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Technical Report

Study on reinforced lightweight coconut shell concrete beam behavior under torsion

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ABSTRACT

This research investigates and evaluates the results of coconut shell concrete beams subjected to torsion and compared with conventional concrete beams. Eight beams, four with coconut shell concrete and four with conventional concrete were fabricated and tested. Study includes the general cracking characteristics, pre cracking behavior and analysis, post cracking behavior and analysis, minimum torsional reinforcement, torsional reinforcement, ductility, crack width and stiffness. It was observed that the torsional behavior of coconut shell concrete is comparable to that of conventional concrete. Compare to ACI prediction, equation suggested by Macgregor is more conservative in calculating cracking torsional resistance. But for the calculation of ultimate torque strength ACI prediction is more conservative compared to the equation suggested by Macgregor. Indian standard is also conservative in this regard, but it was under estimated compared to ACI and Macgregor equations. Minimum torsional reinforcement in beams is necessary to ensure that the beam do not fail at cracking. Compared to conventional concrete specimens, coconut shell concrete specimens have more ductility. Crack width at initial cracking torque for both conventional and coconut shell concrete with corresponding reinforcement ratios is almost similar.

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1. Introduction

1.1. General

A monolithic construction of reinforced concrete structure tends to introduce torsional moments into the members which, in general, cannot be ignored in design. Torsional strength of sections made with homogeneous materials can be estimated quite accurately using the theory of elasticity. However, it is very difficult to assess the torsional strength of heterogeneous reinforced concrete sections. The problem becomes even more acute because such members are seldom under pure torsion; rather they are subject to bending, shear and torsion [1].

1.2. Importance of torsion

Torsion has always been an interesting and important aspect of structural behavior. Axial loads, flexure, shear and torsion are the basic loading situations for which independent theories have been developed for conventional concrete, and the more complicated interactive loading situations have been well established with as combinations of these basic effects. In this context the study of torsional behavior of structural members is indeed very important [2]. A common example of torsional loading is that of peripheral beams in each floor of a multistoried building, in which the slab is cast monolithic with the beam giving rise to L-beam configuration. Another example of torsional loading is that of a ring beam provided at the bottom of an elevated circular water tank. Such a ring beam is subjected to bending moment, shear force and torsional moment. The beams supporting cantilevered canopy slabs are also subjected to significant torsional loading. Other prominent examples of loadings are edge beams of concrete shell roofs, and helicoidal staircases [3]. In the case of reinforced concrete structural systems torsion has been generally considered as secondary in importance, but modern structural configurations do require the study of torsional behavior. The brittle catastrophic nature of failure of concrete under shear stress developed due to torsion is of importance under present day context of seismic design [4].

1.3. Need for this study

Since structural concrete is used extensively in the construction of various kinds of buildings, consumed at a rate of approximately one ton for every living human being [5] and aggregate contributes

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significantly to the structural performance of concrete [6], the high demand for concrete using normal weight aggregates such as gravel and granite drastically reduces the natural stone resources and this damages the environment thereby causing ecological imbalance. Therefore, there is a need to explore and to find suitable replacement material to substitute the natural stone aggregate [7,8]. Some of the lightweight aggregates used for lightweight concrete production are pumice, perlite, expanded clay or vermiculite, coal slag, sintered fly ash, rice husk, straw, sawdust, cork granules, wheat husk, no fines, foamed type concrete, oil palm shell, and coconut shell [9–12].

Coconut shell concrete (CSC) is one of the special concrete under lightweight concrete which is recently developed in the concrete world. Though the basic properties of CSC [12], mechanical properties of CSC [12], bond properties of CSC [12] and long term performance of CSC are in acceptable range, for structural applications, knowledge of the behavior of structures is essential for design so that an economical structure can be obtained consistent with safety and serviceability. Since, behaviors of reinforced lightweight CSC beam under flexure and shear had been already studied and published in the earlier publication [7,8], this study investigated and presented the experimental evaluation of reinforced lightweight CSC beam under torsion.

2. Coconut shell aggregate

Enough discussion about the productivity of coconut in worldwide, countrywide, availability of coconut shell (CS) and its different uses in different fields were already made in earlier publications. Also the process of making of CS as aggregate, physical and mechanical properties of CS, the methodology to be followed in using CS as aggregate in the production of concrete were also been discussed and published already. However, for the benefit of readers of this manuscript some of the important properties of CS are given here.

