EXPERIMENTAL STUDY OF BAMBOO AS A HOUSE RETROFITTING MATERIAL FOR DEVELOPING COUNTRIES

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ABSTRACT

Earthquake is one of the main natural disasters which frequently occur in West Sumatra. Large earthquake September 30, 2009, has caused damage to the structure and caused many casualties. Due to this condition, this research was made to study bamboo as a house retrofitting material for developing countries. Mechanical and physical properties such as moisture content testing, testing density, testing of compressive strength and tensile strength were conducted. It is obtained from the test results, the highest compressive strength and tensile strength are 94.958 MPa and 183 MPa, showed by Betung bamboo. Shaking table test are also undertaken to investigate the seismic behavior of bamboo masonry wall. Two degree of masonry walls, 60° and 90° are tested in order to check the strength of masonry wall by direction of the coming of an earthquake. From the shaking table test, it was observed that a 60° masonry wall showed a better seismic performance than those of a 90° masonry walls. Small cracks were observed at 90° masonry walls after 20 seconds, while there was no crack at a 60° masonry wall. As a result of these test, using bamboo as a house retrofitting material could be chosen, both of technically and economically.

Keywords: earthquake, retrofitting, bamboo, tensile test, shaking table test

INTRODUCTION

The geographical location of the Sumatra Island, West Sumatra in particular, is on a meeting point of two large plates of the world, namely the Eurasian plate and Indo-Australia plate, and also passed by the fault Semangko Mentawai (near the confluence of two plates). This condition makes the areas along this plate especially West Sumatera become vulnerable to the earthquakes. Large earthquake that occurred on 30 September 2009 with Magnitude 7.6, has resulted in damage to both buildings were slightly damaged, moderately damaged, or destroyed. The earthquake has also caused a number of fatalities to 1,100 people died and 3,000 were wounded (SNS, 2010). The number of houses that were damaged severely damaged category reached 114 797, 67 198 were damaged, and 67 839 with minor damage (Andalas University Centre for Disaster Studies, 2010). The majority of the damaged houses are houses without retrofitting of masonry (brick masonry unconfined) or with a reinforced concrete frame (confined brick masonry) (*SNS, 2010*).

BUILDING STRUCTURE ANALYSIS IN POST-EARTHQUAKE PADANG 30 SEPTEMBER 2009

Survey were conducted a few days after the earthquake 30 September 2009 shows variety of conditions the collapse of several masonry houses located in Padang city, as shown below

Figure 1. Condition of Masonry Houses after earthquake

Generally, the damage condition occurs in non engineered buildings, but no less severe failure occur in engineered buildings, caused by an incorrect construction practices or building code (*Steffie, 2010*). An earthquake occurs in West Sumatra in September 2007 has provided an early warning that the possibility of a larger earthquake could occur and would cause severe damage if construction authorities do not pay attention to the correct building code in construction practices. In fact, many people do not learn from the experiences and only a moment's attention to get more profits. Based on a field survey to several buildings and masonry houses in Padang, various damages were obtained (Figure 1 and Figure 2).

Figure 2. Mitsubishi Motors Building

Types of collapse that occurred in these buildings due to earthquake 30 September 2009 include; beam-column joint failure, soft story effect, short column effect, joint failure, and overturning

COMPARISON STUDY TO BAMBOO

Earthquake that has frequently occur give a lesson to us about what we have to prepare before the quake come, so that it can reduce the damaging effects arising from the earthquake. The use of bamboo as a reinforcement material quake-friendly house has been piloted in El Salvador (*Stephen Jones, 2009*), having tested the strength and modulus of elasticity of the building structure. The use of bamboo as a building capable of vertical reinforcement provides increased strength at the time the quake occurred at a time can reduce the crack in the wall (*Andrew Smith, 2009*). Installation of a vertical bamboo tied with chicken wire that is placed horizontally *(Andrew Smith, 2009*). Sydney University, Australia, also conducted research on the use of bamboo as reinforcement by placing a vertical bamboo on the inside and outside of the wall (*J.Macabuag, 2010*).

