THE TORRE MAYOR

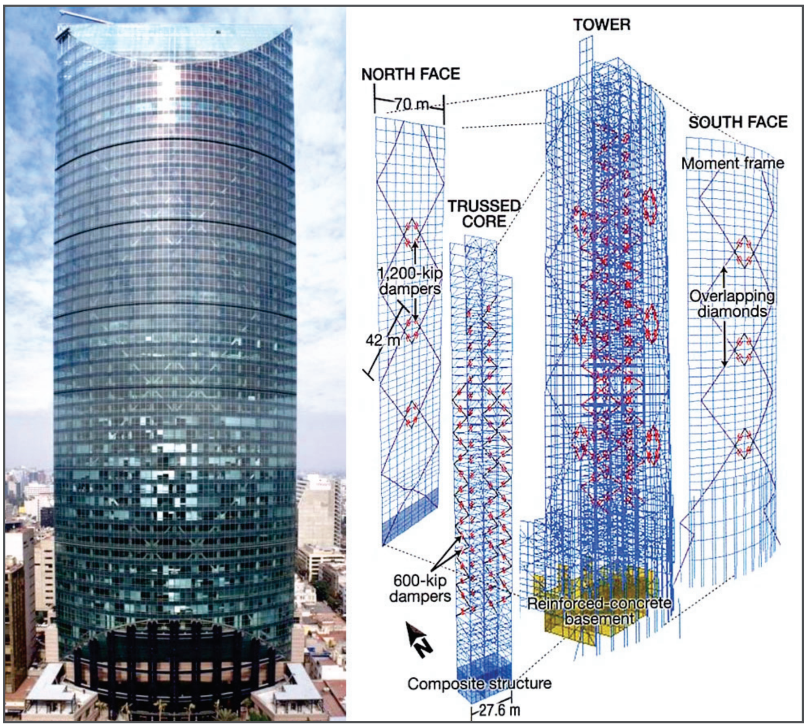
A Pinnacle of Seismic Engineering in Mexico City

Completed in 2003, this 55-story skyscraper not only dominates the skyline but also represents the forefront of earthquake-resistant design. Built to last 2,500 years!

The City of Mexico City is growing vertically with skyscrapers dominating the skyline and Torre Mayor, a pinnacle of earthquake engineering, stands at its middle, soaring at a height of 225 meters as one of Latin America's tallest building.

The design and construction challenges that the City of Mexico presents are multi-faceted due to its location in one of the most adverse geologic and tectonic environments in the world. In 1985 a devastating earthquake claimed over 9,000 lives, despite its epicenter being almost 400 kilometers away from the city. Apparently, the subsurface below the center of this city of millions amplifies earthquakes. As per Leobardo Dominguez, "*Mexico City is built on a lakebed, there are strata of soft clay going down 30 meters. When the seismic waves reach this sediment and are transferred to the surface, the whole layer begins to rock. It's a dynamic effect that amplifies earthquakes.*"

Trumping nature with advanced technologies, Torre Mayor stands tall as a testimony to fine engineering and a landmark building resilient to earthquakes. The architecture of the building was done by Adamson Associates Architects, Zeidler Roberts Partnership, IDEA Asociados de los and Estados Unidos Méxicanos. WSP Group was entrusted with the structural engineering.



Building details

Designed as an office space, Torre Mayor is a 55 storied building, covering a total area of 84,000 sq.m. With contemporary architecture, the tower has 30,000 sq.m. of glass on the south facade with thermal and acoustic insulation. It was constructed in a span of 4 years and is known to be the only skyscraper in the world that has not had any major accidents or deaths during construction. The tower is occupied by more than 8,000 people.

Four underground and nine above-ground parking levels accommodate about 2000 cars. The building consists of 43 typical column-free office floors, with floor plates ranging from 1700 sq.m. to 1800 sq.m. The building has an 80 m X 80 m footprint at below grade levels, which is reduced to an 80 m X 65 m footprint from the 4^{th} to the 10^{th} level. Above the 10^{th} level, the footprint is further reduced to its typical tower size of 48 m X 36, where a geometrical combination of a rectangle merged with an arch segment at the south side of the building forms a curved façade at the south face.

In addition to the elegant architecture and classic engineering, Torre Mayor is an intelligent building. The elevators have a seismic detector that detects any movement of earth and therefore automatically stops the elevator nearest to allow passengers to get off. The Torre Mayor is administered by the Building Management System (BMS), an intelligent system that controls all facilities and equipment harmoniously and efficiently to protect human life from danger.

