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FLEXURAL BEHAVIOR OF STEEL-FREE CONCRETE PANELS PRESTRESSED WITH UNBONDED EXTERNAL BARS

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1. INTRODUCTION

An experimental program is carried out and aims at investigating the new bridge design of steel-free concrete deck slabs. The design concept of those slabs accounts for the internal arching action that occurs in the restrained deck slabs[1]. After investigating the basic concept and the effect of the ratio of the steel confinement that restrains the slabs[2], a new development was made by introducing unbonded external prestressed bars to confine the steel-free slabs. The experiment related to this development involves testing full scale prestressed steel-free slabs and is reported elsewhere. The mentioned experiment is primarily concerned with the punching shear capacity of the slabs rather than their flexural bending capacity. Therefore, the following study was necessary to investigate the flexural behavior by testing a narrow segment of the slab (here called: panel).

Although extensive resources on the flexural behavior of conventionally reinforced and prestressed panels are available, but to the best of the authors' knowledge, no investigation had been carried out for the very exceptional case of completely non-reinforced and externally prestressed panels.

The presented study investigates the effect of the end supports condition and prestressing on the flexural behavior of steel-free panels by undergoing an experimental and theoretical study on a free supported and fixed panels in both prestressed and non-prestressed cases.

2. EXPERIMENTAL WORK

Four specimens were made and tested for the purpose of this study. The specimens were cast with no internal reinforcement and restrained using 17 mm diameter round bars that have an average yield strain of 958 MPa.

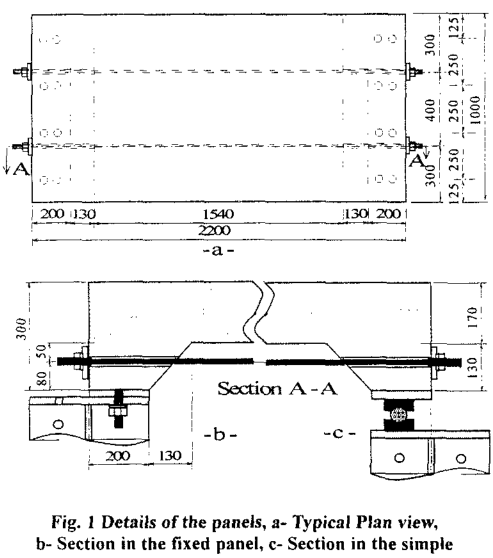

Fig. 1 Details of the panels, a- Typical Plan view, b- Section in the fixed panel, c- Section in the simple supported panel

Table 1. Specimens Specification

Specimen Name	End Support	Prestressing Stress N/mm²	Concrete Comp. Strength N/mm²	Concrete Tensile Strength N/mm²
S1	Fixed	0	45.1	3.6
S2	Fixed	130	45.1	3.6
S3	Simple	0	43.2	3.5
S4	Simple	130	43.2	3.5

Test parameters were the prestressing stress in the bars and the condition of the end support of the panels. Table 1 gives details of the properties of the test specimens.

Dimensions and other details of the panels are given in Fig.1. The panels were cast to a plate that had welded shear studs, and then either simply mounted (Fig. 1-c-) or tightly fixed to the upper flange of the supporting beam (Fig. 1-b-). Prestressing was 30 kN force in each bar and induced a maximum of –50 compression micro-strain in the bottom concrete fiber and + 36 tension micro-strain in the top fiber.

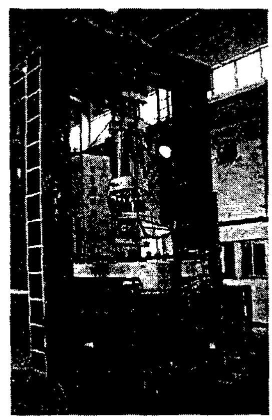

Fig. 2 Test setting

The panels were loaded at their center through a 400x200x 40 mm steel plate simulating a concentrated load. An overall view of the test installation is shown in Fig. 2.

3. EXPERIMENTAL RESULTS

3.1 Cracking Load

The first crack that occurred in all the specimens was a single longitudinal crack along the bottom mid fiber (section of maximum moment). This crack continued its propagation up to the top mid fiber with the increase of load up to bending failure, which was considered to be the compressive failure of the top fiber at mid span. In the fixed specimens, two new cracks located along the top fiber over both haunches areas (the change of thickness areas) appeared after the first crack. In this case a compressive failure was noticed as well at the bottom fiber located along the transition line between the horizontal bottom surface and the inclined one. Because of the non-presence of conventional reinforcing bars the plastic behavior phase was missing and the cracks formed and propagated suddenly in a brittle way. First-crack loads are given in Table 2.

