Influence of Fibers on Interface Shear strength of Cement Concrete Overlays

Jayasree K.V., Prebhakumari K.S.

Abstract Formation of interfaces or joints is more common in the construction of very large structures where mass concreting is required. Interfacial joints play a major role in the overall efficiency of the system. They take part in transferring loads and stresses from one section to other section. Horizontal shear strength at the interface between substrate and overlay layer is essential for safety of a reinforced concrete composite member. In composite bridge and building construction the connection at the interface is commonly provided by using horizontal shear ties. Increase in number of shear ties in the interface may reduce the efficiency of construction by increase in fabrication cost and life cycle cost and by reduction in construction safety. So a better alternative to shear ties is necessary to improve efficiency of construction. This study is mainly aims to find out the influence of steel fibers on horizontal shear strength of composite structures with High strength concrete as substrate and Self compacting concrete as overlay and also to find out amount by which the fibers can be used as replacer for shear ties in interface of concrete composite structures. From the experimental results it was observed that number of shear ties can be effectively reduced by addition of fibers at the interface. Interface shear strength and fracture energy was observed to be increased with addition of hooked end fibers at the interface with an optimum at 0.75% of fiber content.

Index Terms— Fracture, Fiber, Interface, Overlay, Shear strength, Shear ties, Substrate

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1 INTRODUCTION

CONCRETE is a highly versatile and most widely used material for construction. The durability of concrete structures and workability during construction works made it popular among the builders. Construction of very large structures where mass concreting is required, usually consist of formation of interfaces or joints. Concrete may interfaces with another concrete of different strength or with any other construction material like steel. These joints or interfaces represent potential failure sites of crack formation which leads to weakening of mechanical strength. The bond strength at the interface between concrete layers cast at different ages is important to ensure the monolithic behaviour of reinforced concrete composite members such as precast beams with cast-in-place slabs, bridge decks strengthened by adding a new concrete layer and repair and strengthening of existing concrete structural members by adding a new concrete layer.

In reinforced concrete composite bridges, the construction is done in two stages. Initially the precast beams are fabricated at a pre-stressing plant and then shipped to the job site and set in place. After placing the beam, a field cast concrete slab is cast over the precast beams in order to provide integrity and stability to the structural system. As the concrete cures, a bond will form between these prefabricated and cast-in-place concrete and thus allowing the composite beam to possess the continuity and efficiency similar to a monolithic member. The composite interface bond must remain intact in order to maintain purely monolithic behaviour. In composite bridge and building construction shear ties are placed across the flange-slab interface to maintain monolithic behaviour of the section. Shear ties are typically an extension of the shear reinforcement from the precast beam section and are later cast into the slab. The shear ties extending across the interface resist further slip and maintain integrity of the beam-slab system. Shear ties used in these constructions possess some disadvantages regarding to cost, construction safety etc. Increase in number of shear ties results in increase in fabrication cost, Reduction in construction safety and increase in life cycle cost. So, significant advantage can be achieved by reducing the requirements of ties. The efficiency of construction can be improved by reducing the number of shear ties by replacing that with another material which provides sufficient bond strength.

Many studies were conducted on interface horizontal shear strength of concrete members. Jonathan D. Kovach and Clay Naito [2] in 2008 conducted a study on horizontal shear capacity of composite concrete beams without interface ties. They conducted a series of structural tests on composite pre-stressed beams without horizontal shear ties and found out that the interface roughness had a pronounced effect on the horizontal shear capacity of the composite section. Mitchell Gohnert [4] in 2003 experimentally determined the horizontal shear strength along the interface of a roughened surface. It was found out that roughness of the surface had a profound effect on the shear capacity and is a far better indicator of strength than the compressive strength of the concrete. Riyadh Jawad Aziz [6] in 2010 conducted push-off tests to determine the interfacial shear capacity of concrete. Surface textures were varied as smooth interface, rough interface, interface with shear keys and interface with projecting reinforcements. Nukala V. V. Phani Kumar and Julio A. Ramirez [5] in 2013 studied in detail about interface horizontal shear strength of composite decks with precast concrete panels. Horizontal shear and interface slip characteristics at ultimate load was evaluated and it was concluded that stay-in-place precast, pre-stressed deck panels with a broom finished surface do not require horizontal shear connectors if the average horizontal shear stress at the interface is less than 0.8 MPa.

