Utah State Capitol Building Restoration and Seismic Base Isolation

Presented by

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Reaveley Engineers + Associates

for

CSCE Regional Lecture Tour

February 28-29, 2012

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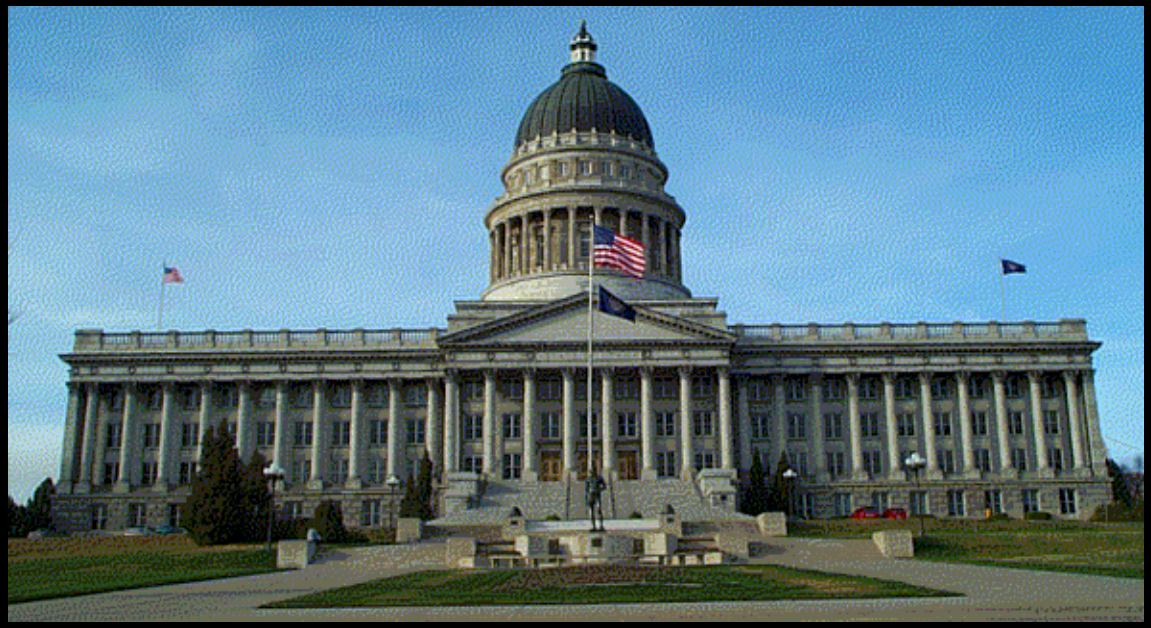
Building Characteristics

- Designed in 1912 by R.K.A Kletting.
- 4 Stories with partial basement / crawl space and dome.
- Approximately 400’ x 215’ in plan.
- Basic structural system is reinforced concrete frame.
- Steel trusses for dome and skylights, otherwise sparse use of structural steel.



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Nonstructural Features

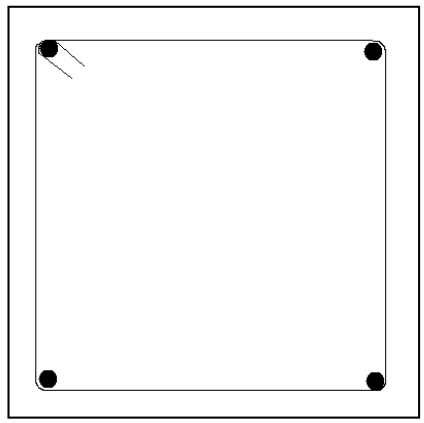
- Stacked Granite Columns on South, East and West Sides.
- Exterior carved/stacked granite cladding.
- Skylights and atrium.
- Pediments and parapets.
- Rotunda and dome.
- Interior tile, marble, other unusually heavy components.
- Unusually heavy overall structural massing. The building is roughly 2 times the weight of a modern office building of comparable space

Primary Findings of Early Studies

- Structural frame is inadequate with respect to the expected seismic motion.
- Inadequate reinforcement in walls, columns and beams to provide ductile performance.
- Large diaphragm openings in levels 3, 4, attic, roof.
- Non-continuous infills comprised of HCT and URM.
- Exterior cladding backed by URM.
- Lack of bracing for parapets, pediments, and balustrades.
- Window penetrations of dome create ‘soft’ story.
- Dome seismic forces are amplified due to its height.
- Lack of uniform lateral stiffness. Rotunda is stiff, wings are flexible.
- Inadequate anchorage of cladding.

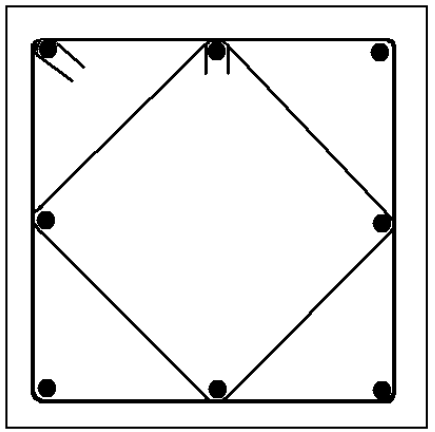
The Need for Seismic Retrofit:

- Primary structure is reinforced concrete beams and columns. Although innovative in its day, the concrete is lightly reinforced by today's standards. Concepts of seismic design did not exist 90 years ago.
- The building is within a very short distance of the active Wasatch Fault.
- Expected seismic performance (pre-retrofit) was extremely poor. Significant earthquake would likely have meant loss of life and loss of the building.



Typical Column - Utah State Capitol
As=0.4% of Gross Column Area (Ag)

Top of existing column in attic of Capitol



Typical Column - Modern Construction
As=1.0% of Gross Column Area (Ag) Minimum

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Owner Performance Expectations:

Life Safety (FEMA 356 Basic Safety Objective)

Historic Preservation

Results of Studies:

The expected seismic performance was extremely poor with a high likelihood for loss of life and property.

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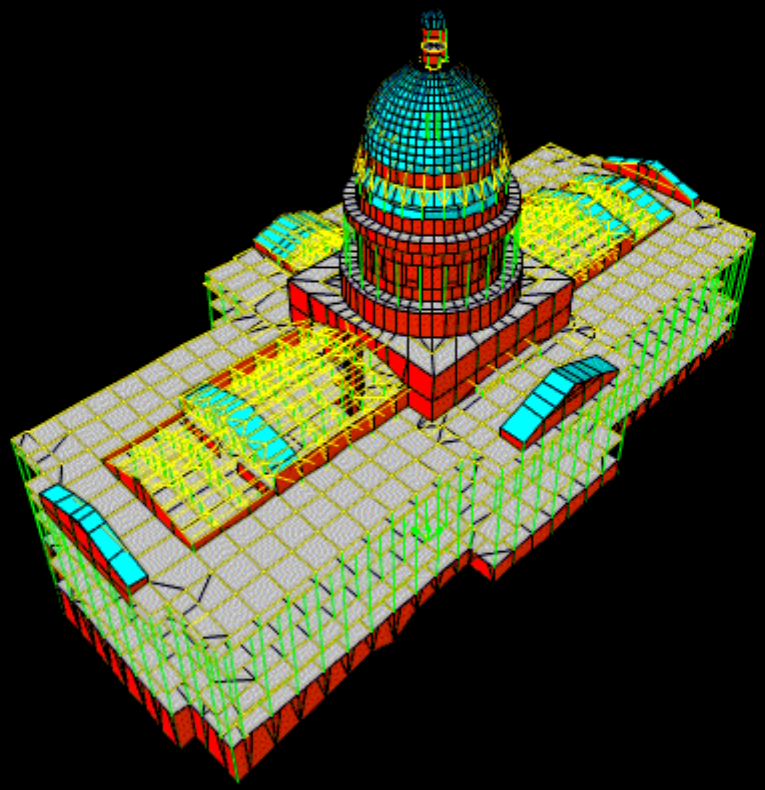
As Is Building Model - 30x Amplification

(Click on image to start animation)



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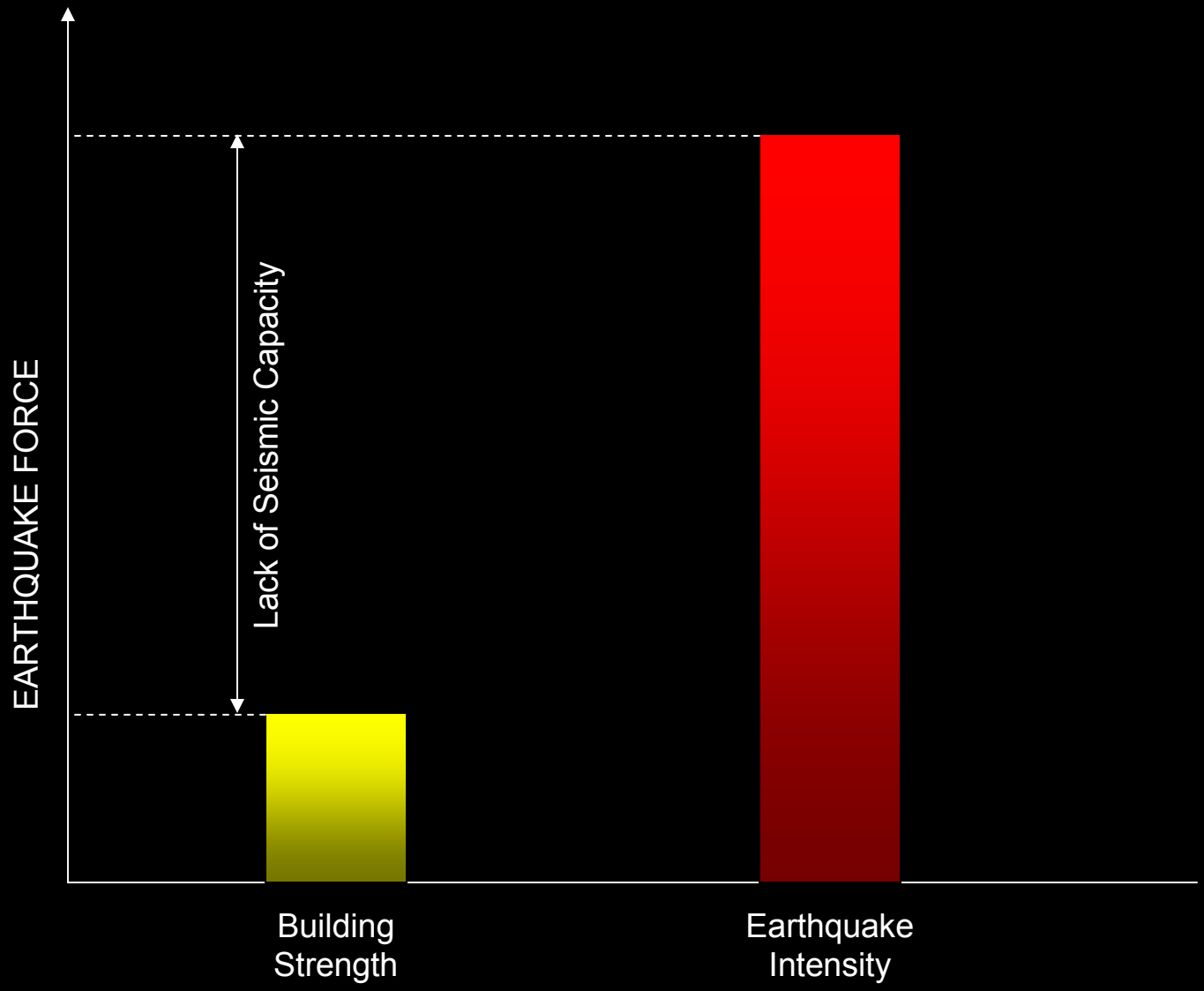
Potential Retrofit Schemes

- Increase the strength, stiffness and ductility of the existing building.
- Reduce the seismic demand with a base isolation system.
- Use a combination of these approaches.

Potential Retrofit Scheme: Add Strength to Existing Building



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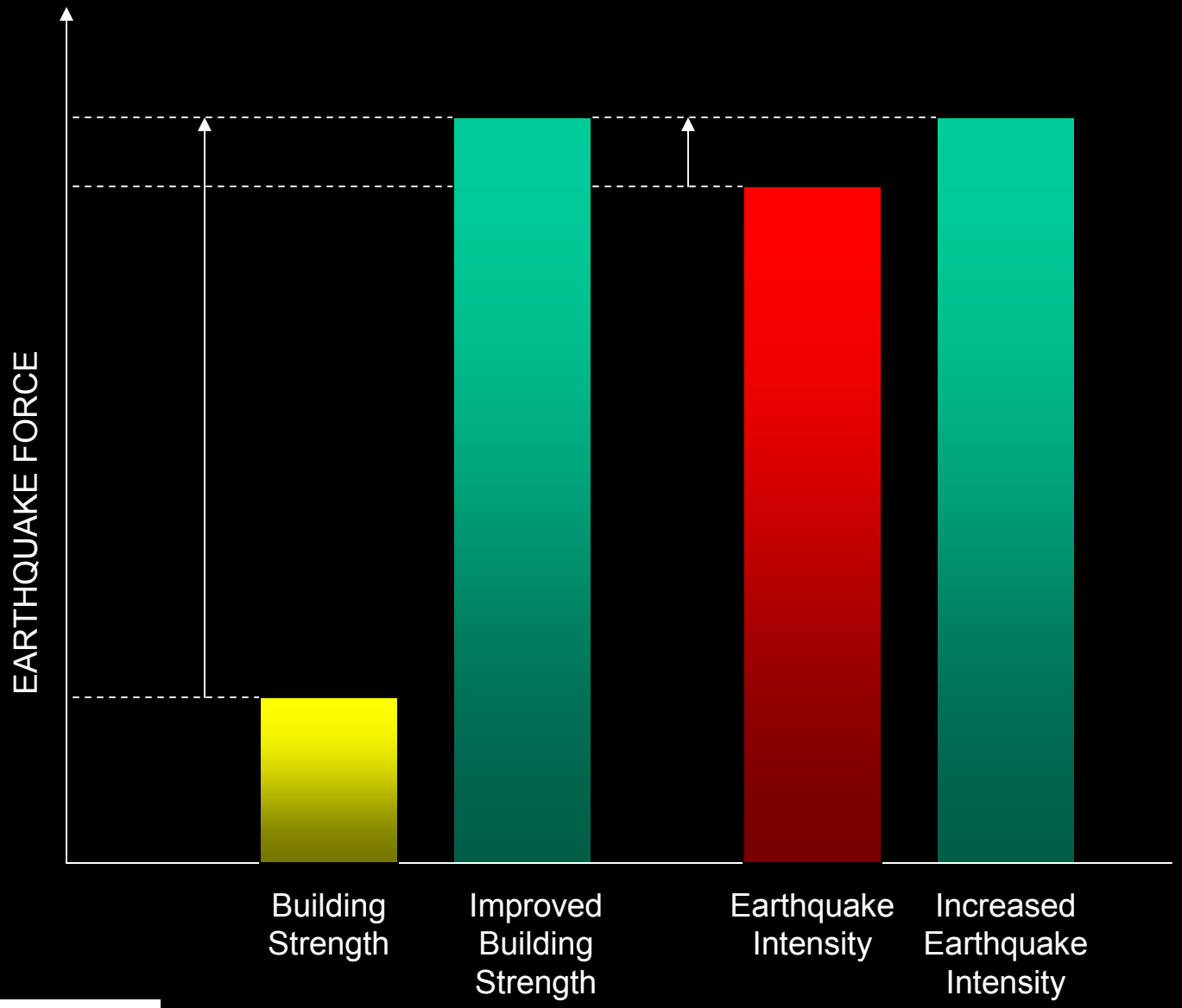
Potential Retrofit Scheme: Add Strength to Existing Building



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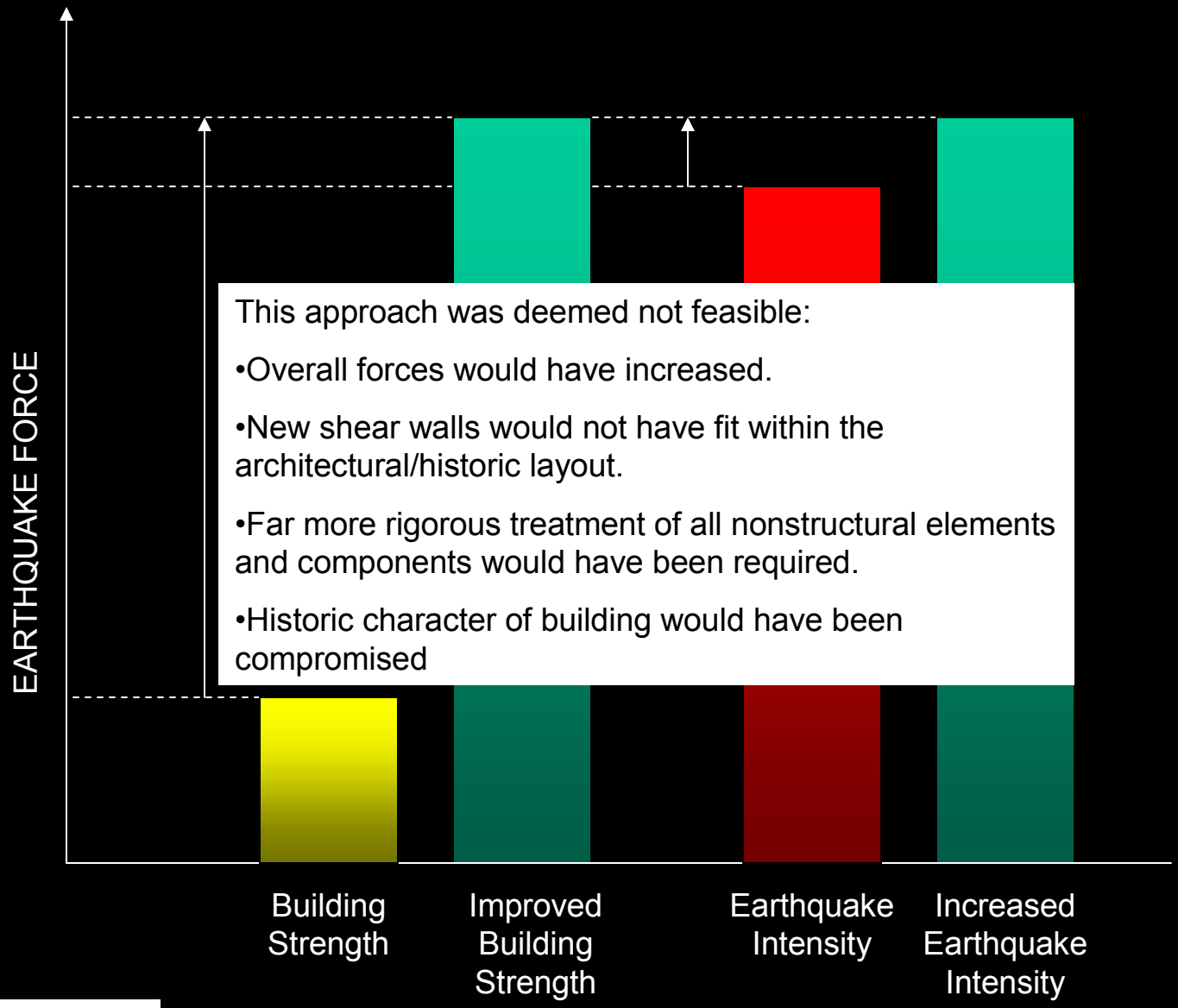
Potential Retrofit Scheme: Add Strength to Existing Building



This approach was deemed not feasible:

- Overall forces would have increased.
- New shear walls would not have fit within the architectural/historic layout.
- Far more rigorous treatment of all nonstructural elements and components would have been required.
- Historic character of building would have been compromised

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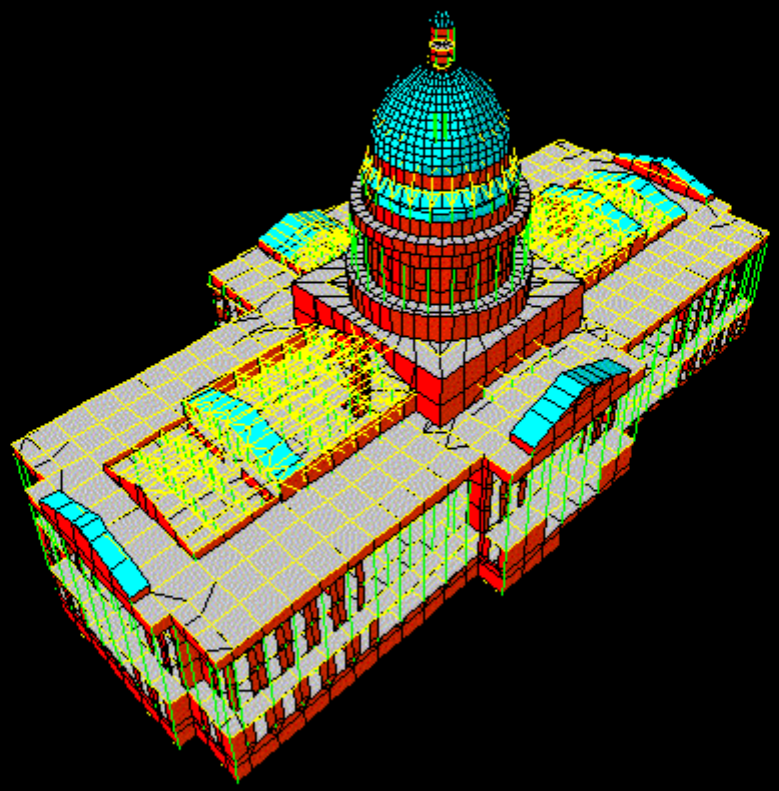
Fixed Base Model - 30x Amplification

(Click on image to start animation)



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The Solution

Seismic Base Isolation was selected as the preferred solution since most readily met performance objectives while being sensitive to historic preservation and costs.

