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3D-ISOLATION BEARINGS FOR THE UNASUR BUILDING IN ECUADOR

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ABSTRACT: The new headquarters building for the Union of South American Nations (UNASUR) was recently constructed just north of Quito, Ecuador in a high seismic region. This building is a unique design in that two of the wings cantilever out from the base 55 and 38 meters respectively. As part of the earthquake protection plan the floors of the cantilevered sections are isolated in a strategy to mitigate severe seismic forces. The alternative scheme of increasing the stiffness of the cantilevers could fix the serviceability vibration problems but it would be expensive and could make the building more vulnerable to earthquake attack in the horizontal and vertical directions. As a result 3D-Isolation Bearings with flexible properties in all directions were designed and fabricated to solve these problems. The 3D-Isolation Bearings for the UNASUR Building are comprised of a hybrid disk/spherical type bearing to accommodate the horizontal displacements with specialty polymer springs designed to allow for vertical displacements. To dampen the vertical forces a friction damper system is also part of this unique design. The design displacements of these unique bearings are +/-200 mm horizontal and +/-80 mm vertical, which lengthen the period of vibration of the cantilevered sections of the structure. On August 12, 2014 the Quito area was hit with a 5.2 magnitude earthquake and subsequently 80 aftershocks. The epicenter was only 3.2 km from the UNASUR Building. Horizontal displacements measured on site were on the order of 60 mm. No damage was reported and the isolators performed as anticipated.

1. Building and Site Description

The headquarters of the Union of South American Nations, UNASUR, are located in the Middle of the World complex in Quito, Ecuador (Fig. 1). The main feature of this 20000-m^2 building is its sculptural architecture with two massive cantilevers of 55m and 38m. The area at the interior of the cantilevers sums up 2000 m^2 of office space.

The building site is only two kilometers away from an active seismic fault that runs along the city in the north-south direction. This fault is capable of generating up to a 6.5 magnitude earthquake. At the site the soil are uniform deposits of sand and volcanic gravel.

Figure 1 – UNASUR Building

2. Structural Design Approach

In the conceptual design phase, the following criteria were defined as design requirements:(Suarez 2013)

- Cantilevers should be a steel truss designed as light and rigid as possible.
- The building core must be a closed, coupled, wall system, designed to support the cantilevers and transmit the loads to the foundation.
- Due to the building configuration, gravity generates forces and displacements that get greatly amplified during earthquakes, therefore, no earthquake structural damage can be accepted as it can in turn severely reduce the capacity of building to resist gravity loads after an earthquake. It is important, the building should remain operative after the design earthquake (tr 475 years) and should offer life safety after the maximum credible event (tr 2500 years).
- Design should result in tolerable levels of acceleration inside the cantilevers as a result of earthquake and human activity.

The bearing system itself should provide isolation and dissipate energy in the horizontal and vertical directions. However, the vertical displacement should only activate when an earthquake generates a load greater than live load, to avoid movement under service conditions. This requirement resulted in the design of unique 3D isolators.

The initial design parameters for the 3D isolators, that is, effective stiffness and effective damping, resulted from a simplified analysis of the isolated floors as if they were supported by a rigid structure. Later on, the stiffness of the structure was included and the properties of the isolation system was calibrated with a nonlinear time history analysis of the complete building. These analyses were performed using the isolation elements implemented in OpenSees. (McKenna, Mazzoni, Scott, Fenves 2004)

A preliminary design of the cantilever structures showed that without any means of energy dissipation, acceleration at the tip of the longest cantilever could be as much as 2g in the horizontal and vertical directions for the 475-year hazard. This was a result of having the structure period of vibration very close to the site period.

Any attempts of improving seismic performance, by modification of mass and stiffness of the cantilevers, reduced the performance for service conditions. Therefore, the incorporation of seismic isolation technology was investigated as a means to improve seismic and service performance.

