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A Review on Torsional Behavior of RC Beams Strengthened with Externally Bonded GFRP

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ABSTRACT

Structural deterioration due to environmental degradation, increased service loads, aging, poor construction materials, and substandard workmanship has necessitated the rehabilitation and retrofitting of existing structures. Seismic retrofitting, in particular, has become crucial to ensuring structural safety and performance. Fiber-reinforced polymers (FRPs) have been effectively utilized in such applications due to their advantages, including lightweight properties, high strength, and durability. In this study, the performance and behavior of rectangular reinforced concrete (RC) beams strengthened with externally bonded glass fiber-reinforced polymer (GFRP) were investigated under torsional loading. Experimental testing was conducted on rectangular RC beams with GFRP bonding. The test setup involved transferring torque to the main section of the beam using a cantilever arrangement, with each arm subjected to a static load. The testing was destructive, meaning all beams were loaded until failure due to torsion. A total of eight beams were tested, including one control beam (without GFRP strengthening) and seven beams strengthened with different GFRP configurations. The objective was to evaluate the effect of various GFRP layouts on the torsional behavior of the RC beams.

Keywords: bonded glass fiber-reinforced polymer, Fibre-reinforced polymers (FRPs), control beam, GFRP layouts, high strength, and durability

Introduction

The demand for taller structures and engineering marvels requires materials with exceptional strength. Fiber-reinforced polymer (FRP) materials are extensively used as external reinforcement to enhance the structural performance of concrete members. However, the study of strengthening members subjected to torsion has only recently gained significant attention. In earthquake-prone areas, understanding torsional failure is crucial for ensuring structural safety. FRP (Fiber Reinforced Polymer) composite materials are widely used for strengthening and repairing concrete structures due to their high strength-to-weight ratio, corrosion resistance, ease of application, and durability. They are commonly applied as externally bonded reinforcements to improve the flexural, shear, and axial capacity of structural members. Nearly all engineering structures, including houses, factories, power plants, and bridges, experience degradation or deterioration throughout the course of their whole lives. Environmental factors, such as corrosion of steel, gradual loss of strength with age, temperature variation, freeze-thaw cycles, repeated high intensity loading, contact with chemicals and saline water, and exposure to ultraviolet radiation are the main causes of these deteriorations. A significant factor in the degeneration of any construction, in addition to these environmental factors, is earthquakes. The creation of effective structural retrofit technology is required to solve this issue. Therefore, it is crucial to keep an eye on how well the civil engineering infrastructures are performing. There are two solutions for the structural retrofit issue: repair/retrofit or demolition/reconstruction. If upgrading is a practical alternative, total replacement of an old facility may not be a cost-effective choice and may instead become a growing financial burden. Due to the damage caused by degradation, ageing, lack of maintenance, strong earthquakes, and changes in the current design standards, repair and rehabilitation of bridges, buildings, and other civil engineering structures are frequently chosen over reconstruction. Previously, the retrofitting of reinforced concrete structures, such as columns, beams and other 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

Literature Review

Warda Jannat Juhin et al (2024) this study presents a comparative evaluation of torsional behavior among different shear reinforcement configurations, highlighting the effectiveness of welded stirrups and truss-shaped reinforcement patterns. Based on your findings, WRSB demonstrated superior torsional moment capacity, which suggests that welding the stirrups enhances structural performance. Meanwhile, NWWTB exhibited a slight improvement over the conventional NRSB, indicating that the truss-shaped configuration alone may not be as beneficial as expected. Given that WRSB performed best, do you foresee any constructability challenges with welded stirrups in real-world applications Since reinforcement weight was kept constant, would an optimized combination of WRSB and truss-shaped reinforcement improve performance even further.