The current method of reinforcement constituting bamboo is to use it as part of a system involving buttresses, a ring beam, internal vertical reinforcement (bamboo) and horizontal internal reinforcement (also bamboo). It has been shown that this system increases the collapse time of adobe structure but has little capacity to prevent cracking at low intensity ground motions. (*Smith and Redman, 2009*)

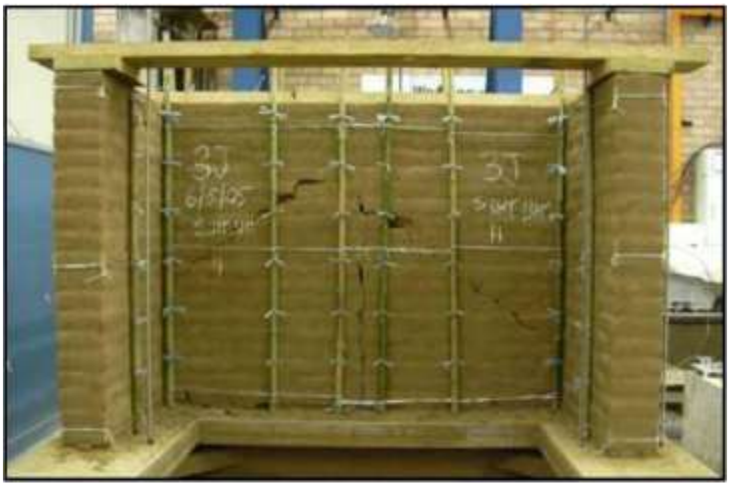

Figure 3. Bamboo reinforced wall with ring beam, Dowling et al.(2005)

It was proposed by *Dowling et al. (2005*) that the same partnership of ring beam and bamboo reinforcement could be used with vertical reinforcement being externally fixed post-construction (see Figure 3). By installing vertical reinforcement after wall construction, complications such as alignment of the reinforcement and trimming of the bricks are avoided. Horizontal chicken wire mesh was used in one of the models alongside the bamboo and ring beam. During testing, all reinforced structures survived up to a 100% increase in displacement intensity, where collapse was then imminent. Better reinforced models survived up to a 125% increase and one heavily reinforced model up to 400%, with collapse still not imminent.

If fixed to wall exterior, method is easily buildable. If horizontal reinforcement is tied on the exterior of the wall, it will overlap openings causing practical and aesthetic problems. Mud bricks surrounding the bamboo will not provide adequate protection against water intrusion and also makes maintenance/inspection of bamboo difficult. Installation is quick to learn for local builders but they need to understand the key earthquake engineering concepts involved.

Retrofitting systems for masonry buildings aim to enhance the integrity of the structure by (*J. Macabuag, 2010*):

- Providing proper connections between resisting elements in such a way that inertia forces generated by the vibration of the building can be transmitted to the members that can provide resistance, and/or:

- Holding disintegrated elements together so as to preventing collapse.

Methods required to meet the needs of the large populations in danger of non-engineered masonry collapse must be simple and inexpensive to match the available resources and skills (*Mayorca, 2003*). Some examples of low-cost retrofitting techniques suitable for non-engineered, non-reinforced masonry dwellings are given in Table 1. This list is not exhaustive (*Redman*).

Table 1: Existing retrofitting techniques for non-reinforced masonry in the developing world

Method	Developing Institute	Description
Polypropylene (PP) Meshing	Institute of Industrial Science (IIS), Tokyo University, Japan	Encasing masonry walls with a mesh constructed of polypropylene strapping (*Mayorca*)
Wire Meshing	Pontificia Universidad Católica del Peru, Peru	Similar to pp-meshing, but using a steel wire mesh (*San Bartolome*)
External Vertical Bamboo Reinforcement	Sydney University, Australia	Vertical bamboo canes placed adjacent (inside and outside) to main external wall (*Dowling*)
Internal Vertical Bamboo Reinforcement	Pontificia Universidad Católica del Peru, Peru	Applied to double-leaf walls. Bamboo placed vertically between inner and outer leaves Geogrid mesh reinforcement
Geogrid mesh reinforcement	Pontificia Universidad Católica del Peru, Peru	Similar to pp-meshing, but using civil engineering geogrid, used for slope stabilisation

The use of natural materials are also much recommended today due to the material adverse impact on nature and lead to global warming (global warming), enhance the creativity of the population and reduce costs, so well known by the term "Eco-Retrofitting" (Janis Birkeland, 2009) . Therefore, as one of earthquake prone countries, and with the availability of bamboo, it is good to use this material as one of retrofitting materials for houses.

EXPERIMENTAL RESEARCH

International Standard ISO 22157-1, Bamboo-Determination of physical and mechanical properties, is used as method in this experimental research. Mechanical and physical properties such as moisture content testing, testing density, testing of compressive strength and tensile strength were conducted. The location of the bamboo made in two areas, in Solok and Padang. There are seven types of bamboo taken in Solok; Buluh bamboo, Betung bamboo, Kuning bamboo, Licin bamboo, Aur duri bamboo, Talang bamboo, and Talang kuning bamboo. While in Padang we used three types of bamboo; Betung bamboo, Buluh bamboo and Kuning bamboo. However, the main bamboo used for the test is Buluh Bamboo.

