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Early Punching Resistance of Concrete Slabs

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ملخص البحث

يحتوى هذا البحث على دراسة معملية لسلوك البلاطات الخرسانة المسلحة تحت تأثير القوي المبكرة للقص الثاقب. و قد تم اجراء دراسة معملية على عدد 3 بلاطات خرسانية مسلحة وقد شمل البحث المتغيرات الاتية : التحميل المبكر للعينات و المقاومة المميزة للخرسانة وقد شمل البحث ايضا خصائص المواد المستخدمة، و ادوات القياس المستخدمة.

ABSTRACT

This paper investigates the structural behavior of reinforced concrete flat slabs under concentric punching load and the influence of the early loading conditions on the punching shear strength. Punching is one of the most important phenomena to be considered during the design of reinforced concrete flat slabs. As concrete compressive strength is one of main factors affect the punching behavior, this paper will focus in the effect of early loading in punching shear strength and concrete compressive strength of the tested reinforced concrete slabs. In the current research, three half scale specimens are cast and tested. The specimens had dimensions of 1100 x1100 mm and a total thickness of 120 mm. All specimens were connected to a square column of dimensions 150 x150 mm and loaded at the four corners with a span 1050 mm. The parameters considered in this research included time of loading and concrete compressive strength. During testing, ultimate capacity, steel strain, cracking pattern and deformation were recorded.

KEYWORDS: Slabs, Early punching capacity, Premature concrete, Early-age, Punching shear behavior.

Introduction

Flat slab structures consist of reinforced concrete slabs supported by columns without beams or drop-panels. This type of structure is an economical form of high-rise construction, because the absence of projected beams, drop panels and column capitals simplifies formwork and allows the application of interior finishes directly to the soffit of slab. However, the flat slab is at a disadvantage in comparison to two-way slabs supported by beams because of the risk of brittle punching shear failure at the slab-column connection.

Modern construction techniques enable reinforced concrete structures to be constructed in a very short time. The loads occurring due to the construction process on the partially completed structure can be larger than the design service load. The available strength of the immature partially completed structure is dependent upon the available concrete strength which may be less than the specified strength. Failure would occur if the available strength is less than that required to support the construction loads.

Slabs are usually designed by using the theory of bending and shear. A slab may be loaded prematurely when it has not been allowed to develop its full characteristic strength at the normal 28 days period after casting and with adequate curing procedure following proper mixing and placing of the concrete. When loading is made on a slab prematurely, it will result in misbehavior in service hence, it is necessary to investigate the effect of premature loading on reinforced concrete slabs in order to avoid such failures as wide cracks, de-bonding, other defects and consequently failure. Premature loading of reinforced concrete members may not be deliberate as we find in the construction industry and site procedures. It occurs most of the time in order to meet project time targets as individual structural elements is not allowed to fully develop their characteristic strength before being loaded. For example, a slab may be used to support the formwork for another floor or other structural elements, or it may be loaded with masonry blocks for walls before being laid.
One of the common cause of failures of flat-slab structures during construction is insufficient early-age punching shear capacity under relatively high construction loads. Punching shear failure is a local phenomenon which generally occurs in a brittle manner, at concentrated load or column support region. This type of failure is catastrophic because no external, visible signs are shown prior to occurrence of the failure.

1 Experimental Program

The performed experimental work consisted of three half -scale concrete slabs. All specimens with an overall length of 1100mm, slabs were simply supported and tested under the effect of one concentrated load.

The group consists of four slabs (S1-1, S1-2, S1-3) with ordinary Portland cement. Each of the specimens (S1-1, S1-2 and S1-3) has an average concrete compressive strength of 35 MPa, and (S1-1) will be tested after 28 days, while (S1-2) will be tested after 14 days and (S1-3) will be tested after 7 days. All specimens have the same steel ratio equal to 1.9%. Details of the typical test specimen are shown in table (1). Figure (1) show the specimens details illustrating the cross-section type and number and diameter of steel bars.

Table (1) Details of specimens.

