Design Guidelines for Strengthening of RC Structures using FRP Materials – State of Art Review

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Abstract— Strengthening of RC structures using FRP (Fibre Reinforced Polymer) is been practiced all over the world There are various guidelines available for FRP in different countries stating the method of its use. This project is to develop the guidelines for strengthening of RC structures using FRP materials with reference to the other country codes and it is an empirical approach like SP16, showing various plots for moment ratio and reinforcement ratio. This is done by making a comparative study of various guidelines of various countries across the globe. Journals are collected from ASCE, ACI, ICI, RILEM, SCIENCE DIRECT etc., we work upon the flexural strength, shear strength of beams. Comparative study on, bending moment, reinforcement ratio, young's modulus of FRP and steel etc., for different loading span for various beams are to be made. From this data collection and valuations, the developed guidelines in an empirical way like SP16 for FRP will be achieved with graphs and their relations.

Key words: FRP, RC

I. Introduction

Fiber-reinforced polymer (FRP) is a composite material made of a polymer matrix reinforced with fibers. The fibers are usually glass, carbon, or aramid, although other fibers such as paper or wood or asbestos have been sometimes used. The polymer is usually an epoxy, vinylester or polyester thermosetting plastic, and phenol formaldehyde resins are still in use. FRPs are commonly used in the aerospace, automotive, marine, and construction industries.

Many countries like USA, CANADA, JAPAN, UK, AUSTRALIA, JAPAN etc., consist of the guidelines for the use of FRP materials. Each and every guideline has its specific design with respect to their own country standards. But India doesn't have a particular guideline for the usage of FRP in the construction. India uses the ACI methodology for the usage of FRP materials in construction; this is because the Americans follow a clear procedure determining the strength of material properties to the reinforcing limits. But then occurred the de-bonding issue of the FRP materials and this is faced and given a clear procedure for de-bonding stress is given by the Japanese.

This project is about deriving a design guideline for strengthening of RC structures using FRP according to Indian Standards. For this we have collected design strengthening of FRP materials out of which a graph will be plotted for any two parameter like Load and Deflection, this will be done for over 100 beams creating a database consisting of various parameters like Young's Modulus, Strain of concrete, steel and FRP, Load Span, Shear span etc., and new guideline will be suggested according to the Indian Standards.

II. FRP

Fiber-reinforced polymer (FRP) systems for strengthening concrete structures are an alternative to traditional strengthening techniques, such as steel plate bonding, section enlargement, and external post-tensioning. FRP strengthening systems use FRP composite materials as supplemental externally bonded reinforcement. FRP systems offer advantages over traditional strengthening techniques: they are lightweight, relatively easy to install, and are noncorrosive. Due to the characteristics of FRP materials as well as the behavior of members strengthened with FRP, specific guidance on the use of these systems is needed. This document offers general information on the history and use of FRP strengthening systems; a description of the unique material properties of FRP; and committee recommendations on the engineering, construction, and inspection of FRP systems used to strengthen concrete structures. The proposed guidelines are based on the knowledge gained from experimental research, analytical work, and field applications of FRP systems used to strengthen concrete structures.

III. Data collection

The data collection involves the various parameters from over 30 Journals in both flexural and shear strengthening. Various parameters like depth , breadth, length, young's modulus of concrete and FRP, compressive strength of concrete, yield strength of steel, thickness of FRP, etc., were collected. All the Journals were segregated according to their mode of failures and this project involves the plotting of graphs for the ratio of experimental moment and control beam moment against the ratio of the reinforcement of FRP and steel for flexural strengthening and graphs were plotted for the ratio of experimental shear capacity to that of the control beam shear capacity against the reinforcement ratio for shear strengthening. This tabulated data includes the paper title, author and year of publish with all the other guidelines from various countries across the Globe and also data required for the plot about 50 journals regarding the flexural and shear.

IV. Basic findings

A. *Crushing Failure:*

When the tensile steel in concrete reached its yield strength and when the compressive strain in concrete reaches 0.003, the crushing of concrete occurs. Crushing failure in FRP is a major look up and various graphs are plotted for load and deflection. It shows from the evidence of sudden appearance of a crack in the compression zone.