The solution involved the isolation of the floor inside the cantilevers from the main structure. The mass of the steel deck composite floors and the live load mass participating with it accounted for 30% of the mass of the cantilevers. Therefore, shifting the periods in the isolated floors reduces the seismic demand in the structure as it falls into the descending branch of the design spectrum and adds damping. In the same way a tune mass damper works but without the additional mass.

3. Isolator Design

After a thorough search of existing isolation technology it was determined that none of the current devices offered the displacement and damping requirements in both the vertical and horizontal directions. As a result unique 3D Isolators were developed for this signature structure.

The UNASUR Building Isolators have two distinct components. The first is a hybrid disk/spherical bearing, (Watson 2002) to accommodate the horizontal displacements while simultaneously providing damping. Disk bearings were first developed in the late 1960's as a bearing device for bridges designed to accommodate loads, movements and rotations (Fig. 2). The key component of a disk bearing is the load and rotational element comprised of a polyether urethane material. Polyurethanes have tremendous compressive strength and outstanding weathering properties. In addition, they have a wide temperature operating range. The polyurethane material used in the disk bearing remains flexible and stable from -70°C to +121°C, which means that during normal atmospheric conditions the material is stable. The thousands of disk bearing installations all over the world for the past 40 years have an outstanding performance history.

Figure 2 – Disk Bearing

The disk bearing component of the UNASUR 3D Isolators is sandwiched between two concave spherical dishes faced with mirror finish stainless steel. The upper and lower bearings plate surfaces are machined convex to fit into the concave surfaces and are faced with a proprietary sliding material designed to take the wear and tear of daily service conditions as well as seismic forces, (Giarlelis, Kostikas, Lamprinou, Dalakiouridou 2008). As displacement occurs the disk bearing component rotates to adjust to the varying concave surfaces and maintain a level surface at the floor level of the building cantilevers. Horizontal damping occurs through sliding friction. As the velocity increases, the damping level also increases. This works well since earthquake motions are high velocity events. The upper concave plate is much smaller in diameter compared to the lower concave plate and forces the disk bearing device to slide back and forth during seismic excitation. The entire assembly is contained in a steel box affixed to the upper concave slide plate in order to limit the ultimate displacement of the isolator.

Below the hybrid disk/spherical components of the 3D isolators is a spring damping system comprised of specialty polymers springs (Fig.3). The polymer material used has been utilized on bridge bearing isolation systems for the past 20 years, (Watson 2007). On the UNASUR Isolators, there are four springs 114 mm in diameter and 150 mm in height. Since they are pre-compressed they allow for ± 80 mm of displacement in the vertical direction.