Overall design of the structure

The innovative approach taken in the seismic design of Torre Mayor embraces a performance-based criterion, which is becoming the standard of advanced seismic design. This criterion is concerned not only with the final safety of the building in an event of a strong earthquake, but it also expects the building to be operational after a strong earthquake.

The building's superstructure is a combination of steel and concrete. The columns at the interior and perimeter of the tower are encased in reinforced concrete for the lower half of the tower. Typical floor framing is comprised of 75 mm thick composite metal deck with 50 mm of concrete supported on steel framing connected via shear-studs, except at the mechanical floor, where thicker slabs are used. The selected structural system is based on a redundant multiple system. This is accomplished by introducing a dual conventional (deflection sensitive) lateral-force resisting system in combination with a supplementary damping system (velocity sensitive).

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In effect, a "trio" system, composed of a primary braced frame at the perimeter of the tower coupled with a perimeter moment frame, forms an HSS system, and a trussed HSS at the core of the building is provided to respond to the seismic energy from an earthquake. The bracing connecting the composite core columns creates a structural spine in the building core. The perimeter frame and the powerful super-diagonal system create an efficient HSS structure, joining the spine in resisting the seismic forces. This system is augmented by the supplemental viscous dampers that are highly effective in reducing the impact of seismic motion on both the structure and the non-structural elements. The system reduces the overall and inter-story sway of the tower, as well as the vibration and the seismic forces of the structural elements.

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Seismic design of the structure – design and implementation of fluid dampers

A combination caisson and mat system was selected for the foundation of the tower. The reinforced concrete mat system connected a series of caissons of up to 1.2 meter diameter, reaching down only 40 meter into a rubble layer below the soft surface soil. The concrete mat thickness varies from 1 meter to 2 meter in thickness and ties together the caissons and the 0.8 meter thick foundation walls.

Addition of viscous dampers to the structure was resorted to reduce structural stress during seismic loadings. The underlying design concept was to use the dampers to reduce stress, then lighten the building frame by removing steel until the stress crept up to the allowable limit of the code. Conceptually, the steel that had been "removed" by this process was then used to add additional floors. For the Torre Mayor, inherent structural damping in the frame was assumed to be 1% of critical. Multiple computer runs were made with added fluid damping in 2% increments. The approach used was to add damping until a lightweight 55 story building would result or until damping reached a value of 30% critical, at which the peak stresses would begin to increase. When the added damping in the structure reached 10% critical the resulting maximum height structure was calculated to be 55 floors. The structural detailing of the new tower could begin, having achieved the goals of the building's owner for a 55 storied structure.

The first step in the design process of damper implementation involved an extensive structural analysis to determine the desired overall damping level. The number of dampers and damper sizes were roughly