RESULTS AND ANALYSIS

Based on the test results it can be seen that Betung bamboo has a very good quality. However, growth of Betung in Padang is not as much as Buluh Bamboo so that we used Buluh Bamboo as reinforcement material in the wall. Design of retrofitting walls using Buluh bamboo can be seen in Fig. 4, where the installation of bamboo mesh were applied inside and outside of the walls and tied by chicken wires.

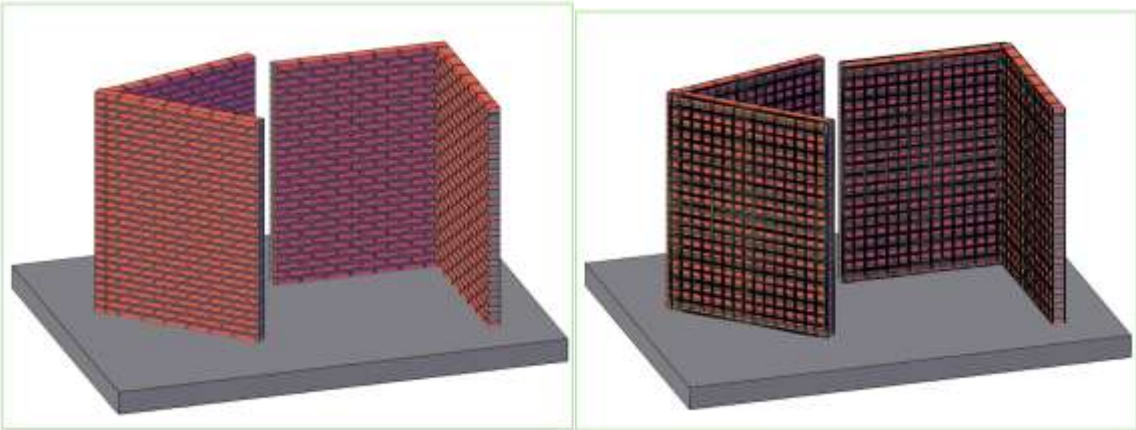

Figure 4. Design of Retrofitting walls without and with bamboo

The water content of bamboo was very influential on the compressive strength of bamboo. Bamboo Solok deliver great results for water content and compressive strength, due to the percentage of water content which is smaller in the appeal of bamboo Padang. In addition, the growing of bamboo is also very influential on the water content of bamboo. Buluh Bambu took in Padang which growing at the edge of the river, so that water absorption is higher than the bamboo in Solok (Fig.5).

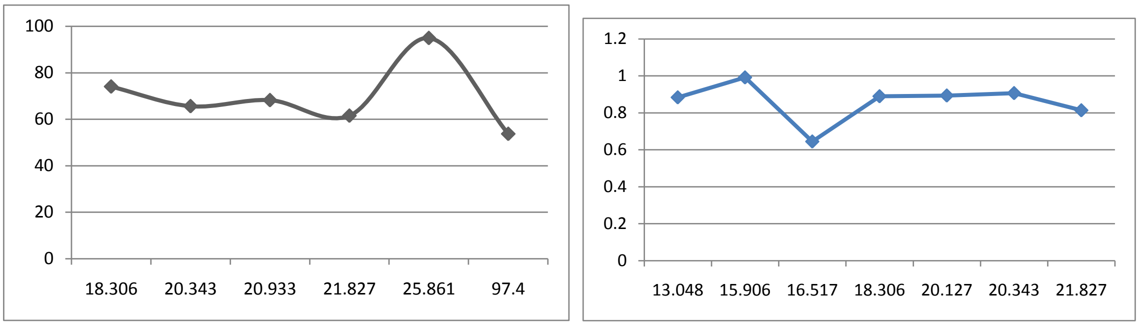

Figure 5. Water Content vs Compressive Strength (left) and Water Content vs Density (right)

From the test result it is showed that the lowest water content and the highest density (Fig.5), the highest compressive strength and tensile strength. Betung bamboo showed the highest compressive strength and tensile strength which are 94.958 MPa and 183 MPa. Buluh bamboo showed 61.494 MPa of compressive strength and 50 MPa of tensile strength. Kuning bamboo reached a higher compressive strength than Buluh bamboo is 68.188 MPa, but it is difficult to find and tested for tensile

strength as in international standard. Due to the availability and easiness to find, Buluh bamboo is likely suggested to use as retrofitting material, although its strength lower than Betung bamboo.

