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Punching Shear Strength of High Strength Fibre Reinforced Concrete Slabs

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Abstract: *The experimental study of punching shear behavior of High Strength fiber reinforced concrete slabs is carried out in the present work. Each of 24 square slabs was simply supported along four edges and loaded to failure under a concentrated load over a square area at the center. The test parameters were the effective span to depth aid ratio, volume fraction of 3 types of steel fibers, slab thickness h, concrete strength fck, and size of load-bearing plate r. Test results indicate that the load-deflection curve of slabs exhibits four distinct regions that may be characterized by first cracking, steel yielding, and ultimate load. Within the scope of the test program, an increase in the values of pf, h, or r was found to lead to an increase in both the punching shear strength and the ductility of the slab. The ultimate punching shear strength of the slabs was compared with the predictions of equations available in the literature and code equations for reinforced concrete.*

Key Words: *Steel Fibres, High Strength Fibre Reinforced Concrete, Punching shear strength, deflection.*

I. Introduction

High StrengthFibres Reinforced concrete (HSFRC) is being increasingly used in civil engineering construction due to its improved resistance to cracking, fatigue, abrasion, and impact and its greater durability, than conventional reinforced concrete (Vondran 1991). Some examples are its applications in shotcrete, precast concrete products, pavements, concrete floors, seismic structures, and structural repair.

HSFRC-slab applications are suited for bridge deck slabs, industrial floors or in flat-slab construction where, besides resistance to fatigue or damaging dynamic forces, additional reinforcement is required to avoid punching shear failure due to concentrated loads. Although much research has been carried out on HSFRC ("State" 1982), little attention has been focused on the punching shear behavior of HSFRC slabs. As a result, the full economical benefits of steel fibers in such applications may not be realized.

In this study, an investigation has been carried out on the punching shear behavior of HSFRC slabs. Each of 24 square slabs was prepared and tested under a concentrated load. The load-deflection characteristics and cracking pattern of the slabs were observed and compared. The ultimate punching shear strength of the slabs was compared to predictions made using the equations available in the literature as well as those given in building codes ("Building" 1989; "Code" 1972; "Model" 1978; "Structural" 1985; "Standard" 1986) for the punching shear strength of reinforced concrete slabs.

Objectives and Scope

The investigation is focused to study the effect of various types of fibres on punching shear strength of HSFRC slab.

The water to cementitious material ratio considered for the study of HSFRC of M70 grade was 0.27. The content of silica fume and fly ash in every mix was 5% and 10% by the weight of cementitious material. Three types of fibres considered for the study include, Hook Ended Steel Fibres (HESF), Flat Steel Fibres (FSF) and Waving Steel fibres (WSF). Dosage of fibre was varied from 0.5% to 4% at an interval of 0.5% by weight of cementitious material. Type of cement, fine aggregate, coarse aggregate, type of superplasticiser and its dosage are kept constant in every mix.

II. Test Program

Twenty fourHSFRC slabs were tested. The parameters investigated included the effective span to depth ratio, aid volume fraction of steel fiber p_f, thick-

Table 2.1: Schedule of Experimental Program

Sr. No.	Mix designation of M70 grade HSFRC	Fibre content (%)	No. of specimen (cubes, cylinders and prisms each) using types of Fibres		
			HESF	FSF	WSF
	M0	0.0	3		
	M1	1.0	3	3	3
	M2	2.0	3	3	3
	M3	3.5	3	3	3
	M4	4.0	3	3	3

2.1. Materials

Ordinary Portland Cement of 53 Grade conforming to IS: 12269-1987 was used in the investigation. The properties of cement are presented in Table 2.2.