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This study mainly aims to find out the influence of steel fibers on horizontal shear strength of composite structures with High strength concrete (HSC) as substrate and Self compacting concrete (SCC) as overlay and also to find out amount by which the fibers can be used as replacer for shear ties in composite structures.

2 FRACTURE MECHANICS AND FRACTURE

Fracture mechanics is the branch of science describing how a crack initiates and propagates under applied loads in many engineering materials like ceramics, rocks, glasses and concretes. Fracture is a form of failure, and it is defined as the separation or fragmentation of a solid body into two or more parts under the action of stress. Fracture occurs in a very short time period under both static and complex loading conditions [8].

2.1 Modes of Fracture

There are three basic modes of fracture, mode I, mode II and mode III as shown in Fig. 1.

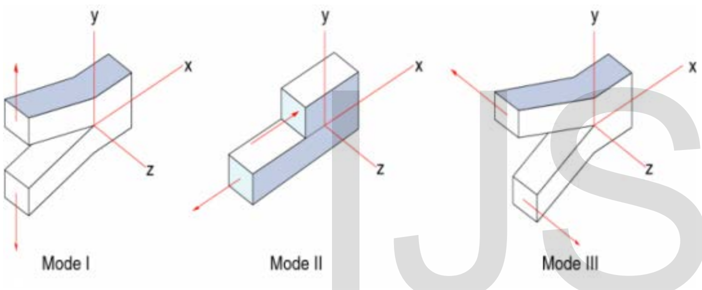


Fig.1. Modes of fracture

1. Mode I (Tension/Opening mode): Mode I fracture is the type of fracture in which the crack plane is perpendicular to the direction of the applied load.
2. Mode II (In-Plane Shear/ Sliding mode): Mode II fracture is type in which the crack plane is parallel to the direction of the applied load.
3. Mode III (Out-Of-Plane Shear/Tearing mode): Mode III fracture corresponds to a tearing mode and is only relevant in three dimensions.

2.2 Fracture Energy

Fracture energy is the amount of energy necessary to create one unit area of crack. Energy release rate G is the net change in potential energy due to increment of crack extension.

$$G = \frac{W}{A\ eff}$$

Where,

G = Fracture energy

W = Total energy dissipated in the test

A eff =Effective area of cross section of the specimen

3 EXPERIMENTAL INVESTIGATION

Experimental investigation was carried out to determine effect of fibers on horizontal shear strength of cement concrete overlays. Push off specimen of dimension 520x300x125 mm was used for the study.

3.1 Materials Used

1. Cement

53 grade ordinary Portland cement conforming to IS 12269-1989 was used for the study.

2. Fly ash

Fly ash of specific gravity 1.8 obtained from Thermal power plant in Thirunelveli was used for the study.

3. Fine aggregate

Manufactured sand having specific gravity 2.66 and passing through 4.75 mm IS sieve and conforming to zone II was used.

4. Coarse Aggregate

Aggregates of 12mm and 6 mm of specific gravity 2.86 and conforms to IS 383 (part III): 1970 was used.

5. Water

Potable clean drinking water was used for casting as well as for curing of the test specimen.

6. Super plasticizer

In order to increase the workability of the mix, super plasticizer Cera Hyperplast XR-W40 was added to the concrete.

7. Steel Fibers

Hooked end steel fiber of aspect ratio 60 was used for the study.

8. Steel Reinforcement

High yield strength deformed bars of 8 mm and 6 mm diameter was used for the study.

3.2 Mix Proportion

High strength concrete and self- compacting concrete of M60 grade is developed for the experimental study. For high strength concrete, mix was developed using the recommended guidelines of ACI 211.4R-93. Optimum mix ratio of 1:1.36:2.14 is adopted after various trial mixes with a water-cement ratio of 0.28 and super plasticizer content of 0.53%.For Self compacting concrete, mix was developed using Okamura's method as per EFNARC specifications. Table 1 shows mix proportion of self compacting concrete.

TABLE 1
MIX PROPORTIONING OF SCC

Material		Quantity
Cement (kg/m^3)		535
Fly ash (kg/m^3)		165
Fine Aggregate (kg/m^3)		850
Coarse aggregate(kg/m^3)	6 mm	254
	12 mm	506
Water content (litre/m^3)		225
Super plasticizer dosage (% of total powder content)		0.9 %

3.3 Sepcimen description

Push-off specimens of size 520 x 300 x 125mm were used for this study. Specimens with monolithic and bi-lithic nature were cast. Fig.2 shows geometry and reinforcement details of push off specimen. Steel reinforcements consist of 6mm diameter bars as vertical stirrups and 8mm diameter bars as main longitudinal reinforcement. Reinforcement is provided for the purpose of avoiding all types of failure modes other than interface failure.

