A Partially Precast-Prestressed two-way action slab Structural System

by LUIS BOZZO

In precast construction industry there are many one-way prestressed or steel-concrete composite structural systems. However, due to transportation limitations there are almost no solutions that may provide two-way action. In this article, I'll describe an innovative prestressed partially precast structural system for construction of two-way slabs that allows long-spans and high span-to-depth ratios. Since the system was developed in 2003, more than 250,000 m^2 of civil and residential structures have been built.

PRESTRESSED PARTIALLY PRECAST SYSTEM

The following basic elements that made up the system are illustrated in Figs. 1 and 2:

- Prestressed precast slabs 0,8m to 2,5m wide and 60 to 250 mm thick, such as the ones shown in Fig. 2 in a precast yard in Spain (ATEFOR company facility).
- Shear reinforcement (stirrups or lattice girders), embedded in the precast slab elements and extending to near the top of the completed section;
- Positive moment reinforcement just on top of the precast slabs and running perpendicular to the direction of prestressing. These bars are denoted "orthotropic reinforcement";
- Negative moment reinforcement on top of the completed section and running in both directions; and
- Cast-in-place concrete to complete the section.

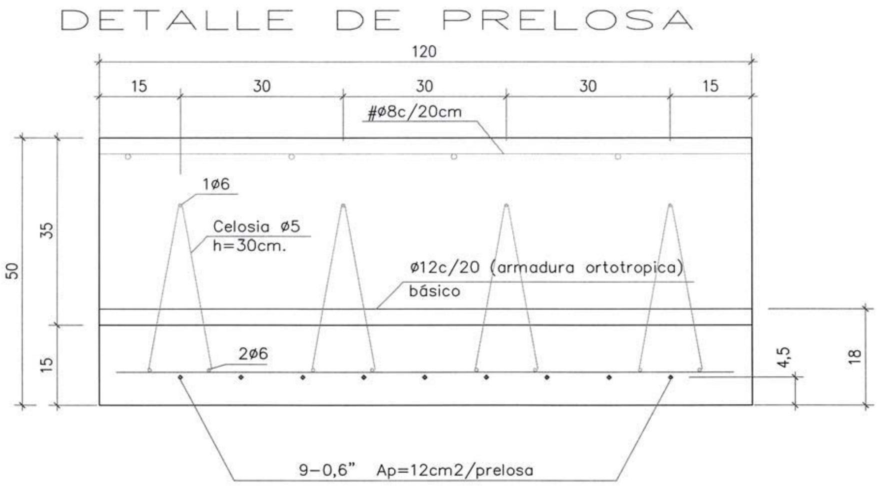


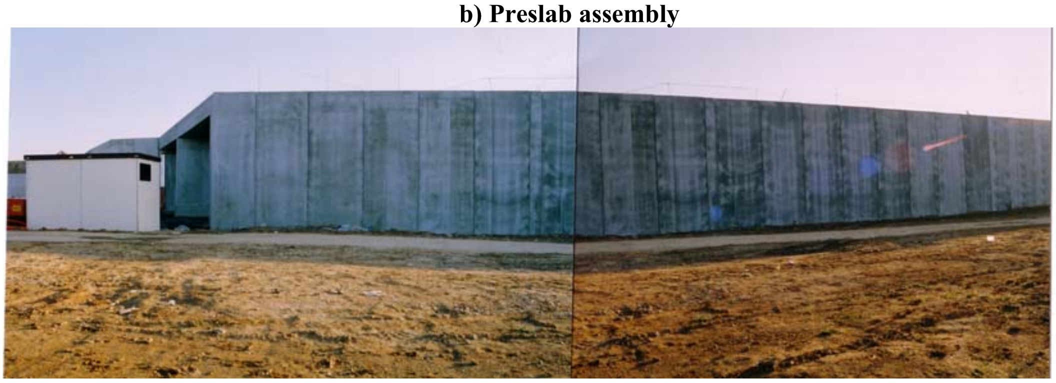
Fig. 1: Typical complete section using the proposed system including a 150 mm prestressed precast slab, orthotropic positive reinforcement running perpendicular to the precast slab span, negative reinforcement in both directions at the top of the slab, and a 350 mm (13.8 in.) cast-in-place upper slab

Fig. 2: Prestressed precast slabs at ATEFOR casting yard in Barcelona-Spain

The prestressed slabs have a maximum width of 2,5m so they can be easily transported and placed in their final position. This narrow width allows construction of curved elements using straight slabs and "in situ" compensation borders. The self weight for a 10m span, 7cm thick and 2,5m wide slab is only 42kN. Furthermore only one crane operation for the10m span slab covers a 25m2 area providing as fast as day mounting average ratios of 500m2 (see figure 3). According to our experience, if the building access allows this montage process can be up to 800m2 per day. 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.

