Bamboo as a New Retrofitting Material for Existing Masonry Walls with Improving the Walls Aesthetic View

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Abstract— *Sri Lankan architecture is mainly based on masonry since ancient time. Among different types of masonry, Un-Reinforced Masonry (URM) construction has possessed the local culture of Sri Lanka especially in home/ residential building construction since ancient time. Unfortunately, URM buildings are the most vulnerable for earthquakes. It reveals that, the need of introducing proper techniques for retrofitting of URM buildings, especially for existing buildings is time essential. Bamboo is a unique building material in that it is strong in both rigidity and density; is now being used more prominently in all types of architecture. The objective of this study is to evaluate the performances of bamboo strips as an architectural material to retrofitting the existing URM walls against earthquakes.*

The test walls were constructed in double wythe with the size of 600 x 600 x 215 mm and retrofitted by using bamboo strips arranging as a mesh with the pitch of 50 mm. The retrofitted walls and the control wall were subjected to diagonal compression test. Bamboo strip mesh help the masonry wall to increase lateral resistance by 172.6%, compared to the non-retrofitted wall. Retrofitting technique improve the initial stiffness, energy dissipation and deformation capacity of the URM wall. Bamboo strip mesh enhances the ductility of URM walls. Therefore, Retrofitting of URM walls with bamboo strip mesh proved to be an effective and reliable strengthening technique against earthquake while improving the aesthetic view of the wall.

Keywords— Un-Reinforced Masonry Wall, retrofitting, aesthetic view

I. INTRODUCTION

Masonry structures are popular in Sri Lanka due to low cost, durable and less labour intensive and easy method of Un-Reinforced Masonry (URM) construction. Masonry is also eco-friendly, architecturally flexible, fire resistant and heat and sound insulation. Therefore URM construction has possessed a deep seated view in the local culture since ancient time.

Throughout the centuries, earthquakes have caused severe damages to human life and property in all around the world. Most of the deaths were recorded as a result of an earthquake was due to collapse of brick masonry structures as shown in Figure 1. December 26th 2004, when Sumatra Tsunami has adversely affected the Sri Lanka with the greatest human loss of around 30,000 and massive property damage. It is believed that there is diffused plate boundary in the making some 500 km south of the southern tip of the island (Dissanayake, 1999).

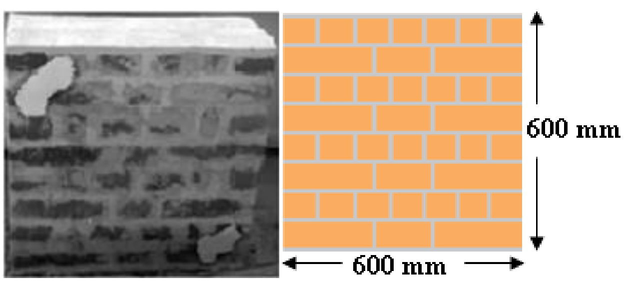
Figure 1: Failure of masonry Building against earthquake

Sri Lankans have experienced with minor earth tremors in and near the country region, since December, 2004. People have been increasingly affected by these tremors within last year. In addition, an earthquake occurred in Colombo area in 1615, has caused around 2000 of human deaths (Kodippili, 2009 and Uduweriya *et al.*, 2013). The threat of earthquakes has been risen up again with the number of earth tremors occurred in 2012 in Ampara, Monaragala and Badulla district areas. Earth tremors were recorded in Geological Survey and Mines Bureau (GSMB) stations in Pallekele, Hakmana and Mahakanadarawa. The Richter magnitude of the tremors was between 2 to 4. The tremors were developed small cracks in masonry structures and expansion of existing cracks. Most of the earth tremors affected areas in Ampara; Monaragala and Badulla districts are rural villages, where the main occupation of the villagers is farming(Mendis, 2014). Therefore, it is suitable to identify and introduce suitable techniques to strengthen the existing URM buildings to be earthquake resistant.

Bamboo is a unique building material in that it is strong in both rigidity and density; is now being used more prominently in all types of architecture. Application of bamboo reinforcement may generate several advantages. Cost effectiveness, easiness of applying, no expert knowledge to apply, and availability of materials are some of them. The objective of this study is to evaluate the performances of bamboo strips as an architectural material to retrofitting the existing URM walls against earthquakes.

