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# Comparative Study on Flexural Strength of Two Way RC Slabs Retrofitted with CFRP, GFRP and PPFRP

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***Abstract*—Fiber reinforced polymer (FRP) use in civil structures is particularly frequent in the fields of repair, retrofit and strengthening of existing building constructions. The strengthening or wrapping of existing concrete structures to resist higher design loads, or increased ductility has traditionally been accomplished using conventional materials and construction techniques. New technology options in retrofitting and rehabilitation are being developed from polymers. Wrapping is one type of retrofitting. Many research works are going on in using different materials for wrapping. In this work square wrapping technique is used. The experiment work was conducted on slabs to study the flexural behavior of the slabs under square wrapping technique for Carbon fiber reinforced polymer (CFRP), Glass fiber reinforced polymer (GFRP) and Polypropylene fiber reinforced polymer (PPFRP). The CFRP, GFRP and PPFRP were to be introduced to slabs in the form of square wrapping at flexural zone by wet lay-up technique. Control slabs were casted and tested after 28 days under uniformly distributed load. Strengthened slabs were tested after 7 days of retrofitting. Comparative study of flexural strength of slabs with square wrapping of CFRP GFRP and PPFRP with control slabs is investigated.**

**Index Terms—CFRP, GFRP, PPFRP, FRP, Retrofit, Static loading, Strengthening, Wrapping**

## I. Introduction

As we know, concrete is a building material with a high compressive strength and a poor tensile strength. The failure occurs suddenly in most cases and in a brittle manner. The most common way to reinforce a concrete structure is to use steel reinforcing bars that are placed in the structures before the concrete is cast. Since a concrete structure usually has a very long life, it is quite common that the demands on the structure change with time. The structures may have to carry larger loads at a later date or fulfil new standards. In extreme cases, a structure may need to be repaired due to an accident. Another reason can be that errors have been made during the design or construction phase so that the structure needs to be strengthened before it is used. If any of this situation arise it need to be determined whether it is more economical to strengthen the structure or to replace it.

Floor and wall structures are some of the most commonly existing structural elements in buildings. Nowadays, rebuilding of existing structures has becoming quite common due to structural or functional requirements from the clients as well as the end users. Today, the use of fiber reinforced polymer to strengthen existing components of the structure becoming more popular, partly due to ease of installation and partly due to space saving.

## II. Material and Methodology

### A. Material

*Carbon Fiber:* Carbon fiber is a high-tensile fiber or whisker made by heating rayon or polyacrylonitrile fibers or petroleum residues to appropriate temperatures. Fibers may be 7 to 8 microns in diameter and are more that 90% carbonized. These fibers are the stiffest and strongest reinforcing fibers for polymer composites, the most used after glass fibers. Made of pure carbon in form of graphite, they have low density and a negative coefficient of longitudinal thermal expansion. Carbon fibers are very expensive and can give galvanic corrosion in contact with metals. They are generally used together with epoxy, where high strength and stiffness are required, i.e. racecars, automotive and space applications, sport equipment. Depending on the orientation of the fiber, the carbon fiber composite can be stronger in a certain direction or equally strong in all directions. A small piece can withstand an impact of many tons and still deform minimally. The complex interwoven nature of the fiber makes it very difficult to break.

*Glass Fiber*: Glass fiber also called fiberglass. This material made from extremely fine fibers of glass Fiber glass is a lightweight, extremely strong, and robust material. Although strength properties are somewhat lower than carbon fiber and it is less stiff, the material is typically far less brittle, and the raw materials are much less expensive. Its bulk strength and weight properties are also very favorable when compared to metals, and it can be easily formed using molding processes. Glass is the oldest, and most familiar, performance fiber. Fibers have been manufactured from glass since the 1930s.

