Omnilife Soccer Stadium for Guadalajara's Chivas

Geometry, function, and form are linked to provide a highly efficient structure

BY LUIS M. BOZZO

In August 2010, the Omnilife Stadium in Guadalajara, Mexico, became the new home of Club Deportivo Guadalajara, the soccer club commonly known as Chivas. Constructed as part of *el Centro JVC*, a development that will also include auditoriums, convention centers, and residential buildings, the stadium is aesthetically designed to evoke the image of a "volcano with a cloud" rising from the countryside (Fig. 1). This design fits in well with the nearby *Bosque de la Primavera* (Forest of the Spring), an extensive park with huge tree-covered hills that form a natural backdrop for the development.

The stadium has capacity for 45,000 and includes more than 200 full-visibility locations for people with disabilities and their companions as well as 330 private boxes in the two levels above the main concourse. The facility includes 70,000 m^2 (750,000 ft^2) of green space and 5000 parking spaces, and it's linked to Guadalajara via a road network that allows evacuation of the stadium in under 20 minutes.

DESIGN OPTIMIZATION

In an early design solution, the stadium was to be surrounded by 25 m (82 ft) tall vertical retaining walls supporting backfilled berms (forming the slopes of the volcano). Pile foundations were to be used throughout the structure, as the soil capacity was apparently insufficient to support the heavily loaded macrocolumns supporting the roof (the cloud) and seismic requirements would not allow the use of a mixed foundation system