It can be seen that fixed panels had higher cracking loads than the simple supported ones, and in either type, the prestressed panels had higher cracking load than the non-prestressed ones. From the data Table 2 it is calculated that changing the end support condition from simple to fix

Table 2. Test and Theoretical Results

Specimen Name	Cracking Load			Ultimate Load		
	Exper. kN	Theor. kN	Theor/ Exper	Exper. kN	Theor. kN	Theor/ Exper
S1	84.0	86	1.02	178.1	190	1.07
S2	122.9	129	1.05	218.3	218	1.00
S3	49.0	47	0.96	176.5	176	1.00
S4	74.2	70	0.94	220.3	211	0.96

has increased the cracking load of the non-prestressed panels by 71 %, and of the prestressed panels by 66 %.

Figure 3 shows the influence of prestressing on cracking load. Prestressing has increased the cracking load of the simple supported and fixed panels by almost the same rate, that is, 50 % (0.38 % per 1 N/ mm^2). a slightly higher prestressing stress (180 N/mm^2) would give the exact same effect as support fixation. It is therefore concluded that prestressing gives the same restraining effect as fixing the supports on the cracking loads.

3.2 Ultimate Load

The ultimate bending loads are given in Table 2. Figure 3 shows the effect of prestressing on ultimate loads for the simple and fixed end support panels. Prestressing has increased the ultimate load of the simple supported and fixed panels by the same rate, that is, 24 % (0.38 % per 1 N/ mm^2). End support condition, however, had no effect on ultimate bending failure load. This can be explained by the two previously mentioned cracks that appeared after the first crack over the haunches areas in the fixed panels. Examining the deflection curves of the four specimens given in Fig. 4 shows the effect of these two cracks. It can be seen that both fixed panels graphs underwent a sharp disturbance twice at the moments when the cracks appeared. Those two cracks formed two hinges over the haunches areas and rendered the fixed specimens similar to the simple supported ones given the same ultimate loads.

4. Theoretical Analysis

A method proposed by Naaman[3)4)], was used to calculate the cracking and bending ultimate loads of the panels. According to this method, stress in unbonded tendons is a function of the applied loading, the steel profile, and the ratio of the crack width to the span. These factors can all be accounted for through the use of a strain reduction coefficient Ω for the uncracked state and a similar coefficient Ω_u for the cracked state. This coefficient assumes that strain increase in unbonded tendons can be obtained through the strain increase in equivalent amount of bonded prestressing tendons. Naaman gives expressions[3)] for Ω, depending on the loading case and the tendon profile, that yields the value of 0.5 in this case. As for Ω_u , the following empirical equation[4)] (Eq. 1) is suggested:

$$\Omega_u = \frac{2.6}{(L/d_{ps})} \quad (1)$$

where (L) is the span (for the fixed end support panels a post -cracking span, equals to the distance between the two formed hinges, was used). (d_{ps}) is the depth from the extreme compression fiber to the centroid of the prestressing steel. The application of Eq. 1 yielded a value for Ω_u equals to 0.286 and 0.357 for simple supported and fixed panels respectively.

Using this coefficient makes the remaining calculations similar to the case of fully bonded prestressed beams.

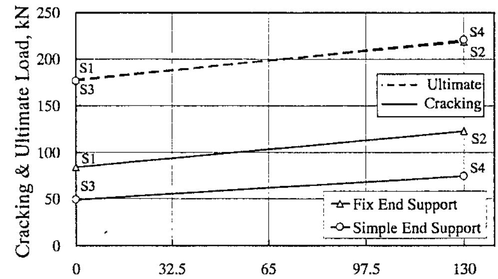

Fig. 3 Influence of prestressing on Cracking and ultimate loads of fixed end and simple supported panels

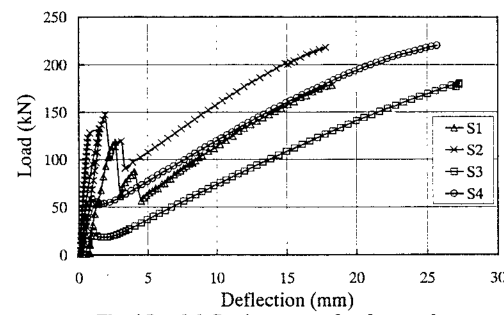

Fig. 4 Load deflection curves for the panels

Table 2 gives the estimations of cracking and ultimate loads using the above methodology. It can be seen that the estimated loads correlate well with the experimental results.

5. Conclusions

- Although end support confinement is efficient in restraining the steel-free slab in the pre-cracking state, it is not reliable in the post-cracking state. If cracks developed and created hinges in certain positions, the end support confinement would loose its role in restraining the slab and another confinement system is needed in order for the arching action to develop.
- External prestressing proved to increase both the cracking loads and the ultimate bending loads. In addition, prestressing can counter-balance the lost of the restraining effect of the end support after cracking.
- The panels didn't have any conventional reinforcement and were prestressed with external bars making it very difficult to apply most of the methods and assumptions of the analytical studies found in the related literatures. Nevertheless, one theoretical method was found to be suitable to predict the cracking and ultimate bending loads of these panels.

References

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