Experimental Investigation of Size Effect on Inplane Shear Strength of Normal, Self Compacting and High Strength Concrete from Push Off Test

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Abstract - *This paper illustrates the result of an experimental investigation conducted to study the direct shear transfer capacity of Normal Strength Concrete (NSC), Self Compacting Concrete (SCC) and High Strength Concrete (HSC) by conducting a recently developed push off specimen. The shear friction concept has physical applications in reinforced concrete structures such as shear keys, web flange stress transfer, brackets in column, corbel, ledger beams, punching resistance, coupled shear walls, wall to foundation connections, and cast-in-place concrete toppings where shear friction forces must be assured at the connection interface. Change in crack geometry, crack density and effective failure planes in NSC, SCC and HSC changes the Inplane Shear. Hence an attempt has been made to study the Inplnae Shear behaviour of concretes considered. Size of the Push- Off Specimen chosen was 150mm × 150mm × 260mm, notches of 10mm thick and 150mm length were cut perpendicular to the loading axis on the specimen. The end blocks of the Push Off specimens were strengthened with a mesh of 5mm diameter TORKARI bars of grade Fe 550. The parameters considered in the research were types of concrete (M30-NSC; M30-SCC and M70-HSC) and shear plane height (80mm, 100mm & 120mm). The load was applied through two steel bars of dimension 10mm× 10mm, which are placed between the fixed loading crosshead of the compression testing machine. Failure patterns, Ultimate shear strength and fracture surfaces are presented in this investigation. Obtained experimental ultimate shear stress results were compared with different codal provisions and regression analysis was carried out to formulate prediction equations, to estimate the ultimate shear strength.*

Key Words: In Plane Shear, Push off Specimen, Shear Plane Height.

1. Introduction

Concrete is a highly versatile and most widely used material for construction. Failure of concrete members usually occurs by combined effect of flexure and shear, among these shear failure is one of the most undesirable modes of failure due to its rapid progression. This sudden type of failure made it necessary to explore more effective ways to design the reinforced concrete structural members. The reinforced concrete structures exhibits different behaviour at the failure stage in shear compared to that of bending, which is considered to be unsafe mode of failure. Although we can calculate the safety of structural members with respect to bending failures with a fair degree of certainty, the same cannot be said in regard to shear failures. The mechanism of shear failure is as yet clearly understood and all formulae developed for the calculation of shear strength of reinforced concrete members are either wholly or partly empirical. This is due to lack of rationality in our approach to the problem of shear. For introduction of ductility or toughness parameter in relevant structural design, knowledge of shear failure is essential [*8*, *9*]. Birkeland et al [*20*] proposed a shear friction concept to evaluate the interface shear strength of concrete block.

Shear strength of specimens depends both on concrete and reinforcement contribution and also aggregate interlock or crack shear friction [*1, 7, and 16*]. WALRAVEN [*20*] analysed the aggregate interlock by means of push-off tests. As per his observation spherical aggregates shows effective aggregate interlock. Aggregate interlock phenomenon is different in HSC, SCC, FRC compared with NSC. KIM [*21*] in his test on push-off specimen (>70MPa) confirmed that shear strength is related to amount of aggregate fracture. Shear strength of concrete increases with increase in compressive strength of concrete [1, 2].

In present experimental investigation Shear strength variation with respect to height of shear plane was studied using 80mm, 100mm and 120mm shear plane height on NSC (M30), SCC (M30) and HSC (M70).

2. Scope of present investigation:

- To obtain mix proportion for M30 NSC using 20mm, M30 SCC and M70 HSC using 12.5mm and downsize aggregates.
- To observe the variation and comparison of shear stress values of different grades of concrete and different shear plane height.
- Obtained shear stress values compared with different codal provisions.

- To observe the failure mode and fracture surface of the failed specimen.

