International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 02 Issue: 04 | July-2015 www.irjet.net p-ISSN: 2395-0072

EVALUATION OF IN-PLANE SHEAR STRENGTH IN SCC USING INCLINED PLANE PUSH-OFF SPECIMEN

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Abstract – *Concrete that possesses the ability to flow under its own weight without any external effort is termed as Self Compacting Concrete (SCC). The use of SCC has been increasing in recent years because of its advantages such as increased productivity, reduced labour and higher quality of construction. Many researchers have reported on fresh and durability properties of SCC, but work on mechanical property, particularly on shear behavior is limited. Failure due to direct shear in concrete members like brackets, corbels, shear key, bearing shoes etc is brittle and catastrophic in nature. There is no universal test for determining the shear characteristics of concrete. Most of the researchers have used push-off test specimen to study the in-plane shear behaviour, as the test method is simple.*

The present study is aimed at the experimental investigations of in-plane shear strength of self-compacting concrete (SCC) by using push-off test specimen. M30 grade of SCC mix is used for the investigation. Specimen of dimension 150x150x260mm with two notches of 10mm thick at 100mm apart perpendicular to the axis of loading on specimen and at equidistance from the mid depth was used. The line joining the notch tips is considered as the shear plane for analysis. The shear strength characteristics are also analyzed by changing the shear plane from vertical to inclined. The shear plane inclinations were induced by changing the width of notches. The inclinations attempted are 0°, 11°, 22° and 31°. Shear stresses are obtained for end-block strengthened self-compacting concrete (R-SCC) push off specimens and the results are compared with plain self-compacting concrete (P-SCC) push off specimens. A linear regression model was also developed to estimate the shear stresses from the test data.

Key Words: SCC, Direct compressive stress, Shear plane inclination, Cracking shear stress, Ultimate shear stress

1. INTRODUCTION

Concrete is a versatile and dominant construction material. Failure of concrete elements in direct shear is remarkably sudden and brittle. This is considered as Mode-II failure which requires prime importance in shear keys, deep beams, corbels, brackets, shear walls.

The shear behaviour of SCC is substantially different from that of NSC. When large quantity of heavy reinforcement is to be placed in concrete members, it becomes difficult to ensure that the formwork gets completely filled with concrete, in spite of compaction without the formation of voids or honeycombs. Compaction by manual or by mechanical vibrators will be very difficult in such situations. The typical method of compaction, vibration, generates additional cost and delays to the projects. Underwater concreting always requires fresh concrete, which could be placed without the need of compaction; in such circumstances conventional vibration is next to impossible. This problem can be solved by using self-compacting concrete that flows easily around the reinforcement and into all corners of the formwork.

Even though many research have been carried out from past few decades, there is still discrepancy between the codes of different countries which predicts the shear capacity of concrete. Shear carrying mechanisms is understood by the aggregate interlock, interface shear transfer, or shear friction. Japanese Society of Civil Engineering(JSCE) standard method, Federation Internationale de la Precontrainte(FIP) standard Test, Bairagi and Modhera model, Push-Off Test are some of the test methods available to evaluate the shear characteristics of concrete [2]. But the fact is, none of the methods have been accepted universally [4]. Push-off Test has been used to study the behavior of concrete in shear, since the test method is simple. Even though Push-Off test is a non-standard test it is widely recognized. Ridha Boulifa et al [4] has used a complex method to determine the influence of failure surface inclination on the behavior of concrete in shear. In our present study, shear in concrete is being evaluated at different inclinations of shear plane using Push-Off specimen shown in Figure 1. This test has been widely used from late 1960's. According to Mariano O. Valle [8], shear resistance is the due to the three considerations namely i) the shear transferred by the uncracked portion of the concrete section ii) interface shear transfer across the crack by aggregate interlock and friction and iii) the dowel action by the longitudinal reinforcement. When shear strength was evaluated at various angles of shear plane, test results of B J Al-Sulayavani [6] showed approximately linear increase in shear capacity due to compressive stresses induced normal to the shear plane. According to Omar A. ABD Elalim [7], presence of axial compressive stress improves both cracking strength and ultimate strength.

The push-off test is based on the concept of applying an axial force (P) to produce a pure shear on a predetermined shear plane of the specimen [5]. Shear plane is the plane where slip occurs at a location where either the load or the geometry is discontinuous in a direction perpendicular to the axis of the member. A shear load is a force that tends to produce a sliding failure on a material along a plane that is parallel to the direction of the force. The stress that develops at maximum load or rupture in which the plane of fracture is centrally located along the longitudinal axis of the specimen between two diametrically opposed notches machined halfway through its width is termed as In-Plane Shear Strength.

