The Santa Fe II Tower

A central core, tall, slender building in Mexico

by Luis M. Bozzo

The Santa Fe II tower (Fig. 1) is one of the newest dramatic features in the skyline of Mexico City, Mexico. At a height of 167 m (548 ft), the building is the tallest residential building in all of Mexico. In fact, only the Torre Mayor and Torre Ejecutiva Pemex, both office buildings in Mexico City, are taller. In addition to its height, the Santa Fe II tower is unique in regard to its façade, with its many discontinuous white columns.

Fig. 1: Views of the Santa Fe II tower, Mexico City, Mexico. The building's height and its irregular patterns of precast concrete façade elements add interest and drama to the city's skyline

Design Concept

Symmetry, load paths, spans, and materials significantly define the total cost of a building. Good conceptual design is the basis for an efficient structure, particularly today when computers allow fast and efficient structural analysis. In general, a building will be economical if its load transfer mechanisms are clearly and logically defined, allowing the analytical model to be used to optimize the individual members. In other words, poor conceptual design cannot be replaced by a good or even excellent structural analysis.

The load paths for the Santa Fe II tower are simple and clear: a post-tensioned (PT) floor slab is supported at the central core and perimeter beams that are, in turn, supported by the columns. Most of the seismic load is transferred by the central core.

So, in spite of the irregular appearance of the façade, the building structure is quite regular. Lateral loads are transferred mainly by the central core, allowing elimination of all interior columns. As a result, there are only nine columns—four located at the corners of the floor plate, three centered on three of the building sides, and two more located near the third points of one side (Fig. 2).

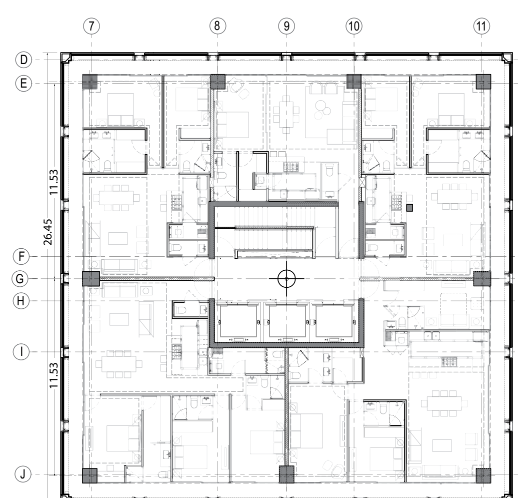


Fig. 2: Architectural floor plan of a typical residential level for Sante Fe II, showing central core, nine perimeter columns, and façade elements. The columns along the sides of the building were located to coincide with demising walls between individual apartments

The tower comprises eight lower levels for parking and 44 levels for residential housing, and it includes a rooftop heliport. The parking levels of the structure each cover an area of 60 x 30 m (197 x 98 ft), and the residential stories each cover an area of 26.5 x 26.5 m (87 x 87 ft). In the parking levels, the lateral walls plus the central core walls comprise 2.5% of the total floor area. In the residential levels, the walls in the central core comprise 1.5% of the total floor area. For comparison, it's common for buildings in highly active seismic regions in South America to have walls comprising 2% of the floor area, and it's common for buildings in the seismic regions of the United States to have walls comprising only about 0.5% of the floor area. However, because the stiffness of a central core is a function of the shape of the core as well as the area, wall systems cannot be compared in terms of plan area alone.

Comfort criteria

An important aspect of tower design is ensuring that comfort criteria are met in terms of human response to building motion. Certainly, all tall buildings move during wind loading. The acceleration level at which a majority of people will perceive motion is between 0.1 and 0.25 m/s^2 (0.32 and 0.82 ft/s^2). However, sensitive people can perceive motion at accelerations between 0.05 and 0.1 m/s^2 (0.16 and 0.32 ft/s^2). Consequently, a minimum acceleration of 0.1 m/s^2 is a good maximum target.