*Polypropylene Fiber*: Polypropylene fibers were first suggested as an admixture to concrete in 1965 for the construction of blast resistant buildings for the US Corps of Engineers. The fiber has subsequently been improved further and at present it is used either as short discontinuous fibrillated material for production of fiber reinforced concrete or a continuous mat for production of thin sheet components. Since then the use of these fibers has increased tremendously in construction of structures because addition of fibers in concrete improves the toughness, flexural strength, tensile strength and impact strength as well as failure mode of concrete.

Polypropylene twine is cheap, abundantly available, and like all manmade fibers of a consistent quality.

### *B. Methodology*

*Wrapping configurations:*

In this research work, square type of wrapping configurations will be used for retrofitting of RCC slab using different fibers Carbon Fiber Reinforced Polymer (CFRP), Glass Fiber Reinforced Polymer (GFRP) and Polypropylene Fiber Reinforced Polymer (PPFRP). The wrapping will be done only at the flexure zone. Effectiveness of the wrapping configurations will be evaluated.

*Experimental program:*

The experimental program consists of casting reinforced concrete two-way slab specimens with two control specimens and remaining six specimens with CFRP, GFRP and PPFRP wrapping. Experimental results of ultimate load carrying capacity, deflection and failure mode of slabs are investigated. Table 1. Shows the slabs specifications and their notations.

TABLE I
SPECIMEN SPECIFICATION AND DESIGNATIONS

| S. No. | Particular | Notations | Pattern | No. of slabs |
|---|---|---|---|---|
| 1 | Control slab | CS 1 & CS 2 | - | 2 |
| 2 | Carbon fiber | CF 1 & CF 2 | Square wrapping | 2 |
| 3 | Glass fiber | GF 1 & GF 2 | Square wrapping | 2 |
| 4 | Polypropylene fiber | PPF 1 & PPF 2 | Square wrapping | 2 |

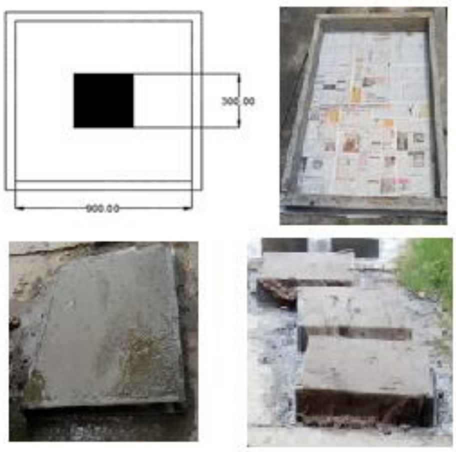


Fig. 1. Externally bonded FRP sheets, Formwork, Compacted concrete, curing of slab using gunny bags

*Retrofitting of Slab:*

*Grinding of surface:* On the slab, flexure zone is marked in both the directions and surface is grounded by grinding machine.

Application of primer coat: Primer is the mixture of two solutions, which is mainly the base and the hardener, is mixed with the same volume in a plastic cup so that it does not stick on to the metal surface. After the application, the primer is air cooled for maximum of 90 minutes.

*Application of Concresive coat:* After the air-cooling, it is checked that the primer has been fully dried and ready for the next coat, then take a board to mix the concresive paste with equal volume of base and hardener and mix the paste with a blade thoroughly and then start applying the concresive coat over the primer. After the application, the slab with concresive coat is air cooled for maximum of 90 minutes. Application of Saturant coat: After the air-cooling of the concresive coat make sure it is dried fully, now mix the saturant solution with the equal parts of base and hardener in a bucket and mix thoroughly, care has to be taken while applying the saturant since it immediately sets and hardens very soon.

*Application of fabric:* As soon as the saturant coat is applied on the surface of the slabs, the fabric should be made ready to occupy its place over the saturant. The main reason of applying the fabric immediately is because the saturant solution when mixed with base and hardener gets hard very soon and it tends to lose its adhesive power. So necessary care should be taken while applying the fabric and after application of fabric, the surface of fabric should be made pressed with the help of a roller. Application of saturant coat over a fabric: After the fabric has been laid on the saturant coat, allow it to air cool for a period of 90 minutes, and then apply the saturant coat over the fabric evenly in large amounts so that the surface of the fabric gets well bonded and then it sticks harder.