Table 2.2: Physical Properties of Ordinary Portland Cement (OPC)

Sr. No.	Description of Test	Results
01	Fineness of cement (residue on IS sieve No. 9)	6.5%
02	Specific gravity	3.15
03	Standard Consistency of Cement	30
04	Soundness test of Cement (With Le-Chaterlier'sMould	1.5mm
05	Setting time of cement Initial setting time Final setting time	 40 minute 190 minute
06	Soundness test of cement (with Le-Chatelier'smould)	1mm
04	Compressive strength of cement (a) 3 days (b) 7 days (c) 28 days	 33.00N/mm^2 55.44N/mm^2 74.45N/mm^2

Crushed stone metal with a maximum size of 12.5 mm from a local conforming to the requirements of IS: 383-1970 was used. Locally available river sand passing through 4.75 mm IS sieve conforming to grading zone-II of IS: 383-1970 was used. The properties of aggregates are presented in Table 2.3

Table 2.3: Physical Properties of Fine and Course Aggregate

Sr. No	Property	Results	
		Fine Aggregate	Course aggregate
01	Particle Shape, Size	Rounded, 4.75 mm down	Angular, 10mm down
02	Fineness Modulus	3.20	7.79
03	Silt content	2%	-----
04	Specific Gravity	2.582	2.70
05	Bulking of sand	4.00%	0.4%
06	Bulk density	1850 kg/m^3	1603 kg/m^3
07	Surface moisture	Nil	1.03%

Sulphonated melamine based super plasticizer supplied by Roff. Chemicals India Pvt. Ltd. Mumbai is used as water reducing and self retarding admixture in the experimental work. The properties comply with the requirements of IS 9103-1999 (Amended 2003) as well as ASTM C 494-type F.

The fly ash are used which available from Nashik. The specific gravity of fly ash was 2.3. The properties of fly ash are presented in Table 2.4

2.4: Physical Properties of Fly Ash

Sr. No.	Description of Test	Results
01	Specific Gravity	2.3
02	Colour	Grayish white
03	Bulk Weight	Approx. 0.9 metric ton per cubic meter
04	Specific density	Approx. 2.3 metric ton per cubic meter
05	Average Particle size	0.14mm
06	Particle shape	Spherical

The properties of various types of fibres considered for the study are presented in Table 2.4

Table 2.4: Properties of Fibres used

Sr. No.	Property	Properties of various types of fibres		
		HESF	**FSF**	**WSF**
2	Length (mm)	30mm	30mm	30mm
3	Width (mm)	--	1mm	--
4	Diameter (mm)	0.5mm	--	0.25
6	Aspect Ratio	60	30	120
	Colour	White	Bright in clean wire	White
8	Specific Gravity	7.85	7.85	7.86
9	Density kg/m^3	1.36	1.36	1.36
10	Tensile strength MPa	1050	1050	1050
11	Melting point	$253^{\circ}C$	$253^{\circ}C$	$253^{\circ}C$
12	Young's modulus kN/mm^2	25.19	25.19	25.19
13	Water absorption	0.04%	0.04%	0.04%
14	Minimum elongation	8%	8%	8%
15	Resistance to alkali in high strength concrete	Excellent	Excellent	Excellent
16	% Elongation	8	8	8
17	Effective Diameter mm	0.476mm	1mm	0.25

2.2. Production of HSFRC Concrete

The high strength concrete of M70 grade was designed as per DOE method. Table 2.5 shows the weights of various constituents of HSFRC.

Table 2.5: Mix Proportion

Sr. No	Material	Weight of material in Mass kg/m^3
1	Ordinary Portland Cement (85 % of CM)	472
2	Silica fume (5 % of CM)	27.8
3	Fly Ash (10 % of CM)	55.6
4	Fine Aggregate	702
5	Coarse Aggregate	1042
6	Water	150
7	Superplasticizer	18 ml per kg of Cement
8	Water Binder Ratio	0.25

III. RESULT AND DISCUSSION

The Thickness of slab *h*,concrete strength*fck* and width of the loading platen *r*. The slabs were accordingly grouped into three for three different types of fibres.

For all the slabs, welded skeletal steel fabric with an average yield strength of 415MPa and a area of 500 mm 500mm was used as the main simply supports for testing. The total volume fraction of main reinforcement was 0.76 for each slab, and the reinforcement was placed longitudinal and lateral directions at 50mm c/c distance.

3.1. Central Deflection of Hooked End Steel Fibre High Strength Fibre Reinforce Slab.Variation of Central Deflection with Respect to Load for *a/d*= 1.25

Results ofcentral deflection of beams for *a/d*= 1, *a/d*= 1.25, *a/d*= 1.5,are obtained, and are presented in Table (4.1.3), (4.1.4), (4.1.5) respectively. Central Deflection with respect to Load is presented in Figure 3.1, 3.2 and 3.3 respectively.

