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Strength Evaluation of High Performance Concrete Slabs in Punching Shear

N.Venkata Ramana[1], T. Naresh Kumar[2] and S. Vinay Babu[3]

[1] Assistant Professor, Civil Engineering Department,
JNTUA-CE, Anantapur, A.P-515002, India
rccramana@gmail.com

[2] Lecturer, Department of Civil Engineering,
JNTUA-CE, Anantapur, A.P-515002, India
naresh.yamykhan@gmail.com

[3] Lecturer, Department of Civil Engineering,
JNTUA-CE, Anantapur, A.P-515002, India
vinaysake@gmail.com

Abstract: *This paper presents the punching shear behavior of high performance concrete slabs. M60 grade concrete was designed as per IS standards and treated as high performance concrete (HPC). The high performance concrete was prepared with admixture of silica fume and low water cement ratio. An attempt has been made to assess the strength of slab element in punching shear. For comparison purpose M25 grade concrete slabs (RCC) cast and tested. The results showed that the high performance concrete posses high performance than the standard concrete (M25). In addition to the slab specimens, cubes and cylinders are cast and tested in order to check the ACI and IS codes provisions. After applicability of the results to codes (ACI and IS), it is observed that IS code provisions shown more conservative than ACI code provisions.*

Key words: *Punching shear, slab element, high performance concrete, ACI and IS code provisions.*

1. INTRODUCTION

Nowadays flat system has been adopted and widely used for many structures such as supermarket, stores and underground garages, bridge decks etc. The designers are designing the slab elements with standard grade concrete; this leads large thickness to the structural system. To decrease the size of element some designer are proposing huge amount of steel instead of using large quantity of concrete, this type of approach leads to higher cost to the whole building or structure. In order to find new technology, research found that the utilization of various fibres and shear studs incorporation in the standard concrete is shown good performance than the ordinary concrete. A brief review is presenting herein to know the research in this arena. Kuang J.S and Morley C.T [1] proposed a model to estimate the punching shear of laterally restrained slabs and the proposed model shown good agreement with a wide range of experimental results.M.H Harajli ,D.Maalouf [2] conducted the experimentations on punching shear behavior of concrete containing hooked fibres. The results showed that the concrete with fibres have good ductility and high strength than the ordinary concrete. They also proposed some models to predict the strength of punching shear. Menetrey.Ph [3] conducted the research work on concrete to differentiate the flexure and shear

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failure. A detailed analytical analysis was carried and presented in his research article.Martina Schellenbach-Held and Karsten Pfeffer [4] investigated the behavior of hollow slab with plastic as hollow bodies. They performed the nonlinear Finite Element Method to estimate the behavior and also modified the existing design recommendations of German code (DIN 1045). Hegger J et.al [5] investigated the punching shear behavior on footings. The results indicated that the angle of shear failure plane is steep in footings when compared with flat slabs failure plane. Kyoung-Key Choi et.al [6] made theoretical study on interior slab-column connection reinforced with steel fibres. The study was focused in punching behavior and few models are developed to identify the behavior with correlation of earlier research test bank data. Ran Li et.al. [7] Studied the punching shear behavior of flat plate slab, reinforced with carbon fibre reinforced polymer rods. The results indicated that the polymer rods usage in flat slab has better foreground. Sudarsana Rao H et.al [8,9] conducted the experimental work on SIFCON with and without conventional reinforcement two way slabs under punching shear. The results exhibited the SIFCON behavior is dominating the ordinary concrete in strength and ductility aspect. Stefan lips and Aurelio Muttoni [10] conducted experimental work on reinforced concrete slabs cast with shear studs. The performance of results was analyzed and compare to with design codes. Daniel Heinzmann et.al [11] conducted punching test on reinforced concrete slabs with and without shear reinforcement. In their work the shear reinforcement was placed on probable punching shear locations and strengthened with the shear reinforcement (shear studs) and this type of provision enhances the shear capacity of slab specimens. Liana L et.al [12] conducted the research work under punching shear on reinforced concrete flat plates with openings. The methods given in ACI and MC90/EC2 codes are reviewed and some models were proposed to estimate strength. From the literature it is observed that many of research works are focused with different methodologies to enhance the shear capacity of slab elements. But few works has been carried out on HPC under shear. In this concern the authors of this paper has been thrown a ray of light to estimate the punching shear capacity of HPC slab specimens with two adjacent edges fixed and other two simply supported. The detail experiment work has been presented in the following sections.

