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Seismic performance of coconut-fibre-reinforced-concrete columns with different reinforcement configurations of coconut-fibre ropes

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HIGHLIGHTS

- Columns with three different rope configurations were considered.
- Coconut-fibre-reinforced-concrete and coconut-fibre ropes were used.
- Columns were tested under scaled El Centro earthquake loadings.
- A decrease in columns natural frequency was observed with incremental loading.
- Out of three, column with multiple central coconut-fibre ropes performed well.

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ABSTRACT

Three different reinforcement patterns of coconut-fibre ropes in columns are investigated in this experimental study. Coconut-fibre-reinforced-concrete is used to cast columns. This new material is under investigation for the production of low cost but safe housing in earthquake prone regions. Overall ductile behaviour of structure is a basic requirement; therefore coconut fibres are selected because of their highest toughness amongst all natural fibres. Incremental ground motion excitations are applied to the columns using a shake table. The excitations are time-scaled to produce damage in columns. This is to match the frequency of excitation with that of structure. The dynamic properties of coconut fibre and rope reinforced concrete columns are determined by an impact test after each excitation. A change in natural frequency is observed, showing that there is some non-visible material degradation in the specimen before cracking. Out of three patterns, column with multiple central ropes performed well showing rocking phenomenon.

1. Introduction

The ductile behaviour of structures depends on many factors, such as geometry, connections, material properties and structural members. Among all parameters, members subjected to direct lateral seismic loads (e.g. shear walls and columns) are most important for making a structure ductile along with its own material properties. Composites, like concrete, entirely depend on their reinforcing materials for toughness, as concrete itself is brittle. This can be achieved by adding fibres to concrete. Coconut fibres can be used in concrete for improving its properties. It may be noted that coconut fibres have the highest toughness among all natural fibres. Munawar et al. [1] and Satyanarayana et al. [2] reported strain of 24% and 39%, respectively, for coconut fibres, whereas other natural fibres have strains in the range of 3–6%. The investigation on coconut fibre and rope reinforced concrete beams has shown that the fundamental frequency of these beams decreases while damping ratio increased with an increased damage due to static loading [3]. Ali and Chouw [4] tested coconut fibre and rope reinforced concrete beams for their load transmission behaviour. It is observed that the transmitted dynamic load is amplified with increasing damage. Static load is transmitted approximately equal up to linear stage, and then transmitted forces vary between the two supports depending upon crack location.

One of the purposes of recording original earthquake loadings is that these can be applied to the structures using shake table in laboratories. Such tests are conducted to study the performance of structures under consideration. Different researchers used different techniques to scale earthquake loadings to suit their requirements. Scaling is usually done in three ways, i.e. scaling of (i) only amplitude, (ii) only time and (iii) both amplitude and time. For example, the ground motion of Michoacan earthquake 1985

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has a very narrow-band frequency content. Ian et al. [5] scaled time axis of Michoacan earthquake 1985 to obtain a very severe excitation scaled to shift the narrow spectral peak to the approximate first natural frequency. Kanazawa et al. [6] reduced time scale of El Centro earthquake according to law of similarity to test their structure. Mathew et al. [7] did time scaling of Parkfield 1966, El Centro 1940, Golden Gate 1957, Northridge 1994, and Helena 1935 earthquake loadings. The researchers claimed "*time scaling is often implemented to account for scale effects between the model and the represented structure, this was not necessary because analyzing a specific structure is not the goal. Instead, a suite of time histories with significantly different primary impulse characteristics is desired*". Therefore, there can be number of reasons for scaling of input ground motions, but the main emphases is the introduction of damage in structures due to these loadings [8–10].

To the best of author knowledge, the use of coconut-fibre ropes in concrete columns is a new way of reinforcing structural member. Therefore, the performance of columns, made of coconut-fibre-reinforced-concrete with same mix design, is studied with three different reinforcement configurations of coconut-fibre ropes. These columns were tested under time scaled El Centro earthquake loadings and their performances and response are compared in this research work.

2. Experimental procedures

2.1. Background

Twigden et al. [11] tested coconut fibre and rope reinforced concrete columns under different types of loading. These columns had rope reinforcement at corners. They used El Centro record several times to produce damage in the column without any success. No visible damage was observed; even though the El Centro record was scaled up (amplitude only) to the maximum capacity of the shake table and the mass at the top was increased up to 165 kg. This situation can be explained by the difference between the natural frequency of specimen (between 15 and 20 Hz depending upon the attached mass) and the dominant frequency content of the earthquake (under 10 Hz) that does not allow dynamic amplifications. Finally, for producing damage, harmonic loadings were used. Dynamic tests revealed that the non-visible degradation occurred prior to the cracking of column; this was detected by the decrement of fundamental frequency. Therefore, for this study, El Centro earthquake loading is time-scaled so as to match natural frequency of specimen with the dominant frequency content of the shake table excitation.