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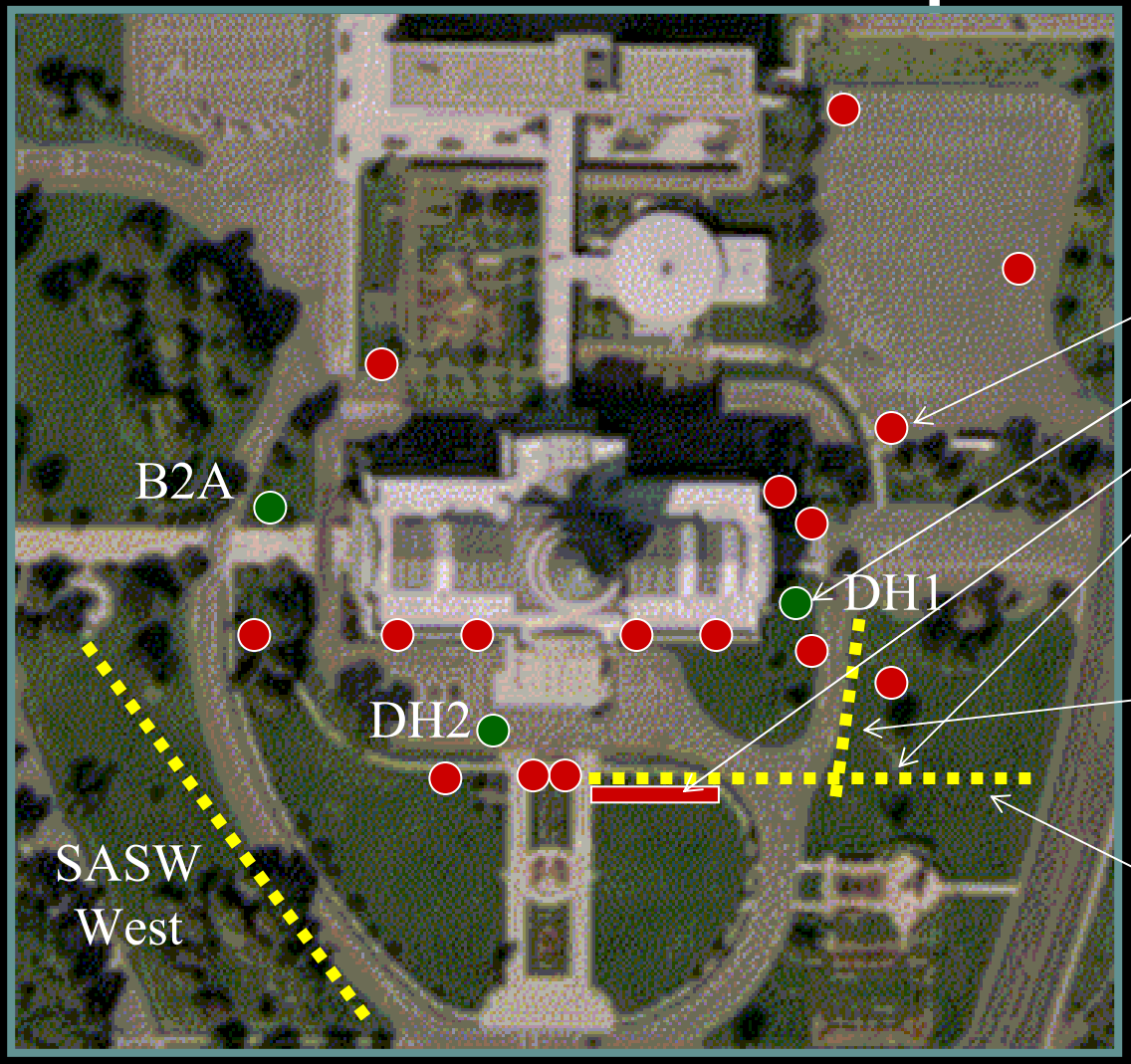
Site Response



Geotechnical Borings
Down-Hole Shear-Wave
Fault Trenching
SASW Surveys

SASW
East

SASW
South

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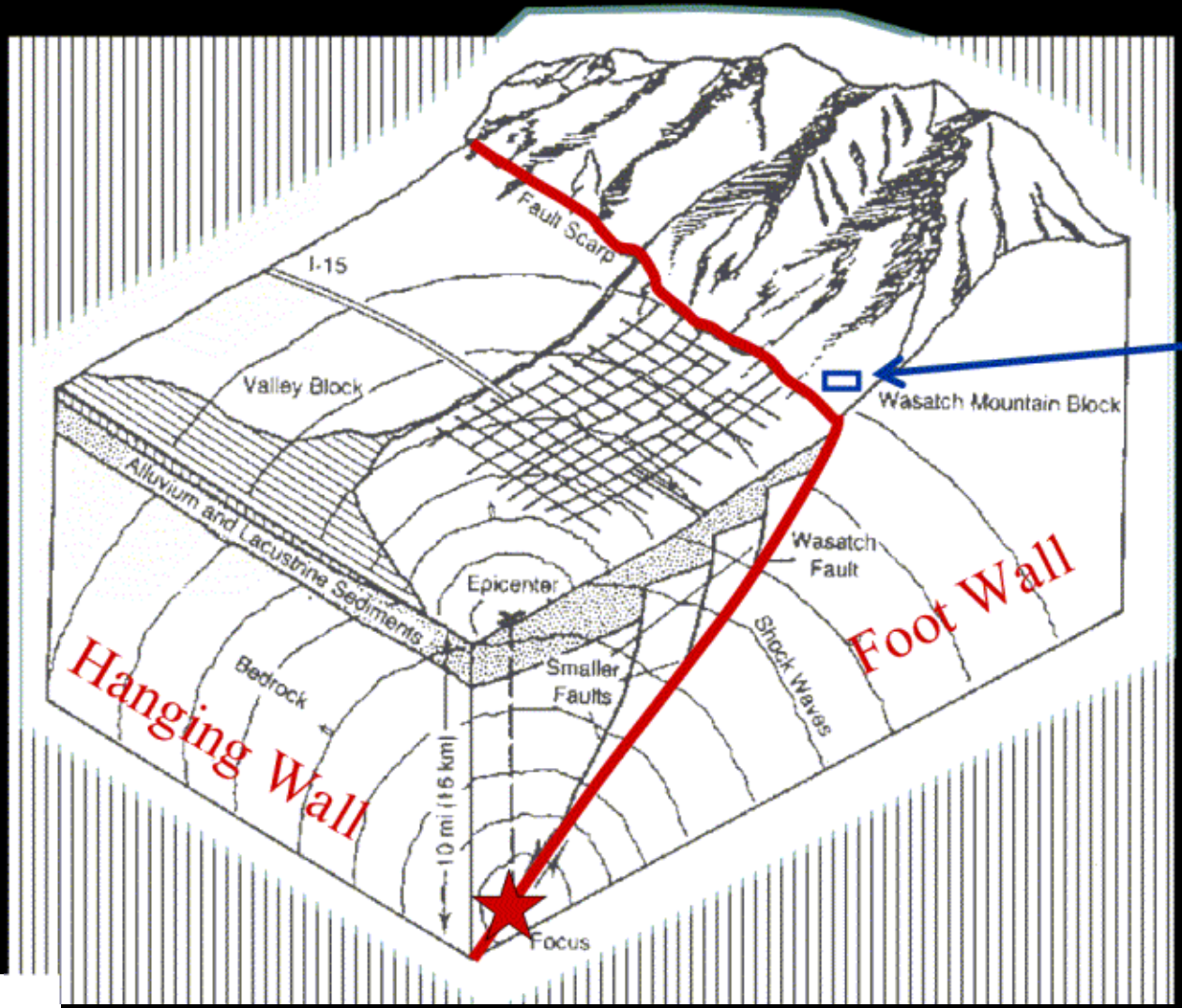
Courtesy AMEC

Source-to-Site Geometry



Utah State Capitol Building

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Courtesy AMEC

Composite Source Methodology

17 Three Component Histories

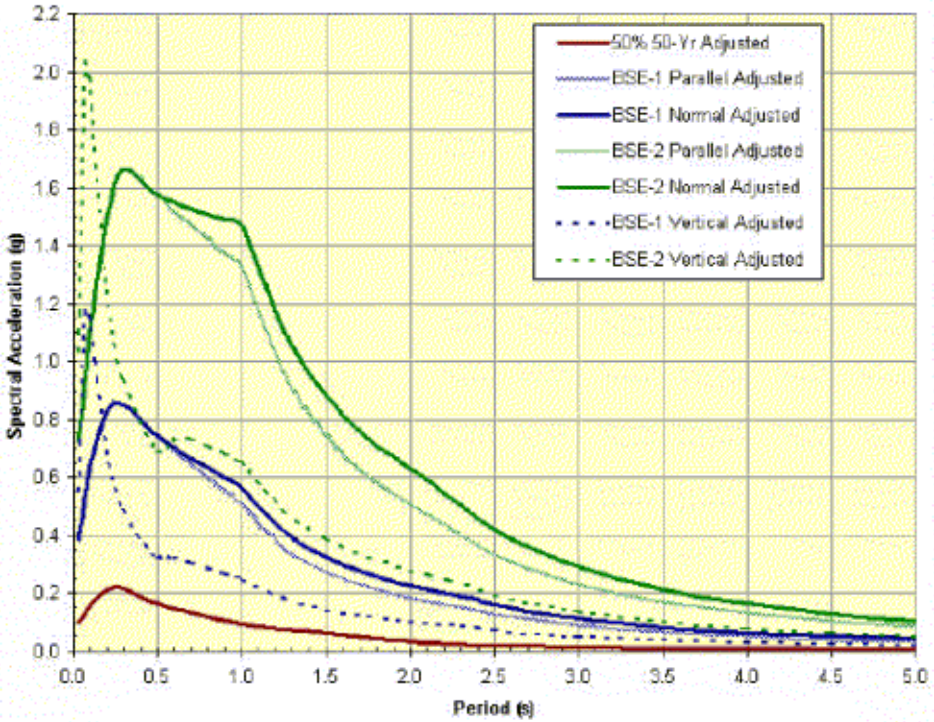

Figure 8. Adjusted spectral acceleration based on constant spectral displacements above periods of 2 to 2.5 s. Vertical spectra were adjusted based on ratios of vertical to horizontal spectral ordinates.

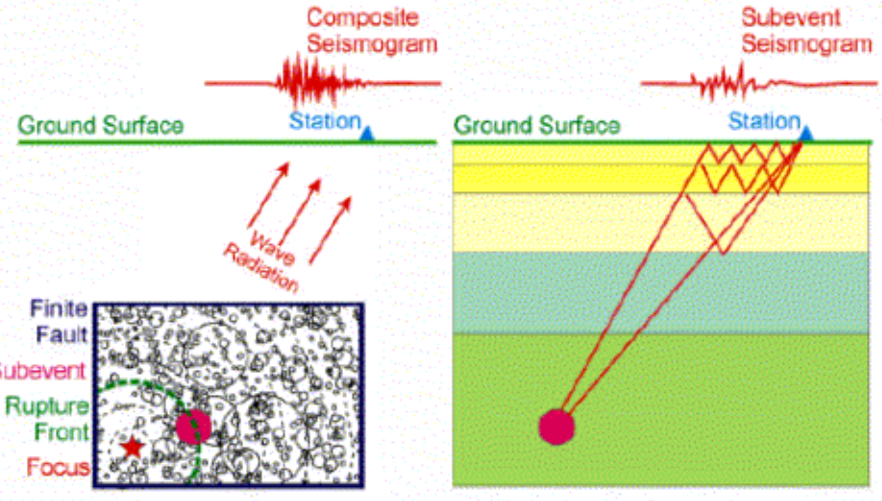

Figure 9. General features of the Composite Source Model.

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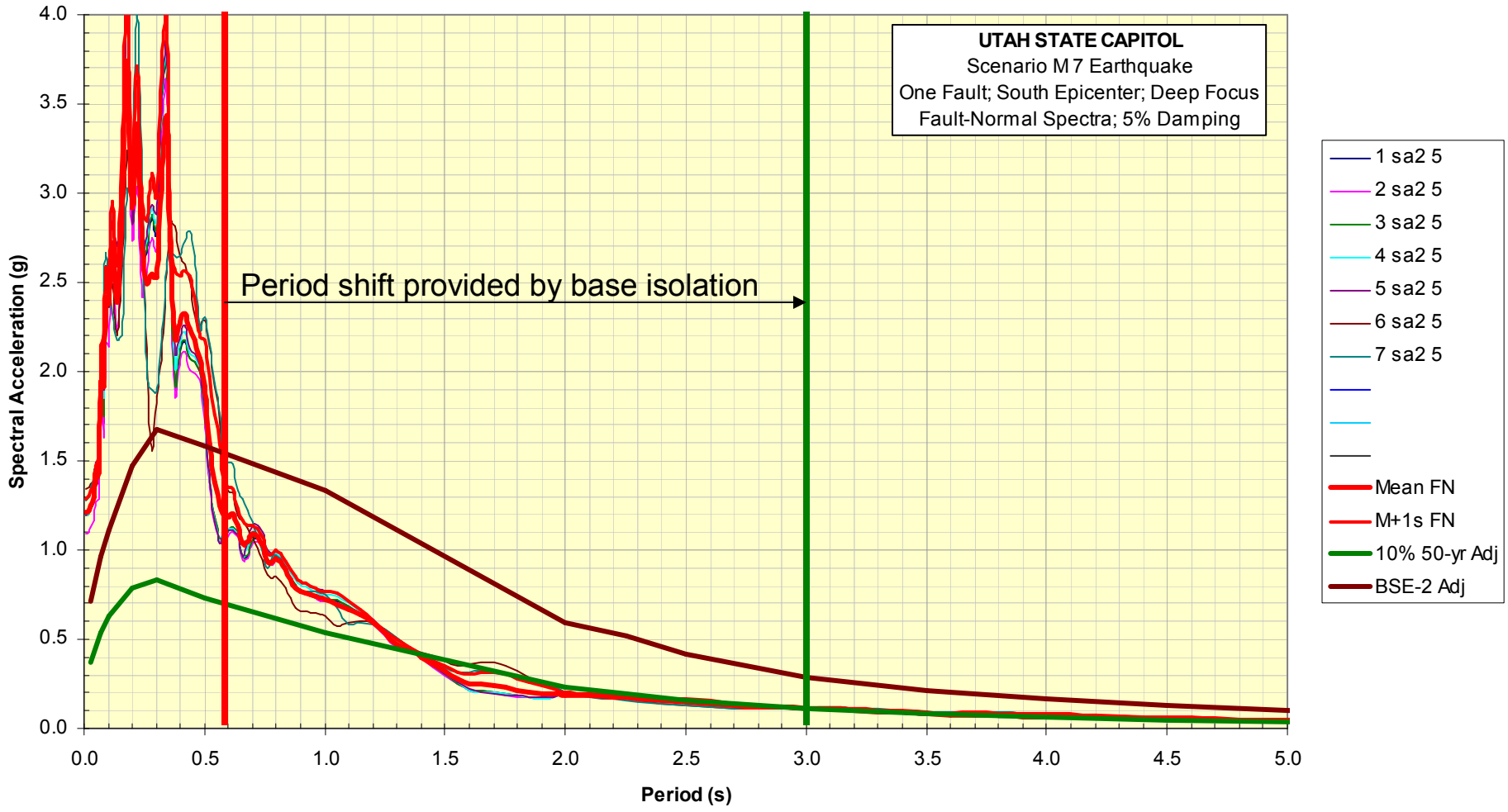
Courtesy AMEC

Utah State Capitol Fault-Normal Spectra



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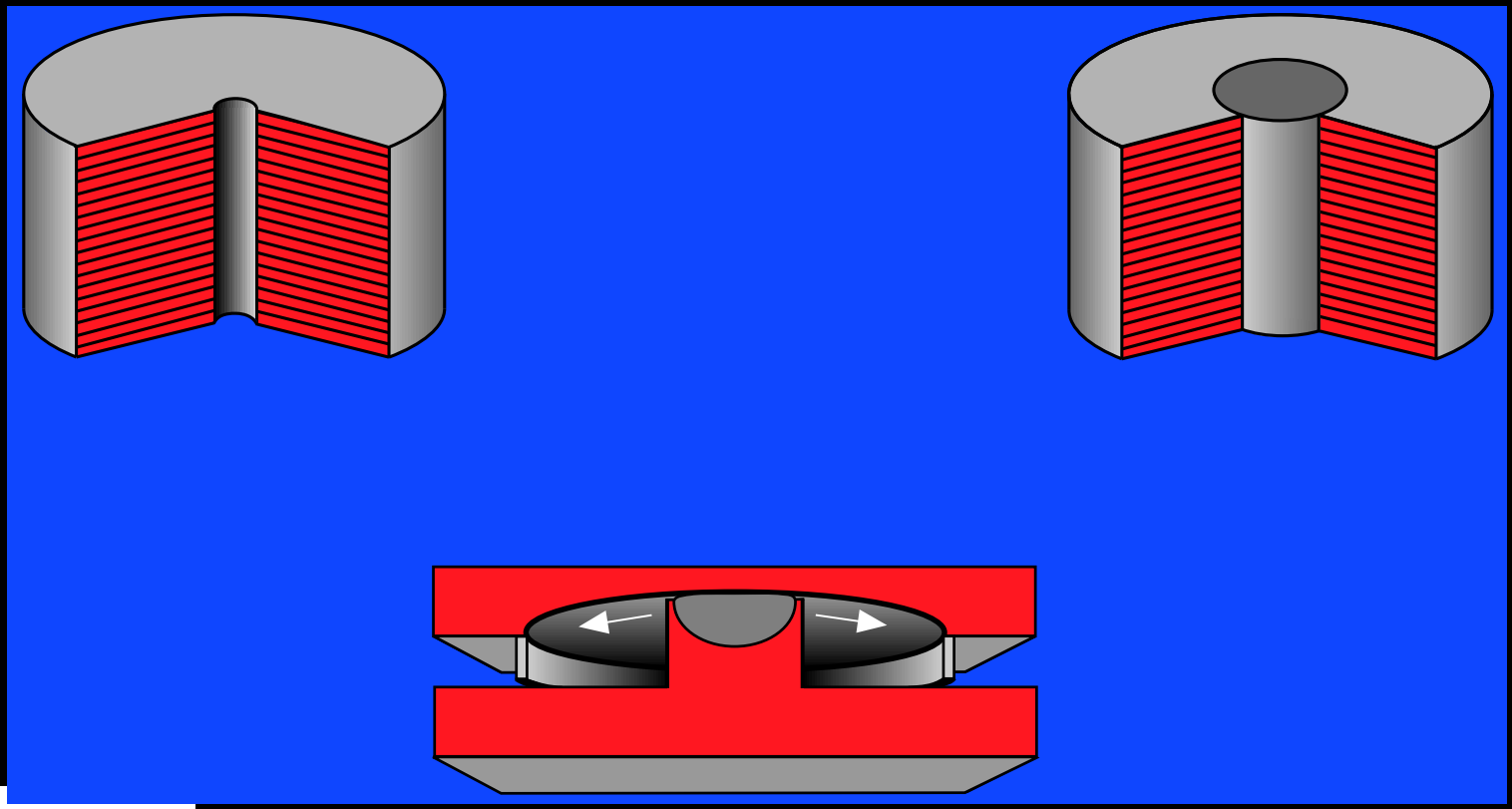
Courtesy AMEC

Base Isolation Fundamental Concept

- A base isolator is a bearing mechanism upon which a building rests. It is very stiff vertically but very limber horizontally.
- A group of base isolators tied together beneath a building creates a seismic base isolation system.
- Because a base isolation system is very limber horizontally it can dramatically increase the fundamental period of the global system (base isolation system and building structure).
- An increase in period generally results in a decrease of earthquake forces.