	M_0		M_1		M_2		M_3		M_4	
Sr. No.	**Load (kN)**	**Deflection (mm)**	**Load (kN)**	**Deflection (mm)**	**Load (kN)**	**Deflection (mm)**	**Load (kN)**	**Deflection (mm)**	**Load (kN)**	**Deflection (mm)**
1	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000
2	25	0.0000	25	0.0000	25	0.0000	25	0.0000	25	0.0000
3	50	0.0000	50	0.0460	50	0.1060	50	0.1400	50	0.1900
4	75	0.0560	75	0.0760	75	0.1120	75	0.1720	75	0.2200
5	100	0.1460	100	0.1690	100	0.2100	100	0.2700	100	0.3200
6	125	0.2750	125	0.3460	125	0.3700	125	0.4100	125	0.5900
7	150	0.4120	150	0.4900	150	0.5400	150	0.6200	150	0.7400
8	175	0.5360	175	0.7400	175	0.7760	175	0.9600	175	1.0400
9	200	0.6920	200	0.9200	200	0.9600	200	1.0300	200	1.1700
10	225	0.7960	225	1.0200	225	1.0960	225	1.1400	225	1.3500
11	250	0.9200	250	1.1100	250	1.2200	250	1.3200	250	1.4900
12	275	1.1200	275	1.3200	275	1.3700	275	1.4700	275	1.5700
13	293	1.2700	300	1.4460	300	1.4900	300	1.6200	300	1.7960
14					322	1.5440	325	1.8700	325	1.9860
15							336	1.9340	349	2.0340

Table: 3.2 Central Deflection of Flat Steel Fibre High Strength Fibre Reinforce Slab. Variation of Central Deflection with Respect to Load for *a/d*= 1.25

	M_0		M_1		M_2		M_3		M_4	
Sr. No.	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
1	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000
2	25	0.0000	25	0.0000	25	0.0000	25	0.0000	25	0.0000
3	50	0.0000	50	0.0760	50	0.1460	50	0.2120	50	0.2760
4	75	0.1120	75	0.1460	75	0.2200	75	0.2900	75	0.3750
5	100	0.1560	100	0.2460	100	0.3270	100	0.4900	100	0.5120
6	125	0.3200	125	0.4560	125	0.5960	125	0.6760	125	0.7460
7	150	0.5700	150	0.6200	150	0.7460	150	0.9060	150	1.0220
8	175	0.7600	175	0.8400	175	0.9640	175	1.0760	175	1.1760
9	200	0.9560	200	1.0200	200	1.0760	200	1.1700	200	1.2760
10	225	1.0460	225	1.1960	225	1.2190	225	1.3960	225	1.5460
11	250	1.1700	250	1.2900	250	1.3960	250	1.5700	250	1.6960
12	275	1.2900	275	1.4300	275	1.4790	275	1.6740	275	1.8600
13	286	1.3460	298	1.5420	300	1.6940	300	1.8900	300	1.9670
14					314	1.7900	325	1.9760	325	2.1760
15							327	2.0460	338	2.2460

Table: 3.3 Central Deflection of Waving Steel Fibre High Strength Fibre Reinforce Slab. Variation of Central Deflection with Respect to Load for *a/d*= 1.25

	M_0		M_1		M_2		M_3		M_4	
Sr. No.	**Load (kN)**	**Deflection (mm)**	**Load (kN)**	**Deflection (mm)**	**Load (kN)**	**Deflection (mm)**	**Load (kN)**	**Deflection (mm)**	**Load (kN)**	**Deflection (mm)**
1	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000
2	25	0.0000	25	0.0000	25	0.0000	25	0.0000	25	0.0000
3	50	0.0960	50	0.1700	50	0.2660	50	0.3120	50	0.3760
4	75	0.1650	75	0.2200	75	0.2800	75	0.3300	75	0.4200
5	100	0.2400	100	0.3200	100	0.3920	100	0.4960	100	0.6220
6	125	0.3700	125	0.5760	125	0.7560	125	0.8760	125	0.9560
7	150	0.5940	150	0.7340	150	0.9640	150	1.0200	150	1.0490
8	175	0.7200	175	0.8960	175	1.0470	175	1.1740	175	1.2420
9	200	0.9760	200	1.0760	200	1.1760	200	1.2900	200	1.3760
10	225	1.0920	225	1.2340	225	1.3490	225	1.5200	225	1.6790
11	250	1.1940	250	1.3760	250	1.5230	250	1.7460	250	1.9460
12	275	1.3240	275	1.5200	275	1.6940	275	1.8450	275	2.0460
13	281	1.4560	291	1.6700	300	1.8950	300	1.9460	300	2.2450
14					307	1.9640	325	2.2400	325	2.4740
15							319	2.3240	331	2.5640

