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EXPERIMENTAL EVALUATION OF THE FLEXURAL BEHAVIOR OF CONCRETE BEAMS REINFORCED WITH STIFF BIAXIAL GEOGRID

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Limited research exists on the benefits of using geogrids to reinforce Portland cement concrete structural and non-structural members. Preliminary research findings have shown that the inclusion of geogrids in Portland cement concrete leads to a definitive improvement in the post-cracking behavior in terms of ductility, load capacity, and crack propagation control. However, the geogrid sheet caused partial discontinuity in the concrete section which in some cases lead to complete separation of the bottom concrete layer. Through a rigorous experimental program, this study aims to verifying and further enhancing the current knowledge regarding the behavior of geogrid-reinforced concrete elements as well as proposing a geogrid reinforcing configuration that is expected to maintain the continuity throughout the concrete section while achieving or improving the aforementioned benefits. A total of nine concrete beam specimens were prepared and tested under four-point bending. Testing results and observations re-confirmed the reinforcing benefits of geogrids and proved that the proposed configuration is very effective as it resulted in better post-cracking behavior while overcoming the concrete separation problem.

Keywords: Post-cracking behavior, Four-point bending test, Crack opening, PCC, Reinforcement.

1 INTRODUCTION

Geogrids are geosynthetic materials made from geotextiles or polymers such as polypropylene, polyethylene or polyester. They are commonly used for soil stability purposes in road embankments or reinforced earth walls due to their tensile reinforcing capability. They can be classified as uniaxial, biaxial, or triaxial based on the number of directions they reinforce. Each of these types can be further classified as stiff or flexible geogrids based on their physical and mechanical properties (Tang *et al.* 2008).

The use of geogrids in concrete is not as common as their use in soils. However, efforts are recently being invested to assess the feasibility of using geogrids to reinforce Portland cement concrete (PCC) in order to benefit from their tensile strength and ductility. Studies conducted so far have resulted in promising findings as concrete gained both post-cracking ductility and load capacity (Tang *et al.* 2008, El Meski and Chebab 2014, Itani *et al.* 2016).

The objective of this study is to verify and enhance the current knowledge regarding the behavior of geogrid-reinforced concrete elements and investigate the effectiveness of circular geogrid reinforcement which is expected to maintain the continuity throughout the concrete section while providing more ductility and post-cracking load capacity. The experimental program encompasses testing nine plain and geogrid-reinforced beam specimens. The structural behavior of each sample type was analyzed and compared to that of the control samples based on load-deflection patterns and the maximum load capacity attained.

2 LITERATURE REVIEW

While geogrids are widely used in geotechnical applications, and significant research exists on the use of geogrids as reinforcements of pavement structures, only few studies investigated the advantages and limitations of using geogrids to reinforce Portland cement concrete elements.

Itani *et al.* (2016) introduced uniaxial geogrids in thin concrete overlays to study their effectiveness in preventing reflective cracking. Two experimental setups were adopted: the direct tension and the flexure tests (both monotonic and cyclic) to simulate thermal and traffic loads respectively. The results of both tests indicated that geogrids provided concrete with post-cracking ductility and extra load capacity. However, it was observed that geogrid-reinforcement weakened the concrete section during the pre-cracking phase and, in some cases, lead to the separation of the upper and lower concrete layers along the geogrid sheets. El Meski and Chehab (2014) used uniaxial, biaxial, and triaxial geogrids with different physical and mechanical properties to reinforce normal and high strength concrete beams. The specimens were subjected to four-point monotonic bending until failure. Comparing the load-deflection patterns of geogrid-reinforced and plain concrete beams, a much larger deflection was observed for all geogrid-reinforced samples indicating a ductile post-cracking behavior. Tang *et al.* (2008) also investigated the behavior of geogrid-reinforced PCC members by comparing the effect of introducing one or two layers of stiff and flexible biaxial geogrids. Similar benefits of using geogrid reinforcement were observed in terms of improved post-cracking ductility and load capacity. Stiff geogrids were found to achieve better overall results compared to flexible geogrids, which implies that the physical and mechanical properties of the geogrids are key factors in the effectiveness of geogrid reinforcement.

Chidambaram and Agarwal (2014) tested the effectiveness of confining concrete specimens with geogrids under compressive, flexural and tensile loading. It was concluded that the use of geogrids as a confinement mechanism for concrete resulted in a significant improvement in the behavior of concrete compared with conventional confinement techniques. Furthermore, it was found that the number of layers of geogrids used for confinement as well as their mechanical properties had a major effect on the load-deformation behavior of concrete. In a separate study, Chidambaram and Agarwal (2015) used geogrids for shear reinforcement in steel-reinforced PCC beams. Specimens were tested under single point monotonic loading. Testing results showed that geogrid shear reinforcement significantly enhanced the post-cracking behavior of the beams.