2. EXPERIMENTAL PROGRAM

To evaluate the punching shear of HPC slab elements, three HPC specimens with dimensions of1100 x 1100 x 50 mm. (length x breadth x depth) were cast and tested. For all slabs clear span was taken as 1000mm. M60 grade concrete was adopted for HPC slab specimens with design mix proportion of 1:1.37:1.98. Water cement ratio was arrived as 0.3.Silica fume was used as admixture in the design mix and silica fume to cement ratio was provided as 0.17. To improve the workability of mix, Conplast-P211was used and the dosage of this is 5.95 liters per cubic meter of concrete. For comparison purpose three more specimens with M25 grade of concrete were cast and tested. These slabs were named as RCC in the present text. For RCC (M25) slab specimens design mix was arrived as 1:2.07:2.51 and the water cement ratio provided as 0.53. The obtained test results were checked with the existing codes of IS and ACI codes. (Cubes and cylinders are also cast and tested and the results are substituted in appropriate place of code provisions).

2.1Materials used in the investigation

2.1.1 Cement

Ordinary Portland cement of grade 43 conforming to IS 8112: 1989 is used. The specific gravity of the cement is 3.01. The initial and final setting times were found as 90 minutes and 340 minutes respectively.

2.1.2 Fine aggregate

Locally available river sand passing through 4.75 mm I .S .Sieve is used. The specific gravity of the sand is found to be 2.62

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2.1.3 Coarse-Aggregate

Crushed granite aggregate available from local sources has been used. To obtain a reasonably good grading, 60% of the aggregate passing through 20 mm I.S. sieve and retained on 12.5mm I.S. Sieve and 40% of the aggregate passing through 12.5mm I.S. Sieve and retained on 10 mm I.S. Sieve is used in preparation of RCC of M25 and HPC of M60 grade. The specific gravity of the combined aggregate is 2.6.

2.1.4 Silica fume

Silica fume manufactured by Elkem is used in this work with the following physical properties
Color: Grey
Specific gravity: 2.2 - 2.3 g/cm^3
Bulk density: 150 - 700 kg/m^3
Specific surface: 15 - 30 m^2/g
Average particle size: 0.5 µm

2.1.5 Water

Potable fresh water available from local sources was used for mixing and curing of HPC and RCC slabs.

2.1.6 Super Plasticizer

To improve the workability of HPC, SIKAMENT NN SP a high range water-reducing agent has been used.

2.1.7 Reinforcement

8mm diameter bars of HYSD are used as reinforcement in the slabs. The yield strength of bars was 415 MPa.

2.2 Casting of test specimens:

Steel moulds were used to cast the slab specimens of required size i.e. 1100 x 1100 x 50 mm. Initially the steel mould is coated with waste oil so that the slab specimens can be removed easily from the moulds. Then the 8mm diameter HYSD rods at 105mm center to center are placed in both directions by maintaining a clear cover of 10mm. Then the prepared concrete is poured in to the mould to the entire volume and compacted with plate vibrator. The deposition of reinforcement and cast specimen can be viewed in figure 1. The cast specimens were later demoulded and kept in curing pond for a period of 28 days. After removing all the specimens from the curing pond, they were allowed to dry under shade for a while and then they are coated with white paint on both sides, to achieve clear visibility of cracks during testing. Cubes (150x150x150mm) and cylinders (150mm dia and 300mm height) were tested under compression to obtain the compressive strengths and the results are presented in Table1.0.These a value were used in this article, while checking the validity of ACI and IS code provisions.