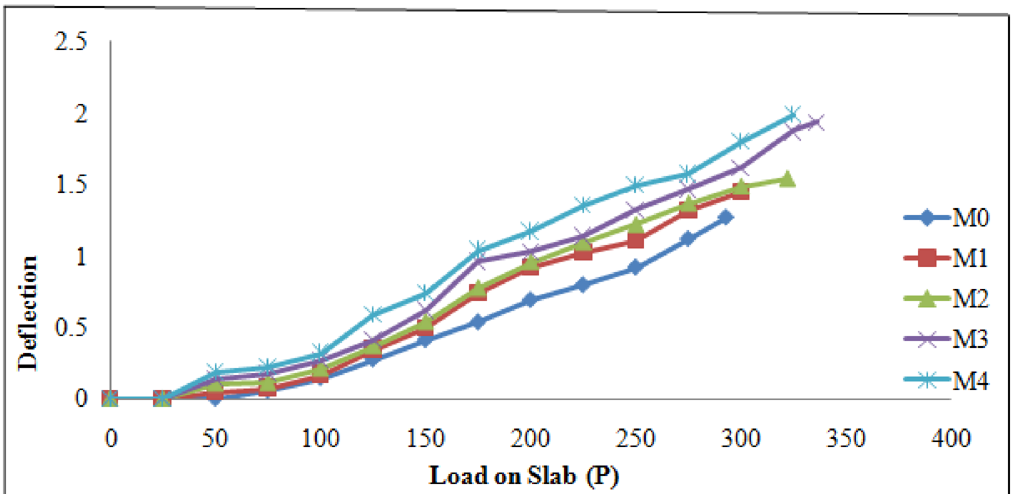

Fig.3.1 Variationof Deflection at 28 Days With to Percentage Fibre Volume Fraction up to failure of slab

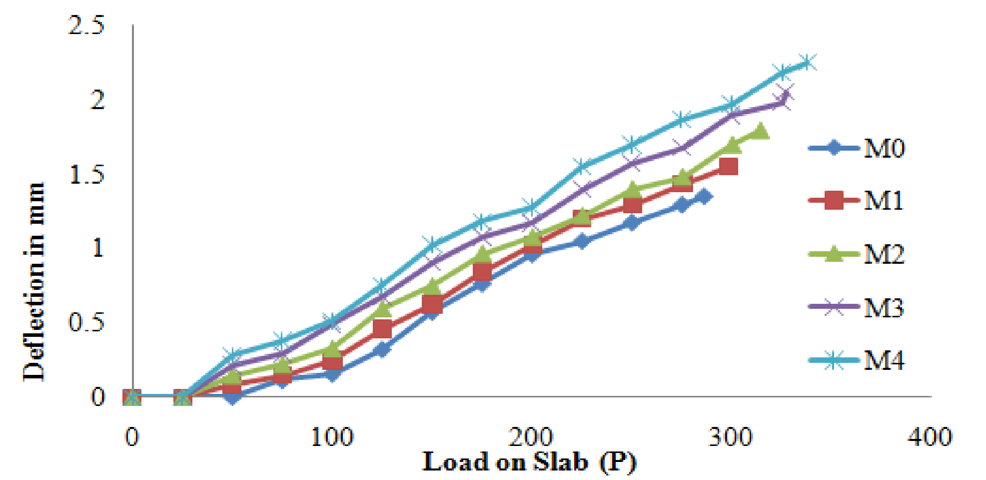

Fig.3.2 Variationof Deflection at 28 Days With to Percentage Fibre Volume Fraction up to failure of slab

