The CUBE Tower

A work of structural art in Zapopan, Mexico

BY LUIS M. BOZZO

The form of the CUBE Tower not only provides a singular statement, it provides office space with great views, abundant daylighting, and good ventilation. Obstruction-free office modules jut out as cantilevers from curved central core structures (Fig. 1). A skin of Finnish wood lattices with sliding panels provides a brise-soleil (sun baffle). Office modules receive additional lighting and ventilation at the open central space (Fig. 2) among the vertical circulation cores. The resulting structure gives a light, floating sensation and offers dramatic, yet comfortable and diaphanous floor spaces that take full advantage of Guadalajara's very mild weather.

The building consists of 20 levels, including four parking levels. The below-grade parking levels cover the full 50 x 60 m (164 x 197 ft) building site to provide 10,000 m^2 (108,000 ft^2) of parking at elevations ranging from –12.90 to –4.35 m (–42.3 to –14.3 ft).

The CUBE tower in Zapopan, near Guadalajara, Mexico. The building is located in a high profile area with a highly competitive market for office space. Thus, the clients stressed the need for singularity

Fig. 1: Office modules jut out from the curved central cores constructed of white concrete, giving the tower a light, airy feel

View looking up through the open central space that provides daylighting and ventilation to the offices

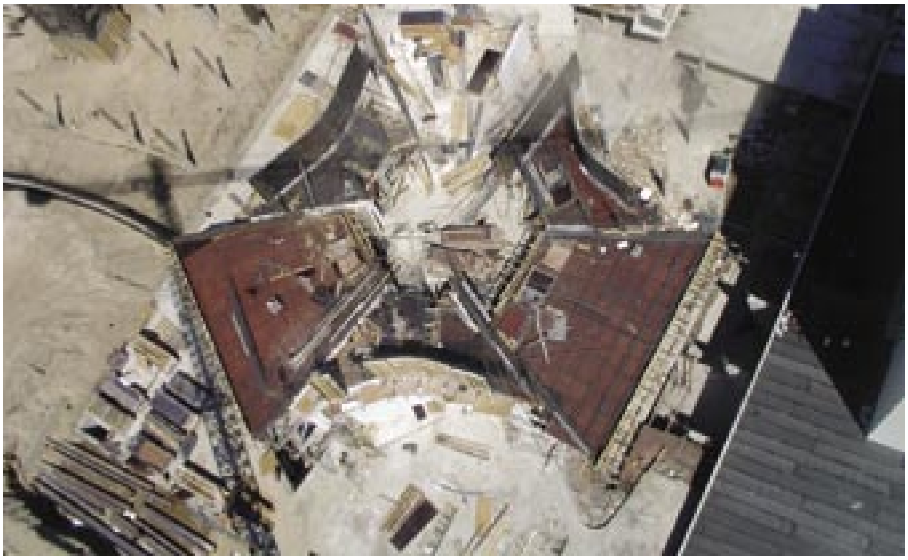

Fig. 2: Plan view of CUBE Tower under construction showing the three central cores, two office modules, and the open central space

The 16 office levels comprise three different modules bound by the three service cores and provide 7000 m^2 (75,000 ft^2) of office space at elevations ranging from –1.50 to +51.05 m (–4.9 to +167.5 ft).

STRUCTURAL SCHEME

From a structural perspective, the design challenges for the CUBE Tower included limiting the total construction cost while 1) providing a lateral force resisting system for a highly irregular building (in both plan and elevation) located in a region with high seismic risk; and 2) providing column-free floor slabs. Despite the architectural shape of the building and its extremely complex geometry, as seen in the floor plan shown in Fig. 3, the load path for the office structure is simple and clear. Floor plates are supported on two sides by the curved walls of the concrete cores as well as by steel wall beams (trusses) that cantilever from the walls. The core walls, in turn, transmit their load to three separate mat foundations.