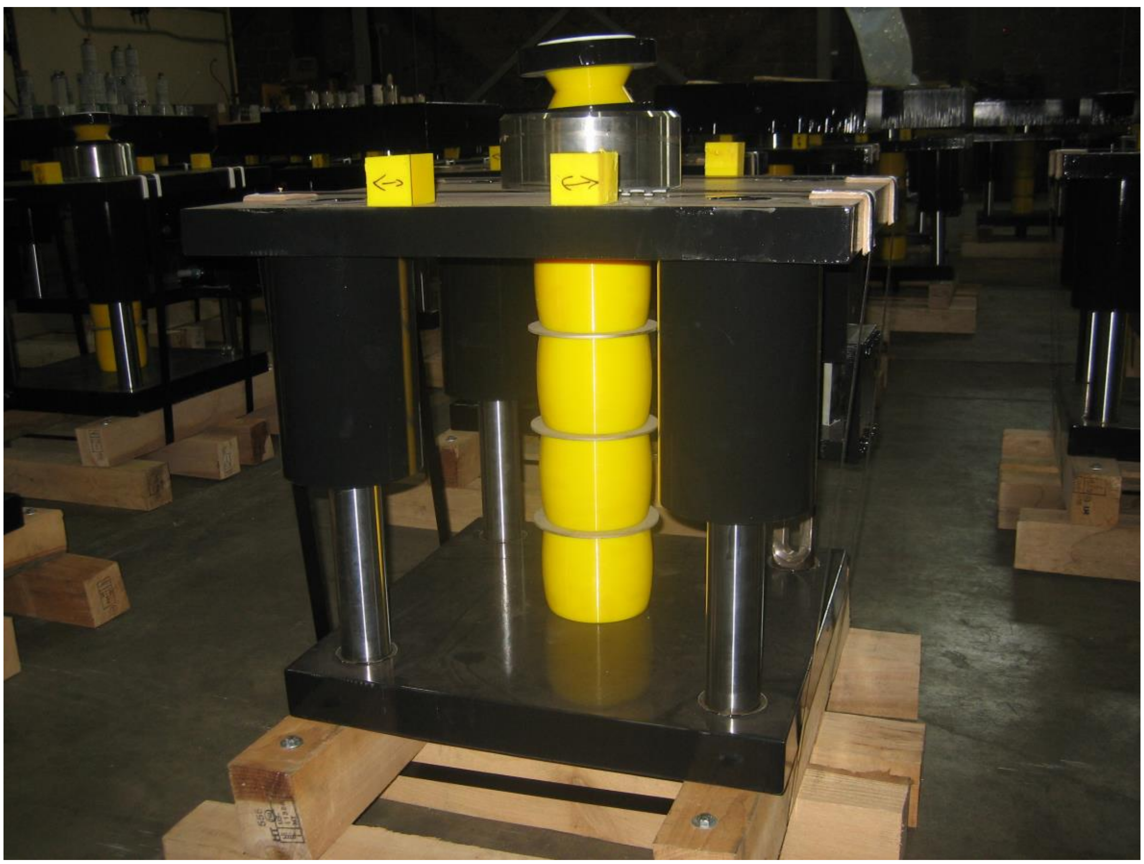

Figure 3 – Spring/Damper Design

For damping a specialty, friction damper was affixed to the steel rod so as the isolator translates vertically energy is dissipated through friction, (Constantinou, Reinhorn, Mokha, Watson 1991). The vertical load capacity of the isolator is 130 kN. The horizontal displacement capacity is ± 200 mm and the device has a rotational capacity of 0.02 radians. The horizontal yield strength of the isolator is 10.5 kN and it has a post elastic stiffness of 0.2 kN/mm and has an effective stiffness of 0.253 kN/mm giving it an equivalent damping ration of 0.1 (Fig. 4). The vertical properties of the specialty springs combined with the friction damper are 30 kN of yield strength, 0.8 kN/mm of post elastic stiffness, 1.18 kN/mm of effective stiffness and a damping ratio of 0.2 (Fig. 5).

