A COMPARITIVE STUDY ON STRENGTHENING OF R.C SLAB WITH MULTIPLE OPENINGS BY NSM AND EBR TECHNIQUES

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Abstract : This Near Surface Mounted (NSM) and Externally Bonded Reinforcement (EBR) are now emerging as a promising techniques, for increasing flexural and shear strength of RC members by FRP rods and laminates. Introducing openings in existing reinforced concrete (RC) slabs can severely weaken the slabs due to the cut out of both concrete and reinforcing steel. In this thesis, the use of Glass Fiber Reinforced Polymers (GFRP) strengthening alternatives to restore the flexural capacity of the RC slab after having multiple openings in the slab have been studied. The structural performance of RC Slab with multiple openings strengthened with NSM and EBR by GFRP rods was investigated. NSM technique consists of placing FRP rods in a groove cut into the surface of the member while, EBR technique consists of placing and bonding of FRP sheets on the pre-cut grooves named Externally Bonded Reinforcement On Grooves (EBROG). The FRP bars and sheets may be embedded in an epoxy or cementitious based paste, which transfers stresses between the substrate and the bar. The slab have dimensions of 1050mm x 1050mm x 70mm were provided with two openings of 150mm x 150mm which was loaded at the centre of the slab, whose load carrying capacity and specific failure patterns were investigated. Six slabs were tested in which the two control slabs are casted with and without openings and three slabs with openings strengthened with GFRP rods in two different patterns such as strengthening around the opening and strengthening in diagonal form and remaining slab is strengthened with GFPR sheets in two different directions. The test results shows that the load-carrying capacity of RC slab reduced up to 37% while reducing an area about 5% by providing openings and the RC slab with openings strengthened by placing GFRP rod around the opening improves the load carrying capacity about 39% than strengthening in diagonal pattern which is about 23% respectively. While, the test results of EBR technique, by placing GFRP sheets around the slab openings improves the load carrying capacity about 20%.

IndexTerms - RC slab, Openings, Strengthening, GFRP rods, NSM and EBR techniques.

I. INTRODUCTION

Concrete has long been used as a building material for its high compressive strength, good durability and low cost. However, its well-known that it has brittleness and limited tensile strength. Further, steel rebar's penchant to conduct electrical and magnetic fields makes it undesirable in concrete specified for certain power-generation, medical/scientific-imaging, nuclear and electrical/electronic applications.

Glass fiber-reinforced polymer (GFRP) rebar is slowly gaining market share as government entities begin to include it in building codes and design guidelines and as test methods have been developed. As a result, a growing number of agencies, such as the Manitoba Floodway Authority, have selected GFRP rebar as the most effective long-term solution for public projects. The use of corrosion-resistant composite rebar will ensure the guideway's long-term durability and, thus, will extend the train system's useful life and reduce maintenance/repair costs.

1.2 NEED FOR OPENINGS IN RC SLAB

Reinforced concrete (RC) structures often require strengthening or repair at some point during their design lifetime. The requirement for strengthening can arise for a variety of reasons, including a need for upgrading the load-carrying capacity, a necessity to make changes in the structure or a need to solve problems that occurred during construction. When dealing with RC slabs, post-construction installation of escalators, elevators or utilities such as air conditioning, heating or wiring ducts is often required. The introduction of CFRP material for strengthening the RC slab by the NSM technique improves the load carrying capacity to a greater extent.

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1.3 NEED FOR STRENGTHENING

Reinforced concrete slabs require strengthening during the following conditions

Increase in the applied loads

Mistakes or unsafe design

Cracks in concrete or stress less than design stress.

Reinforced steel corrosion or insufficient number of bars

The settlement in the foundation is more than the allowable.

In these conditions the Load Carrying capacity of the RC slab will be reduced and also there will be the formation of cracks.

In order to increase the Load carrying capacity and to reduce the cracks formed the RC structure should be strengthened.

1.4 MATERIAL USED FOR STRENGTHENING

Fiberglass Rebar is used to reinforce concrete in applications where concrete is exposed to water, salt water, or chemical environments. Fiberglass Rebar is produced through the process of pultrusion in which several thousand glass filaments are saturated with resin and pulled through a gauge die, then helical wrapped creating a slight bar deformation and cured under tension along several graduated temperature zones until the cure is complete.

GFRP Rebar

1.4.1ADVANTAGES OF GLASS FIBER REINFORCED POLYMER REBAR

The following are some advantages of current FRP reinforcement in concrete Structures

Corrosion resistant: since FRP is a nonmetallic material, it doesn't corrode when it comes in contact with water and air or salt water and most soil conditions. Therefore, durability problems associated with steel reinforcement do not exist. Consequently, the life cycle of the composites is potentially longer with lower maintenance costs.