2.2. CFRC preparation

A fibre length of 5 cm and a content of 3% by cement mass were used for preparing coconut-fibre-reinforced-concrete (CFRC). The mix design of cement: sand: aggregate was 1:2:2 with water cement ratio of 0.48. The fibres preparation, casting CFRC and pouring of CFRC into moulds were performed as described by Ali et al. [12], in which mechanical and dynamic properties of coconut-fibre-reinforced-concrete were determined experimentally.

The basic static properties of CFRC were determined by standard procedures, normally used for plain concrete. It may be noted that the cylinders of 100 mm diameter × 200 mm height and beams of 100 mm width × 100 mm depth × 500 mm length were used for this purpose. Fig. 1 shows all specimens under current study.

Fig. 1. Specimens under study.

2.3. Column specimens

Column specimens having cross-section of 100 mm × 100 mm and height of 850 mm were cast along with base beams with cross-section dimensions of 100 mm × 100 mm and length of 600 mm. The longitudinal rope reinforcement was pre-tensioned (i.e. up to 50–100 N force) so that there should not be sagging while pouring CFRC, and the removable steel rods (placed at 100 mm centres) were also used for this purpose. These steel rods were removed after filling the mould with CFRC, and finally the top surface was levelled. Coconut fibre and rope reinforced concrete columns are termed, in general, as CFRRC columns.

2.3.1. Rope configuration 1 (RC-1)

Coconut-fibre ropes of ~10 mm and ~5 mm diameter were used as longitudinal and transverse reinforcement, respectively. The longitudinal reinforcement was used at corners (i.e. in terms of reinforcement ratio, it was 3.1%) and the transverse reinforcement was placed at 100 mm centres (Fig. 2a). The same reinforcement was used in the base beam. Knots were provided near corners and at the intersection of the beam and column, to provide anchorage. A clear concrete cover of 15 mm was maintained with the help of pre-tensioning longitudinal reinforcement and removable steel rods. This is designated as RC-1 and shown in Fig. 2a.

2.3.2. Rope configuration 2 (RC-2)

Coconut-fibre rope of ~35 mm diameter was used at centre as longitudinal reinforcement. Two additional ropes having ~10 mm diameter were attached to the central rope up to 350 mm height from base. These ropes were bent into the base beam. This column had a reinforcement ratio of 11.2%. This is designated as RC-2 and shown in Fig. 2b.

2.3.3. Rope configuration 3 (RC-3)

Coconut-fibre rope of ~25 mm diameter was used at centre as longitudinal reinforcement. This is basically combining all ropes at centre instead of providing at corners like in RC-1. It may be noted that combining four ropes of ~10 mm diameter each generates a single rope of ~25 mm diameter. This column had a reinforcement ratio of 4.9%. This is designated as RC-3 and shown in Fig. 2c.

It may be noted that the base beam was reinforced in a same manner for RC-2 and RC-3 as that of RC-1.

2.4. Properties of CFRC and coconut-fibre ropes

Table 1 summarizes the material properties obtained from tested cylinder and beamlet specimens. These include compressive strength (σ), corresponding strain (ε), modulus of elasticity (E), splitting tensile strength (STS), modulus of rupture (MOR), corresponding deflection (Δ), cracking load (P_{Crack}), and the maximum deflection (Δ_{max}). Cracking load is the load taken by bridged fibres and part of CFRC section after the first visible crack is produced. All values are the average of three readings. Three values are quite close to each other showing the CFRC was well mixed and compacted. It was observed that the cracks were produced in CFRC cylinders while performing compressive and tensile tests. CFRC specimens did not break into two pieces after crack was produced, ensuring the advantage of fibres.

It may be noted that coconut-fibre ropes were soaked in tap water for 4 h to remove coir dust and then ropes were dried in open air. Table 2 summarizes the properties of coconut-fibre ropes. These include ultimate tensile strength, corresponding strain, elongation at peak and total elongation. All values are the average of five readings.

2.5. Testing of columns

2.5.1. Shake table set up

The column specimen mounted on shake table is shown in Fig. 3. The base beam was fixed on shake table with the help of steel plates, washers and bolts. A mass of 125 kg was attached at the top of the column; this mass represents the equivalent mass of the super-structure. An accelerometer was attached at the top of column to measure response time histories.

2.5.2. Loading sequence

El Centro record (Fig. 4) was time scaled for producing damage in columns. The time scaling is shown in Table 2. First, a small impact load was applied three times at mid height. Note that the impact load was applied three times to take the average of resulting three values of a particular dynamic property. The original El Centro was applied to the shake table, and then impact load was again applied. Since the goal was to determine the dynamic properties at the damage stage, the magnitude of the impact load was kept low so that no additional damage was produced. After that, the decremental time scaled El Centro loading was applied to the shake table; followed by modal testing for determination of dynamic properties (Table 2). This was repeated until the occurrence of the first visible crack. Initially, a reduction of 10% in time scaling was selected, but due to crack in column RC-1 at 90% time scaled El Centro loading, a reduction of 2% was applied to columns RC-2 and RC-3.