All monolithic specimens (both halves of the specimens were cast at the same time) were used as control specimens and all other specimens were cast as bi-lithic (two halves of the specimen was cast separately). For bilithic specimen, substrate layer (bottom layer) is cast with HSC and overlay layer is cast with SCC. Thirteen different combinations of specimens were cast including control specimens, Specimen with shear ties across the interface, specimen with only fiber at the interface and specimen with shear ties and fibers at the interface. Different specimen combinations are listed in Table 2.

TABLE 2

DETAILS OF PUSH-OFF SPECIMENS

Sl no:	Specimen	Designation
I	Control specimen	
1	HSC (Monolithic)	HSC
2	SCC(Monolithic)	SCC
3	Specimen without shear ties and fibers across the interface (bi-lithic)	HSSCC
II	Specimen with 3 shear ties	SCC3C
III	Specimen with Hooked end steel fibers	
	0.5 %	SCC0CH0.5
	0.75%	SCC0CH0.75
	1%	SCC0CH1
IV	Specimen with shear ties and fibers	
I	With 3 shear ties and Hooked end steel fibers	
	0.5%	SCC3CH0.5
	0.75%	SCC3CH0.75
	1%	SCC3CH1
II	With 2 shear ties and Hooked end steel fibers	
	0.5%	SCC2CH0.5
	0.75%	SCC2CH0.75
	1%	SCC2CH1

3.4 Sepcimen Preparation

Two types of specimens were cast. Monolithic specimens were used as control specimen. All remaining specimens were cast as bi-lithic by varying no of shear ties crossing the interface and percentage of fiber at the interface. Wooden moulds of size 300 x 520 x125mm were used for casting specimens. Reinforcement cage was placed in position and the moulds were filled with concrete mix. For monolithic specimen whole specimen was cast at the same time. For bi-lithic specimen, two halves of the specimens were cast separately. Initially first half of the specimen was cast with high strength concrete and after 7 days of curing of the first half, second half was cast over first half using self compacting concrete.For specimen with fibers and shear ties at the interface, first layer was cast with shear ties projecting from the surface of concrete at the interface and second layer was cast with fiber reinforced self compacting concrete. Entire arrangement was kept for 24 hours and demoulded later. These demoulded specimens were water cured for 28 days.

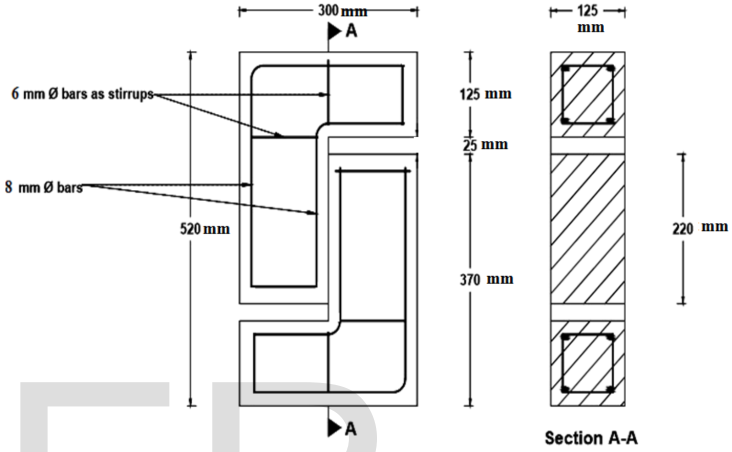


Fig.2. Push-off Specimen

3.5 Testing of Specimen

Test setup was common for all the specimens. Horizontal and vertical displacements were measured using two LVDTs attached to the specimen. Fig.3 shows test setup, loading condition and position of LVDTs. All the specimens were subjected to direct compressive loading using UTM of 3000 kN capacity. Specimens were loaded till failure and horizontal and vertical displacements were noted for corresponding load values. Fig.4 shows the experimental setup.