The average moisture content and water absorption of the CS was 04.20% and 24.00% respectively. The average specific gravity and the apparent specific gravity were found as 1.05–1.20 and 1.40–1.50 respectively, which is for less than the conventional aggregates. This implies that, when CS is used in concrete it may fall in the category of lightweight concrete. The average crushing value and impact value of the CSs are 2.58% and 8.15% respectively; hence, CS can offer better resistance against crushing and impact. The average percentage loss in abrasion test on the CS is 1.63%; hence, CS can also offer more resistance against abrasion, compared to normal aggregate. The average bulk densities in loose and compacted conditions are in the ranges of 550 kg/m^3 and 650 kg/m^3 respectively. Hence, CS aggregates will result in less unit weight of concrete compared to normal weight aggregate and qualify for producing lightweight concrete [12].

3. Coconut shell concrete (CSC)

Ordinary Portland cement, river sand, coconut shell, and water are the constituents used for making CSC. Crushed granite stones (CGSs) were employed to prepare control concrete (CC) beams for comparison. Both for CSC and CC, minimum compressive strength of 25 N/mm^2 at 28-days was fixed as target strength with minimum workability considerations. Coconut shells were collected from the local oil mill and transported to SRM University premises. Collected CS and the crushed CS aggregate are shown in Fig. 1a and b respectively. From the previous studies, mix proportions were selected for both CSC and CC and the properties of those mixes are shown in Table 1.

4. Experimental investigation

4.1. Test program

Lightweight concrete has been produced using crushed coconut shell as coarse aggregate. Eight beams, four with CSC (CSC1–CSC4) and four with normal CC (CC1–CC4) were fabricated and tested. Study includes the general cracking characteristics, pre cracking behavior and analysis, post cracking behavior and analysis, minimum torsional reinforcement, torsional reinforcement, ductility, crack width and stiffness.

4.2. Specimen and reinforcement details

The cross sectional dimension of beam was taken as 200×275 mm and the length of the beam was taken as 1200 mm centre to centre for both CC and CSC beams. In both the cases the grade of concrete has been considered as M25. In this study, minimum longitudinal reinforcement as suggested by Ali and White on their study on towards a rational approach for design of minimum torsion reinforcement has been considered [13]. Also as suggested by Macgregor and Ghoneim on their study on design for torsion has been considered for the calculation of minimum longitudinal reinforcement [14]. Similarly, minimum spacing of transverse reinforcements has been considered as suggested by them [13,14]. The equation suggested by Hsu and Hwang has been used for the calculation of total volumetric torsional reinforcement percentage and provided [15]. The Fe 415 grade of steel was used for both longitudinal and transverse reinforcements. Table 2 shows the details of minimum longitudinal reinforcements and spacing of transverse reinforcements required and actually provided respectively.

The diameter and the number of bars used for longitudinal reinforcements, diameter and the spacing of bars for transverse reinforcements and also the total volumetric torsional reinforcement percentage calculated are given in Table 3, respectively. Fig. 2 shows the schematic diagram of the top view of the specimen with loading points. For all the beams cantilever portions has been designed and made strong to avoid the failure of this portion, especially at the joint between the beams and the cantilever portion. Cantilever portions of the beam also cast monolithically with the two ends of the main beam. The cross sectional and the reinforcement details of the cantilevered portion are shown in Fig. 3. Accompanying the beam, 3 numbers of cubes were tested on the same day as the beam testing to establish the properties of both CC and CSC concrete which are given in Table 1. The beam size and length were chosen to ensure that the beams would fail in torsion and also to test the specimen with the loading frame and the testing facilities available in the structural laboratory of SRM University.

4.3. Specimen preparation

Formwork making use of plywood was prepared for the beam size. Reinforcements were made ready as per the details given in Tables 2 and 3. The inner surfaces of the mould were coated with a thin film of crude oil to prevent adhesion of concrete with the mould before placing the reinforcements. All the ingredients of the mix were weighed and machine mixed. The concrete was placed in three layers and internally compacted using a needle vibrator after placing the reinforcements. Care was taken to give uniform compaction for the specimens. Without delay after the beam cast, the beams were covered with plastic sheet to minimize the evaporation of water from the surface of the beam specimen. After 24 h, the sides of the formwork were removed and cured

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