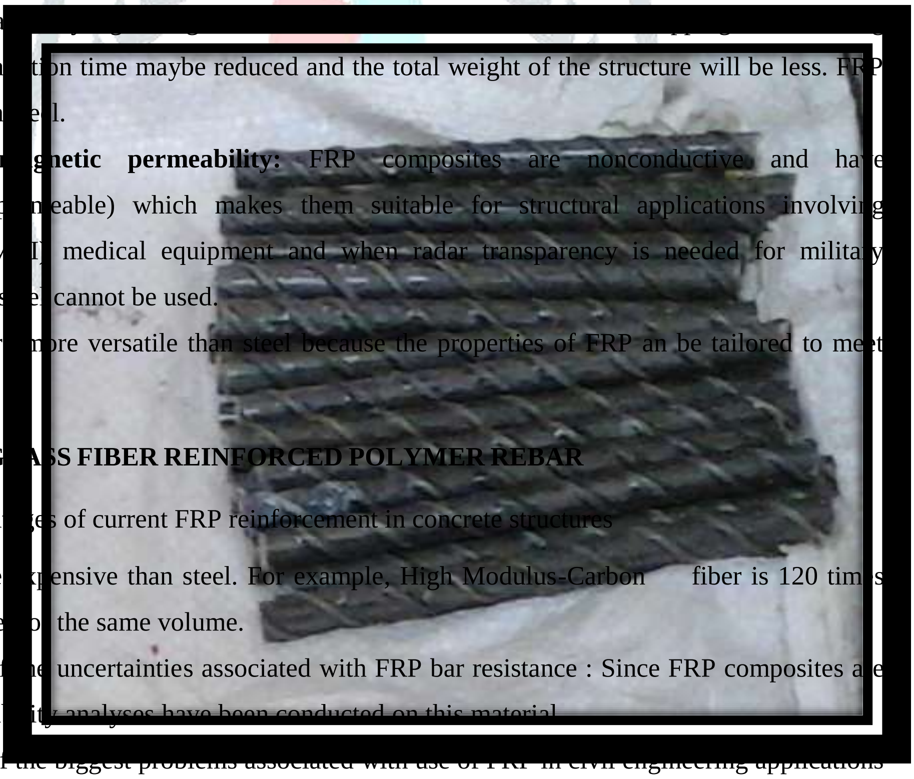
High strength: the tensile strength of some FRP composites is greater than steel when the load applied in the direction of loading. For example, the tensile strength of S-glass fibers is 4300 MPa (625 ksi) whereas the ultimate tensile strength of steel grade 60 is 650 MPa

High specific Modulus: which is defined as the modulus of elasticity of the unidirectional fibers divided by the density of the material. For example; specific modulus of carbon fiber is between 15.7 to 85.6 whereas the specific modulus ofsteel is 3.9.

Lightweight: FRP composites a[illegible] significantly. Moreover, the insta[illegible]on time maybe reduced and the total weight of the structure will be less. FRP weighs three tosix times less than [illegible]l.

Non-conductive and electro[illegible]etic permeability: FRP composites are nonconductive and have electromagnetic transparency ([illegible]eable) which makes them suitable for structural applications involving Magnetic Resonance Imaging(M[illegible]I) medical equipment and when radar transparency is needed for military installations where conventional s[illegible] cannot be used.

Tailor-ability: FRP materials ar[illegible]ore versatile than steel because the properties of FRP an be tailored to meet specific functional requirements.



1.4.2 DISADVANTAGES OF G[illegible]S FIBER REINFORCED POLYMER REBAR

The following are some disadvan[illegible]s of current FRP reinforcement in concrete structures

1. FRP materials are more [illegible]ensive than steel. For example, High Modulus-Carbon fiber is 120 times more expensive that stee[illegible] the same volume.
2. Lack of consideration of [illegible] uncertainties associated with FRP bar resistance : Since FRP composites are relatively new, few relia[illegible]
3. Lack of ductility: One of [illegible] is ductility. However, hybrid bars can overcome brittle failure.
4. Small modulus of elasticity: Glass fiber reinforced polymer (GFRP) and aramid fiber reinforced polymer (AFRP) composites have small elastic moduli which may affect serviceability of the structure, particularly deflection. However, carbon fiber reinforced polymer (CFRP) has an elastic modulus close to that of steel and higher. Lack of standards: although FRP composites have been recognized by ACI, AASHTO, PCI and other agencies, still there are no uniform manufacturing standards. For example,

different manufacturers provide different FRP composite mechanical properties under the same designated name.

5. Lack of long term performance data: The performance of FRP composites are still under research regarding fatigue, creep, creep rupture, relaxation, thermal expansion, moisture, chemical deteriorations, and other environment effects.
6. Lower temperature of combustion: It has been concluded that both strength and stiffness of the FRP composite decrease when temperatures rise. At high temperatures, the resin becomes flammable. Fire resistant resins are currently under research.
7. Anisotropy of material properties: The mechanical properties are different in different directions, resulting in more complex analysis and design.

