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Punching of Self Compacting High Strength Reinforced Concrete Flat Slabs at Edge Column

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ملخص البحث

البلاطات المسطحة اصبحت تستخدم على نطاق واسع لخصائص عديدة تميزها مثل سهولة الشدة الخشبية, والانسيابية المعمارية. على الرغم من ذلك تعد البلاطات المسطحة حساسة جدا للتعرض للانهيار القص الثاقب. تم عمل برنامج عملي في معمل خرسانة بكلية الهندسة جامعة عين شمس بالقاهرة لدراسة تاثير الخرسانة ذاتية الدمك عالية المقاومة على الاعمدة الطرفية حيث تم دراسة عوامل نوع الخرسانة و تاثير وجود حديد القص.يتكون البحث من عدد اربع عينات ابعادهم 1800*1000*160 مم عينتان منهم مصنوعان من الخرسانة العادية واحده منهم بحديد قص الاخرى بدون حديد قص,في حين العينتين الاخريتين مصنوعتان من الخرسانة ذاتية الدمك عالية المقاومة حيث توجد عينة بحديد قص والاخرى بدون حديد قص. اظهرت النتائج ان استخدام الخرسانة ذاتية الدمك عالية المقاومة ساهمت في تحسن المقاومة البلاطة للقص الثاقب بنسبة 41% , بينما اظهرت نتائج البحث ان حديد القص اعطى تحسن طفيف في مقاومة البلاطة للقص الثاقب.

ABSTRACT

Flat slabs are widely used as structural system due to several advantages such as easier formwork, shorter construction time, and architectural flexibility. However they are sensitive to punching shear failure where the column along with a surrounding part of the slab suddenly punches through the remainder of the slab which is characterized by its brittleness. An experimental program has been carried out at the Concrete Research Laboratory at Ain Shams University in Cairo to investigate the effect of the different parameters on punching shear strength where four specimens were casted, two of them made of Normal Strength Concrete and the other two made of Self-Compacting High Strength Concrete with dimensions 1800x1000x160 mm with column stub extended above the slab 200x200x500 mm. The parameters investigated were type of concrete and presence of shear reinforcement. During testing ultimate capacity, steel strain, cracking pattern and deformation were recorded. The test results showed that all the specimens failed in brittle punching shear failure using of Self-Compacting High Strength Concrete improved the performance of slab behaviour and increased the shear punching capacity, also showed that the presence of shear reinforcement did not have a significant effect on the punching shear capacity.

KEYWORDS

Flat Slabs, Edge Columns, Self-Compacting Concrete, High Strength Concrete, Shear Reinforcement, punching shear failure.

1 INTRODUCTION

The flat slabs are widely used for flooring systems in most residential and commercial concrete building. They are appropriate and convenient for most floor situations as they provide architectural flexibility. Among their benefits is the flexibility to layout the architect planes and the capability to have larger spaces without columns obstacles. They also provide less building height, easier formwork and, consequently shorter construction time. On the other hand, as a result of their relatively small thickness, punching shear failure occurs where the column along with a surrounding part of the slab suddenly punches through the remainder of the slab. This type of failure is extremely dangerous because of its brittle nature which does not give any warning to the occupants of the building before failure. Furthermore, the failure of one joint in the system may lead to loss of the structure integrity and, accordingly, a progressive collapse of the whole structure when the adjacent connections fail to support the additional loads imposed on it. Punching shear failure occurs as a result of the high shear stresses caused by the inevitable combination of shear force and bending moment transferred between the slab and the column at a slab-column connection. Consequently increasing the punching shear strength of slab-column connection have been received special attentions from researchers.

The use of high strength concrete (HSC) has steadily increased over the past few years regardless its brittleness due to the great development of concrete technology which allows production of high strengths and advantages of producing smaller sections, reducing the dead weights, allowing longer spans and more durable structures. High strength concrete is defined by its lower limit of 28 day compressive strength; the lower limit of 60 MPa is generally used nowadays. Adding self-compaction property to HSC ensures that no honeycomb could occur in concrete members and provides ease in construction, saves time and minimizes labours required for construction.

