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Flexural and shear behavior of geo-grid confined RC beams with steel fiber reinforced concrete

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HIGHLIGHTS

- This study examines the feasibility of geo-grid confinement in RC beams.
- Geo-grid confined RC beams with SFRC under flexure and shear is investigated.
- Grid confinement enhances the stiffness degradation and energy dissipation property.
- Composite action of grid and SFRC alters the failure mode.
- Flexural and shear behavior authenticates the feasibility of geo-grid in RC beams.

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ABSTRACT

An experimental study is carried out to examine the feasibility of geo-grid as additional shear reinforcement in RC beam specimens. The use of geo-grid as confinement in the RC beams is easier and less laborious and may also be an effective solution along with the conventional way of confinement. Basically, geo-grid is not as rigid as conventional steel reinforcement and its reliability of anchorage with flexure reinforcement in the form of hoop under severe earthquake may advocate the use of another alternative path not only for resisting the flexure and shear but also to make more effective confinement in the form randomly distributed steel fiber in reinforced concrete (SFRC). Twelve sets of beam specimens are divided into three types with different configuration based on ratio of longitudinal and transverse reinforcement, strength of geo-grid and volume of steel fiber. These geo-grid beam specimens are tested under single point static loading to obtain the comparative load–deflection behavior. The experimental test shows a significant improvement in the strength and post-yield behavior of beam specimens depending on % of steel fiber reinforced concrete and the use of partial geo-grid confinement. The test results indicate that the proper application of geo-grid with steel fiber reinforced concrete not only helps to achieve the ductile behavior but also alters the brittle mode of failure.

1. Introduction

Based on the seismic design philosophy of earthquake resisting design of moment resisting building frames the concept of “strong column-weak beam” prevails in Indian codes as well as in majority of international standards. The failure mechanism recommended in the beam is again flexure rather than shear that can be achieved by avoiding deliberately the shear mode of failure by increasing its shear strength capacity. The conventional way to increase the shear capacity in beam is to provide confined shear reinforcement in the possible location of plastic hinges in beams. The test results show that the conventional confinement of reinforcement is only able to increase the shear capacity up to a certain extent and simultaneously it creates a number of constructional problems such as congestion of reinforcement with difficulty in concreting, laborious and time expensive. An alternative way to avoid closer stirrups in the critical plastic hinge region is the use of randomly distributed steel fiber in reinforced concrete (SFRC). This steel fiber acts as additional effective shear reinforcement in reinforced concrete elements by bridging the cracks [1–4]. ACI [5] also recommends the SFRC in RC structural elements with optimum amount of stirrups. However, SFRC may act as effective shear reinforcement but it also requires adequate amount of transverse reinforcement to exhibits ductile behavior [6]. As per literature [5–12], SFRC with higher volume of steel fiber is not recommended because of fiber segregation, fiber balling and poor dispersion. There is always a

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possibility for uneven dispersion of steel fibers also. The role of fibers in concrete ductility depends on fiber orientation and good distribution within the concrete to attain utmost benefits of SFRC. This both can be affect during concrete mixing, concrete flow and during compaction [9–12].

In this study, the possibility of confinement of plastic regions with the help of geo-grid and steel fibers along-with minimum amount of transverse reinforcement is explored with the objective to achieve higher shear capacity and enhanced ductile behavior. Generally, geo-grid is a flexible material which can be transformed/molded into any shape and is available in various forms such as polymer based, poly-propylene based, poly-ester based, poly-ethylene based. Geo-grid has two ribs, machine direction (MD) ribs and cross machine direction (CMD) ribs, based on that they are classified as bi-directional (BD) and uni-directional (UD) geo-grid. The strength of geo-grid is represented by its tensile strength in machine/main direction is expressed in terms of kilo-Newton per meter (kN/m). In BD grids the strength of both the ribs are same, whereas in UD, the strength of grids in both the directions differ. The principal application of geo-grid is to reinforce the loose soil to provide adequate tensile strength and deformation properties [13]. It also helps to bridge the voids below the load bearing granular layers and in landfill applications. Recently the feasibility of geo-grid application in concrete work is also explored [14–18]. The present study is focused on the use of geo-grid as a confining reinforcement with steel fibers in RC beam specimens. These specimens are tested under the static loading and there load–deflection, strength and stiffness degrading with the crack patterns are examined.

