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Effects of Geo-grid and Conventional Stirrups on Reinforced Concrete Beams With Polypropylene Fibers

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A R T I C L E I N F O

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A B S T R A C T

The aim of the present study was to investigate the effects of different confinement techniques (i.e., conventional shear reinforcement bars and confinement provided by a geo-grid) on flexural strength of full scaled reinforced concrete beams with and without the use of polypropylene fibers. Few studies have been performed using the geo-grids as shear reinforcement bars, and these were limited by flexural strength tests with scaled structural members. Meanwhile, no study has been performed that elucidates the contribution of geo-grids on bond-slip relationships. This is the subject of the present study. Fifteen reinforced concrete beams were tested under static bending tests for different scenarios. The effects of plastic fibers were examined for flexural strength, energy absorption capacities, bond-slip, and moment-curvature relationships for two different confinement techniques. The test results indicated that the use of geo-grids as a shear reinforcement in the available literature does not show good agreement in terms of performance provided by conventional stirrups. The performance of geo-grids as a shear reinforcement was limited with the use of a greater amount of plastic fibers.

1. Introduction

One of the design capacity principles is to ensure that reinforced concrete (RC) buildings exhibit a ductile behavior with the help of stirrups under the impact of earthquakes. For this purpose, a number of experimental studies have been conducted to investigate the effects of steel (e.g., [1,2]) and plastic (e.g., [3–5]) fibers on the flexural and shear strength of RC members. New materials are also being investigated by the construction industry. These materials have characteristics such as increased ductility and low weight to reduce inertial forces as well as reduce cost. The geo-grid is a geo-synthetic material that has been widely used in research studies. Different studies have been performed to obtain new solutions for the construction industry, which has shown increasing interest in geo-grids. While many studies have been performed on geo-grids for asphalt (e.g., [6,7]), retaining walls, foundations (e.g., [8,9]), and pavement (e.g., [10,11]), only a few studies have used geo-grids as alternative transverse reinforcement bars in RC members (e.g., [12]). One of the novel studies was conducted by Itani et al. [13], who examined the performance of a uniaxial geo-grid used as bending reinforcement bars for Portland cement concrete slabs with a 150-mm width, 50-mm thickness, and 380-mm length. The performance of the geo-grid was compared with plain concrete (without reinforcement bars). Another study was conducted by Chidambaram and Agarwal [14] on a geo-grid with and without using steel fibers, where two different geo-grid layers (i.e., single layer and double layer) were used as longitudinal bars. Twelve beam specimens of 100-mm width, 100-mm height, and 500-mm length were examined under flexural strength tests. Plain concrete beams without bending reinforcement bars were compared with concrete beams with a geo-grid used with steel fibers. In [14], given that the comparisons were based on plain concrete specimens, the test results were extremely positive for geo-grid specimens; the obtained energy dissipation was 1 to 10 times that of plain concrete beams. No analyses were presented for geo-grids used as shear reinforcement with regard to bond strength. Meski and Chehab [15] examined the flexural strength of RC beams with different types of geo-grids, such as uniaxial, biaxial, and triaxial. Twenty-one notched beam specimens with a size of 150 × 150 × 530 mm were tested. Study done by Meski and Chehab [15] indicated all used different types of geo-grids provided ductile behavior, high flexural strength, and large deflection. Similar to the study of Chidambaram and Agarwal [14], the test results of Meski and Chehab [15] showed a comparison of geo-grids against on plain concrete.

In the available literature, the use of a geo-grid in structural members presented parameters that were not previously known. The confinement effect induced by conventional transverse reinforcement bars affects the bond-slip relationships, including the structural performance levels. Previously performed experimental studies did not consider the effects of geo-grid on bond-slip relationships. Moreover, geo-grids were

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compared against plain concrete. Chidambaram and Agarwal [16] investigated the effects of a geo-grid as a confinement material in concrete with steel fibers. Twenty-four concrete beam specimens with a size of 100 × 150 × 1000 mm were examined under a flexure strength test. The study reported that with the help of the geo-grid with steel fibers, the failure mechanism of the tested beams changed from brittle shear to flexural failure. Chidambaram and Agarwal [16] did not examine the performance of geo-grids without steel fibers. The confinement provided by geo-grids were also limited by the results of the flexural strength tests. Bond-slip relationships and moment-curvature relationships of geo-grids with and without steel fibers were not examined. Bond-slip relationships, which affect the displacement of a structure during an earthquake, became an interesting subject because of the lack of information in the available literature concerning the use of geo-grids. Although considerable research has been conducted to predict the performance of geo-grids, contradictions were also found in the literature regarding the cracking forms of geo-grids (e.g., [13,14]).

Therefore, in this study, a series of experimental tests were performed to investigate the effect of geo-grids on full scaled of RC beams with and without using polypropylene fibers. The confinement provided using conventional transverse reinforcement bars and geo-grids was examined under flexure tests. In contrast to previous studies found in the available literature, the present study evaluated the structural behavior by including the flexure strength, load-deflection, energy absorption, moment-curvature relationships, bond-slip relationships, and crack patterns for two types of confinement techniques with and without using fibers.