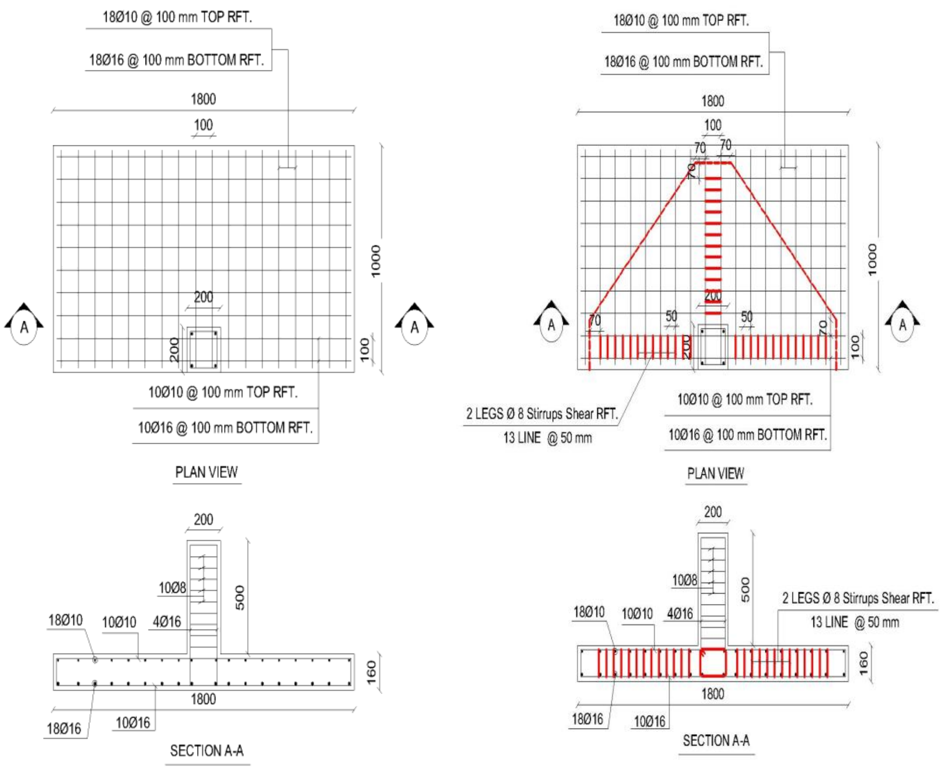
This paper forms part of a research program conducted at the concrete laboratory at Ain Shams University investigating improving punching shear behaviour of flat slabs at edge column by using Self-Compacting High Strength Concrete (SCHSC).

2 EXPERIMENTAL PROGRAM

The experimental program introduced in this paper consisted of four specimens were conducted and tested at concrete laboratory of structural engineering department at Ain Shams university.

2.1 Specimen details

All specimens had dimensions 1800x1000x160 mm with column stub 200x200 mm and extended 500 mm above the slab. All the specimens had the same flexure reinforcement 10ϕ16/m in both directions at the tension side with reinforcement ratio of 1.25%. At the compression side, 10ϕ10/m reinforcement in both directions was used with reinforcement ratio of 0.49%. SE1 and SE2 were made of NSC where SE2 with shear reinforcement while SE1 without shear reinforcement. SE3 and SE4 were made of SCHSC were SE4 contained shear reinforcement while SE3 were without shear reinforcement. Specimens details were presented in figure 1.



(a) SE1,SE3 (b) SE2,SE4

FIG.1: specimen details

2.2 Material and specimen preparation

There were two mix design presented here where several trails were made to reach the mix design of SCHSC. Table 1 shows the material mix design. Compressive concrete strength of NSC was 25 MPa while SCHSC was 68 MPa.