Al Hedad *et al.* (2017) studied the effect of using geogrids on the drying shrinkage behavior of concrete pavements. To do that, beam and slab samples were prepared and reinforced with a sheet of biaxial geogrid at different locations along the specimen depth. They were cured for 7 days and then placed in a drying chamber until day 56. Results showed that geogrids tended to decrease the drying shrinkage strains by 7-28 % compared to plain concrete specimens.

3 TESTING PROGRAM

A total of nine simply supported concrete beams were prepared and tested under monotonic four-point bending until they failed in flexure. The flexure test was conducted following the ASTM Standard Test Method for Flexural Strength of Concrete (ASTM C78/C78M-16 2016). Three of the specimens were reinforced with one sheet of biaxial geogrid placed at 3 cm from the bottom. Another three samples were reinforced with the proposed circular-shaped geogrid while maintaining a minimum concrete cover of 3 cm. The remaining three plain concrete beams served as control samples for comparison. All the specimens had the same length of 56 cm and a cross section of 15x15cm. Beam dimensions and geogrid reinforcing details are shown in Figure 1. The plain concrete, one-layer geogrid, and circular-shaped geogrid specimens were labeled as P, S, and O respectively. A 100-ton closed-loop, servo-hydraulic universal testing machine was used to apply a monotonic load at a constant crosshead displacement rate of 0.02 mm/sec to each simply supported beam. A vertical spring-loaded linear variable differential transducer (LVDT), with a range of +/- 25mm, was used to measure the vertical displacement at the middle of the bottom surface of each specimen. Data was then collected using a 16-bit data acquisition system.

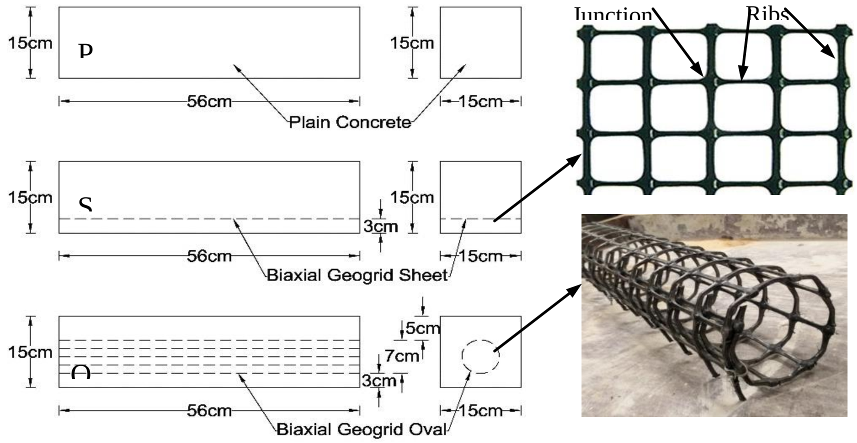

Figure 1. Specimen dimensions and reinforcing details.

4 MATERIAL PROPERTIES

4.1 Geogrids

Biaxial geogrids consist of two-directional thin ribs joined together at thicker junctions; hence, they provide tensile reinforcement in both longitudinal and transverse directions. The geogrids used for this study are non-woven stiff geogrids made up of polypropylene. Table 1 presents the properties of the used geogrid as obtained from the manufacturer.

Table 1. Physical and mechanical characteristics of the biaxial geogrids used.

Property	Unit	Value
Load at 2% strain	KN/m	14
Load at 5% strain	KN/m	28
Ultimate Tensile Strength T_{ult} (L/T)	KN/m	40/40
Strain at T_{ult} (L/T)	KN/m	11/10

Note : L = Longitudinal direction ; T = Transverse direction

4.2 Portland Cement Concrete

In brief, the concrete mix adopted in this study was prepared using medium-size coarse aggregates having a nominal maximum aggregate size of 9.5 mm, fine aggregates consisting of natural sand, Type-I Portland cement and a water to cement ratio of 0.5. For 1 cubic meter of concrete, the weights of cement, sand, aggregates and water are respectively: 395, 815, 1080 and 217 Kg. The given mixture proportion is corrected based on the absorption capacity of the aggregates. After several trial mixes, the aggregate gradation and the water to cement ratio which resulted in the best mix workability in the presence of geogrids were adopted.

