Post-Tensioning a Structure in Spain

Plan dimensions, loads, and maximum long-term deflection limits make the design of the new Sabadell club unique

BY LUIS M. BOZZO

The Sabadell swimming club is one of the largest in Spain. Its previous facility was built many years ago and was located very close to the central area of the city. Challenges of the new facility—which accommodates two Olympic-sized pools and one recreational pool—were to build it very near to the old one and to occupy the same area, about 10,000 m². The Sabadell club found a perfect location, but local regulations limited the height and occupancy of the building. To overcome the limiting plan dimensions of the site, the architect decided to partially bury the building, which restricted the amount of natural light that could enter the structure.

Even with the building partially buried, it was necessary to span an area of 50 x 45 m without interior columns, while supporting the loading of a 1.3-m-deep swimming pool and providing easily accessible installations. Large long-term deflection in the main roof could cause cracking in the upper swimming pool and future water leakage. Post-tensioning proved to be the solution to the facility's challenges.

The main structure of the new Sabadell club facility is a bi-directional, post-tensioned space frame. The load transfer scheme is relatively simple—there is a main double-box girder (marked as FASE 1 in Fig. 1) and several secondary beams (marked V0 to V6). Secondary beams transfer load to the main double-box girder at one end and to the sculptural columns at the other (Fig. 2). To increase the amount of natural light inside the structure, there are no columns in the side areas. Both architectural and maintenance requirements

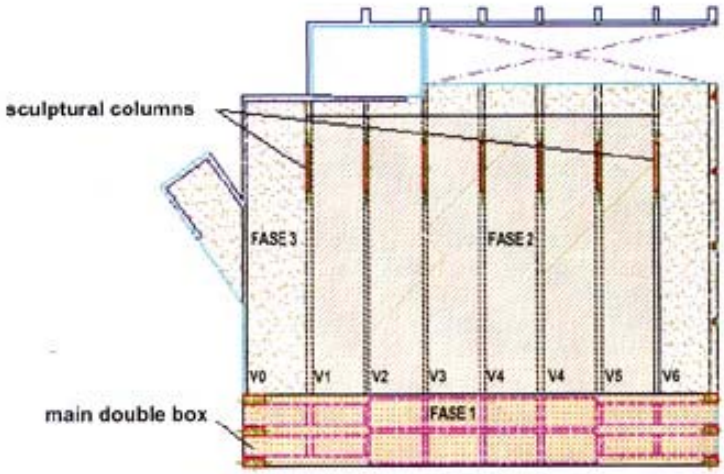


Fig. 1: Plan view of the bi-directional, long-span, post-tensioned space frame for the new Sabadell swim club facility



Fig. 2: The sculptural columns and the double-box girder are already formed at the completion of Phase 1

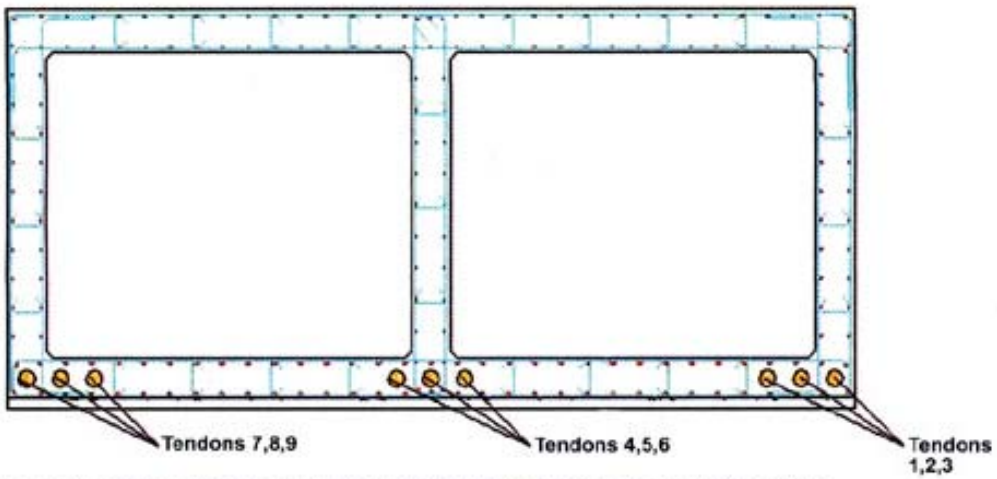


Fig. 3: A section of the main double-box girder showing the location of the nine post-tensioning tendons



Fig. 4: Transition zone between the M-shaped and double-box sections of the main girder. Notice the M-shaped section is missing the bottom slab

restricted the design of the structure; it is necessary to frequently access the swimming pool equipment from an area close to the sculptural columns. The structure requires a double roof to access the equipment and to support the swimming pool, which has a maximum load of 30 kN/m^2.