*Final finishing of surface:* After a period of 7days air-cooling, finally the retrofitted slabs are ready for testing.

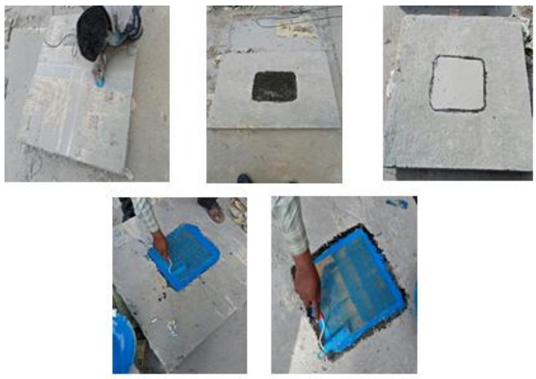

Fig. 2. Application of FRP (CFRP, GFRP, and PPFRP) sheets

## III. EXPERIMENTAL SETUP

The experimental study was conducted to test the reinforced concrete slabs. This included testing a control slab and retrofitted slabs. The test specimens i.e., reduced scale model slabs were designed as two-way slabs of 1070 mm x 1070 mm with a thickness of 90 mm and is tested under uniformly distributed load. Reinforcement of 8 mm diameter was provided along both the directions. The same testing program was applied to both controlled as well as retrofitted slabs. The setup was carried out with a 25-ton loading frame, a loading jack was fixed on top of the specimen to apply load. Totally five dial gauges were used for this experiment to measure the deflection. The placement of these dial gauges is, one at the center of the slab and other four at the supports as shown in the figure 3. The load was applied using a hand-driven lever with uniform increment up to the failure load. The dial gauge readings were noted down to calculate the deflection of the slab. The deflection was tabulated at every increment of loading. The complete crack patterns and the failure load were recorded for each specimen. The load-deflection curve has been plotted for the same.

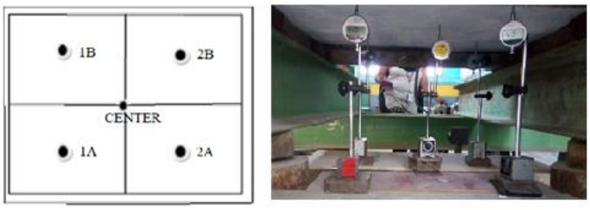


Fig. 3. Layout and positioning of dial gauges

## IV. Results and Discussion

The parameters studied are ultimate load carrying capacity, load-deflection variation and failure pattern.

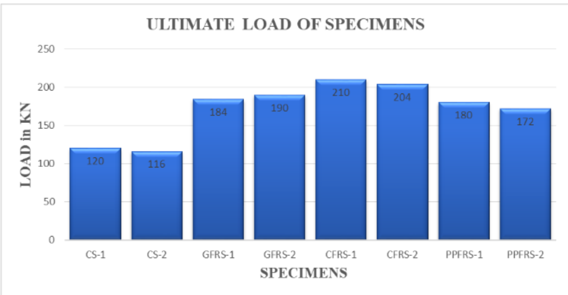


Fig. 4. Comparison of ultimate load of CFRP, GFRS, PPFRS and CS

TABLE II
ULTIMATE LOAD, MID SPAN DEFECTION OF ALL SPECIMENS

| Specimen | First crack at Load (KN ) | Ultimate (KN) | Mid Span Deflection (mm) |
|---|---|---|---|
| CS-1 | 32 | 120 | 19.972 |
| CS-2 | 20 | 116 | 18.564 |
| CFRS-1 | 92 | 210 | 11.673 |
| CFRS-2 | 96 | 204 | 10.513 |
| GFRS-1 | 52 | 184 | 12.98 |
| GFRS-2 | 56 | 190 | 13.424 |
| PPFRS-1 | 40 | 184 | 16.589 |
| PPFRS-2 | 44 | 172 | 15.789 |

The load carrying capacity of the control specimen and strengthened specimens with CFRP, GFRP and PPFRP wrapping is recorded and graph were plotted as shown in figure 4. It can be seen that the ultimate load carrying capacity of the specimen strengthened with square wrapping technique shows better performance when compare to control specimen.

