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Case study

Torsional behaviour of reinforced concrete beams with ferrocement U-jacketing—Experimental study

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ABSTRACT

Wrapping technology is one of the effective ways of strengthening concrete elements. Several researchers reported the effectiveness of Glass fiber reinforced polymers and carbon fiber reinforced polymers for improving the strength of the concrete elements. Wrapping on three sides is one of the effective methods for strengthening the beams supporting slabs. Available literatures on the strength enhancement of "U" wrapped concrete elements subjected to torsional loads do not give a detailed insight, whereas this investigation is an attempt to address the issues with ferrocement "U" wrap. Ferrocement "U" wraps are preferred over FRPs because of its cost factor. The "U" wraps are found to provide better torque carrying capacity under all states of torsion while under reinforced members provide better toughness over other states of torsion. Similarly completely over reinforced beams provide more torque resisting capacity than the others. Increase of torsional capacity is more prominent in states of torsion while improvement in torsional strength with number of mesh layers in ferrocement "U" wrap is minimal.

1. Introduction

A reinforced concrete (RC) structural element such as peripheral beams, ring beams at bottom of circular slab, beams supporting canopy and other types of beams are subjected to torsional loading. Strengthening or upgrading becomes necessary for these beams when they are unable to provide the resistance. Increased service loading, diminished capacity through aging and degradation and more stringent updates in code regulations have also necessitated for the retrofitting of existing structures [31]. Repair and strengthening of RC members can be done by epoxy repair, steel jacketing or by fibre-reinforced polymer (FRP) composite. Each technique requires a different level of artful detailing. Availability of labour, cost and disruption of building occupancy plays major role to decide type of repair [24]. FRPs can be effectively used to upgrade such structural deficient reinforced concrete structures. Torsional retrofitting using FRP has received less attention [15,29,37]. Strengthening structures with FRP increases the strength in flexure, shear and torsion capacity as well as changes the failure mode and failure plane [13]. In practice it is seldom possible to fully wrap the beam cross section due to the presence of either a floor slab, or a flange. However, most of the research on FRP strengthened RC members investigated rectangular section fully wrapped with FRP [15,30,36,3] with the exception of a few studies that investigated T-beams with

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U-jacket [30,9]. Few studies regarding torsion strengthening using FRP have shown that the continuous wrapping is much more effective than using the strips [15,30,9,14]. Recent studies have shown that the basic deformation of the torsionally strengthened beams is similar to unstrengthened ones, however, the externally bonded limits the crack formation, propagation, widening and spacing between cracks [17,3,9].

Retrofitting by FRP is restricted to developed countries and urban areas of developing countries due to their high cost and skilled workmanship for its application [4]. It is well-known that although common concrete jackets enhance the strength, stiffness and toughness and improve the overall performance, they exhibit substantial shortcomings. These disadvantages are (a) the required labour-intensive procedures and (b) the increase of the member sizes, which reduces the available floor space, increases mass, change in stiffness and alters the dynamic characteristics of the building. Steel jacketing and FRP wrapping have the advantage of high strength and eliminate some of the limitations of concrete jacketing. However, they have poor fire resistance due to strength degradation of resin under moderate temperature. With due consideration on simplicity and constructability, a rehabilitation method for beam–column joints using ferrocement jackets with embedded diagonal reinforcements is proposed. Tests on reinforced concrete columns and beams strengthened by ferrocement have shown significant enhancement in strength [26]. From cost effective point of view and also from strength point of view ferrocement may be a substitute for FRP as it possess high tensile strength, water tightness and easy on application [2].

Ferrocement laminates in the form of Welded Wire Mesh (WWM) when encapsulated with a properly designed thin mortar layer can provide good alternative and low-cost technique in strengthening and repairing different structural elements for enhancing their load carrying capacities and ductility. Ferrocement meets the criteria of flowability and strength in addition to impermeability, sulfate resistance, corrosion protection and in some cases frost durability. Such performance is made possible by reducing porosity, inhomogeniety, and microcracks in the cement matrix and the transition zone [38]. The study by kumar et al. [25] under three different axial load ratios confirmed that confining columns using ferrocement jackets resulted in enhanced stiffness, ductility, and strength and energy dissipation capacity. The mode of failure could be changed from brittle shear failure to ductile flexural failure. Experimental and analytical study of thin concrete jacketing with self compacting concrete and “U” shaped stirrup was found to be beneficial in changing stiffness and altering the dynamic characteristics of the beam [11].

1.1. Significance of present investigation

Torsion, due to its circulatory nature, can be well retrofitted by closed form of wrap. Few analytical and experimental studies are found to quantify the torsional strength of FRP bonded full wrap [29,16,36,3,8]. But inaccessibility and extension of flanges over the web has necessitated strengthening the beams by “U” wrap rather than full wrap [5]. For quantification of torsional strength of “U” wrapped beams very few attempts have been taken by Panchacharam and Belarbi and Deifalla et al. [30,12]. U-jacketed flanged beams exhibited premature debonding failure at the concrete and the FRP sheet adhesive interface [9]. From the above points, it is clear that the “U” wrapped beams cannot perform in the same manner as that of full wrapped beams under torsional loading as it lacks one torsion resisting element(reinforcement) on un-wrapped face.

The mentioned literature in the introduction substantially recommends ferrocement as a retrofitting substitution for FRP. Few studies are available to quantify the torsional strength of ferrocement “U” wrapped beams. Experimental and analytical estimation of torsional strength of “U” wrapped RC beams reported by the author earlier was limited to plain beams only [5].

This paradigm motivated to take up the present investigation. The torque-twist response of reinforced beams is characterized by different salient stages such as elastic, cracking and ultimate stages [7,5]. Elastic and cracking torque of a beam is dependent upon its constituent materials and cross sectional area [1,7]. The reinforcement provided in longitudinal and transverse direction controls the torque twist response in the post cracking stage [27,33,31,32,7]. Literature review reveals that the torsional response of a wrapped beam is dependent on aspect ratio, constituent materials of core and wrapping material [35,34,28]. A beam if wrapped with ferrocement “U” wrap, then its torque twist response is influenced by ferrocement wrap (ferrocement matrix strength and number of layers along with reinforcement in the core) and states of torsion. The four possible states of torsion (arrangement of reinforcement in longitudinal and transverse direction that can be arranged in a beam) are as follows

i. Under reinforced beams.
ii. Longitudinally over reinforced and transversely under reinforced.
iii. Longitudinally under reinforced and transversely over reinforced.
iv. Completely over reinforced.

The objective of the present experimental study is to evaluate the effectiveness of the use of number of mesh layers on the “U” wrap and the states of torsion. In the present investigation mesh layers are varied on four possible cases of arrangement of reinforcement, keeping ferrocement matrix strength, core concrete strength and aspect ratio constant.