Table 1: Concrete Mix Designs

Material proportions (Kg/m3)	Cement	Fine aggregate	Coarse aggregate	water	Silica fume	Super plasticizer
MIX(1) NSC	350 Grade (42.5)	700	1200	180	----	----
MIX(2) SCHSC	480 Grade (52.5)	750	930	150	50	12

All the formwork, steel rebar, concrete casting and curing were performed in the concrete laboratory at structural engineering department of Ain Shams University. The concrete were mixed using blender mixer while the curing was through water and the specimens were covered with burlap with continuous watering as in figures 2 to 5.

Fig.2: formwork and steel rebar

Fig.3: mixing materials

Fig.4: casting of specimen

Fig.5: specimen curing by covering with wet burlap

2.3 Test set-up and instrumentation

Before casting the slabs, electric resistance gauge were mounted and glued to the reinforcement. The strain gauges were attached to the flexure reinforcement bars on the tension side from column face for both directions for all specimens without shear reinforcement and for specimens with shear reinforcement the strains were attached to the flexure reinforcement and to the shear reinforcement as shown in figures 6 and 7.

Five dial gauges were used to record vertical deflection of the slabs at various locations. The gauges were installed on the bottom surface of slab as shown in figure 8.

The connections were tested in an upside-down position with respect to the position of a real structure. This was done due to the test setup available in the laboratory which allows the vertical shearing force to be applied from top to bottom. Therefore, tension cracks appeared at the bottom side of the slabs. The loading steel frame used to support the slabs consists of four steel I-beams sections installed on four columns. The slabs were simply supported on heavy steel I-beam arrangement along three of the four edges while the fourth edge where the column exists was left free. To ensure full contact between the specimen surface and the supporting steel beams a rubber mat of 1 cm thickness and 10 cm width was used underneath the slab edge. The specimens were prevented from uplift by using upper supporting frame. The load had been applied vertically using hydraulic jack with 1000 Kn capacity acting at the centre of the column. A steel plate was installed underneath the hydraulic jack to uniformly transfer the applied load to the upper surface of the column and to ensure full contact with the column. The hydraulic jack was hanging from the standard I-beam steel section. Hanging the hydraulic jacks from the I-beam section ensured the verticality of the jack during all steps of the test. The I-beam is very rigid to not exhibit any deformation under the applied actuator load. Test set-up shown in figure 9.

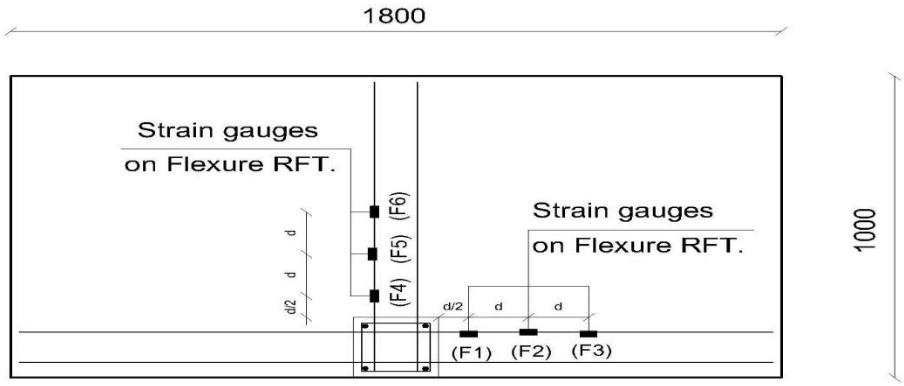


Fig.6: Strain gauge arrangement for specimens without shear Rft.

