Int. Journal for Housing Science, Vol.35, No.2 pp. 91-102, 2011
Published in the United States

SPAN IN CONSTRUCTION OF CONCRETE PRECAST PRODUCTS: BEARING BEAMS AND REINFORCED SLABS

A. Torre, J. A. M. Martínez, V. O. López
Department of Civil Engineering
EPS University of Burgos
Spain

A. R. Sáiz
Department of Construction Engineering
EPS University of Burgos
Spain

ABSTRACT

The recent introduction in Spain of the Building Technical Code (CTE) means that CE labelling is now mandatory on construction products that will be permanently incorporated in buildings. One of the requirements with which manufacturers of precast slabs must comply in order to obtain the CE mark of conformity on their products is the satisfactory completion of tests that guarantee the resistance/strength qualities that are shown on the certificate of conformity.

Load-bearing beams and reinforced concrete precast slabs imply greater quality control at the manufacturing plant, shorter construction periods and improved safety at the construction site. They may also be used as resistant plank moulds during execution.

The purpose of this study is to determine the span in construction (the distance between false-work) for the bearing beams and RC slabs during the construction phase. It is intended to optimize the number of false-work structures to be calculated

0146-6518/02/91-102, 2011

to withstand their own weight, the weight of the poured concrete and an additional under construction load of 1KN/m^2.

The criteria used to calculate the span in construction were the ultimate bending strength, the ultimate shear strength and the flexural rigidity. The tests are in compliance with Standard UNE-EN 13747:2006 whereby the distance between props or temporary bearings of the span in construction is specified.

The testing method used was four-point bending. The test consisted of supporting the bearing beam or slab on two end supports and applying two equidistant equal loads to the span.

The results for extreme bending strength are very similar and a fraction higher than the theoretical results that might have been expected. The fineness ratio corresponds to the curve of the upper bars observed in the flexural load tests. The results of the extreme shear strength are about twice as high as the expected theoretical values; values which may be readjusted with a lower slenderness ratio.

Key words: Concrete, Precast, False-work.

Introduction

The recent introduction in Spain of the Building Technical Code (CTE) means that CE labeling is now mandatory on construction products that will be permanently incorporated in buildings. One of the requirements with which manufacturers of precast slabs must comply in order to obtain the CE mark of conformity on their products is the satisfactory completion of tests that guarantee the resistance/strength qualities that are shown on the certificate of conformity.

The precast slab appeared on the market as an industrial product towards the end of the 20th century. It has not only improved quality control at the place of manufacture, but has also provided technical performance qualities that are reducing building project execution times, leading to lower final costs and greater safety at the building site. The precast slab is a flat reinforced or pretense concrete plate that serves as a resistant plank mould for on-site execution of the solid or lightweight slab.

It consists of a concrete sheet that is reinforced with corrugated steel that contributes to the mechanical functioning of the floor structure, and of the rebar lattice work which forms the rib reinforcement and an expanded polystyrene ceiling. Once the precast slab is in place, it will serve as permanent formwork thereby making the planking of the entire floor unnecessary. Its strength means it is possible to move about on it with complete safety. Its surface appearance is completely flat and smooth, making a good finish possible without the need for a false ceiling. Furthermore, it is a product that is easy to handle. Once the reinforcing wire mesh and the negatives are in place, concreting of the compressive layer is undertaken.

One-directional joist floor structures are falling into disuse. Instead, those that are made of precast slabs have enjoyed moderate growth, particularly in industrial, non-residential buildings. They are frequently used in multi-storey car parks. In these buildings, precast slabs have advantages over beams because the finish of the floor structures may be left visible, with no other type of finish required.

Ribbed and lightweight precast RC slab structures are particularly suited to buildings in which there are significant spans and/or loads, as they considerably reduce the weight of the structure and the quantity of poured concrete in the construction work. These are lightweight floor structures with polystyrene ceilings, which produce a light structural element with a high degree of thermal isolation. There is also the fire resistant version which gives the floor a Standard Fire Resistance R 120 (EHE) [2] without any type of additional coating.

Another industrialized product available is the prefabricated bearing beam, the mechanical behavior and technical performance qualities of which are similar to those of the precast slab. It involves concreting the heel of the beam with the necessary reinforcement and providing a lattice framework which gives it rigidity during execution and serves as a transversal reinforcement once concreted together with the floor structure.