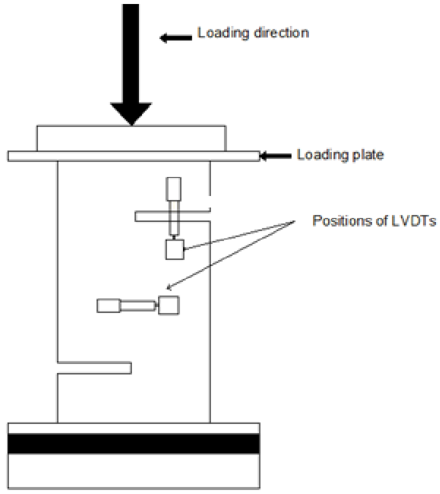


Fig.3 Schematic diagram of test set up

Fig.4 Experimental setup

4 RESULTS AND DISCUSSION

The horizontal and vertical deflections were determined with the help of LVDTs, for each load increment until failure. Ultimate load was noted. Table 3 shows the ultimate load and shear stress of various specimens obtained from the experiment. Shear stress was calculated by dividing ultimate load with shear plane area of 220 x 125mm.

TABLE 3

PUSH-OFF SPECIMENSTEST RESULTS

Specimen	Ultimate Load (kN)	Shear Strength (N/mm^2)
HSC	196.2	7.14
SCC	225.63	8.21
HSSCC	53.95	1.96
SCC3C	115.76	4.21
SCC3CH0.5	132.435	4.82
SCC3CH0.75	156.96	5.71
SCC3CH1	128.51	4.68
SCC2CH0.5	109.87	3.99
SCC2CH0.75	135.38	4.92
SCC2CH1	106.93	3.89
SCC0CH0.5	63.77	2.32
SCC0CH0.75	78.48	2.85
SCC0CH1	58.86	2.14

Fig.5 to Fig. 12 shows load Vs displacement of push off specimens. The shear strength of control specimens i.e. SCC, HSC and HSSCC specimens was obtained as 8.21 N/mm2, 7.14 N/mm2 and 1.96 N/mm2 respectively. From the test results, it was observed that among the control specimens monolithic specimens showed higher shear strength than bilithic specimens. Shear strength of monolithic control specimen was observed to be 4 times more than bi-lithic control specimen. Among monolithic specimens, SCC specimen shows 15% more shear strength than HSC specimen.

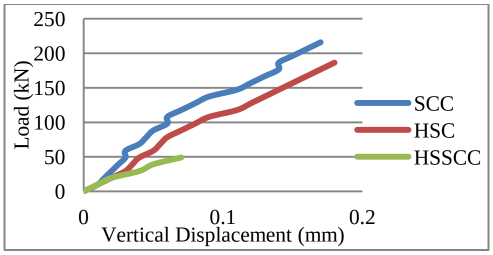


Fig.5 Load Vs Vertical Displacement of Control Specimens

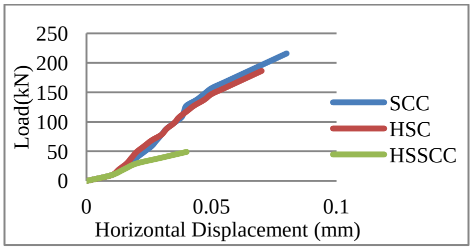


Fig.6 Load Vs Horizontal Displacement of Control Specimens

For the bilithic specimen, value of shear strength was observed to be smaller than monolithic specimen. But specimen with shear ties and fibers at the interface showed more shear strength than bilithic control specimen. For specimen with 3 shear ties at the interface, shear strength was observed to be 4.21 N/mm². This shear strength at the interface was observed to be increase with addition of fibers. Maximum value was observed for specimen with 0.75% of hooked end fibers at the interface. Same trend was observed for specimen with two shear ties and zero shear ties at the interface. The shear strength of specimens without any shear ties was observed to be lower than specimen with shear ties. For SCC2CH0.75 specimen shear strength was observed to be 4.92 N/mm². This value was found to be greater the SCC3C and SCC3CH0.5 specimen. This indicates that number of shear ties can be reduced to 2 numbers from 3 by adding 0.75 % fibers at the interface

