Strengthening of Reinforced Concrete Structures

Dear Editor,

I refer to the above feature article by Engr Prof Dr Mohd Zamin bin Mohd Jumaat and Md Ashraful bin Alam as published in the July 2007 issue of IEM Bulletin. It is indeed an interesting introduction to all IEM readers on the current trend of using steel plate and Fibre Reinforced Polymer (FRP) for strengthening to under-reinforced concrete structures.

The paper concludes that "FRP laminate is more effective in increasing the flexural capacity of R.C. beam compared to steel plate". This conclusion, however, needs to be qualified due to lack of several objective test parameters as listed below:

a) The R.C. beam is only mentioned as 2300mm long, 125mm wide and 250mm deep. The steel reinforcement details and concrete grade are not given.
b) The method of loading (single point or two points) and support details are not given.
c) The details of the steel plate and FRP laminates (material dimensions, strength properties, method of fixing, etc) are not provided.

The paper as presented, therefore, merely serves as a qualitative confirmation that steel plates or FRP laminates can be used to enhance the load carrying capacity of existing under-reinforced R.C. beams as indicated by the particular test result for the adopted laboratory R.C. beams.

Since brittle mode of failure was reported for the two (2) strengthened R.C. beams, it must be assumed that both of them would have been over-reinforced in terms of flexural tensile capacity. Therefore, extreme care should be exercised by engineers to carry out proper evaluation and analysis to determine the manner and extent of such external strengthening to existing R.C. beams.

By: Engr. Tham Kum Weng (F01513)

Response from Authors

Dear Editor,

We are referring to the comments made by Engr. Tham Kum Weng (F01513) on our papers entitled 'Strengthening of reinforced concrete structures' which was published in the July issue of the monthly bulletin of The Institution of Engineers, Malaysia, JURUTERA.

Firstly, we would like to thank Engr. Tham for the positive and constructive comments. We agree with his comment in the summary of the paper which is 'FRP laminate is more effective in increasing the beam strength compared to steel plate'. The reason for this is because the paper only highlighted a few aspects of the full study due to space constraint. The full study, however, is reported in the Master of Engineering's thesis of the second author*. To provide more details of the study, we summarised the objective test parameters as required.

Details of steel reinforcement

For the fabrication of beams, three types of steel bars were used in this research. Two 12mm diameter high yield deformed bars were used as the flexural (tensile) reinforcement. The measured yield and tensile strength of the bars were 551MPa and 641MPa respectively. 10mm diameter plain bars were used as the hanger bars in the shear span zone. A 6mm diameter plain bar was used for stirrups. The spacing of the stirrups was 75mm centre to centre and it was only used in the shear span zone.

Concrete properties

The average concrete strength (cube) of beams A1, B1 and C1 are 35MPa, 40MPa and 38MPa respectively.

Support details and methods of loading

First, the beam was lifted and placed onto two rubber support leaving 150mm length of beam at both ends so that the beam was simply supported with a span of 2,000mm. The hardness of the rubber pad was 90 durometer. The spreader beam was placed on the top surface of the beam providing two-point loads of 700mm spacing at the mid-span of the beam. All tests were conducted using a closed-loop hydraulic Instron Universal Testing Machine 8505.

The machine was capable of both displacement and load control for monotonic and cyclic loading. For all beams, the load was applied at 5.0kN increment up to 70kN in a load controlled manner and then it was shifted to the displacement control mode up to the failure of the test beams. The combination of the loading modes allows the full history of failure behaviour to be recorded. The readings for deflections, steel and concrete strains were read from a data logger.

Strengthening materials

For beam strengthening, mild steel plates and CFRP laminates (Sika CarboDur S812) were used. Steel plates were 1,900mm long with a cross section of 2.76mm x 73mm, CFRP laminates Sika CarboDur S812 were of 1,900mm long with a cross section of 1.2mm x 80mm. The yield strength, tensile strength and modulus of elasticity of the steel plates were 320MPa, 375MPa and 200GPa respectively, whereas the tensile strength and modulus of elasticity of CFRP laminates were of 2,800MPa and 165GPa respectively. The design and ultimate strain of CFRP laminates were obtain from the experiment's data and test 0.85% and 1.7% respectively.

Application of plates to beam specimens

Proper concrete surface treatment prior to plating works has a significant effect in guaranteeing a perfect bonding between the concrete and the strengthening plates. For perfect bonding, the concrete surface was first grounded using a diamond cutter to expose the coarse aggregates. Concrete dust was then blown out using an air compressor. The surface of the steel plate was also sand blasted to expose the original texture of the steel and to eliminate any rust. Dust on the steel and carbon plates was removed using acetone. After the surface treatment, a putty was applied to fill the cavities or holes on the concrete surface.

The well mixed sikadur (an adhesive produced by Sika) was then trowelled onto the surface of the concrete specimens to form a thin layer. It was also applied onto the steel plate and CFRP laminate using a special dome-shaped spatula. The thickness of the applied sikadur ranged from 2mm to 3mm in line with the varying roughness of the beam's surface. The strengthening plates were then placed onto the prepared surface. Using a rubber roller, the plates were then gently pressed into the adhesive until the material was forced out on both sides of the laminates. The surplus adhesive was then removed.

On the second query on the strengthened r.c. beams, beams being over-reinforced in terms of flexural tensile capacity. Our explanation is as below,

All strengthened beams were designed as under-reinforced r.c. beams. This was done by limiting the tensile strength of the strengthening plates so that the beams will fail in tension. However, though these beams were under-reinforced, they were observed to fail in a brittle manner. This occurred because of 'debonding' of the strengthening plates at the time of failure. This debonding failure initiated from the shear cracks which occurred starting from the end of the strengthening plate.

Excessive shear and normal stress developed near the end of the plate due to discontinuity of the plate. When the shear stress exceeded the shear resisting capacity of the concrete, a shear crack would occur. Due to this shear crack, the strengthening plate is debonded either at the level of the internal reinforcement or at the level of the bonding interface. Both of these debonding failure modes were found to be sudden and brittle. ■

*Alam, M. A. (2006), 'Behaviour of flexurally strengthened r.c. beams using externally bonded plates and anchorages', Master of Engineering's Thesis, University of Malaya.

Editor's Note:

We wish to thank both the authors for their interesting and informative contributions to share their constructive discussions with IEM Members and readers of IEM Bulletin. This shows the maturity in having good technical discussions on interesting topics which can benefit the engineering fraternity through such information dissemination.

Thank You – Chief Editor