3. Materials and Mix Proportions

The following materials were used in the present investigation.
Cement: 53 Grade OPC as per IS 12269- 1989 with specific gravity 3.15. Fly Ash: Fly Ash conforming to ClassF IS 3812:2003. Coarse Aggregates: 20mm downsize Aggregates with specific gravity 2.65 for NSC. 12.5mm down size aggregates with specific gravity 2.62 for SCC & HSC. Coarse aggregates were conforming IS 383:1970. Fine Aggregates: Manufactured Sand with specific gravity 2.57 and Fineness Modulus 3.05 conforming to zone II of IS 383:1970. Super Plasticizers: Naphthalene based polymer (Conplast SP 430) complying with IS: 9103:1999 for HSC. Glenium B233 Modified poly-carboxylic ether for SCC. Viscosity Modifying Agent: Glenium Stream 2 for SCC. Steel: 5mm diameter TORKARI bars for strengthening of end blocks of Push Off Specimen. Water: Potable water conforming to IS 456:2000.
Mix Proportions:
Mix design adopted for the present investigations are as follows: NSC M-30 as per IS 10262:2009; SCC M-30 NAN–SU (Chinese) method. HSC M-70 design procedure given by R. P et al

Table 1: Mix Proportions of NSC, SCC and HSC

	NSC	SCC	HSC
Cement in kg/m³	348.33	214.28	500
Fly Ash in kg/m³	-	326.06	-
Fine Aggregates in kg/m³	681.66	849.2	666.01
Coarse Aggregates in kg/m³	1146.8 (20mm)	681.1 (12.5 mm)	1000 (12.5mm)
Water in lit/m³	191.58	172.9	150
Super Plasticizer	-	1.3%	2.5%
VMA	-	0.18%	

4. Experimental Investigation

To evaluate the In Plane shear behaviour of concrete total 27 Push Off specimens were casted using different types of concretes such as NSC (M30), SCC (M30) and HSC (M70). The end blocks of the Push Off specimens were strengthened using 5mm diameter TORKARI bars. The dimensions of Push Off Specimen chosen from available literatures. The size of specimen was 150mm × 150mm × 260mm with varying shear plane area i.e. 80mm × 150mm, 100mm × 150mm and 120mm × 150mm as shown in Figure 1. Three specimens in each category (NSC, SCC & HSC) were tested in present investigation with different Shear Plane (SP) heights (80mm, 100mm and 120mm) to observe the in plane shear behaviour.
The moulds were lubricated well using oil before the placement of concrete, care was taken to avoid the leakage of concrete from the moulds. Standard procedure was adopted for the mixing, casting and curing. Companion cubes were also casted to know the compressive strength of concrete.
Specimens were tested for ultimate shear stress after a curing period of 28 days. Testing of the specimens was done in Compression Testing Machine at PG laboratory of Civil Engineering Department at MSRIT Bengaluru. 10mm thick square rod was used to apply the line load on the specimen.

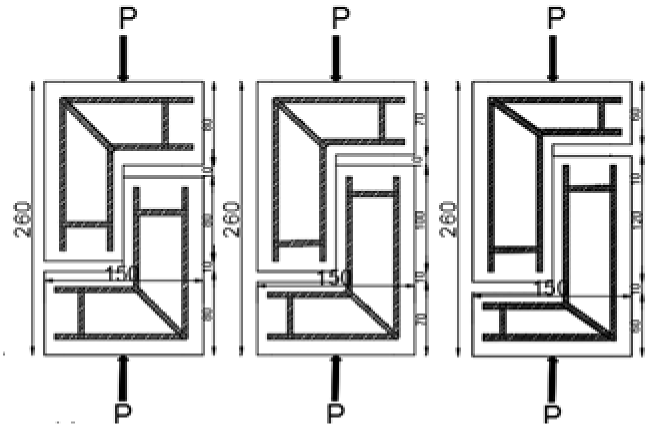

Figure 1. Push Off Specimens used in the Present Study

5 .Results and Discussions

In Table 2 results of cube compressive strengths of different grades of concretes NSC, SCC and HSC after trail mixes used to cast push-off specimens are tabulated.