Specimen No.	**Slab Dimensions**			**Comp. Strength (N/mm2)**	**[Testing Time**
	B(mm)	**L (mm)**	**d (mm)**		
Slab (1-1)	1100	1100	100	35	28 days
Slab (1-2)	1100	1100	100	35	14 days
Slab (1-3)	1100	1100	100	35	7 days

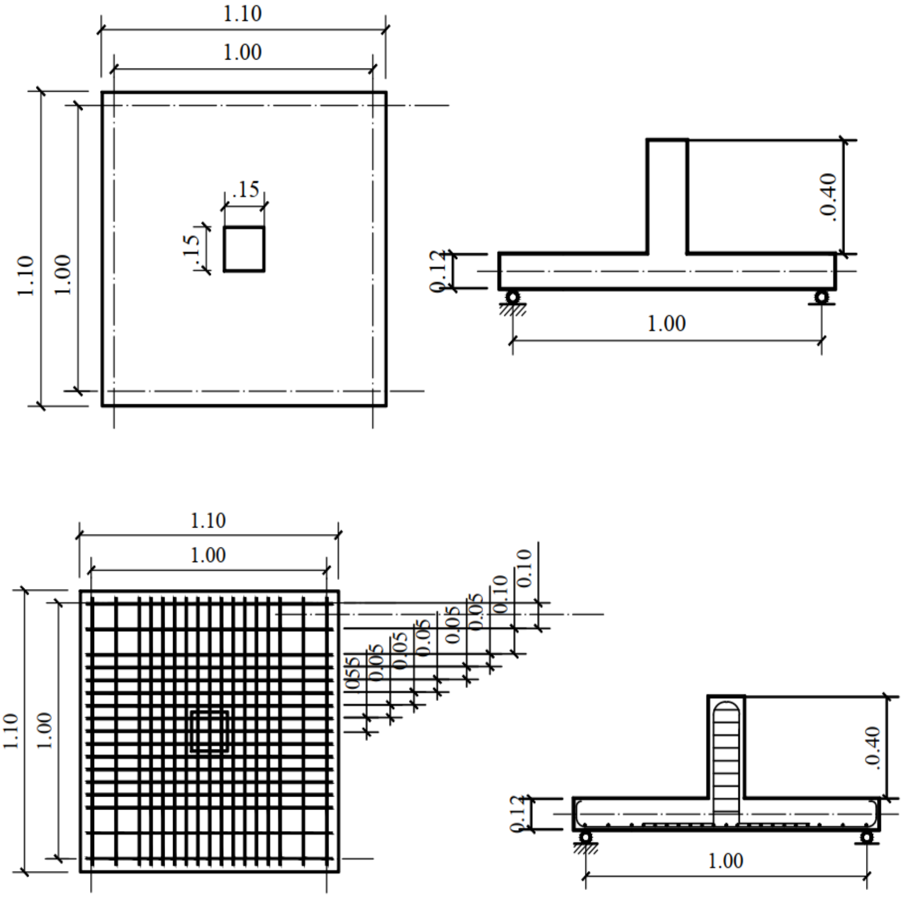

Fig.1 Details of specimens

1.1 Concrete Mixtures Evaluated

The quantities required by weight for one cubic meter of fresh concrete for the specimens are as given in table (2)

Table 2 Material Quantities in Kg/m^3 for The Specimens.

Mix number	Comp. Strength f_{cu} N/mm^2	Component materials / m3 concrete batch kg /m3				W/C ratio	CA/ FA ratio
		Cementitious material	FA	CA	Water		
Mix-1	35	375	600	1200	200	.54	2

1.2 Preparation of Specimens

Wooden forms were designed and prepared to allow for simple and correct placing of concrete. The forms were coated with a thin layer of oil to make their removal after hardening of concrete easier. The bottom steel bars for slabs and columns were fixed in the forms figs. (2). These electrical strain gauges of 6 mm length and 120-ohm resistance were fixed on the steel bars, in order to follow the reinforcement strains during loading. The strain gauges were covered with silicon sealant to protect them during casting and consolidation of concrete.

Fig.2 Details of specimens.

1.3 Mixing and Curing

Dry materials and water were mechanically mixed in a drum mixer for two minutes as shown in Figure 3.8 and cast in the forms just after mixing as shown in Figure 3.9. The cast concrete was then vibrated with an electrical needle vibrator, and hence the final concrete surface was smoothed. The forms were removed after 24 hours from casting, and specimens were moisture continuously with water for 7 days and kept in laboratory atmosphere until they were tested.