Considering a very strong wind event, the maximum calculated displacement at the top of the Santa Fe II tower was found to be 150 mm (6 in.). Assuming a first mode response, this indicates a maximum acceleration of 0.1 m/s^2. While this value is at the maximum target value, it's important to consider that the façade elements were not included in the structural model. The façade elements will, however, reduce the maximum potential acceleration by significantly stiffening the structure and adding damping as well as reducing the dynamic forces on the structure by disrupting the vortices that would normally form on a clean, homogeneous façade. Consequently, while the building acceleration may be felt by the building occupants, the calculated acceleration is clearly within acceptable limits for human comfort.

Seismic analysis

The Santa Fe II is located in Mexico's Seismic Zone 1. The local building code specifies a seismic coefficient of 0.16g for this region. Even with reduction factors, the minimum seismic coefficient is 0.04g, resulting in significant lateral loads.

The structure was analyzed in two orthogonal directions using a concentrated mass model. The first mode mass participation exceeded 50% in each of the directions, and only 27 modes were needed to satisfy the local code's minimum 90% mass participation requirement. The central core system thus provides a significant advantage over a conventional frame or dual system, as it requires a lower number of modes to attain 90% mass participation and thus reduces the uncertainties in obtaining the stresses for combined modes.

The fundamental periods were 6.8 and 6.6 seconds in the two directions, indicating a quite symmetric structure. The height from the street level up to the main roof, excluding the helipad, is 163 m (535 ft). Consequently, the building height-period ratio is about 25. While this may appear quite small, response spectrum analyses without any reduction (as required by the local code) indicated maximum drift ratios of about 0.0043 and 0.0040. These values are clearly below the 0.007 maximum values accepted in most modern international codes.

Structural Details

The building's structural subsystems comprise:

- Eighteen drilled shaft foundations, each 1500 mm (59 in.) in diameter and 33 m (108 ft) long;
- A central 9 x 8.5 m (30 x 28 ft) core with wall thickness varying from 300 to 500 mm (12 to 20 in.);
- A perimeter frame comprising 600 mm (24 in.) deep and 300 mm (12 in.) wide beams supported by the nine perimeter columns; and
- Two-way PT, 250 mm (10 in.) thick concrete slabs supported on the perimeter beams and central core.

Foundation

Each of the building's nine columns is supported by a single drilled shaft, and the base slab for the central core is supported by nine additional drilled shafts (Fig. 3). The concrete compressive strength in the shafts was 50 MPa (7250 psi), which is relatively high for such elements. The soil stratum that carries a significant part of the loads contains "blue-clays" and allows a cost-efficient foundation.

Fig. 3: The building was founded on 18 drilled shaft foundations, with one shaft per column and nine shafts supporting the concrete base slab at the central core

PT slabs

Concrete slabs in the Santa Fe II tower are two-way PT elements. The total slab depth is 250 mm (10 in.). Polystyrene foam blocks were used to define 200 mm (8 in.) webs in both directions and reduce the weight of the slabs while allowing them to be constructed with flat soffits (Fig. 4).