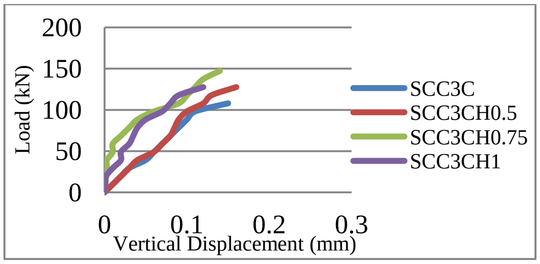


Fig.7 Load Vs Vertical Displacement of Specimen with 3 shear ties

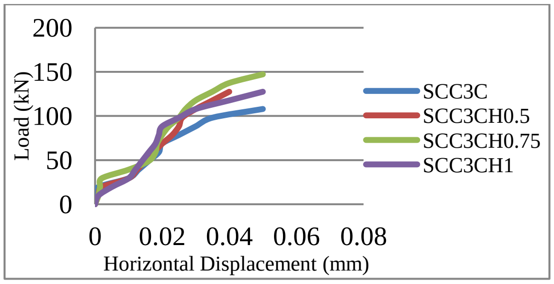


Fig.8 Load Vs Horizontal Displacement of Specimen with 3 Shear ties

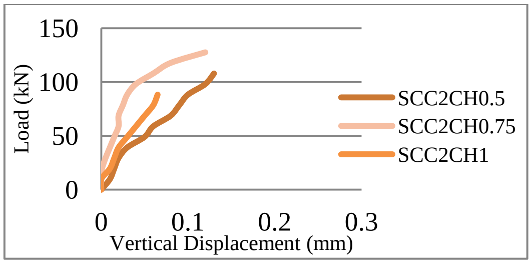


Fig.9 Load Vs Vertical Displacement of Specimen with 2 shear ties

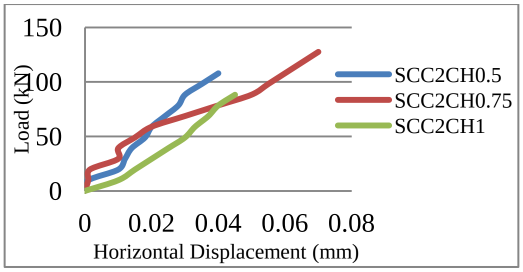


Fig.10 Load Vs Horizontal Displacement of Specimen with 2 shear ties

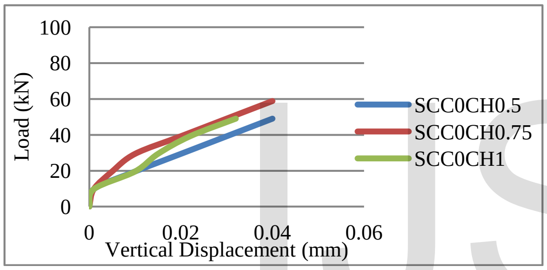


Fig.11 Load Vs Vertical Displacement of Specimen without shear ties

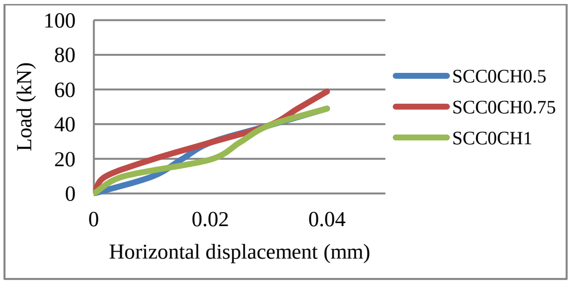


Fig.12 Load Vs Horizontal Displacement of Specimen without shear ties

Fig.13 and 14 shows failure pattern of the specimens. Fig.13 shows failure pattern of the control specimens. All the control specimens were fractured into two parts along the interface after reaching the peak load. Specimens without any shear ties, fracture along the interface and fail into two L halves at the ultimate load. Specimen with fibers and shear ties across the interface, fail by cracking along the interface but do not loss the integrity and didn't split into two halves due to the bonding provided by the shear ties.

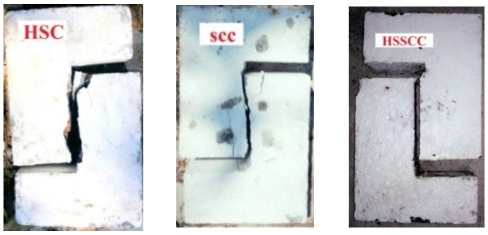
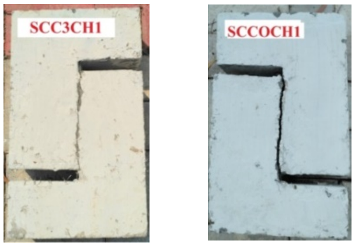


Fig.13 Failure pattern of control specimens



(a) (b)

Fig.14 Failure pattern of bilithic specimen (a) with shear ties across the interface (b) with only fibers without any shear ties at the interface

4.1 Fracture Energy

Fracture energy is the amount of energy required to create unit area of crack. Fracture energy of specimens were found out by dividing area under load vs vertical displacement graph of each specimen by cross section area at the interface and these values are given in Table 4. Fracture energy of the specimens was observed to be increased with addition of fibers and shear ties at the interface.