Vivek V. Mane et al (2023) Concrete is one type of composite material composed of fine and coarse aggregate bonded together with cementations paste that is durable in its hardened state over time. It has now become an important and widely used building material. However, it possesses a brittleness material property in tension even though it is strong in compression. Here the study is restricted to the concrete subjected to torsion phenomena. In the past decades, various ways have been explored to improve the ductile material strength property of the concrete matrix in proposed new construction. Reinforced concrete is constructed by using conventional reinforcements; prestressed concrete is an example of that. Also, various types of fibers in the form of discrete nature are applied to improve the tensile strength capacity of concrete in proposed construction, and retrofitting techniques using various materials are exercised to strengthen the existing structures. Hence, remarkable research in the literature on fiber reinforced concrete and on FRP techniques has been carried out. However, welded wire mesh with high yield strength can be encased in concrete members to improve composite material property and avoid abrupt cracking with an increase in torque carrying capacity of plain and reinforced concrete beam specimens used for proposed construction.

Shubanshu Sharma et al (2022) was study fiber reinforced polymer (FRP) is widely used as an external reinforcement in structural systems to meet flexure and shear strength requirements. However, the strengthening of members subjected to torsion has only recently been investigated. Torsion failure is an unfavorable brittle type of failure that should be avoided, particularly in earthquake prone areas. The behavior and performance of rectangular reinforced concrete beams reinforced with externally bonded Glass Fiber Reinforced Polymer (GFRP) fabrics subjected to combined flexure and torsion are investigated experimentally in this work. RC Rectangular beams that were externally connected with GFRP fabrics and were rectangular in shape were tested until they failed using a system that transferred torque to the central portion of the beam through two opposing cantilevers known as moment arms. During the experiment, an equal static loading is applied to each arm. For the study, a total of nine RC beams were cast and evaluated. Every beam was intended to fail in torsion. Eight beams were strengthened utilizing various configurations and GFRP fabric types, with one beam serving as a control beam. The investigation is limited to GFRP fabrics that have been continually wrapped. Experimental information was gathered on the ultimate and initial cracking loads, twist angle, and failure modes of each of the beams. Investigated were the effects of various GFRP kinds and configurations on the first crack load, ultimate load carrying capability, and failure mode of the beams. Using ANSYS software, the experimental data were finite element analysis confirmed and found to be in good agreement with analytical values. According to the experimental findings, externally bonded GFRP can greatly boost the beam's torsional capability. The full-wrap of GFRP textiles appears to be the most efficient arrangement, according to the results. Additionally, GFRP applied in 45 degree with the beam's axis provides greater strength than GFRP applied in 90 degree with the beam's axis.

Manish raj et al (2021) Many 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 beams to the columns. Such beams are deficient in torsional shear capacity and are in need of strengthening.. Fibre Reinforced Polymer (FRP) as an external reinforcement is used extensively to address the strength requirements related to flexure and shear in structural systems, but the strengthening of beams subjected to torsion is yet to be explored. In this project, the behaviour and performance of reinforced concrete beams strengthened with externally bonded Glass FRP (GFRP) sheets subjected to pure torsion has been studied. Experimental resultreveal that externally bonded GFRP sheets can significantly increase both the cracking and the ultimate torsion capacity. Concrete with mix proportion 1:1.8:3.6 was used during the casting of the specimens. Glass fibre sheets used was bi-directional woven roving mat. Polymer matrix Epoxy resin with 10 % hardener was used as the binder of GFRP sheets with the concrete surface. The obtained result shows that the load carrying capacity of the retrofitted beam is far more than the control beam. FRP based strengthening has better aesthetic appearance compared to other methods and is easier to implement and is light in weight.

Mahendra Kumawat et al (2018) the effect of glass fibre on flexural strength, split-tensile strength and compressive strength was studied for different fibre content on M-20 grade concrete designed as per IS 10262.The maximum size of aggregates used was 20mm. To study the effect on compressive strength, flexural strength, split-tensile strength 6 cubes,6 prisms and 6 cylinders were casted and tested. Glass fibre (or glass fibre) is a material consisting of numerous extremely fine fibers of glass. Glassmakers throughout history have experimented with glass fibers, but mass manufacture of glass fiber was only made possible with the invention of finer machine tooling. In 1893, Edward Drummond Libbey exhibited a dress at the World's Columbian Exposition incorporating glass fibers with the diameter and texture of silk fibers. Glass fibers can also occur naturally, as Pele's hair. Glass wool, which is one product called "fiberglass" today, was invented in 1932–1933 by Russell Games Slayter of Owens-Corning, as a material to be used as thermal building insulation. It is marketed under the trade name Fiberglas, which has become a generalized trademark. Glass fiber when used as a thermal insulating material is specially manufactured with a bonding agent to trap many small air cells, resulting in the characteristically air-filled low-density "glass wool" family of products.Glass fiber has roughly comparable mechanical properties to other fibers such as polymers and carbon fiber. Although not as strong or as rigid as carbon fiber, it is much cheaper and significantly less brittle when used in composites. Glass fibers are therefore used as a reinforcing agent for many polymer products; to form a very strong and relatively lightweight fiberreinforced polymer (FRP) composite material called glass-reinforced plastic(GRP), also popularly known as "fiberglass". This material contains little or no air or gas, is denser, and is a much poorer thermal insulator than is glass wool.

