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Laboratory Investigation on Performance of Strengthening Techniques of RCC Beam

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Abstract Reinforced concrete members are the most abundantly used construction elements in civil engineering. These members are normally designed to sustain various types of loads. But due to several reasons the members experience much more load beyond their capacity. Inadequate attention during design and construction of new additional RCC story in our country has raised question about the performance of existing structures. RCC beam is such an important member which sometimes needs to be strengthened. There are various methods of strengthening that have been studied by the researchers such as section enlargement, use of additional bars, use of FRP and CFRP, use of ferrocement, steel plates, etc. This thesis work aims to study and compare the effect of three distinct strengthening techniques- providing additional steel bars from underneath with U shaped shear reinforcement, use of wire mesh and providing single layer of geo-textile with adhesive. The experimental results show that the percentage increase in ultimate load carrying capacity for the steel, wire mesh and geo-textile were found to be 51.96%, 26.5% and 14.5% respectively with respect to reference beams. The value of deflection at failure were 5.63mm, 6.18mm and 5.83 mm respectively while for reference beam the value was 5.33mm. The performance of geo-textile was very poor. The use of wire mesh provides greater value of deflection at failure compared to other two methods but the increase in load carrying capacity is about half of that for steel bar. The application of additional steel is labor intensive compared to other two methods but in terms of ultimate load, it overweighs the advantages compared to other two strengthening techniques.

Keywords: *strengthening, repairing, additional steel, wire mesh, geo-textile*

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1. Introduction

Reinforced concrete beam is the most important element that resists the load in flexure. If this member is not designed properly, some problems, such as excessive deflection, flexural and shear failure as well as materials degradation may occur. Strengthening and repairing of degenerated reinforced beams is therefore being call for on a large scale and there is requirement for designing and devising method of sound and foolproof repair or retrofitting operations. During the previous decade, fiber-reinforced polymers (FRP) have been widely used to improve flexural and shear capacity of rein- forced concrete (RC) beams and columns. Benefits and peculiarities of the effects of FRP application on RC structures have been deeply investigated, both experimentally and theoretically [1,2]. Cementitious matrix indeed exhibits significant heat resistance, allows vapor permeability, and can be applied at low temperatures or on wet surfaces [1]. In recent years, the easy handling and speedy repairing technique, with numerous advantages, are making the wrapping system of locally available wire mesh jackets the preferred technique for the repair and strengthening of a large number of projects. It has been found previously that wire mesh jacket can provide an effective confinement of reinforced concrete beams and therefore, it has a great potential to be used as a strengthening material. Although it is labor intensive, the workmanship required for the fabrication of wire mesh is fairly low level and its constituents are typically locally available. It has been found that use of ferrocement is advantageous in terms of enhancement of load carrying capacity [3], better cracking behavior, ductility, energy absorption properties, stiffness and flexural capacity [8]. Furthermore, additional metallic glass ribbon fibers in sprayed concrete improved the crack pattern and ultimate capacity of RC beams. Adding metallic glass ribbon fibers to reinforced concrete beams improved flexural strength, enhanced cracking pattern, reduced tensile stress and greatly increased the first cracking moment [4]. Exposing and undercutting of reinforcing steel is applicable to horizontal, vertical, or overhead locations. They are also applicable to removal by hydro-demolition, hydro-milling, and electric, pneumatic or hydraulic impact breakers [5].

Depending on the specific conditions of deteriorated structure, the option of the strengthening method could be one or more of the following: Grouting and crack repair, patch repair, replacement of structurally weak concrete, replacement of carbonated concrete surrounding steel reinforcement, water proofing and/or protective coating, section enlargement and concrete jacketing, e.g., reinforced concrete jackets, external reinforcement, e.g., external tendons, external steel reinforcement, e.g., web-bonded continuous steel plates, un-bonded type, e.g., wire rope units, concrete repair, e.g., epoxy injection, use of ferrocement, using different type of fiber such as FRP or CFRP laminates, etc. [5,10].

The use of special chemical adhesives anchored to the bars into two pieces and welded them together in the soffit level of beams significantly decreased the width of cracks, deflections, and the moment carrying capacity was increased compared to un-retrofitted beams [6]. Use of sprayed concrete to strengthen reinforced concrete beams can effectively increase their load carrying capacity or stiffness. Again, the use of small amount of steel reinforcement dramatically increases the load carrying of RC beams [7].