1.5 STEPS INVOLVED IN THE APPLICATION OF NSM TECHNIQUE

The following steps are usually adopted in the application of the NSM technique:

1. A groove is cut in the desired direction into the concrete surface.
2. Clean the slits with compressed air
3. Clean the GFRP rods with an appropriate cleaner (e.g., acetone)
4. Prepare the epoxy adhesive according to the supplier recommendations
5. Fill the slits and cover the lateral faces of the GFRP with the epoxy adhesive
6. Flow between the GFRP and the slit borders.
7. The groove is then filled with more paste and the surface is leveled.

1.6 STEPS INVOLVED IN THE APPLICATION OF EBR TECHNIQUE

1. Check the substrate quality, and remove any unsound material.
2. Fill honey combs and level the uneven surfaces.
3. The surface must be prepared to remove laitance layer of concrete and irregularities and form work marks

II LITERATURE REVIEW

2.1 Overview of literature review

Yeoi Choi (2013)et al. investigated on "strengthening of RC slab with symmetric opening using GFRP composite beams" and presented the results of GFRP composite beam strengthened reinforced slabs with two symmetrical openings. The test results showed that the strengthened slabs seems to increase in load-carrying capacity on an average of 20% over that of control specimen for diagonal ,parallel and surround strengthening respectively.

Seliemet al.(2008) worked on "Field testing on RC slabs with openings strengthened with CFRP laminates" and reported the results of CFRP strengthened RC slab after having large openings cut out at the center of a slab in the positive moment region. Test results also showed that creating an opening in the slab reduces its strength by as much as 18% up to failure.

Casadeiet al. (2003)worked on "Experiments on Two-way RC slabs with openings strengthened with CFRP laminates" and presented the experimental results of one-way slabs with openings from on existing parking garage externally strengthened with CFRP laminates. In this study, a total of six one-way square slab specimens were used from an existing parking garage building as a test bed. Test results showed that the use of CFRP laminates in slab strengthening was effective with an increase in load by approximately 30%, and shear failure was found to be the controlling mechanism when cutouts were placed in the negative moment region of one-way slabs.

III RESEARCH METHODOLOGY

3.1 Material Characterisation

In the following sections the characterization of reinforced concrete, GFRP rod and epoxy adhesive used in the experimental research is described.

3.2. Reinforced Concrete

The properties of the materials such as cement, fine aggregate, coarse aggregate and reinforcing bars are investigated by conducting various laboratory tests and the test results obtained are compared with the Indian Standard values.

3.3 Test Results Of Material Samples Used In Present Work

3.3.1 Cement

The following experiments were conducted to find the properties of cement as per IS-4031,

i. Standard Consistency Test

ii. Initial Setting and Final Setting Time Test

iii. Specific Gravity Test

Iv. Compression Strength test for Mortar C

3.3.1.1 Initial Setting Time

Table 3.1 Initial Setting Time of Cement

Time at which water is added to cement (min)	Time at which the needle fails to pierce the test block by 5.0mm (min)	Initial Setting time
0	45	45

3.3.1.2 Final Setting Time Of Cement

Table 3.2 Final Setting Time of Cement

Time at which water is added to cement (min)	Time at which the needle makes an impression on surface of block (min)	Final setting time (min)
0	445	445

3.3.1.3 Specific Gravity Of Cement

Table 3.3 Specific Gravity Of Cement

Sl.no	Description (gm)	Trial 1	Trial 2	Avg
1	Weight of empty bottle	0.675	0.675	3.14
2	Weight of bottle + cement	1.303	1.298	
3	Weight of bottle + cement + kerosene	1.772	1.812	
4	Weight of bottle + kerosene	1.401	1.400	
5	Specific gravity of cement	3.145	3.14	

3.3.1.4 Compressive Strength Test

Table 3.4 Compressive Strength of Mortar Cube

Sl.no	Period of curing (days)	Compressive strength (N/mm^2)
1	3	31
2	7	40
3	28	52

3.3.2 Fine Aggregate

The following experiments were conducted to find out the properties of fine aggregate as per IS-2386,

i Sieve Analysis Test
ii Specific Gravity Test
iii Water Absorption Test

Thus the properties of the fine aggregate used in the concrete has been tested under codal provisions and the values obtained for the above mentioned tests are tabulated as follows