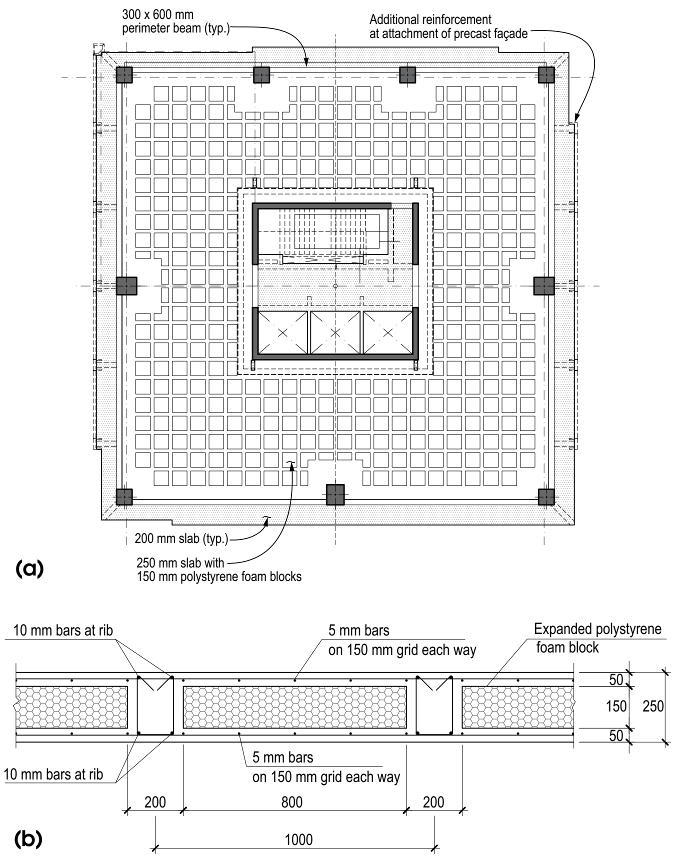


Fig. 4: Structural drawings for the two-way PT concrete slab: (a) plan view showing border beam and central core; and (b) cross section of ribbed slab

Theoretically, this structural system allows a flat concrete slab without any perimeter beam. However, the perimeter beam provides important structural advantages, including stabilizing the whole structure against overturning. In fact, lateral load analyses indicated that while the shear forces induced in the columns were low, the axial tension and compression forces induced in the columns by seismic effects were as high as 7000 kN (1574 kip)—about 30% of the service axial force in a typical column. Consequently, in the author's opinion, the central core combined with a perimeter beam and columns is the optimal structural system for this building.

Differential vertical settlement between the central core and the perimeter columns was predicted to occur during construction. The displacements would be unique at each level, so a special analysis was required for each slab. For example, in the 51st (roof) level, the service maximum vertical displacement in the central core was calculated to be about 51 mm (2 in.) while the calculated displacement at the perimeter columns was 78 mm (3 in.). The resulting differential displacement of 27 mm (1 in.) causes negative bending moments in the slabs.

The combination of the polystyrene blocks and post-tensioning allowed the floor slab self-weight to be only 3.5 kN/m^2 (73 lbf/ft^2). In contrast, a normal slab of the same thickness would weigh 6 kN/m^2 (125 lbf/ft^2). For a building with 52 levels, the benefits were quite significant for the column and foundation designs.

Parking level

The parking-level structure comprises 250 mm (10 in.) deep, two-way lightened PT concrete slabs supported on girders with maximum depths of 800 mm (31 in.). The parking-level floors are sloped to optimize the space without compromising parking slots due to a ramp (Fig. 5).

The average bay is 15 x 9 m (49 x 29.5 ft). In some cases, the girders required a light amount of post-tensioning.

Fig. 5: Parking zone construction. Girders and lightened PT concrete slabs are sloped

Construction

Foundation construction began in April 2012. The drilled shafts and base slab were completed in about 4 months, and the construction of the building's 52 stories took about a year (less than 1 week per level). The structure was completed in July 2013.

Figure 6 shows the construction of the central core and lightened PT slab for the first and second levels. Figure 7 shows the construction process for the precast façade elements.

This construction schedule was extremely tight, particularly because of the need to design each level for the effects of differential settlement. Although the residential level floors were similar in geometry, each required different reinforcing steel configurations. Even so, construction was completed without a single accident.

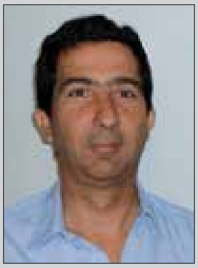
Fig. 6: Central core and lightened PT concrete slab construction: (a) reinforcement placement on the first level, in July 2012; and (b) concrete placement on the second level, in August 2012

Project Credits

Structural Engineer: Luis Bozzo Estructuras y Proyectos SL
Architect: Teodoro González de León
Builder: Anteus
Owner: Citicapital

Selected for reader interest by the editors.

Fig. 7: A progress photo taken in April 2013, showing the construction process for the architectural white precast façade elements



Luis M. Bozzo is President of Luis Bozzo Estructuras y Proyectos SL, Barcelona, Spain. Born in Lima, Peru, Bozzo attended the Universidad Nacional de Ingenieria and received his MS and PhD from the University of California, Berkeley. He has authored over 60 articles in international journals and three books about seismic resistance design and mixed reticular slabs. He has designed the largest free-form Catholic church without interior columns and 52- and 62-story central core buildings in Mexico.