Table 2: Compressive strength of NSC, SCC and HSC

It was observed from the above Table 2 the 28 days strength of NSC, SCC was greater than the target strength. However for M70 concrete this 28 days strength was less than this target strength.

Type of concrete	Grade of concrete	Cube size (mm²)	Cube compressive strength, f_{ck} (MPa)	
			7days	28days
NSC	M30	150×150	24.12	38.76
SCC	M30	150×150	25.00	45.78
HSC	M70	100×100	54.93	71.12

Concrete strength and Shear plane area are the important variables considered in the present investigation. It was generally believed that large part of the shear force transfer depends on aggregate interlock. The crack pattern was found to be trans-granular (passing through aggregate) in HSC and cracks were found to be surface-granular (passing over the surface of the aggregates) in case of NSC and SCC. Cracked surface of failed push-off specimens are shown in Figure 2

NSC SCC HSC

Figure 2: Cracked surfaces of failed push-off specimens

The cracks were observed along the shear plane in all the Specimens. Cracks were initiated from one end of the notch face approximately at notch tip and propagated towards the other end of notch tip, however few specimens were failed producing cracks in the sides and propagated towards the notch tip as shown in Figure 3. Ultimate shear stress of NSC (M30) was observed to be less compared to SSC (M30), while HSC (M70) was observed to have higher shear stress compared to NSC and SCC.

The Push Off specimens were failed in brittle manner. Failure patterns of specimens observed was shown in Figure 3. The results obtained from the experiment are tabulated in the Table 3.

NSC SCC HSC

Figure 3: Failure pattern in push-off concrete specimens

Typical Plot of ultimate shear stress with respect to shear plane height variation was plotted for NSC, SCC and HSC (Figure4). It was observed that, in NSC 80mm SP specimens showed 19.8% increase in ultimate stress but in 120mm SP specimens the ultimate shear stress was decreased by 4.8% with reference to the 100mm SP specimens. In SCC 80mm SP specimens showed 15.8% increase in ultimate stress but in 120mm SP specimens the ultimate shear stress was decreased by 12.72% with reference to the 100mm SP specimens. In HSC 80mm SP specimens exhibited 13.4% increase in ultimate stress but in 120mm SP specimens there was no significant change in the ultimate shear stress with reference to the 100mm SP specimens.

Table 3: Test results of the Push Off Specimen

Sl n	Specimen	Shear plane height (mm)	f_{ck} MPa	f'_c MPa	Vu (kN)	τ_u MPa
1	NSC/80	80	40.38	32.3	71.94	6
2	NSC/100	100	38.67	30.94	75.21	5.01
3	NSC/120	120	39.87	31.9	85.84	4.77
4	SCC/80	80	42.73	34.18	94.01	7.83
5	SCC/100	100	47.96	38.37	101.37	6.76
6	SCC/120	120	47.52	38.02	106.28	5.9
7	HSC/80	80	73.58	58.86	119.36	9.95
8	HSC/100	100	67.69	54.15	128.35	8.56
9	HSC/120	120	69.65	55.72	142.25	7.9

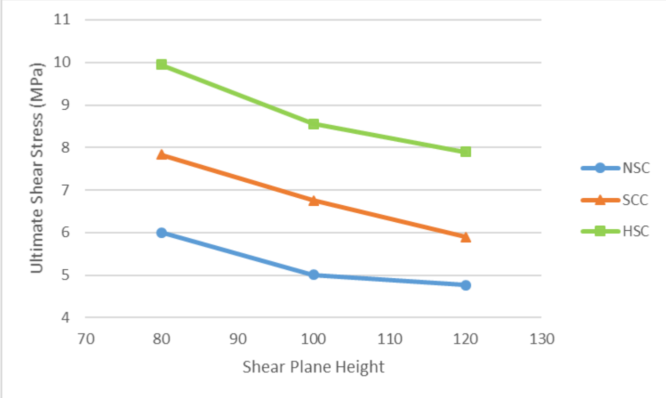

Figure 4: Ultimate Shear Stress v/s Shear plane Height

After discussing the test results of all of the experimental study, an attempt has been done to bring about a comparative study between the experimental data and various available codes and their expressions regarding the shear stress. The expressions which have been found from nonlinear regression analysis also brought into consideration.

