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Investigation Of Elasticity, Compression And Shear Strength Of Masonry Wall From Indonesian Clay Brick

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ABSTRACT

Hand made clay brick as local material most widely used as structural walls of buildings and dwelling in Indonesia. The problems that arise concerning this material are very much in earthquakes. Design of load-bearing brick masonry buildings to withstand vertical and lateral loading due to earthquake depends on the knowledge of behavior and failure mode of masonry in compression and shear. In Indonesia this material is studied with reference refers from western country. Research originating from Indonesia is still limited number of publications. It required more research about the properties of this brick, so that problems arising out of this material will be more rational and precise handling. These studies focused on the elasticity, compressive and shear strength of masonry wall. Materials for this research came from several areas in East Java. The masonry wall models were made according to the way people's habits in East Java. Standard tests were the ASTM and SNI (Indonesian code). The results and discussion show the behavior of local brick wall is different from those described in the foreign references (western country). Based on this study required a different theory in analyzing the strength and the failure mode of the masonry wall structures.

Keywords **–** clay brick, hand made, modulus of elasticity, theory, western country

1. INTRODUCTION

materials for the walls of the most widely used in Indonesia is the local red brick. these materials used as structural walls of buildings and dwelling. building with red brick wall structure in indonesia have not been using rebars as reinforcement. it is known as unreinforced masonry. the use of confined masonry has also been widely recognized in urban areas, and vice versa in rural areas. in the countryside there are still many dwellings without confined masonry structures. it is thus necessary to note that indonesia was in the earthquake zone, so the load that destroyed the building is earthquake load. this is shown in the events of earthquake some time ago.

Structural wall is necessary to be supported by their constituent materials, especially brick unit. In fact, the bricks around East Java has not met the quality as desired by the code in Indonesia [1, 2].

According to code in Indonesia about a clay brick [3,4,5], the range of compressive strength is at 25 kg/cm^2 to 250 kg/cm^2. The dimensions of the bricks is in the range 55 mm to 65 mm thick, 90 mm to 110 mm for width and 190 mm to 230 mm for length. Bricks are sold on the market have dimensions that deviate quite far from the code.

When the strength is below that required, it needs to be reviewed on the deformation and rigidity of the elastic properties. It is very important to know the behavior of structures when exposed to earthquake load. Design of load-bearing brick masonry buildings to withstand vertical and lateral loading due to earthquake or wind depends, in part, on the knowledge of the behavior and failure mode of masonry in compression and shear.

In Indonesia this material is studied with references refer from western countries. Research originating from Indonesia is still limited number of publications. This study focused on the compressive strength, shear strength, and elasticity of masonry structures from local materials, particularly from East Java. Research focuses on hand molded bricks

2. RESEARCH METHODOLOGY

Materials for this research were the red brick from several areas in East-Java. All of bricks were hand molded brick or country brick that was not created using brick molding machine. But these bricks are widely used as building material in the vicinity of East Java. Wood and rice husk are the fuel in the manufacture of bricks. The bricks used came from these areas:

a) Pakis, Malang.
b) Gondanglegi, Malang.
c) Watesumpak, Trowulan, Mojokerto.
d) Silir, Wates, Kediri.
e) Wonorejo, Sumber Gempol, Tulungagung.

Sand used as material for mixing mortar was Wlingi sand with gradations in Table 1. Cement materials using type OPC (Ordinary Portland Cement). This cement is commonly used in practice. Standard test for materials were the ASTM and SNI (Indonesian code).

TABLE 1. GRADATION OF WLINGI-MALANG NATURAL SAND

Sieve size	Percent passing
9.5 mm	100
4.76 mm	96.17
2.38 mm	87.06
1.19 mm	68.69
0.59 mm	45.45
0.30 mm	16.88
0.15 mm	5.95
0.075 mm	0

The research was conducted in the laboratory by making a model test object. The shape and relationship test object shown in Fig. 1. Hand made clay brick and test set up in the laboratory shown in Fig.2. Modulus of elasticity for mortar test uses a standard cylindrical shape in order to use existing equipment.

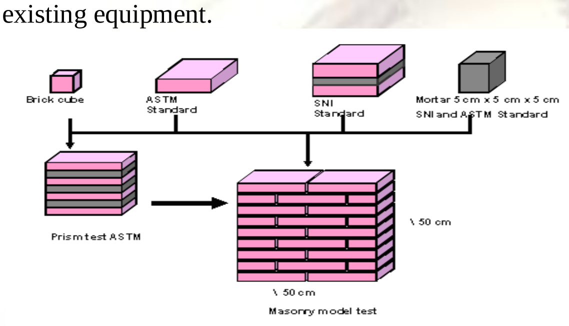

Figure 1. Chart of models test and its components.

