INVESTIGATIONS ON EFFECT OF CFRP STRIPS RETROFITTED USING NSM METHOD ON TWO-WAY NSC AND HSC SLABS SUBJECTED TO CONCENTRATED LOAD

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Abstract

Experimental investigation on the effect of strengthening by NSM method using CFRP strips was conducted on simply supported two-way slabs. A total eight slabs, four control slabs and four NSM strengthened slabs, with an effective span of over 940mm and an effective depth of 74mm were tested under a single point loading. Parameters varied in the study was the grade of concrete and reinforcement percentages. The performance of these specimen under the changing parameters were studied on the first crack load, ultimate load and on their corresponding deflections. Further the effect of NSM strengthening on all these parameters was also studied. The combined load deflection behaviour of slabs was plotted to understand the slab behaviour and the relevant conclusions were presented.

Keywords: *Two-Way Slabs, NSM, Strengthening, Retrofitting, NSC, HSC.*

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1. INTRODUCTION

Concrete has become a widely used construction material due to its versatility, ease of preparation, applicability, durability and serviceability. Slabs are two-dimensional elements which rests on beams and columns in a structure. Slabs form the most important part of any structure which provide the most useful area for working in the structure.

HSC are gaining wide popularity in the present day field applications due to its advantages like early strength gain, better durability, impact and toughness characteristics. HSC are seen to exhibit better durability and corrosion resistance in comparison to Normal Strength Concrete (NSC). HSC provides higher strength per unit cost, per unit weight and per unit volume thus can lead to reduced size and weight of structures, increases stability and reduces deflections. The mechanism of crack formation and propagation, deformation etc., depend on the mechanical properties of concrete and thus changes from NSC to HSC.

Slabs which have undergone deformity or have been rendered insufficient to perform under a given loads need to be repaired and being the most important structural component it is not easy to be removed and recast as it is very difficult, hinders the operational capacity of the structure during such reconstruction. The concept of strengthening the slabs is a suitable solution to such problem. Of all the available retrofitting procedures the most preferred one under high strain rate conditions is retrofitting using Fibre reinforced polymers (FRP). The methods widely used for retrofitting using FRP are External bonding (EB) and Near surface mounting (NSM). NSM technique is the strengthening system which involves provision of additional reinforcement in form of bars or strips in the groove made in concrete cover. The use of Near-Surface Mounted (NSM) Fibre-Reinforced Polymer (FRP) is the latest method for increasing both flexural and shear strength of deficient Reinforced Concrete (RC) beams and slabs.

2. LITERATURE REVIEW

SUDARSANA RAO HUNCHATE et.al, [1]The authors have carried out investigations to give design mix for HPC by using silica fume and superplasticizers. Total six mixes were prepared by keeping w/c ratio 0.29 constant, varying silica fume percentage from which cubes and cylinders were casted. As the replacement increases the compressive strength increases up to optimum percentage and then decreases gradually.**BANTHIA et.al, [2]** They have reported the general bending load versus load point deflection graphs were plotted for various specimens for both static and dynamic loading. The higher values of fracture energies obtained from the composites than the unreinforced matrix. The conventionally reinforced concrete with its strategically placed reinforcing bars was found to be most impact resistant of other concretes such as normal strength plain concrete, High strength concrete, normal strength polypropylene fibre reinforced concrete and normal strength steel fibre reinforced concrete.**RAKESH KUMAR SAHU et.al, [3]**The present study was aimed to develop high strength concrete (HSC) mix design using locally available materials and Normal strength concrete (NSC) mix design. The functional formulas to determine the parameters for High strength concrete are obtained for water cement ratio, water content, FA content, CA content and cement content. Those equations are used to develop the mix designs for M50, M60 and M70.**RP et.al.[4],** have given the mix design procedure of HSC using 20mm downsize aggregate, without using silica fume and keeping the water cement ratio between 0.23 to 0.25 With these they have achieved concrete of strength up to 120 MPa. This method provides the best strength gain with least cement content.

MICAEL INACIO, et.al, [4]An experimental research was conducted to investigate the punching behaviour of high strength concrete (HSC) flat slabs, presenting a compressive concrete strength of 130 MPa. All specimens exhibited a decrease of stiffness when the flexure cracks start to form and develop. Furthermore, before cracking, the stiffness of the HSC specimens was slightly higher than of the NSC specimen. The test results also showed a displacements decrease at failure with the increase of the longitudinal reinforcement ratio, while stiffness increased slightly. From the results obtained, and for this set of tests, it is possible to conclude that the use of HSC instead of NSC led to an increase up to 43% of the punching capacity. The increase of reinforcement ratio from 0.94% to 1.48% led to an increase of punching capacity of 12%. **ANDREAS ANDRESSON [5]**The load carrying capacity of concrete slabs subjected to concentrated loads are studied considering both static and impact loads. The slabs failed in one-way flexure. The concrete fallout was more in the slabs with rebar mesh than the slabs with SFRC. The residual strength after the impact was sufficient to carry the static load of impact test.