Three standard concrete cylinders were prepared and tested for compressive strength measurement. The average 28-day concrete compressive strength was 25 MPa. The relatively low value of the strength is expected due to the adopted water to cement ratio, which is needed for flowable concrete to easily penetrate the apertures of the geogrids. It should be noted that the use of superplasticizers wasn't necessary since the needed workability was achieved by increasing the water to cement ratio while maintaining an acceptable strength. Concrete for all beams and cylinders was cast in three successive layers with proper vibration. The reinforcement was positioned in place after laying the first 3cm concrete cover layer. All specimens were subjected to soaked curing conditions. Some pictures showing the specimen fabrication process as well as the concrete texture and slump obtained are presented in Figure 2.

Figure 2. Concrete slump/texture, and specimen fabrication.

5 RESULTS AND ANALYSIS

The load-displacement curves for the different specimens tested with related images showing the observed modes of failure in the unreinforced and geogrid-reinforced samples are presented in Figure 3. The three curves for each beam type refer to the three replicates. The plot in Figure 3-a reveals the brittle behavior of the plain concrete specimens (P), with a minimal displacement of 0.8 mm obtained at the failure load of 15 KN.

As for the beams with one layer of geogrid "S", initial cracking occurred at a similar value of load as that for the plain concrete specimens. However, the crack growth was limited and was arrested by the geogrid layer. Its further propagation slowed down significantly as the section gained post-cracking ductility. Upon failure of the geogrids, the crack instantly reached the top surface leading to complete beam failure. Since the initial crack occurred at a similar value of load as that for the plain concrete specimens, this suggests that the geogrids were not engaged and thus did not contribute mechanically during the pre-cracking phase; their main contribution was limited to providing post-cracking ductility and extra load capacity. Figure 3-b shows the load-displacement curves for the three replicates of beam specimens with one geogrid layer. Upon careful observation, it appears that geogrids failed in two modes, junction failure and rib failure. Within the post-cracking phase, the curves exhibited multiple steep drops in the load; each drop corresponds to the failure of one or more ribs or junctions. The specimen that experienced rib failure exhibited relatively higher ductility but lower load capacity than the specimens that exhibited junction failures. This was indicated by the higher displacement (9mm) and lower load attained (1.5KN) just before failure. It is believed that when the initial crack hits the geogrid ribs first, they start to fail one after another resulting in the observed shape in Figure 3-b of the load-displacement curve for the rib failure mode. However, for specimens in which the initial crack propagated and reached the geogrid junctions first, the post-cracking load capacity is sustained without any noticeable drops in load until sudden failure at higher load (14KN) and slightly lower displacement values (7mm). It should be noted that the maximum load reached in the post-cracking phase (approximately 14KN) was more than 90% of the load that initiated the first crack in the concrete section.