Mortar is a mixture of OPC and sand with a volume ratio of 1:5. The amount of water to meet the needs for consistency of 0.8 to 0.9 of the OPC. The thickness of mortar in prisms and walls is 1.5 cm. Another standard test is also performed as a test absorption, IRA, unit weight and dimensional measurements. These tests followed the ASTM standards for brick [6].

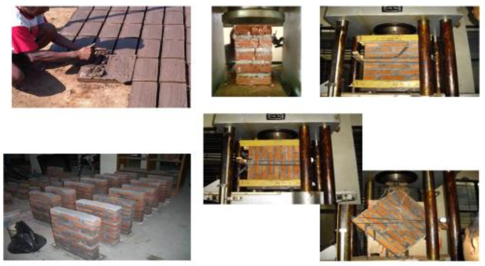

Figure 2. Hand made brick and test set up in the laboratory.

Deformation behavior is discussed in the test specimen cube of brick, mortar, prisms and masonry wall models. In line with this also discussed the behavior of elasticity. Brick materials is ceramic, then test using the chord modulus as ASTM E-111-97 with 0.05 and 0.33 from maximum stress to take a modulus of elasticity.

Compression test for wall models is done two types, first is perpendicular to bed joint and second is parallel to bed joint. Shear test is based on ASTM E 519-02 [7] or SNI 03-4166-1996 [8].

3. RESULTS AND DISCUSSION

After testing and do a comparison with the brick wall structure from western countries, it shows that theoretical calculations in the reference are based on conditions in the wall structure of those countries. This condition is different from results of this study. Masonry walls from western countries were formed from the strength of brick is higher than the mortar [9,10,11,12]. The results obtained in this study generally found that the strength of brick was under the strength of mortar, so the mortar becomes an important role in the behavior of the wall structure. The bricks are part of the weakest in the process of structural damage of masonry walls.

Unit bricks, mortar and interface are the three components that determine the strength of the masonry structure [13, 14]. Interface between brick and mortar influenced the physical properties at brick and mortar attached. In this study attempted influence of these physical properties as small as possible by treating the water content of the brick after reviewing the value of the IRA and the absorption of bricks. Quality mortar made equal for all test treatments. Thus the main influence in this study only the characteristics of the bricks.

Characteristics of bricks from some areas of East Java is shown in Table 2 and Table 3. The results show the characteristics of local brick wall is different from those described in the foreign references. Elasticity properties associated with the stress-strain behavior shown in Fig. 3 to Fig. 6 about stress-strain relationship of mortar, unit brick and prisms in compression. The pictures shows the elasticity or stiffness of mortar is higher than the bricks and prisms that result. Fig. 7 is a common occurrence for the behavior of masonry on the western countries and all of the masonry equations derived from such conditions. Fig. 7 shows mortar has a lower strength and stiffness than the brick units.

Reviewing the relationship stress and strain of each ingredient masonry wall (Table 4 and Table 5) appear the biggest deformation at the ultimate on the brick units. With a modulus of elasticity lower than mortar, and larger deformation than mortar can be suspected cause of the initial collapse was a brick unit.

Table 2. Compressive strength characteristics of bricks

Location	Test cube (kg/cm2)	Test SII-78 (kg/cm2)	ASTM C67-07 (kg/cm2)
Pakis,Malang	8.32 (0.29)	6.09 (0.41)	7.17 (0.54)
Mojokerto	21.28 (0.42)	12.58 (0.60)	9.36 (0.33)
Kediri	10.50 (0.30)	7.89 (0.38)	5.97 (0.64)
Tulungagung	27.21 (0.47)	18.26 (0.44)	--

Note: Numbers in parentheses indicate coefficient of variation.

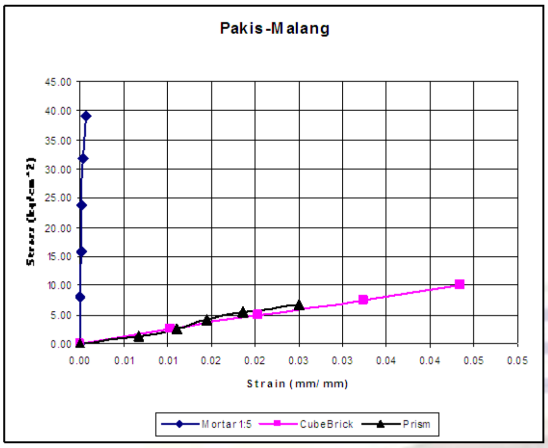

Figure 3. Stress-strain mortar brick and prism for brick from Pakis-Malang up to peak load.

