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Behaviour and Analysis of Voided Concrete Slabs

Comportement et analyse des dalles creuses en béton

Verhalten und Analyse von Beton-Hohlplatten

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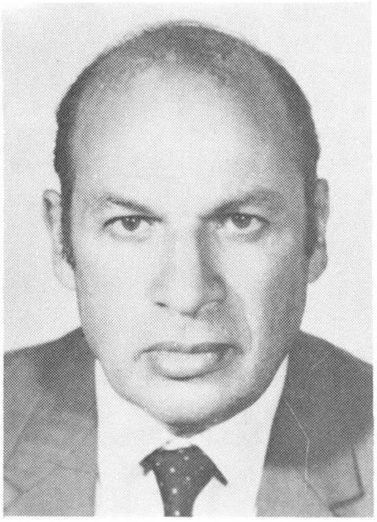

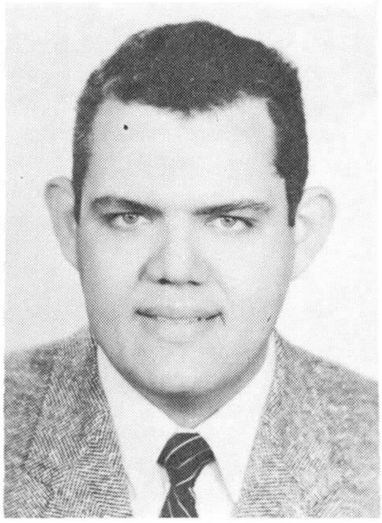

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SUMMARY

An experimental-theoretical study was conducted to explain the general deformational behaviour of voided reinforced concrete slabs under different loading conditions. Six voided reinforced concrete slabs were tested. The varying parameters were the void's diameter and the percentage of reinforcement. The experimental results are compared with those obtained theoretically using the orthotropic plate theories. The effect of crack on the slabs behaviour was studied. General conclusions are summarized.

RÉSUMÉ

Une étude expérimentale et théorique a été conduite pour définir le comportement général de déformation des dalles creuses en béton armé sous différents cas de charge. Six dalles ont été testées. Les paramètres variables était le diamètre du creux et le pourcentage de renforcement. Des conclusions générales sont présentées.

ZUSAMMENFASSUNG

Eine experimentelle und theoretische Studie wurde durchgeführt, um die allgemeine Verhaltensweise von Stahlbeton-Hohlplatten unter verschiedener Belastung zu ermitteln. Sechs Stahlbeton-Hohlplatten mit verschiedenen kreisförmigen Aussparungen oder unterschiedlicher Bewehrung wurden getestet. Die Ergebnisse der Versuche wurden mit denen der Theorie orthotropen Platten verglichen. Die Wirkung von Rissen auf das Verhalten der Hohlplatten wurde studiert. Allgemeine Schlussfolgerungen werden dargelegt.

1. INTRODUCTION

Circular voids running in the longitudinal direction of reinforced concrete slabs are frequently introduced in order to reduce the self weight of the structure. This type of slabs are used in the construction of floor slabs, short and medium span slab bridges. Voids of circular shape are simpler for construction. Furthermore, the stress concentration around these voids is less critical than any other shape.

The presented study is concerned with the general deformational behaviour of the reinforced concrete voided slabs under symmetrical and unsymmetrical cases of loading. Six voided reinforced concrete slabs of dimensions 1.04x1.8 m, having void diameters of 63, 50 and 40 mm, and different reinforcement percentages, were tested.

The cross distribution of deflections, longitudinal moments and transverse moments were calculated using the orthotropic plate theory, and these results were compared with those obtained experimentally. The effect of longitudinal and transverse cracking on the behaviour of the slabs is studied. From the results of this experimental-theoretical study, conclusions are drawn concerning the design, construction and the evaluation of the stiffnesses of this type of structures.