Table 3.5 Sieve Analysis of Fine Aggregate

Sl.no	Sieve Opening size	Weight of F.A Retained (gm)	Cumulative weight of F.A retained (gm)	Cumulative percentage of F.A retained (gm)	Cumulative percentage of F.A passing
1	10mm	0	0	0	100
2	4.75mm	10	10	1.0	99.0
3	2.36mm	39	49	4.9	95.1
4	1.18mm	235	284	28.4	71.6
5	600µ	304	588	58.8	41.2
6	300µ	290	878	87.8	12.2
7	150µ	95	973	97.3	2.7
8	<150µ	25	998	-	0.2
		0	0	-	-
		990		Total = 278.2	

Fineness modulus = 278.2/100 = 2.78

Table 3.6 Specific Gravity of Fine Aggregate

Sl.no	Description (gm)	Trail 1	Trail 2	Trail 3	Mean
1	Weight of empty pycnometer	681	681	681	2.56
2	Weight of pycnometer+ fine aggregate	1385	1395	1393	
3	Weight of pycnometer+ fine aggregate + water	1961	1973	1968	
4	Weight of pycnometer + water	1534	1534	1534	
5	Specific gravity of FA	2.56	2.59	2.56	

Specific gravity of fine aggregate = 2.56

Table 3.7 Water Absorption of Fine Aggregate

Sl.no	Description (gm)	Trial
1	Weight of saturated surface dry sample	751
2	Weight of oven dry sample	760
3	Water absorption	1.2%

Water absorption of fine aggregate = 1.2%

3.3.3 COARSE AGGREGATE

The following experiments were conducted to find out the properties of coarse aggregate as per IS-2386,

i. Water absorption Test
ii. Impact Test
iii. Specific Gravity Test
iv. Sieve Analysis Test

Table 3.9 Impact Value Of Coarse Aggregate

Sl.no	Weight of sample (kg)	Aggregate passed through 2.36mm sieve (kg)	Weight retained in sieve (kg)	Aggregate impact value (%)	Mean (%)
1	575	41	534	7.1	7.1
2	580	42	538	7.2	
3	573	40	533	7.0	

Table 3.10 Specific Gravity Of Coarse Aggregate

Sl.no	Description	Trial 1	Trial 2	Trial 3	Mean
1	Weight of empty bottle	681	681	681	2.66
2	Weight of bottle + coarse aggregate	1397	1390	1395	
3	Weight of bottle + coarse aggregate + water	1978	1978	1979	

4	Weight of bottle + water	1534	1534	1534	
5	Specific weight of coarse aggregate	2.66	2.67	2.65	

Table 3.11 Sieve Analysis For Coarse Aggregate

Sl.no	IS sieve size (mm)	Weight retained	Cumulative weight retained	Cumulative % retained	Cumulative % passing
1	80	0	0	0	100
2	40	0	0	0	100
3	20	1030	51.5	51.5	48.5
4	10	966	48.3	99.8	0.2
5	4.75	3	0.15	99.95	0.05
6	2.36, 1.18, 600, 300µ,150µ	-	-	99.95	-

Fineness modules = 3.51

3.3.4 REINFORCING BARS

The steel reinforcing bars of Fe500 grade are tested under universal testing machine up to failure. The test is conducted based on IS 1786:2008.

3.3.4.1 GLASS FIBER REINFORCED POLYMER REBARS

The properties of the strengthening material that is Glass Fiber Reinforced Polymer Rebar has been tested and given in the table below

Table 3.12 properties of GFRP Rebars

Properties	Description
Diameter (mm)	8mm
Tensile strength (MPa)	>2200
Young's modulus (GPa)	150
Ultimate strain (%)	1.4

3.3.4.2 Epoxy Adhesive

The material used for bonding external reinforcement into the groove in the existing concrete surface is Epoxy resin. It is used as per the market standard and the properties of the adhesive is shown in the table below

Table 3.13 Properties of Epoxy Adhesive

Properties	Description
Compressive strength (MPa)	90
Flexural tensile strength (MPa)	30
Young's modulus (GPa)	8.15
Bond strength to concrete (MPa)	>3.5
Pot life at 20°C (min)	80
Time of cure (days)	3

IV RESULTS AND DISCUSSIONS

The following conclusions are drawn from this study

1. The degradation in the load carrying capacity due to the provision of openings has been observed and there was an increment in the load carrying capacity by strengthening using GFRP rods.
2. The NSM method of strengthening is the most promising technique which enhances the durability of the RC structure to a greater extent.
3. It was observed that reduction of area of about 5% by providing opening will reduce the load carrying capacity by 37%
4. On strengthening around the opening, the load carrying capacity has been improved by 39% and the deflection has been reduced.
5. Meanwhile strengthening in diagonal form there was a slight improvement in the load carrying capacity to 23% and the deflection has been greatly reduced.
6. Strengthening around the opening by FRP laminates, the load carrying capacity has been increased by 20% which is slightly less strength than by the strengthening by FRP rods i.e., by NSM technique.
7. From the results it was shown that strengthening of the RC slab around the openings by NSM technique is more effective and economical than EBR technique.

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