Types of Base Isolators

- Elastomeric with HDR (High Damping Rubber)
- Elastomeric with Lead Core
- Friction Pendulum



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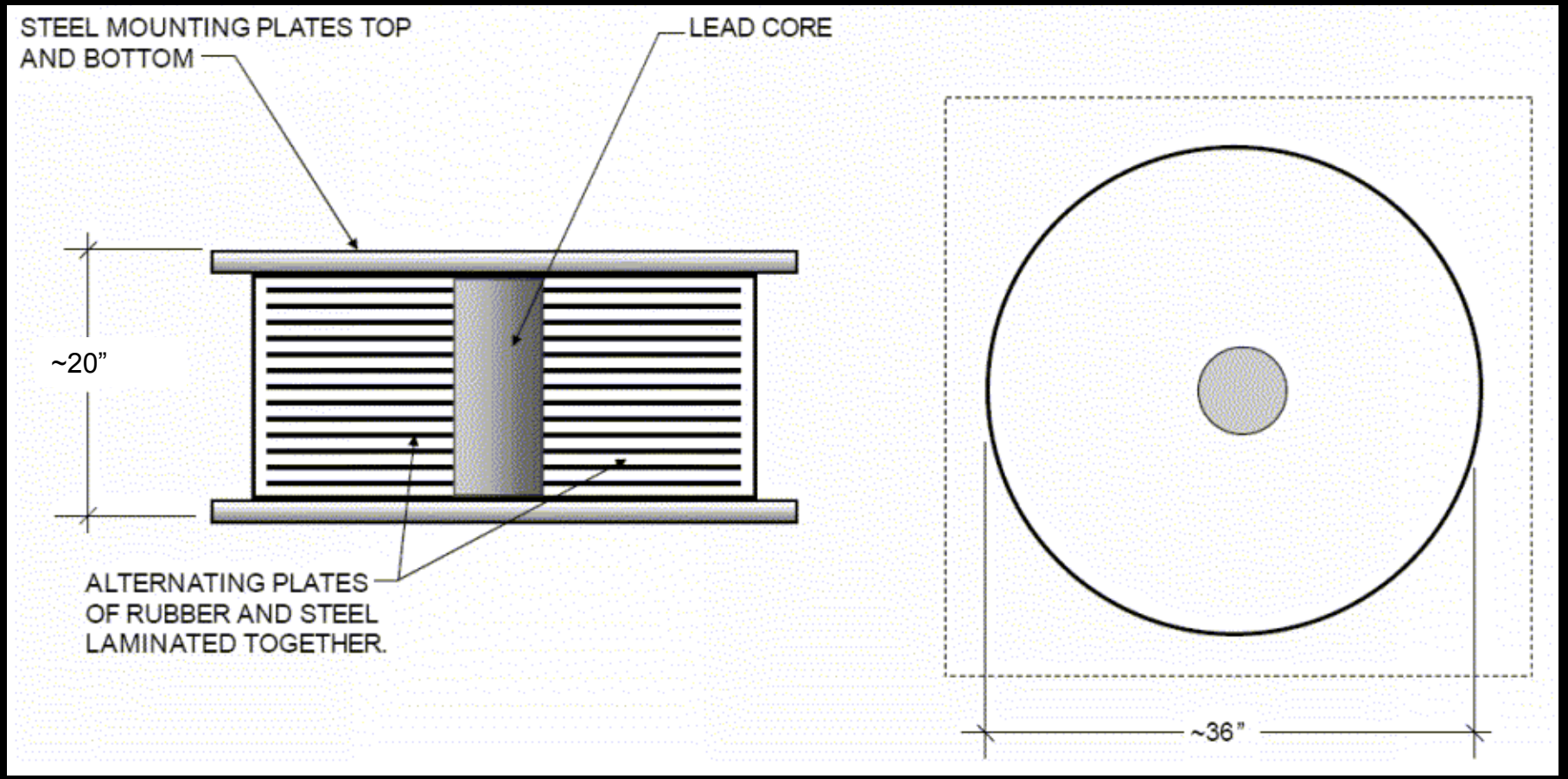
Isolator Anatomy



- Note– Each isolator weighs approximately 5000 pounds.

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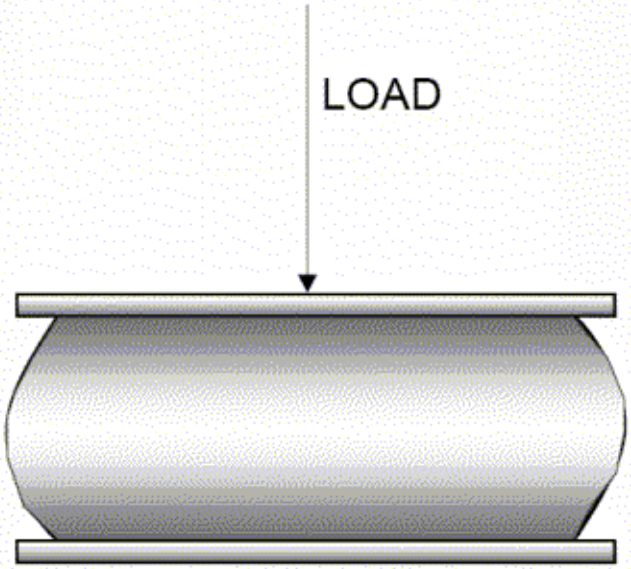
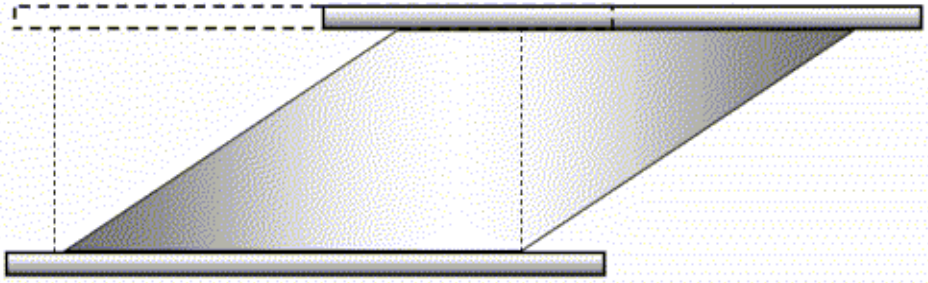
Isolator Anatomy – Why Steel Plates?



Without steel plates the isolator would suffer a "bellying" effect, and lose vertical stiffness



Steel plates prevent the isolator "bellying" effect, making it rigid vertically, while the rubber enables it to be limber horizontally.

Note: depicted deflection is true to scale

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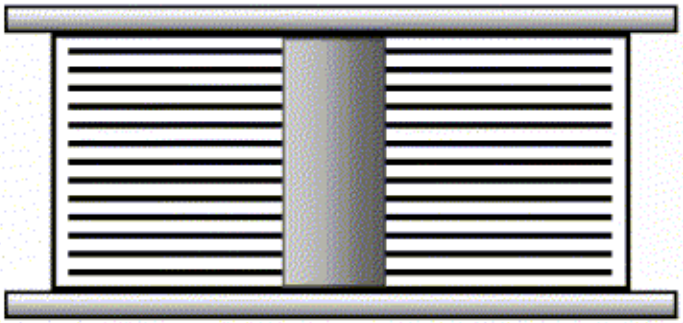
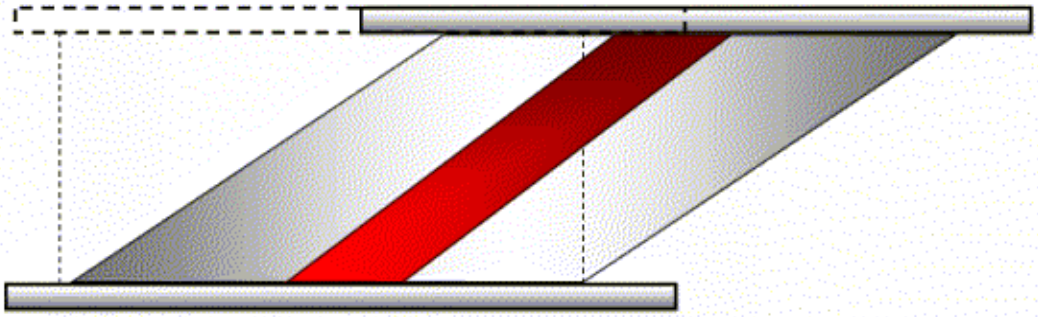
Isolator Anatomy – Why Lead Core?

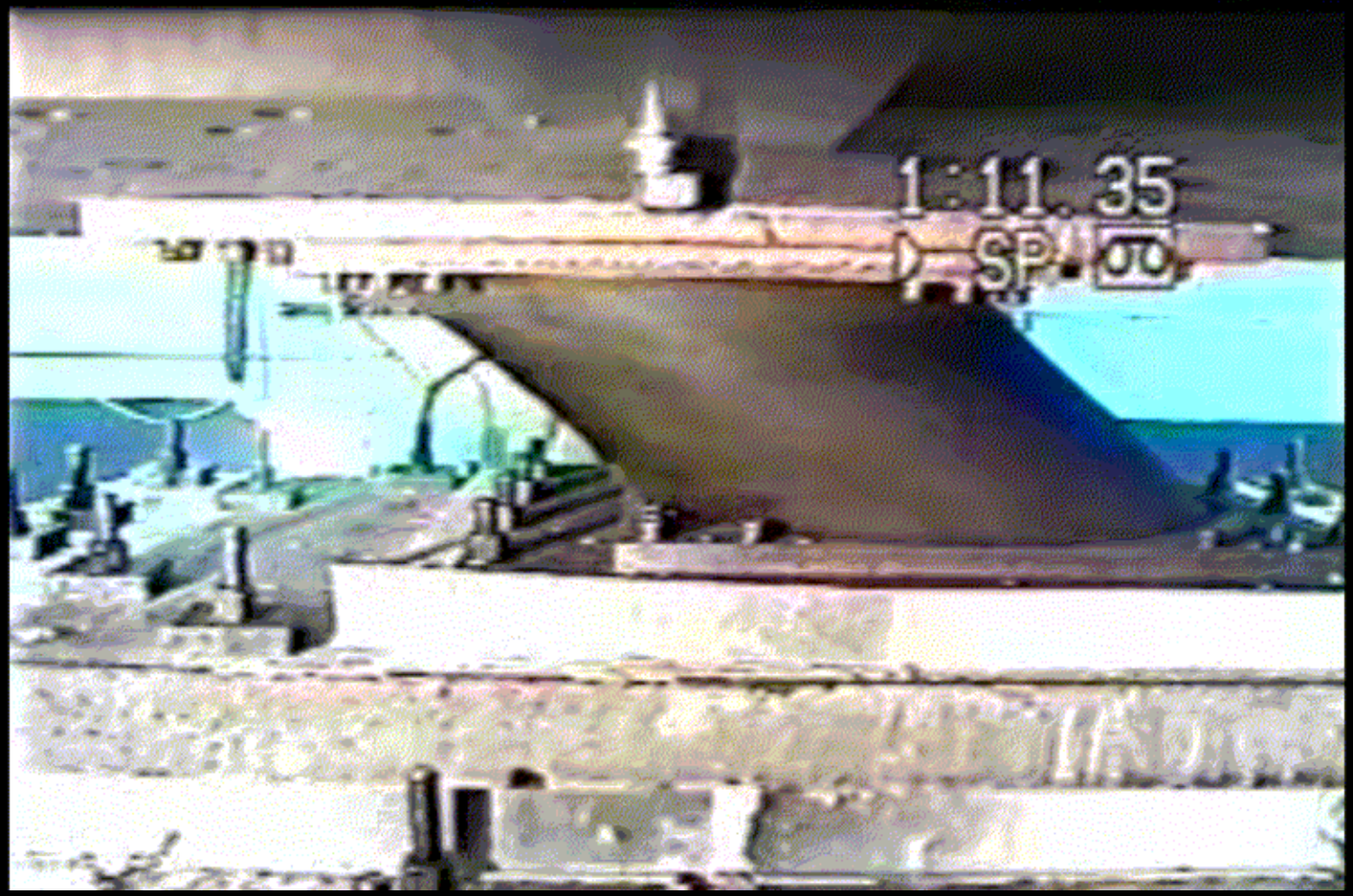


The lead core acts as an energy dissipating mechanism.



As it suffers a forced distortion, the lead core partially liquefies. This dissipates large amounts of energy in a safe, controlled manner. When motion stops, the lead will re-crystallize.

Real Time Isolator Testing



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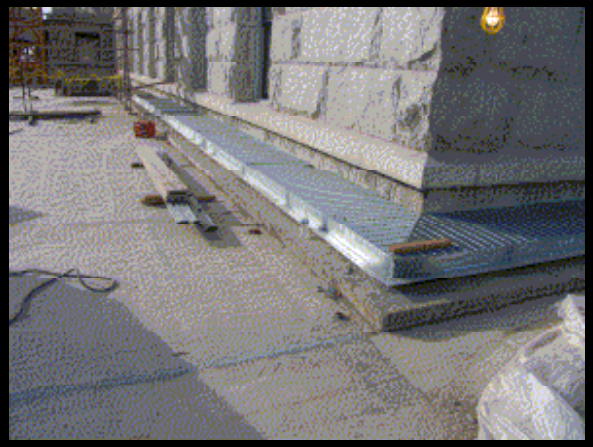
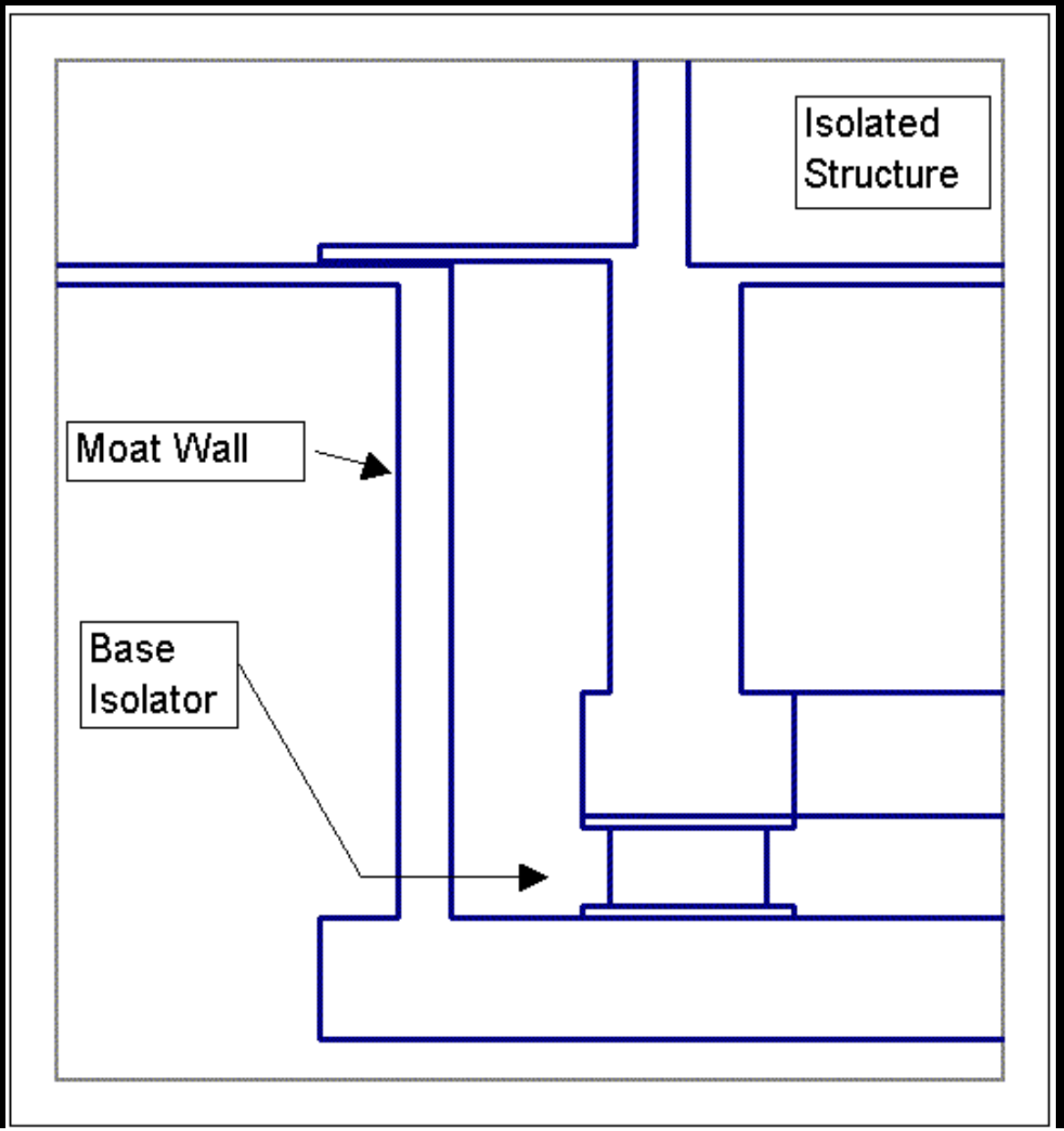
Behavior of Base Isolated Building at Moat

(Excel Based Animation.)





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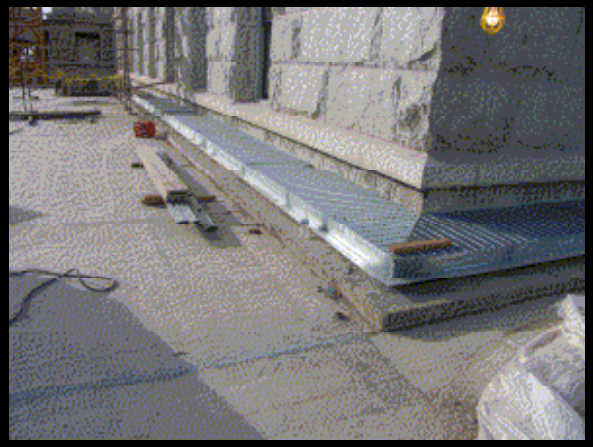

