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Performance of bamboo reinforced concrete masonry shear walls

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HIGHLIGHTS

- Bamboo reinforcement provides enhanced shear capacity and ductility compared to unreinforced concrete block masonry.
- Bamboo reinforced shear walls showed remarkably similar behaviour to one reinforced with steel.
- Special care needs to be taken to prevent moisture absorption by bamboo in a cementitious matrix.
- The use of low strength block compared to regular strength block did not significantly affect the shear wall behaviour.
- Bamboo reinforcement presents a potential alternative to steel reinforcement for low-cost housing application.

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ABSTRACT

In this study, the results from tests on a total of seven squat concrete masonry walls under quasi-static, in-plane, cyclic loading are reported. One wall was reinforced with conventional steel reinforcement vertically and horizontally in bond beams. The other walls were reinforced with varying amounts of Tonkin cane bamboo reinforcement both vertically and horizontally in bond beams. The performance of the walls is presented in this paper comparing different reinforcement layouts and both partially and fully grouted walls. The significance of this study is that it shows bamboo to be a viable alternative to steel reinforcement, which could be of use in low-cost housing applications in regions where bamboo is more cost-effective than steel.

1. Introduction

In developing regions, affordable, safe housing is not readily available. The process of urbanisation traditionally goes hand in hand with economic advancement, as well as social progress, including the improvement of education, literacy, and health. However, with the rise of rapid urbanisation in developing regions, a handful of problems, such as the development of high-density 'slum' areas inevitably occur. Housing in these areas not only suffers from unsanitary conditions leading to the proliferation of disease, but is also generally unsafe in terms of providing shelter from storms and seismic events. Governments and individual municipalities in these regions face the huge task to find a balance between economics and safety for future housing projects. It has been estimated that as of 1993, only 73% of all housing structures in developing regions were permanent structures, and only 63% of permanent structures were in compliance with their respective building regulations [1]. Housing problems in developing regions have also been exacerbated by the poor development of housing technology, under use of the abundant unskilled labour, as well as the adoption of inappropriate housing policies and construction standard [2]. Estimates of the need for housing in these regions are in the order of 35 million units annually from the year 2000 to 2010, and 39 million units annually between the years 2010 and 2020 [3].

In Fig. 1, the distribution of seismic hazard around the world illustrates that a large portion of these hazards is present in developing regions. In conventional construction, reinforcing steel plays a significant role in creating earthquake and storm-proof housing. However, even at the low point of the fluctuating cost of steel, its use can be unaffordable in developing regions. Therefore, finding alternative, effective, low cost materials becomes extremely important to provide safe housing. This paper focuses on the use of bamboo as a replacement for steel reinforcing in masonry structures. It should be recognised that this is only a possible solution where bamboo is a native material and that there may be many

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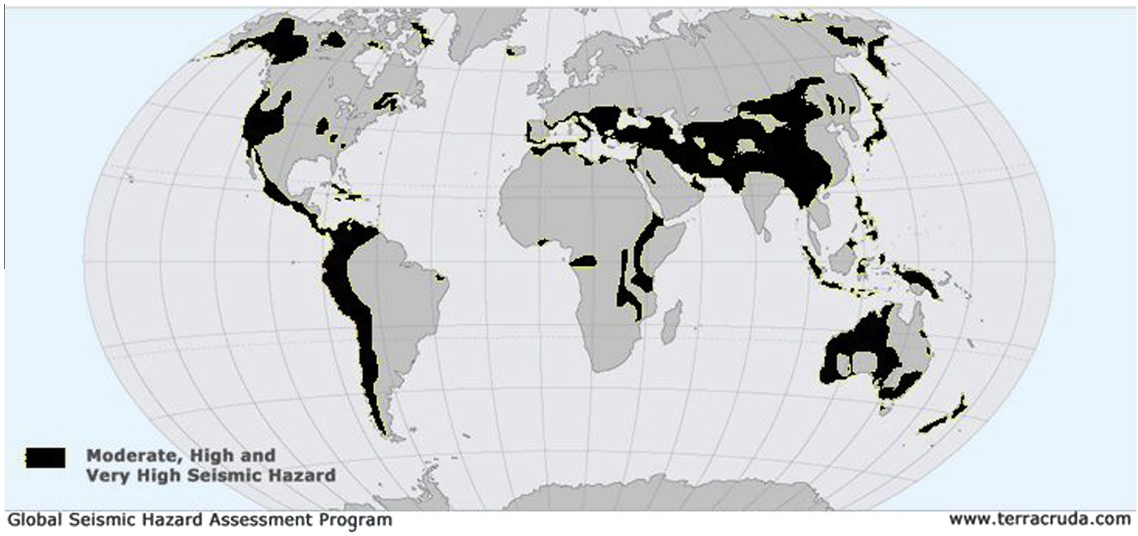

Fig. 1. World distributions of moderate and high seismic hazard [4].

other solutions. Each region will have its own unique culture and resources, both of which will influence the materials and manner in which safe housing could be constructed using technologies, aesthetics, and construction techniques that are embraced by the local population, utilising their own unique labour force.