Objective

The objective of this paper is to determine the span in construction (distance between false-work) for lightweight plates or reinforced precast slabs and pre-fabricated bearing beams during the construction stage. This involves optimizing the number of false-work structures provided on-site during the concrete pouring stage, while ensuring that the precast slab withstands its own weight, that of the poured concrete and an additional construction load of 1 kN/m^2. The pre-fabricated bearing beam must also withstand the load transmitted to it by the part of the structural element which it supports during the construction and false-work stage.

The criteria used for determining the spans in construction were as follows:

- Ultimate bending strength
- Ultimate shear strength
- Flexural rigidity or deformability

The tests are in compliance with standard UNE-EN 13747:2006 [3] which specifies the distances between temporary props and supports of the construction span.

Background

Before testing was performed, a technical report was produced with the theoretical studies to determine the length of the construction span in accordance with the type of precast slab. These studies were performed to obtain the ultimate bending strength and the ultimate shear strength.

The procedure to obtain the calculated positive bending moment was to determine the maximum compression supported by the upper rebar of the lattice. The specifications in Spanish Standard EA-95 [4] were followed, which establishes the following expression (eq.1) for the buckling calculation of elements subjected to centered compression:

$$\sigma_u \geq N \cdot \frac{\omega}{A} \tag{1}$$

where:

σ_u, is the steel resistance calculation
N, is the normal compressive stress
A, is the area of the raw section of the piece
ω, is the buckling coefficient, which is a function of the slenderness ratio of the item "λ" and of the type of steel.

To calculate the buckling coefficient "ω", Standard EA-95 uses the Dutheil method which establishes the point of failure when the elastic limit of the material is reached in the fiber under the greatest stress. The mean stress that causes a point of the section to reach its elastic limit is called the critical stress. From experimental data, a mean statistical imperfection in the form of a sinusoid may be assumed, which allows us to formulate the expression of the buckling coefficient (eq.2):

$$\omega = 0.5 + 0.65 \cdot \left(\frac{\sigma_e}{\sigma_E} \right) + \sqrt{\left[0.5 + 0.65 \cdot \left(\frac{\sigma_e}{\sigma_E} \right) \right]^2 - \left(\frac{\sigma_e}{\sigma_E} \right)} \tag{2}$$

where:

σ_e, is the elastic limit of the steel
σ_E, is the Euler Stress, the value of which may be calculated as per (eq.3):

$$\sigma_E = \frac{\pi^2 \cdot E}{\lambda^2} \tag{3}$$

where:

E, is the steel elasticity modulus

λ, is the slenderness ratio of the piece

Having determined the maximum axial compression "N" supported by the upper rebar, the maximum positive moment supported by the precast slab or the bearing beam was directly obtained by multiplying the maximum axis by the mechanical leverage, which practically corresponds to the height of the lattice.

The length of false-work or the maximum distance separating the straining pieces was determined in accordance with Article 16 of Standard EFHE [5], taking into account that, during the on-site concreting process, the characteristic action on the precast slab is the total weight of the floor structure itself plus an additional execution load of no less than 1 kN/m^2.

The data used (Table 1) for the bending strength calculations of the precast slabs are shown below:

Table 1 : Data for calculated bending strength of precast slabs

Buckling coeff. β	Spacing of lattice rebar work (cm)	Buckling length (cm)	Width of pre-cast slab (cm)	Nº of lattices	Elastic Limit (MPa)
1	20	20	120	3	500

The data calculated for the bending strength (Table 2) of the various possibilities for manufacturing the precast slabs, and taking into account a load increase coefficient of 1.25 for calculating the length of the false-work, are:

Table 2 : Theoretical ultimate bending strength of precast slabs

Floor structure (cm)	Weight (kN/m^2)	Lattice Height (cm)	ϕ_s = 7 mm		ϕ_s = 8 mm	
			M_u (kN·m)	L_False-work (m)	M_u (kN·m)	L_False-work (m)
16+5	3.28	15	1.98	1.57	3.30	2.03
19+5	3.49	18	2.38	1.68	3.96	2.17
21+5	3.64	20	2.64	1.74	4.40	2.25
24+5	3.85	23	3.04	1.83	5.06	2.36