II. Methodology

A real scale model test makes possible to obtain data similar to real structures. Therefore, full scaled models were used in this experimental programme. Burned solid clay bricks (i.e., size of a brick: 215 x 102.5 x 65 mm) which are commonly used in constructing load bearing masonry walls in Sri Lanka, were used to build the test walls (Figure 2(a) and (b)).

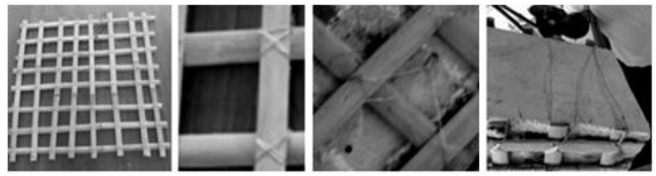


(a) (b)

Figure 2: Wall configuration; (a) Un-reinforced burned clay brick masonry wall and (b) Wall geometry

Mortar joint thickness was 10 mm and the 1:6 cement-sand mortar (i.e., in volume basis) was used. A certain number of holes were made at designed suitable spacing only in one wall which would be retrofitted with bamboo strip mesh, by placing plastic straws at the construction of these test walls. Those holes would be used to inserting galvanized steel binding wires to connect the bamboo strip meshes to the wall. The walls were cured with water spray for 28 days. At the end of curing process, bamboo meshes were attached to the walls as retrofitting technique.

People are capable of finding bamboo with little or no cost worldwide. Bamboos are also popular in most countries in earthen wall construction where bamboo strips are used to prepare the internal frame work.



(a) (b) (c) (d)

Figure 3: Bamboo strip mesh method; (a) Prepared bamboo mesh, (b) Binding cross points of mesh, (c) Connecting mesh on wall surfaces and (d) Connecting two meshes each other

Two meshes were prepared to retrofit the selected URM wall having 5 mm thick and 20 mm wide sixteen yellow bamboo strips were arranged in a mesh pattern with a pitch of 50 mm to prepare the mesh as shown in Figure 3(a), Each cross point of the mesh was tightly connected using galvanized steel binding wires (Figure 3(b)). The masonry wall was symmetrically retrofitted with two meshes as one mesh on each wall surface of 600 x 600 mm, using binding wires inserted through holes in the wall as shown in Figure 3(c). Afterwards, two meshes were connected each other (Figure 3(d)) at four wall surfaces of 600 x 215 mm with binding wires. Meshes were bonded each other due to purpose of giving effect of foundation, roof and supporting walls at bottom level, top level and left and right sides of the wall, respectively. The resulting structure was an integrated matrix, with strong connection between wall and the mesh.

A. *Experimental Test Setup*

Figure 8 shows the experimental setup used in the laboratory to determine the shear failure masonry walls and to evaluate the effectiveness of proposed retrofitting methods against in-plane static loads. Diagonal compression test which is available to investigate the in-plane diagonal shear strength of masonry walls was carried out on test specimens and ASTM E-519-02 standard guidelines were used in the test setup.

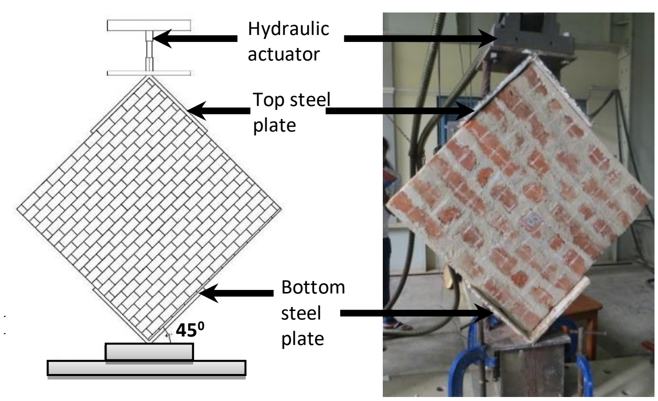


Figure 4: The test setup; (a) Schematic diagram and (b) NRUMW at the test setup

Two steel angle plates were used to bolt the specimens to the loading frame. A 5 mm thickplaster of paris layer was applied on both steel plates where the interface between the test wall and the steel plate. This layer is crucial to carry out a better load tranformation from steel plate to the test wall. One of steel angle plates was bolt to hydraulic actuator and other plate was placed on a support attached to the loading frame just below the actuaor as shown in Figure 8(b). Then, specimen was carefully installated into loading frame and the specimen was checked for vertical alignment using plumb bob.

