O-14

Elegant Rhythms in Concrete

By Jaime M. Ocampo

Among the assortment of iconic structures in Dubai, O-14 is truly unique. Its perforated concrete exterior shell, which serves as an environmentally smart *brise soleil*, i.e. sunscreen that allows light, air and views, is its main architectural feature and also its primary structural system. This exoskeleton-sunscreen wall (*Figure 1*) features more than 1,300 openings of different sizes, arranged in an apparently random pattern. Far from being random, however, the seemingly arbitrary arrangement of the openings in the wall creates a diagonal grid that enables its use as a gravity and lateral supporting system. This design solution represents the use of concrete at its best.

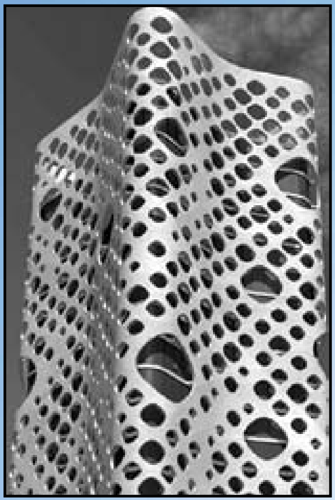

Figure 1: The O-14 Exterior Shell. Courtesy of Reiser + Umemoto.

O-14 is prominently located along the waterfront esplanade of the extension of Dubai Creek. The 22-story tall commercial building is enclosed by a two-story podium that is not attached to the tower. Five pedestrian bridges, each passing through a wall opening, provide access between the tower and the podium. O-14, named after its lot designation, stands on a site of 34,392 square feet, while the building has a total area of 300,000 square feet, including four levels of basement. The typical office floor area is 6,000 square feet.

With the exterior shell being a primary structural element, the architect, Reiser + Umemoto (RUR) and the structural engineer, Ysrael A. Seinuk, P.C. (YAS) collaborated closely in configuring the entire façade. The sizes and locations of the openings were carefully coordinated in order to make the wall effective in channeling both gravity and lateral loads down to the base of the building. Several iterative analyses determined the size and reinforcement of each solid shell element between the openings.

In order to allow for four levels of parking below grade, a continuous 4-foot deep ring beam at the ground level supports the entire exterior wall (*Figure 2*). Vertical loads from the exterior shell are transferred to (15) large garage columns that the design team strategically located in order to maximize parking spaces. Meanwhile, the lateral forces that accumulated in the wall are transferred to the foundation walls and core shear walls in the basement levels through the ground floor slab.

Figure 2: Continuous pick-up beam at the ground level picking up the exterior wall. Courtesy of Reiser + Umemoto.

The shape of the exterior wall in plan is also an interesting feature (*Figure 3*). It resembles a rectangle with curved corners and concave sides. The core walls that are surrounding the main office stairs and elevators, and the irregularly shaped exterior wall, constitute the gravity and lateral supporting system of the building. The central core is basically supporting gravity loads, until some lateral loads are transferred to it at the ground level.

The building is free of interior columns; the floor slabs span between the interior core and the exterior shell. This allows future tenants to arrange a flexible floor space according to their individual needs.

A space nearly 40 inches wide exists between the shell and the main enclosure. This gap creates a space for hot air to rise, thereby effectively cooling the surface of the glass windows behind the concrete exterior shell. The floor slabs connect to the exterior wall (*Figure 4*) by crossing this gap with 16-inch thick slab links to solid portions of the wall. Because the openings vary throughout the façade, the slab connections are located at different points at each level.

The floor system of O-14 is a conventional flat plate system, with spans ranging from approximately 22½ to 35 feet. Slab thicknesses are 8 inches and 12 inches at the

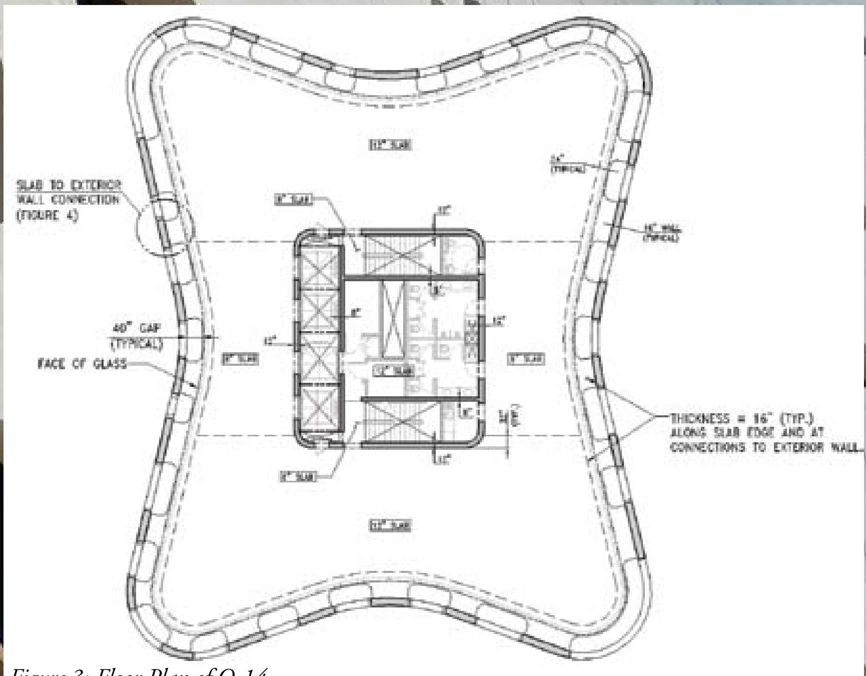

Figure 3: Floor Plan of O-14.

typical office floors, with 16-inch thick spandrel beams running along the perimeter of the floor slabs. At the underground parking levels, the floor slabs are 12 inches thick, with columns spaced at approximately 20 to 35 feet apart.