The method used for the shear strength is similar, taking in this case the slenderness ratio β = 0.7, considering that the diagonal of the lattice rebar work was embedded in the concrete precast slab and articulated in the upper knot. The data calculated for the shear strength (Table 3) of the various manufacturing possibilities are as follows:

Table 3 : Theoretical ultimate shear strength of precast slabs

Floor structure (cm)	Weight (kN/m^2)	Lattice Height (cm)	$\phi_t = 4$ mm		$\phi_t = 5$ mm	
			V_u (kN)	L_False-work (m)	V_u (kN)	L_False-work (m)
16+5	3.28	15	8.38	2.61	19.33	6.02
19+5	3.49	18	6.29	1.87	14.82	4.40
21+5	3.64	20	5.27	1.51	12.52	3.60
24+5	3.85	23	4.13	1.13	9.88	2.72

Test Model

The slabs studied in the test are coded as type PL-2 by the manufacturer. They consist of a concrete precast slab of a thickness of 5.5 cm and a width of 120 cm. Lengths may vary according to the requirements of the construction job. To determine the ultimate bending strength, two pieces were manufactured which were 4.20 m in length. To determine the ultimate shear strength, a further two pieces were manufactured which were 2.20 m in length.

A PL-2 typology has three ribs, reinforced with three longitudinal lattices (one per rib) measuring 19 cm in height and 20 cm spacing, plus 1 longitudinal rebar with a diameter of 10mm placed on each rib. The concrete that is used for the manufacture of the precast slabs is HA-35. The longitudinal corrugated reinforcing steel is B500SD, and that of the basic electro-soldered lattice formwork is B500T. The geometrical characteristics and formworks employed are shown below (Fig. 1.).

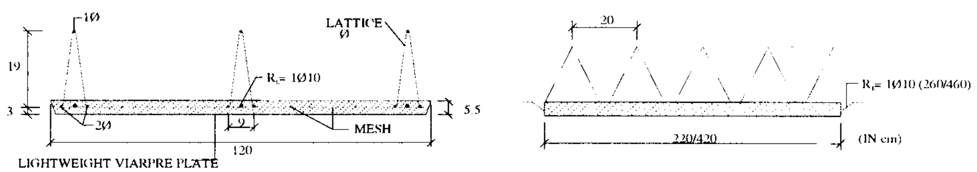

Figure 1 : Pl-2 type precast slab tested

Two types of bearing beams were tested: width of 50 cm and thickness of 5 cm with 3 longitudinally laid out lattices measuring 23 cm in height and 20 cm spacing, and 40 cm in width and 8.5 cm in thickness with two lattices measuring 23 cm in height. The same materials were used in their manufacture (HA-35 and B500).

A four-point bending test method was employed to determine both the ultimate bending strength and the ultimate shear strength. The test consisted of supporting the precast slab or bearing beam on two end supports and applying two equal and equidistant loads.

Long pieces were used to determine ultimate bending strength, and centered loads were applied, which produced significant bending at low loads (Fig. 2). Short pieces were used to determine ultimate shear strength, and the loads were applied near the supports, which produced significant shear stress with low bending (Fig. 2).

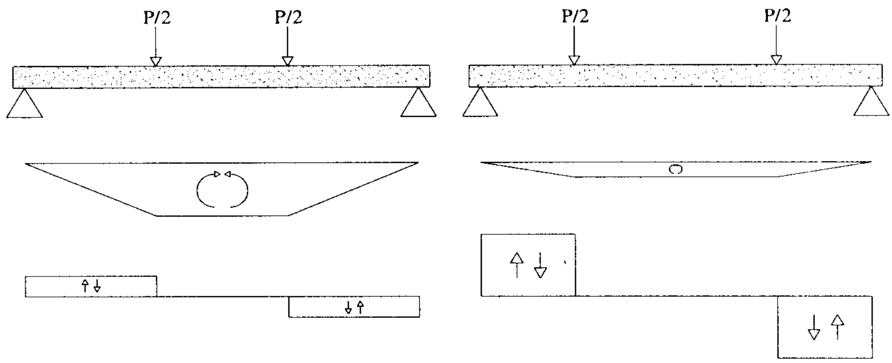

Figure 2 : Model of bending and shear test

Test Resources

The tests were performed in the Large Civil Engineering Structures Laboratory at the "Campus Milanera" Escuela Politécnica Superior of the University of Burgos, located at the following address: C/ Villadiego s/n 09001, Burgos.