The load was applied on test walls along the vertical diagonal of the wall using the server controlled hydraulic actuator at a rate of approximately 0.1 mm/s under the displacement controlled method. The applied diagonal force on the walls and the corresponding displacements along the vertical diagonal (i.e., along the loading direction) of the walls were recorded over the time. Crack initiation and propagation and failure pattern of the walls were also observed.

III. RESULTS AND DISCUSSIONS

Figure 5 shows the crack patterns observed on control specimen just before its collapse. Crack initiation in URM wall was observed in the mortar bed joints and mortar head joints and cracks were developed and propagated along the mortar joints. There were no cracks initiated and developed through bricks. It could be observed that, propagation of cracks was in wider area on surface of wall with bamboo strip mesh (Figure 5(b)), instead of concentration few major cracks into specific area as in control wall.

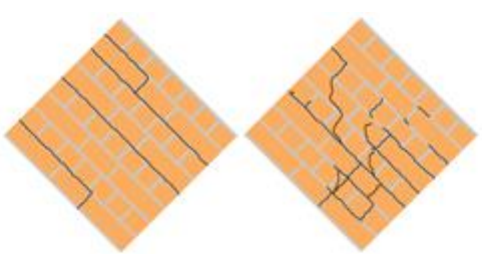


Figure 5: Crack formation of test specimens; (a) Control wall panel (b) retrofitted wall panel

“Diagonal shear cracking” is the common masonry failure mode under seismic loads and happens for a combination of vertical and horizontal loads where the principal tensile stresses developed in the wall due to this action, exceed the tensile strength of masonry. Afterwards, cracks were along a bed joint causing sliding of the upper part at that location which is generally called as “shear sliding” (Figure 6).

(a) (b)

Figure 6: Wall panels at the end of the test; (a) Control wall panel (b) retrofitted wall panel

The bricks have not been damaged at failure of conventional URM wall and bricks have been separated due to the failure of mortar joints (Figure 6(a)) leading to collapse of the wall. The main effect of the bamboo strip mesh is to restrain the separated masonry fragments for allowing the redistribution of the load within the masonry itself.

Vertical bands apply normal compression once sliding of rows (Figure 6(b)) occurs, resulted in increasing the masonry’s frictional resistance to shear sliding. Through friction, energy from alien stresses is dissipated. Vertical bands also redistribute the load eliminating the concentration of load at same masonry course but allowing deformation of wall panel. Horizontal bands directly bear load by resisting the separation of bricks within the same row allowing vertical bands to keep redistribution of the load over long period preventing or delaying loss of debris. Both types of bands together give an improving of ductility with rigid box like action of enclosures resulted in preventing the collapse of damaged masonry walls on occupants, passengers and nearby buildings.

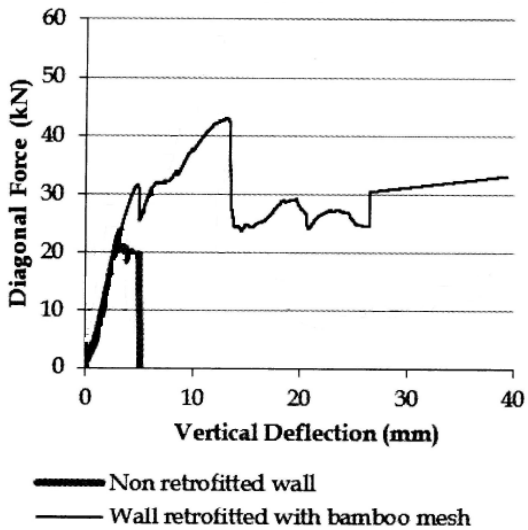


Figure 7: Load variation with deflection

Figure 7 shows the diagonal compressive force variation with deflection of vertical diagonal of wall along the loading direction for all the test walls with and without retrofitting.The load at critical crack initiation (i.e., also peak strength) of control wall was 26.70 kN. However, there was no regaining of strength again and no residual strength left after cracks appeared in control wall. The control wall exhibited an approximately linear behaviour up to first visible cracking and then failed suddenly along a diagonal step joint and bed joint when they reached their diagonal tensile strength.

