Full Scale Test of Continuous Prestressed Hollow-Core Slab

I. Rosenthal, DSc
Senior Research Fellow
Building Research Station
Technion
Haifa, Israel

Reports test results of a preliminary study aimed at finding an efficient continuous connection for a multispan system of precast prestressed hollow-core slabs without a concrete topping.

Precast prestressed hollow-core slabs with or without a concrete topping, are an important element in industrialized and large-panel building construction. These slabs, produced on long casting beds and cut later to shorter specified lengths, are mainly used in one-way floors freely supported by transverse walls (or beams) (see Fig. 1) in a spine wall-type and sometimes in a cross wall-type residential structure.

Connections between the precast elements of large panel structures are recognized as the weak link in this structural system, due to lack of continuity through these connections. Therefore, when ties are provided across them both horizontally and vertically, general structural integrity of a large panel structure is ensured.

The present study, carried out at the Building Research Station of the Technion, was undertaken in a search to find a system with a higher degree of continuity (than obtained using longitudinal ties only) for a hollow-core slab without a concrete topping. A continuous slab system, besides providing tensile strength between the hollow-core elements only, is also capable of transferring moments, resulting in smaller in-place bending moments, deflections, and less possibility for cracking.

The solution consists in casting in place the inner support slab zone and filling its voids in the negative mo-
ment zone with reinforcing bars. In this casting operation, concrete of the same type as the slab is used rather than grout.

To test the effectiveness of the continuity connection and for comparison purposes a simply supported prestressed hollow-core slab of identical cross section was tested simultaneously.

The cost of this proposed continuity technique was not examined. Therefore, for an actual project the added cost must be weighed against the structural advantages derived from a continuous slab system.

It should be mentioned that this testing program was only a preliminary study and that a more comprehensive research investigation on continuous prestressed hollow-core slabs is currently underway at Technion.

**Experimental Program**

The continuous system has two 2.92 m (9.6 ft) main spans and also an inner short one, formed by resting the slabs on a pair of separate supports, 38 cm (15 in.) apart. This configuration corresponded to the width of a standard prestressed beam support. As a result, the continuous slab was actually converted from a two-span into a three-span system (see Fig. 2). The cross section of the slabs was 120 cm wide,
Fig. 2. Test setup of continuous hollow-core slab showing location of reinforcement and strain gages. (Note: 1 in. = 2.54 cm.)
16 cm deep (47.0 x 6.3 in.). The slabs also contained eleven longitudinal 6.5 x 11 cm (2.5 x 4.3 in.) voids.

The prestressed hollow-core slabs and cast-in-place concrete had a compressive strength of 500 kg/cm² (7.1 ksi) and a modulus of elasticity of 400,000 kg/cm² (5700 ksi).

In both the continuous and simply supported systems prestressing was applied using 34 indented high tensile 5 mm (0.200 in.) diameter wires with an ultimate strength of 18 t/cm² (255 ksi) and a 0.2 percent proof stress of 16 t/cm² (230 ksi).

The wires were arranged in two levels: 28 at the bottom and six at the top with none located under or over the voids. Each wire was initially tensioned to 2.6 tons (5.8 kips), equivalent to a stress of 13.0 t/cm² (185 ksi), with a residual stress of 10 t/cm² (142 ksi). Concrete stresses were 110 kg/cm² (1560 psi) at the bottom and almost zero at the top.

The hollow-core slabs used in the continuous system were produced so that their voids remained open from above over a portion of the negative moment zone. This arrangement made it easy to place the negative reinforcing bars (see Fig. 3). The above operation was carried out at the plant shortly after casting and before the concrete had hardened completely, without affecting the six top prestressing wires.

The reinforcing bars, held in position 2 cm (0.8 in.) below the top face, comprised nine 12 mm (½ in.) deformed bars 2.30 m (7.50 ft) long. The steel had an ultimate strength of 4500 kg/cm² (64 ksi), a yield stress of 2650 kg/cm² (37.5 ksi), and a rupture elongation of 25 percent.

**Experimental Procedure**

The slab was loaded through spreading beams by two forces per span (at quarter-span points) so as to maximize the negative moment. The load was produced by Amsler hydraulic jacks applied against frames bolted to the test floor.

**Synopsis**

The objective of this study was to find an efficient continuous connection for a multispans system of precast prestressed hollow-core slabs without a concrete topping.

Comparative load tests were carried out using a simply supported slab and a two-span continuous slab. Strain measurements were taken of the concrete and the reinforcing steel. Deflection readings were also recorded.

Continuity was obtained by casting in place the inner support slab zone and filling its voids in the negative moment zone with reinforcing bars. The effectiveness of the connection depended upon the strength of the cross section over the inner support.

Note that concrete of the same type as the precast slab was used for the connection rather than grout.

A major advantage of continuity is that the moments will be distributed resulting in smaller positive moment, less deflection, and a smaller possibility for cracking. Moreover, the provision of horizontal ties in the floor structure will improve the general structural integrity of the building.
Fig. 3. Negative reinforcing bars held in position in open voids of hollow-core slab close to inner support before concrete casting. The white cables belong to the electrical strain gages bonded to the reinforcing bars.