According to ACI 318-11:

$V_u = V_c + V_s$ .... (1)

$V_c = 2\lambda\sqrt{f'c}\ \ bw \times d$

$V_s = A_v\, f_y$

According to IS 456: 2000

$V_u = \tau_c b\, d + 0.87 f_y A_{st}$ .... (2)

Where,

$\tau_{cmax} = 3.5 N/mm^2$ (M30)

$\tau_{cmax} = 4\ N/mm^2$ (≥M40)

According to NZS 3101: Part 1:2006

$V_n = V_C + V_S$ .... (3)

$V_c = k_a\, k_d\, V_b\, A_{cv}$

$V_b = 0.5\sqrt{f'c}$

$V_S = A_v f_{yt}$

Where,

k_a= 1 for 20mm aggregates & 0.85 for 10mm downsize aggregates.

k_d =1

From the experimental results and the calculated values from the codal provisions, Nonlinear regression analysis was carried to formulate prediction equation,

$$\tau_u = 6.258(f^1_{ck})^{0.815795} (SP)^{-0.63954} \quad \text{............(4)}$$

The Ultimate shear Strength was calculated theoretically for all the tested specimens using the equations 1, 2 & 3. The ratio of Experimental ultimate Shear stress and calculated Shear stress from the codal provisions was obtained and further Mean, SD and CV were calculated and shown in Table 4.

From the Table4, it was understood that for Push-off specimens ACI code adequately predicted with experimental results with mean value of 0.88. Whereas for predicted equation obtained from regression analysis also showed good comparison with a mean value of 1 and with least coefficient of variation of 0.07.

Table 4: Experimental / Calculated Shear Stress for NSC, SCC & HSC Push Off specimens

Sl no	Specimen	$\tau_u Exp/ \tau_u Cal$			
		ACI	IS	NZ	Predicted
1	NSC/80	0.76	1.71	2.11	0.93
2	NSC/100	064	1.43	1.8	0.93
3	NSC/120	0.61	1.36	1.69	0.97
4	SCC/80	0.99	1.96	2.68	1.16
5	SCC/100	0.86	1.69	2.18	1.05
6	SCC/120	0.75	1.48	1.91	1.04
7	HSC/80	1.26	2.49	2.59	0.94
8	HSC/100	1.09	1.98	2.33	1.00
9	HSC/120	1.00	1.8	2.12	1.02
Mean		0.88	1.8	2.16	1.00
SD		0.22	0.37	0.34	0.07
CV		0.25	0.21	0.16	0.07

6. CONCLUSIONS

The specimens of NSC, SCC and HSC were tested with varying Shear Plane heights using End block strengthened push-off concrete specimen and following observations and conclusions are made.

- Trial mix was an important factor for arriving at final mix proportions. Workability of concrete is also an important criteria to be considered in arriving at final mix proportions
- The average 28 days compressive strength of NSC, SCC and HSC are 38.76MPa, 45.78 MPa and 71.12 MPa respectively.
- It was observed on testing that the first crack initiated at one end of the notch face approximately at tip and propagated towards the other notch tip.
- Cracks were observed to be passed over the aggregates (Surface granular cracks) in case of NSC and HSC, however the cracks passed through the aggregates (Trans granular crack) in case of HSC.
- For the same grade of concrete SCC specimens exhibited higher shear strength by 30% compared to NSC.
- It was observed that in all types concrete as the height of shear plane increases, ultimate shear stress decreases. Thus the Ultimate Shear stress was sensitive to the height of the shear plane.
- ACI code gives good prediction of shear stress values with a mean of 0.88. and the prediction equations gives better results of shear stress values with a mean 1.00.

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