2. METHOD OF ANALYSIS OF VOIDED SLABS

Simply supported right voided slabs subject to different concentrated loads, are generally analysed using the orthotropic plate theory. This load distribution theory was first introduced by Guyon (1946) & Massonnet (1950), which was formulated into a design procedure by Morice and Little (1956) and Rowe (1962). Morice, Little and Rowe also presented this method in the form of design charts (1956).

The theory assumes that the voided slab or bridge, being analysed, can be simulated as an equivalent orthotropic plate having the same average stiffness properties as the actual bridge or slab. This assumption is valid if there is no significant cell distortion.

Cusens and Pama (1969) prepared new design charts, by which the 10 % under-estimation in the early load distribution theory by Morice, Little and Rowe is being avoided.

To consider the effect of cell distortion in the analysis, Massonnet and Gandolfi (1967), developed a theory for shear weak rectangular orthotropic plates, which are simply supported on two opposite sides. Furthermore, Bakht, Jagear & Cheung (1981) simplified the previous method by introducing the concept of magnifier. This magnifier is the ratio of the maximum intensity of moment or shear with transverse cell distortion to that without it.

For reinforced concrete voided slabs, the main problem arising in this method, is the determination of the slab stiffnesses. For an uncracked section, Elliot & Clark (1982), proposed values for these stiffnesses based on a finite element solution for a monolithic section. For a cracked reinforced concrete voided slab, the flexural stiffnesses can be calculated as concrete section cracked due longitudinal bending only, or cracked in both the longitudinal and transverse directions. On the other hand, there is no known method for calculating the torsional inertia of a cracked voided slab, therefore it is assumed constant before and after cracking.

This method is used throughout the research work for the analysis of the tested slabs.

3. EXPERIMENTAL WORK

Six reinforced concrete voided slabs with 10 voids were tested. The dimensions of these slabs are 1.04 x 1.80 m. and thickness 12 cm. These slabs were tested, as simply supported on span of 1.60 m., twice. Once with a single concentrated load acting at center of gravity of the slab within the elastic range, and the second time, with an eccentric concentrated load, of eccentricity 0.3 m. from the center of the mid section. The six slabs were divided into two groups, each group consisted of three slabs;

Group (1) : The three slabs had a bottom reinforcement of 10 Ø 6 mm/m' in the longitudinal direction and 10 Ø 6 mm/1.5 m' in the transverse direction. The varying parameter was the void's size (For slab S1/6 the void diameter was 63 mm., slab S2/6 the void diameter was 50 mm. and for slab S3/6 the void diameter was 40 mm). The spacing of center line of voids was 0.1 m.

Group (2) : The three slabs had the same void sizes as used in group (1) but the reinforcement used was Ø 8 mm instead of Ø 6 mm. The slabs were named S1/8, S2/8 and S3/8, respectively.

4. ANALYSIS OF THE EXPERIMENTAL RESULTS

4.1 The centric loading test

In this test all slabs behaved in a similar manner. No cracks appeared during the first test of the six slabs. Good symmetry was observed during these tests and the results showed a good correlation with those obtained theoretically.

4.1.1 Deflections

The experimental results were higher than those obtained theoretically by about 10-20 % as shown in fig. 1 . It was noticed that the deflection decreases as the void's diameters decrease, and also as the reinforcement increases.

4.1.2. Bending moments

During the analysis of the longitudinal bending moments, the cross distribution of this moment is assumed to be similar to the cross distribution of the longitudinal strains in the slab. For the centric loading test, good correlation was observed between the experimental and theoretical results. A better cross distribution of strains was observed for the slabs with smaller void diameter, than those with larger ones, and also this cross distribution improved with the increase of the percentage of reinforcement.

Form the results of deflection and bending moments it is clear that it is essential to include the contribution of steel in calculating the uncracked section inertias.