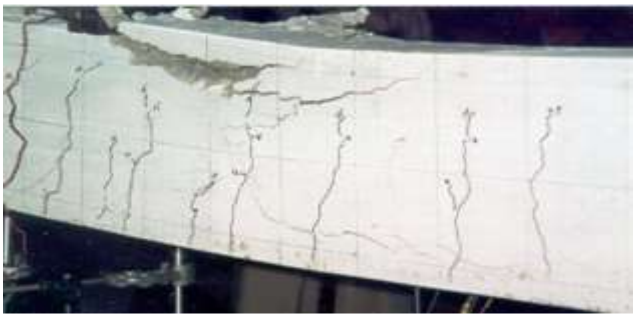
Fig. 1: Crushing failure of beam

B. Rupture Failure

The term rupture defines to the ultimate failure of the RC structure due to the failure in the tension zone. Vertical flexural cracks originating from the tensile face may occur first. The FRP is immediately torn at its most highly stressed location when its ultimate strength is reached. Rupture of the FRP then propagates along the diagonal shear crack in the concrete leading to the collapse in the member


Fig. 2: Rupture failure of beam

C. Debonding Failure:

When the FRP starts to peel off, the beam will fall quickly. The ductility of beams failing in this mode is usually very limited. De bonding failures almost always occur in the concrete at a small distance from the concrete/adhesive interface with some concrete attached to the de bonded FRP. The properties of the concrete play a key role in this failure mode.


Fig. 3: Debonding failure of beam

V. DESIGN MODELS

The design models involves the graphs plotted for crushing, rupture and de bonding failure for both flexural and shear strengthened beams. The parameters considered here is the ratio of experimental and control beam moments to that of the reinforcement ratio of FRP and steel for flexure and the ratio of experimental shear capacity and the control beam shear capacity to that of the reinforcement ratio of FRP and steel and two more graphs are plotted for different parameter keeping the y-axis same, the x- axis is the product of the reinforcement ratio of FRP to the ratio between the young's modulus of FRP and tensile strength of it. The shear capacity is calculated by their formula given in the guidelines and the moment values are calculated taking every loading spans. These eight graphs are kept one below the other and the tabulated values are also given for which the graph is plotted

A. Crushing Failure in Flexural Strengthening:

In order to plot this model data is collected from different journals and the beams failed in crushing alone are segregated. The two major parameters considered in this model is the ratio of the experimental moment, i.e., the moment of beams failed in crushing using FRP to that of the moment of the control beam i.e., the beam un-strengthened by FRP. Another parameter is the reinforcement ratio of FRP and steel.. The values for both the parameters are given below and also the calculation of reinforcement ratio follows.

$$\rho_f = A_f/bd,$$
$$\rho_s = A_s/bd$$

Where, ρ_s – Reinforcement ratio of steel, ρ_f - Reinforcement ratio of FRP

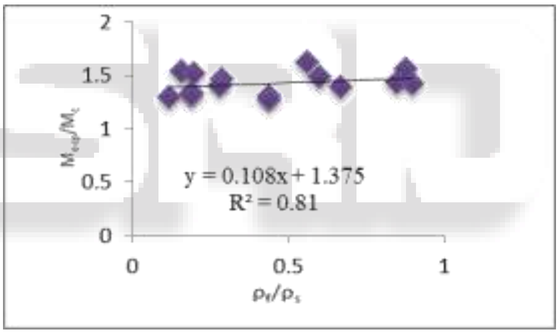

Fig. 4: Crushing Failure in Flexural Strengthening

B. Rupture Failure in Flexural Strengthening:

In order to plot this model data is collected from different journals and the beams failed in rupture alone are segregated. The two major parameters considered in this graph is the ratio of the experimental moment, i.e., the moment of beams failed in crushing using FRP to that of the moment of the control beam i.e., the beam un-strengthened by FRP. Another parameter is the reinforcement ratio of FRP and steel.

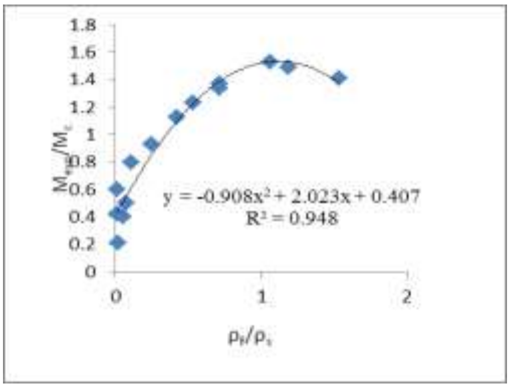

Fig. 5: Rupture Failure in Flexural Strengthening

C. Debonding Failure in Flexural Strengthening:

In order to plot this model data is collected from different journals and the beams failed in debonding alone are segregated. The two major parameters considered in this graph is the ratio of the experimental moment ,i.e., the moment of beams failed in crushing using FRP to that of the moment of the control beam i.e., the beam un-strengthened by FRP. Another parameter is the reinforcement ratio of FRP and steel.