To optimize space without losing parking spaces to ramps, the parking level floors are inclined. The parking level structures comprise one-way post-tensioned slabs supported on the perimeter walls, core walls, and special support elements shown in Fig. 4. Located at various points in the parking levels, the vertical portions of these special elements function as cantilevers resisting constant bending moments. To minimize the encroachment in the parking areas, the depth of the projecting element was minimized at the base by matching the moment of inertia at the top (neglecting the contribution of the adjacent wall) with the moment of inertia at the base (including flanges in the adjacent wall with widths equal to the height of the wall).

In the parking areas, spans are typically 11 m (36 ft), with two-way post-tensioning. The self-weight in the parking areas is only 350 kg/m^2

(72 lb/ft^2) and the average unit weights for post-tensioned and deformed bar reinforcing are only 2.2 and 8 kg/m^2 (0.5 and 1.7 lb/ft^2), respectively.

The open, column-free office areas were achieved using one-way post-tensioned floor plates with variable-length spans. While portions of the floor plates are directly supported by the core walls, the floor plates extend up to 10 m (33 ft) beyond the concrete core walls themselves. At these extensions, the slabs are supported by the chords of the steel trusses. The slabs were designed as simply supported and are 400 mm (16 in.) thick. Sections of the floor plate showing the draped tendon profile and the lightweight fill placed within the plates are shown in Fig. 5. At the exterior edge, the maximum spans are about 22 m (72 ft), resulting in a very high length-to-thickness ratio of 55. The average unit weights for post-tensioned and deformed bar reinforcing are only 3.3 kg/m^2 (0.7 lb/ft^2) and 10 kg/m^2 (2.1 lb/ft^2), respectively.

Early in the design process, post-tensioned concrete beams were considered for support of the cantilevered portions of the office modules. A number of concerns, however, eliminated this as an option. First, concrete beams would have blocked more light than steel trusses. Second, the connection between a concrete beam and the 300 mm (12 in.) concrete walls would have been more difficult to achieve than the connection of steel chord members to the concrete walls. Third, a post-tensioned beam would not provide structural redundancy—a highly important consideration for a building in a zone of high seismic risk. Finally, studies indicated that the construction speed for the concrete beam solution would not be as rapid as with the steel truss solution. This was verified during construction as the entire construction