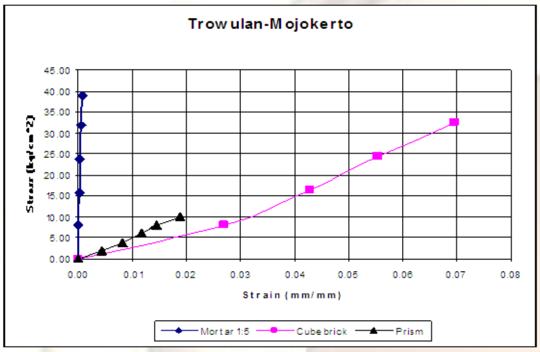

Figure 4. Sress-strain mortar brick and prism for brick from Trowulan-Mojokerto up to peak load.

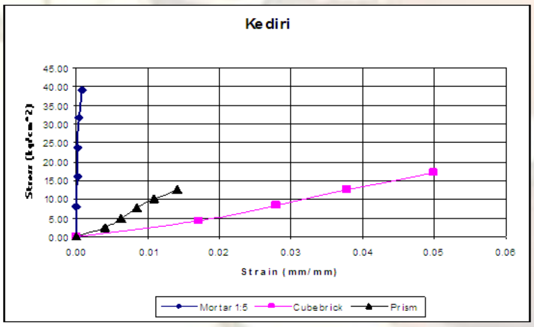

Figure 5. Stress-strain mortar brick and prism for brick from Kediri up to peak load.

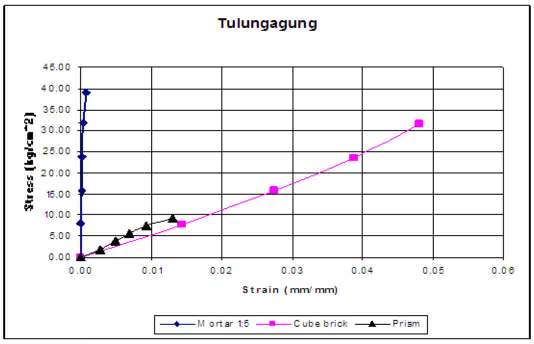

Figure 6. Stress-strain mortar brick and prism for brick from Tulungagung up to peak load.

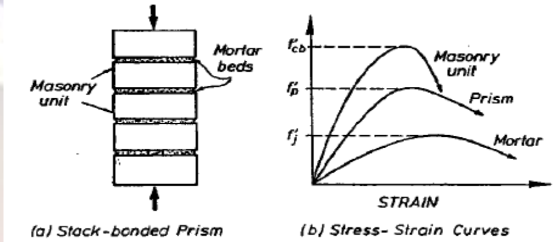

Figure 7. Stress-strain behavior in masonry prisms in Western country [9].

Deformation that occurs on the masonry wall at the ultimate load is lower than the brick. This will result in increased modulus of elasticity of the wall. This increase is caused by the other constituent materials. That material is mortar. The role of mortar is important because it can increase the modulus of elasticity of the wall. This is different from the western countries that brick is more dominant than mortar [9,15]. Thus the need to review about theory of masonry wall for conditions such as in this research for local brick.

Table 5 shows the same role of the mortar. When the orthogonally strength of brick is the same, then that causes increased strength and reduced deformation is the mortar. In general it can be shown strength in the parallel to bed joint greater than the perpendicular to the bed joint. This also occurred in the modulus of elasticity of models. Modulus of elasticity for the loading direction parallel to the bed joint is greater than the direction perpendicular to the bed joint.

TABLE 3. OTHER IMPORTANT PROPERTIES OF BRICKS

Location	Absorption (%)	IRA (gr/mnt/30in^2)	Modulus of Rupture (kg/cm2)	Brick mortar tensile strength (kg/cm2)	Dimension l . w . t (cm x cm x cm)	Density (gram/cm3)
Pakis, Malang	12.80 (0.51)	114.45 (0.44)	2.93 (0.60)	0.28 (0.59)	24.20x11.71x4.31	1.37
Mojokerto	17.19 (0.22)	151.76 (0.25)	6.34 (0.24)	0.83 (0.47)	19.36x9.85x5.22	1.45
Kediri	17.33 (0.29)	165.31 (0.24)	6.02 (0.27)	0.20 (0.50)	20.92x9.73x4.47	1.49
Tulungagung	15.15 (0.32)	143.11 (0.31)	9.50 (0.55)	0.46 (0.54)	22.65x10.39x4.31	1.50

IRA: Initial Rate of Absorption
l . w . t: length x width x thickness
Data are the average value. Numbers in parentheses indicate coefficient of variation.