Quality control specimens were prepared during casting specimens to obtain the mechanical properties of the used concrete. Two sets of six cube specimens (15.8 cm. side) and nine cylindrical specimens (15 cm. diameter and 30 cm. height) ware cast alongside the beams, weighted and tested at the age of 7, 14 and 28 days (the same day of beam testing). After 24 hours, the specimens were kept under water until the day of testing.

1.4 Loading of Specimens

The specimens were loaded in increments up to failure. The tested specimens were instrumented to measure the deformational behavior after each load increment. The recorded data include measurements in concrete, main steel and longitudinal bars strain; deflection and crack propagation. After each load increment, the cracks were traced and marked on the painted sides of the specimen according to their sequence of occurrence.

1.5 Test procedure

The slabs were prepared and tested at the reinforced concrete laboratory of the department of structural engineering at Cairo university. All the tested slabs were loaded using hydraulic jacks of 500 KN capacity, manually operated by pump. The tested slabs were put in horizontal position between the jack and rigid steel frame as shown in figure. All slabs were tested as simply supported slabs. To achieve the simply supported condition in the Lab, a bar of diameter 22 mm was welded on the top of the steel frame. Loading was applied to specimens in increments of (1) ton with measurements of deflection, reinforcement and concrete strains after each load increment as shown in figure (3).

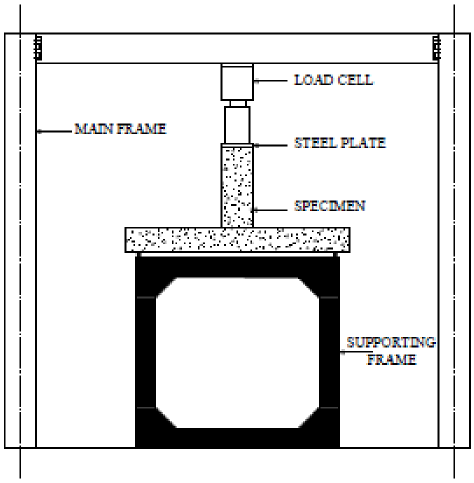

Fig.3 Test Setup.

2 EXPERIMENTAL RESULTS AND DISCUSSION

2.1 Cracking and Failure load

For all specimens, despite their loading time, the first radial crack was observed over the column area at almost constant load and became obvious around (1/3) failure load as shown in table (3), This behavior referred to reaching the concrete tension strength at the tension fibers side of the specimens. However, the behavior changes after the appearance of the first crack, as the load increases the cracks widened and extended towards the slab support but with different speeds. The process went on till the punching failure occurs at different loads and different shapes, but the loud sound at the punching failure occur with only specimen that tested after 28 days.

Table 3 Summary of test results for slab specimens.

Specimen No.	Type Of Concrete	Target Comp. Strength (N/mm2)	Testing Time	Cracking Load (KN)	Failure Load (KN)
Slab (1-1)	Normal	35	28 days	80	340
Slab (1-2)	Normal	35	14 days	70	240
Slab (1-3)	Normal	35	7 days	60	195

Fig.5 Crack pattern of slab specimens.

2.2 Load Deflection Response

Deflection of all slabs was measured using linear variable displacement transducers (LVDT's) and recorded data using a data acquisition system. The applied load versus mid-span deflection relationships of all specimens at different load stages are shown in figure (6). For all specimens, the deflection increases in linear behavior with the load till first crack appear, after this range the stiffness of specimens decreases as a result of propagation of the cracks, and the slope of load deflection curve decreases and tends to be non-linear.

