Experimental and Analytical Study on Torsional Behaviour of RC Flanged Beams Strengthened with Glass FRP

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Abstract: **Environmental degradation, increased service loads, reduced capacity due to aging, degradation owing to poor construction materials and workmanships and conditional need for seismic retrofitting have demanded the necessity for repair and rehabilitation of existing structures. Fibre reinforced polymers has been used successfully in many such applications for reasons like low weight, high strength and durability. Many previous research works on torsional strengthening were focused on solid rectangular RC beams with different strip layouts and different types of fibres. Various analytical models were developed to predict torsional behavior of strengthened rectangular beams and successfully used for validation of the experimental works. But literature on torsional strengthening of RC T- beam is limited. In the present work experimental study was conducted in order to have a better understanding the behavior of torsional strengthening of solid RC flanged T-beams. An RC T-beam is analyzed and designed for torsion like an RC rectangular beam; the effect of concrete on flange is neglected by codes. In the present study effect of flange part in resisting torsion is studied by changing flange width of controlled beams. The other parameters studied are strengthening configurations and fiber orientations. The objective of present study is to evaluate the effectiveness of the use of epoxy-bonded GFRP fabrics as external transverse reinforced to reinforced concrete beams with flanged cross sections (T-beam) subjected to torsion. Torsional results from strengthened beams are compared with the experimental result of the control beams without FRP application. The study shows remarkable improvement in torsional behavior of all the GFRP strengthens beams. The experimentally obtained results are validated with analytical model presented by A.Deifalla and A. Ghobarah and found in good agreement.**

I. INTRODUCTION

Modern civilization relies upon the continuing performance of its civil engineering infrastructure ranging from industrial buildings to power stations and bridges. For the satisfactory performance of the existing structural system, the need for maintenance and strengthening is inevitable. During its whole life span, nearly all engineering structures ranging from residential buildings, an industrial building to power stations and bridges faces degradation or deteriorations. The main causes for those deteriorations are environmental effects including corrosion of steel, gradual loss of strength with ageing, variation in temperature, freeze-thaw cycles, repeated high intensity loading, contact with chemicals and saline water and exposure to ultra-violet radiations. Addition to these environmental effects earthquakes is also a major cause of deterioration of any structure. This problem needs development of successful structural retrofit technologies. So it is very important to have a check upon the continuing performance of the civil engineering infrastructures. The structural retrofit problem has two options, repair/retrofit or demolition/reconstruction. Demolition or reconstruction means complete replacement of an existing structure may not be a cost-effective solution and it is likely to become an increasing financial burden if upgrading is a viable alternative. Therefore, repair and rehabilitation of bridges, buildings, and other civil engineering structures is very often chosen over reconstruction for the damage caused due to degradation, aging, lack of maintenance, and severe earthquakes and changes in the current design requirements.

II. TORSIONAL STRENGHTENING OF BEAMS

Early efforts for understanding the response of plain concrete subjected to pure torsion revealed that the material fails in tension rather than shear. Structural members curved in plan, members of a space frame, eccentrically loaded beams, curved box girders in bridges, spandrel beams in buildings, and spiral stair-cases are typical examples of the structural elements subjected to torsional moments and torsion cannot be neglected while designing such members. Structural members subjected to torsion are of different shapes such as T-shape, inverted L–shape, double T-shapes and box sections. These different configurations make the understanding of torsion in RC members of complex task. In addition, torsion is usually associated with bending moments and shearing forces, and the interaction among these forces is important. Thus, the behaviour of concrete elements in torsion is primarily governed by the tensile response of the material, particularly its tensile cracking characteristics. Spandrel beams, located at the perimeter of buildings, carry loads from slabs, joists, and beams from one side of the member only. This loading mechanism generates torsional forces that are transferred from the spandrel beams to the columns. Reinforced concrete (RC) beams have been found to be deficient in torsional capacity and in need of strengthening. These deficiencies occur for several reasons, such as insufficient stirrups resulting from construction errors or inadequate design, reduction in the effective steel area due to corrosion, or increased demand due to a change in occupancy. Similar to the flexure and shear strengthening, the FRP fabric is bonded to the tension surface of the RC members for torsion strengthening. In the case of torsion, all sides of the member are subjected to diagonal tension and therefore the FRP sheets should be applied to all the faces of the member cross section.

III. CASTING OF SPECIMENS

For conducting experiment, eleven reinforced concrete beam specimen of size as Shown in the fig (Length of main beam (L) = 1900mm, Breadth of main beam(bw) = 150mm, Depth of main beam(D) = 270mm, Length of cantilever parts = 400mm, Width of cantilever part= 200mm, Depth of cantilever part= 270mm, Distance of cantilever part from end of the beam= 350mm) and all having the same reinforcement detailing are cast. The mix proportion is 0.5: 1:1.67:3.3 for water, cement, fine aggregate and course aggregate is taken. The mixing is done by using concrete mixture. The beams were cured for 28 days. For each beam three cubes, two cylinders and two prisms were casted to determine the compressive strength of concrete for 28 days.

4.1 Fiber Reinforced Polymer (FRP)

Continuous fiber reinforced materials with polymeric matrix (FRP) can be considered as composite, heterogeneous, and anisotropic materials with a prevalent linear elastic behaviour up to failure. Normally, Glass and Carbon fibers are used as reinforcing material for FRP. Epoxy is used as the binding material between fiber layers For this study, GFRP sheet was used during the tests i.e., a bidirectional FRP with the fiber oriented in both longitudinal and transverse directions, due to the flexible nature and ease of handling and application, the FRP sheets are used for torsional strengthening. Throughout this study, E-glass was used manufactured by Owens Corning.