2. Experimental program

2.1. Specimen configuration section properties

In this study, test specimens were first divided into three main groups. The first group of specimens was defined as concrete beams without stirrups and was named NS (non-shear reinforced concrete beams). The second group of specimens was defined as conventional RC beams and was named C (conventional reinforced concrete beams where both bending and stirrups were steel). The third main group was defined as confinement provided by geo-grids and was named G (geo-grid confinement where the stirrups were geo-grids). The three main groups were then divided into three subgroups having three different volume fractions (V_f) of polypropylene fibers at 0%, 0.5%, and 1.5%. In the current study, the moderate confinement for the same amount of fibers was also tested by increasing the intervals of the stirrups. Thus, six other RC beams having increased intervals of shear bars were tested. The moderately increased intervals of shear reinforcement bars of conventionally designed reinforced concrete beams was named MC (fourth group), and geo-grid specimens having increased intervals of shear reinforcement bars were named MG (fifth group). The fourth and fifth groups were also divided into three subgroups having three different V_f of fibers at 0%, 0.5%, and 1.5%. Thus, in the current experimental study, 15 RC beams were tested. Fig. 1 shows the different designs of RC beams prior to pouring concrete.

All reinforced concrete beams were designed as under reinforced beams to resist a moment capacity of 94 kN·m by an applied axial load of 150 kN. Fig. 2 shows the clear length of the beam at 2500 mm. The width of the supports was taken as 300 mm. Four deformed steel bars with 16-mm diameters were used as bending reinforcement bars. Two 12-mm-diameter deformed steel bars were used as compression bars. Steel ratios of bending and compression reinforcement bars were 0.00858 and 0.00241, respectively. The depth and width of the RC beams were 400 and 250 mm, respectively. The concrete cover was taken as 25 mm for all specimens. The shear strength that was resisted by the concrete was taken as 0.65 times the cracking shear strength of the concrete based on TS500 [17] to calculate the required amount and intervals of stirrups. For the second group (C) of concrete specimens, the calculated interval of the transverse reinforcement bars was 130 mm at supports and 180 mm at spans. 8 mm diameters of stirrups having a steel ratio of 0.00107 were used for group C specimens. The length of the stirrup densifications at the two supports was 980 mm. The hook of the transverse reinforcement bars was tied at 135° to prevent anchorage failure. For group G, all steel stirrups were replaced with geo-grid material. Two 14-cm layers of geo-grids were used. These layers had the same tensile strength provided by the 8-mm diameter of a conventional stirrup. The geo-grids were strongly tied with steel wires at the corners of the longitudinal bars. For groups MC and MG, the intervals of the stirrups were increased from 130 mm to 200 mm and 180 mm to 250 mm at the supports and spans, respectively. By increasing the intervals of the stirrups, the total number of stirrups used for the conventionally designed RC specimens (MC) and the confinement provided by the geo-grid was reduced from 17 to 12 and 12 to nine, respectively. The detailed configuration for all RC beams is summarized in Table 1.

2.2. Material properties and casting concrete

Ready-mixed concrete was used for all RC beams. All RC beams were poured at the same time using the same quality of concrete. Waterproof plywood was used for each RC beam. The recorded average compressive strength of the concrete based on 150 mm side cubic samples at the age of 28 days was 30 MPa. The coefficient of variation (CV) of concrete strength from tested six samples was 3.4%. The concrete mix design with weight of mix ingredients is given in Table 2.

Although slump tests were not performed and used fibers were not produced by water absorption, the concrete specimens having a 1.5% volume fraction of fibers had very low slump compared to those with a 0.5% volume fraction. The mechanical properties of the reinforcement bars were calculated by performing tensile tests on three randomly selected reinforcement bars. The calculated average mechanical properties of the longitudinal reinforcement bars with a gauge length of 320 mm were as follows: yield strength at 490 MPa (CV: 2%), rupture strength at 600 MPa (CV: 2.2%), strain at yielding and rupture at 0.00245 (CV: 4%) and 0.0115 (CV: 0.9%), respectively. The calculated elastic modulus of the reinforcement bars was 2×10^5 MPa. The mechanical properties of plastic fibers were provided by the manufacturer. In the current study, a uniaxial geo-grid was used with an average tensile strength in the machine and cross-machine directions were 110 kN/m and 30 kN/m, respectively. The tensile strength of the fibers was 650 MPa, and the modulus of elasticity was 5400 MPa. The elastic modulus of used geo-grids in the machine and cross-machine directions were 600 and 200 MPa, respectively. The lengths of the fibers ranged between 54 and 60 mm with a density of 0.91 g/cm^3. The lengths of the fibers ranged between 54 and 60 mm with a density of 0.91 g/cm^3. The diameters of the fibers ranged between 0.44 and 0.48 mm. Thus, calculated average aspect ratio of polypropylene fibers was 124. The grouped amount of fibers was gradually added into the concrete mixers before the concrete was poured. Fig. 3(a–b) show the used plastic fibers and a geo-grid for the current study.

2.3. Loading setup and measurement instrumentation

Three points static bending tests were performed to investigate the flexural strength, moment-curvature, and bond-slip relationships for all RC beams. The test setup and schematic diagram for the loading are shown in Fig. 4(a–b). In Fig. 4, the adopted shear span-to-effective depth (a_v/d) ratio was 2.53. A 600-kN-capacity hydraulic jack was used, suspended from a steel loading frame. The simply supported beams were loaded gradually. One of the supports was designed as a roller, and the other was a pin. RC beams were placed on two rigid reinforced concrete blocks. Based on the observations during the tests and considered degrees of freedom for the tested beams, the effect of movements occurred at the supports during the loadings were very small and