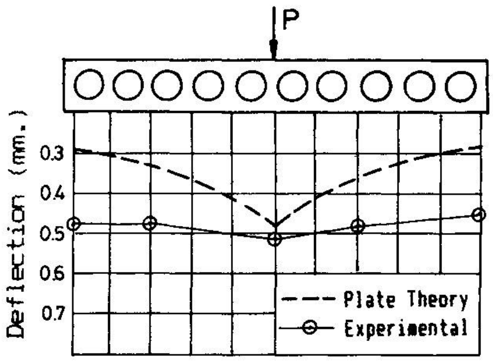

Fig. 1 Deflection distribution along the mid section of slab S1\6 at P = 15 KN (Centric loading)

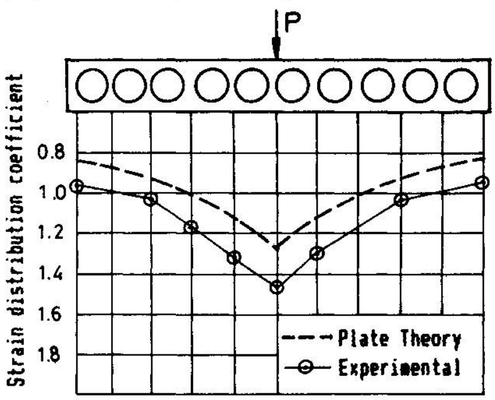

Fig. 2 Strain distribution coefficient along the mid section of slab S1/6 at P = 15 KN (Centric loading)

4.2 The eccentric loading test up to failure

For the six slabs, the first crack appeared at a load of about one quarter of the ultimate load. At higher load levels cracks due to transverse moment and torsion appeared. It was noticed that the cracks appeared earlier in the slabs with smaller percentage of reinforcement, than those with higher ones. Within the same group, cracks appeared earlier in slabs with larger voids, than those with smaller ones. Failure occurred in all slabs due to a combined action of bending and torsion. Slabs of group (1) failed at lower load level than those of group (2), but within the same group the difference between the failure loads was small.

4.2.1 Deflections

The experimental and theoretical distributions of deflections at different stages of loading along the cross section at the midspan of slab S1\6, is shown in fig.3. The experimental results differed from the theoretical ones by about 10-20 % before cracking, and exceeded it by about 20-30 % after cracking. Similar curves are obtained for all six slabs.

A comparison between the load deflection curves, at a point under the load, for all six slabs is shown in fig. 4. From the fig. it is noticed that, as the reinforcement was kept constant, and the void size increases, the deflection values increases. Also as the percentage of reinforcement increases, the deflection value decreases.

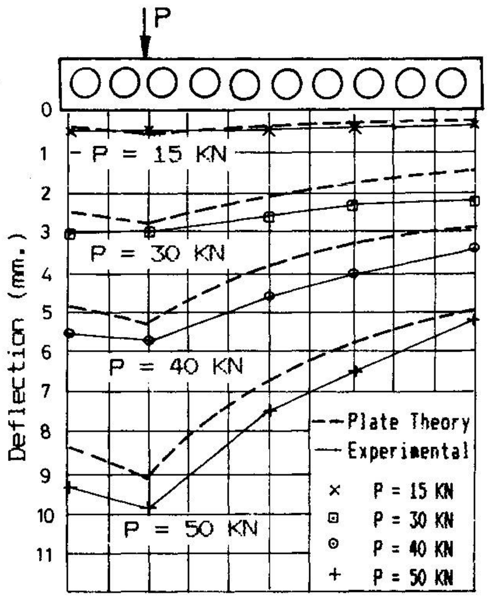

Fig. 3 Deflection distribution along mid section of slab S1/6 at different load levels.