The ultimate load carrying capacity of CS is 118KN whereas CFRS, GFRS and PPFRS specimen's strength increased to 210KN, 190KN and 180KN respectively. The increase in strength of CFRS, GFRS and PPFRS were found to be 75.5%, 58% and 50% respectively when compare to control specimen. Out of three materials (CFRP, GFRP and PPFRP) CFRP is giving more strength compare to GFRP, PPFRP.

Load deflection variation: The load v/s deflection variation of all slab specimen were recorded and is plotted. The mid span deflection of CFRS GFRS and PPFRS specimen were compared with control specimen. From the result, it is observed that the variation in the deflection of the strengthened slabs using CFRP GFRP and PPFRP gave the better results when compare to that of the control specimen. Figure 5 shows the comparison of average load deflection variation of the specimen CFRS GFRS and PPFRS with CS at mid span under the UDL. The failure started with the popping sound in the fiber as the load increased. The deflection of the specimen is linear up to the limit and later it increased rapidly at the ultimate load. It is observed that compare to control slab CFRS GFRS and PPFRS deflection is reduced.

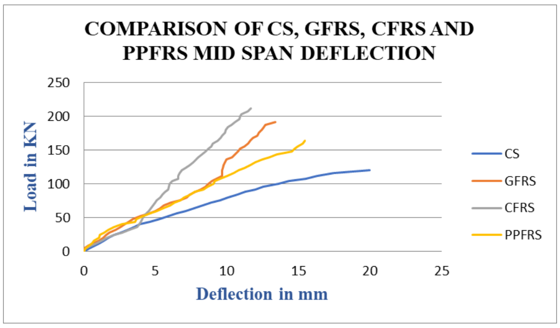


Fig. 5. Load v/s Deflection Curves for CS, CFRP, GFRP and PPFRP

## V. Conclusion

Based on the experimental results and observation the following conclusion were draw:

1. The retrofitted specimens showed appreciable increase in the load carrying capacity of the slab.
2. Deflection in strengthened slab specimen is less compared to that of control specimen.
3. All the two-way RC slabs strengthened with CFRP, GFRP and PPFRP in single layer were capable to take more load than the slab without strengthening [control slab.
4. The two-way slab strengthened using CFRP with square wrapping technique were found to be more efficient and the load carrying capacity was increased by about 75.5%.
5. The two-way slab strengthened using GFRP with the square wrapping technique were found to be more efficient and the load carrying capacity was increased by about 58%.
6. The two-way slab strengthened using PPFRP with the square wrapping technique were found to be more efficient and the load carrying capacity was increased by about 50%.
7. Ultimate load carrying capacity of CFRP is more compared to GFRP and PPFRP.

8. When compared to GFRP and PPFRP ultimate load carrying capacity of GFRP is more than PFRP.

*Scope for Further Studies:*

1. The FRP retrofitted slab specimens were analyzed under static loading conditions, they can be further analyzed under dynamic loading conditions and their behavior can be studied.
2. Higher grade of concrete and the different reinforcement percent can be selected to study to effectiveness of confinement in high strength concrete.
3. The analysis can be made by varying the percentage of the fiber.
4. The analysis can be made by varying the orientation of the fiber.
5. The analysis can be done by increasing the number of CFRP, GFRP and PPFRP layers.
6. Analytical work can be carried out using software.

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