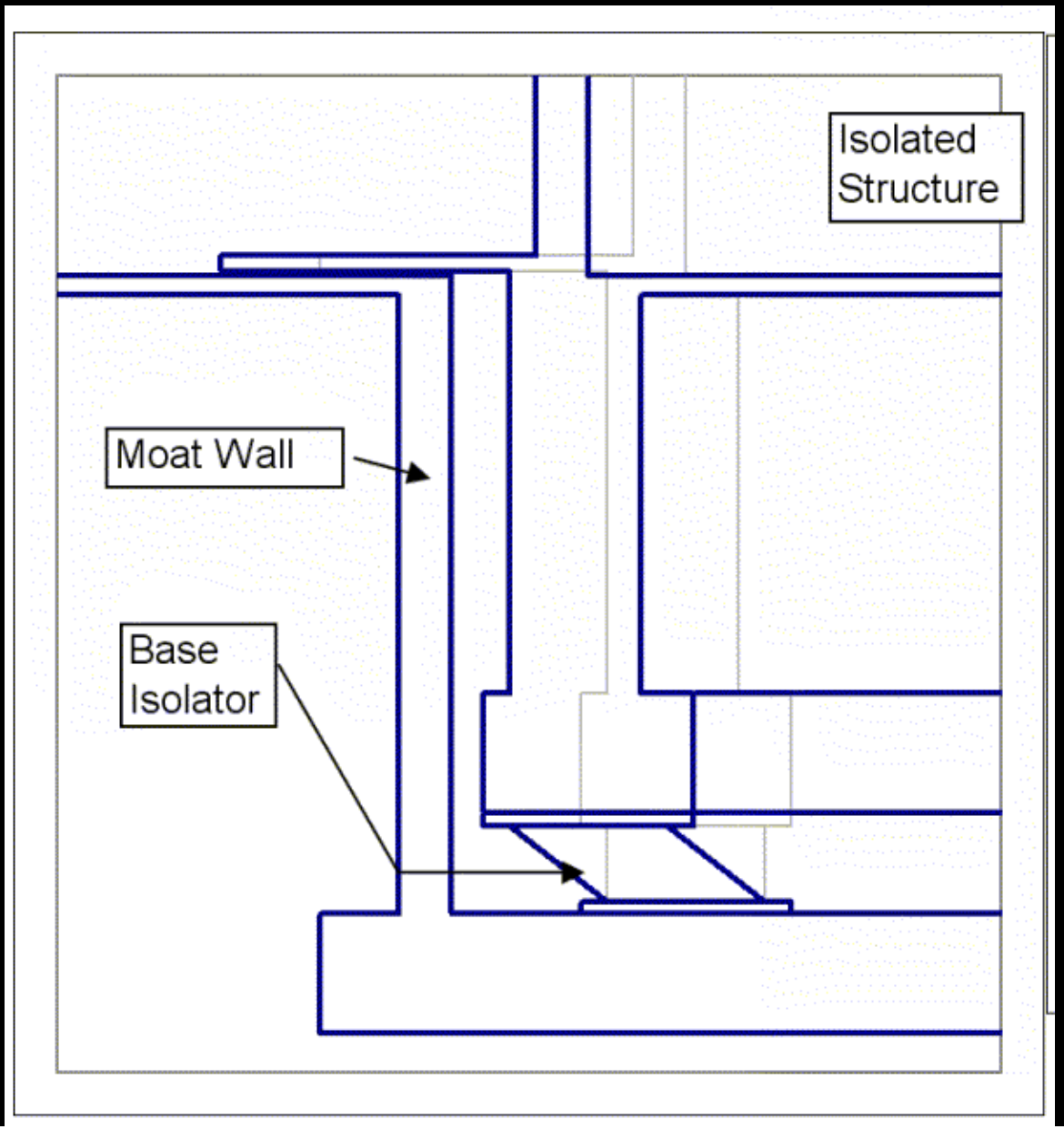

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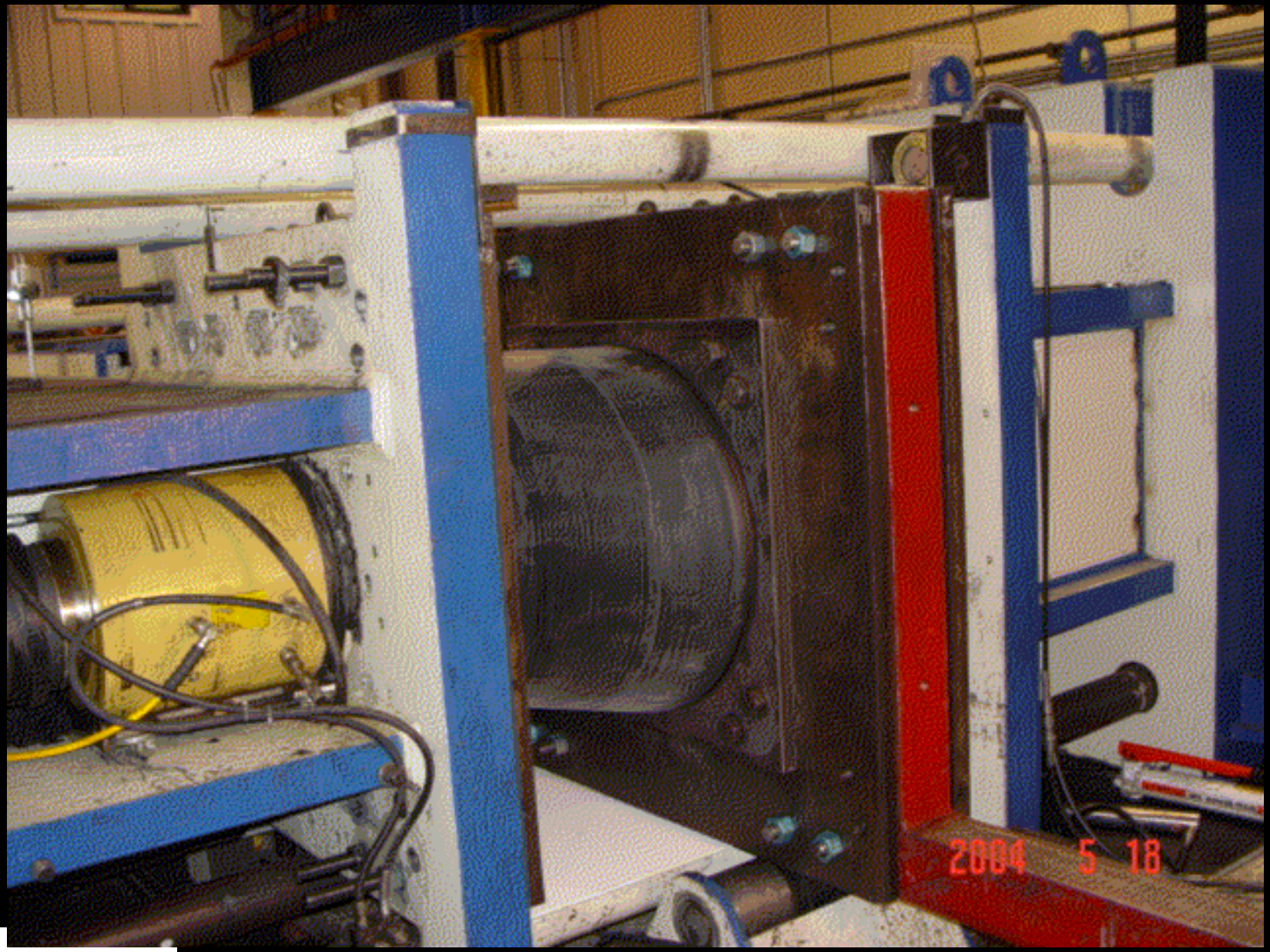
Isolator Prototype Testing



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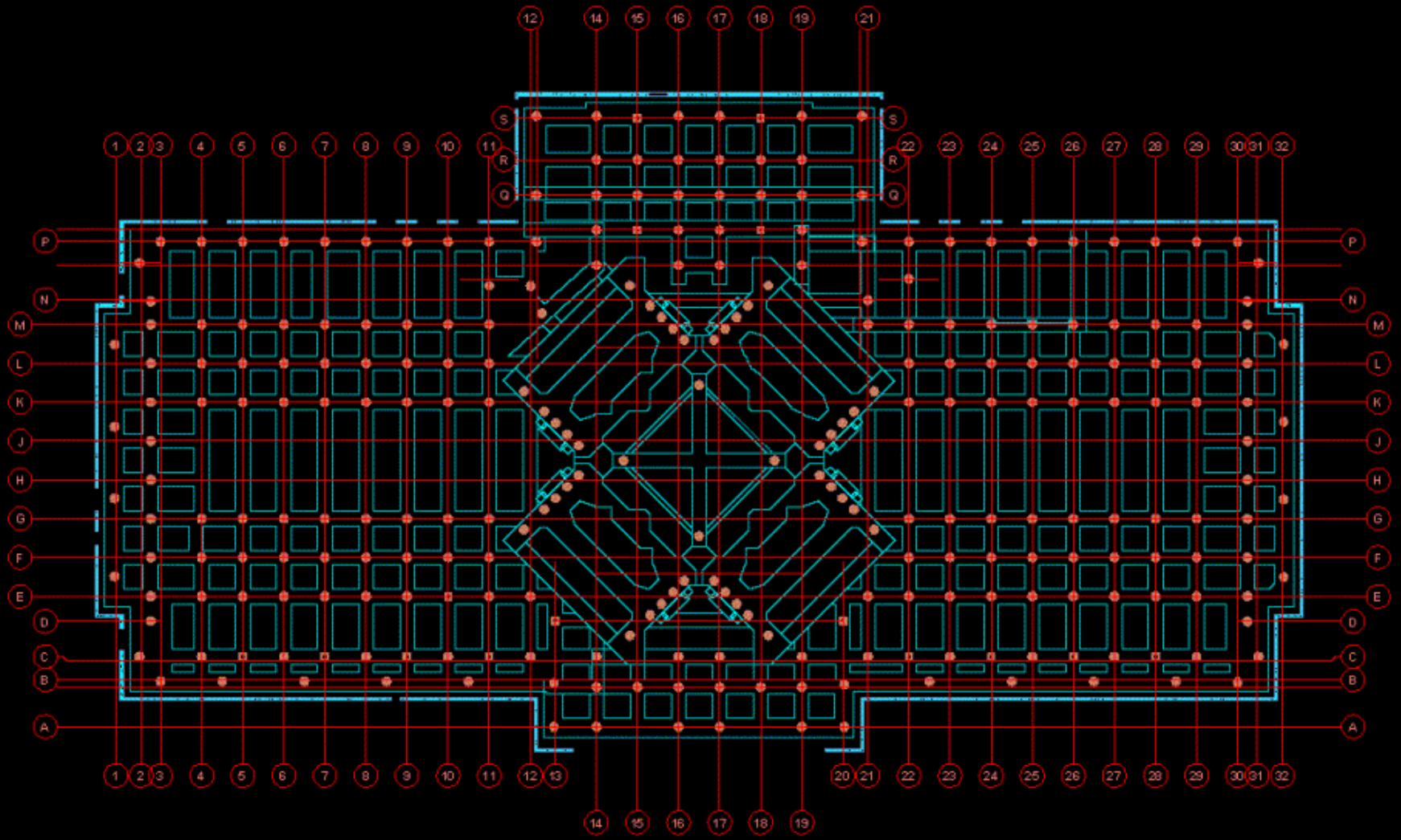
Isolator Plan



265 Isolators

15 Sliders

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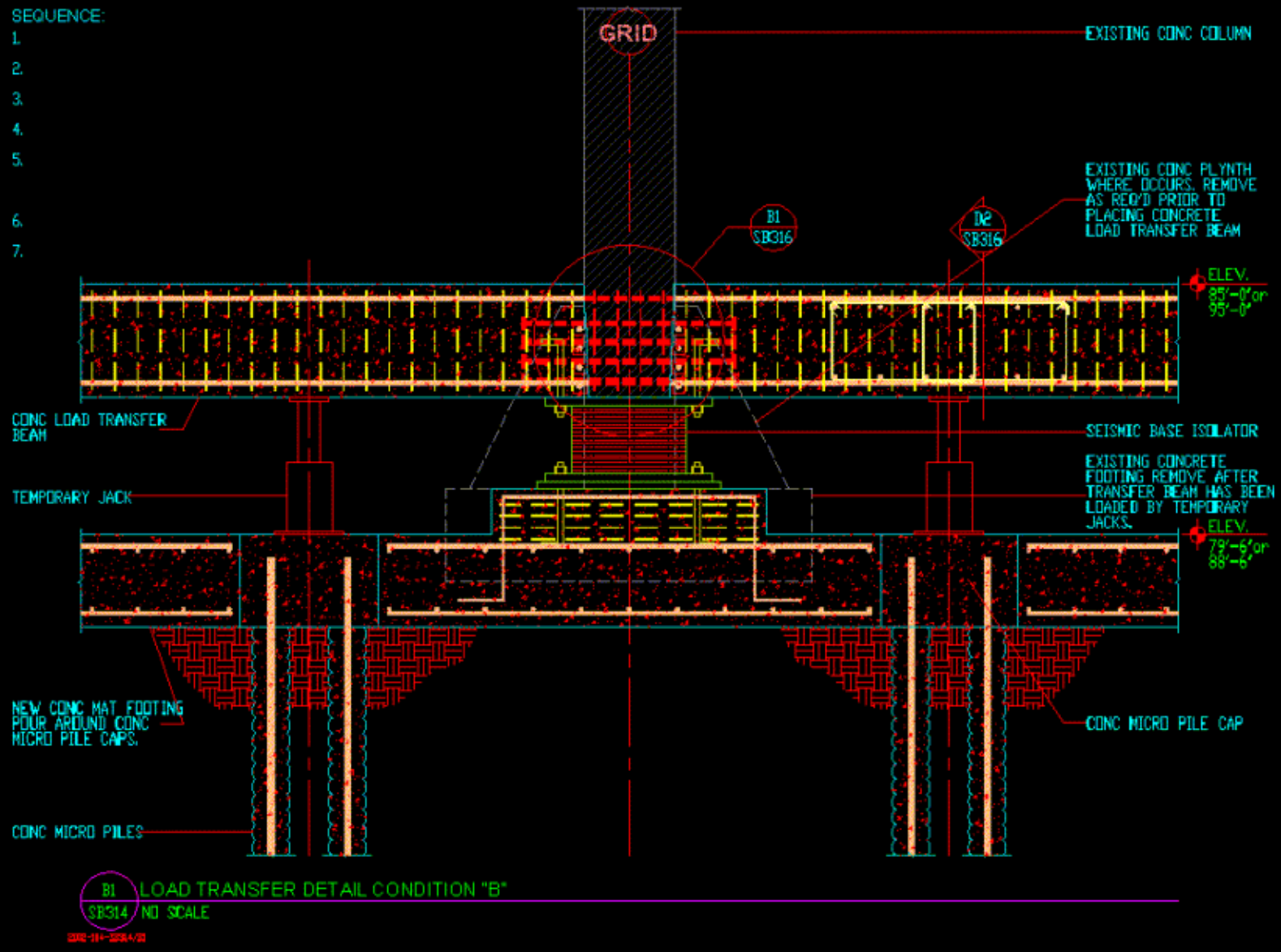
Load Transfer Scheme(s)



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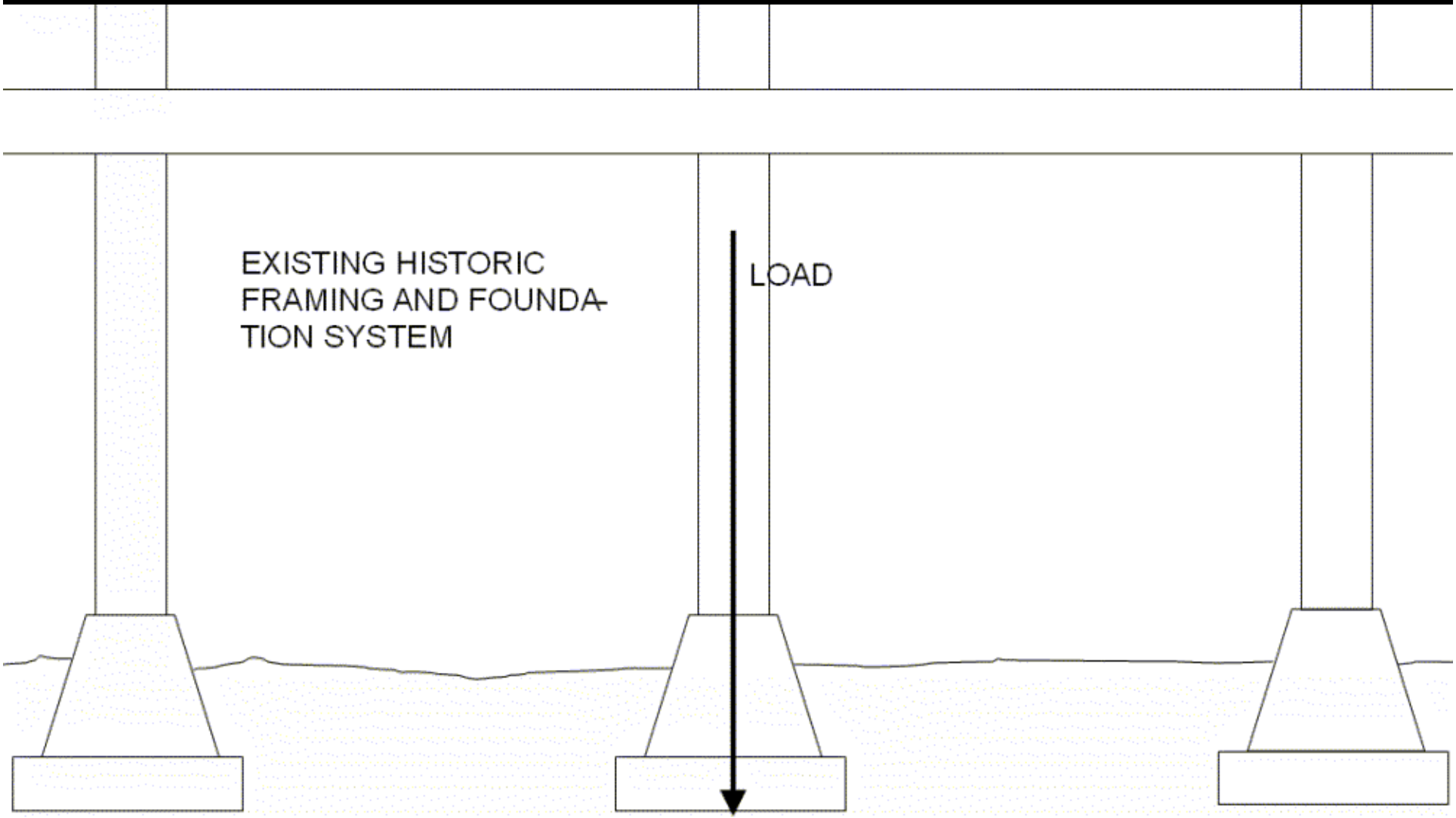

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LOAD

COLUMNS
PREPARED FOR
“KEYING” EFFECT

NEW MICRO-PILES AND
PILE CAPS INSTALLED
BETWEEN EXISTING
COLUMNS

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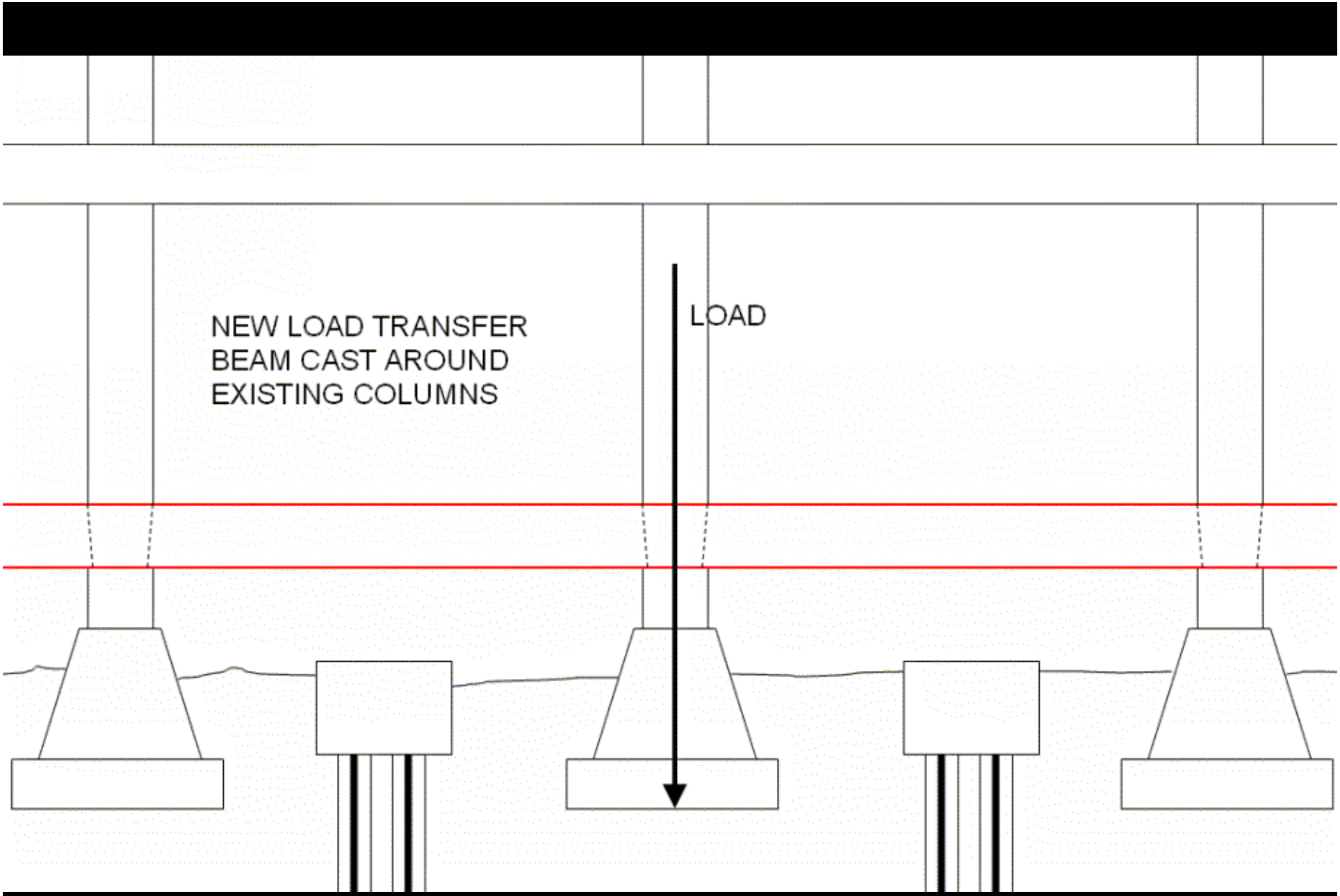