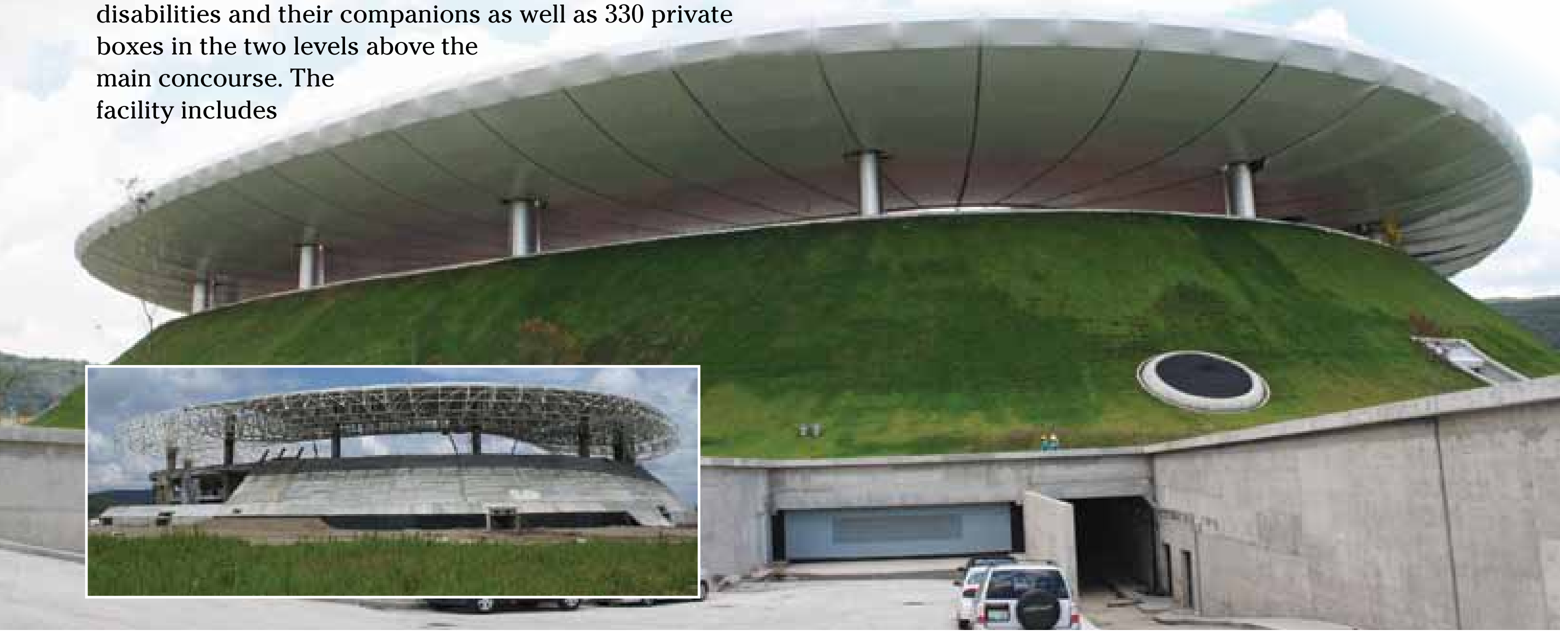

Fig. 1: Omnilife stadium in Guadalajara, Mexico. Inset: The "volcano and cloud" take shape. Access to the stadium is gained through a large opening through the volcano. The large opening (shown in the inset) and five smaller openings provide egress. The volcano is formed by a truncated cone formed of concrete. This feature significantly reduces potential seismic loading and provides a beautiful, 20 m (65 ft) tall meeting place on the main concourse

Fig. 2: Construction of the berm of the volcano. The upper support for the slab units consists of a horizontal diaphragm with two ring beams connected by diagonal struts: (a) view from the concourse as a slab unit is installed in the berm. In the foreground, stair formwork is assembled at a secondary column *(photo courtesy of Juan Pablo Beas)*; and (b) view from the stairs leading to the upper concourse, showing a macrocolumn in the foreground and a secondary column (with stair formwork) in the background