HUBERT WITKOWSKI et.al., [6] have presented the bond test results of CFRP strips to concrete with respect to variations of concrete strength, beam span, bond length and ratio of internal steel reinforcement. Bond behaviour is dependent on bond length, concrete strength, adhesive property, dimensions of groove, FRP type, location of FRP with respect to concrete edge and interaction between steel and FRP reinforcement. ***E.* BONALDO et.al., [7]**This paper presents the study conducted to assess the efficiency of NSM strengthening to increase flexural resistance of RC Slabs Maximum load taken by strengthened slab was almost five times unstrengthened slab. Maximum strain recorded in CFRP was about 80% of its ultimate strain. Providing of 0.12% of CFRP laminates increased service loads by 54%.

2. OBJECTIVES

- To obtain the workable mix proportions for NSC (Normal Strength Concrete) and HSC (High Strength Concrete) which satisfies strength criteria.
- To record the flexural behaviour of slabs under static loading.
- To record the change in static behaviour when slabs are strengthened with NSM technique
- To analyse the static test results over the influencing parameters such as cracking load, ductility index, Energy absorption and failure criteria and how they change with strengthening.

3. MATERIALS AND MIX PROPORTIONS

Characterisation of materials used in the present investigation has been carried out as per the standard procedure. The various materials used in the experimental work are Cement, fine aggregate, coarse aggregate, water, reinforcing steel and admixtures. Each of the material used in the experiment has been discussed in detail below.

- CEMENT - In the present work, Ordinary Portland Cement of 53 grade conforming to IS: 12269-2013 has been used.
- FINE and COARSE AGGREGATES - The fine and coarse aggregates used was as per the specifications as per IS 383-1970.
- REINFORCING STEEL - The reinforcing steel was found to satisfy the specifications as per IS 1786: 2008.
- ADMIXTURE - The superplasticizer used in the present work is Master Glenium Sky 8233 which is commercially marketed by BASF Construction Chemicals (India) Private Limited is used for M70 concrete and Siri plast is used for M20 concrete.
- WATER - Potable water free from injurious salts for both mixing and curing is used as per IS 456:2000
- CFRP strips, sponsored by FOSROC CHEMICALS, Bangalore which is marketed under the name “Nitowrap CFP” was used in the present study for retrofitting both NSC and HSC slabs
- The epoxy used for bonding the CFRP to slab in the study was manufactured by FOSROC CHEMICALS(India) Pvt. Ltd., Bangalore marketed under the name Nitowrap 40

3.1 Mix Design Procedure

There are many methods of mix design available for the Normal Strength Concrete (NSC) such as New British Method, IS method, ACI method, British method, Fineness modulus method, Maximum Density method, Road note No.4 method and minimum voids method. All these methods give a channelized procedure for proportioning the basic ingredients of the NSC. However, there is no single and channelized procedure available for HSC since there are many methods by which, one can get proportioning of HSC.

Fig. 1: Mixing of trial mix for NSC

Fig. 2: Cube casting of NSC

Mix design procedure was formulated by combining the BIS method, ACI methods for concrete mix design and available literatures. This procedure was adopted as it gives the least cement requirement (kg/m^3) for any particular mix compared to other methods. Also the charts and curves available Fig 1 shows the mixing of trial mix. Fig 2 shows the trial mixes which were cast into cubes.

3.2 Trial Mixes

NSC (M20) as per IS 10262:2009 and HSC (M70) as per R P et.al Mix Design

Table 1: Trial Mix design specifications for NSC and HSC

Ingredient	NSC	HSC
Cement (kg/m^3)	405.00	500
Coarse Aggregate (kg/m^3)	904.40	714
Fine Aggregate (kg/m^3)	801.33	1000
Water (kg/m^3)	202.50	150
Superplasticizer (kg/m^3)	-nil-	7.47
Compressive Strength (MPa)	25.51	76.02


Fig.3: Failure of NSC cubes **Fig.4:** Failure of HSC cubes

Fig.3 shows the failure of NSC trial mix cubes under compression. Fig.4 shows the failure of HSC trial mix cubes under compression

3.3 Specimen Casting

The specimen casting was done to carry out the tests for studying the behaviour of slabs in static loading by varying the parameters such as grade of concrete, percentage of reinforcement and drop height. A total of 8 slabs were


Fig.5: Reinforcement in the mould. **Fig.6:** Pouring and vibrating of concrete

required for all these parameters to be effectively studied.Fig.5 shows the typical reinforcement and mould used for casting. Fig 6 shows the pouring of concrete and vibrating it. The specimen naming was done in an efficient manner to identify the slabs with ease.NSM0 indicates control slabs with no strengthening and NSM1 indicates NSM strengthened slabs with 0.048% of reinforcement The table 2 provides the various slab identifications and the details of the specimen. Fig 7 shows the slump test being done on casting mix. Fig 8 shows the compaction factor test for NSC. Fig 10 shows the casting of cubes cylinders, prisms for casting mix. Fig 10 shows the finished test slabs.