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Assembly of
Casting Deck

Assembly of
Reinforcement

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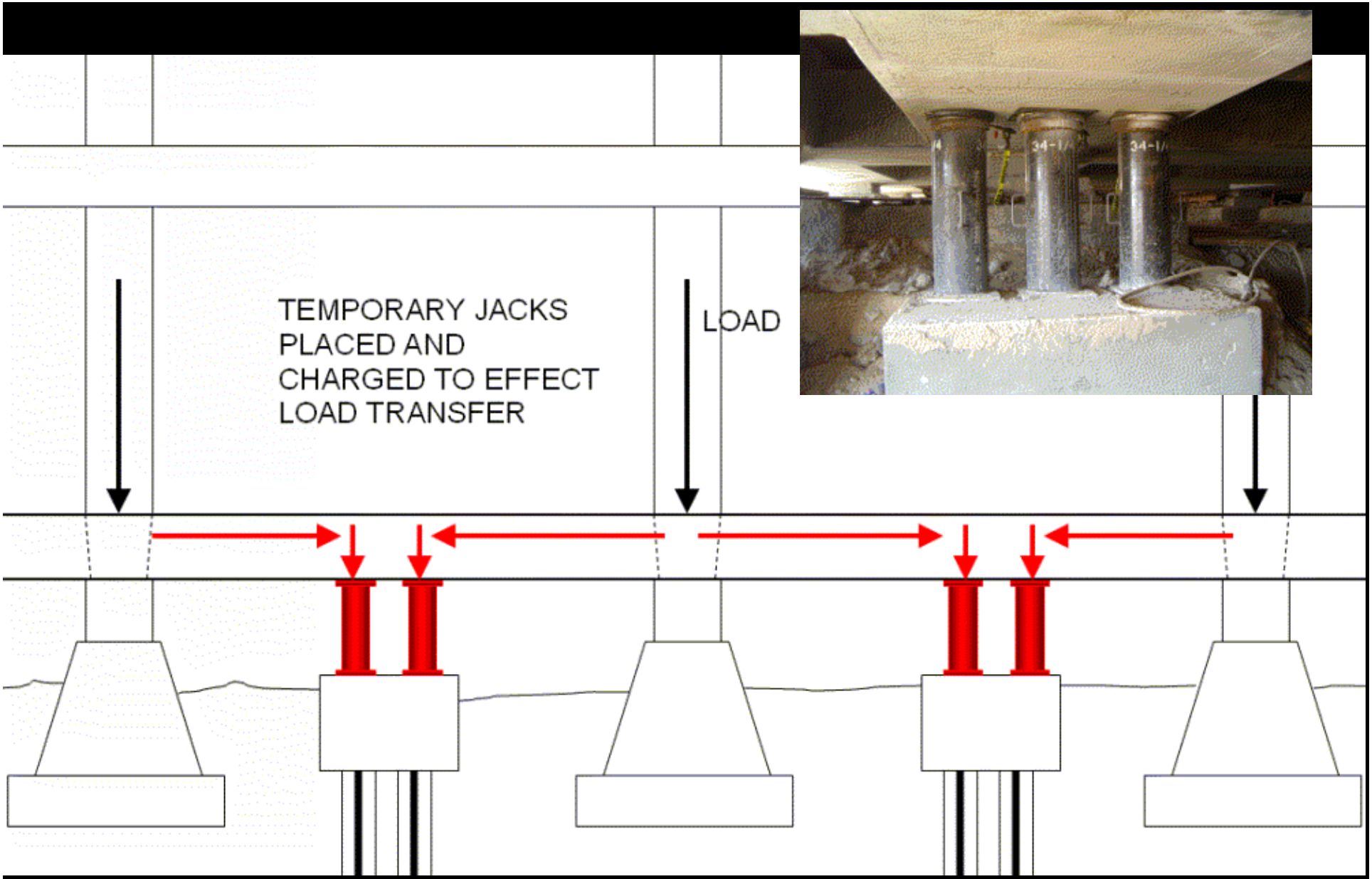

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EXISTING FOOTINGS
WERE REMOVED

LOAD

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NEW BASE ISOLATORS
WERE HUNG IN PLACE

LOAD

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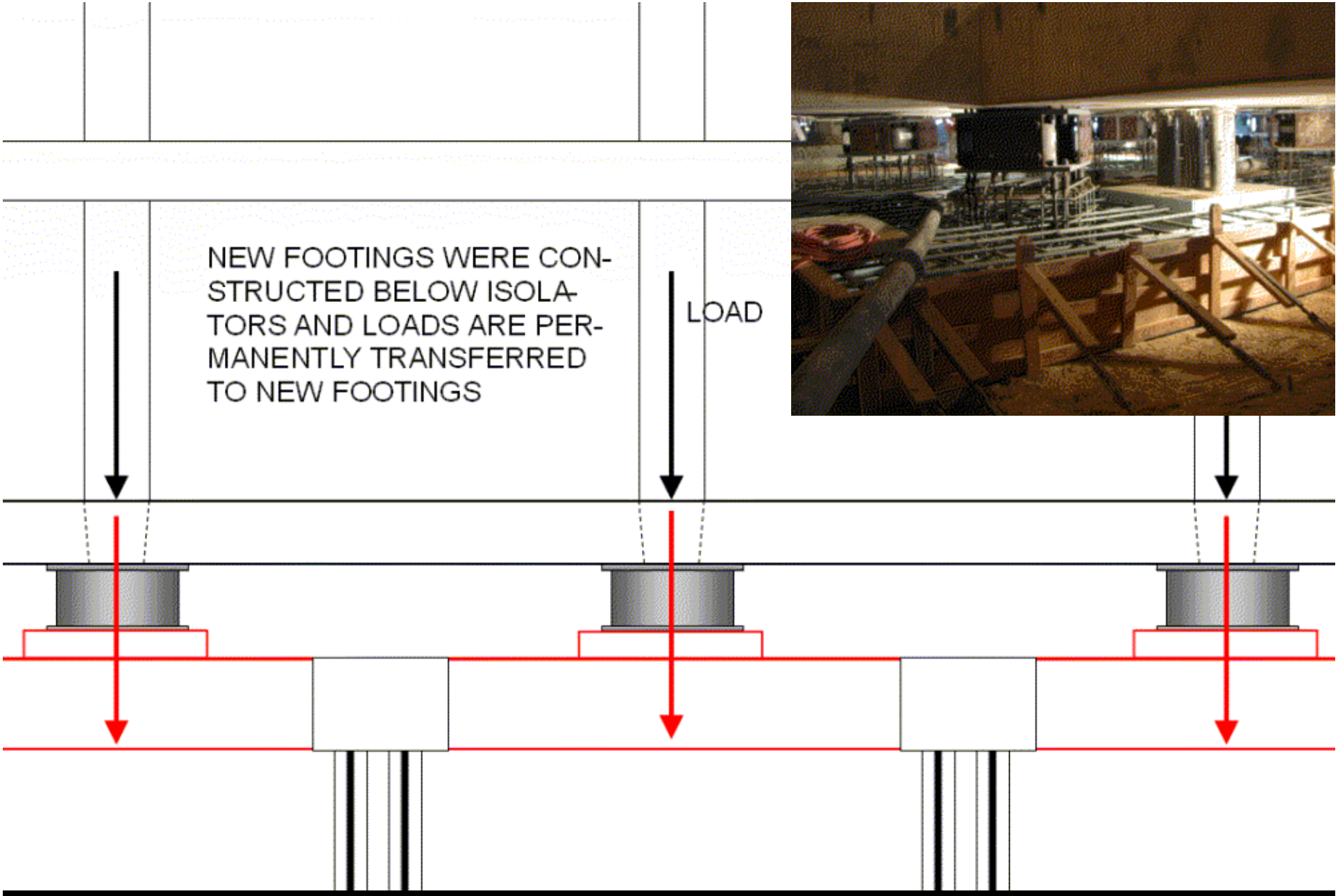

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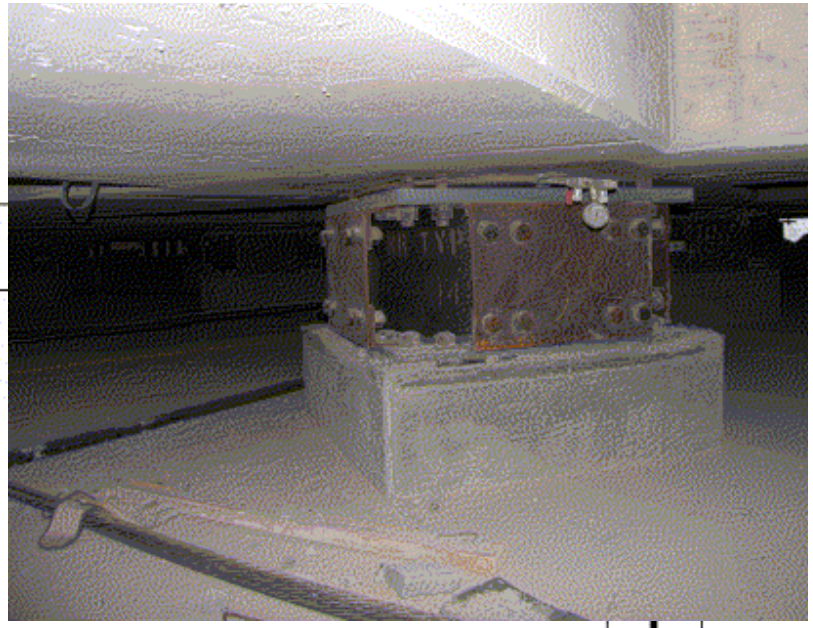
PERMANENT CONDITION

LOAD



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Footing Removal

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Installation of First Isolator – May 16, 2005

Isolator Placement w/ Flat Jack

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Locking Plate Removal

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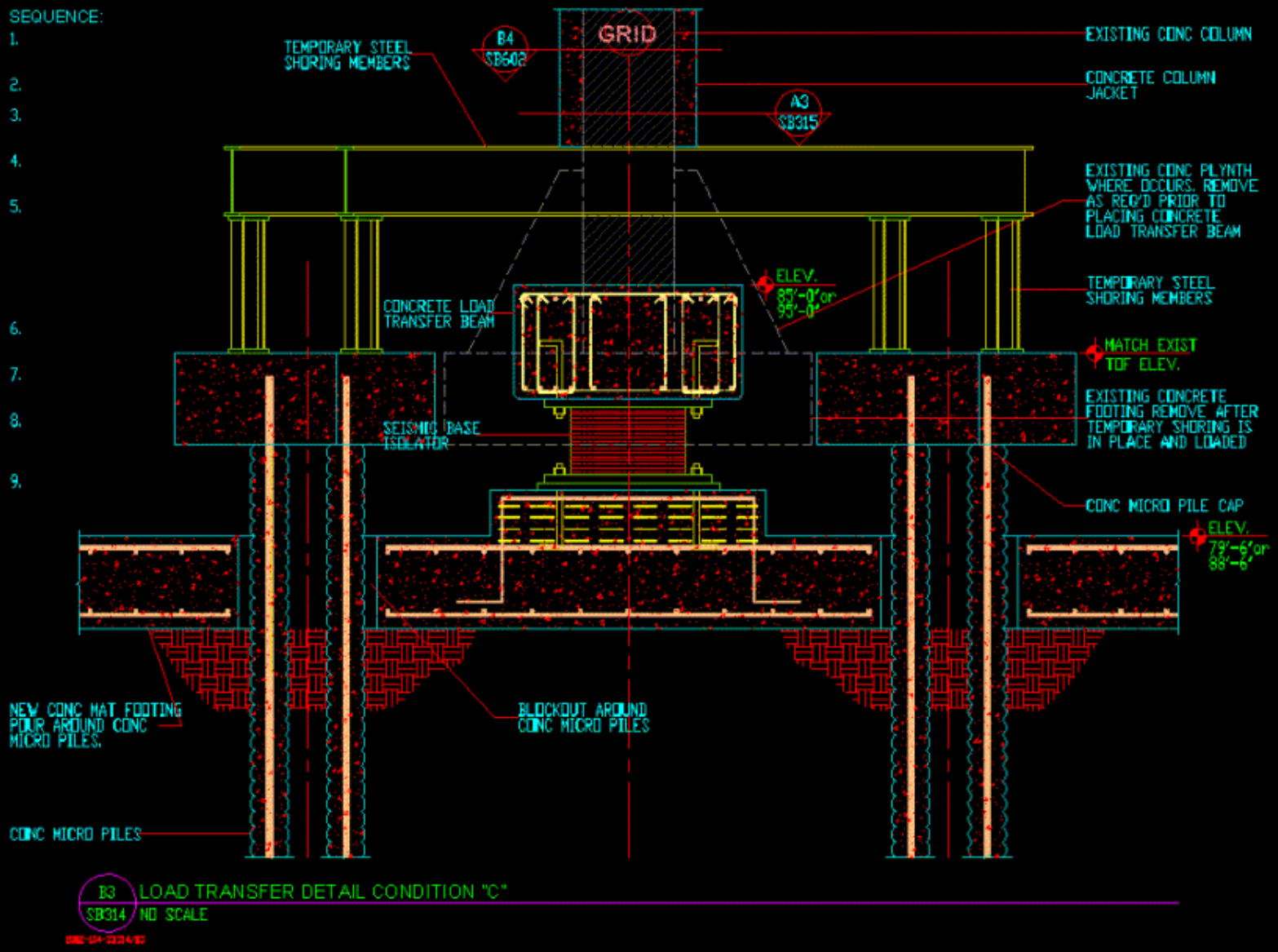
Load Transfer Scheme(s)



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Load Transfer Scheme(s)

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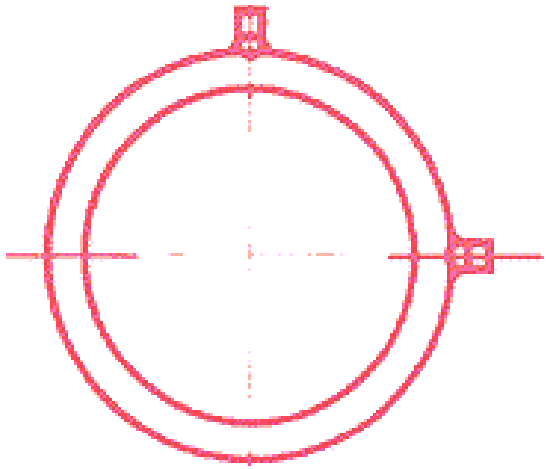
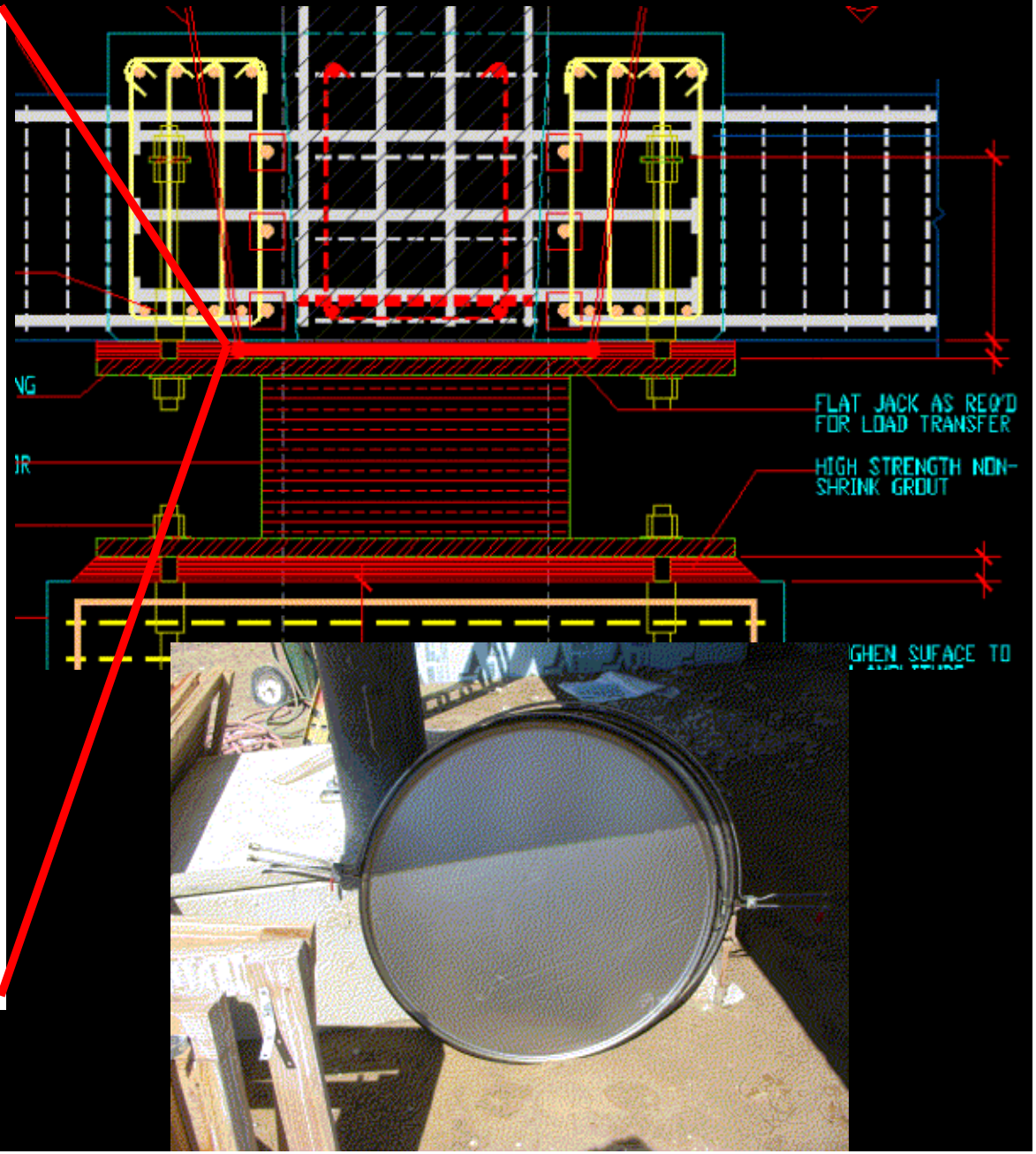
Load Transfer Mechanism



Before Pressurizing

After Pressurizing



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Load Transfer Scheme – Mockup and Testing

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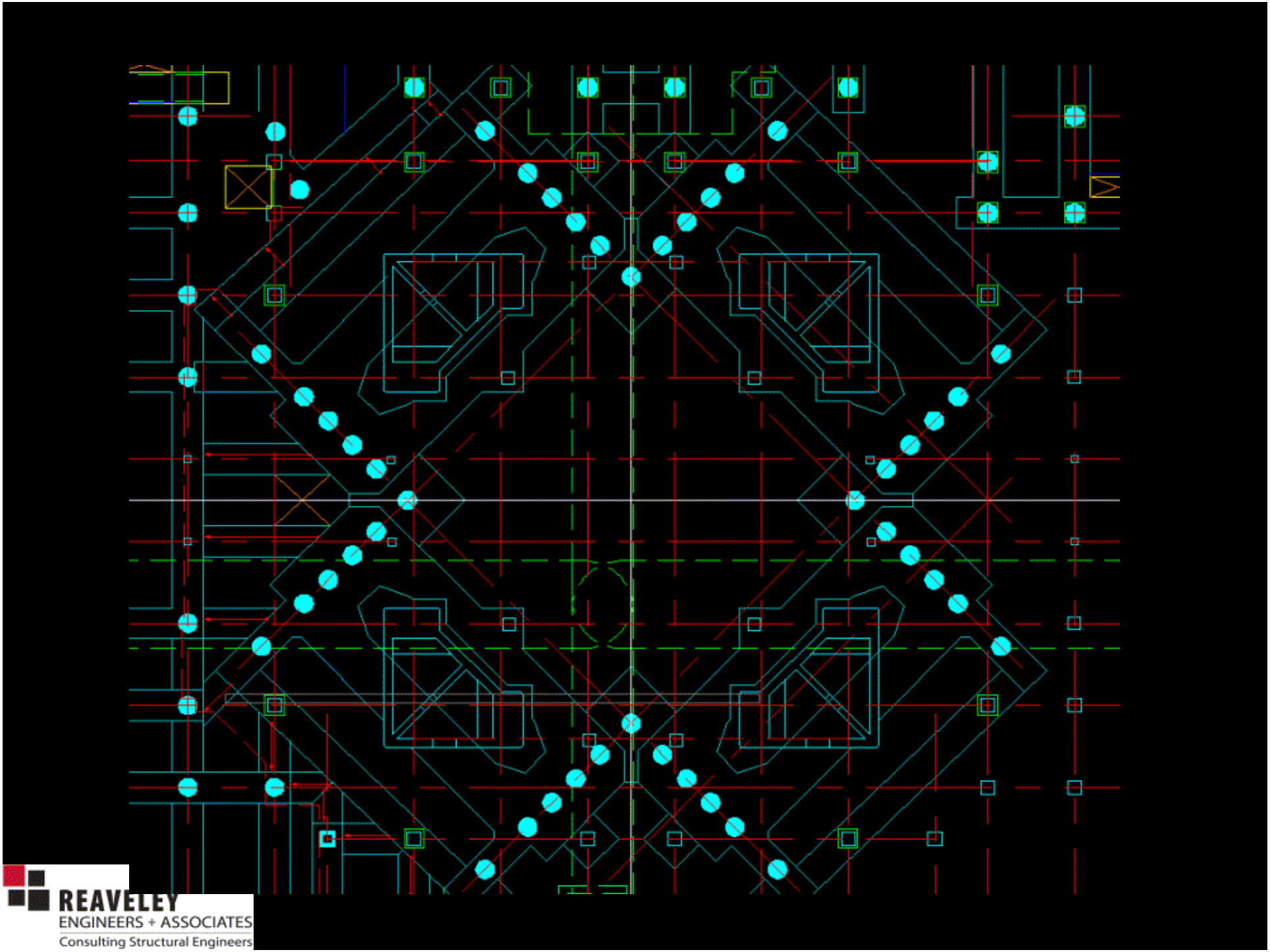