The podium encircling the tower is supported by a truss at the north side and nine circular columns in its interior. At the east and west property lines, it is supported by reinforced concrete walls. The truss is approximately 165 feet in length and spans the entire width of the site. The architect and the structural engineer developed a truss configuration that blends with the entire structure and does not restrict the views of the wide open exhibit spaces.

The entire structure is supported on drilled cast-in-place piles. The lowest basement floor, at approximately 51 feet below grade, is a pressure slab with a minimum thickness of 40 inches. The ground water level is approximately 10 feet below ground. Lateral earth pressures at the basement levels are resisted by thirty two-inch thick perimeter diaphragm walls with tie-backs or earth anchors.

The Exterior Shell

From the ground floor to the top of the parapet wall, the total height of the exterior shell is 347 feet. The wall thickness is 24 inches from the ground to the 3rd level, and 16 inches from the 3rd level to the roof. In the transition area, void forms (see *Construction Methodology* below) were fabricated with a special detail utilizing extra foam pieces, which were added to the forms on the interior face of the wall. For the entire wall, normal weight concrete with a strength of 10 kips per square inch was used.

Modeling and analyzing the shell of O-14 was one of the biggest challenges of the design process. With coordination between RUR and YAS, the analyses were conducted so that the final shell design would satisfy both architectural and structural requirements.

The design process began with RUR using *Rhino* (modeling software) to generate a 3D model of the shell, which contained the preliminary locations of the openings. The architect then converted it into a 3D AutoCAD model, which YAS later imported into the SAP2000 software for analysis. The engineer applied the gravity and lateral forces to the shell, and then determined the stresses in the elements between the openings. He identified the overstressed elements, and the design team adjusted the sizes and locations of the openings, which resulted in a slightly different grid pattern. YAS then sent the structural comments to RUR in order for them to study the architectural implications of the changes. The architect revised their model and returned it to the engineer for another round of analysis. This disciplined process took several iterations until the shell openings, elements and grid pattern became acceptable to both the architect and the structural engineer.

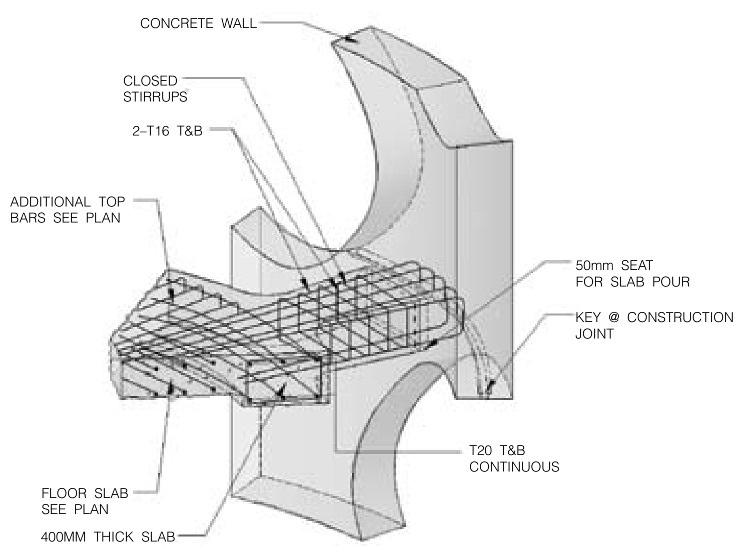

Figure 4: Slab connection to the exterior wall.

Figure 5: O-14 topped out. Courtesy of Dubai Construction Update ***ImreSolt.com*** *– 2009.*

Another consideration in the layout of the shell openings were the connection points of the interior slab to the exterior shell, which occur at the solid portions of the wall. Basically, the widths of the openings at each level dictated the lengths of the edge spans of the interior slab. In some instances where the spans became excessively large because of a very wide opening, adjustments were made to the size and/or location of the opening.

Special attention was given to the detailing of the reinforcement. Each individual element had to mesh completely with the greater system to ensure adequate transfer of forces. The engineer determined the overlaps and splice points based on embedment at each "node" location. In designing the reinforcement, the engineer always considered the ease of placement of concrete. Overall, the reinforcing requirements were moderate and economical.

Construction Methodology

In order to create the perforated exoskeleton, the contractor of O-14 used the slip-form construction technique: modular steel forms that move up along the building axis. This method prevented costly dismantling and setup of complex shapes. Computer Numerically Cut (CNC) polystyrene void forms were woven into the reinforcement matrix of the shell, with the slip forms of the shell set to outline each face of the wall. Concrete was then cast around the fine meshwork of reinforcement and void forms. Once the concrete had cured, the construction crew loosened the forms and moved them up the tower to the next level, where the process began again. Dubai Contracting Company worked closely with Beijing Aoyu Formwork Company in systematizing the production of the foam pills on site, and in streamlining the assembly process of the sheathing, steel reinforcement, and foam pills prior to casting.

More About O-14

O-14's innovative design has generated extraordinary interest around the world. It was featured in an hour-long documentary about Dubai ("Impossible City"), which was produced by CBS News and shown on the Discovery Channel in October, 2008. On May 14, 2009, the tower's concrete structure was completed (*Figure 5*), making it one of the first towers to appear in the skyline of Business Bay. O-14 is scheduled to open in the spring of 2010.

Although meticulously designed, engineered and executed, O-14 displays the abilities of concrete design to achieve an elegantly rhythmic structure. It truly epitomizes concrete at its best.▪

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