Figure 1: Slab specimen

2.3 Loading arrangement and testing:

The slab consists of a solid plate of 100 x 100 x 20 mm placed at the center of the top face of slab specimen. Over this solid plate, solid circular rod of 50 mm diameter was kept to distribute the load from hydraulic jack to the slab specimen. This simulates the footing/slab and column effect. For better fixidity, the slab edges clamped to the loading platform with the 'C' type clamps, which are tightened by bolt and nuts. The whole arrangement has been made to obtain the punching shear effect on the slab specimen, and it can be viewed in Figure 2.0. The load was applied through hydraulic jack and was measured with a calibrated proving ring (100 KN) with a least count of 40N. The vertical deflections were measured by using dial gauge with a least count of 0.01 mm. The vertical deflections were measured at the centre of the slab specimens.

The load increment was selected such that there will be as many number of readings as possible. The load was applied with an increment of 200 N (0.2KN) which corresponds to one unit of proving ring. Deflections have been recorded for each load increment. The failure punching shear load and corresponding deflection at the centre were also observed and recorded.

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Figure 2 Loading arrangement

3. ANALYSIS OF TEST RESULTS

The results of the experimental investigation are presented in Table 2 and 3.

3.1 First crack stage

From the Table.2 it is observed that the HPC slab specimens possesses higher first crack load than the RCC slab specimens. The HPC slab specimens show 8.18 KN to cause first crack, which is higher load than the specimen with RCC. The specimen with RCC shows lesser value i.e. 6.75kN. This confirms that HPC slabs are superior to RCC slabs at first crack stage. The HPC slabs have shows considerable increase in punching shear strength compared to RCC slabs, there is an increase of 21.18% in punching shear capacity at first crack stage. From the above discussion it is clear that HPC slabs are superior to RCC slabs at first crack stage.

3.2 Ultimate failure Stage:

From the same table (Table2) it is noticed that the HPC slab specimens possesses higher ultimate failure load than the RCC slab specimens. The HPC slab specimens show 49.51KN to cause ultimate failure, which is higher load than the specimen with RCC. The specimen with RCC shows lesser value i.e. 31.19kN. This confirms that HPC slabs are superior to RCC slabs at ultimate failure stage. The HPC slabs have shows considerable increase in punching shear strength compared to RCC slabs, there is increase about 58.70% in punching shear capacity at ultimate failure stage. From the above discussion it is clear that HPC slabs are superior to RCC slabs at ultimate failure stage.

3.3 Load – Deflection behavior

The load deflection behavior is presented in Table 3.0 and Figure 3.0.From these it is observed that for a given load there is a decrease in central deflection in HPC slab specimens when compared with the RCC specimens. This is due to greater stiffness of HPC specimens. HPC slabs recorded a deflection in punching shear load is about 0.32mm at first crack stage and about 14.81mm at ultimate failure load. Whereas the RCC slab specimens recorded 0.46mm and 22.24mm at first crack and ultimate failure stages respectively. The ultimate deflections of HPC slabs are an order higher than those of RCC slabs. This demonstrates that greater stiffness of the HPC slab specimens.

3.4 Failure pattern

From the experimental study it is observed that the crack pattern is almost similar in all HPC and RCC slabs. During experimentation, it is observed that the first crack originated at the centre and subsequently it propagated radially toward the corners. At higher loads it is observed that already formed cracks getting widened with formation of new cracks. At the same time the damaged influence area beneath the slab specimen can be observe very clearly. Just for view, one of the tested HPC slab specimen is depicted in figure.4. From this figure the crack pattern can be watched both at top and bottom. This type of failure pattern was observed by Hegger et.al [5] Ran Li et.al [7] and Sudarsana Rao [8, 9].