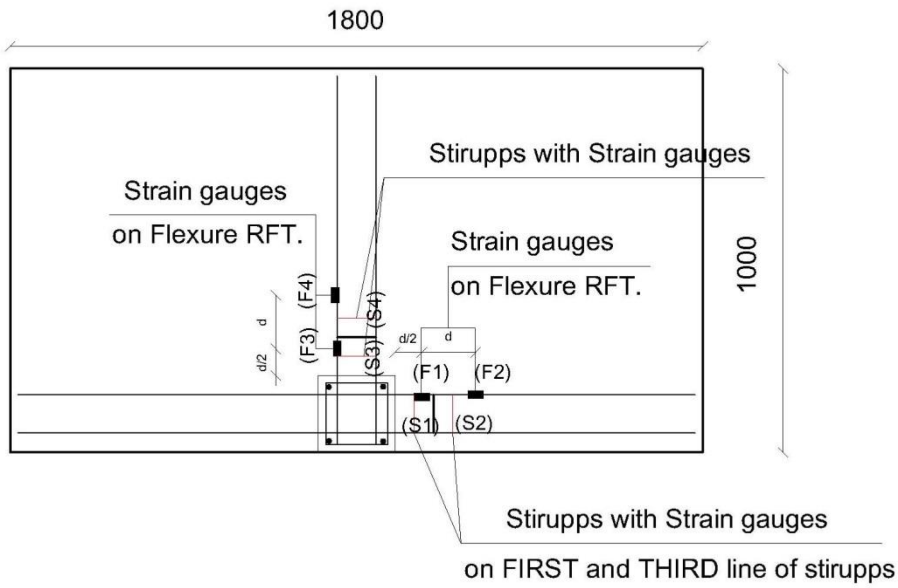


Fig.7: Strain gauge arrangement for specimens with shear Rft

Fig.8: LVDT arrangement for specimens

Fig.9: Test set-up for specimens

3 EXPERIMENTAL RESULTS AND DISCUSIONS

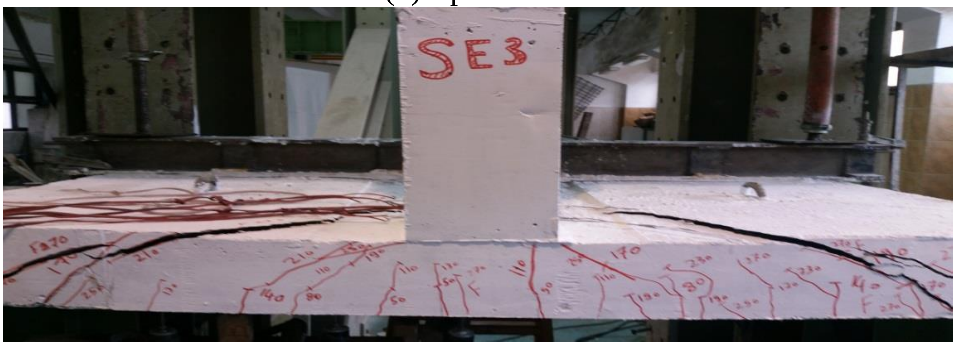
The behaviour of the connections is discussed in terms of the cracking pattern and mode of failure, deflection measurements, strain measurements, the ultimate capacity.

3.1 Crack pattern and Failure mode

The four connections failed in a brittle punching shear mode with no signs of flexural failure, concrete crushing at the compression face of the slab. The failure was characterized by a severe drop in the vertical load when the column along with a conical portion of the slab punched through the remainder of the slab as going to be shown below. However the four connections failed in brittle punching shear mode, they have showed slight differences in the cracking pattern. it was obvious that the crack patterns for all specimens were similar at early stage of loading as the first crack was on the tension side of the slab and mainly below the column and the first crack appeared for the six specimens at close loads, while the significant difference was noted closer to their failure load as diagonal cracks appeared during loading and the first cracks became wider till punching shear cone failure appeared as shown in figure 10.