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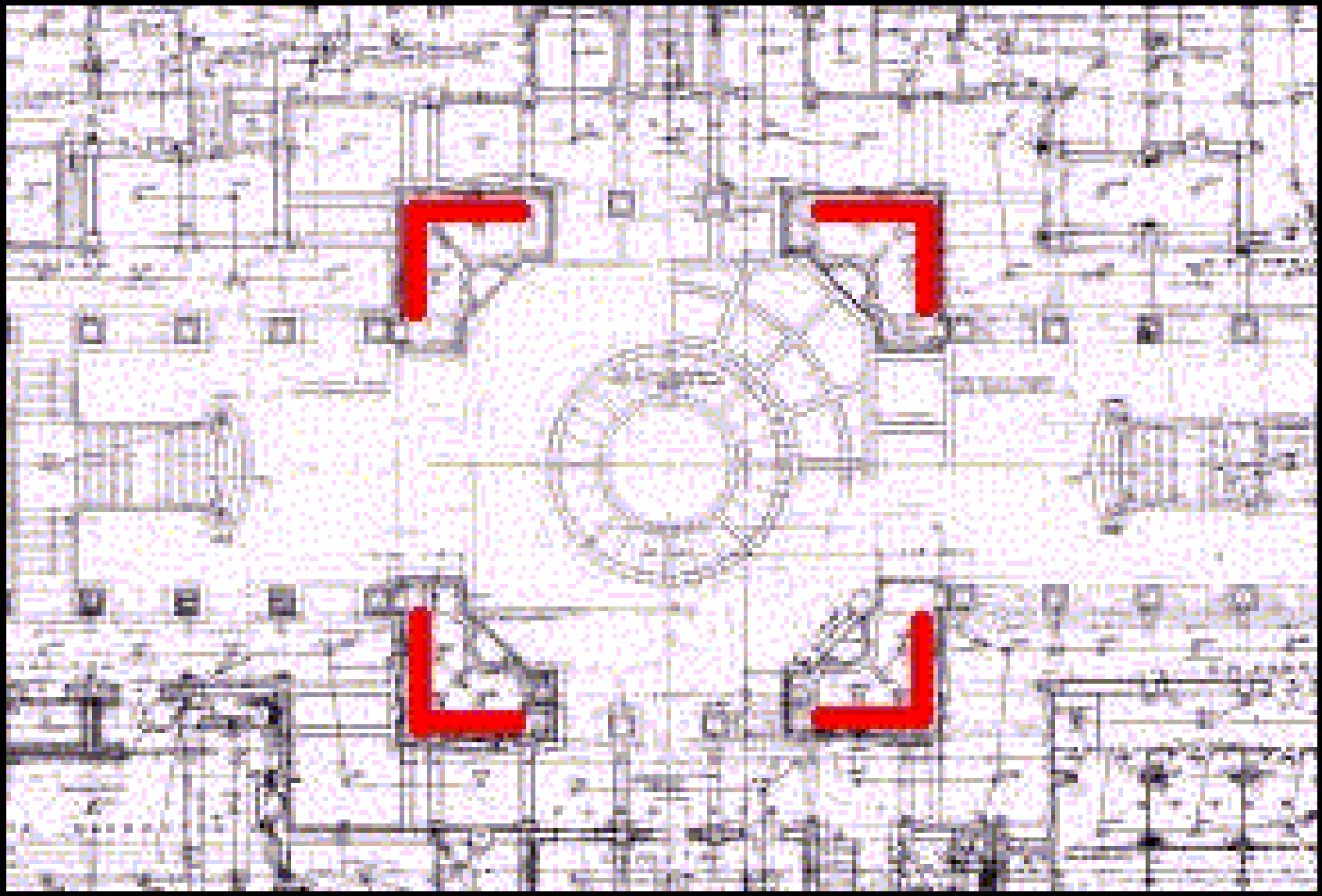
Isolator Installation at Rotunda



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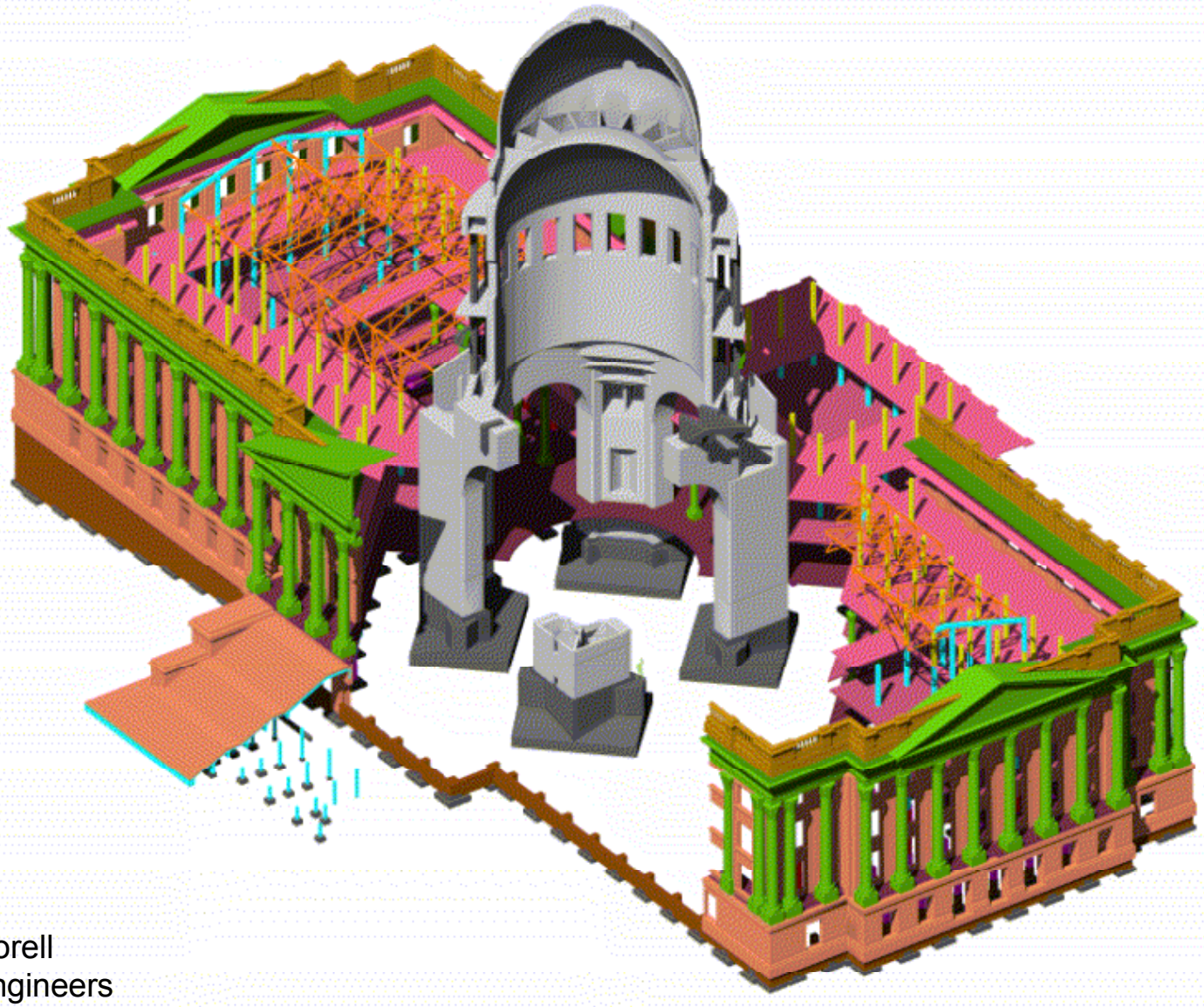

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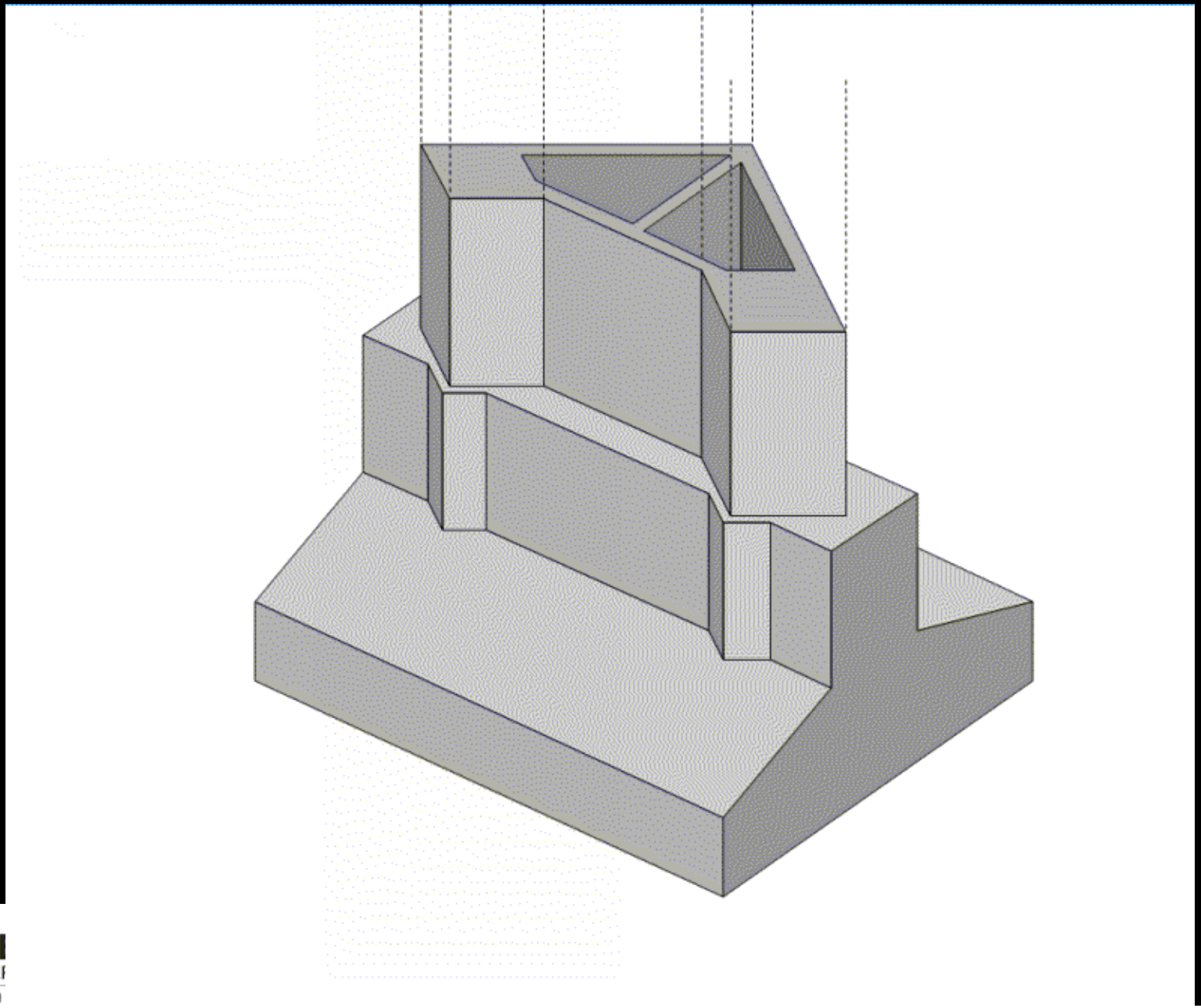
Isolator Installation at Rotunda



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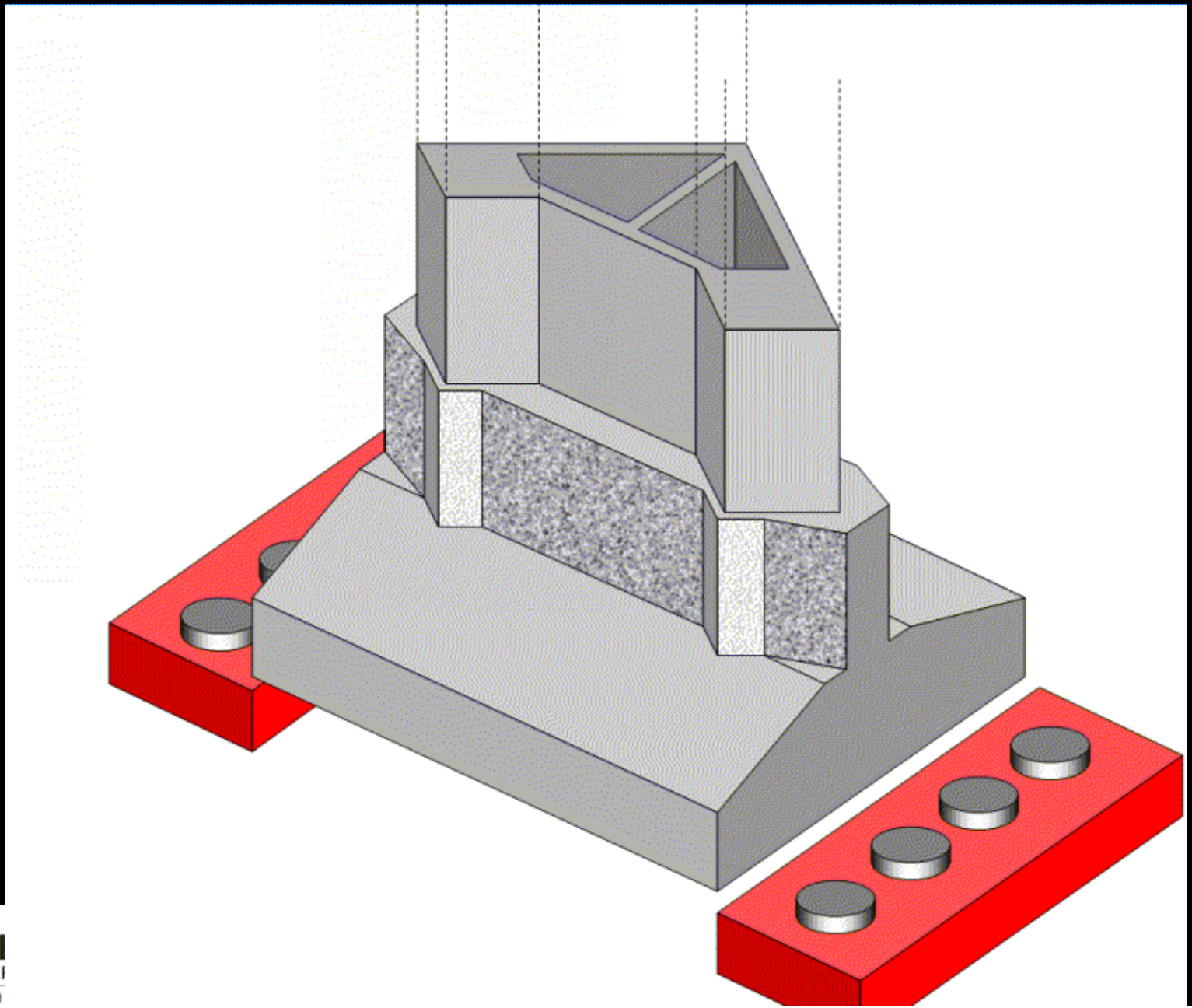

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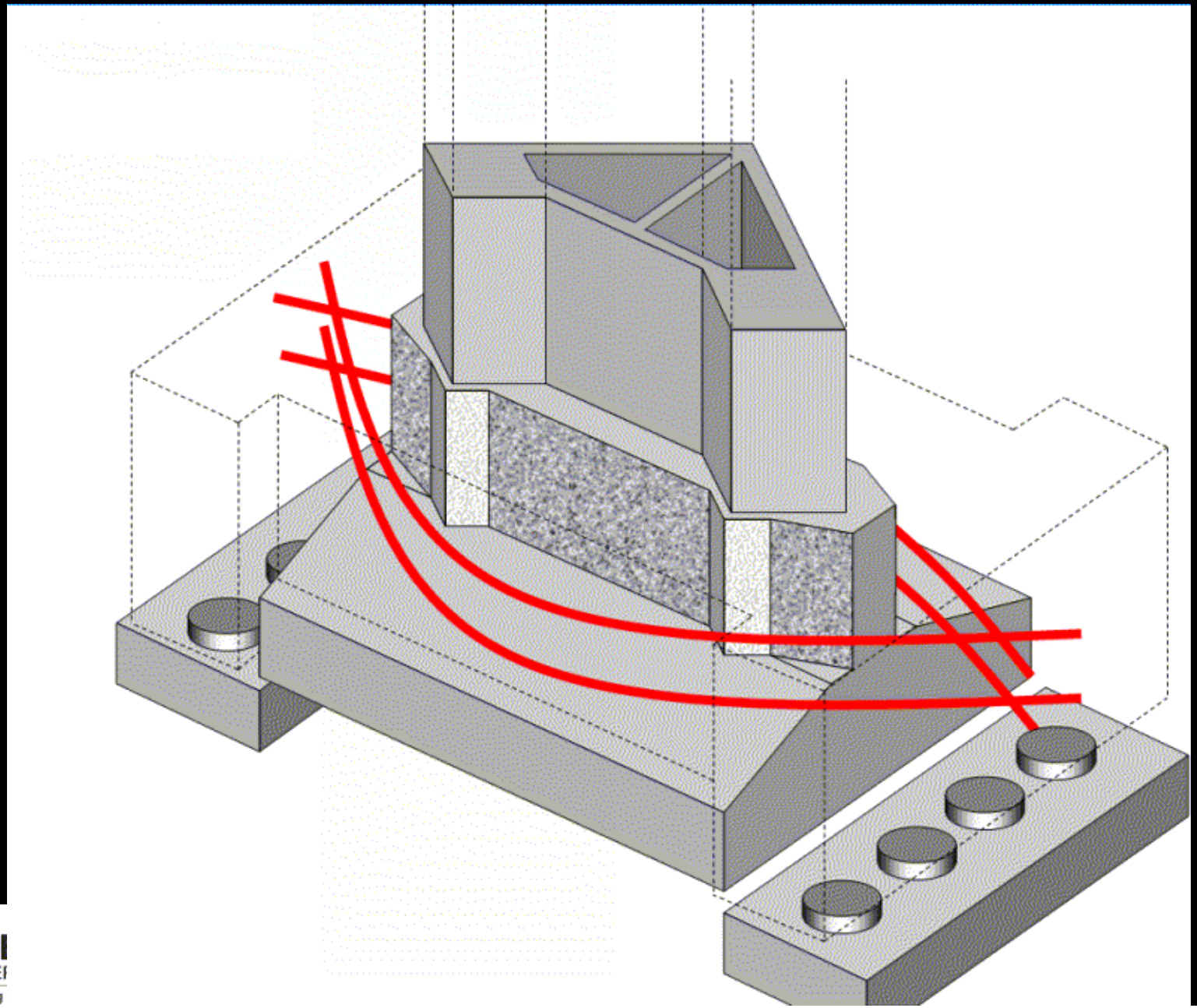

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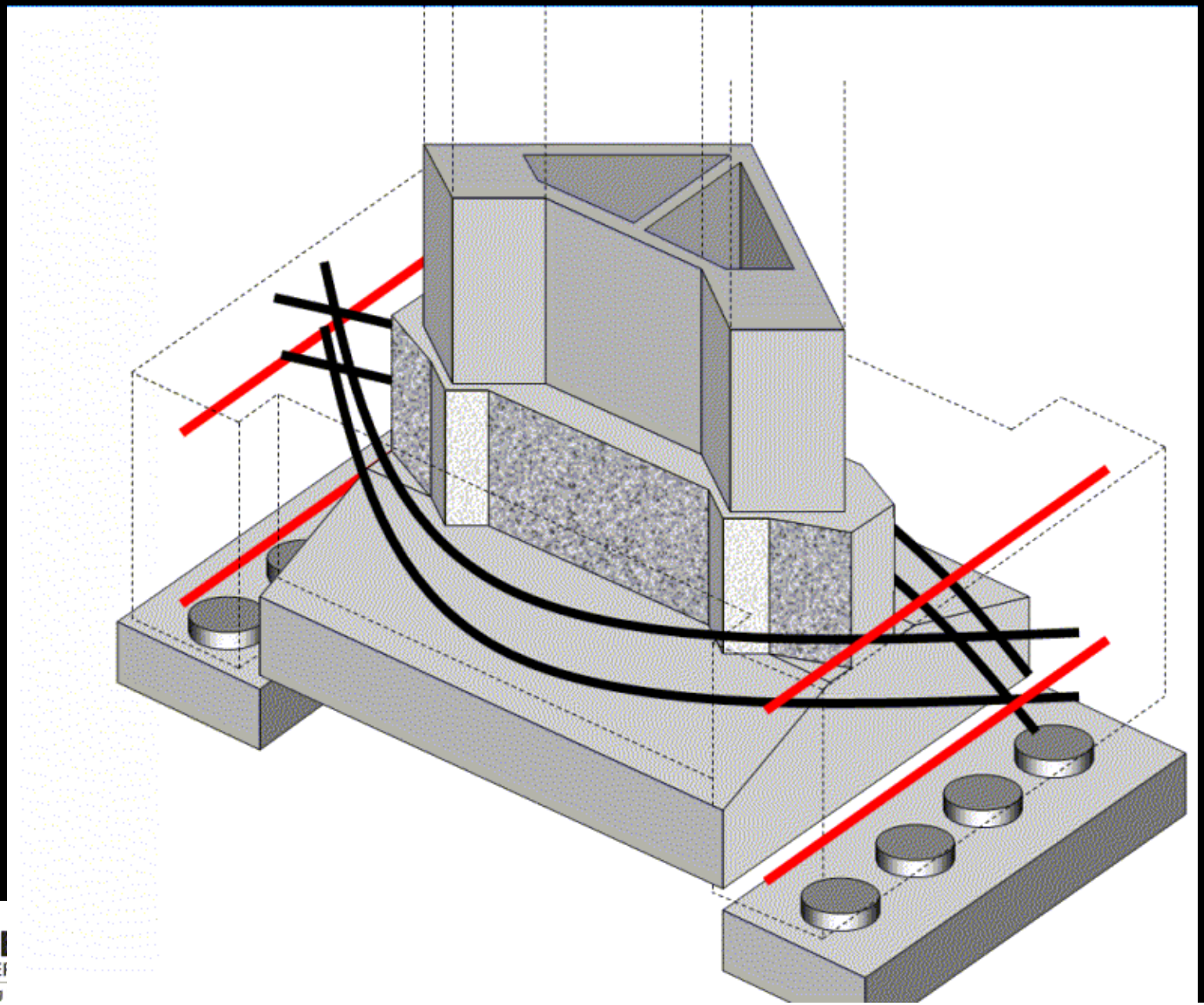

