
E-Defense Shake Table, Japan
Over US $100 Billion in Constructed Value of Important Buildings, Bridges, and Industrial Facilities in 27 Countries

Rely on Engineered Friction Pendulum Solutions by Earthquake Protection Systems

California, USA
Important Considerations - Seismic Isolation

Safety

Manufacturer Qualifications

100% Testing – Preferably Realistic Condition

Seismic Performance – “Continued Functionality”
EPS Engineers have 30 years experience implementing Friction Pendulum solutions.

Victor Zayas, Ph.D., P.E.
Stanley Low, M Eng, S.E
Anoop Mokha, Ph.D., S.E.
Thank You

for considering EPS

Continued Functionality
Seismic Solution