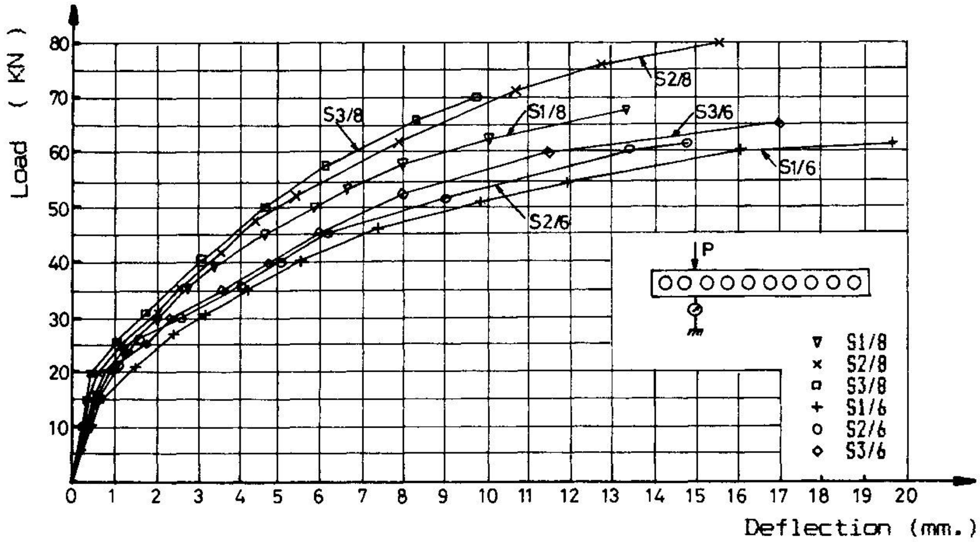

Fig. 4 Load deflection curves of the six tested slabs for a point under the load (Eccentric loading).

4.2.2 Longitudinal bending moments

The strain distribution coefficient across the mid section of the slabs within the elastic range of loading showed a similar correlation with those obtained theoretically, as in the case of centric testing.

Fig. 5 shows the distribution of strains across the slab after cracking. The calculated values of distribution coefficient using inertias of completely cracked section, underestimates the real value. These values are more likely to correlate with those obtained using monolithic section inertias. This is because of the omission of the tension stiffening of concrete in tension between cracks, in calculating the cracked section inertia.

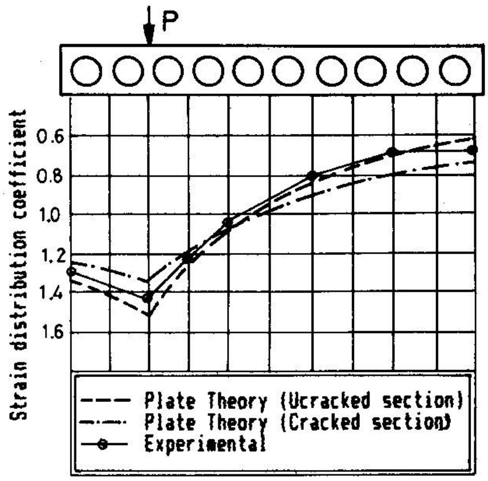

Fig. 5 Strain dist. coefficient across slab S1/6 at P = 30 KN.

The relation between the strain distribution coefficient and the applied load is shown in figure 6. From the figure the following comments can be concluded;

Before cracking the distribution factors differed by about 15-30% from theory.

After cracking the distribution of the moment improved. This can be explained by that, after cracking the longitudinal flexural stiffness decreases due to the sudden decrease in the sections inertia while the transverse bending and torsional stiffness are approximately constant, and hence the distribution of moment among the webs should improve.

The distribution coefficient, after cracking, for the web under the load, was found to be greater than that obtained theoretically, (using cracked section inertias), but as the load increases this value decreases to converge with the calculated one. This is because, as the load increases, the cracks spread and, the tension stiffening' is gradually broken down, causing the distribution coefficients to approach the calculated values.

After the slab began to crack due to transverse moment and torsion, the transverse flexural and torsional stiffness decreased. Consequently, the stresses began to concentrate under the load as shown in the figure.

This behaviour is similar for all the tested slabs, but it was noticed that as the void size decreases the distribution of load improves. Also increasing the percentage of reinforcement improves the load distribution across the section.

