

An evaluation of mechanical properties of clay brick for masonry wall in Indonesia

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Abstract. In principle, the main construction of the non-engineered building in Indonesia is the wooden structure. It can be seen from traditional houses in Indonesia. However, In the last two centuries, the use of brick masonry as wall component has been becoming the primary material. Another side, some places in Indonesia are the seismic areas and earthquake-prone areas. Learning from the earthquake that has happened in the last ten years, the building that used clay brick for masonry wall mostly suffered damage and destruction when subjected to a relatively high intensity of the earthquake. This paper used data from several places and some references. There have significant differences in the mechanical properties of the bricks. Generally, Indonesian bricks masonry have limited capability and substantial differences in the mechanical properties when compared to another country bricks. By the considering, the Indonesian bricks masonry that has low mechanical properties, so that it is proposed to use brick masonry to non-seismic only. It should be considered to use clay brick as the main component of the wall for a particular region in Indonesia. Next, the zoning of allowed masonry structure in Indonesia is proposed.

Keywords: mechanical properties, brick, masonry wall.

1 Introduction

The brick masonry structure has become a favorite choice for society building in developing countries, notably in Indonesia as a base material for build the society buildings. Here, the resource of the main elements for the brick is straightforward to obtain, so it has become a source of small industries that grow like the mushroom in every region. In Another side, the emergence of trend uses of the brick masonry into a prestige for the community. It would be a pride to have a house that is mostly using the material from a brick and is called a permanent home. Likewise, the brick masonry wall is low price and influenced the Europa style. The house of in Indonesian people is from wood. It was seen from the existence of traditional houses from across the archipelago, and all the houses are from wood. The general Indonesia people had known that buildings made from wood are resisted to the effect of seismic loading. In fact, in every region of Indonesia, almost 80% use bricks as the primary material of masonry [1]. In some developing countries, traditional clay bricks are produced locally without following any technical inspection or standard and the quality varies from region to region. These bricks are used for houses and simple buildings, not only in village areas but also in the urban region. In general, masonry structures are very good in resisting gravity loads, but do not perform well when subjected to lateral in-plane and out-of-plane loading, such as seismic loads caused by an earthquake. As

countries locate in a high risk seismic region, many masonry houses experienced severe damage during past earthquakes that caused many injuries and deaths. The houses collapsed gradually in brittle failure without ductility.

Ridwan *et al.* [2] in his research to verify and validate the calculation method proposed in obtaining the ability of out-of-plane from masonry is very low

Based on the findings mentioned above, the mechanical characteristics of brick quality of masonry structure need to be evaluated.

2 Active seismic zone in the world

Indonesia and some developing countries locates in active seismic zone in the world. There are have five active tectonic plates, earthquakes occurred daily in the region, with a magnitude of 5 in Richter scale or larger. **Fig. 1** shows the epicenters of recorded earthquakes during the period of 2017. A total of 11,594 earthquakes are plotted. This seismic has the potential to produce an earthquake with magnitude greater than 8.7. As example, the subduction zone in Sumatra is known for producing mega-thrust earthquakes such as the moment magnitude Mw 8.8-9.2 in 1833, the Mw 8.3-8.5 in 1861, the Mw 9.0-9.3 in December 2004, the Mw 8.7 in March 2005 and the Mw 8.4 in September 2007 [3]. Based on the recent seismic activity, Aydan O. et al. [4] identified a segment of the subduction zone facing Padang City that has not ruptured in the last 213 years. This seismic gap has the potential to produce an earthquake with

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magnitude greater than 8.7. The seismic gap is located in between the 1833 and 1861 fault ruptures, and it is estimated to have an approximate recurrence interval of 230 years [5]. As a result, the potential earthquake rupture length in the Sumatra fault is not likely to exceed 100 km, so the maximum magnitude expected from such an event is estimated as Mw 7.5 [6,7].