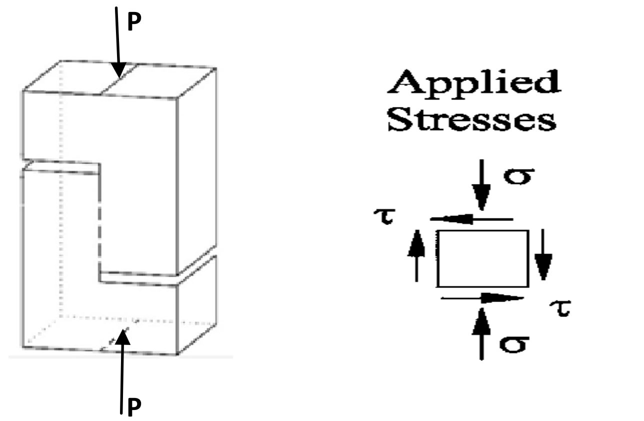

Fig 1: Push-Off Test Concept for Vertical Shear Plane

The principal objective of the present study was to investigate the shear capacity of SCC at different inclination of shear plane with 0°, 11°, 22° and 31°. Plain SCC push-off specimen (P-SCC) and end-block strengthened push-off specimens (R-SCC) were used to study the inclined shear plane on the shear strength. Regression analysis is also carried out to correlate the shear stress and the induced compressive stresses on the inclined shear planes.

2. EXPERIMENTAL PROGRAM

2.1 Materials and Mix Proportion

The following materials are used for preparing the concrete mix.

Cement: Ordinary Portland cement of 53 grade with specific gravity 3.15. Fly Ash: Class F Fly ash obtained from "Raichur thermal power station", Karnataka, India with specific gravity 2.15. Coarse Aggregate: Crushed angular aggregates (granite stones) with a maximum nominal size of 12.5mm with specific gravity 2.65. Fine Aggregate: Locally available manufactured sand (M-Sand), free from silt and organic matter Superplasticizer: GLENIUM B233 free of chloride & low alkali Viscosity Modifying Agent: GLENIUM STREAM 2 to enhance viscosity and rheological properties. Mix design for SCC is carried out according to NAN-SU Method (Chinese) [9]. The final mix design is as shown in Table 1.

Table -1: Mix Composition of SCC

Materials	Quantity
Cement	214.28 kg/m^3
Fly ash (Class F)	248.43 kg/m^3
Fine Aggregate (M-Sand)	925.63 kg/m^3
Coarse Aggregate (12.5mm downsize)	743.69 kg/m^3
Water	148.07 liters/m^3
Superplasticizer (GLENIUM B233)	1.3%
Viscosity Modifying Agent (GLENIUM STREAM 2)	0.18%

2.2 Description of Push-off Specimen and Mould

Dimension of push-off specimen used was 150x150x260mm [10]. Two notches of 75mm wide and 10mm thickness were cut 100mm apart, perpendicular to the axis and for the full breadth of the specimen. Notch depth of 75mm, 65mm, 55mm and 45mm would induce inclined shear planes with inclinations of 0°, 11°, 22°, 31° respectively with the vertical, the cross sectional view of which are as shown in Figure 2. Shear plane area for push-off specimen with 0°, 11°, 22°, 31° shear plane inclinations were 150x100mm, 150x101.87mm, 150x107.85mm, 150x116.66mm respectively. End-block of push-off specimens were strengthened using 5mm diameter steel bars (f_y=550 N/mm^2) bent to proper shape in order to cause shear failure in the push-off specimen along the predetermined planes [7], the cross sectional view of which are as shown in Figure 3. The schematic diagram of the mould used is shown in Figure 4 where two specimens could be casted simultaneously.

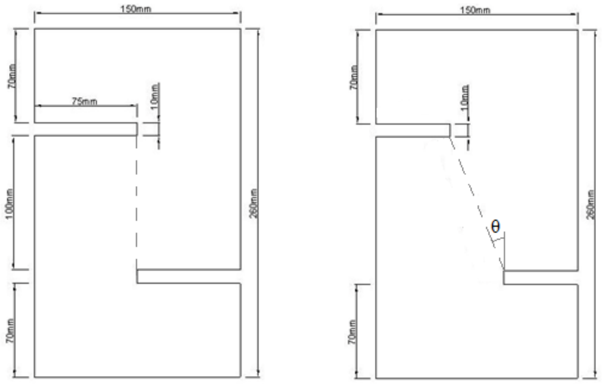

Fig -2: Push-off specimen with vertical shear plane and inclined shear plane (θ variation 11°, 22°, 31°)