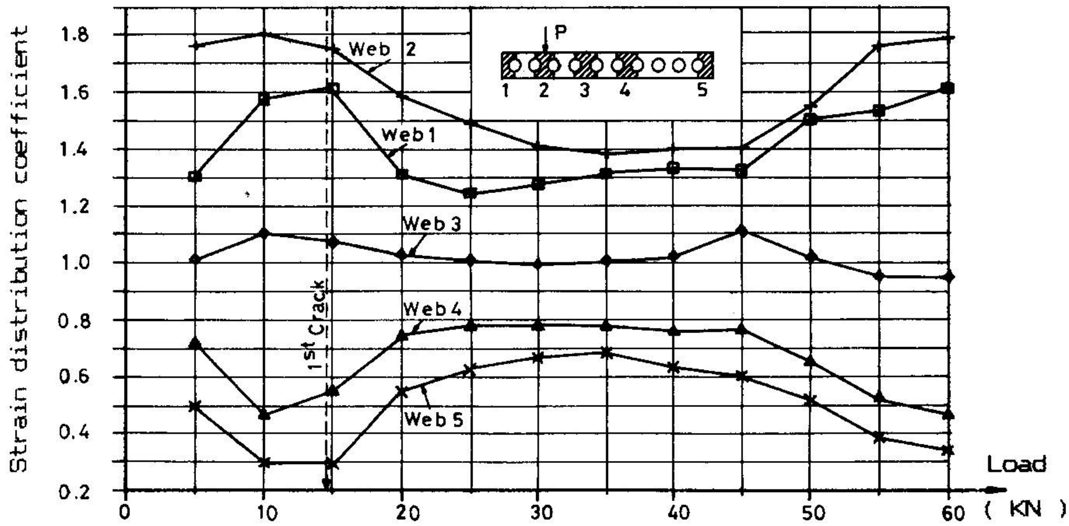

Fig. 6 Variation of strain distribution coefficient with load for slab S1/6. (Eccentric loading)

4.2.3 The transverse moment

The distribution of strains in the transverse steel at mid section of the slab S1/6 is shown in fig. 6. The ratio of the transverse to the longitudinal strains increases as the void-depth ratio increases. This ratio was ranging from 0.1 to 0.16 for slabs S3/6, 0.15 to 0.2 for slab S2/6 and 0.2 to 0.3 for slab S1/6. The same ratios were obtained for slabs S1/8, S2/8 and S3/8.

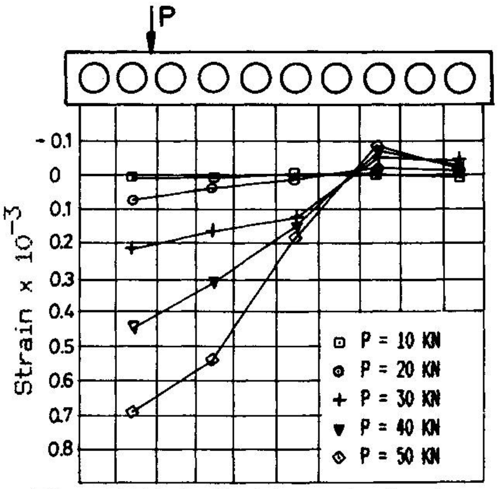

Fig. 7 Distribution of strain in transverse steel of slab S1/6 at different load levels.

6. CONCLUSIONS

1. The orthotropic plate theory can be used for the analysis of circular voided concrete slabs with the condition that the stiffnesses of the slab are defined.

2. Decreasing the void-depth ratio improves the load distribution across the voided slabs.

3. Cracking of concrete due to longitudinal moment decreases the stress concentration beneath the loaded web, and hence, the load distribution among the other webs of the voided slab increases.

4. The ratio of transverse to longitudinal moments increases with the increase of the void-depth ratio.

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