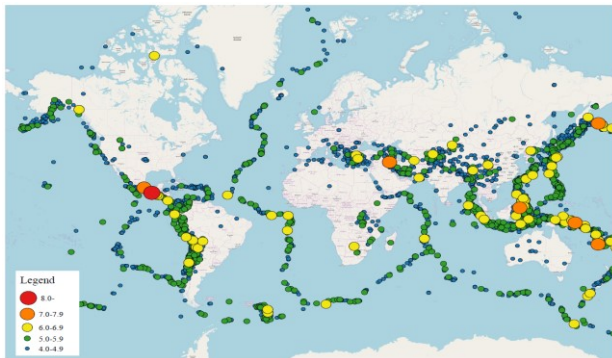


Figure 1. World earthquakes during the period of 2017 [28]

From previous seismic events, it has been seen that brick masonry often presents an inadequate behavior to seismic actions, showing extensive cracking and disintegration due to combined in-plane and out-of-plane loadings. This behavior is due to the low quality of materials,

3. Conditions of non-engineered construction in developing countries

Most of the buildings in Nepal, Pakistan, Indonesia, India, Peru, Turkey and Egypt utilize fired clay bricks as wall material, with one brick thickness (see Fig. 2 and Fig. 3). In terms of wall height to thickness ratio, the highest ratio is found in Indonesia (19.83), while the smallest is found in Egypt (9.00) [8]

Most of non-engineered constructions provide beams and few of them provide columns. This depends on the structural system adopted in the surveyed country. In Indonesia, most of the surveyed sites exhibit confined masonry, so both columns and beams are available. On the other hand, in Pakistan, Egypt, and India, where most of the selected sites are unconfined masonry, the buildings are only provided with beam/lintel. From all of the selected countries, it was found that most of non-engineered construction had poor detailing on the connection of the structural elements [8].

Most of countries have building regulation/codes and/or guideline on non-engineered construction at the national level, such as India, Indonesia, Pakistan, Peru and Nepal. Unfortunately, the building regulation/codes or guidelines on non-engineered structure are mostly not implemented by the countries, excepting for a few big cities. It was also found that some countries have problems on disseminating these regulations to the workers. In Turkey and Egypt, the non-engineered building code at the national level is not available. However, both countries have local offices in charge of

building administration in the surveyed cities. In Turkey, the national building code is only for engineered structure [8].

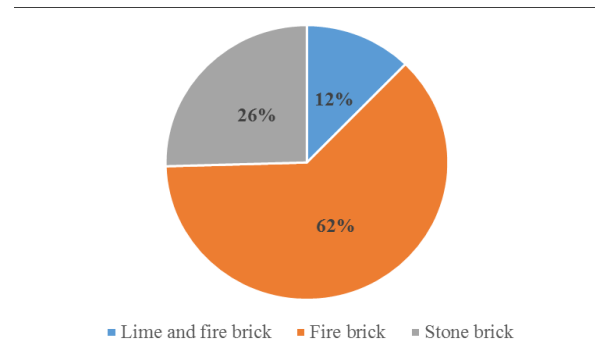


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 Percentage of wall materials used in developing countries

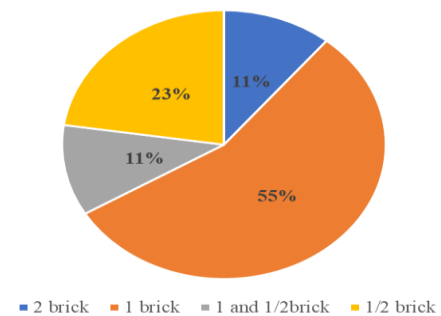


Figure 3 Percentage of wall thickness used in developing countries

Some mistakes are often found in many masonry houses or simple structures. In Fig. 4, fence wall built on not properly connected to the column and supporting beam. This wall was constructed without any column or tie beam. Such brick wall will collapse during earthquake because there is no lateral in plane stiffener in wall structures.



Figure 4 Buildings in Padang, Indonesia after earthquake September 30, 2009 (7.6 on Richter scale). Damages to an unconfined single story school building [29]

A masonry house (shown in Fig. 5) is considered to be a semi engineered structure, since the structural column and tie beam were not properly installed.



Figure 5 Confined masonry: formwork present after construction of walls; note lack of columns on right side. [30]

There is no closed tie beam constructed at the upper part of the wall to confine the whole structure. It can be expected that some partial damages will occur during earthquake.