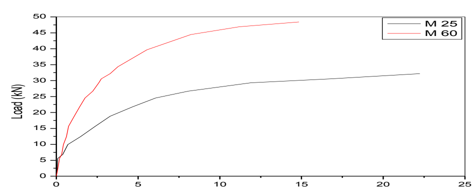

Figure 3 Load deflection curves of HPCand RCC slabs

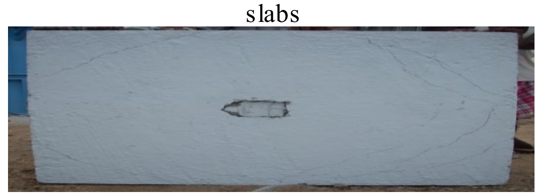

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Figure 4: Top & Bottom view of failure specimen

4. COMPARISON OF EXPERIMENTAL ULTIMATE PUNCHING SHEAR STRENGTH WITH DESIGN CODAL PROVISIONS

To evaluate the punching shear, two major building codes ACI 318M-11 and IS 456-2000 for R.C.C is considered in the present analysis.

In the ACI 318M-11 code the ultimate punching shear strength P_u is taken as the smallest value given by the following.

$P_u=(0.17+(0.34/B_c))\sqrt{f_c}ud$..........................(1)

$P_u=(0.166+(0.083\alpha d/u))\sqrt{f_c}ud$……………...(2)

$P_u=0.33\sqrt{f_c}ud$………………….……… (3)

Where,

P_u = Ultimate punching shear strength (N).

B_c = The ratio of long side to short side of the loaded area

f_c = Specified cylinder compressive strength of concrete N/mm^2 and

α = 40 for symmetric punching.

u = Length of the critical perimeter (mm), taken at a distance of d/2 from the column/pedestal

According to the Indian standard code IS: 456-2000, the expression for calculating the punching shear strength Pu by considering partial safety factor for material as unity is given as

$P_u=K_s\tau_c$ u d ……….………………….. (4)

Where,

P_u =ultimate punching shear strength (N).

K_s = $(0.5+B_o)\leq 1$

B_o = ratio of short side to long side of column

τ_c =0.25 $\sqrt{f_{ck}}$

τ_c = shear stress in concrete (N/mm^2)

f_{ck}= Characteristic cube compressive strength of concrete (N/mm^2)

u = Length of the critical perimeter (mm), taken at a distance of d/2 from the column/pedestal

d = effective depth at the critical section (mm)

Table1: Cube and Cylinder compressive strength of RCC and HPC

S.No.	Description	Cube compressive strength (MPa)	Average Cube compressive strength (MPa)	Cylinder compressive strength (MPa)	Average Cylinder compressive strength (MPa)
1	RCC specimen 1	32.88		27.12	
2	RCC specimen 2	33.11	33.25	26.50	26.65
3	RCC specimen 3	33.77		26.34	
4	HPC specimen 1	73.33		58.67	
5	HPC specimen 2	71.11	71.85	58.31	57.71
6	HPC specimen 3	71.10		56.16	

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Table 2: Punching Shear Strength of HPC and RCC slabs.

S.No	Type of slab		First Crack Load (KN)	Average First Crack Load (KN)	Ultimate Load (KN)	Average Ultimate Load (KN)
1.	RCC	Specimen 1	6.50	6.75	30.75	31.19
		Specimen 2	6.80		32.34	
		Specimen 3	6.95		30.50	
2.	HPC	Specimen 1	7.80	8.18	48.56	49.51
		Specimen 2	8.25		49.72	
		Specimen 3	8.50		50.25	

Table 3: Deflections at First Crack and Ultimate stages.

S.No	Type of slab	Average First Crack Load (KN)	Average Deflection (mm)	Average Failure load (KN)	Average Deflection (mm)
1.	RCC	6.75	0.46	30.75	22.24
2.	HPC	8.18	0.32	48.17	14.81

Table 4: Comparison of punching shear test results for slabs with standard codes of practice

S.No.	Nomenclature	Ultimate Punching Shear loads (kN)			EXP values/ ACI 318M-11	EXP values/IS 456-2000
		Exp values	ACI 318M-11	IS : 456-2000		
1	RCC	30.75	17.58	25.64	1.74	1.19
2	HPC	48.17	25.87	37.74	1.86	1.27