Shengqiang Ma et al (2016) the present study focuses on the torsional strengthening behavior of reinforced concrete (RC) box section beams that are widely used in bridges. Four RC box beams were fabricated, and three of them were wrapped by carbon fiber-reinforced polymer (CFRP) U-wrap strips with or without longitudinal strips. The different wrapping configuration, cracking angle, failure pattern, and tensile strain of fibers were investigated and discussed accordingly. The experimental results addressed that U-wrap strips strengthening also can upgrade the ultimate torque of beams moderately. In particular, using U-wrap and longitudinal strips to bond the box beams increased the torsional stiffness slightly. The same equation from different codes for calculating RC specimens can accurately predict the ultimate strength of the control beam, but the calculation of the fib model overestimated the torsional strengthening improvement of the wrapped specimens. However, Ghobarah et al. assumed approximately 3000με of the average ultimate fiber strain in calculating the ultimate strength of the wrapped box beams which shows in relatively appropriate agreement with testing results.

U.Arun Kumar et al (2015) this experimental study investigates the behavior and performance of rectangular reinforced concrete (RC) beams externally strengthened with glass fiber-reinforced polymer (GFRP) under torsional loads. The experiment was conducted on rectangular RC beams bonded with GFRP, designed to assess the transfer of torque to the central part of the beam using a cantilever setup with opposing arms. Each arm in the setup was subjected to a static load.

The experiment followed a destructive testing methodology, with all beams designed to fail under torsion. A total of eight beams were tested, with one beam serving as the control specimen. The remaining beams were strengthened using different GFRP wrapping configurations to evaluate their effect on torsional resistance. The study specifically focuses on continuously wrapped GFRP fabrics and their influence on torsional performance.

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.

Ghobarah et al. (2002) conducted an experimental investigation on the improvement of the torsional resistance of reinforced concrete beams using fiber-reinforced polymer (FRP) fabric. A total of 11 beams were tested. Three beams were designated as control specimens and eight beams were strengthened by FRP wrapping of different configuration and then tested. Both glass and carbon fibers were used in the torsional resistance upgrade. Different wrapping designs were evaluated. The reinforced concrete beams were subjected to pure torsional moments. The load, twist angle of the beam, and strains were recorded. Improving the torsional resistance of reinforced concrete beams using FRP was demonstrated to be viable. The effectiveness of various wrapping configurations indicated that the fully wrapped beams performed better than using strips. The 45° orientation of the fibers ensures that the material is efficiently utilized

Panchacharam and Belarbi (2002) experimentally found out that externally bonded GFRP sheets can significantly increase both the cracking and the ultimate torsional capacity. The behaviour and performance of reinforced concrete member strengthened with externally bonded Glass FRP (GFRP) sheets subjected to pure torsion was presented. The variables considered in the experimental study include the fiber orientation, the number of beam faces strengthened (three or four), the effect of number of FRP plies used, and the influence of anchors in U-wrapped test beams. Experimental results reveal that externally bonded GFRP sheets can significantly increase both the cracking and the ultimate torsional capacity. Predicted strengths of the test beams using the proposed theoretical models were found to be in good agreement with the experimental results.

Salom et al. (2004) conducted both experimental and analytical programs focused on the torsional strengthening of reinforced concrete spandrel beams using composite laminates.