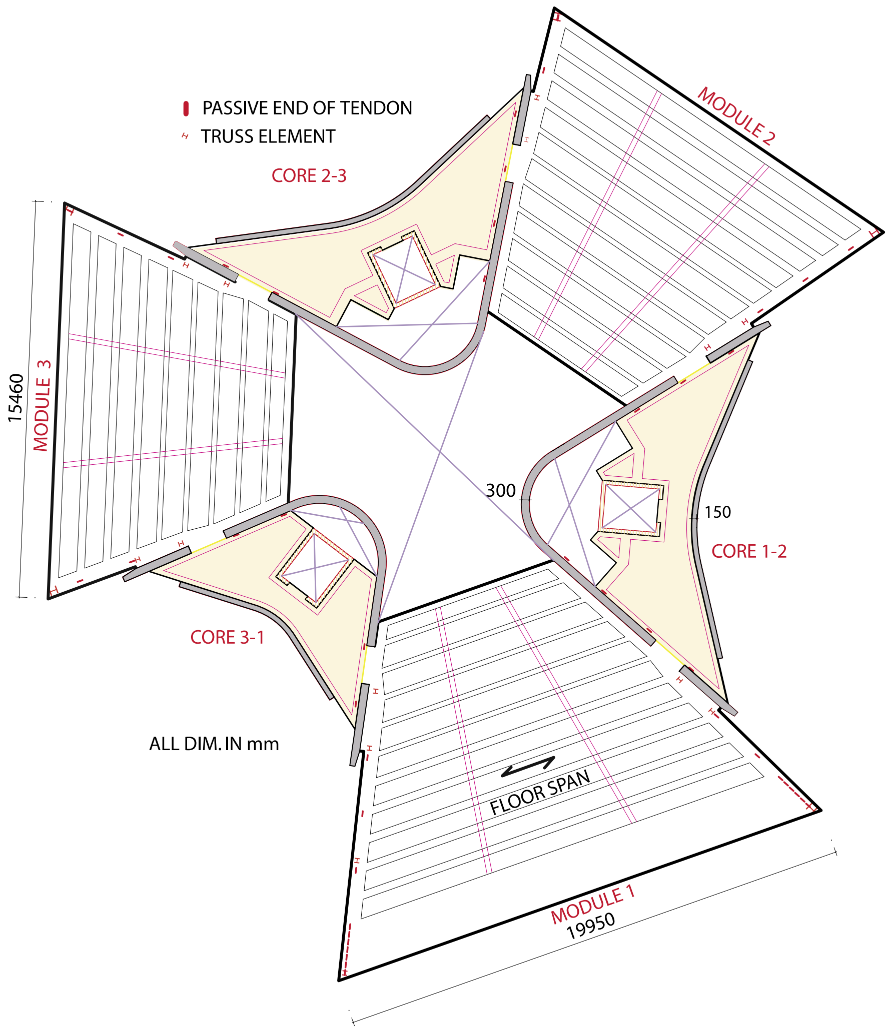

Fig. 3: Typical floor plan illustrating the complex geometry of the structure

Fig. 4: Variable cross section supports for the parking levels

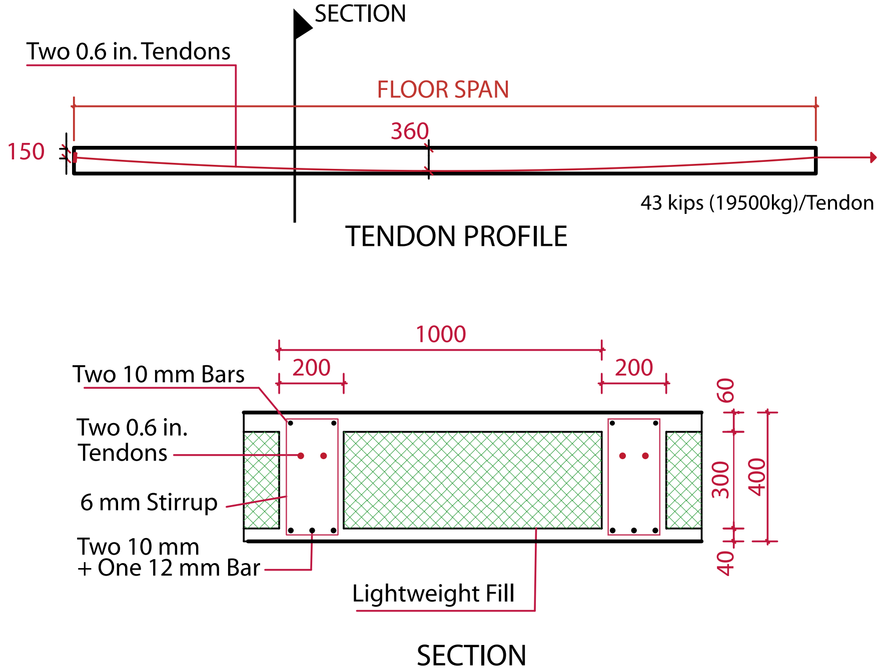

Fig. 5: Sections of the 400-mm-thick (16 in.) office module floor plates. Note the lightweight fill placed within the plate to reduce the dead load of the structure. (Dimensions in red are in mm)

Fig. 6: Connection between the concrete walls of the central core and the steel trusses supporting the floor plates: (a) during construction; and (b) after installation of the trusses and floor

cycle for a full floor plate was only 7 days.

Connections for the steel chord members included horizontal rolled steel shapes cast inside the walls. At Level 1, vertical struts were added to drag the forces from Level 1 up into the wall above (Fig. 6). These tension ties were necessary because portions of the wall did not extend into the basement.

The connection points were fabricated using round structural tubing plus rectangular plates. Although only two connections were required to anchor each horizontal steel chord, an additional diagonal connection element was added to provide redundancy for seismic loads.

