Experimental and Analytical Study on Torsional Behavior 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 strengthen beams. The experimentally obtained results are validated with analytical model presented by A.Deifalla and A. Ghobarah and found in good agreement.** **Keywords: Adaptive Control, Low Voltage Ride Through (LVRT), Photovoltaic (PV) Power Systems, Power System Control, Power System Dynamic Stability.**

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. Previously, the retrofitting of reinforced concrete structures, such as columns, beams another structural elements, was done by removing and replacing the low quality or damaged concrete or/and steel reinforcements with new and stronger material. However, with the introduction of new advanced composite materials such as fiber reinforced polymer (FRP) composites, concrete members can now be easily and effectively strengthened using externally bonded FRP composites Retrofitting of concrete structures with wrapping FRP sheets provide a more economical and technically superior alternative to the traditional techniques in many situations because it offers high strength, low weight, corrosion resistance, high fatigue resistance, easy and rapid installation and minimal change in structural geometry. In addition, FRP manufacturing offers a unique opportunity for the development of shapes and forms that would be difficult or impossible with the conventional steel materials. Although the fibers and resins used in FRP systems are relatively expensive compared with traditional strengthening materials, labour and equipment costs to install FRP systems are often lower. FRP systems can also be used in areas with limited access where traditional techniques would be impractical. Several investigators took up concrete beams and columns retrofitted with carbon fiber reinforced polymer (CFRP) glass fiber reinforced polymer (GFRP) composites in order to study the enhancement of strength and ductility, durability, effect of confinement, preparation of design guidelines and experimental investigations of these members. The results obtained from different investigations regarding enhancement in basic parameters like strength/stiffness, ductility and durability of structural members retrofitted with externally bonded FRP composites, though quite encouraging, still suffers from many limitations. This needs further study in order to arrive at recognizing FRP composites as a potential full proof structural additive. FRP repair is a simple way to increase both the strength and design life of a structure. Because of its high strength to weight ratio and resistance to corrosion, this repair method is ideal for deteriorated concrete structure.

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. However, it is not always possible to provide external reinforcement for all the surfaces of the member cross section. In cases of inaccessible sides of the cross section, additional means of strengthening has to be provided to establish the adequate mechanism required to resist the torsion. The effectiveness of various wrapping configurations indicated that the fully wrapped beams performed better than using FRP in strips.

REVIEW OF LITERATURE

Externally bonded, FRP sheets are currently being studied and applied around the world for the repair and strengthening of structural concrete members. Strengthening with Fiber Reinforced Polymers (FRP) composite materials in the form of external reinforcement is of great interest to the civil engineering community. FRP composite materials are of great interest to the civil engineering community because of their superior properties such as high stiffness and strength as well as ease of installation when compared to other repair materials. Also, the non-corrosive and nonmagnetic nature of the materials along with its resistance to chemicals made FRP an excellent option for external reinforcement.

Research on FRP material for use in concrete structures began in Europe in the mid 1950's by Rubinsky and Rubinsky, 1954 and Wines, J. C. et al., 1966. The pioneering work of bonded FRP system can be credited to Meier (Meier 1987); this work led to the first on-site repair by bonded FRP in Switzerland (Meier and Kaiser 1991).Japan developed its first FRP applications for repair of concrete chimneys in the early 1980s (ACI 440 1996).By 1997 more than 1500 concrete structures worldwide had been strengthened with externally bonded FRP materials. Thereafter, many FRP materials with different types of fibres have been developed. FRP products can take the form of bars, cables, 2-D and 3-D grids, sheet materials and laminates. With the increasing usage of new materials of FRP composites, many research works, on FRPs improvements of processing technology and other different aspects haven been performed.

Though several researchers have been engaged in the investigation of the strengthened concrete structures with externally bonded FRP sheets/laminates/fabrics, no country yet has national design code on design guidelines for the concrete structures retrofitted using FRP composites. However, several national guidelines (The Concrete Society, UK: 2004; ACI 440:2002; FIB: 2001; ISIS Canada: 2001; JBDPA: 1999) offer the state of the art in selection of FRP systems and design and detailing of structures incorporating FRP reinforcement. On the contrary, there exists a divergence of opinion about certain aspects of the design and detailing guidelines. This is to be expected as the use of the relatively new material develops worldwide. Much research is being carried out at institutions around the world and it is expected that design criteria will continue to be enhanced as the results of this research become know in the coming years.

Several investigators like Saadatmanesh et al., (1994); Shahawy, (2000) took up FRPstrengthened circular or rectangular columns studying enhancement of strength and ductility, durability, effect of confinement, preparation of design guidelines and experimental investigations of these columns.

Saadatmanesh et al. (1994) studied the strength and ductility of concrete columns externally reinforced with fibre composite strap. Chaallal and Shahawy (2000) reported the experimental investigation of fiber reinforced polymer-wrapped reinforced concrete column under combined axial-flexural loading. Obaidat et al (2010) studied the Retrofitting of reinforced concrete beams using composite laminates and the main variables considered are the internal reinforcement ratio, position of retrofitting and the length of CFRP.