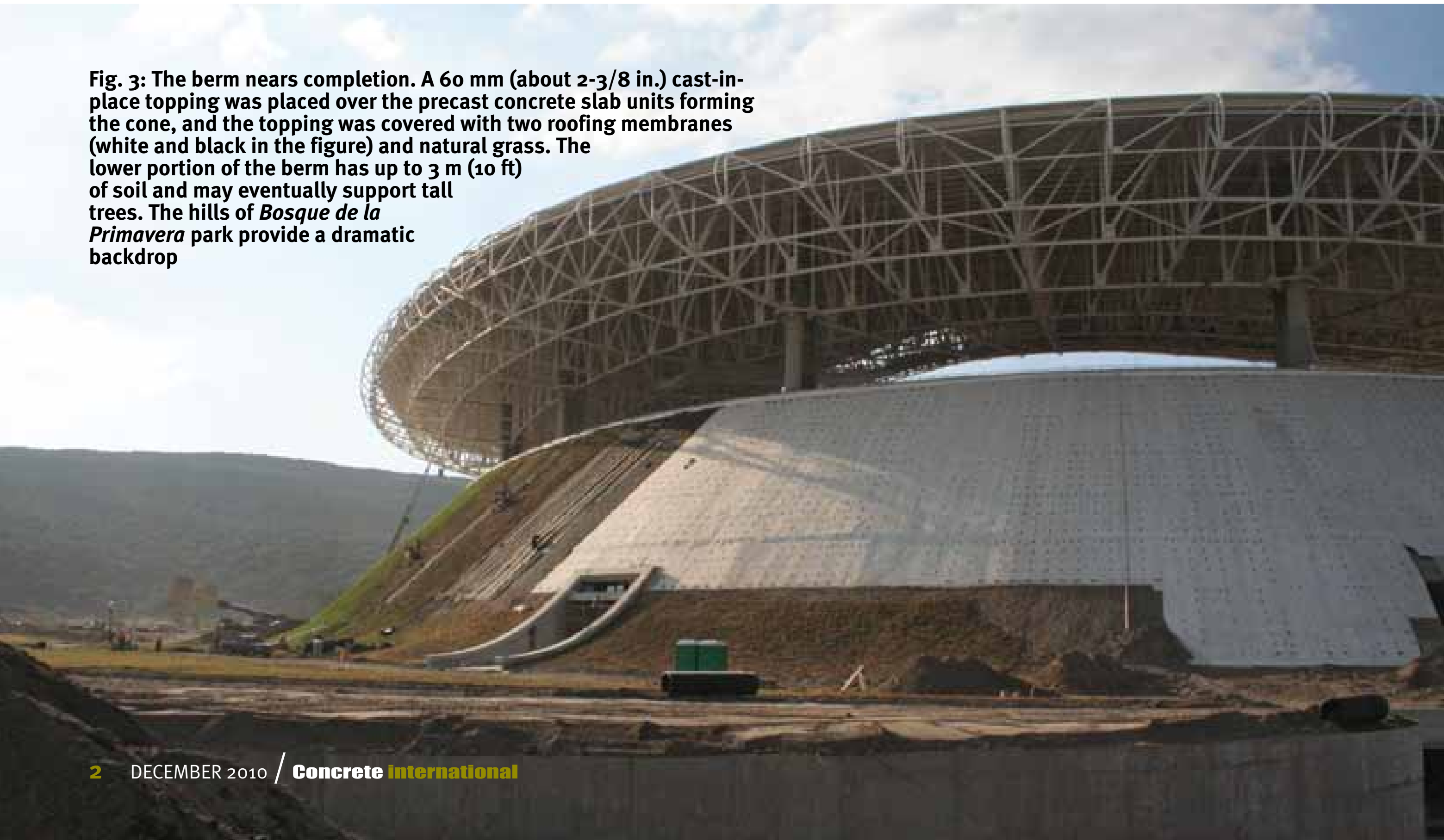

Fig. 3: The berm nears completion. A 60 mm (about 2-3/8 in.) cast-in-place topping was placed over the precast concrete slab units forming the cone, and the topping was covered with two roofing membranes (white and black in the figure) and natural grass. The lower portion of the berm has up to 3 m (10 ft) of soil and may eventually support tall trees. The hills of *Bosque de la Primavera* park provide a dramatic backdrop

with footings at the secondary elements such as walls and stairs. The macrocolumns were to be independent of the seating bowl structure, so the large overturning moments imposed by the roof cantilever had to be taken at the foundation level. Finally, the complex geometry of the roof structure was to be created using a space frame constructed of thousands of imported, individually numbered bars.

Following the maxim that a particularly efficient structure is one that has a “resistant shape” that links geometry, function, and form as seamlessly as possible, our firm optimized the structure of the stadium and reduced the project cost by 50% from its original $200 million (USD) budget. While the revised design maintained the overall architectural concept of a volcano and a cloud, it incorporated significant changes that allowed dramatic cost reductions:

- The volcano is created using sloped slabs covered with a thin layer of soil and grass (Fig. 1 to 3). This eliminates the need for massive retaining walls as well as extensive cut and fill, and it creates an open, tall space within the stadium;
- Footings were used throughout the structure. While the soil-bearing capacity in Guadalajara is high and allows service-load values of 600 to 1000 kPa (12,000 to 20,500 psf), local soil improvement was still needed where heavy loads were to be supported. The additional cost of soil improvement was more than offset, however, by allowing the use of footings rather than piles at secondary elements connected to the structure;
- The macrocolumns supporting the roof are incorporated into the supporting structure for the sloped slabs of the volcano, and they provide support for the upper seating areas (Fig. 2 and 3). The sloped walls and raker beams and columns work together with the macrocolumns to resist overturning moments from the large cantilever of the roof;
- The inclined slabs for the berm create a continuous concrete cone-shell structure that is inherently highly resistant to seismic effects, thus making design requirements for seismic actions insignificant relative to requirements for gravity effects. Consequently, the structure is made up of two structural systems: an interior three-dimensional ductile spatial frame and an

Fig. 4: The private box levels comprise field-topped precast floor elements and precast seating units supported by post-tensioned double cantilever beams: (a) in April 2008, construction of the lower level was underway; and (b) in March 2009, the structure for the two private box levels and upper concourse levels was nearly complete

exterior incline concrete cone linked together by a top horizontal Warren truss diaphragm; and

- The roof structure was simplified to consist of large, locally fabricated trusses, and the number of unique trusses was optimized to provide additional savings.

Other innovations also contributed to the success of the design. The stadium bowl structure combines post-tensioned and precast elements to provide clear spans of up to 22 m (72 ft). The precast, prestressed seating units were made continuous to avoid joint leakage (a common problem in stadiums with simply supported seating units). Also, although it's a very large building (the perimeter of the grid defining the location of the macrocolumns is more than 680 m [2200 ft] long), the stadium structure includes no expansion joints, as these would significantly diminish the cone's resistance to earthquakes.