The equipment and other test resources are detailed below: A hydraulic service block, make MTS. Hard Line. Manifold. A hydraulic service block, make MTS. A 50 kN actuator, make MTS, model 244.20, with a 150 mm cylinder run, this being controlled by an internal LVDT. A 50 kN load cell. FlextestGT control software. This is used for the control of the MTS equipment. For testing purposes, the research team developed a "test apparatus", to house the 50 kN actuator (Fig. 3) and two axle stands, the height of which can be adjusted so that they act as the supports for the precast slabs.

Description of the Test

Four tests were performed on the PL-2 (19 + 5) precast slabs. Two of these were for ultimate bending strength and the other two for ultimate shear strength. In addition, 4 tests were performed to determine the ultimate bending strength of the pre-fabricated bearing beams. Two of these were 50 cm wide and 5 cm thick and the other two were 40 cm wide and 8.5 cm thick.

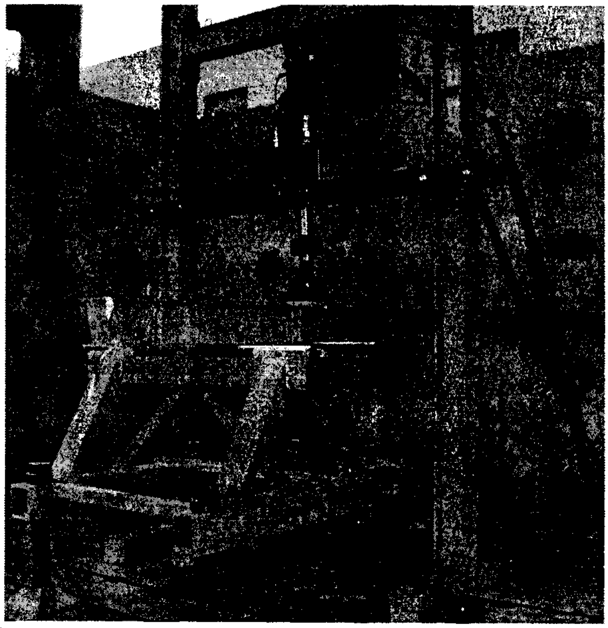

Figure 3 : Test apparatus, 50 kN actuator and adjustable axle stands

The distance between supports in the bending strength test for the precast slabs was 380 cm and the loads were applied at 150 cm and 130 cm from the supports, respectively. In the case of the shear strength testing, the distance between the supports was 180 cm and the loads were applied at 70 cm and 30 cm from the supports, respectively. The four bending strength tests on the bearing beams were performed with a distance of 320 cm between the supports and the loads were applied at 110 cm from the supports.

Expected Test Data

Taking into account the values of the traction tests on the reinforcements used in the models and the compression breakage of the graduated concrete cylinders (Table 4) the expected values for the moment and shear to be withstood by the piece were recalculated.

Table 4 : Traction resistance of the bars and compression of the concrete

	∅s	∅t	Concrete
Cylinder 1	498.8	752.1	35.2
Cylinder 2	498.0	762.2	36.3
Cylinder 3	508.3	782.3	34.7
Mean value (MPa)	501.7	765.6	35.4

In the case of the bending moment, the elastic limit of the upper rebar "ϕs" practically coincided with the estimated figure of 500 MPa and the expected value was 3.96 kN·m, as can be seen in Table 2 for a structural element of 19 + 5.

However, the elastic limit of the diagonal rebars "ϕt" indicated a much higher value than the estimated value of 500 MPa. The expected ultimate shear value (Table 2), assuming an elastic limit of 765.6 MPa, increased slightly to 6.4 kN.

In the case of the bending strength of bearing beams, the expected value for the 50 cm wide beam and 3 rebar lattice works was 3 kN·m for the 23 cm high lattice and 2.6 kN m for the 20 cm lattice. For the type with a width of 40 cm, a thickness of 8.5 and 2 lattices of 23 cm in height the expected value was 1.8 kN·m.