It may even lead to failure of RC section in a ductile manner, if a beam is designed for steel above the balanced reinforcement percentage [9]. Ferrocement is also known to be a forgiving material and can, therefore, sustain varying atmospheric conditions satisfactorily. It can also sustain abuses due to lesser skill of rural workers in comparison to other construction techniques [9]. Performance of chicken wire-mesh has been found to be better than any other type in terms of cracking resistance and bending moment, whereas cover thickness has a significant influence on the static moment capacity, flexural fatigue life, crack spacing and width, based on theoretical and experimental studies [9]. Jacketing by reinforced concrete could improve resistance against applied loads and enhances the durability at same time. Furthermore, section enlargement and concrete jacketing maybe easier and cheaper compared to other approaches such as steel plate jacketing [10]. Similar to section enlargement method concrete jacketing can be easy, effective and inexpensive technique to rehabilitate and strengthen concrete structures. Retrofit of RC beams can be achieved by adding external longitudinal reinforcement to the RC beams in order to increase their load carrying capacities. This method can overcome many drawbacks of other methods. It is inexpensive and easy to execute [10].

Geo-textiles are made from poly- propylene, polyester, polyethylene, polyamide (nylon), polyvinylidene chloride, and fiberglass and they have got some tensile properties. Taking into account their tensile characteristics, their behavior under load is needed to be studied. That's why this material is used for flexural strengthening of beams in this experimental study. This work aims to investigate and compare the effect of additional steel bars with U shaped stirrup, wire mesh confinement and the use of geo-textiles in the strengthening of reinforced concrete beams under loading condition.

2. Experimental Program

2.1. Materials

Proportioning of concrete was performed according to the ACI 211.1 standard volumetric proportioning method. The concrete mix for every specimen was based on the mix design and desired strength of concrete was 23 MPa. The weight portion of the concrete mixture was 1 (cement): 2.75 (sand): 3.25 (stone) by volume, giving a w/c ratio of 0.51 by weight.

Compressive strength of concrete after 28 days was found 21.5 MPa using cylinder of diameter 100 mm and height 200 mm.

2.1.1. Specimen Details

There were four sets of beams each including 3 beams. The first set was considered as reference beam and other three sets were to be strengthened in three distinct methods. The section of beams was 115mm * 150mm and the length was 900mm as shown in Figure 1.

2.1.2. Test of Reference Beam

The reference beams (RB) were tested in Universal Testing Machine (UTM) under two-point loading until failure. The beam was simply supported as shown in Figure 2. The value of load in KN and corresponding from dial gauge were recorded at 1KN load increment.

2.1.3. Strengthening with Geo-textile

One single layer of geo-textile was provided at the bottom and in critical shear zone of first set of beams denoted as GB where G stands for Geo-textile. Synthetic rubber based adhesive was used to attach the geo-textile with the beam. Then the beams were kept for about 24 hours and tested in UTM machine in the same manner as used for reference beams. The testing arrangement of strengthening of beam with geo-textile is shown in Figure 3. The values of load and corresponding deformation were recorded.

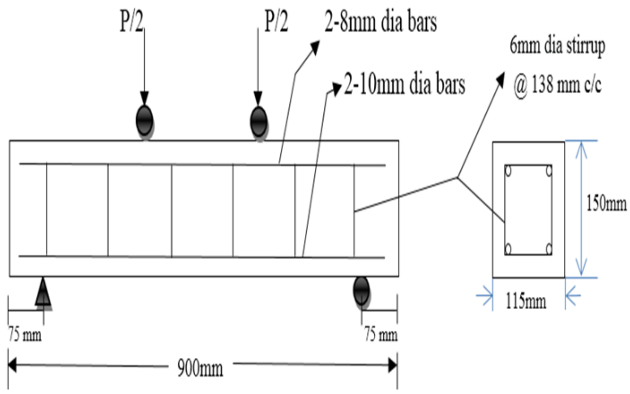

Figure 1. Geometry and sectional details of test specimen

Figure 2. Reference beam (RB) under testing

Figure 3. Testing of beams strengthened with geo-textile

Figure 4. Beam strengthened with wire mesh under testing with failure pattern

2.1.4. Strengthening with Wire Mesh

Another set of beam was strengthened by applying wire mesh (WB) along with a half inch thick cement-sand mortar on three sides. The mesh was set on the beam, a mortar with cement/sand ratio 1:1.5 and w/c ratio of 0.35 by weight was applied over the mesh. The samples were then kept in water for 14 days for curing and then tested shown in the Figure 4.

2.1.5. Strengthening with Additional Steel Bars (SB)

At first, the bottom 3" concrete was removed using hammer. The 10mm diameter reinforcing main bar in tensile zone and the exposed shear reinforcements were cleaned. The exposed surface was kept rough for better bonding with new concrete. Then two additional 10mm diameter bars were attached below the existing bars with 6mm diameter U shaped stirrups to all the three samples. A clear spacing of 25mm was maintained between the existing bars and attached bars. Finally, casting concrete was poured over the exposed reinforcement. Then, the samples were cured under water for 28 days and tested until failure as shown in Figure 5.