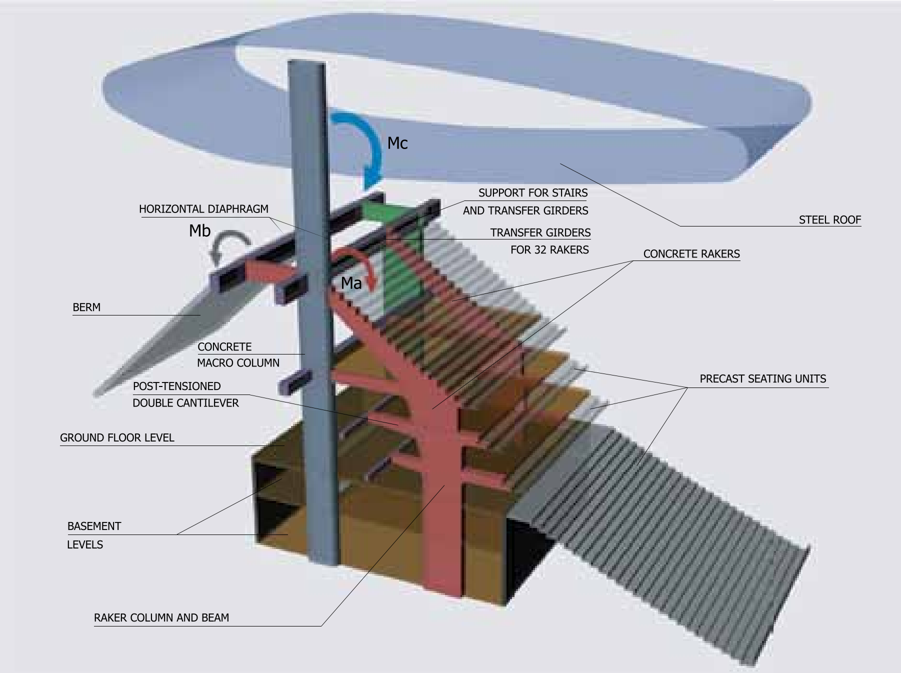

Fig. 5: Schematic of the stadium structure. The total cantilever moment from the roof is resisted by the raker beams and columns (red) and the sloped slabs of the berm

SYSTEMS DESIGN

Foundations

As previously indicated, the entire building is supported on footings. Where high loads were expected (at raker beam columns and macrocolumns), the existing soil capacity was improved by excavating below the bearing elevation, mixing the soil with cement, and compacting the mixture. The bearing elevation of the footings was therefore maintained nearly constant over the whole stadium, minimizing local seismic stress factors (it's common to find local failure of short beam-columns after any strong earthquake, as these attract excessive shear forces).

Raker beams and concourse floors

The stadium footprint is approximately elliptical, with a distance of 42 m (138 ft) between each pair of macrocolumns. A smaller, intermediate column is located along the circumferential grid between each pair of macrocolumns. Most of these intermediate columns include cantilever stairs providing access to the upper concourse level. Thirty-two raker beams are supported on transfer girders spanning between the macrocolumns and the intermediate columns, and 16 raker beams frame directly into the macrocolumns. All raker beams are supported on raker columns located on an inboard circumferential grid. The system permits clean views of the soccer field from most places inside the volcano, thus increasing the sense of open space.

The raker beams and raker columns are 750 mm (30 in.) wide and have variable depths. Floor slabs for the two private box levels are supported on post-tensioned double cantilevers (Fig. 4 and 5). The tendons for these elements are straight, minimizing friction losses, and the cantilever beams vary in depth to provide the necessary eccentricity for the tendons. Supported on these elements are semi-continuous, prefabricated hollow-core units and seating units, as seen in Fig. 4. A cast-in-place topping course provides continuity of the precast hollow-core elements, and a cast-in-place joint at each raker beam establishes continuity of the seating units. This feature is described in more detail in a following section.