The office modules are positioned so that they balance each other. Overturning moment induced by each module is compensated between the three wings, thus avoiding gravity-induced base shear in the foundations. Balancing of the system was important because it would have been complicated and expensive to anchor the mat foundations to the ground.

As shown in Fig. 7, the entrance stairway to the reception area has very slender sections. The stair is formed by a two-way, variable section slab with minimum depth on the visible side.

VIBRATION ANALYSIS

An important consideration for the design of any slender slab is the effect of vibrations on occupant comfort. Because excessive vibrations can cause the closure of an office and can result in litigation, and because this structure had very slender slabs, particular attention was paid to the dynamic behavior of the slabs.

The floor system was modeled as a series of independent, one-way beam elements. The natural frequencies were calculated for five representative spans at three different load levels:

1) self-weight only; 2) self-weight plus 1 kN/m^2 (20 lb/ft^2) of permanent load; and 3) self-weight plus 3 kN/m^2 + 2.5 kN/m^2 (60 lb/ft^2+ 50 lb/ft^2) of permanent and live loads, respectively.

The analyses indicated natural frequencies of 3.4 Hz for the very low probability case of self-weight + 5.5 kN/m^2 (110 lb/ft^2) loads and 5.73 Hz for self-weight only. According to European standards, the minimum natural frequency for office buildings is 3 Hz. Although the slabs met this code requirement, our previous experience with long span slabs indicated that this structure could still have vibration problems. Consequently, we decided to connect the floor slabs with vertical 100 mm (4 in.) steel tubes welded to connections embedded in the edges of the slabs. These elements are spaced about 2.5 m (8 ft) on center along the slab edge and also serve to support the wood façade elements.

During construction, even with self-weight only, just the footfalls of a single man induced sensible vibrations in the floors. Further, before installing the façade, even a single person walking around in an office caused vertical vibration of the roof. After installing the vertical tubes for the façade, however, vibrations were no longer noticeable.

ECONOMY OF DESIGN

In general, the final cost of a building is the result of diverse factors. Major factors include, however, the adopted scheme for the load path, the resulting spans, and the selected materials. In general, because analysis models will be more precise and effective and because sections and members will be more readily optimized, a building will be most economical if unambiguous mechanisms for the load paths are defined. Finally, because the selection of both the material and the structural shape will influence the final cost, function and form must be bound together as far as possible.

The total construction cost for the CUBE Tower, excluding office finishes, is only \$350 USD/m^2 (about \$35/ft^2) and is only slightly higher than more typical construction in this

Fig. 7: The slender main stairway, leading to the reception area, under construction

Fig. 8: This view looking out over Guadalajara from within one of the office modules demonstrates the clean, open feel of the office areas

View of cutouts in the central core structures at the main lobby level

market. Given the very large, dramatic spans and cantilevers, as well as the beauty of the structural forms, the low cost is particularly notable.

Figure 8 shows a view looking out from within an office module. Before even placing the façade, the beauty of the offices is clear with clean, open spaces inundated by exterior light. The clean steel-concrete connection allows simple glass and façade connections providing a safe, earthquake-resistant structure. Cooperative work between the architects and engineers made it possible to achieve a piece of structural art while keeping costs low.

Selected for reader interest by the editors.

PROJECT CREDITS

Owner: CUBE Group
Builder: Anteus
Architectural Designer: Carme Pinós of Estudio Carme Pinos
Architectural Collaborators: Juan Antonio Andreu, Samuel Arriola, Frederic Jordan, and Cesar Vergés
Structural Engineer: Luis M. Bozzo of Luis Bozzo Estructuras y Proyectos SL
Structural Collaborators: Edgar Pallarols and Francisco Cervantes

Luis M. Bozzo is President of Luis Bozzo Estructuras y Proyectos SL, Barcelona, Spain. Currently, his company is designing a new stadium for the soccer team Chivas de Guadalajara, Mexico. Born in Lima, Peru, Bozzo attended the Universidad Nacional de Ingenieria and received his MS and PhD from the University of California at Berkeley. He has authored more than 60 articles in international journals and three books about seismic resistance design and mixed reticular slabs.