It can be claimed from the simulation results that the LVRT capability of grid-connected PV power plants can be further enhanced using the proposed adaptive control strategy whatever under grid temporary or permanent fault condition. By this way, the PV power plants can contribute to the grid stability and reliability, which represents a greater challenge to the network operators. Moreover, the proposed algorithm can be also applied to other renewable energy systems for the same purpose.

Chalioris (2007) addressed an analytical method for the prediction of the entire torsional behaviour of reinforced concrete (RC) beams strengthened with externally bonded fibre- reinforced-polymers (FRP) materials. The proposed approach combines two different theoretical models; a smeared crack analysis for plain concrete in torsion for the prediction of the elastic behaviour and the cracking torsional moment, and a properly modified softened truss theory for the description of the post-cracking torsional response and the calculation of the ultimate torque capacity. The contribution of the FRPs is implemented by specially developed (a) equations in a well-known truss model and (b) stress - strain relationships of softened and FRP-confined concrete. In order to check the accuracy of the proposed methodology an experimental program of 12 rectangular beams under torsion was conducted. Tested beams were retrofitted using epoxy-bonded Carbon FRP continuous sheets and discrete strips as external reinforcement. Strengthened beams with continuous sheets performed improved torsional behaviour and higher capacity than the beams with strips, since failure occurred due to fibre rupture. Comparisons between analytically predicted results and experimental ones indicated that the proposed behavioural model provides rational torque curves and calculates the torsional moments at cracking and at ultimate with satisfactory accuracy.

Hiiand Al-Mahaidi (2007) briefly recounted the experimental work in an overall investigation of torsional strengthening of solid and box-section reinforced concrete beams with externally bonded carbon fiber-reinforced polymer (CFRP).

Mohammadizadeh et al. (2008) found that the increase in CFRP contribution to torsional strength concerning the beams strengthened by one ply and two plies of CFRP sheets is close for various steel reinforcement ratios, when compared to increasing the total amount of steel reinforcement.

Behera et al. (2008) conducted an experimental programme consisting of casting and testing of beams with “U” wrap was conducted in the laboratory to study the effect of aspect ratio (ratio of depth to breadth), constituent materials of ferrocement (viz., number of mesh layers, yield strength of mesh layers and compressive strength of mortar) and concrete strength on ultimate torsional strength and twist. This experimental results briefly recounts that wrapping on three sides enhance the ultimate torque and twist.

Deifalla and Ghobarah (2010) developed an analytical model for the case of the RC beams strengthened in torsion. The model is based on the basics of the modified compression field theory, the hollow tube analogy, and the compatibility at the corner of the cross section. Several modifications were implemented to be able to take into account the effect of various parameters including various strengthening schemes where the FRP is not bonded to all beam faces, FRP contribution, and different failure modes. The model showed good agreement with the experimental results. The model predicted the strength more accurately than a previous model. The model predicted the FRP strain and the failure mode.

Mahmood and Mahmood (2011) conducted several experiments to study the torsional behaviour of prestressed concrete beams strengthened with CFRP sheets. They have taken eight medium- scale reinforced concrete beams (150mmx250mm) cross section and 2500mm long were constructed pure torsion test. All beams have four strands have no eccentricity (concentric) at neutral axis of section. There are classified into two group according uses of ordinary reinforcements. Where four beams with steel reinforcements, for representing partial prestressing beams, while other four beams have not steel reinforcements for representing full prestressing beams. The applied CFRP configurations are full wrap, U jacked, and stirrups with spacing equal to half the depth of beam along its entire length. The test results have shown that the performance of fully wrapped prestressed beams is superior to those with other form of sheet wrapping. All the strengthened beams have shown a significant increase in the torsional strength compared with the reference beams. Also, this study included the nonlinear finite element analysis of the tested beams to predict a model for analyzing prestressed beams strengthening with CFRP sheets.

Zojaji and Kabir (2011) developed a new computational procedure to predict the full torsional response of reinforced concrete beams strengthened with Fiber Reinforced Plastics (FRPs), based on the Softened Membrane Model for Torsion (SMMT). To validate the proposed analytical model, torque-twist curves obtained from the theoretical approaches are compared with experimental ones for both solid and hollow rectangular sections.

Ban S. Abduljalil (2012). Strengthening of T beams in torsion by using carbon fiber reinforced polymer (CFRP). The experimental work includes investigation of five reinforced concrete T beams tested under pure torsion. Variables considered in the test program include; effect of flange strengthening, effect of fiber orientation (90º or 45º CFRP strips with respect to the beam longitudinal axis), and the effect of using additional longitudinal CFRP strips with transverse CFRP strips. Test results were discussed based on torque - twist behavior, beam elongations, CFRP strain, and influence of CFRP on cracking torque, ultimate torque and failure modes. Results indicate significant increases in ultimate torque capacity with the use of CFRP.