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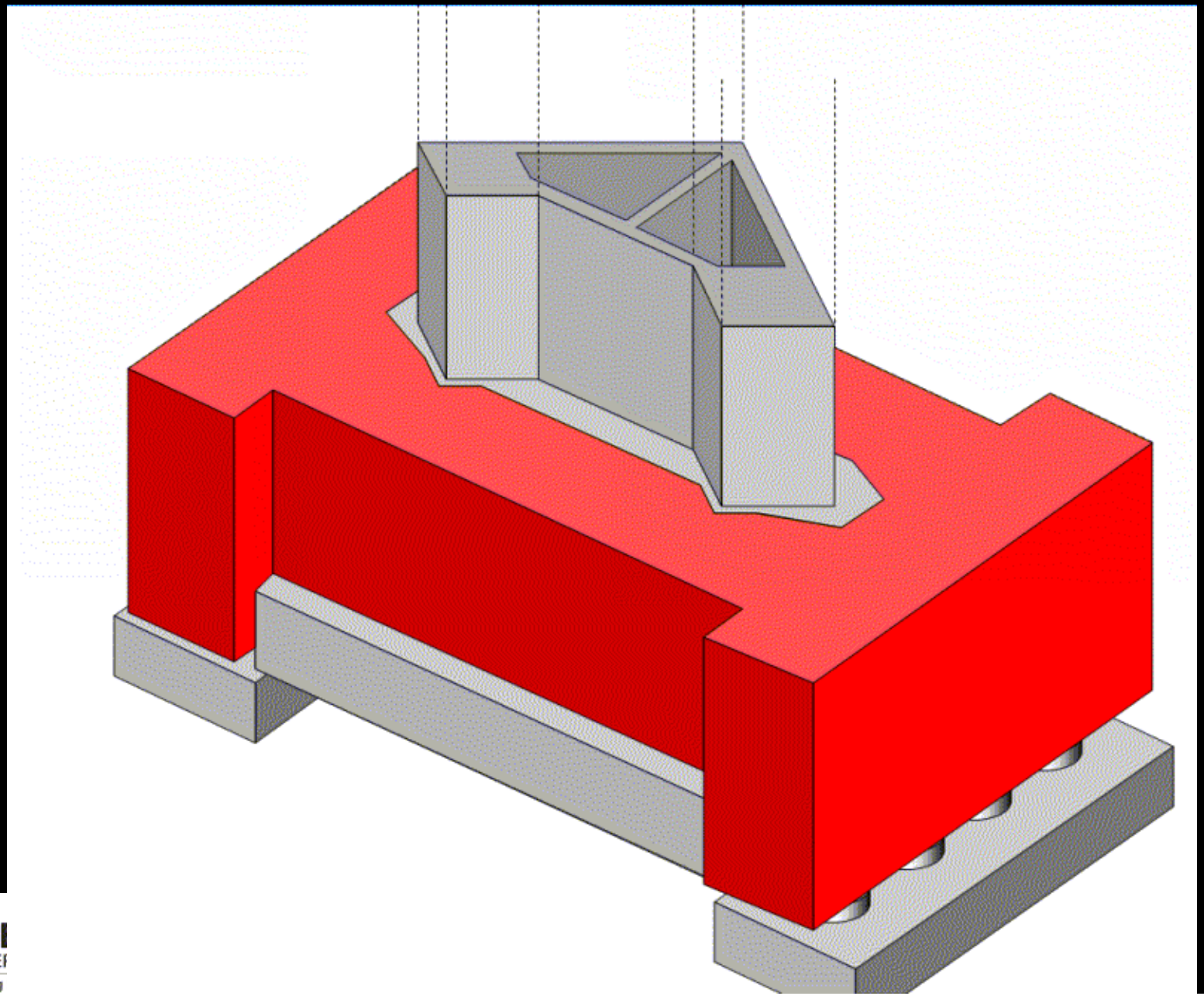

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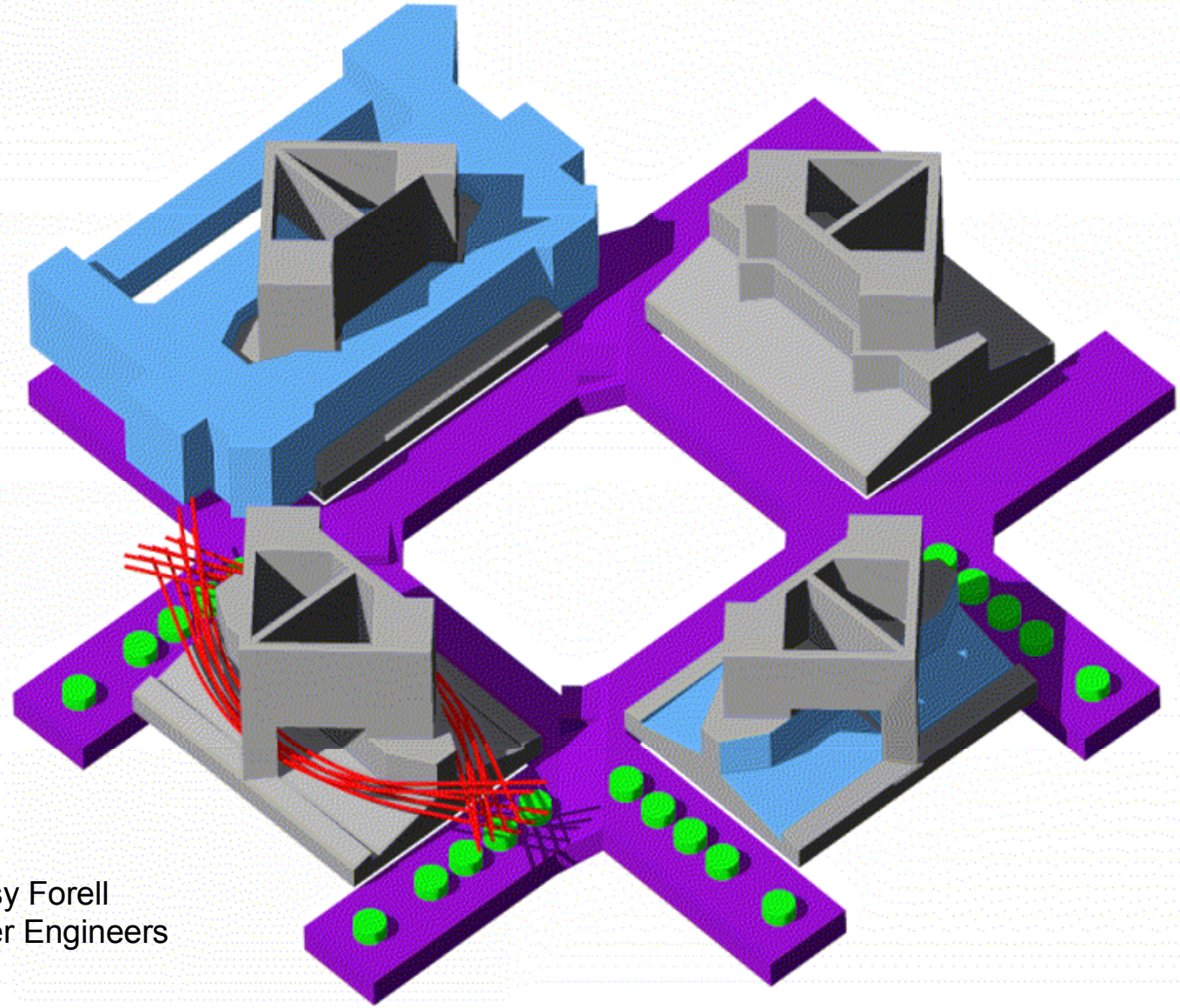
Isolator Installation at Rotunda



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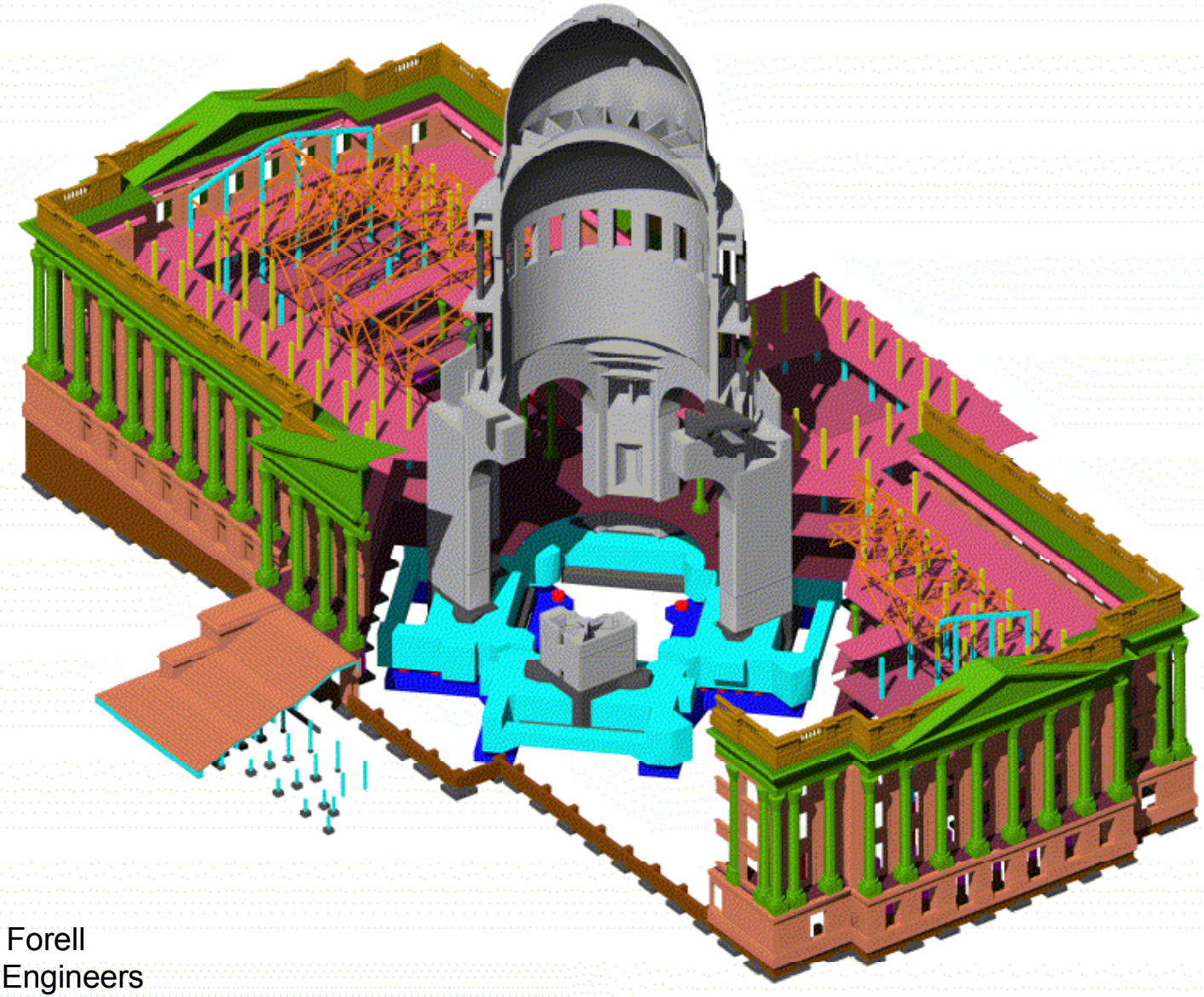
Isolator Installation at Rotunda



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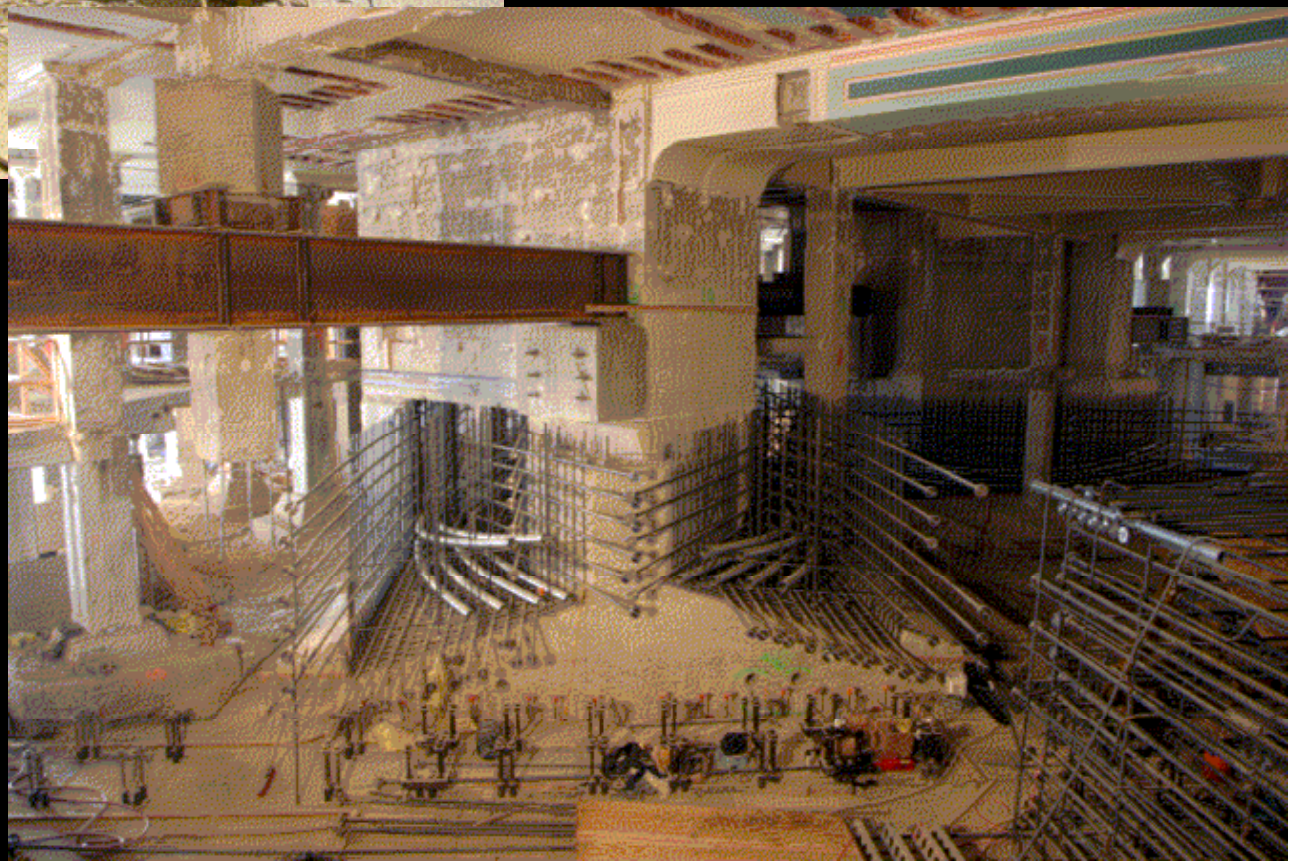

Photos courtesy of
Forell Elsesser
Engineers

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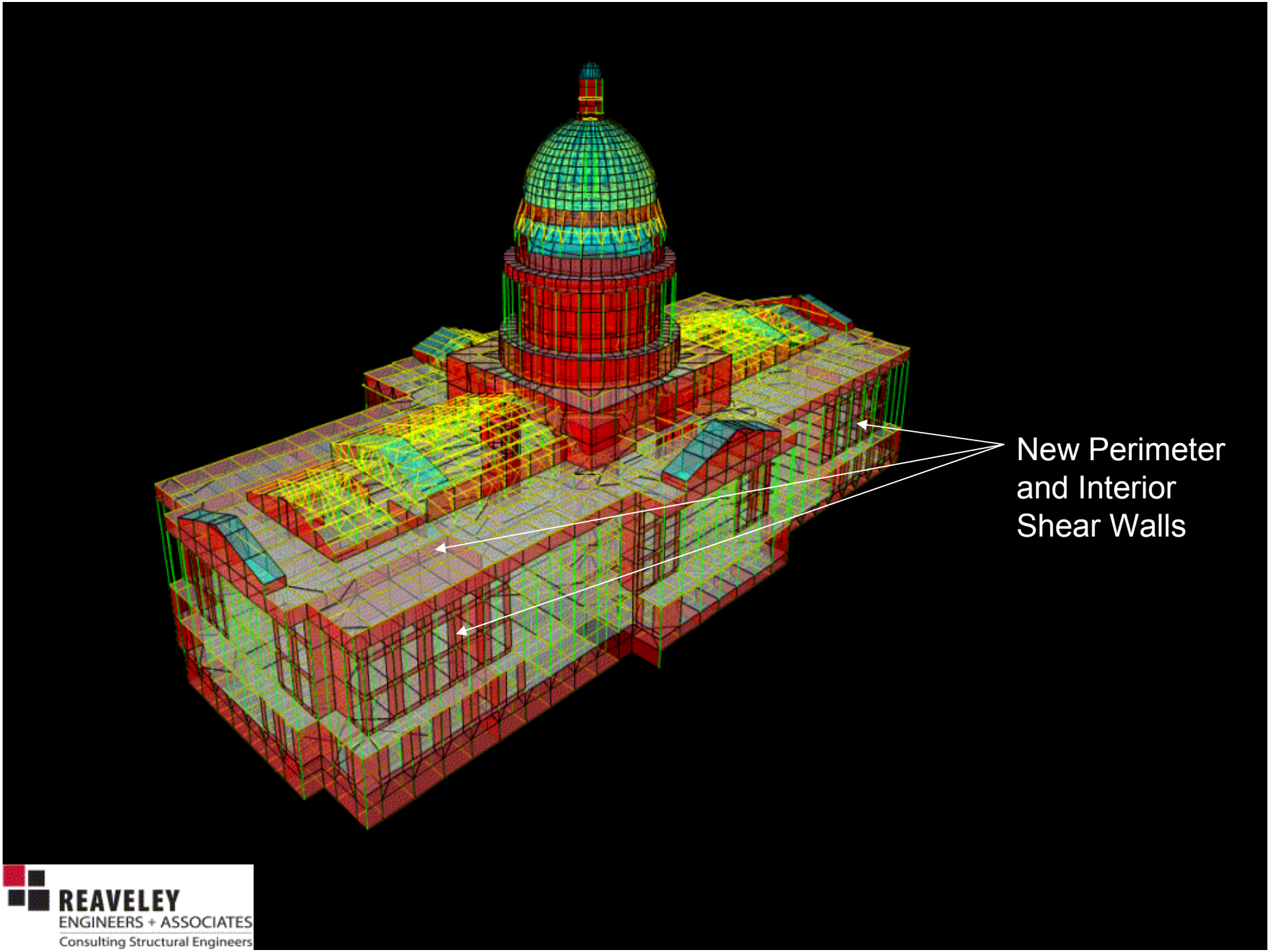

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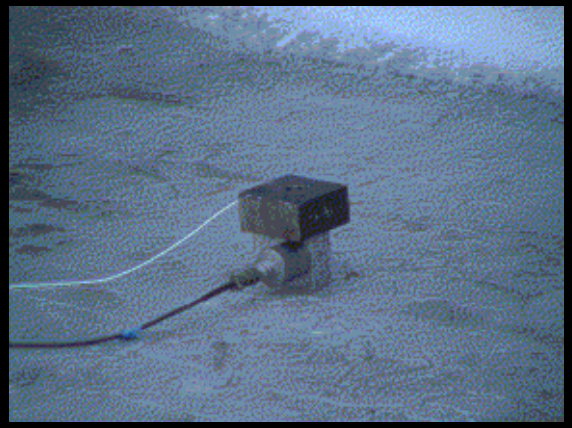
Forced Vibration Testing