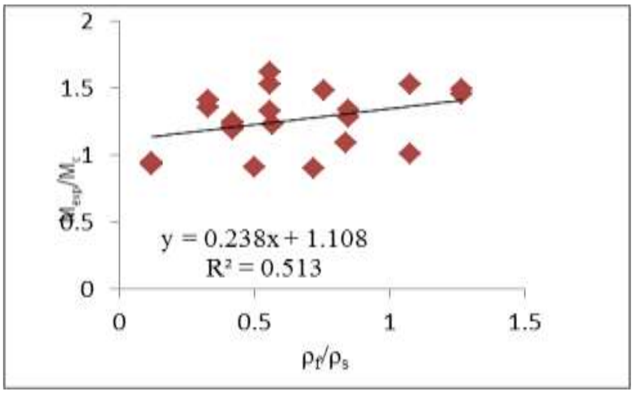

Fig. 6: Debonding Failure in Flexural Strengthening

D. Model Plotted Between $P_f\{E_f/F_{fu}\}$ and M_{exp}/M_c for Crushing Failure:

This model is also similar to the previous ones but the difference is that the y-axis parameter is the ratio of experimental moment to that of the control beam moment. The x-axis parameter is the product of the reinforcement ratio to the ratio between the young's modulus of FRP and the flexural strength of FRP. This parameter is decided because the young's modulus and the flexural strength also governs the moment

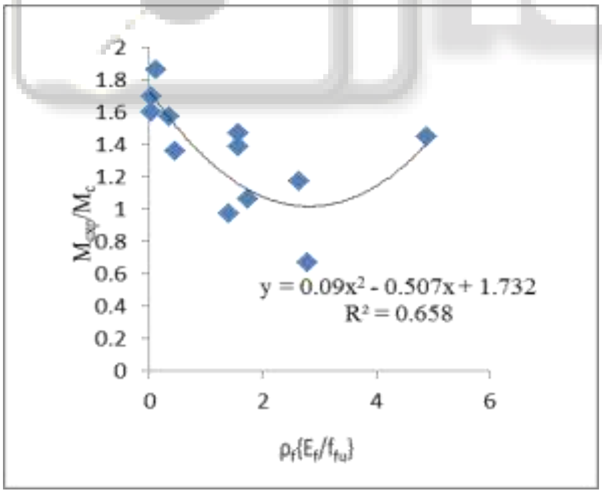

Fig. 7: Model Plotted Between Pf{Ef/Ffu} and Mexp/Mc for Crushing Failure

E. Crushing Failure in Shear Strengthening:

In order to plot this model data is collected from different journals and the beams failed in crushing alone are segregated based on the shear strengthening. The two major parameters considered in this model is the ratio of the experimental shear capacity, i.e., the shear capacity of beams failed in crushing using FRP to that of the shear capacity of the control beam i.e., the beam un-strengthened by FRP. Another parameter (x-axis) is the reinforcement ratio of FRP and steel.

$$\rho_f = A_f/bd\ ,$$
$$A_f = 2t_{frp}w_{frp}$$

where, ρ_s – Reinforcement ratio of steel
ρ_f - Reinforcement ratio of FRP
t_{frp} – Thickness of FRP
w_{frp}- width of frp

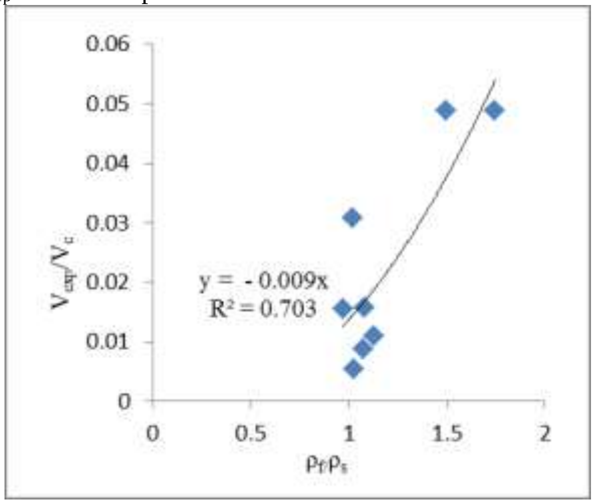

Fig. 8: Crushing Failure in Shear Strengthening

F. Rupture Failure in Shear Strengthening:

In order to plot this model data is collected from different journals and the beams failed in rupture alone are segregated based on the shear strengthening. The two major parameters considered in this model is the ratio of the experimental shear capacity, i.e., the shear capacity of beams failed in crushing using FRP to that of the shear capacity of the control beam i.e., the beam un-strengthened by FRP. Another parameter (x-axis) is the reinforcement ratio of FRP and steel.