TABLE 4. COMPRESSION STRESS-STRAIN RELATIONSHIP OF BRICKS (CUBE) WHEN IT REACHES THE ULTIMATE LOAD

Location	Stress (kg/cm2)	Strain (cm/cm)
Pakis, Malang	10.07 (0.21)	0.043 (0.28)
Mojokerto	32.56 (0.38)	0.087 (0.24)
Kediri	16.98 (0.25)	0.067 (0.27)
Tulungagung	31.55 (0.24)	0.058 (0.49)

Data are the average value.
Numbers in parentheses indicate coefficient of variation.

Modulus of elasticity data can be seen in Table 7. Modulus of elasticity values in Table 7 differ from the modulus of elasticity of the western country. The range of values of modulus of elasticity only about 45 to 165 times the compressive strength of prism or brick wall. Reference states this value exceeds 300 times [9,11].

In this research the average compressive strength of mortar with a ratio cement:sand of 1:5 is 79.316 kg/cm^2 and the coefficient of variation is 0.17. This value is above the compressive strength of all bricks. The modulus of elasticity of mortar is 110524 kg/cm^2 with coefficient of variation 0.20.

Masonry efficiency is the ratio of strength of masonry wall to the strength of brick. The closer one or bigger is better. The value of this efficiency can be calculated from Table 4 and Table 7. The values are in the range of 0.29 to 0.74.

TABLE 5. COMPRESSION STRESS-STRAIN RELATIONSHIP OF MASONRY WALL MODELS AT ULTIMATE LOAD

Location	Load perpendicular bed joint		Load parallel bed joint	
	Stress (kg/cm2)	Strain (mm/mm)	Stress (kg/cm2)	Strain (mm/mm)
Gondanglegi, Malang	20.89	0.0306	26.90	0.0256
Tulungagung	19.97	0.0201	13.56	0.0143
Kediri	18.24	0.0183	19.51	0.0123
Mojokerto	12.55	0.0182	14.77	0.0186

Data are the average value.

Shear stress tested and calculated based on ASTM E 519-02 [7]. Shear stress result are shown in Table 6. The highest value of shear stress obtained from Kediri. Shear stress is lower than 2 kg/cm^2 are under the terms of shear strength for seismic loads [16].

TABLE 6. BRICK WALL SHEAR STRESS FROM VATIOUS REGIONS

Location	Shear stress (kg/cm^2)	Coefisien of Variation
Gondanglegi, Malang	2.54	0.55
Tulungagung	1.69	0.19
Kediri	4.03	0.09
Mojokerto	1.46	0.43

TABLE 7. MODULUS OF ELASTICITY OF BRICKS, PRISMS AND WALL MODELS

Location	Modulus of elasticity of brick (Kg/cm2)	Modulus of elasticity of prisms (kg/cm2)	Modulus of elasticity of masonry wall model (kg/cm2)	
			Load perpendicular bed joint	Load paraller bed joint
Pakis, Malang	308.64 (10.07)	258.62 (5.70)	--	--
Gondanglegi, Malang	--	--	884.81 (20.89)	1275.38 (26.89)
Mojokerto	323.33 (32.56)	519.55 (10.03)	980.22 (12.54)	1804.35 (14.767)
Kediri	279.07 (16.98)	1253.65 (12.65)	1307.69 (18.24)	1675.38 (19.51)
Tulungagung	541.10 (31.55)	753.23 (9.33)	828.16 (19.97)	2206.89 (13.55)

Data are the average value.
Numbers in parentheses are the compressive strength (kg/cm^2).

4. CONCLUSION

The results and discussion show the behavior of Indonesian local brick wall from East-Java is different from those described in the foreign references especially western country.

In general the compressive strength of masonry walls is below the strength of mortar and brick. For modulus of elasticity it seem that effect of mortar joint is more dominant rather than brick. Shear strength of masonry walls are in the range of 1.46 kg/cm^2 up to 4.03 kg/cm^2.

The empirical equations from the literature can not be used directly for the local brick for this condition. Equations must be adjusted to material test results from the laboratory.

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