Testing bamboo as retrofitting material on the wall is made from brick masonry with measurement 1.5 m in width and 2 m in height. Two models of retrofitting walls are tested which angle of 90° and 60° (Fig. 6). It can be seen in Figure 7, bamboo wall at angle of 90º had more crack and collapse first than bamboo wall at angle of 60º angle.

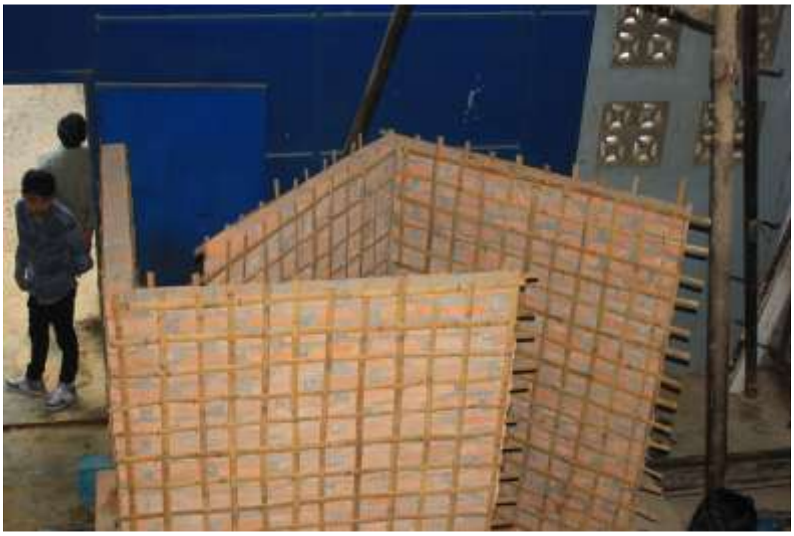

Figure 6. Bamboo wall at 90° and 60° angle before testing

Figure 7. Bamboo wall after shake table testing

The following is the result of comparison of water content, density and compressive strength and tensile strength of each type of bamboo Padang and Solok:

Table 2 Water Content Moisture (%) and Density (gr/cm^3)

Type of Bamboo	Padang		Solok	
	Water Content	Density (gr/cm^3)	Water Content	Density (gr/cm^3)
Buluh	97.400	0.527	21.827	0.814
Betung	25.861	0.841	18.306	0.890
Kuning	20.933	0.826	20.343	0.907
Aur Duri	-	-	20.127	0.894
Licin	-	-	15.906	0.992
Talang	-	-	13.048	0.884
Talang Kuning	-	-	16.517	0.645

Table 3 Compressive Strength of Bamboo

Type of Bamboo	Compressive Strength (MPa)	
	Padang	Solok
Buluh	53.659	61.494
Betung	94.958	74.046
Kuning	68.188	65.590
Aur Duri	-	70.140
Licin	-	56.812

Table 4 Compressive Strength vs Water Content

Type of Bamboo	Water Content (%)	Compressive Strength (MPa)
Betung Solok	18.306	74.046
Betung Padang	25.861	94.958
Buluh Solok	21.827	61.494
Buluh Padang	97.400	53.659
Kuning Solok	20.343	65.590
Kuning Padang	20.933	68.188

Table 5 Tensile Strength of Bamboo (Padang)

Type of Bamboo	Sampel	Lo (mm)	to (mm)	A (cm^2)	Pu (kgf)	Tensile Strength	
						kg/cm2	MPa
Buluh	1	18.0	4	72.00	245	340	33
	2	20.4	3	64.46	330	512	50
	3	19.7	3	63.04	210	333	33
Betung	1	23.7	3	66.36	1240	1869	183
	2	21.7	2	52.08	810	1555	153
	3	19.4	3	52.38	720	1375	135

CONCLUSION

It can be concluded that:

1. Earthquake is a natural disaster due to the geographical conditions. Type of collapse that often to occur are beam-column joint failure, soft story effect, short column effect, joint failure, and overturning.

2. The damage varied in a variety of structures due to lack of knowledge of the Building Code and the lack of proper supervision by both consultants and other authorities.

3. Using bamboo for retrofitting is one of good alternative, because it is simple, cheap, and easy to find, no skill needed to make the retrofitting and have high tensile strength.

4. Due to the limited availability of this bamboo in Padang, Betung was replaced by Buluh bamboo which also has high compressive strength and tensile strength. In addition, Buluh bamboo is more economical because it is easy to find in Padang.

5. Based on the research above, it means that bamboo can be used as one alternative for retrofitting earthquake-friendly masonry house. Especially in West Sumatra, where bamboo is quite commonly found.

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