(a) Specimen SE1

(b) Specimen SE2



(c) Specimen SE3

(d) Specimen SE4

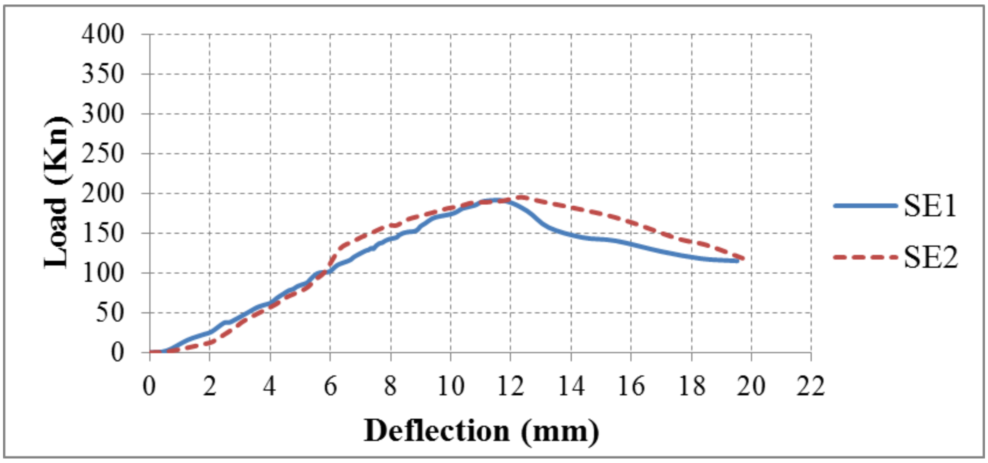
Fig.10: Crack pattern and failure mode for Specimens SE1, SE2, SE3 and SE4.

3.2 Load Deflection Relation and Ultimate Capacity

Table 2 shows the ultimate failure load for the connections and the ultimate deflection while figure 11 shows the load deflection curves for the four specimens at column face in the direction perpendicular to the free edge.

Table 2: load and deflection at failure stage

Specimen	Load (Kn)	DEFLECTION (mm)
SE1	190	11.13
SE2	195	12.34
SE3	269	12.88
SE4	292	14.51



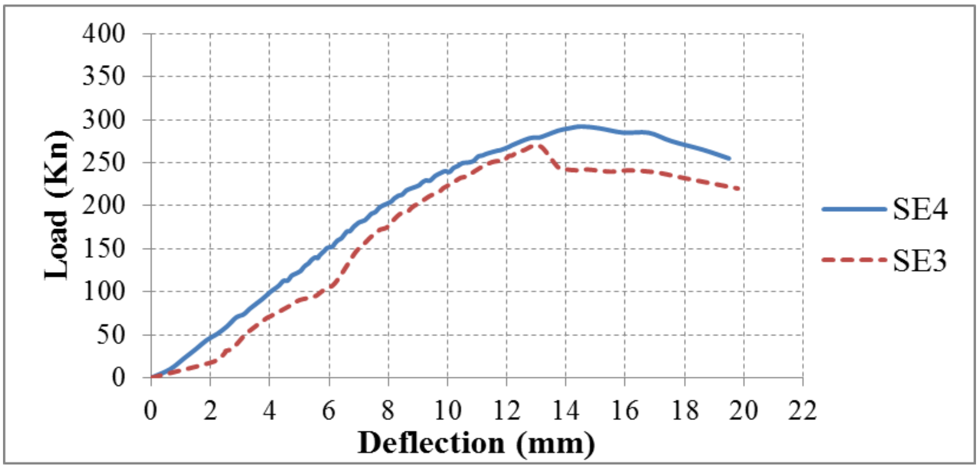


Fig.11: Load Deflection for specimens SE1, SE2, SE3 and SE4.

4 CONCULSION

- All the tested specimens failed in punching shear failure with no signs of flexure failure, however at early stage of loading there were some flexure cracks at the tension side of the slab just below the column.
- Using of self-compacting high strength concrete improved the performance of slab behaviour, the punching shear capacity increased by 41%, ductility and absorbed energy also improved and the crack width and crack density were smaller than for normal strength concrete slab at the same load level.
- The presence of closed stirrups as shear reinforcement for the slab caused a very slight enhancement as the punching shear capacity increased by 2.65% for normal strength concrete while increased by 8.55% for self-compacting high strength concrete.
- The flexure steel reinforcement exhibited the maximum strain near the column face, however all specimens failed in punching shear before yielding of steel reinforcement.
- The flexure steel reinforcement in the direction parallel to the free edge exhibited higher strain than the flexure reinforcement in the direction perpendicular to the free edge.
- The shear reinforcement has nearly similar strains for both directions and the strain decreased as the stirrups away from the column face; the stirrups did not reach the yield strain.

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