In **Fig. 6**, a simple reinforced concrete frame is placed at the corner of masonry house. The beam, which is retaining part of the wall structure, is not correctly connected with anchorage to end support. There are also no closed tie beam and column found in this structure. This type of house is classified as a non-engineered structure and will experience damage during an earthquake, especially at the corner of wall opening.



Figure 6 Typical earthquake damage: a house without vertical tie-columns and without top bond-beams in Attics (1988 Bovec earthquake) [31]

4. Investigation of the quality of bricks masonry

Brick masonry (BM) is a building construction method in which a two-phase composite material is formed of regularly distributed brick and mortar [9]. Normally, bricks (clay bricks) contain the following ingredients: silica (sand) around 50% to 60% by weight, alumina (clay) around 20% to 30% by weight, lime around 2 to 5% by weight, iron oxide $\leq 7\%$ by weight and Magnesia less than 1% by weight [10]. Usually, the bricks show higher values for compressive strength and stiffness than the mortar. However, the opposite is true in some of the developing countries. For example, the mechanical properties of bricks in some areas of Indonesia show significantly lower values than those of mortar because

construction materials are sometimes manufactured in family-run industries [11]. This is due to culture, economics, source and material of the bricks. In spite of the use of low-quality bricks, the design code for masonry structures in Indonesia (SNI-2094-2000) is based on the design code of other countries, namely, the DIN 105 standard of Germany and the ASTM C 67-94 standard of the USA.

Hence, most investigations are focused on bricks showing higher strength and when compared to the mortar used in masonry structures. However, as mentioned above, this is not always the case [12] in some developing countries. It was reported in [Indra et al. 2013] that bricks in Payakumbuh, located in the West Sumatera Province of Indonesia had a significantly low compressive strength of 2.9 MPa on an average. Similarly, Putri [13] reported a brick strength of 2.5 MPa in Padang city. Elhusna *et al.* [14] observed that the compressive strength of bricks in Bengkulu Province was within the range of 2.4–6.7 MPa. Wisnumurti et al. [15] investigated the strength of bricks from four different areas in East Java. According to their investigations, the compressive strength was within the range of 0.55–0.9 MPa, and the modulus of elasticity of the low-quality bricks was within the range of 279–571 MPa. In addition, Basoenondo [16] reported that the compressive strength and the modulus of elasticity of bricks in the West Java Province were 0.5–2.87 MPa and 220–540 MPa, respectively. It is noteworthy that the test was based on the American standard ASTM E-111 owing to the lack of an Indonesian standard for the evaluation of the elastic modulus of bricks.

Most of the non-engineered constructions at countries use baked clay or stone masonry for the wall materials. Brick sizes in Turkey, Nepal, Indonesia, Peru and Pakistan are relatively similar, meanwhile in India and Egypt bricks have different sizes compared to the others. Peru has the highest brick compressive strength, while Turkey has the smallest brick compressive strength compared to the other countries. Test results from sites in each country showed that some do not have adequate strength for the brick (see **Fig. 7**). [8]

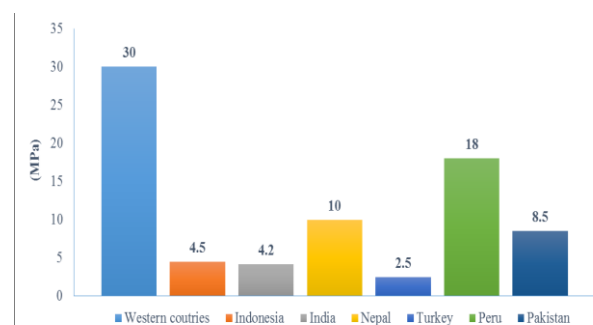


Figure 7 Average bricks compressive strength

General-purpose bricks in western countries have higher strength and stiffness than mortar, as discussed by Gumaste *et al.* [12]. They reported that bricks in India have a relatively lower strength (3–20 MPa) and elastic modulus (300–15000 MPa). Similarly, Indonesian bricks have lower strength and stiffness [16].

The general theory is based on the assumption that mechanical properties of brick elements are higher than those of mortar [17]. In most cases, the ideal elasticity used in the design refers to formulas specified in overseas regulations. These assumptions may result in inappropriate design for the construction of masonry structures using Indonesian bricks.