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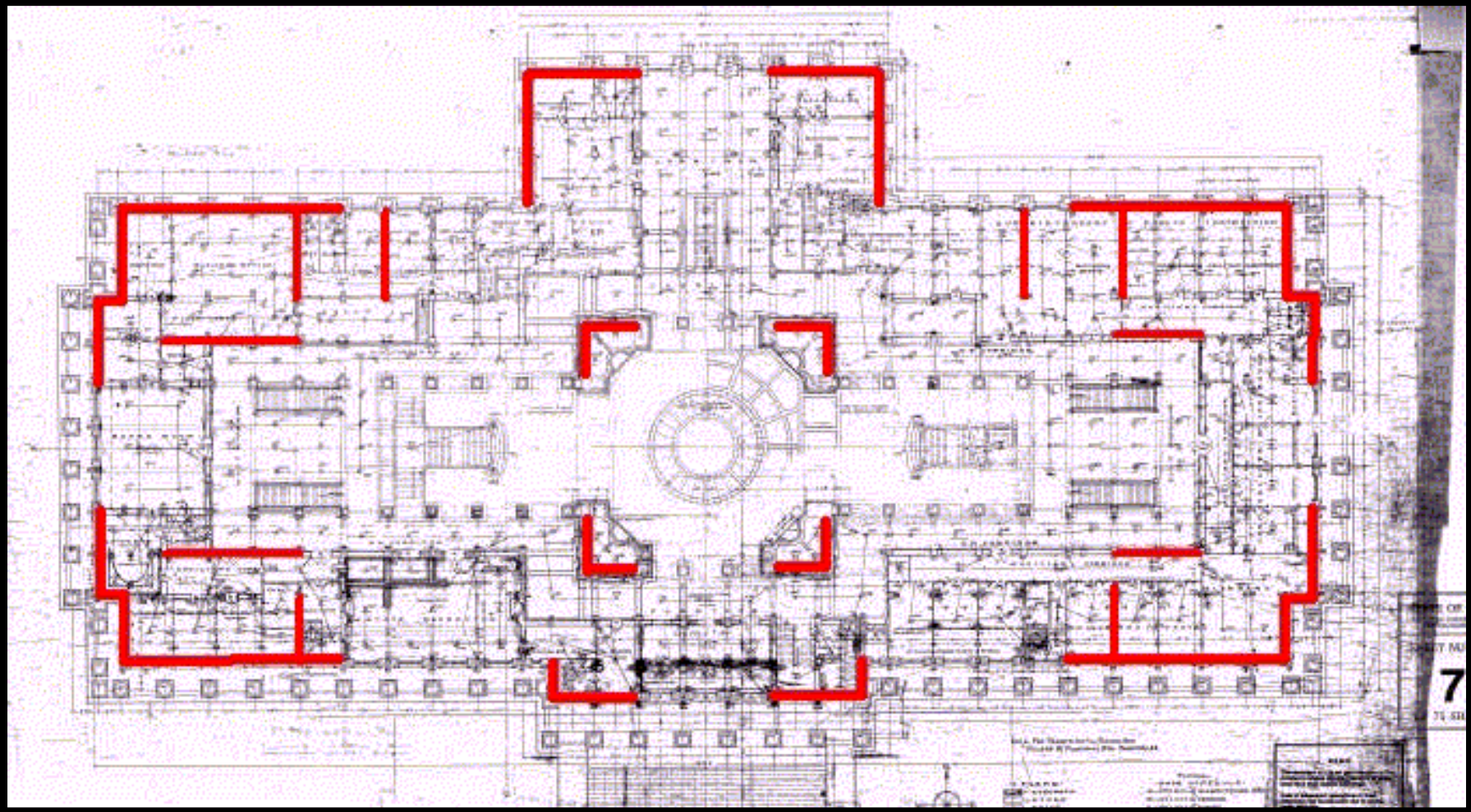
New Shearwall Configuration



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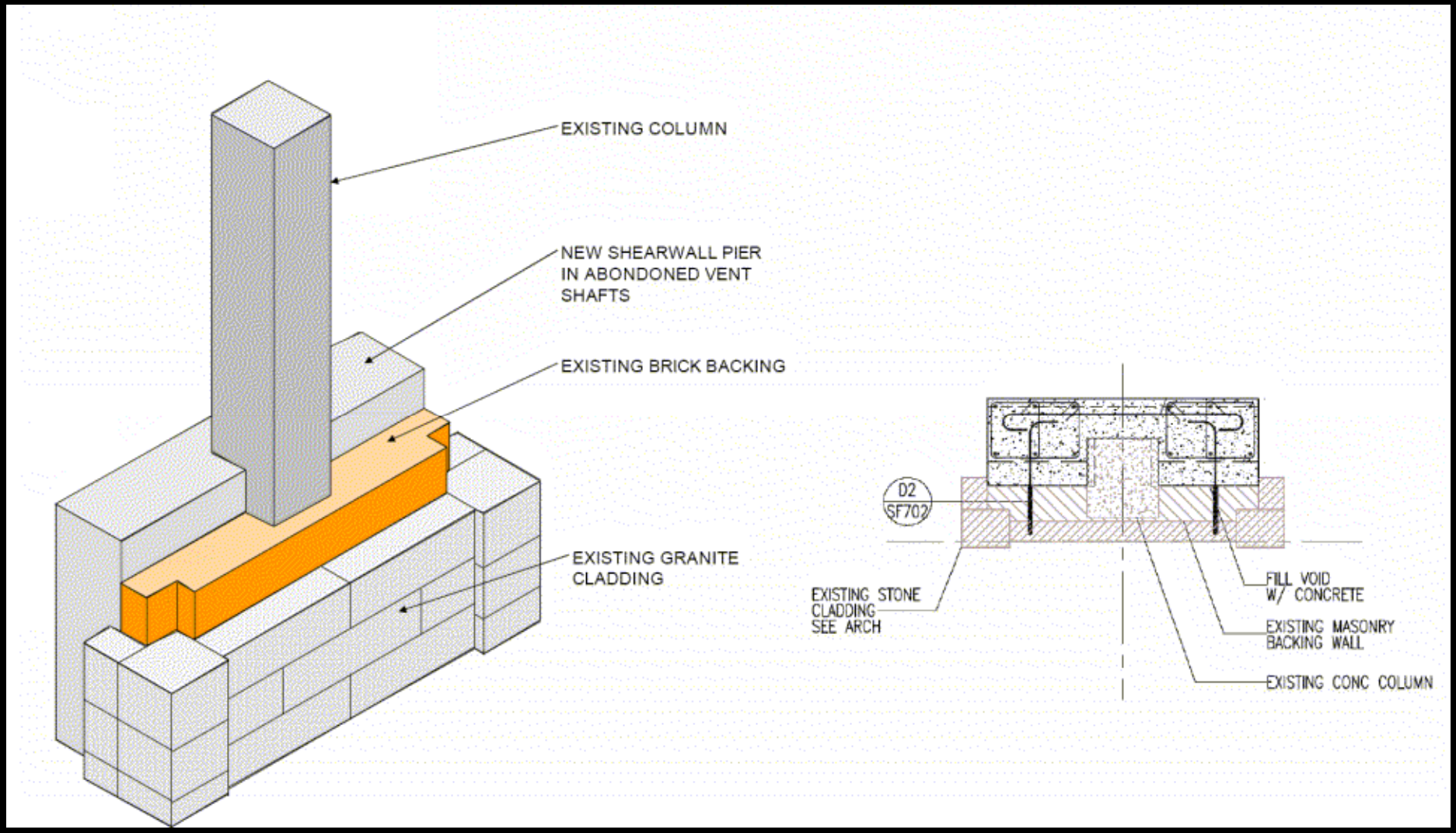
New Shearwalls

Shear Walls at Perimeter



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Shear Walls at Perimeter

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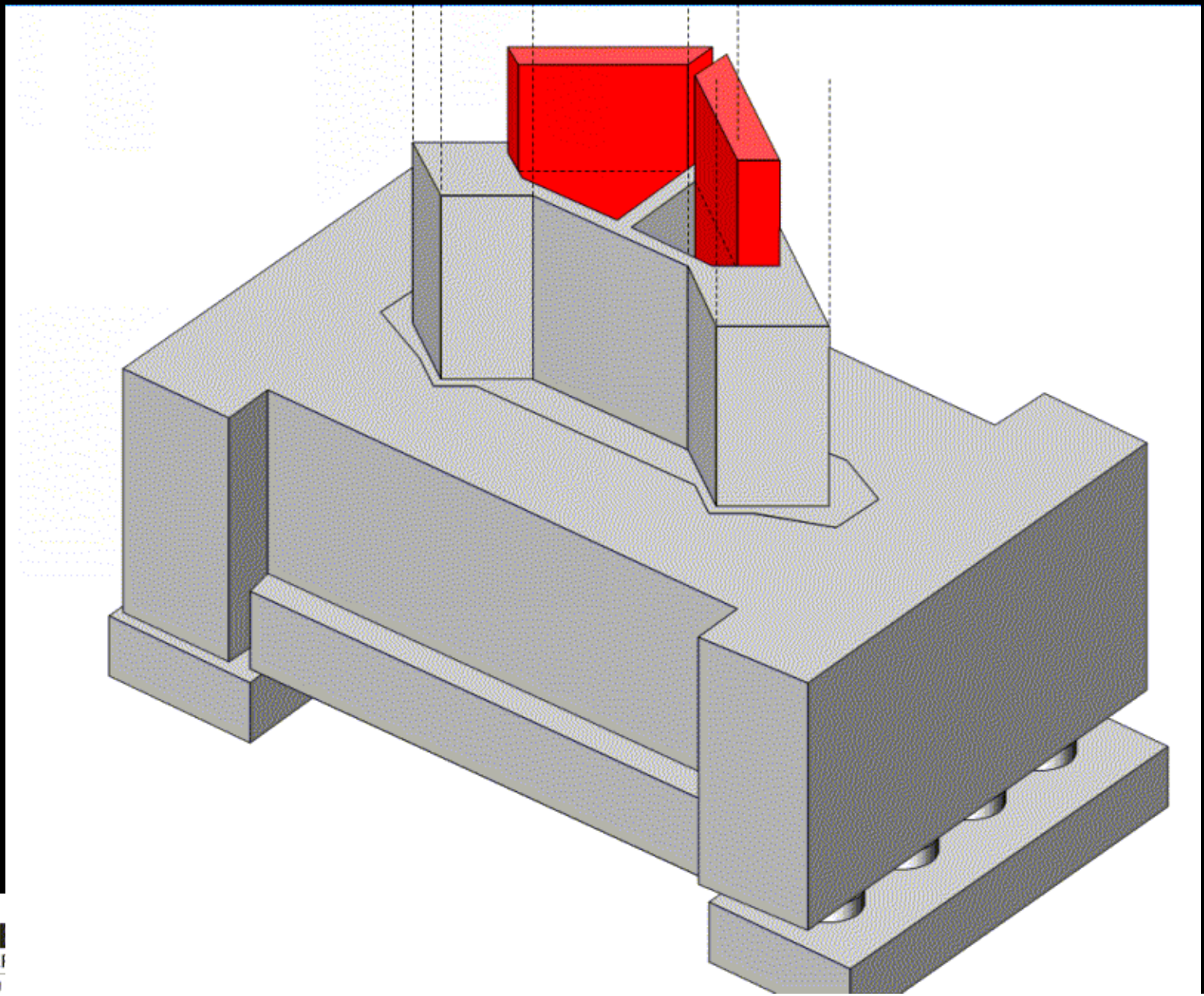
Isolator Installation at Rotunda



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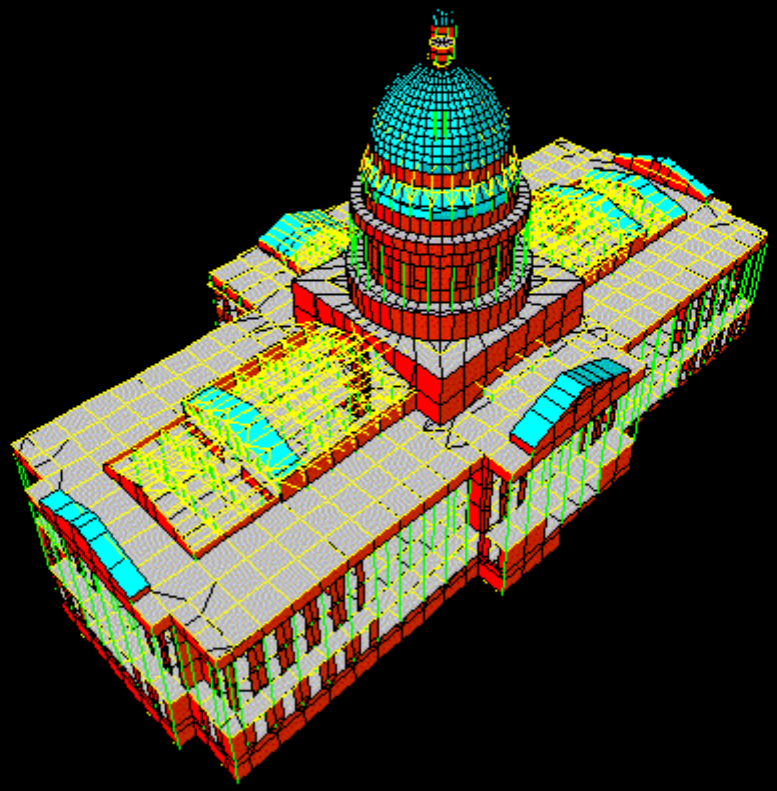
Base Isolated Model - 30x Amplification

(Click on image to start animation)



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How does Base Isolation benefit the Utah State Capitol?

- Horizontal Seismic Accelerations are reduced by approximately 75% to 80% for a large earthquake.
- Preservation of Life.
- Preservation of Utah Heritage.

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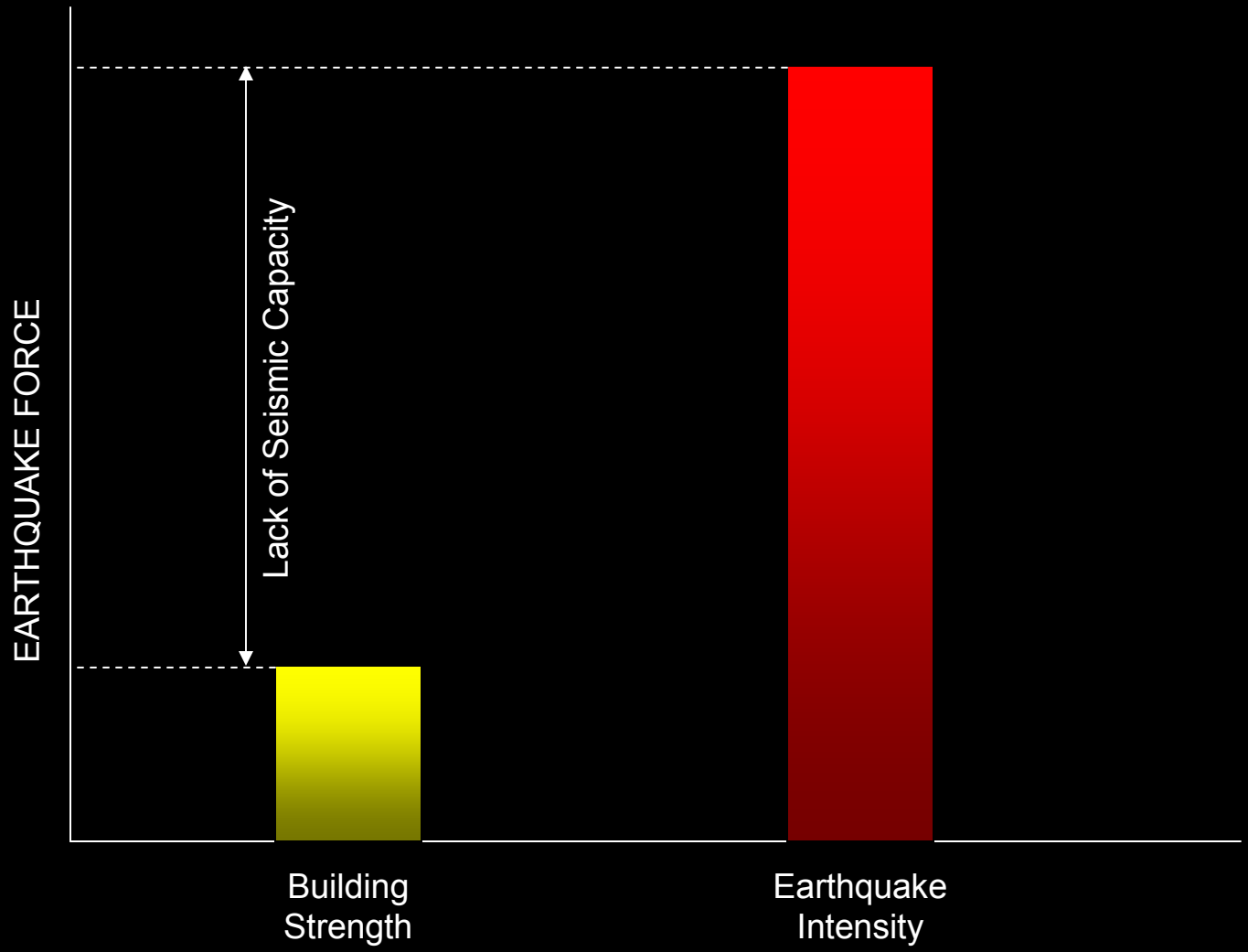
How does Base Isolation benefit the Utah State Capitol?



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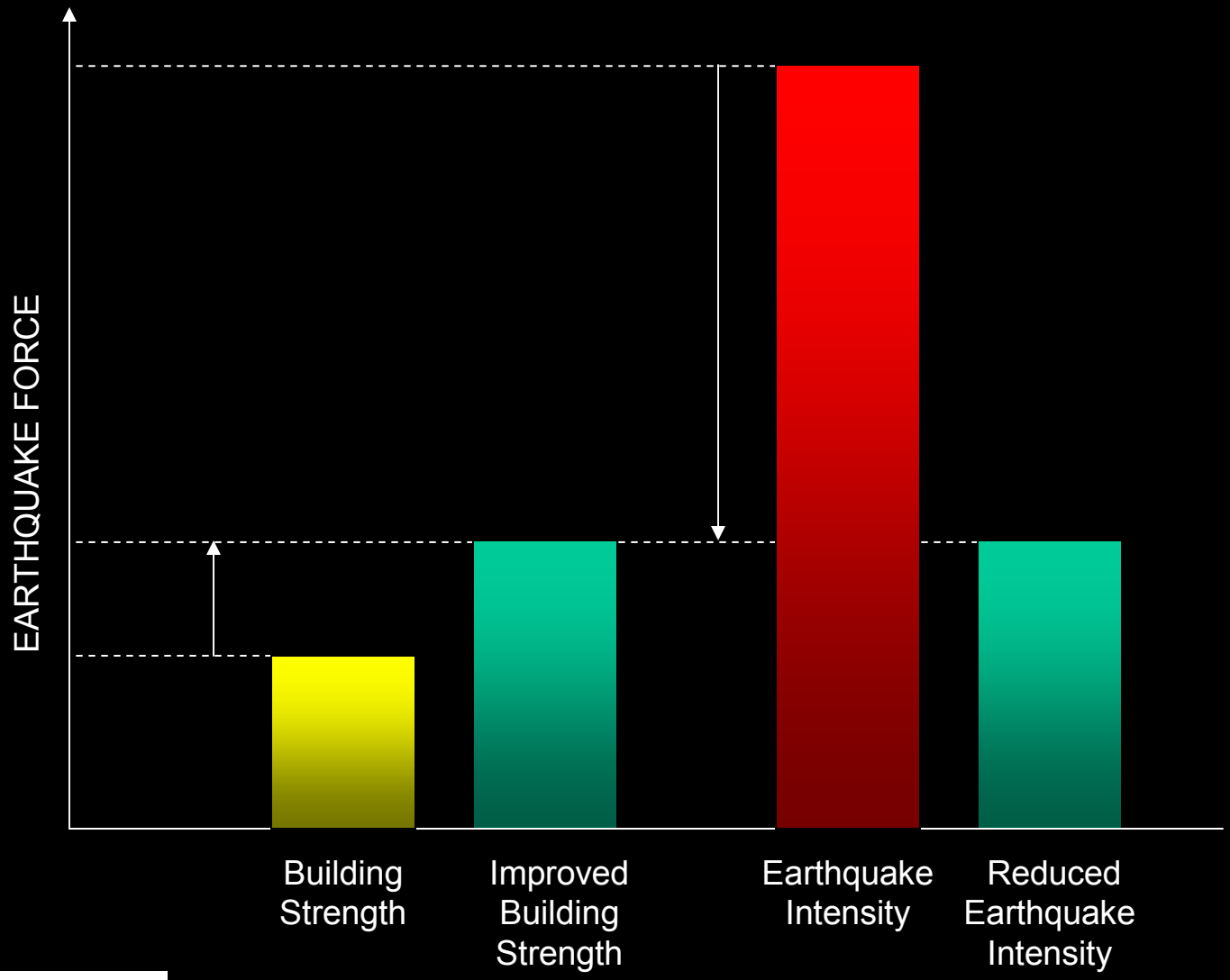
How does Base Isolation benefit the Utah State Capitol?



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Credits:

Owner: Utah State Capitol Preservation Board, David H. Hart, Architect of the Capitol
CMGC: Jacobsen Hunt Joint Venture

Architect: Capitol Restoration Group, a joint venture of VCBO Architecture, MJSA Architects, Schooley Caldwell Associates

Structural Engineer: Reaveley Engineers + Associates, Forell Elsesser Engineers

Mechanical Engineer: Spectrum, Heath

Electrical Engineer: Spectrum

Geotechnical/Geoseismic Engineer: AMEC

This presentation provided by Reaveley Engineers + Associates

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