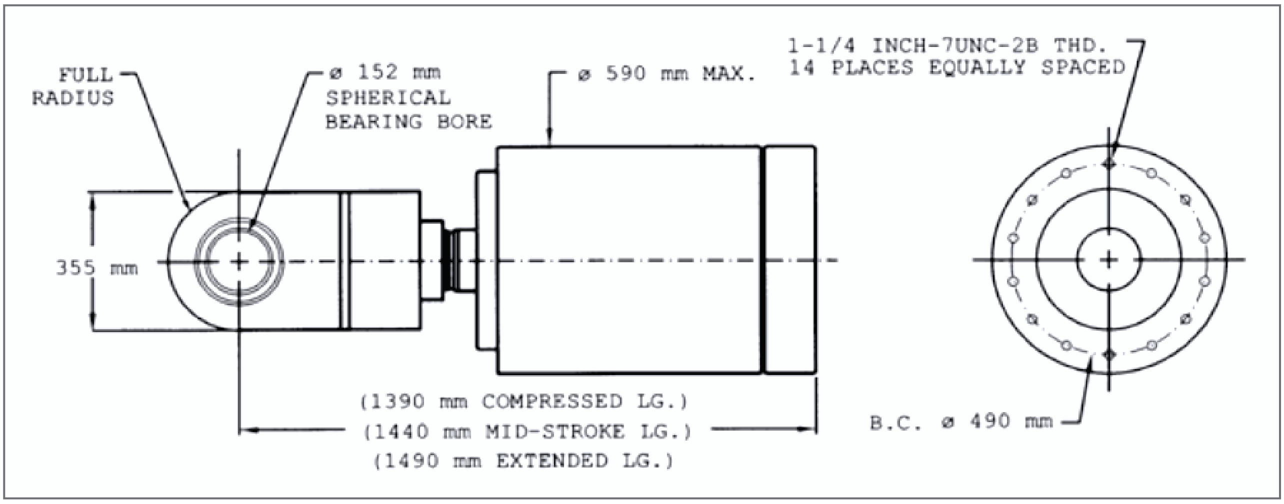

Fig. 1: 570 TONNES FORCE FLUID VISCOUS DAMPER

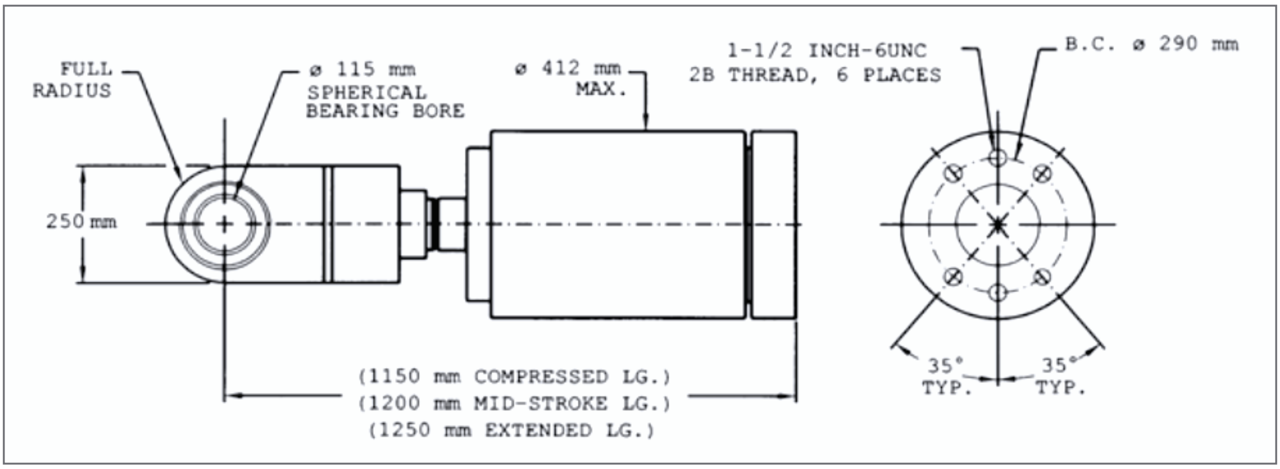

Fig. 2: 280 TONNES FORCE FLUID VISCOUS DAMPER

Fig. 3: Building frame duiring construction

Fig.4: Damper installation

estimated at this point to balance the cost of the dampers vs. the overall performance and cost of the structure. After the desired level of performance was achieved, the next step in the design process was to adjust the number of dampers and damper sizes against the available mounting locations in the structure and the desired architectural configuration. The third step in the design and implementation process was to optimize the performance of the individual dampers within the structure by varying the damping coefficients and exponents. A total of twenty-four large dampers of 570 tons rated force (Fig. 1) in the long walls of the structure and seventy-four pieces of a smaller 280 tons rated force dampers were used in the short walls of the structure (Fig. 2). Each damper spans over multiple floors, using a so-called “mega brace” element, installed in a diamond pattern. Fig. 3 indicates the building frame taken during construction which illustrates the diamond arrangement of the installed large dampers in their mega brace elements.

On January 21, 2003, the coastal region of the State of Colima, Mexico experienced a 7.6 magnitude earthquake. This earthquake affected a very large land area, including the nearby Mexican States of Jalisco and Michoacan, including the entire Mexico City area. Even though the epicenter of the quake was in an area of low population, damage was extensive. More than 13,000 residential structures and 600 commercial structures reported damage. Of these, more than 2,700 structures were totally destroyed. When the quake reached Mexico City it was amplified by the soft soils in the area. This resulted in a relatively strong response with some 30 seconds of shaking. At the time of the quake, 31 floors of the building were occupied, while the balance were still undergoing final interior finishing. Post-earthquake inspection was performed and there was no evidence of damage in the structure.

The Torre Mayor’s design was again put to the test during the 2017 Puebla earthquake. It was a 7.1 magnitude event that caused significant damage throughout Mexico City. However, no structural damage reported for the building. The state-of-the-art engineering ensured that the occupants were safe, and operations within the building were uninterrupted.

Conclusion

The Torre Mayor is not just a landmark in Mexico City; it is a benchmark for earthquake-resistant design worldwide. As urbanization continues to accelerate in seismically active areas around the globe, the Torre Mayor stands as a model for future high-rise constructions. It demonstrates that with thoughtful design and advanced technology, it is possible to build structures that not only reach for the sky but also offer unparalleled safety and resilience against the most adverse loading conditions.

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