(a) Semi-prefabricated walls assembly. Note the curvature in plan

b) Preslab assembly



(c) Finished structure

Figure 3. Complete wall-slab Precast solution in "Sant Cugat del Valles", Barcelona

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 section due to the prestressing steel 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 thick slab cast over a 100 mm thick precast slab has a depth of 550 mm in one direction and 450 mm in the other direction. Thus the longitudinal and transversal inertia ratio is only 0,55. Various finite element computer analysis programs can incorporate this particularity, but its effect in most practical applications is negligible since such a large inertia variation originates just a 10% maximum moment redistribution (just cracking in non-presstress reinforced concrete structure may cause a similar moment redistribution).

The precast slabs incorporate stirrups or lattice girders that extend out of the surface to connect to the cast-in-place concrete, forming a flexible construction system but 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 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 upwards. 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) and Figure 5 shows a typical panel detailed for a beam/column connection that allows continuity of the vertical column reinforcement.

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

PROJECTS

A list of recent projects is on table 1. Among them a tunnel that passes below a runway at "Prat de Llobregat" airport stands out. The span is only 13.5 m in two cells, but the loads include selfweight, dead load of 7 kN/m^2 , live load of 4 kN/m^2 , and concentrated aircraft wheel loads of 490 kN per wheel. The total depth of only 800 mm 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 (800m2 per day slab mounting rations). According to the construction company, the time was reduced by more than 30% compared to a conventional slab.

Another significant work using the system is the tunnel roof of the “AVE 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 to the walls. The depth and construction time were significantly reduced relative to those for conventional prestressed hollowcore slabs.

Table 1:

Most outstanding works with this structural system built up to date are:

Builder	**Description**	**Area, m^2**
CTNES.JUANES,S.A.	PARKING-PZA GATASSA- MATARO	1700
U.T.E EDAR IGUALADA	U.T.E EDAR IGUALADA	67
EMCOFA,S.A.EMPRESA CTRA	DEPURADORA UIPSA LA PAPELERA-POBLA CLARAM.	688
EMPUB,S.A.	FONT DEL CUC ANDORRA	419
U.T.E GORG L-9		4830
PBS CTNES,S.L.	IRMI-CORNELLA	2445
CORSAN-CORVIAM,CONST.S.A.	RDA.NORD-ST.CUGAT DEL VALLES	15,164
FCC CONSTRUCCION,S.A.	INTERCANVIADOR DE LEVANTE-BADALONA	1330
COMAPA,S.A.SDAD.UNIPERSONAL	COBRIMENT RDA.NORD-ST CUGAT DEL VALLES	1911
COMSA,S.A. EMPRESA CONSTRUC.	AEROPUERTO DEL PRAT-PRAT DE LLOBREGAT	3507
U.T.E TRAMMET		2036
SIX CONSTRUCT.ASSOCIATS,S.A.	COLECTOR FIRA 2000	2323
U.T.E DEPURBESOS	Ampliación Tratamiento Biológico Depuradora Besos	1702
U.T.E. DIPOSIT TAULAT	CUBIERTA LOCALES BOMBA	253
U.T.E TRAMBESOS		720
COMSA,S.A.EMPRESA CONSTRUC.	A-2 Sortida PGA Golf Catalunya CALDES MALAVELLA	2000
EXCOVER,S.A.	Remod.Colector c/Tortosa de BADALONA	2673

COMSA,S.A.EMPRESA CONSTRUC.	PARKING AEROPORT GIRONA	150
DRAGADOS, S.A.	COLECTOR L´HOSPITALET	376
U.T.E . C-31	MODIFICACION CTRA. C-31 AEROPUERTO BCN	2581
SIX CONSTRUCT.ASSOCIATS,S.A.	C/TANGER - BARCELONA	148
U.T.E RDA.NORD GRANOLLERS II	U.T.E RDA.NORD GRANOLLERS II	245
U.T.E GRAN VIA NORTE	POBLE NOU BARCELONA	14,846
U.T.E ASCENSORS L-1	ESTACIO HOSTAFRANCS BARCELONA	205
COMSA,S.A.EMPRESACONSTRC.	AEROPORT SABADELL	694
EMCOFA,S.A. EMPRESA CTRA.	CARDEDEU	595
SIX CONSTRUCT. ASSOCIATS,S.A.	C/Taulat,266 –TUNEL ACCES-BARCELONA	100
ENCOFRADOS CASTELL,S.L.	C/Sicília ,17 -CORNELLA	5176
COMAPA,S.A.SDAD.UNIPERSONAL	Centro AMMA-Valle Hebrón-HORTA	307
ENCOFA,S.A.EMPRESA CTRA.	PUMSA-MATARO	3115
U.T.E INTERCAMBIADOR SAGRER.	U.T.E INTERCAMBIADOR SAGRERA-Meridiana L-9-BCN	2000
G Y C	Escola de Música en Alquerias	1000
CORSAN-CORVIAM.CONSTR,S.A	Linea alta velocidad Madrid-Zaragoza-Bcn-tramo St.boi-Hosp.	35,000
Total		121,318

IRMI PROJECT

This project is the largest span and span-to-depth ratio constructed so far using this system. The building has a total area of about 8000 m^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 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 high live loads of 17 kN/m^2.