Results of the Tests

In the two bending tests on the precast slabs, the buckling of the upper rebar of the lattice (Fig. 4) occurred at load values of 5.7 and 6.8 kN applied by the actuator. The values of the ultimate moment withstood by the PL-2 type precast slab were Mu = 0.5 x 5.7 kN x 1.5 m = 4.3 kN·m and Mu = 0.5 x 6.8 kN x 1.3 m = 4.4 kN·m, which were very similar to the expected value of 3.96 kN·m.

Figure 4 : Buckling of upper lattice rebar in the bending test

In the two shear tests on the precast slabs the buckling of the lattice rebar ends (Fig. 5) occurred at load values of 25.4 and 26.2 kN applied by the actuator. The ultimate shear value withstood by the PL-2 type precast slab was Vu = (25.4 + 26.2) / 4 = 12.9 kN, which was much higher than the expected value of 6.4 kN.

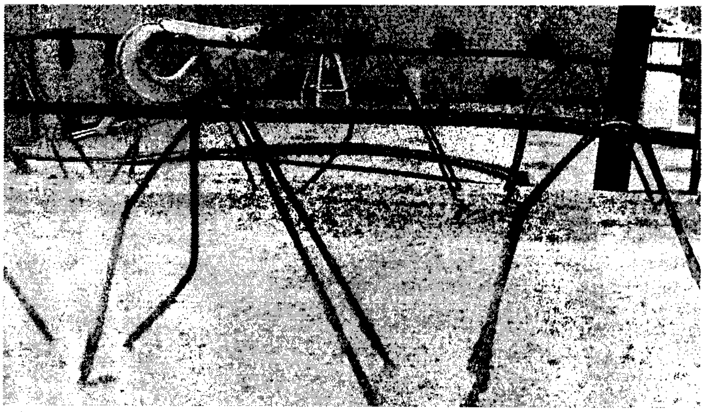

Figure 5 : Buckling of diagonal ends of the rebar lattice in the shear test

We can see (in Fig. 5) how the buckling of the lattice corresponds more to a biembedded model in the concrete precast slab and in the upper knot with the longitudinal reinforcement. It would be more correct to consider the slenderness ratio $\beta = 0.5$, which increased the expected ultimate shear value to 12.09 kN, which is very similar to the value obtained in the tests.

In the two bending tests on the bearing beams of 50 cm in width and 3 lattices, the buckling of the upper rebar of the lattice occurred at load values of 8.2 and 7.1 kN applied by the actuator (Fig. 6). The values of the ultimate moment withstood by the bearing beam were Mu = 0.5 x 8.2 kN x 1.1 m = 4.5 kN·m and Mu = 0.5 x 7.1 kN x 1.1 m = 3.9 kN·m, which were much higher than the expected values of 3 kN·m and 2.6 kN·m.

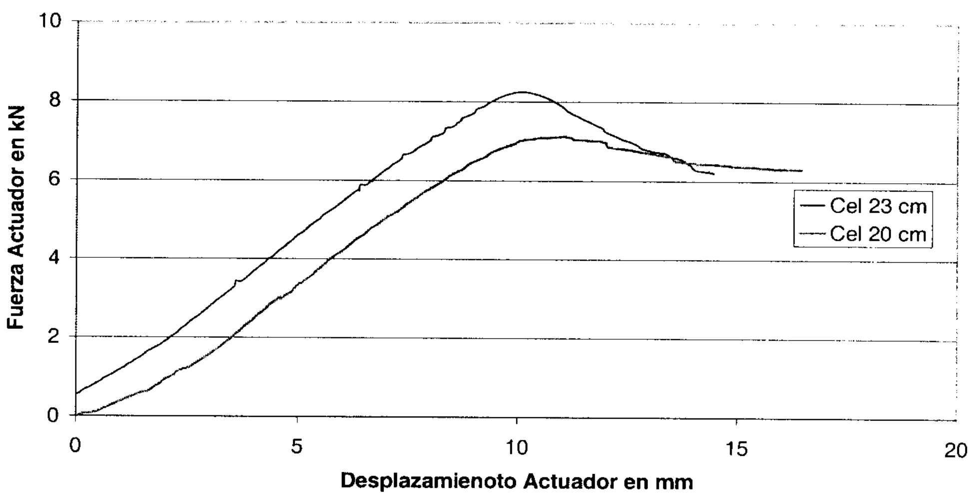

Figure 6 : Graph of bending tests on bearing beams of 50 cm in width

In the next two bending tests on the bearing beams of 40 cm in width and 2 lattices, the buckling of the upper rebar was visually observed for a load value of 5 kN. The value of the ultimate moment withstood by the bearing beam was Mu = 0.5 x 5.0 kN x 1.1 m = 2.6 kN·, which was much higher than the expected value of 1.8 kN·m.