Fig.7: Slump test **Fig.8:** Compaction factor testing for NSC


Fig.9: Casting of cubes, cylinders and prisms **Fig.10:** Finishing of placed concrete

Table 2: Specimen characterization and naming

Sl no	Slab ID	Concrete Grade	Reinforcement details	
1	M20/PT1/NSM0	M20	PT1=0.34%	8mm @ 240 C/C
2	M20/PT2/NSM0		PT2=0.79%	12mm @240 C/C
3	M70/PT1/NSM0	M70	PT1=0.34%	8mm @ 240 C/C
4	M70/PT2/NSM0		PT2=0.79%	12mm @240 C/C
5	M20/PT1/NSM1	M20	PT1=0.34%	8mm @ 240 C/C
6	M20/PT2/NSM1		PT2=0.79%	12mm @240 C/C
7	M70/PT1/NSM1	M70	PT1=0.34%	8mm @ 240 C/C
8	M70/PT2/NSM1		PT2=0.79%	12mm @240 C/C

3.4 Strengthening of Slabs by NSM Technique

The strengthening of slabs was carried out by NSM technique using CFRP strips. The strengthening was done in diagonal direction based of earlier researches. A zone of NSM strengthening marked by L/5.31 from the ends of the slab was identified for provision of NSM reinforcement. Fig 11 shows the CFRP laminates used in experiment. Fig 12 shows the groove cutting to apply epoxy and CFRP strips. Fig 13 shows a typical groove on the concrete surface. Fig 14 shows the typical groove layout. Fig 15 shows the placing of CFRP strips into epoxy filled groove. Fig 16 Surface finishing of NSM strengthened slab.

Fig 11: CFRP Laminates cut into strip

Fig 12: Groove Cutting

Fig 13: Typical Groove

Fig 14: Typical Groove Layout

Fig 15: Placing of Strips

Fig 16: Surface finishing

4. EXPERIMENTAL SETUP

The static test setup was as shown in the figure17. The LVDT was used to measure the deflections and data acquisition system was used to capture the load deflection data. The rate of loading was 0.5kN/second.

Fig.17: Test setup with specimen ready for testing

5. RESULTS

5.1 First Crack Load and Ultimate Load

From the experimental investigation conducted in the laboratory the first crack load and the ultimate load with their corresponding deflections were tabulated in the table 3.

Table 3: First crack Load and Ultimate Load with corresponding deflections

SLAB ID	Pcr (kN)	Δ_{cr} (mm)	Pu (kN)	Δ_u (mm)
M20/PT1/NSM0	28.6	1.99	83.5	24.8
M20/PT2/NSM0	43	2.2	121.7	14.45
M70/PT1/NSM0	40.9	1.86	85.9	28.29
M70/PT2/NSM0	37	2.48	126.4	15.02
M20/PT1/NSM1	35	1.21	111.5	14.67
M20/PT2/NSM1	49	1.52	146.9	13.73
M70/PT1/NSM1	40.1	2.44	89.8	13.21
M70/PT2/NSM1	41.2	2.15	125.6	17.6

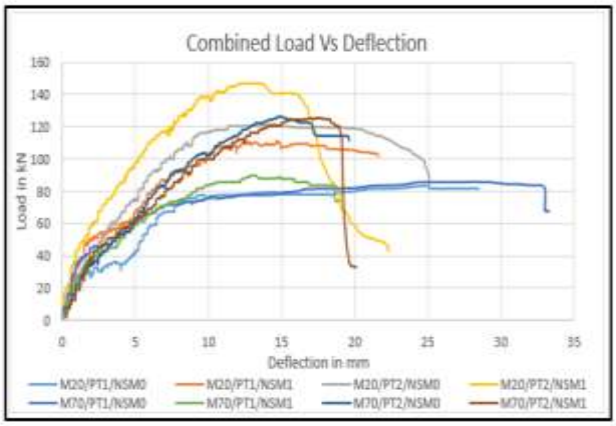

Fig.18: Combined Load deflection curves of Test Specimen

From table 3, it was that the first crack load of control slabs of NSC slabs were increased by 50.35% and that of HSC slabs decreased by 10.54% when reinforcement ratio increased from 0.34% to 0.79%. However, the ultimate load for NSC slabs increase by 45.75% and HSC slabs increased by 47.15% as the reinforcement increased from 0.34% to 0.79%. In case of strengthened slabsfirst crack load NSC slabs were increased by 40% and that of HSC slabs increased by 2.74% when reinforcement ratio increased from 0.34% to 0.79%. However, the ultimate load for strengthened NSC slabs increase by 31.75% and HSC slabs increased by 39.87% as the reinforcement increased from 0.34% to 0.79%.