As shown in the structural plan in Fig. 6 and the photo in Fig. 7, the main structure has a17 x 55 m column-free area. Even though the slab is designed for the aforementioned large live loads, the total slab depth is only 500 mm and the span-to-depth (L/h) ratio 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 wide and 150 mm thick as shown in Figure 1. Consequently, the cast-in-place concrete is only 350 mm thick. The structure is supported by a perimeter wall and one column row with columns spaced each 7.5 m, as shown in the structural drawings.

The 1.2 m wide precast slabs along the column line were dropped 150 mm 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 and the minimum depth would be 800mm. This is because the beams would carry a heavy load while a slab transfers them directly to the supports.

Finally, during construction the precast slabs were supported along only two temporary lines of falsework. This was a particular advantage compared to a conventional slab or even postensioning since in this case the height of the slab was considerable. The connection between the precast slabs and the cast-in-place concrete is by welded space lattice reinforcement shown also in Figure 1..

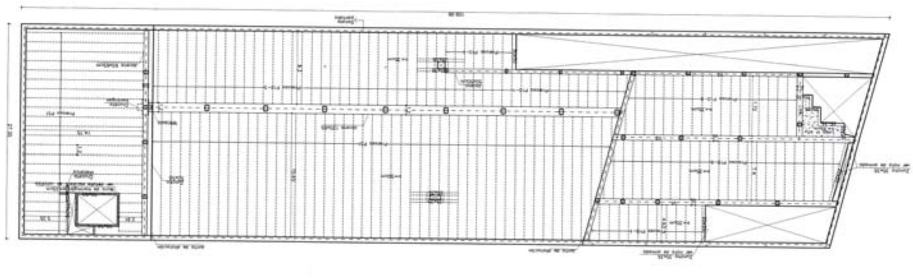


Fig. 6: Structural floor plan showing the 17 x 55 m (56 x 180 ft) column-free area near the center of the building

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

JVC URBAN VIADUCT IN MEXICO

This project uses a one directional variation of the system that uses planar postensioned beams and hollow prestress slabs. This unique architectonical project developed by our company is an elevated overpass in Guadalajara, Mexico. It is the main access to the chivas soccer team stadium in the JVC center. In this case we proposed the architectonical and structural solution for the whole overpass including the main span using a singular cable stay bridge. Figure 8 shows and overview of the viaduct and Figure 9 shows a typical plan view. The structure in the areas of prestress slabs is formed by inverted 15 degrees inclined “V” columns conventional (or postensioned) girders and perpendicular hollows slabs.

A typical four rows car circulation section of the overpass has a 16mx8m span where the girders are in the 16m direction and the prestresses slabs in the 8m direction. The total depth is 1m constant (there is just a 2% variation for drainage) and therefore the 16m span girders are postensioned. The slabs in the 8m direction has a minimum reinforcement and therefore they are hollow. The final appearance of the overpass will be flat without any hanged beam showing the beauty of precast concrete.

Fig. 8: JVC overpass including a singular curved cable stay bridge shown at the center. Left and right bridges are formed by pre-stress slabs and conventional or postensioned girders, according to their span resulting in a totally 1m flat system. On the back the chivas soccer team stadium that we designed using also prestess slabs.

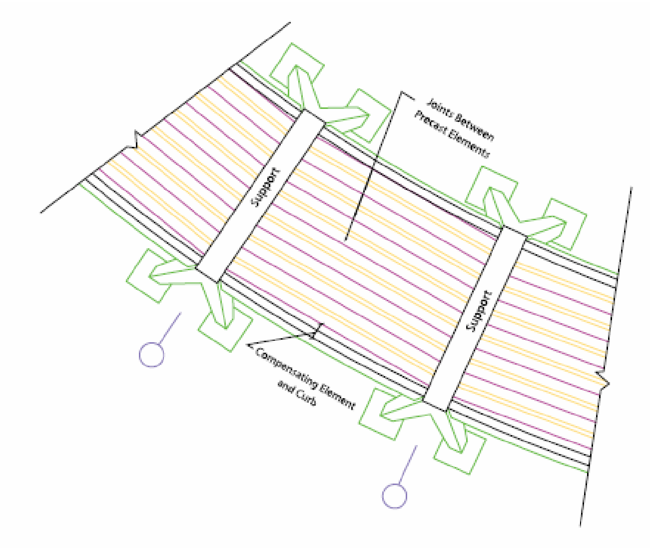


Fig. 9: The narrow width of the precast slabs required to make them transportable also helps them work well with curved highway spans as shown for the JVC overpass in Mexico

Finally as many overpasses the plan circulation is curved. In this case the highway radius is 67 m and the support spacing is about 10 m. Using straight 1,2m wide slabs it is required cast-in-place compensating element at the edge of the roadway of only 200 to 300 mm wide.

Luis Bozzo is President of Luis Bozzo Estructuras y Proyectos SL, Barcelona, Spain. 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. He recently designed the JVC main access three level highway overpasses, the structure for the Chivas soccer stadium, and the Santuario de los Martires church, which is currently the largest span and height catholic church under construction.