A DOUBLE-BOX GIRDER

The main girder carries the negative bending moments from the secondary beams by torsion. Due to the spans and loads, the torsion was very large (about 40,000 kN-m) and, therefore, the engineer used a double-box section (a closed section has larger torsional resistance than an open section).

Figure 3 shows a section of the main girder, which is 6.8 m wide and 2.7 m high, with a rib thickness of only 300 mm (to reduce the girder's weight). The main girder contained nine, 4500 kN tendons. Each tendon had a parabolic drape on the sides and a straight profile at the bottom of the girder's middle section. Post-tensioning the main girder was necessary because of the significant span length, the loads, and the long-term deflection limit of 50 mm. Due to the large torsional moment, and to minimize warping of the cross section, the secondary beams joined the main girder at a maximum distance of 1000 mm from the bottom of the girder. This distance was used to accommodate the passive post-tensioning anchorage for the secondary beams by being accessible inside the double box during the construction process and for inspections afterward.

Another interesting point regarding the structure is that the geometry of the double-box girder changed in the middle section due to architectural issues with illumination, causing the lower slab to disappear. Consequently, the section transforms into an M-shaped section by removing the lower slab of the box girder. Unfortunately, the M-shaped section occurs in the zone where the structure requires maximum torsion resistance (Fig. 4).

Before performing any numerical analysis, a preliminary analysis revealed that it was not possible to carry the torsional moment just by dividing it into the three ribs of the girder's cross section. However, an alternative mechanism based on dividing the torsional moment by the distance between the lateral ribs (40,000 kN-m/5.97 m = 6700 kN) resulted in shear forces that were easy for the main girder to accommodate. This mechanism was achieved by providing a "rigid diaphragm" where the main girder transitioned between the double box and the M section. At the M section, the ribs' thicknesses were increased from 300 to 900 mm, and this dimension was continued to the next secondary beam after the transition zone. Finally, the engineer performed a refined finite element analysis at the transition zone to verify the torsion transmission mechanism.

Besides allowing for illumination, there was an advantage of the M section for the prestressing. The center of gravity of the M section is above that of the double box and, consequently, the eccentricity of the tendons is larger at the same relative tendon position.

CONSTRUCTION SEQUENCE

The construction sequence for this structure included three phases. These phases were:

Phase 1: Construction and post-tensioning of the planar main frame, which consisted of the main double-box girder. This phase was considered mandatory to

keep the prestressing load from dissipating into the slab or other zones. Due to the singularity of the structure, it was necessary to apply 100% of the prestressing load to the main double-box girder without any loss of prestress in surrounding elements, controlling the response and calibrating the model with "in place" measurements.

Phase 2: Construction and post-tensioning of the secondary beams. In this phase, the contractor built and prestressed the secondary beams before connecting the slab to the surrounding wall. Again, this was adopted to fully control the applied load. Figure 5 shows this construction phase, illustrating how the secondary beams frame into the main girder.

Phase 3: Construction of the surrounding elements and adjacent walls.

ANALYSIS

Due to the complexity of the structure, the engineer used three models for analysis:

- A planar frame using a precise fiber constitutive steel and concrete model including long-term strains. This model was validated during construction by monitoring the vertical displacements caused by the prestressing;
- A linear 3-D model using the equivalent prestressing loads and the corresponding instantaneous and long-term losses; and
- A 3-D shell finite element model for the transition zone between the columns and the main girder with the M-shaped and the double-box sections.

The structure was monitored during the prestressing, and the vertical deflections in the middle and at the quarter points of the girder were measured. Measured values were 3.4 mm and 2.1 mm at L/2 and L/4 locations, respectively. The difference with respect to theoretical values was smaller than 10%, which is insignificant due to variables such as precise dimensions, material properties, or boundary conditions.

THE FINISHED STRUCTURE

Figure 6 shows an inside view of the finished structure with the sculptural columns and the natural light from the sides. The secondary beams are not visible because there is a lower prestressed slab element for architectural reasons. The columns have variable thickness to outline their shape and to facilitate the passing of reinforcement during construction.

The new structure for the Sabadell swim club required a design that took advantage of the capabilities of post-tensioning technology. Now, members of the club can focus on continuing the club's tradition of membership while enjoying their new facility.

Selected for reader interest by the editors.



Fig. 5: Phase 2 of construction showing the reinforcement for the secondary beams



Fig. 6: Interior view of the finished structure showing the natural light from the sides of the building



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