In wall with bamboo strip mesh, initial visible cracking was followed by a sharp drop with remaining of 77.9% its peak strength. After it, subsequent strength drop was quickly regained due to characteristics of both elastic behaviour of materials (i.e., bamboo) and the arrangement of mesh formation. The peak load, after first visual cracking, for wall with bamboo strip mesh was nearly around 44 kN. At the end of the test, the control wall showed stepped joint sliding and bed joint sliding, the retrofitted walls with bamboo strip mesh did not lose its stability. This is due to the better rigid box like action by bamboo strip mesh. The wall with bamboo strip mesh also showed cracks which were larger in number, smaller in magnitude and propagated over wider area. Wall with bamboo strip mesh also kept residual strength in better manner compared to control wall (Figure 7). Bamboo strips have higher tensile and compressive strength which give higher frictional resistance against shear sliding resistant to avoid separation of bricks within same brick course of enclosures of wall with bamboo strip mesh vertical bands give higher frictional resistance against shear sliding and dissipate more energy, while horizontal bands give more resistant to avoid separation of bricks within same course.

A. *Architectural use of Bamboo Strips*

Bamboo is currently used as architectural material for constructing roofs and ceilings, walls and non-load bearing columns (Figure 8).

Figure 8: Bamboo as construction material (a) Roof and columns (b) walls

The use of bamboo as retrofitting material to strength the existing masonry wall has benefits other than strengthening the walls. The surface of existing wall may blemish and discolour due to aging and environmental conditions. Sometimes, vegetable cover (i.e. algae) may present on the wall surface. The plaster may be damaged. Covering the wall surface by using bamboo strips will refresh the wall surface. Further, it reduce the cost for repairing and painting of the wall surfaces. Use of bamboo strips with patterns (ex. Figure 8b)) improve the aesthetic view of the building. Even, colouring of the bamboo strips can be used to improve the architectural properties of the walls. Use of natural material as retrofitting work will give artistic view for the existing building.

B. *Increasing Durability of Bamboo Strips*

Bamboo mat walls usually last around 4-5 years at outdoor conditions without any treatment. However, when using bamboo for retrofitting purpose, it is important to apply a chemical preservative treatment to resist insect attack for long life period of reinforcement. Simple chemical preservative treatment methods will increase the durability of bamboo in 3 or 4times of their normal life period though they increase the cost by 20 – 25% of retrofitting procedure. After treatments they will last for 15 – 20 years. For this purpose, a typical preservative can be prepared to be mixed in the tank in the following proportions: Copper sulphate 4%, Sodium Dichromate 4%, Boric Acid 2% and Water 90%, in volume. The materials should preferably be freshly harvested, but dry ones can also be treated. Bamboo battens and mats are to be first soaked in water for at least 24 hours and then dried. They are then to be immersed completely in the chemical preservative solution for 24 hours. Then they must be dried in an open shaded

iv. CONCLUSIONS

Past earthquakes have shown that the collapse of seismically weak URM structures is responsible for most of the fatalities in developing countries. It is thus urgent to improve their seismic performance to reduce future fatalities and protect the existing housing stock.

The diagonal in-plane shear behaviour of URM walls retrofitted using bamboo stripswas investigated. The effectiveness of the schemes of reinforcing mesh type to restrain the diagonal cracking failure mode was studied. The study grid pattern reinforcement applied to double-wythe thick walls. Parameters pertaining to seismic behaviour were determined, including ultimate load carrying capacity, diagonal deflection, crack pattern and failure mode and degree of failure. The results were compared to those obtained from non-retrofitted URM wall. The increment of ultimate in-plane load carrying capacity of a masonry wall by bamboo strip mesh was 36.9%. The control wall showed a sudden brittle failure and was unable to maintain further load. This catastrophic failure possesses significant danger to building occupants during earthquakes. According to the experimental results, cracks in URM wall originate and spread along the mortar joints of the wall. The wall with bamboo strip meshallowed specimens to maintain load after initial failure with regaining and redistributing of load over the masonry and dissipation energy by friction; and prevented the brittle failure by allowing occupants to identify the damage level and evacuate from the houses. Further, proposed retrofitting technique of bamboo strip mesh caused the smaller cracks propagating over wider area of the wall.Bamboo strip mesh technology may potentially be used to delay the brittle failure of URM structures under static diagonal in-plane shear loading due to its effective behaviour as well as low cost, high availability and relative simplicity of the technique.

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