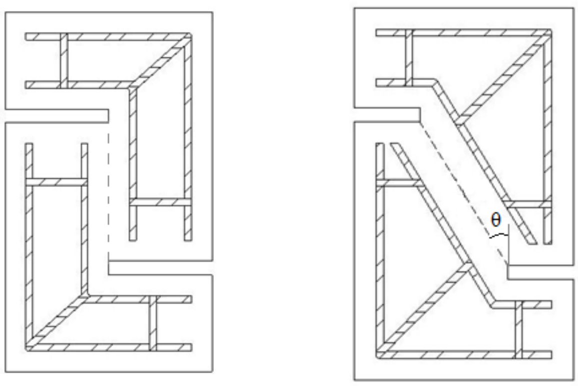

Fig -3: End-block strengthened Push-off specimen with 5mm dia bars inclination parallel to shear plane

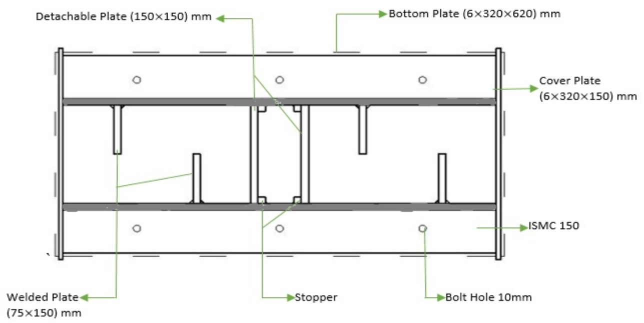

Fig 4: Top view of the mould

2.3 Casting and Test Procedure

Batched quantities of materials as per Table 1 are mixed using pan mixer, when a homogeneous and flowable mix is obtained, the mix was poured into the mould. The specimen obtained is basically two 'L' shaped blocks that are connected through a ligament termed as shear plane. Push off specimen after demoulding at the end of two days is as shown in Figure 5. After demoulding specimens were placed for water curing. The specimens were tested in structural laboratory of the Dept of Civil Engineering at M.S.R.I.T Bengaluru under compression testing machine having 1000kN capacity. The test set up is shown in Figure 6. The vertical load is applied through rectangular steel plates of size 15mm width, 15mm thick and 150mm depth. These plates are placed centrally at the top and bottom of the specimen so that the load passes along the vertical shear plane.

Fig -5: Demoulded Push-off specimen

Fig -6: Compression testing machine used for testing

3. TEST RESULTS AND DISCUSSION

The average cube compressive strength obtained for SCC specimen at 28 days was 44.47 MPa. Surface-granular fracture (passing over the surface of the aggregates) was noticed and could be due to the failure of weaker interfacial transition zone, the fracture is shown in Figure 7. Though the cracks were observed along the shear plane in case of plain push-off specimens, the final failure was at the end-block as shown in Figure 8. In case of end-block strengthened push-off specimens, with the gradual application of load, several cracks appeared near the top and bottom notch and the cracks joined along the shear plane and failure occurred forming a single crack band along the shear plane as shown in Figure 9. Plain push off specimens failed in brittle manner. Test data and computation of stresses are tabulated in Table 2.

Fig -7: Surface granular fracture

Fig -8: Failure pattern in plain self-compacting concrete push-off specimens

Fig -9: Failure pattern in end-block strengthened self-compacting concrete push-off specimens

Table -2: Computed shear stress for plain SCC and strengthened SCC push-off specimens

Specimen	f_{ck} (MPa)	Cracking Shear stress (MPa)	Ultimate Shear Stress (MPa)	Direct Compressive stress (MPa)
P-SCC/0°	48.84	2.62	2.70	0
P-SCC/11°	45.87	3.47	3.72	0.72
P-SCC/22°	40.32	6.07	6.61	2.67
P-SCC/31°	42.85	7.33	7.57	4.54
R-SCC/0°	48.84	5.34	7.70	0
R-SCC/11°	45.87	7.32	9.10	1.77
R-SCC/22°	40.32	7.52	9.72	3.92
R-SCC/31°	42.85	7.57	9.58	5.76

Shear stress and normal compressive stress results are graphically represented in Figure 10 and Figure 11 for P-SCC and R-SCC respectively.