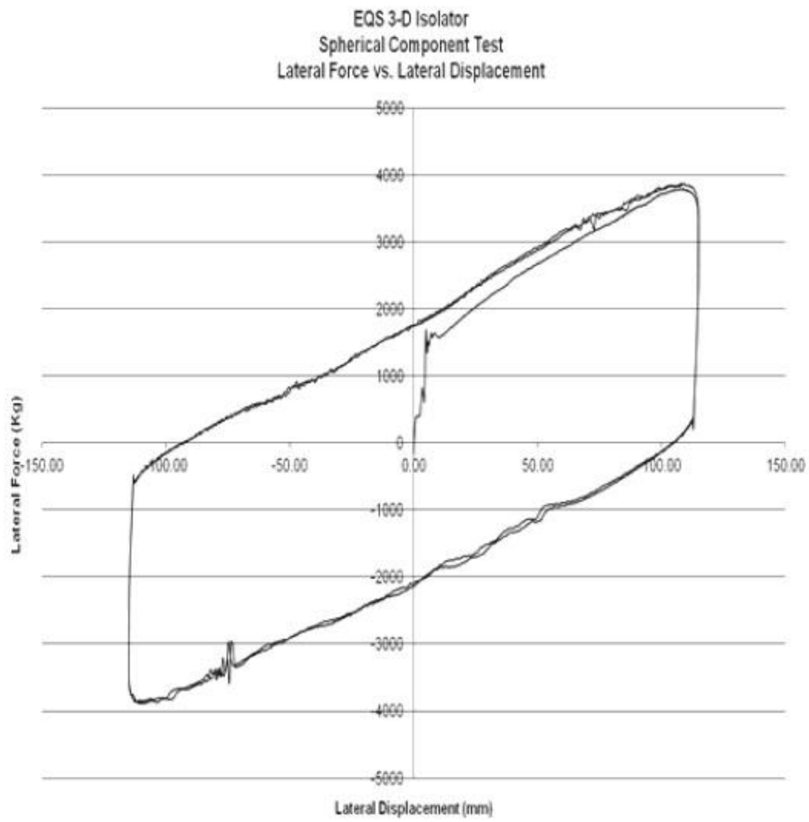

Figure 4 – Lateral Force vs. Displacement

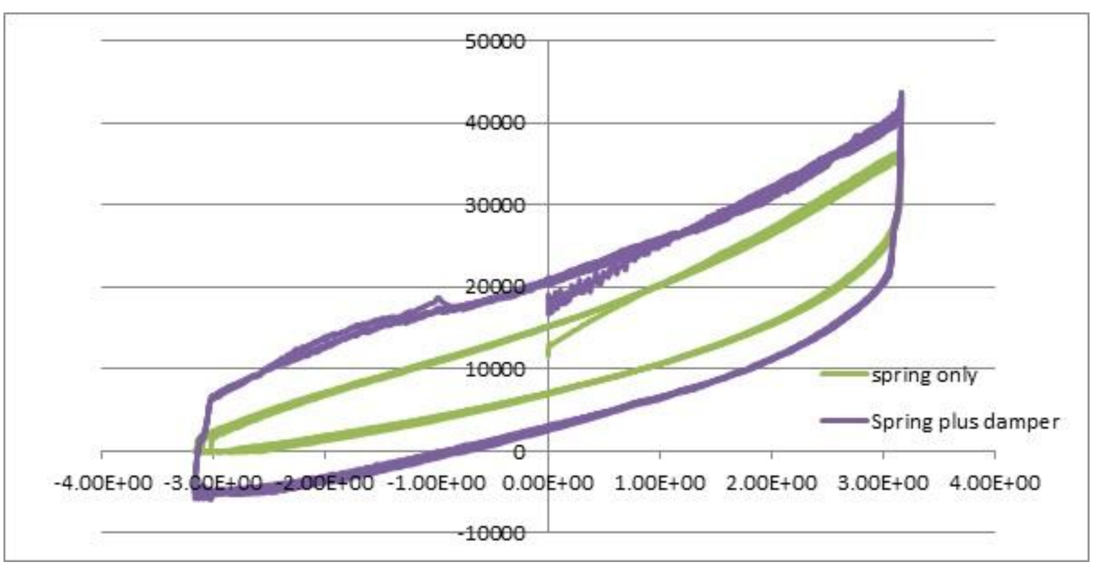

Figure 5 – Vertical Force vs. Displacement

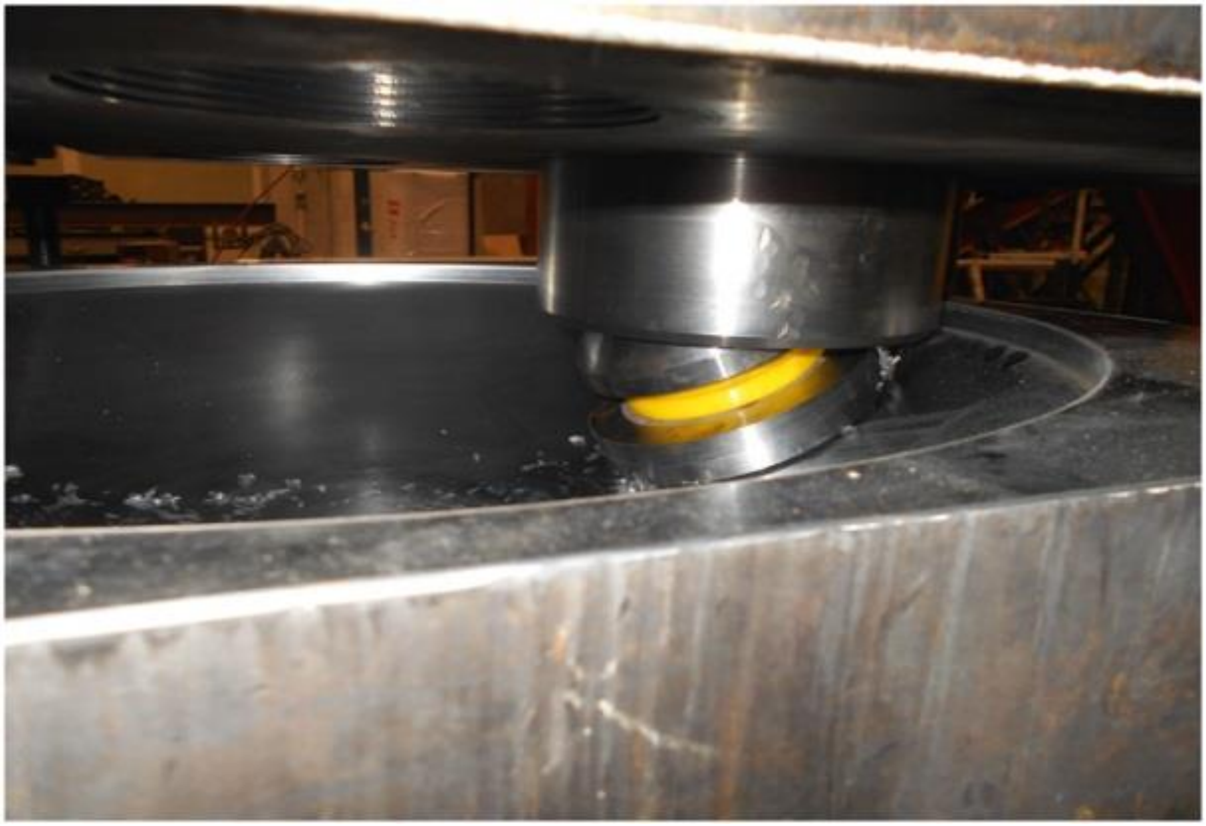

Figure 6 – Testing at MCEER

The 3D Isolation Bearing was tested at The Multidisciplinary Center for Earthquake Engineering Research (MCEER) Structural Engineering and Earthquake Simulation Laboratory located at the State University of New York at Buffalo in accordance with project specifications (Fig. 6). All tests met or exceeded the specification requirements.

A static vertical load test was performed on the lower spring damper assembly to obtain the vertical load carrying capacity at the specified pre-compressed height (Fig. 7). At the pre-compressed height of 567.3 mm detailed on the approved shop drawings, the restoring force or resistive load that the isolator maintained was 8,437 Kg. At the requested resistive load of 10,000 Kg the assembly height was measured to be 552.1 mm. The values tested were acceptable to the contractor and the project engineers.

Figure 7 – Spring/Damper Testing

4. Conclusion

On August 12, 2014 the Quito area was hit with a 5.2 magnitude earthquake and subsequently 80 aftershocks. The Epicenter was only 3.2 kM from the UNASUR Building. Measurements taken of horizontal displacement from the isolated floor perimeter to the fixed cantilever structure were 60 mm compared to the 200 mm capacity. The closest accelerometer to the UNASUR Building registered a peak ground acceleration of 0.08g. No damage structural or non-structural was registered. While this was not a major earthquake, the ground accelerations were potent enough to test the 3D Isolators and they performed as designed to mitigate any damage to the structures.

Figure 8 – UNASUR 3D Isolator

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