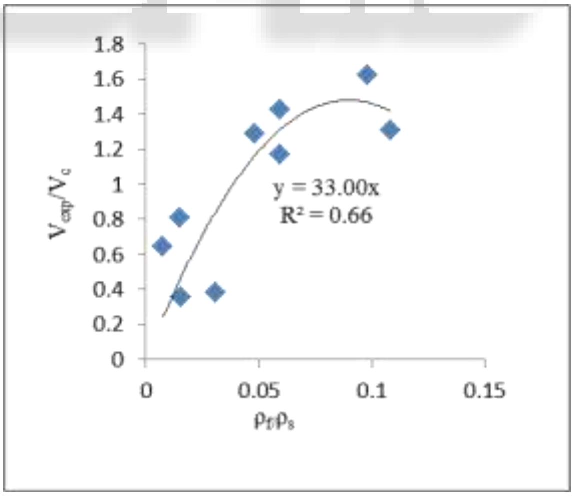

Fig. 9: Rupture Failure in Shear Strengthening

G. Debonding Failure in Shear Strengthening:

In order to plot this model data is collected from different journals and the beams failed in debonding alone are segregated based on the shear strengthening. The two major parameters considered in this model is the ratio of the experimental shear capacity, i.e., the shear capacity of beams failed in crushing using FRP to that of the shear capacity of the control beam i.e., the beam un-strengthened by FRP. Another parameter(x-axis) is the reinforcement ratio of FRP and steel

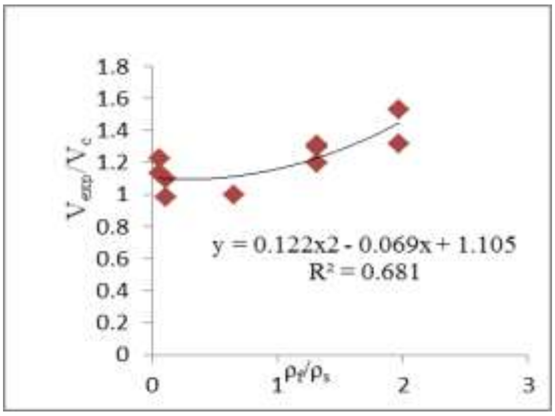

Fig. 10: Debonding Failure in Shear Strengthening

H. Model Plotted Between $P_f\{E_f/F_{fu}\}$ and V_{exp}/V_c for Rupture Failure:

This model is also similar to the previous ones but the difference is that the y-axis parameter is the ratio of experimental shear capacity to that of the control beam shear capacity and the x-axis parameter is the product of the reinforcement ratio to the ratio between the young's modulus of FRP and the flexural strength of FRP. This parameter is decided because the young's modulus and the flexural strength also governs the shear capacity and more over here the flexural strength of FRP affects the rupture failure

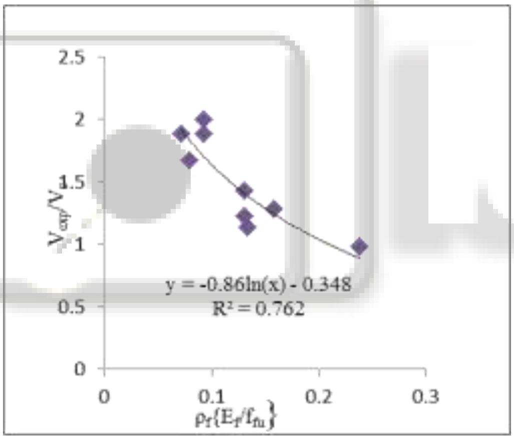

Fig. 11: Model Plotted Between Pf{Ef/Ffu} and Vexp/Vc for Rupture Failure

VI. Managerial aspects

There are various strengthening techniques been used over decades, among all those strengthening using FRP has drawn a wide attention. Application of FRP has become very popular all over the foreign countries but only in few places in India. This attention was acquired due to its various advantages like high strength to weight ratio, corrosion resistance and ease of execution. The higher cost of FRP material will be compensated or rightly to be said as , offset by reduced cost of labor, use of equipment and downtime during installation , making them more cost effective than traditional strengthening techniques. Also the original shape and size of the structural member is not altered when strengthening using FRP is adopted. Various advantages of FRP will help in reducing the cost of strengthening when compared to other processes.

VII. Conclusion

From this project we have gained more knowledge about the Fiber Reinforced Polymer, its uses and properties etc. We have collected more than 30 Journals regarding flexural strengthening and shear strengthening. We had a great opportunity to go through all the Journals and studied all the experimental works carried on.

We obtained graphs for different relation comparing the moment of control beam with that of the moment of the strengthened beams for flexural and similarly shear capacity of strengthened and un strengthened beams for shear strengthening. We went through the guide lines of more than 5 countries and compared them with their reduction factors. We obtained a graphical guideline for the experimental studies and the values can be checked and compared with the graphs which we have formed. Our product is actually formulating failure models which will be helpful in comparing these models when we perform experimental tests using FRP. This will further increase the use of FRP and also conducting many researches to evolve much more usage of composite material in India. We know that the least quoted projects are given tenders in India, but according to us projects involving effective materials which will favour various advantages, if given preference would perform well. People may think that FRP materials are costly but that will be balanced by its various advantages

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