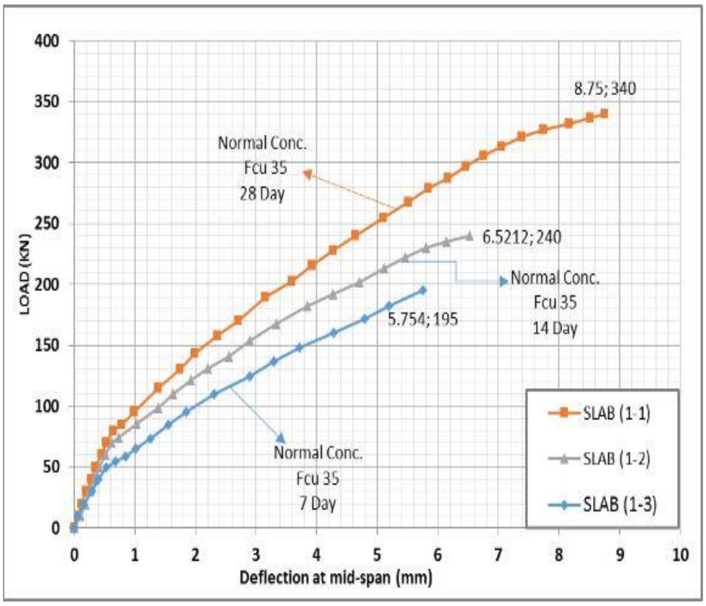

Fig.6 Applied load versus deflection for slab specimens.

2.2.1 Longitudinal Steel Strain

Attached strain gauges at the bottom longitudinal bars were used to measure the steel reinforcement stain during testing process connected to data acquisition system. The applied load versus longitudinal steel strain relationships of all specimens at different load stages are shown in figure (7). From the following figure we can see that flexural steel didn't reach the yield stress, as brittle failure of concrete occurs first and all slabs experienced punching failure before steel yields, the maximum steel strain occurs with specimen S1-1 that tested after 28 days and was equal to (1790*10^-6).

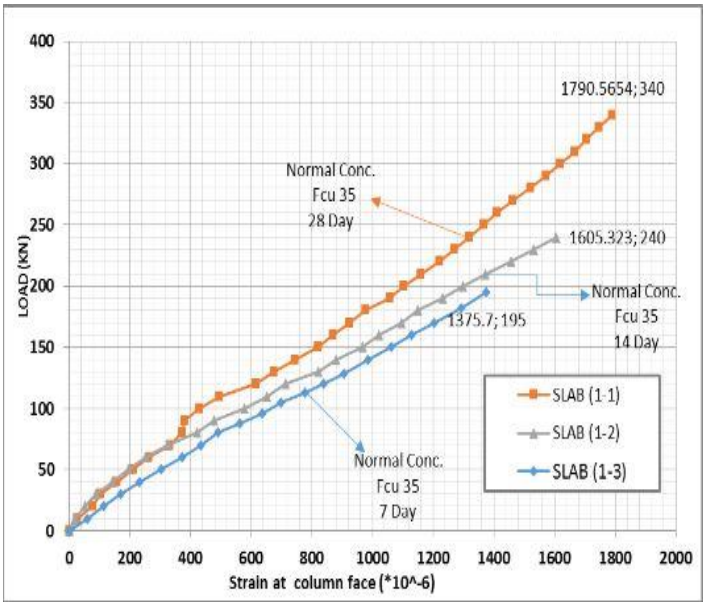

Fig.7 Applied load versus longitudinal steel strain for slab specimens.

3 CONCLUSIONS

1. Test results indicate that Punching shear capacity of slabs doesn't develop with concrete compressive strength at early age loading as the following findings demonstrate that: -
   - Punching capacity of normal concrete slab tested after 7 days reached about 57 % of punching capacity of the same slab after 28 days although its concrete compressive strength reached 69% of the compressive strength of the same slab after 28 days.
   - Punching capacity of normal concrete slab tested after 14 days reached about 70 % of punching capacity of the same slab after 28 days although its concrete compressive strength reached 80% of the compressive strength of the same slab after 28 days.

2. Depending on the different national and international code provisions, the ACI, BS, EC2 and ECP show that
   - BS and EC2 have the most accurate and applicable equations regarding punching shear capacity after 28 days, because they take into consideration the effect of main flexural reinforcement steel ratio in their equations and they believe that punching shear capacity is proportional to the cubic root of concrete strength.

   - While ACI and ECP are too conservative as their equations don't take steel ratio into consideration, and square root of concrete strength is the controller in determining punching shear capacity.

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