2. Alternative materials

The key to any housing project is the choice of appropriate technologies for the specific region. For example, while the structural soundness of reinforced concrete is widely accepted, producing and using these conventional materials requires skilled labour, along with educated supervision, and the cost of producing or transporting them to a developing area is often prohibitive. Most developing regions have an abundance of labour, however, the labour force tends to be unskilled. In the case of developing regions, it has been recognised that "*it is intuitively obvious that housing production should evolve into a labour intensive industry with products which meet the effective demand for housing, using indigenous building materials*" [2].

Technologies for producing building materials in this case should have high labour intensity with limited specialised machinery, be locally manufactured and have a minimum of engineering input, once past the initial research phase. While this is not always possible, this has to be the ultimate goal of all low cost housing projects and research. Taking advantage of the abundance of local labour and resources can also stimulate the local economy.

Different structural materials that are a fraction of the cost of conventional materials have been explored in past research. For example, different materials have been investigated as cement replacement for mortar, including rice husk, rice ash, lime, gypsum fly ash, and furnace slag [5–8]. Earthen block is used widely in the world, but can suffer from poor durability, shrinkage and low strength. It has been proposed to stabilize earthen block with cement to increase the strength [5,9] or use fibres such as barley straw to reinforce earthen masonry and reduce shrinkage [10].

Masonry is one of the most common building materials, and is used throughout the world since construction is labour intensive, but the materials are relatively inexpensive, as they are widely available. It is used extensively in developing nations since it can be constructed by nearly anyone. In low cost housing applications, however, the high cost of steel reinforcement results in it being left out in the construction. It has long been reported and accepted in literature that the use of unreinforced masonry (URM) in seismic areas is not recommended, as it is one of the most vulnerable types of construction [11]. With the absence of reinforcement, these types of structures tend to exhibit a brittle, or non-ductile behaviour, and therefore are often unable to accommodate large inelastic deformations leading to sudden, catastrophic failure. This paper focuses on the use of bamboo as a replacement for steel reinforcing in masonry structures.

3. Bamboo as a structural material

Bamboo is a wood-like plant that is part of the grass family, consisting of a cylindrical hollow shoot, or culm. This culm is covered with a waxy surface, which prevents moisture from escaping. At intervals, the culm has raised ridges called nodes, from which branches will offshoot. The plant grows up from a throng of underground stems and roots, called 'rhizomes'. Some species can grow to a height of up to 30.5 m, with a diameter as great as 305 mm. An interesting property of bamboo is that the diameter of the shoot that grows out of the ground is the greatest diameter it will ever grow to. As one of the world's true "rapid" renewable resources, bamboo can have an extremely high growth rate, with some species growing up to 600 mm per day. Unfortunately, despite this high speed of growth, it still takes four to five years for the bast fibres, or so called "wood" fibres to mature [12]. The general physical features of bamboo are shown in Fig. 2.

One of the first major studies on the use of bamboo in a cement matrix came as early as 1914 [14]. The continued short supply of steel in the first half of the 20th century lead to further research of bamboo and many other materials for their construction poten-

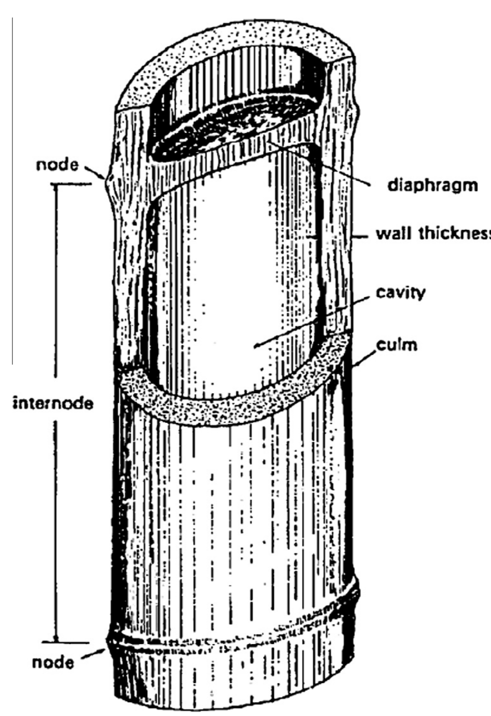

Fig. 2. General features of a bamboo culm [13].