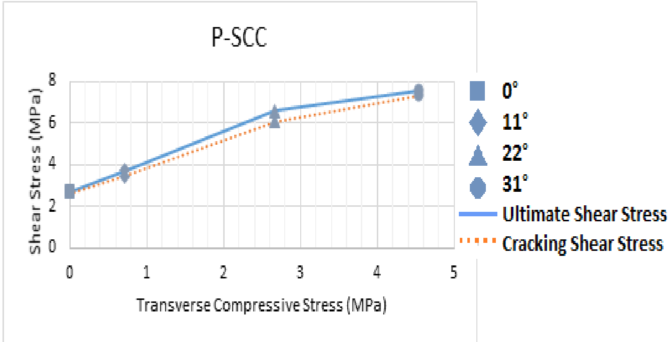

Fig -10: Variation of the shear stress with the normal compressive stress for plain-SCC

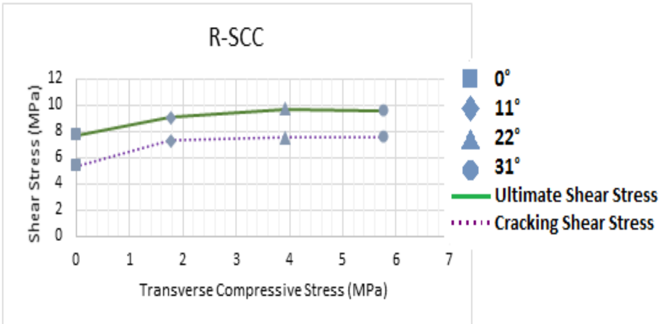

Fig -11: Variation of the shear stress with the normal compressive stress for end-block strengthened SCC

From the Figure 10 and Figure 11, it can be observed that shear strength in both P-SCC and R-SCC increased with the increase in shear plane inclination. This increase is due to normal compressive stress induced on the shear plane. In case of R-SCC, shear strength was approximately same at 22° and 31°. In case of plain SCC, there was not much difference between the cracking shear stress and ultimate shear stress indicating sudden failure. But in case of end-block strengthened SCC, approximately a difference of 2MPa was observed between cracking shear stress and ultimate shear stress.

Using the experimental data, linear regression analysis was carried out to obtain equations to predict the shear capacity of plain SCC and strengthened SCC specimen.

For P-SCC, $\tau_u = 12.66 – 0.20 f_{ck} + 0.82 f_n$

For R-SCC, $\tau_u = 15.95 – 0.16 f_{ck} + 0.12 f_n$

4. CONCLUSIONS

Surface-granular fracture (passing over the surface of the aggregates) was observed in SCC. In case of plain SCC most of push-off specimen failed (cracked) perpendicular to the axis of shear plane and the cracks were propagated along the notch tip of specimen, which indicates that the end block were not withstanding the applied loads. All the end-block strengthened SCC push-off specimens failed along the shear plane.

The failure of plain SCC push-off specimens was observed to be more brittle when compared with end-block strengthened SCC push-off specimens. It was observed that with the increase in shear plane inclination, ultimate shear stress increases, both in plain and strengthened conditions. This is due to the induced compressive normal stress on the shear plane which decreases the diagonal tensile stresses developed by shear, for a given vertical loading. Difference between cracking and ultimate strength was more in case of R-SCC.

In case of plain SCC push-off specimens, shear capacity at 0°, 11°, 22° and 31° was 2.7MPa, 3.72MPa, 6.61MPa and 7.57MPa respectively. In case of end-block strengthened SCC push-off specimens, shear capacity at 0°, 11°, 22° and 31° was 7.7MPa, 9.1MPa, 9.72MPa and 9.58MPa respectively.

The predicted equation obtained from regression analysis to estimate shear stress values is summarized below:

For P-SCC, $\tau_u = 12.66 - 0.20f_{ck} + 0.82f_n$

For R-SCC, $\tau_u = 15.95 - 0.16f_{ck} + 0.12f_n$

Co-efficient of Variance (CV) for calculated shear stress obtained from predicted equation with respect to experimental shear stress for P-SCC and R-SCC was 2% and 2.6% respectively. CV less than 5% indicates consistency in the test results. Coefficient of correlation (R^2) for calculated shear stress obtained from predicted equation with respect to experimental shear stress for P-SCC and R-SCC was 0.999 and 0.895 respectively. R^2 value closer to 1 indicates perfect relationship between the variables.

ACKNOWLEDGEMENT

We acknowledge the support of Management of MSRIT, Principal, HOD, Faculty, staff of Civil Dept., in particular we express our deep sense of gratitude to Hiranyiah, chief engineer Bhagirata constructions.

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