TABLE 4

FRACTURE ENERGY OF THE SPECIMENS

Specimen	Fracture Energy (N/mm)
HSC	0.639
SCC	0.747
HSSCC	0.069
SCC3C	0.341
SCC3CH0.5	0.416
SCC3CH0.75	0.510
SCC3CH1	0.375
SCC2CH0.5	0.281
SCC2CH0.75	0.425
SCC2CH1	0.205
SCC0CH0.5	0.082
SCC0CH0.75	0.107
SCC0CH1	0.079

5 ANALYTICAL WORK

5.1 Predicting Cohesion and Friction Co-efficients

Cohesion and friction are the two key parameters which influence the shear capacity of concrete.Analytical work included prediction of coefficient of cohesion and coefficient of friction. After analysing the values of shear strength, split tensile strength and clamping stress, coefficient of cohesion and friction was predicted using regression analysis and values obtained are shown in Table 5.

TABLE 5

VALUES OF COEFFICIENT OF COHESION AND FRICTION

Type of interface	Coefficient of cohesion	Coefficient of friction
Monolithic	1.8	-
Bilithic- with shear ties	0.50	0.95
Bilithic- Without shear ties	0.44	-

5.2 Equations of shear strength for interface with various connections at the Interface

Equation for shear strength of specimens subjected to various connections at the interface is shown in Table 6.

TABLE 6

SHEAR STRENGTH EQUATIONS FOR VARIED SURFACE TEXTURES

Type of interface	Equation
Monolithic	$V_u = 1.8\, f_{ct}$
Bilithic- With shear ties	$V_u = 0.5\, f_{ct} + 0.95\, \rho f_y$
Bilithic - Without shear ties	$V_u = 0.44\, f_{ct}$

Vu: shear strength
fct: Concrete tensile strength
ρfy: Clamping stress

5.3 Comparison with the Experimental Results

Values of coefficient of cohesion and coefficient of friction were obtained using regression analysis and these values are compared with the experimental values. % variation between experimental values and analytical values are shown in Table 7.

TABLE 7

COMPARISON BETWEEN EXPERIMENTAL VALUES AND ANALYTICAL VALUES

Specimen	Shear strength		% variation
	Experimental	Analytical	
HSC	7.14	7.38	-3.36
SCC	8.2	7.88	4.02
HSSCC	1.96	1.93	2.45
SCC3C	4.21	4.62	-9.74
SCC3CH0.5	4.82	4.98	-3.31
SCC3CH0.75	5.71	5.40	5.42
SCC3CH1	4.67	4.87	-4.28
SCC2CH0.5	3.99	4.16	-4.26
SCC2CH0.75	4.92	4.59	6.70
SCC2CH1	3.89	4.06	-4.37
SCC0CH0.5	2.32	2.24	-3.40
SCC0CH0.75	2.85	2.61	8.40
SCC0CH1	2.14	2.15	0.28

6 CONCLUSIONS

Experimental study involved casting of push-off specimens with various connections at the interface. Variation in shear capacity and fracture energy is studied and following conclusions are obtained:

- Monolithic specimens showed higher shear strength than bi-lithic specimens
- For bi-lithic specimen, specimen with shear ties showed more shear strength than specimens without shear ties
- Shear capacity of bi-lithic specimen increased with increase in number of ties and fibers at the interface
- Shear capacity of bi-lithic specimen increases with addition of hooked end fibers with an optimum at 0.75% fiber content
- SCC2CH0.75 specimen showed more shear strength than SCC3C and SCC3CH0.5. This indicates that number of shear ties can be reduce to 2 number from 3 number by adding 0.75 % fiber at the interface
- Bi-lithic specimen without shear connectors showed brittle failure at ultimate load and specimen split into two L halves. Bilithic specimen with shear ties across the interface fail by cracking along the interface but do not split into two halves.
- Values of shear strength obtained from experimental and analytical study were compared.

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