The variables considered in this study included fiber orientation, composite laminate, and effects of a laminate anchoring system. Current torsional strengthening and repair methods are time and resource intensive, and quite often very intrusive. The proposed method however, uses composite laminates to increase the torsional capacity of concrete beams.

Jing et al. (2005) made an experimental investigation on the response of reinforced concrete box beam under combined actions of bending moment, shear and cyclic torque, strengthened with externally bonded carbon fiber reinforced polymer sheets. Three strengthened box beams and one reference box beam were tested. The main parameters of this experiment were the amount of CFS and the wrapping schemes. The failure shapes, torsional capacities, deformation capacities, rigidity attenuations and hysteresis behaviours of specimens were studied in detail. The experimental results indicated that the contribution of externally bonded CFS to the aseismic capacity of box beam is significant. Based on the text results and analysis, restoring force model of CFS strengthened R.C. box beam under combined actions of bending moment, shear and cyclic torque was established.

Al-Mahaidi and Hii (2006) focuses on the bond-behaviour of externally bonded CFRP in an overall investigation of torsional strengthening of solid and box-section reinforced concrete beams. Significant levels of debonding prior to failure by CFRP rupture were measured in experiments with photogrammetry. Numerical work was carried out using non-linear finite element (FE) modelling. Good agreement in terms of torque-twist behaviour, steel and CFRP reinforcement responses, and crack patterns was achieved. The addition of a bond-slip model between the CFRP reinforcement and concrete meant that the debonding mechanisms prior to and unique failure modes of all the specimens were modelled correctly as well. Numerical work was carried out using non-linear finite element (FE) modelling. Good agreement in terms of torque-twist behaviour, steel and CFRP reinforcement responses, and crack patterns was achieved. Very few analytical models are available for predicting the section capacity (Ameli and Ronagh 2007; Hii and Al-Mahadi 2006; Rahal and Collins 1995).

Santhakumar et al. (2007) presented the numerical study on unretrofitted and retrofitted reinforced concrete beams subjected to combined bending and torsion. Different ratios between twisting moment and bending moment are considered. The finite elements adopted by ANSYS are used for this study.

For the purpose of validation of the finite element model developed, the numerical study is first carried out on the un-retrofitted reinforced concrete beams that were experimentally tested and reported in the literature. Then the study has been extended for the same reinforced concrete beams retrofitted with carbon fiber reinforced plastic composites with ±45and 0/90o fiber orientations. The present study reveals that the CFRP composites with ±45 fiber orientations are more effective in retrofitting the RC beams subjected to combined bending and torsion for higher torque to moment ratios.

Ameli et al. (2007) experimentally investigated together with a numerical study on reinforced concrete beams subjected to torsion that are strengthened with FRP wraps in a variety of configurations. Experimental results show that FRP wraps can increase the ultimate torque of fully wrapped beams considerably in addition to enhancing the ductility.

Conclusion

The use of GFRP (Glass Fiber Reinforced Polymer) wraps as external transverse reinforcement significantly improved the torsional strength and flexural capacity of the tested beams. Beams wrapped with GFRP exhibited improved crack resistance, with a reduction in crack width and propagation compared to unwrapped beams. The wrapping confined the concrete and delayed the onset of cracking under combined loading conditions. The externally bonded GFRP wraps enhanced the ductility of the beams, allowing for better energy absorption before failure. Wrapped beams exhibited a more gradual failure mode, as opposed to brittle failure observed in unwrapped specimens. The test results indicated a noticeable increase in the ultimate load capacity of beams reinforced with GFRP, demonstrating its effectiveness in retrofitting and strengthening applications. Beams without GFRP reinforcement primarily failed due to brittle shear-torsion failure, while wrapped beams exhibited improved performance, with failure occurring in a more controlled manner, typically by delamination of the GFRP or crushing of concrete. The efficiency of GFRP wraps depended on the wrapping scheme. Fully wrapped sections provided superior performance compared to partial wrapping or strip configurations. The study highlights the viability of using GFRP wrapping techniques for the rehabilitation and strengthening of existing concrete structures subjected to torsion and bending. These findings suggest that GFRP wrapping can be a practical solution for enhancing the structural performance of reinforced concrete beams, particularly in applications where combined bending and torsion are critical design considerations.

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