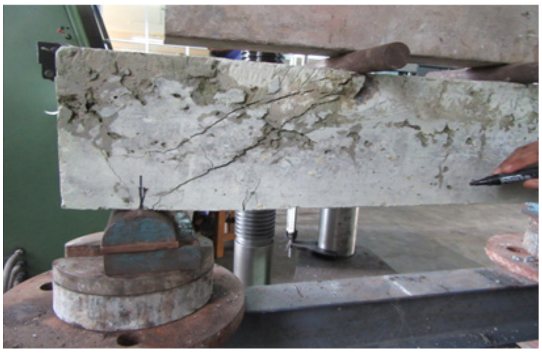

Figure 5. Testing of beam with additional steel bars and its failure pattern

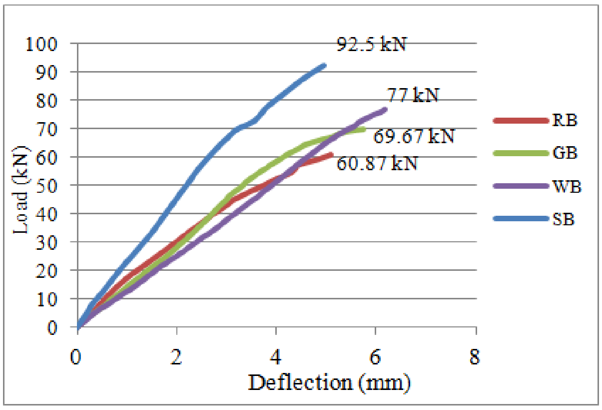

Figure 6. Load-Deflection curve of different tested beam sample

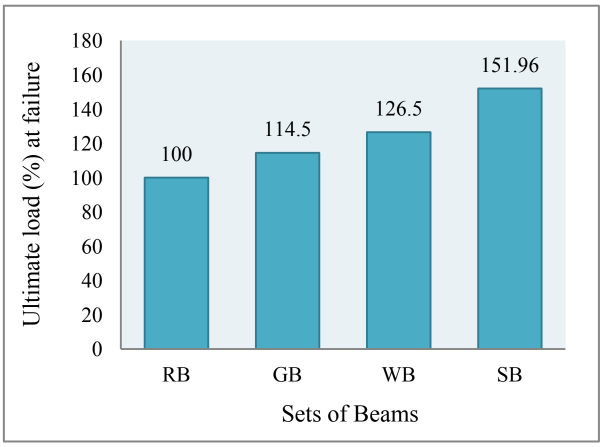

Figure 7. Comparison of ultimate load

2.1.6. Comparison of Test Results

Following graph includes average of load vs. deflection curves of all four sets of beams:

The graph in Figure 6 and bar diagram in Figure 7 shows the load-deflection curve and ultimate failure load of different specimen. It is found from the mentioned figures that the ultimate load is slightly increased (14.5%) in the beams strengthened with geo-textile and the value is 69.67kN. For wire mesh, the value is greater and the increase in ultimate load is almost double (26.5%) compared to that of geo-textile. But the highest value was obtained from additional steel bar in tensile zone. The average value of ultimate load for this set is 92.5kN which 51.96% greater than that of reference beam.

Though the ultimate load is higher for SB group, maximum value of deflection (6.18mm) was obtained in the set of WB. It indicates that wire mesh will provide sufficient warning before failure compared with other two methods. Again the value of deflection for GB group (5.83mm) is also greater than that of SB (5.63mm) but the ultimate load is too small.

2.1.7. Conclusion

The flexural strength of simply supported RCC beams is greatly influenced by the addition of extra tensile bars. This increased the capacity of original beam by 51.96%. But it is labour intensive. In that case wire mesh application may be preferred. The contribution of wire mesh was almost half of that for steel bar. It provided extra 26.5% extra flexural strength and greater deflection at failure (6.18mm). Application of wire mesh in multiple layers (or at least two layers) will provide much more strength to the beam and the depth of the beam will increase only by a few inches compared to that for steel. The action of geotextiles was not quite satisfying as those twos though it also increased the flexural strength by 14.5%. Epoxy based adhesive should be used with geotextile or any other fibers to be applied for better performance. Geotextile has no fire resistance so a suitable coating should be provided to resist fire to some degree if necessary. The mode of failure of steel strengthened beams was shear failure and flexure-shear failure. This might be the effect of larger depth over short span. But for wire mesh flexural failure was dominating. Geotextile neither increases the depth nor the width of concrete section considerably so its failure mode was also alike reference beam.

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