Most of the countries use ordinary Portland cement as plaster and mortar cementing agent. Pakistan found to have the highest mortar strength, even though the mix is similar with other countries. On the other hand, Peru has different mortar mix compared to the other countries, but it produces the same compressive strength. The mortar thickness in Egypt is found to be the thickest (25 mm), while Turkey and Pakistan have the thinnest mortar layer (10-20 mm and 11.5mm respectively) (see Fig. 8). The common plaster mix is either 1:6 or 1:4 (PC:sand), except in Peru where the mix is 1:1. Turkey has the thickest plaster (20-30 mm), while Nepal has the thinnest plaster (10 mm) (see Fig. 9). [8]

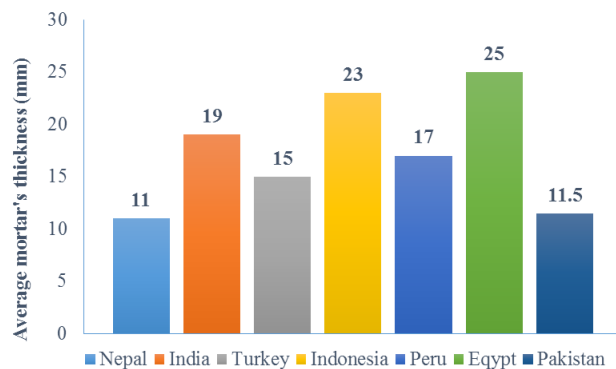


Figure 8 Average mortar's thickness

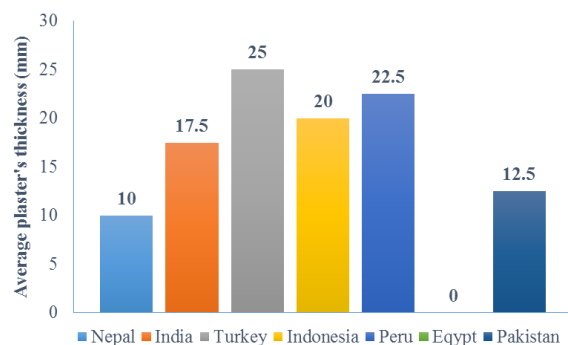


Figure 9 Average plaster's thickness

Ridwan *et al* [1] was observed that typical mortar has a lower elasticity than bricks in the homogenization process (Table 1). His proposed analytical approach can significantly contribute to a safer analysis and design of masonry structural systems built with low-quality bricks in various developing countries, such as Indonesia.

Table 1 Moduli of elasticity for homogenization

Author (s)	Ebrick (MPa)	Emortar (MPa)
[18]	6740	1700
[19]	12500	1200
[20]	1000	Emor/Eb <1
[21]	20000	1<Eb/Emor<1000
[22]	10000	0.49
[23]	11000	Eb/Emor = 1.1-11
[24]	11000	2200
[25]	22000	7400
[26]	13000	4000
[27]	20000	2000

5. Discussion.

The above investigations that need several considerations and to be observed because Indonesia's position is in the seismic area while the quality of the bricks is lower than some another developing countries. Brick masonry walls are assumed to be nonstructural while that is used as building structural part. Based on previous researches data (Table 1) that the concept of a composite of masonry is the compressive strength of the brick is greater than mortar. This condition will be opposite when using the material of brick from Indonesia Mechanical properties of bricks used in western countries for making the regulation are higher brick quality than mortar while In Indonesia the quality of brick is low and mortar quality can be higher.

The production of brick in Indonesia is a majority made by family industry, so it is one causes of difficulty to be improved the quality of brick. By given that Indonesia consists of various areas that have the level of disaster risk due to earthquakes then the use of brick needs to be proposed by divide the area of the Indonesia territory in usage brick for example in the three regions. In this paper, we propose three areas according to the disaster map released by BNPB on Fig. 10 [32]. The division are;

1. Green color zone is safe zone to use masonry.
2. Yellow color zone that is allowed to use masonry with strict rules such as reinforced masonry, using an anchor and confined masonry.
3. Red color zone that are not intended to use masonry.

