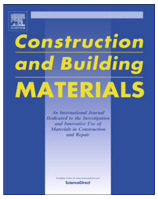
Construction and Building Materials 66 (2014) 533–540

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat



Residual compressive and shear strengths of novel coconut-fibre-reinforced-concrete interlocking blocks

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HIGHLIGHTS

- Residual strengths of interlocking blocks were determined experimentally.
- Blocks were made of coconut fibre reinforced concrete.
- The effects of age and dynamic loading are considered.
- Residual strengths were more than the referenced 28-days strengths.

ARTICLE INFO

Article history:
Received 21 March 2014
Received in revised form 7 May 2014
Accepted 31 May 2014

Keywords:
Coconut-fibre-reinforced-concrete
Interlocking blocks
Residual strength
Age of concrete
Dynamic loading

ABSTRACT

The results of an experimental study to evaluate the residual compressive and shear strengths of novel coconut-fibre-reinforced-concrete (CFRC) interlocking blocks are discussed in this paper. This work is part of a research project in which the development of mortar-free interlocking structures is intended for cheap and easy-to-built earthquake-resistant housing. Recently, mortar-free walls made of these blocks were tested under a series of harmonic and earthquake loadings. Only few blocks at the wall bottom were damaged, the other blocks (with no visual damage) had gone under numerous uplifts which might have affected the block strengths. In parallel, the blocks without any use over a period of time in tropical environment are also considered as coconut fibres are natural materials whose strengths might have decayed. These two cases represent two real scenarios in which (I) a structure stands without having an earthquake over a period and (II) a structure having a series of dynamic loading. In both cases, the residual strengths are of much interest to determine the remaining serviceable life of the structures. The results show that the impact of dynamic load histories on capacities of CFRC interlocking blocks was relatively more in comparison to the effect of age. The compressive and in-plane strengths were increased up to 3.2% and 5.7%, respectively, after undergoing a series of dynamic loading. This shows the advantage of earthquake loading on mortar-free structures.

1. Introduction

Technologies have been developed to safeguard human life and property from earthquake events. However, most seismic-resistant solutions are too expensive for the majority of people living in developing countries, particularly in rural parts [1]. In addition, there is usually a lack of skilled workers and sophisticated equipment to facilitate the construction process. Experience shows that relatively more people were killed or injured due to earthquakes in developing countries compared to those in developed countries. For example, the Armenia earthquake (1988) caused 25,000 deaths, and the Loma Prieta earthquake (1989) near San Francisco caused 63 deaths, while both of their magnitudes were around 6.9. In 2003, the Paso Robles earthquake in California had the same magnitude as that of Bam earthquake in Iran; the death number was 2 in California and 41,000 in Iran. Similar examples can be listed as: 1976 Tangshan in China (M 7.8, 243,000 died), 2005 Kashmir (M 7.6, 100,000 died) and 2010 Haiti earthquake (M 7.0, 316,000 died) in developing countries; and 1964 Alaska earthquake (M 9.2, 143 died), 2010 Chile earthquake (M 8.8, 525 died) in developed countries [2]. Chile earthquake (M 8.8) in 2010 was much more powerful than Haiti's one (M7.0), but the death toll was considerably lower (525 deaths and 316,000 deaths,

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http://dx.doi.org/10.1016/j.conbuildmat.2014.05.094
0950-0618/

respectively). Chile is one of Latin America's most stable and prosperous nations; Haiti is the country with the lowest income in the Western Hemisphere. Hence, the demand for a simple and low-cost seismic solution is a matter of great importance.

Being one possible solution, locally available natural fibres have been used as building construction materials. The main aim is to develop low-cost seismic solutions for the majority of people living in earthquake prone regions. Among seven common non-wood plant fibres, coconut fibre has the highest toughness [3] which makes it a suitable construction material for earthquake-resistant houses. It is abundantly available in tropical areas like Indonesia, India, Philippines, Thailand and Sri Lanka. These developing countries are in active seismic zones. Coconut-fibre-reinforced-concrete (CFRC) has been investigated by many researchers in past. Yipp et al. [4] concluded that compared to plain concrete, CFRC can absorb up to 30 times more energy in impact test. Ali et al. [5] reported that damping of CFRC beams increased with an increase in fibre content and damage level. It was also reported that the CFRC with 5 cm long fibres and 5% fibre content has an increased compressive strength, compressive toughness, modulus of rupture and total toughness index up to 4%, 21%, 2% and 910%, respectively, as compared to that of plain concrete. To achieve an easy-to-build and earthquake-resistant construction technology, Ali, M. invented the special interlocking blocks with unique shape and the blocks were cast with CFRC [6–8]. An optimum mix design ratio was developed to achieve the overall best static and dynamic properties of the blocks. The interlocking blocks can be pre-cast, mass-produced in a factory and delivered to a remote rural area which has no modern industry or construction facility. Hence, the use of CFRC interlocking blocks can also speed up the post-earthquake reconstruction process. No mortar is used in the interlocking block structures. Instead of binding all components by mortar bed joints in conventional masonry structures, interlocking blocks are held in place by gravity using a lock-and-key type mechanism. The distinctive construction mechanism brings several advantages to the mortar-free construction as compared to conventional masonry structures. The advantages include:

(i) dry-stacked interlocking block masonry can be constructed much faster and easier compared to conventional brick masonry [9];
(ii) in comparison to conventional masonry structures, interlocking block structures are subjected to less damage when subjected to earthquake loading [10];
(iii) during earthquake events, every interlocking block is allowed to move relative to each other. In a mortar-free interlocking block structure, earthquake energy input is mainly dissipated through friction between adjacent blocks, relative displacement and form micro-cracks of blocks rather than large cracks in bricks and failure in mortar bed joints in a conventional masonry structure [8,10]. Therefore, interlocking block structures have a high capacity of collapse resistance against an earthquake, so as to protect people from structural failure.

In mortar-free construction, the movable interlocking blocks can go under dynamic stress due to localised uplifts. This may increase or decrease the strength of the visually undamaged blocks after a number of earthquakes. Therefore, residual strength is of great importance. Previous experimental studies have proven that concrete strength can be influenced by the loading history [11,12]. It was found that for both long-term (10.5 years) and short time period (4 h) limited compressive loading (25% and 70% of 28-days strength, respectively) can increase the compressive strength of concrete specimens. Cook and Chindaprasirt [13] have indicated that there was a marginal increment observed to compressive strength of concrete after a sustained load history in which the samples were loaded to either 0.4 or 0.6 of the 28-days compressive strength. For a cyclic load history, the compressive strength was reduced from 2.5% to 16% after 10,000 cycles of 40% or 60% of 28-days compressive strength for 4 sets of concrete with different mix constituents. Zhou et al. [14] reported that after 10,000 fatigue life cycles with the greatest stress level was at 56.25% of the initial stress, the strength of concrete specimens decreased by 14% compared to the reference specimen. However, Bennett and Raju [15] reported that for specimens subjected to 1 million cycles at stress levels ranging from 30% to 53% of maximum stress, the strength increased by 4.8% compared to control specimens. Yip [16] reports that the strength of a core drilled from a parent concrete which had experienced a certain degree of compressive load history was lower than control group. The average strength reductions are 10.4%, 17.3% and 27.7% for 25%, 35% and 45%, respectively, of uniaxial compressive load history. For tensile strength, Cook and Chindaprasirt [17] found that prior sustained tensile loading decreased the strength and strain to peak stress of concrete. And it's worth noting that a cyclic tensile load history has no statistically significant effect upon the strength of concrete. Awad [18] indicates that plain concrete undergoes a "hardening" stage manifested by an increase in the static strength over the static strength prior to a sustained or repeated loading. All these studies state that the loading history can have influence on concrete properties, including strength, strain, and elastic modulus. Since CFRC interlocking blocks are recently invented, obviously no data/relationship is available for their residual strength after number of load histories.

Since coconut fibres are natural material, the strength of CFRC interlocking blocks can get influenced by the environmental conditions after a certain period of time. Ramakrishna and Sundararajan [19] reported that the strength reduction was high when the coconut fibres, exposed to alkaline mediums, were used in mortar, in spite of the fact that coconut fibres are found to retain higher percentages of their initial strength than all other fibres tested, after the specified period of exposure in all three considered mediums. Sivaraja et al. [20] reported that in the alternate wetting and drying curing condition, the rate of increments of compressive strength of CFRC specimens were gradually decreasing; the 2 years-aged specimens had not observed difference in compressive strength compared to 1-year-old specimens, while there was 12.94% of increment over 28-days specimens strength. The researchers also found that CFRC was less susceptible against sulphate attack in terms of mass loss and compressive strength deterioration; up to 49% of compressive strength deterioration was observed in CFRC specimens under the sulphate immersion period of 2 years. The age effect on the strength of CFRC interlocking blocks is also of great interest.

To the best knowledge of the authors, no study has been reported on residual strength of CFRC interlocking blocks after a number of dynamic load histories and over a period of time. This study aims to experimentally evaluate the influence of dynamic loading history upon shear and compressive strength of 15 months blocks. These blocks are obtained after the structure testing under dynamic loading. The strength results of 15 months blocks with no loading history are used to reveal the effect of dynamic loading histories. The strength results of 28-days blocks, presented in a separate study by Ali et al. [8], are used as reference.

2. Experimental work

2.1. Specimens

Interlocking blocks were cast from the CFRC composite material in timber moulds. The mix design ratio of CFRC is 1:4:2:0.64 (cement: sand: aggregates: water) with 5 cm long coconut fibres and 1% fibre content by mass of concrete materials. All specimens were cured for 28 days in tap water. Some specimens were