Strains were measured with electrical strain gages bonded to the negative reinforcing bars and mechanical gages attached to the concrete surface in the positive moment zone. Deflections were measured with deflectometers having an accuracy of \( \frac{1}{100} \) mm (0.0004 in.).

The simply supported slab was also loaded at quarter-span points and, similarly, its midspan deflection and concrete tensile strains were measured.

Fig. 3 shows the negative reinforcing bars and the wires leading to the strain gages which are bonded to the rebars.

**Discussion of Results**

Load deformation data are presented in Figs. 4 through 6.

The first crack formed over the inner support between the precast element and the cast-in-place concrete at a load of 10 tons (22.0 kips). This was followed shortly by more cracks at the top face of the inner support zone. At that stage, the entire tensile force was taken up by the negative reinforcement. The resulting increase in reinforcing steel strains at this loading stage is clearly seen in Fig. 4, while slab deflection and strains remained unaffected (see Figs. 5 and 6).

Cracking of the prestressed slabs occurred at 24 tons (52.9 kips) at the quarter-span section (where the maximum field moment acts) with the concrete tensile stress at about 50 kg/cm\(^2\) (710 psi). This stress level resulted from 110 kg/cm\(^2\) (1560 psi) compression due to the prestressing effect and about 160 kg/cm\(^2\) (2280 psi) tension due to bending (equivalent to about 400 microstrains).

The simply supported slab cracked at the same stress level, but at a much earlier loading stage, namely 18 tons (39.6 kips), which is approximately one-half the calculated failure load. The load was increased up to 34 tons (74.9 kips) without damage, except for a large midspan deflection of 4.9 cm (1.93 in.) or \( \frac{1}{60} \) of the span. At that stage the test was discontinued.

In the continuous system, yielding of the negative reinforcement occurred at 30 tons (66 kips), producing a plastic hinge and converting the prestressed elements, under additional load, into simply supported slabs, with an accompanying increase in their deflection. This test was discontinued at 36.0 tons (79.4 kips).

The negative bending moment \( M_b \) of the continuous slab was determined from the measured reinforcing steel strains and compared with results obtained by theoretical analysis. The system analyzed included two main spans, each loaded by two concentrated forces, \( P/2 \), and a shorter unloaded inner span. The main spans were assumed to have a constant cross...
Fig. 4. Load versus negative reinforcing bar strain in continuous slab.

Fig. 5. Load versus deflection in continuous and simply supported slabs.
Load on each span

Continuous slab

First crack at 1/4 (26.0 T)
(52.9 Kips)

First crack at midspan (18.0 T)
(39.6 Kips)

Simply supported slab

Fig. 6. Load versus midspan tensile concrete strains of continuous and simply supported slabs.

section, and the inner span was taken first as an uncracked and later as a cracked section.

The ratio of the negative moments determined by measurement and analysis is plotted against the load in Fig. 7. For the uncracked case of the inner span, this ratio showed good agreement, but for the cracked case its maximum value obtained was only 0.55. It should be mentioned that, since the nine negative reinforcing bars in the continuous slab had an overall area of 10.3 cm² (1.6 sq in.) instead of the design steel area of 17.4 cm² (2.7 sq in.), i.e., 59 percent of the required quantity, the effective degree of continuity achieved was higher, reaching a level of 0.55/0.59 = 0.93.

After plastic hinges are formed in the continuous slab, the yield moment at midspan becomes $P l/8 + M_B/2$ compared with $P l/8$ only in the simply supported slab. Here, $P$ denotes the yield load of the simply supported slab, found equal to 32 tons (70 kips), and $M_B$ is the yield moment over the inner support of the continuous slab, equal to 3.55 tm (314 in.-kips).

The bearing capacity ratio, for the present investigation, is therefore:

$$1 + 4 M_B/(P l) = 1.15$$

This ratio, which depends on the negative moment at B, can increase if the full required reinforcing steel area is provided according to design; in that case the ratio becomes 1.26.

Acknowledgment

This investigation was sponsored by the Solel-Boneh Precast & Prestressed Concrete Works, Haifa, manufacturer of the test slabs. Contacts with the plant were through the late D. Sternberg, chief engineer.
Conclusions

1. The tests show that it is advantageous to use continuity in precast prestressed hollow-core slabs without a concrete topping provided that the cast-in-place slab portion over the inner supports is adequately strong.

2. The proposed technique produced a high degree of continuity indicating that the reinforcing bars in the negative region were properly anchored with practically no slippage.

3. In comparison to the simply supported slab, the continuous hollow-core slab tested carried higher loads with proportionately smaller deflections.

4. Continuous hollow-core slabs will ensure the integral behavior of the floor system of the structure.

Lastly, it should be emphasized that this testing was only a preliminary study into finding a more efficient continuous system (than obtained with longitudinal ties only) for precast prestressed hollow-core slabs without a concrete topping. A more comprehensive research program on continuous prestressed hollow-core slabs is currently underway at Technion. Based on this investigation it is anticipated that a future report will give more authoritative design recommendations, construction procedures, and cost data.

References