2. Review of literature

Several studies were conducted in the last few decades on SFRC to explore its suitability to increase the strength and deformation capacity of RC structural members under conventional static loading as well as in cyclic loading. The SFRC increased tensile strain property, crack bridging mechanism and has improved the shear resistance behavior. Its integration with concrete imparts ductile response over the brittle response of conventional concrete [19–22]. Moreover; the bridging effect across the cracks has enhanced the aggregate interlock property and allowed multiple crack formation in RC members [23,24]. These unique properties of SFRC may be an alternative for the enhancement of flexural and shear resistant capacity by eliminating the need of closely spaced transverse detailing in the plastic hinge region of a structural member [25–30]. The test results have indicated that an optimum quantity of steel fibers to a reinforced concrete beam may change the failure mechanism from the brittle shear failure to ductile behavior [3–4]. However, the excessive use of SFRC as per volume fraction may sometimes lead to fiber segregation and excessive air entrainment [8] and may reduce its effectiveness. Uneven dispersion of fibers, orientation, aspect ratio and its anchorage behavior may also affect its behavior [5,9–12,30]. Therefore, complete replacement of transverse reinforcement may not be possible by using SFRC in a structural member. Also prediction of shear strength increase using SFRC is difficult [25].

The use of geo-grid with SFRC using minimum conventional transverse reinforcement is a research area for enhancing the flexure and shear capacity of the RC members. In retrofitting of plastic hinge region of RC member, where buckling of longitudinal reinforcement is replaced with the new welded reinforcement , the geo-grid is an effective and easier solution, by virtue of its flexibility, to confine the concrete in retrofitting portion in addition with conventional transverse reinforcement. The feasibility of geo-grid in plain concrete beam using as tensile reinforcement and suggestion for grid reinforced concrete in thin layer concrete work is made [14]. Recently, the flexural behavior of geo-grid reinforced beams and its deflection and energy absorption is studied [15–16]. Geogrid confined concrete specimen with and without steel fiber reinforced concrete under compression is examined and observed better post peak behavior than unconfined specimen [16]. The effect of geo-grid confinement with steel fibers on the flexural and shear behavior of reinforced beams under static and cyclic loading is examined [17–18].

2.1. Research significance

The use of geo-grid with and without steel fibers in RC structural member requires extensive research work to finally prove its worth in construction industry. Only few studies are conducted in the past to examine the feasibility of geo-grid as flexural reinforcement in concrete beams. This study intends to investigate the feasibility of geo-grid application in structural components by conducting an extensive experimental program on simply supported beams constructed with geo-grid and steel fibers. They are tested under three point static loading. Geo-grid confinement may be an alternative solution for the confinement because of its usability, less laborious and efficacy in corrosive environment. The confinement by the geo-grid becomes more reliable and effective by using the steel fiber.

3. Experimental program

3.1. Materials specification

The concrete specimens are prepared using a mix proportion of 1:1.45:2.25 in Ordinary Portland Cement (OPC) of Grade 43, locally available river sand as fine aggregate, and well graded crushed coarse aggregate having 20 mm maximum size. Water–Cement (W/C) ratio is kept 0.45 with 0.5% super-plasticizer for better workability. The hooked end steel fiber of 35 mm length, 0.60 mm diameter with an aspect ratio of 60 having the nominal tensile strength of 1100 MPa is used to prepare SFRC in different volumes (V_f = 0.5%, 1% and 2%). In order to equate the density of conventional concrete a slight modified concrete mix proportion 1:1.40:2.20 is used to prepare SFRC with 1% steel fiber. The reinforcement bars used as longitudinal reinforcement in tension zone are 10 mm in diameter and 8 mm diameter bar in compression zone. Uni-axial geo-grid with an average tensile strength of 100 and 200 kN/m in MD ribs and 30 kN/m in CMD ribs are used in this study. These geo-grids are manufactured using high molecular weight and high tenacity polyester yarn with expected life of 75–120 years. The geo-grid is cost efficient as it is about 5–6 times lesser than conventional reinforcement on the basis of per meter length. Fig. 1 shows the details of steel fiber and geo-grid in MD and CMD. The typical detail of geo-grid used in this study is shown in Fig. 1c.

3.2. Specimen configuration and instrumentation

3.2.1. Compression and split tension specimens

In order to examine the synergetic effect of grid confinement with conventional concrete and SFRC under compression and split tension four types of cylindrical specimens with the standard size of 150 × 300 mm with different configuration were used. The detailed configurations of all compression testing specimens are presented in Table 1.

In order to prepare the geo-grid confined specimens, geo-grids in tubular form bound with nominal steel wire are firstly inserted in the cylindrical mold as shown in Fig. 2 and after that the concrete is laid. All cylindrical specimens are tested under 3000 kN capacity compression testing machine. In split tension test axial deflection in loading direction is measured by placing the LVDT's vertically. This is due to the limited edge space in compression testing machine; measurement of the diametric displacement is difficult.

3.2.2. RC beam specimens

Twenty-four beam specimens with different configurations are tested under three point monotonic loading. The foremost objective of testing beam specimens under flexure is to evaluate the confining effect of geo-grid with SFRC. The primary testing element of this experimental program consists of three types of RC beams with different reinforcement detailing and configurations. The detailed configuration of all beam specimens is summarized in Table 2. The basic reinforcing details and cross section size of beam specimens of all the three types (A, B, C) are given