When comparing control slabs and strengthened slab it was observed that for NSC slab of 0.34% reinforcement ratio, the first crack load increased by 22.38% and ultimate load increased by 33.53%. For NSC slab with 0.79% reinforcement ratio it was noticed that first crack load increased by 13.95% and ultimate load increased by 20.71%. It was also observed that for HSC slabs with 0.34% reinforcement ratio first crack load reduced by 1.99% and ultimate load increased by 4.54% and for HSC slabs with 0.79% reinforcement the first crack load increased by 11.35% and ultimate load decreased by 0.64%

In case of control slabs of 0.34% reinforcement the first crack load increased by 43% and for 0.79% reinforcement it decreased by 16.21% as the grade of concrete increased. However, for strengthened slabs of 0.34% reinforcement the first crack load increased by 14.57% and for 0.79% reinforcement it increased by 2.74% as the grade of concrete increased.

The deflection at first crack, for control slab of NSC was increased by 10.55% and for HSC it was increased by 33.3% with increase in reinforcement ratio from 0.34% to 0.79%. The deflections at ultimate load, for NSC slabs reduced to 71.62% and for HSC slabs it reduced to 88.35% when reinforcement ratio increased from 0.34% to 0.79%. In case of strengthened slab of NSC the deflection at first crack increased by 25.62% and for HSC slabs it decreased by 13.49% as the reinforcement ratio increased from 0.34% to 0.79%. The deflections at ultimate load, for strengthened NSC slabs reduced by 6.84% and for HSC slabs it increased by 33.23% when reinforcement ratio increased from 0.34% to 0.79%.

It was observed with control slabs that for 0.34% reinforcement ratio the deflection at first crack was reduced by 6.99% and for 0.79% reinforcement ratio it was seen to increase by 12.73% with increase in grade of concrete.The deflection at ultimate load of control slabs with 0.34% reinforcement ratio was seen to increase by 14.07% and for 0.79% reinforcement ratio it was seen to increase by 3.95%. In case of strengthened slab, for 0.34% reinforcement ratio defection at first crack load increased by 101.65% and for 0.79% reinforcement ratio it increased by 41.45%. The deflection at ultimate load of strengthened slab with 0.34% reinforcement was seen to reduce by 11.05% and for slab with 0.79% reinforcement it was seen to increase by 28.19%. When comparing control slabs and strengthened slabs it was seen that for NSC slab with 0.34% reinforcement the deflection at first crack reduced by 64.46% and at ultimate load it reduced by 69.05% and with 0.79% reinforcement it was observed that the deflection at first crack load reduced by 44.74% and at ultimate load it reduced by 5.24%. It was observed for HSC slab that with strengthening at reinforcement ratio 0.34% the deflection at first crack load increased by 31.18% and at ultimate load it was seen to reduce by 114.15% and for reinforcement ratio of 0.79% the deflection at first crack load was observed to reduce by 15.34% and at ultimate load it was seen to increase by 49.4%.

5.2 Load Deflection Behaviour

The combined load deflection behaviour as shown in fig.6, it was observed for the control slabs that the maximum load was found to be more for higher percentage reinforcements regardless of the concrete grade. The deflections were found to be more in lower percentage of reinforcements. With strengthening it was observed that higher loads were reached at lesser deflections. This is because as the percentage of reinforcement increases, the stiffness of the member increases and provision of strengthening system was seen to further increase stiffness and hence the higher load capacity was observed. The strengthening system was seen to be most effective with NSC than HSC. This might be due to fact that the characteristic of epoxy and the HSC are not matching on micro level thus no distinct enhancement in strength is observed.

6. CONCLUSION

- As the reinforcement ratio increases the first crack load increases in case of control slab of NSC however it decreased in case of control slab of HSC.
- As the reinforcement ratio increases the ultimate load increases considerable in case of NSC but negligible in case of HSC slabs.
- Ultimate load increased noticeably only in case of NSC slabs upon strengthening. HSC slabs did not show any distinct increase in ultimate load capacity upon strengthening
- The deflections at first crack load was increased as the percentage of reinforcement was increased in case control slabs of both NSC and HSC
- The deflection of strengthened slabs at first crack load was seen to increase with increase in concrete grade for both reinforcement ratios.
- The deflection at ultimate load was seen to reduce for NSC and increase for HSC with increase in reinforcement ratio.
- All the slabs were failed in flexure except the control slab and strengthened slab of HSC with 0.79% reinforcement in which the punching shear failure was observed.

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