# A Prestressed Partially Precast System

## Orthotropic prestressed slabs combine two-way action with advantages of precasting

BY LUIS BOZZO

In precast construction, there are many one-way prestressed or steel-concrete composite solutions. Mainly due to transportation limitations, however, there are almost no solutions that provide two-way action. In this article, I'll describe an innovative prestressed partially precast structural system for construction of long-span, two-way slabs with high span-to-depth ratios. Since the system was developed in 2003, more than 200,000 $m^2$ (2,150,000 $ft^2$) of civil and residential structures have been built with it.

## PRESTRESSED PARTIALLY PRECAST SYSTEM

The system is illustrated in Fig. 1 and 2 and uses the following elements:

- Prestressed precast slabs that are 1 to 3 m (3.3 to 9.8 ft) wide and 60 to 300 mm (2.4 to 11.8 in.) thick, depending on the span;
- Shear reinforcement, comprising stirrups or lattice girders, embedded in the precast slab elements and extending to near the top of the completed section;
- Positive moment reinforcement near the top of the precast slabs and running perpendicular to the direction of prestressing. These bars are denoted "orthotropic reinforcement";
- Negative moment reinforcement near the top of the completed section and running in both directions; and
- Cast-in-place concrete to complete the section.

The prestressed slabs have a maximum width of 3 m (9.8 ft) so they can be easily transported and placed in their final position. This also allows construction of curved structures that are common on highway bridges as illustrated in Fig. 3. In this case, the width of the precast elements is small compared to the support spacing and the radius of curvature of the highway. This allows the use of straight precast elements and compensation for the difference at the borders with cast-in-place elements. For the example shown in Fig. 3, the highway radius is 67 m (220 ft), the support spacing is about 10 m (32.8 ft), and the cast-in-place compensating element at the edge of the roadway is only 200 to 300 mm (8 to 12 in.) wide. At the present time, we've constructed up to 16 m (52.5 ft) spans with a 450 mm (17.7 in.) thick slab cast over a 150 mm (6 in.) thick precast slab.

The orthotropic reinforcement must be above the precast slabs. In the direction of the prestressing, the combination of a greater effective depth and an uncracked

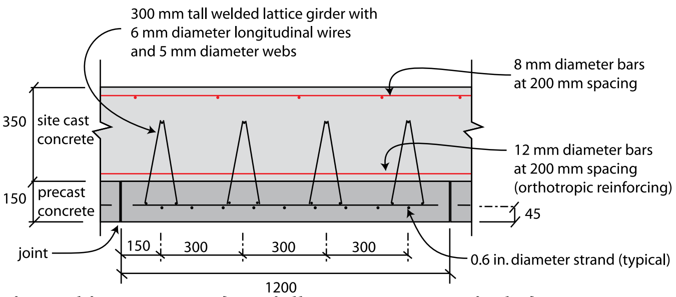


**Fig. 1: This prestressed partially precast system includes a 150 mm (6 in.) prestressed precast slab, orthotropic positive reinforcement running perpendicular to the precast slab span, negative reinforcement in both directions at the top of the slab, and a 350 mm (13.8 in.) cast-in-place upper slab (All dimensions in millimeters; 1 in. = 25.4 mm)**

**Fig. 2: Prestressed precast slabs at a casting yard in Spain**

section due to the prestressing produces a greater moment of inertia for positive bending than in the perpendicular direction, which has a smaller effective depth and a cracked section due to the absence of prestressing. Consequently, the system is a slab with very different longitudinal and transverse moments of inertia. For example, a 450 mm (17.7 in.) thick slab cast over a 100 mm (4 in.) thick precast slab has a depth of 550 mm (21.7 in.) in one direction and 450 mm (17.7 in.) in the other direction. Various finite element computer analysis programs can incorporate this particularity, but its effect in most cases is negligible. Because the precast slab is usually thin compared to the full section, a constant depth analysis is sufficiently precise for most cases. Consequently, ACI 318 equivalent frame or direct design methods are suitable for this system, as well as other simple analytical procedures.