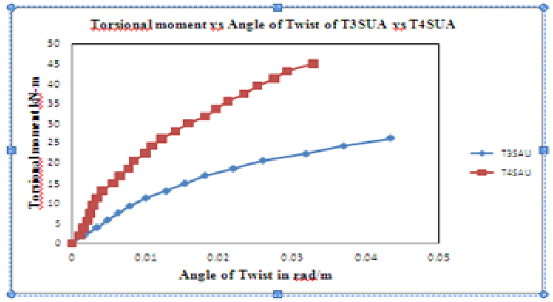
EXPERIMENTAL PROGRAM

To study the most influential strengthening variables on torsional behavior a total of eleven medium scale reinforced concrete beams of 1900 mm long were constructed for this work. T-shaped beams, which are sorted in three groups (T2, T3 and T4) and were tested under combined bending torsion. Three numbers of beams are without torsional reinforcement were the control specimens and eight specimens were strengthened using epoxy-bonded glass FRP fabrics as external transverse rein-forcemeat.

The cross-section of specimens was One beam were flanged beams with T-shaped with dimensions bw/D/bf/df = 150/270/250/80 mm (beams of series T2). In The series-B five beam specimens were flanged beams, and they dimensions are bw/D/bf/df =150/270/350/80 (beams of series T3). And also another five beam specimens were T-shaped cross-section and dimensions bw/D/bf/df =150/270/350/80 (beams of series T4). The cross-section of all beams shown in fig 3.1

Each group comprises one control specimen without transverse reinforcement. Specimens T2C were the control specimen of group-A, it had only longitudinal reinforcement; four deformed bars of diameter 20mmφ, and 10mmφ, at the corners of the cross-section, and control specimen of T3C,and T4C of series six longitudinal deformed bars of diameter 20 mmφ, 10mmφ, and 8mmφ, transverse bars of 8mmφ two legged stirrups. The other eight specimens of the experimental program included the same longitudinal reinforcement as the control specimens of their group and transverse rein-forcement (steel stirrups).

Test beams were identified based on the following naming system. The first character in the name R (Rectangular), T (T-section) is used to identify the cross/section of beam. Second character is the dimensions of the beam. The third two characters are used to specify the strengthening in web or flange or both (U or UA). Fourth character in the name (90, 45) is used to specify the fiber orientation with respect to the longitudinal axis of the beam.



CONCLUSIONS

The experimental program of this study consists of eleven numbers of reinforced concrete T- beams with different flange widths tested under torsion. The main objective of this study is to investigate the effectiveness of the use of epoxy-bonded FRP fabrics as external transverse reinforcement. Based on presented experimental measurements and analytical predictions, the following conclusions were reached

- Experimental results shows that the effect of flange width on torsional capacity of GFRP strengthened RC T-beams are significant.
- Torsional strength increases with increase in flange area irrespective of beam strengthening with GFRP following different configurations schemes.
- With 250 mm wide flange width increase in strength was 13%, with 350mm wide flange was 29% and for 450mm wide flange was found to be 69%. This is due to increase in area enclosed inside the critical shear path.
- The cracking and ultimate torque of all strengthen beams were greater than those of the control beams.
- The increase in magnitude depends on the FRP strengthening configurations.
- The maximum increase in torque was obtained for 900fully wrapped configurations.

Increase of 133.33% to 116.67% in first cracking and 155.55% to 107.23% in ultimate torsion were recorded for series B beams and series C beams respectively.

- Beams fully wrapped with 450 oriented GFRP stripes showed next highest torsional resisting capacity. Increase of 111.11% to 91.667% in first cracking and 81.03% to 95.39% in ultimate torsion were recorded for series B beams and series C beams respectively.

- Beams U wrapped with 900 oriented GFRP stripes showed lowest torsional resisting capacity. Since shear flow stresses take a close path during torsional loading, torsion would not be well resisted in case of U-jacketing strengthening.
- For U wrapped beams increase of 22.22% to 33.33% in first cracking and 23.27% to 36.84% in ultimate torsion were recorded for series B beams and series C beams respectively.
- Beams strengthen with U jacketing in web and top of flange and anchored with bolts exhibited increase of 11.11% to 55% in first cracking and 28.33% to 61.84% in ultimate torsion were recorded for series B beams and series C beams respectively.
- The torsional resisting capacity of these beams was found to be more than beams strengthen with U jacketing only. In such beams anchor bolts carry axial tensile forces as a part of shear flow resisting mechanism developed to resist the applied torsional moment.
- Strengthened beams using GFRP strips as the only transverse reinforcement exhibited better overall torsional performance than the non-strengthened control beams.
- The use of continuous FRP strips that wrapped around the cross-section of T-beams caused a significant increase on the ultimate torsional strength. It is concluded that full wrapping with continuous strips is far more efficient for torsional upgrading than the use of wrapping with the discrete strips.
- Although the extended FRP U-jacket strengthening technique relatively less effective than the FRP full wrapping strengthening technique, it yielded promising results in terms of strength and ductility while being quite feasible for most strengthening practical situations.
- The experimental results were validated with simplified model proposed by A. Deifalla &A.Ghobarah15. The model included the effect of different parameters studied in the present work like strengthening techniques, thickness and number of layers, spacing between FRP strips, FRP orientations, and angle of diagonal cracks.
- Experimental results indicate that the estimation of the GFRP contribution to torsional strength using simplified model proposed by A. Deifalla & A.Ghobarah provided good accuracy for GFRP strengthen beams.

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