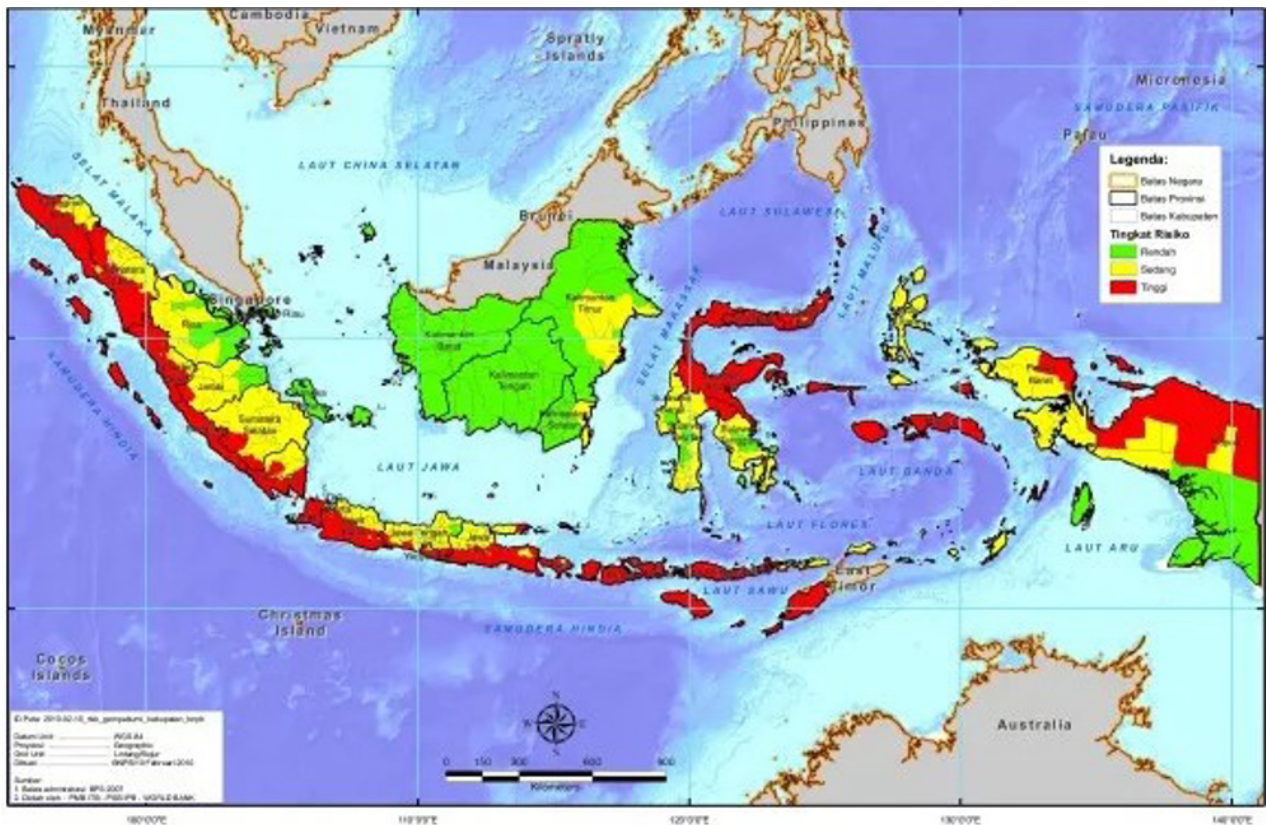


Figure 10. Earthquake risk index in Indonesia

Conclusion

The brick has become a favorite masonry material for society houses including use as building partitions in Indonesia. However, Indonesian bricks is low quality and some places in Indonesia are the seismic zones. The developed countries that are in the earthquake zone have left the brick as the primary material of the wall. This condition need of policy and rule on the use of bricks following the condition of Indonesia brick, as well to improve the quality of bricks. Next, the map zone that have three level from low to high-level disaster for masonry structure is proposed. For the high level of disaster should be no used the bricks anymore for structural of construction and switch to other types of materials. For the middle level of the disaster zone should pay attention to the procedures and specifications of bricks following the regulations to avoid failure. Considering the existence of an existing brick home industry existed then the use of brick is highly recommended for areas that are not prone to earthquake disaster.

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