The above two specified code provisions are used to calculate the ultimate punching shear load and the calculated values are presented in table4.0 (For calculation of ultimate punching shear load, The cube and cylinder compressive strengths are obtained from Table 1.0), Form the Table 4.0 it can be observed that, the experimentally observed loads are deviating about 74 to 86% excess based on ACI provisions for RCC and HPC slab specimens. But IS code provisions are deviated about 19 to 27% (excess) for RCC and HPC slab specimen. From this it concluded that IS code is more conservative than the ACI code. For better estimation of punching shear strength, IS code more reliable than the ACI code provisions.

5. CONCLUSIONS

1. The punching shear carrying capacity of the HPC slabs is much higher than the RCC slab specimens.
2. The increase in punching shear strength of HPC slabs over RCC slabs is 21.18% at first crack stage
3. The increase in ultimate punching shear strength of HPC slabs over RCC slab is 58.70%.
4. The ultimate punching shear strength of HPC and RCC slabs are 31.19KN and 49.51KN respectively.
5. The stiffness of HPC slabs is in the order of higher magnitude than that of RCC slabs.

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6. The HPC slabs recorded the ultimate punching shear deflection of about 14.81mm, OPC concrete slabs recorded 22.24mm with a load of 48.17 KN and 30.75 KN respectively.
7. I.S 456-2000 codal provisions show more conservative results than the ACI 318M-11 code to evaluate the punching shear capacity.

REFERENCES

[1] Kuang J.S and Morley C.T, "A plasticity model for punching shear of laterally restrained slabs with compressive membraneaction", Int.J.Mech.Sci.Vol.35, pp-371-385, 1993.

[2] M.H.Harajli, D.Maalouf & H.Khatib, "Effect of fibres on the punching shear strength of slab column connections", cement and concrete composites, Vol.17, pp-161-170, 1994.

[3] Ph. Menetrey, "synthesis of punching failure in reinforced concrete", cements and concrete composites Vol.24, pp-497-507, 2002.

[4] Martina Schnellenbach-Held, Karsten Pfeffer, "Punching behavior of biaxial hollow slabs", cement and concrete composites Vol.24, pp-551-556, 2002.

[5] J.Hegger,M.Ricker,B.Ulke,M.Ziegler,"Inves tigations on the punching behavior of reinforced concrete footings", Engineering structures Vol.29, pp-2233-2241,2007.

[6] Kyoung-Kyu Choi, Mahmoud M.Reda Taha,Hong-Gun Park, "Punching shear strength of interior concrete slab-column connections reinforced with steel fibers", cement and concrete composites Vol.29, pp-409-420,2007.

[7] Ran Li,Young Sang Cho,Sumei Zhang, "punching shear behavior of concrete flat plate reinforced with carbon fibre reinforced polymer rods",composites: Part B,vol. 38,pp-712-719,2007.

[8] H. Sudarsana Rao, K.Gnaneswar, N.V.Ramana, "Behaviour of simply supported steel reinforced sifcon two way slabs in punching shear", Indian journal of material and sciences,vol.15,pp.326- 333,2008.

[9] H. Sudarsana Rao, N.V. Ramana and K. Gnaneswar"Behaviour of restrained sifcon two way slabs part 2: punching shear" vol. 10, No. 4 ,pp-481-494,2009.

[10] Stefan Lips and Aurelio Mutton, "Expermental investigation of reinforced concrete slabs with punching shear reinforcement", 8th fib PhD Symposium in Kgs.Lyngby,Denmark. June 20-23, 2010.

[11] Daniel Heinzmann, Stephan Etter, Sebstian villager, and Thomas jaeger, "punching tests on reinforced concrete slabs with and without shear reinforcement",ACI structural journal,vol.109,No.6,pp-787-794,2012.

[12] Liana L.J.Borges,Guilherme S.Melo, and Ronaldo B.Gomes, " punching shear of reinforced concrete flat plates with openings", ACI structural journal,vol.110,No.4,pp-547-556,2013.