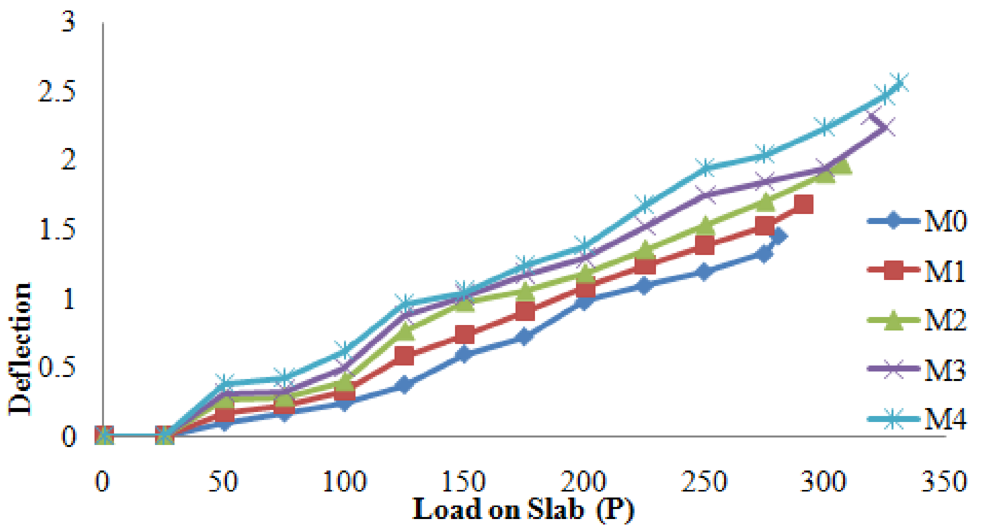

Fig.3.1 Variationof Deflection at 28 Days With to Percentage Fibre Volume Fraction up to failure of slab

3.4. Test Setup and Instrumentation

Slabs, a short platewas used for observed as the formation of cracks stabilized before the load picked up again. As the load further increased, more cracks appeared on the bottom of the slabs and were observed to propagate in a zigzag manner toward the edges of the slabs. Correspondingly, the steel strains increased rapidly, and eventually the yield strains were reached.

Further reduction in stiffness was observed as the applied load was increased and the yielding of steel reinforcement was deemed to have spread outwards to the edges of the slab. During this stage, the slab was observed to deflect excessively, and the increase in load was mainly due to membrane action of the slab. Near the ultimate load, the stiffness of the slab decreased rapidly and cracks started to appear on both the top and bottom surfaces of the slab in a circumferential direction around the loading plate. The loading plate began to punch through and finally, when the circumferential cracks became excessively wide, the load-carrying capacity of the slab dropped sharply.

The postpeak region indicated a further reduction in the load-carrying capacity of slabs. This reduction occurred in several steps, with spalling of the concrete from the bottom of the slab. Fig. 4.1 shows the crack patterns for some typical slabs after the tests.

For all slabs, the critical punching-shear perimeter was found to occur at some distance away from the loading plate. Measurements on both the top and bottom surfaces of the slabs indicated that the critical perimeter formed, on a

IV. Conclusions

Within the scope of the study, the following conclusions may be drawn. The load-deflection curve of HSFRC slabs under a concentrated load exhibits four distinct regions: (1) The initial elastic uncracked region; (2) the crack development region; (3) the post yielding region; and (4) the post peak region.

The critical perimeter for punching shear failure in HSFRC slabs forms at a distance of about 4.5 times the effective depth from the perimeter of the loading platen, with the shear plane inclined at 20^0-30^0 to the plane of the slab.

Punching shear failure in HSFRC slabs is preceded by yielding of steel reinforcement and is accompanied by cracks mainly in the radial direction and partly in the circumferential direction.

An increase in the volume fraction of steel fibers, slab thickness, compressive strength of fiber concrete, or the loaded area generally leads to an increase in the cracking load, yield load, ultimate load, and ductility of HSFRC slabs.

Fig 4.1 Yield line patterns are occurred in slab after application of punching shear.

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