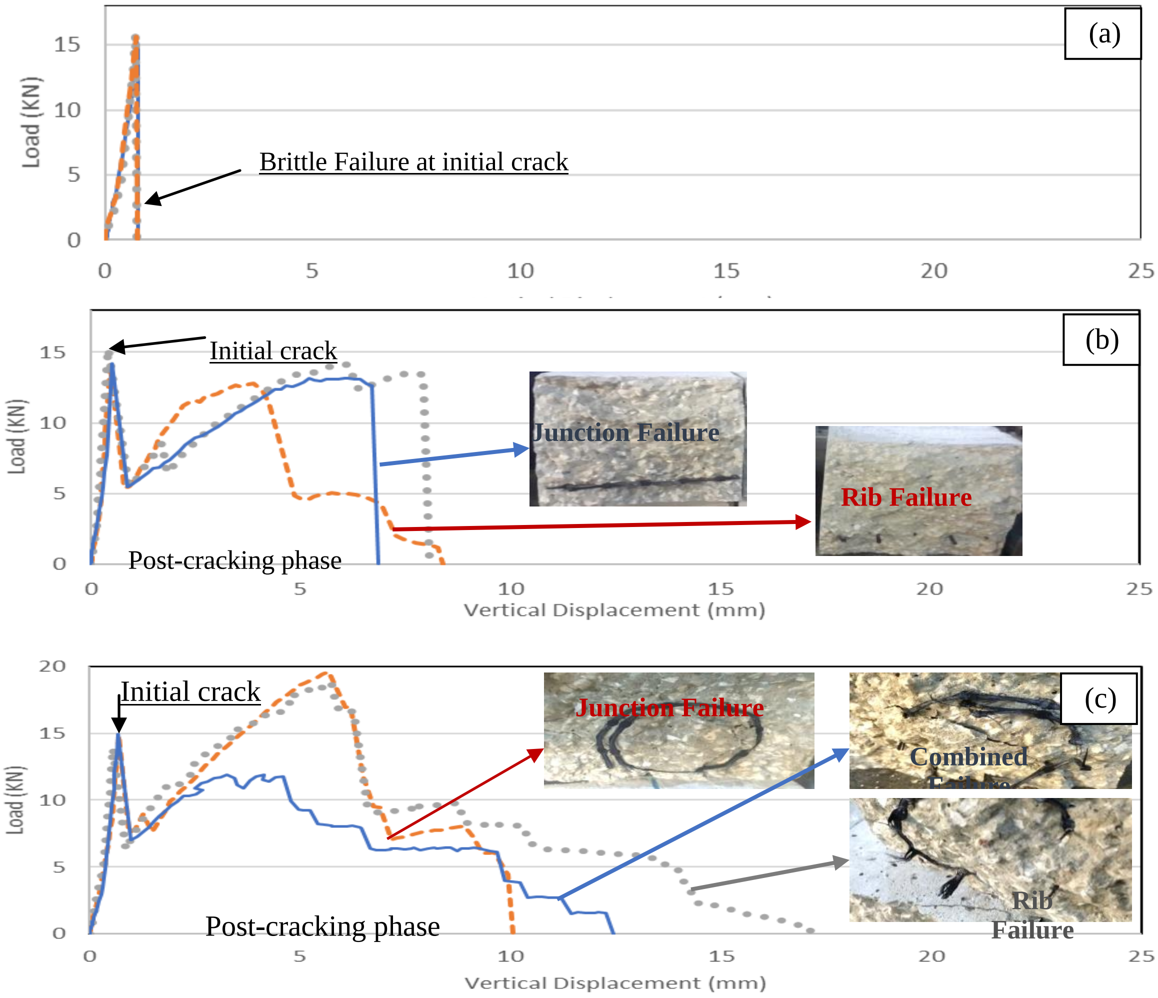

Figure 3. Load vs. vertical displacement patterns and failure modes for beam types: (a) P, (b) S, and (c) O.

As for the "O" category, where the geogrids were rolled and placed to form a circular cross section, the behavior of each replicate varied based on the observed failure mode, rib vs. junction. Similar to the "1-G" samples, geogrids did not contribute much in resisting the load during the pre-cracking phase. After the initial crack, geogrids start to resist the bottom tensile stresses while controlling crack propagation. During the post-cracking phase, the section significantly gained load capacity until it peaked at 20 KN, which is around 130 % of the load at the initial crack, before it started to decrease gradually as some ribs and junctions started to fail progressively. It should be noted that the "O" configuration yielded larger displacements before failure and attained a higher load capacity during the post-cracking phase than the "1-G" category. The load-displacement curves of the "O" specimens as well as the observed failure modes are presented in Figure 3-c. Similar to the "1-G" category, the location and trajectory of the initial crack, and thus the location at which the crack hits the geogrid, is the main factor that controls whether the geogrid will fail along its ribs, junctions, or a combination of both. It can be seen from the load-displacement patterns that specimens failing along ribs exhibited higher ductility with displacement at failure reaching 17mm which can be explained by the relatively stiffer nature of the junctions.

6 CONCLUSIONS AND RECOMMENDATIONS

Reinforcing concrete beams with geogrids, either in the form of a sheet or a circular cross section, provided the samples with post-cracking ductility and load capacity. Furthermore, the circular-shaped geogrid reinforcement resulted in a better performance compared to the geogrid sheet. The circular-shaped geogrid reinforcement was more effective in the control of crack opening and propagation compared to one-layer geogrid reinforcement, which is evident from the lower release in energy (drop in the load) at the initial crack. It also resulted in higher post-cracking load capacity and endured larger displacement before failure. The circular-shaped geogrid addressed the issues of concrete section weakening and concrete separation along the geogrids which were observed in earlier studies.

Furthermore, three different types of failure were observed: Junction failure, rib failure, and a combination of both. It was noticed that ribs exhibited a more ductile behavior where they failed gradually one after another until the section failed at a low applied load. The junctions, on the other hand, provided ductility in terms of the displacement at failure, but they remained intact, maintaining a relatively high load capacity, until they suddenly failed altogether. The results of this study proved the expected benefits of the use of the circular shaped geogrid as a reinforcing tool in concrete beams and validated the behavior of stiff biaxial geogrids in concrete elements.

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