A SURVEY ON SHEAR STRENGTHINGNING OF RC-T BEAM USING FRP

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Abstract: This paper deals with the shear strengthening of RC beams using externally bonded _EB_ fiber-reinforced polymers _FRP_. Current code provisions and design guidelines related to shear strengthening of RC beams with FRP are discussed in this paper. The findings of research studies, including recent work, have been collected and analyzed. The parameters that have the greatest influence on the shear behavior of RC members strengthened with EB FRP and the role of these parameters in current design codes are reviewed. This study reveals that the effect of transverse steel on the shear contribution of FRP is important and yet is not considered by any existing codes or guidelines. Therefore, a new design method is proposed to consider the effect of transverse steel in addition to other influencing factors on the shear contribution of FRP _*Vf*_. Separate design equations are proposed for U-wrap and side-bonded FRP configurations. The accuracy of the proposed equations has been verified by predicting the shear strength of experimentally tested RC beams using data collected from the literature. Finally, comparison with current design guidelines has shown that the proposed model achieves a better correlation with experimental results than current design guidelines.

Keywords: Bonding strength; Concrete beams; Design; Fiber-reinforced polymers.

Introduction

In recent years, an outstanding research effort has been undertaken with a view to understand the behavior of externally bonded _EB_ fiber-reinforced polymer _FRP_ used for strengthening and retrofitting concrete structures. As a result, numerous aspects of the subject have been addressed, and many codes and design guidelines _hereafter called "the guidelines"_ for concrete structures strengthened with EB FRP have been published worldwide _e.g., American Concrete Institute _ACI_ 2008; CAN/CSA 2002 -2006; *fib* 2001_. The use of FRP reinforcement for strengthening RC beams and slabs in flexure and for confinement of columns is well established.

Design values for material properties

As mentioned above, at the time of writing there are no Codes of Practice that set down the requirements for the design and execution of concrete strengthening using FRP. However, there are at least eight national guidelines that have been produced by recognised authorities and these can be accepted as state-of-the-art guidelines for the present. Nevertheless it must be recognized that the use of FRP as a strengthening medium, is a relatively new art and that research is being undertaken in many centres worldwide. The results of this research will undoubtedly cause the recommendations to be varied as experience is gained. The various FRP Design Recommendations treat the strength reduction of the FRP material in different ways. TR 55 [1] postulates that the partial safety factors to be applied to the characteristic mechanical properties are a function of the type of fibre and the manufacturing/site application process. Thus *mF mf mm* γ = γ × γ where *mf* γ depends on the type of fibre and *mm* γ depends on the manufacturing and/or site application process. Typical values are given in and *fd f* is the design value of the FRP tensile strength *fk f* is the characteristic value of the FRP tensile strength *fue* ε is the ultimate FRP strain, and *fum* ε is the mean value of the ultimate FRP strain. The values for the FRP material safety factor *f* γ. Points out that these factors are subject to further study, because of the current lack of comprehensive study. The ratio *fue* *fum* ε / ε normally equals 1.0.

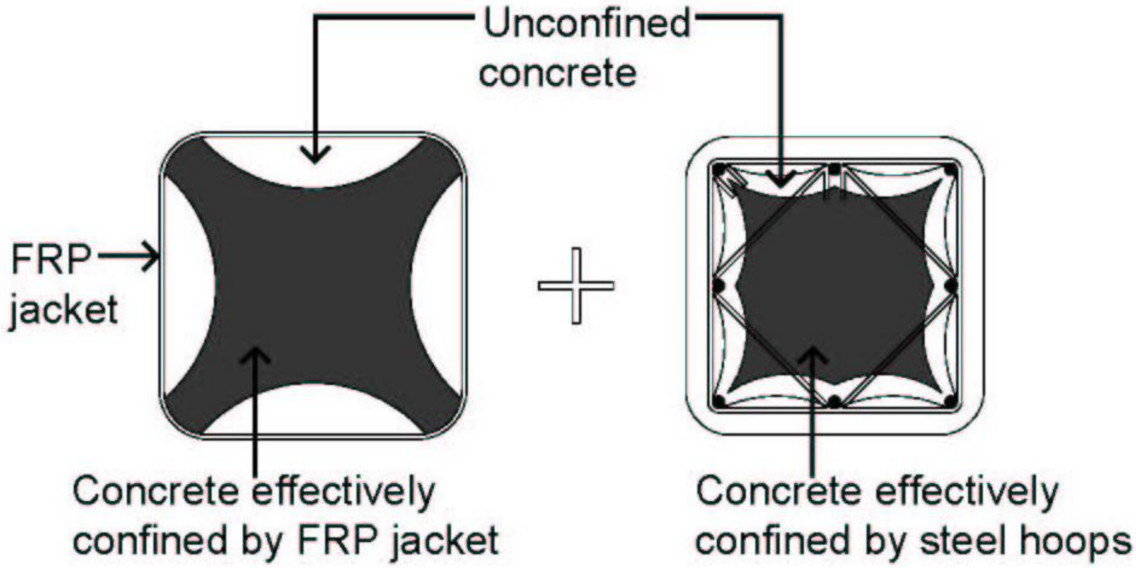

Figure-1– Dual Confinement Effect on a rectangular column with FRP jacket and internal steel hoops.