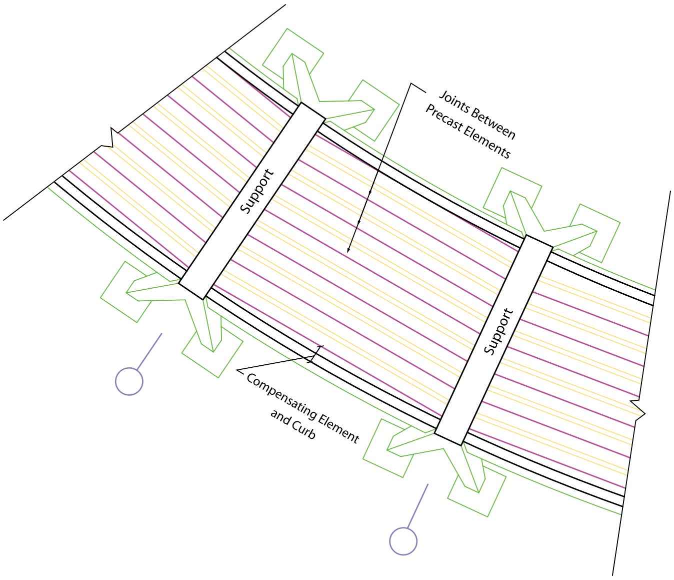


Fig. 3: The narrow width of the precast slabs required to make them transportable also helps them work well with curved highway spans

The precast slabs incorporate stirrups or lattice girders that extend out of the surface to connect to the cast-in-place concrete, forming an efficient construction system with the advantages of precasting. The connecting elements can be designed to avoid brittle failure using capacity design solutions for steel-concrete composite structures.

Supports for the system can be walls or a line of columns. In the first case, the solution is very effective because it is only necessary to add orthotropic and negative reinforcement at the site. Thus, construction time is significantly reduced compared to many conventional solutions. Because the precast slab is prestressed, the structure can start working as soon as the cast-in-place portion of the section reaches a minimum strength. Deflections are usually not a significant factor because there is no cracking in the positive bending moment sections. The total downward deflection due to creep is also smaller than for a conventional system because creep due to prestressing in the precast portion of the slab actually tends to deflect the full slab upward.

When there are supports in two directions, the precast slabs in one direction are usually dropped to support the slabs in the other direction, producing a variable depth slab. This solution was used for an underground parking garage roof (Fig. 4) in Mataró-Barcelona with spans of 15 x 8 m (49 x 26 ft) and a total load of 51.5 kN/m$^2$ (1075 lb/ft$^2$). The slab consisted of a precast slab only

Fig. 4: Dropped precast slabs spanning between the columns partially support the precast slabs spanning in the other direction

Fig. 5: The slab blockout shown here is used in a dropped slab panel spanning between columns and allows the column vertical reinforcement to pass through the precast panel

100 mm (4 in.) thick with a 450 mm (17.7 in.) thick cast-in-place portion, except at one column row where the slab drops 100 mm (4 in.) and the total depth is 650 mm (25.6 in.). A typical dropped panel detail is shown in Fig. 4, and a typical panel detailed for a beam/column connection that allows continuity of the vertical column reinforcement is shown in Fig. 5.

## ADVANTAGES

Relative to a conventional cast-in-place slab/beam system, the prestressed partially precast two-way system provides:

- Simplified and faster construction through elimination or reduction in formwork and falsework;
- Higher strength materials;
- Better quality;
- Reductions in depth of 20 to 40%;
- Reductions in the forces in columns and foundations;
- Considerable reductions in manual labor and therefore in labor costs;
- Elimination or reduction in the number of conventional beams, thus minimizing dropped soffits that can increase required floor-to-floor heights;
- Simplified cutting of holes for electrical or water supply lines; and
- Improved distribution of large live loads such as heavy truck loads.

## NOTABLE PROJECTS

Among the many projects constructed using the new system, a tunnel that passes below a runway at Prat de Llobregat Airport stands out. The span is only 13.5 m (44.3 ft) in two cells, but the loads include a self-weight dead load of 7 kN/m$^2$ (146 lb/ft$^2$), a live load of 4 kN/m$^2$ (84 lb/ft$^2$), and concentrated aircraft wheel loads of 490 kN (110 kip) per wheel. The total depth of only 800 mm (31.5 in.) was 60% less than a conventional slab.

Special mention is also necessary for the deck of the North "Gran Via" access to Barcelona. In this structure, the use of the system not only allowed a significant reduction of depth, but also drastically reduced construction time. According to the construction company, the time was reduced by more than 30% compared with a conventional slab.

Another significant project using the system is the tunnel roof of the Sant Boi-Hospitalet section of the high-speed railway line between Madrid, Zaragoza, and Barcelona. In this case, a simply supported solution was adopted for simplicity and to avoid transferring any bending moments at the walls. The depth and construction time were significantly reduced relative to those for conventional prestressed hollowcore slabs.