Although the straight prestressing strands for the cantilevers pass through the raker columns, the level of prestressing is limited to avoid reducing the ductility of the raker columns themselves. For main structural elements in high-seismic zones, it's appropriate to use prestressing strand only to limit cracking under service loads and provide a maximum axial force between 10 to 30% of the compressive capacity of the column. Although the encompassing concrete cone significantly reduced expected seismic effects, this restriction dictated a considerable amount of passive reinforcement at the connections.

Load-transfer mechanisms

The structural configuration elegantly reduces the moment at the base of the macrocolumns. Although the self-weight of the roof structure is low, the bending moment at the top of the macrocolumns is high due to the 35 m (115 ft) cantilever of the roof. The raker beams and columns, as well as the sloped slab elements forming the volcano, provide horizontal reactions at the top of the seating bowl, so the bending moment induced by the roof is reduced to nearly zero at the macrocolumn foundations (Fig. 5).

The flexibility of the roof is also considerably reduced, because the unbraced length of the column is 1/3 of the total height. Thus, wind-induced vibration—the dominant action for a lightweight structure with a large cantilever—is minimized. This allowed us to use reinforced concrete for the macrocolumns, rather than less economical concrete-filled steel tubes. Figure 6 shows the bottom chord connection at a macrocolumn.

Continuity of seating units

We adopted a precast, prestressed design for the seating units, using four or six 0.6 in. (15 mm) diameter strands per unit (Fig. 7). Mild steel reinforcement was provided at the ends of the units to provide continuity after the initial self-weight deformations had taken place. The construction process was:

- On-site prestressing of the units using straight tendons and self-stressing steel beds;
- Installation of the units on the raker beams without provisional supports, allowing initial deformation due to self-weight to take place; and
- Making the units continuous by infilling between units with nonshrink grout (Fig. 7).

This simple procedure will minimize the leaking of rainwater and beverages through the seating deck to the lower levels. It also provides seating units with much greater stiffness than they would have if spans were simply supported. This is an important consideration for the 14 m (46 ft) spans in the stadium because the sections were highly optimized. The displacement of a fixed-end beam is between 20 and 50% that of a simply supported beam of the same cross section, so the fundamental frequencies of the installed units will be between 1.4 and 2.2 times larger than if they were simply supported, considerably reducing the potential for vibration sensitivity problems.

Fig. 6: Connection detail between a macrocolumn and main radial roof truss and circumferential roof trusses (*photo courtesy of Juan Pablo Beas*)

CONSTRUCTION TIMELINE

The earthwork for the column foundations and raker elements began in 2006, and construction of the stadium itself began in 2007. On September 2, 2009, the steel truss structure of the roof was completed. The stadium opened on July 31, 2010, so the construction period was about 3 years. By July 30, 2009, 1200 workers had completed 200,000 worker hours without serious accidents, indicating the high level of safety attained during the project.

UNIQUE FEATURES

The structural system is not the only unique aspect of the project. The open spaces around the stadium and below the berm will be used by various commercial shops, ensuring continuous use of the facility—even during daily team training. Also, the stadium is the first to incorporate a sixth-generation artificial turf. This turf is a blend of fibers, silica sand, and rubber sand made from recycled sneakers and has been officially recognized by the Fédération Internationale de Football Association (FIFA). Although it cost more than $1 million (USD), the turf has very low maintenance requirements and a high resistance to ultraviolet light.

Selected for reader interest by the editors.

Fig. 7: Precast-prestressed seating elements were produced on site: (a) units included exposed passive reinforcement for subsequent embedment in continuity joints at raker beams; and (b) the continuity joints for the precast seating units (dark concrete) help to avoid leakage from rain and drinks, and they reduce crowd vibration issues, both common problems with simply supported seating units

PROJECT CREDITS FOR OMNILIFE STADIUM

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Architect: Populous (formerly HOK Sport) and Vergara & Fernandez de Ortega (formerly HOK Mexico)
Structural engineer: Luis M. Bozzo
Local engineer: Roberto Dávalos
On-site engineer: Mario Velázquez Zaragoza
On-site chief: Joaquin Rincón
Quality control: ICA (responsible architect: Martha de la Rosa Gudiño)

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