REPAIR AND STRENGTHENING TECHNIQUES FOR BEAM-COLUMN JOINS

Research on the repair and strengthening of joints included epoxy repair, removal and replacement, reinforced or prestressed concrete jacketing, concrete masonry unit jacketing or partial masonry infills, steel jacketing and/or addition of external steel elements, and fiber-reinforced polymer (FRP) composite applications. Each technique required a different level of artful detailing and consideration of labor, cost, disruption of building occupancy, and range of applicability. The main objective of the research was to establish a strength hierarchy between the columns, beams, and joints so that seismic strength and ductility demands could be accommodated through ductile beam hinging mechanisms instead of column hinging or brittle joint shear failures. In gravity load-designed structures, where beams are often stronger than columns, strengthening the column is generally not sufficient by itself since the joint then becomes the next weakest link due to either lack of transverse reinforcement, discontinuous beam bottom reinforcement, or other nonductile detailing. Thus, the shear capacity and the effective confinement of joints must be improved.

Test Setup and Procedure

The beam specimens were tested in three-point bending as shown in Fig. 1. The load was applied at a distance a ¼ 3d from the nearest support, which corresponds to the case of a slender beam in which the shear resistance is governed by the beam action mechanism (i.e., combined bending and shear stress). Hence, no extra strength due to arch action was expected.

Instrumentation

The vertical displacement was measured at the position under the applied load using linear variable differential transformers (LVDTs) 150 mm in length. The longitudinal steel reinforcement was instrumented with a strain gauge at the point load location. Strain gauges were also installed on the transverse steel located in the loading.

Design for Axial Load Enhancement

Retrofitting to enhance the axial compressive strength of concrete members using FRP material is commonly used. By wrapping a column with an FRP jacket, the shear, moment and axial load capacity, as well as the ductility, are improved. The column is wrapped with the FRP fibres in the hoop direction and this provides significant. For design purposes it is necessary to reduce the nominal concentric strength to account for variations in the materials properties, scatter in the design equation, bending of the columns, nature and on sequences of failure and reduction in load carrying capacity under long-term loads. This is done by strength reduction factors and material reduction factors. The compressive load carried by the concrete results from the loads sustained by three distinct regions, viz, the unconfined concrete region, the effective area confined by the FRP jacket and the effective area of the concrete confined by both the FRP jacket and the steel stirrups. Hence the entire uni-axial stress-strain relationship for a concentrically loaded column wrapped with an FRP jacket can be obtained if the constitutive stress-strain relationships for each of the regions and for the reinforcing steel are known. The determination of the compressive strength of the confined concrete and the evaluation of the lateral confining pressure due to the elastic jacket and internal reinforcing stirrups is then able to be calculated.

Effect of the FRP Rigidity Ratio

The FRP rigidity ratio (Rfrp) can be used to quantify the amount of FRP used for each strengthened specimen. The FRP rigidity parameter can be expressed as follows Rfrp =Afrp bw / sfrp × Efrp The effect of the FRP rigidity ratio can be observed by comparing the response of specimens S1-9d260s, S1-12d260s, and S1-12d130s. The FRP rigidity ratios for specimens S1-9d260s, S1-12d260s, and S1-12d130s are 0.26, 0.46, and 0.92 GPa, respectively

Test program

The test program consisted of a total of nine, 2.0 m long RC beams with a rectangular 200-mm · 210-mm cross-section .All beams had internal steel flexural and shear reinforcement, designed to ensure that un-strengthened and shear-strengthened beams would all fail in shear. The steel tension and compression reinforcement consisted respectively of four and two steel deformed bars with 22-mm nominal diameter. The steel shear reinforcement consisted of closed double-legged stirrups. One half of each beam starting from midspan was taken as the ‘‘test side’’, while the other half was designed as the ‘‘strong side’’. Only the test side was strengthened in shear with FRP systems and appropriately instrumented with strain gages to monitor the strain distribution in the internal steel stirrups and in the shear strengthening system, as detailed later. The amount of steel shear reinforcement in the two sides was designed to ensure present study.

Conclusions

The ETS FRP strengthening method has proven to be an effective way to increase the shear capacity of RC beams even in the presence of a limited amount of internal transverse steel reinforcement. In this study, the average increase in shear capacity was 35% for specimens retrofitted using the ETS method. • The shear contribution of FRP drastically decreased for RC beams with narrowly spaced internal steel reinforcement (series S1). The contribution of FRP to shear resistance and the gain due to FRP were significantly greater for beams with no transverse steel reinforcement (series S0) and with widely spaced internal steel reinforcement (series S3) compared with series S1. • For the rods considered in this study, FRP rods with a plain surface were more effective than sand-coated CFRP rods. The superior performance of CFRP rods with a plain surface is due to a better shear transfer between plain-finished CFRP rods and epoxy compared with that between sand-coated CFRP rods and epoxy.

Based on results of the present investigation, the following main conclusions can be drawn: – RP systems and, in particular, NSM FRP reinforcement can significantly enhance the shear capacity of RC beams also in presence of a limited amount of steel shear reinforcement. In this test program, the increase in shear capacity was about 16% for the beam strengthened with externally bonded U-wrapped laminate, and ranged between 22% and 44% for the beams strengthened with NSM reinforcement. The use of NSM reinforcement was more efficient in terms of exploitation of the FRP tensile strength due to early debonding of the externally bonded laminate; – for the beams strengthened with NSM einforcement, the failure mode was in all cases separation of the side concrete covers of the internal steel stirrups; – the use of a stiffer and stronger groove-filling epoxy and, although to a lesser extent, the use of NSM strips instead of round bars, resulted in a lower FRP contribution to the shear capacity. In both ases, the stiffer bond slip behavior of the joints induced larger peak bond stresses and accelerated the initiation of de-bonding cracks in the concrete; – due to the particular failure mode, decreasing the spacing or increasing the inclination of the bars did not benefit the shear capacity of the beam. In both cases, the reduced distance between the bars accelerated the formation of a de-bonding failure pattern involving all the bars together. Further experimental and theoretical research is needed to identify and deeply understand all the possible failure mechanisms of beams strengthened in shear with NSM reinforcement and to develop rational and accurate predictive models accounting for all these possible mechanisms.

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