Whilst it is true that the final buckling (Fig. 7) of the upper rebar took on a bi-articulate shape (β = 1), the start of the buckling (Fig.7) corresponded more to a semi-embedded form in the knots of the lattice (β = 0.8). If we take β = 0.8 as the slenderness ratio value, the recalculated value of the estimated moment coincided with the value withstood in the tests.

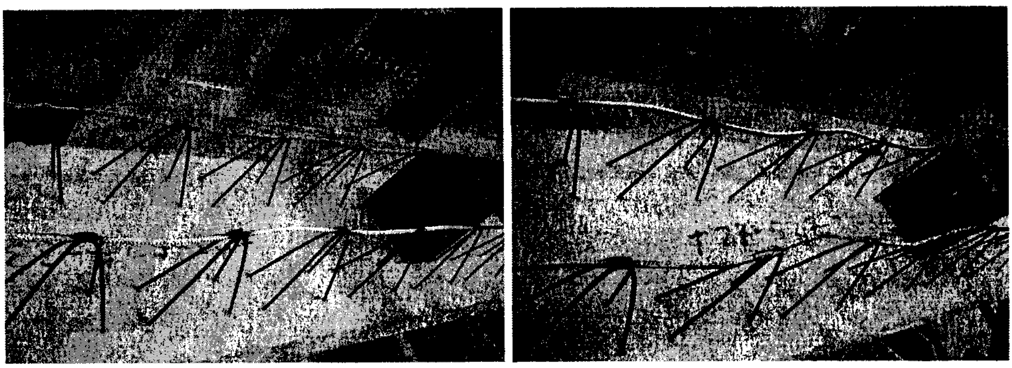

Figure 7 : Initial and final shape of the buckling of the upper rebar

Conclusion

The results obtained for the ultimate bending strength of the precast slabs were very similar to, and slightly higher than, the expected theoretical values and these values may be considered acceptable. The slenderness ratio adopted (β = 1) corresponded to the shape of the buckling of the upper rebars that was observed in the bending strength tests (Fig. 4).

The results obtained for the ultimate bending strength of the bearing beams were much higher –by about 50%- than the expected theoretical values. It was observed that the buckling (Fig. 7) approached a semi-embedded shape, with a slenderness ratio of (β = 0.8). The difference between the precast slabs and the bearing beams was due to the diameter of the lattice, which was 4mm in the precast slabs and 5 mm in the bearing beams. The greater diameter in the bearing beams causes the semi-embedding of the upper rebar.

The results obtained for the ultimate shear strength of the precast slabs were considerably higher than the expected theoretical values, i.e. about double those values, and they may be readjusted with a lower slenderness ratio "β ". The shape of the buckling observed in the shear strength tests was closer to the bi-embedded case with a ratio $\beta = 0.5$.

References

1. CTE "*Código Técnico de la Edificación* [Building Technical Code]". Ministerio de Vivienda, 2006. Madrid, Spain.
2. EHE "*Instrucción de Hormigón Estructural* [Structural Concrete Instruction]". Ministerio de Fomento, 1998. Madrid, Spain.
3. UNE-EN 13747:2006 "*Ensayo para determinar los vanos de construcción* [Test for determining construction spans]".
4. EA-95 "*Estructuras de acero en edificación* [Steel structures in construction]" – Parte 3.2 Piezas de directriz recta sometidas a compresión. Ministerio de Fomento. Dirección General de la Vivienda y el Urbanismo, 1996, 133 p. Madrid, Spain..
5. EFHE "*Instrucción para el proyecto y la ejecución de forjados unidireccionales de hormigón estructural realizados con elementos prefabricados* [Instruction for the project and execution of unidirectional floor slabs of structural concrete made with pre-fabricated elements]" - Artículo 16.1 Condiciones de apuntalado y sopandado. Ministerio de Fomento, 2003, 49 p. Madrid, Spain.