4.2 Epoxy Resin

The success of the strengthening technique primarily depends on the performance of the epoxy resin used for bonding of FRP to concrete surface. Numerous types of epoxy resins with a wide range of mechanical properties are commercially available in the market. These epoxy resins are generally available in two parts, a resin and a hardener. The resin and hardener used in this study are Araldite LY 556 and hardener HY 951 respectively.

IV. CASTING OF GFRP PLATE FOR TENSILE STRENGTH

There are two basic processes for moulding, that is, hand lay-up and spray-up. The hand lay-up process is the oldest, simplest, and most labour intense fabrication method. This process is the most common in FRP marine construction. In hand lay-up method liquid resin is placed along with reinforcement (woven glass fiber) against finished surface of an open mould. Chemical reactions in the resin harden the material to a strong, light weight product. The resin serves as the matrix for the reinforcing glass fibers, , much as concrete acts as the matrix for steel reinforcing rods. The percentage of fiber and matrix was 50:50 by weight.

The following constituent materials are used for fabricating the GFRP plate:

i. Glass FRP (GFRP)
ii. Epoxy as resin
iii. Hardener as diamine (catalyst)
iv. Polyvinyl alcohol as a releasing agent

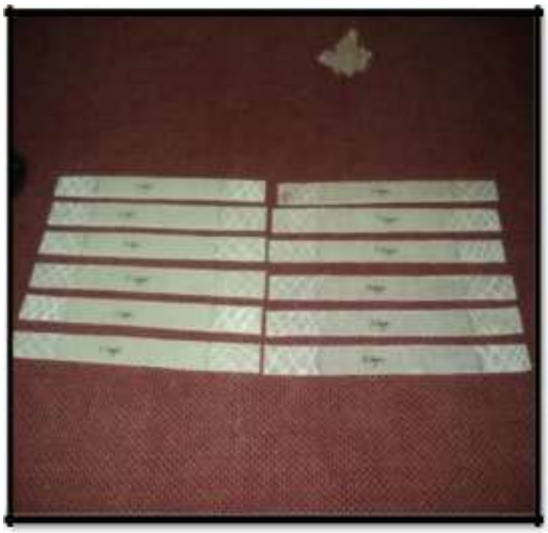

Figure 1 Specimens for Tensile Testing of Woven Glass/Epoxy Composite

Figure 2 Experimental Setup of INSTRON (UTM)

Figure.3 Specimen During Testing

V. STRENGTHENING OF BEAMS

At the time of bonding of fiber, the concrete surface is made rough using a coarse sand paper texture and then cleaned with an air blower to remove all dirt and debris. After that the epoxy resin is mixed in accordance with manufacturer's instructions. The mixing is carried out in a plastic container (100 parts by weight of Araldite LY 556 to 10 parts by weight of Hardener HY 951). After their uniform mixing, the fabrics are cut according to the size then the epoxy resin is applied to the concrete surface. Then the GFRP sheet is placed on top of an epoxy resin coating and the resin is squeezed through the roving of the fabric with the roller. Air bubbles entrapped at the epoxy/concrete or an epoxy / fabric interface are eliminated. During hardening of the epoxy, a constant uniform pressure is applied to the composite fabric surface in order to extrude the excess epoxy resin and to ensure good contact between the epoxy, the concrete and the fabric. This operation is carried out at room temperature. Concrete beams strengthened with glass fiber.

VI. FAILURE MODES

Different failure modes have been observed in the experiments .These include torsional shear failure due to GFRP rupture and debonding .Rupture of the FRP strips is assumed to occur if the strain in the FRP reaches its design rupture strain before the concrete reaches its maximum usable strain. GFRP debonding can occur if the force in the FRP cannot be sustained by the substrate. Load was applied on the two moment arm of the beams which is 0.375m away from the main beam. At each increment of the load, deflections at L/3, L/2 and 2L/3 were observed and noted down with the help of six nos. of dial gauges. At each section two dial gauges were fixed to measure the displacement caused by twisting moment. The relative displacements divided by distance between dial gauges gives angle of twist. Section at L/3 was taken as sec-1, section at middle of beam as taken as sec-2, and section at 2L/3 was taken as section 3.The loading arrangement was same for all the beams.

VII. SCOPE OF THE PRESENT WORK

The objective of present study is to evaluate the effectiveness of the use of epoxy-bonded GFRP fabrics as external transverse reinforced to reinforced concrete beams with flanged cross sections (T-beam) subjected to torsion. Torsional results from eight strengthened beams are compared with the experimental result of 3 control beams without FRP applications. The following FRP configurations are examined

1. Completely wrapped T-beams with discrete FRP strip around the cross section making 900with longitudinal axis of beam.
2. Completely wrapped T-beams with discrete FRP strip around the cross section making 450 with longitudinal axis of the beam.
3. U-jacketed T- beam with discrete FRP strip bonded on web of the beam and bottom sides of the flange.
4. U-jacketed T- beam with discrete FRP strip bonded on web to bottom sides of the flange and anchored with the FRP stirs on top of the flange. An RC T-beam is analyzed and designed for torsion like an RC rectangular beam; the effect of concrete on flange is neglected by codes. In the present study effect of flange part in resisting torsion is studied by changing flange width of controlled beams. Three beams with varying flange widths designed to fail in torsion are cast and tested to complete failure. Their performances are compared with respect to a rectangular beam of same depth and web thickness.

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