### IRMI Project

This project is the largest span and span-to-depth ratio constructed so far using the system. The building has a total area of about 8000 m$^2$ (86,000 ft$^2$) including two underground levels that occupy the entire site and a module of four levels above the street level. The upper levels have spans of 8.3 x 8.3 m (27.2 x 27.2 ft) and are constructed with a conventional reticular slab system. The upper levels are for offices, and the lower levels are used to film special effects for movies. The heavy mobile equipment required for filming resulted in the need to design for very high live loads of 17 kN/m$^2$ (355 lb/ft$^2$).

As shown in the structural plan in Fig. 6 and the photo in Fig. 7, the main structure has a 17 x 55 m (56 x 180 ft) column-free area. Even though the slab is designed for large live loads, the total slab depth is only 500 mm (19.7 in.) and the span-to-depth ratio

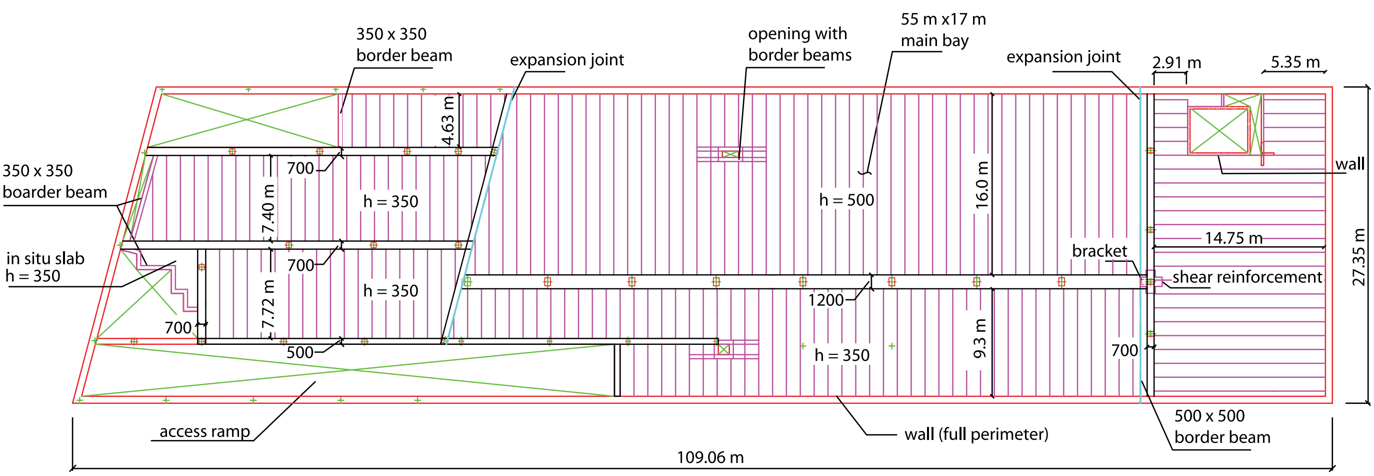


**Fig. 6: Structural floor plan showing the 17 x 55 m (56 x 180 ft) column-free area near the center of the building (all dimensions in millimeters unless noted otherwise; 1 in. = 25.4 mm; 1 ft = 0.3048 m)**

**Fig. 7: Interior view of the 17 x 55 m (56 x 180 ft) column-free area shown in the structural floor plan in Fig. 6**

is 34. The only alternative that can achieve this span-to-depth ratio is a post-tensioned slab. Therefore, the proposed system has benefits similar to post-tensioned slabs, but with the additional advantages of precasting.

The slab was constructed using precast slabs 1.2 m (3.9 ft) wide and 150 mm (6 in.) thick. Consequently, the cast-in-place concrete is only 350 mm (13.8 in.) thick. The structure is supported by a perimeter wall and one column row with columns spaced at 7.5 m (24.6 ft), as shown in Fig. 6.

In addition, the precast slabs were supported along only two temporary lines of falsework during construction. This was a particular advantage in this case due to the considerable height of the slab. The connection between the precast slabs and the cast-in-place concrete is by welded space lattice reinforcement as shown in Fig. 4 and 5.

The 1.2 m (3.9 ft) wide precast slabs along the column line were dropped 150 mm (6 in.) to support the ends of the precast slabs perpendicular to the column line during construction. These zones work as slabs of greater depth and not as conventional beams. If these elements were conventional beams, their reinforcement would be very heavy because the ultimate bending moment would be up to 1800 kN·m (1330 kip-ft). For this moment, the minimum depth would be 800 mm (31.5 in.) reinforced with 14 No. 25 (No. 8) bars, which is much larger than the adopted solution.

Selected for reader interest by the editors.

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