Experimental Study of Shear Strength of Purus Lobang Berkait (PLB): Masonry Wall

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Abstract: The earthquake caused damage to buildings, especially simple houses that were not designed according to engineering rules. Damage caused by earthquakes is often found in the form of cracks to the collapse of masonry walls. Damage due to earthquake forces can be anticipated by increasing the strength of columns, beams, and brick walls. Especially for brick walls, this can be done by increasing the strength of the brick unit, mortar, and brick design that optimizes the function of the mortar. The regular brick stacking pattern produces a square bed joint and head joint area, while the hook-hole purus brick stacking pattern produces a square bed joint and an upright cylindrical head joint that connects from top to bottom. This study aims to determine the effectiveness of the use of PLB masonry in increasing the shear strength of the wall through laboratory tests using two groups of test objects. Laboratory test results were analysed to determine the shear strength of masonry walls based on the SNI formula. Based on the results of laboratory tests, it can be concluded that PLB bricks have a strength of 13.64% greater than ordinary bricks.

1 INTRODUCTION

Indonesia is an earthquake-prone area. Data from the National Disaster Management Agency (BNPB) March 22, 2021, shows 1830 natural disasters caused by earthquakes, volcanic eruptions, forest and land fires, droughts, floods, landslides, tidal waves. The above incident resulted in 409 deaths, 3448 houses were seriously damaged and 88 damaged health facilities (BNPB, March 2021). The BNPB data illustrates that most of the damage occurred in residential houses where most of these buildings were not designed according to engineering rules so they were classified as Non-Engineering Building (NEB). Residential construction practices that do not meet engineering rules are often encountered in the community in the form of using very low-quality concrete due to the uncontrolled mixing of materials (Figure 1).

The use of plain reinforcement and wide stirrups, exceeding the design requirements (Figure 2).

Figure 1: Imperfect concrete manufacture.

Figure 2: Plain reinforcement and wide stirrups.

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Figure 3: The details of the distribution reinforcement donot meet the requirements.

Details of reinforcement at joints that do not meet the distribution length (Figure 3) and others.

Figure 4: Damage caused by an earthquake.

The strength of the NEB needs to be increased so that occupant safety is guaranteed. This increase can be done by increasing the strength of the concrete elements and their reinforcement and/or increasing the strength of the walls. Columns and beams form a frame structure system that supports the building and walls as a filler for the frame structure can also play a role in contributing to the strength of the building. Increasing the strength of the concrete beam-column can be through increasing the quality of the compressive strength of concrete and installing concrete reinforcement that meets the design requirements. Increased wall strength through increasing the strength of bricks, mortar in the bed joint and head joint area. Several studies have shown that portals with infill bricks have better strength than portals without infilling bricks. It can be concluded that bricks have a contribution in contributing to the strength of the building(Cavaleri & Di Trapani, 2015; Farooquddin, 2000; Nguyen & Meftah, 2014). This means that an increase in the overall masonry strength can increase the strength of the infill portal structure. The strength of a masonry wall in resisting lateral forces (earthquake) can be analyzed by modeling it as a strut element in which the series of bricks is simplified into a diagonal strut plane. Some of the lateral forces acting on the joint are distributed to the wall as an axial force received by the diagonal plane of the strut. Approaches in strut modeling can be grouped into two, namely wall modeling as a diagonal plane of one strut and multi-strut. The struts method is proven to be effective in analyzing the contribution of masonry walls in bearing lateral forces (Bolea, 2016; Di Trapani et al., 2018; El-dakhakhni, 2017; El-Dakhakhni et al., 2003).

The strength of the diagonal struts model is influenced by several parameters related to mechanical, geometrical, and empirical properties of masonry infilled frame structure. One of the mechanical properties that are taken into account in determining the strength of the diagonal struts is the shear strength. The shear strength of a series of bricks is also influenced by the bed and head joint bonds. The bed joint bond provides strength in the vertical direction and the head joint bond provides strength in the horizontal direction. Both strengths are required in a masonry wall assembly. The stronger the bed and head joint bonds, the more strength the masonry wall will be.(Francisco J. Crisafulli, 1997b; Pallarés et al., 2021; Smyrou et al., 2011).The arrangement of PLB bricks will provide a different bed and head joint pattern from ordinary bricks. The mortar that fills the hollow of the brickwork produces a peg that acts to resist the horizontal force. The effect of these pegs is similar to that of interlocking masonry with holes filled with sand mortar as in the study conducted by Joyklad(Joyklad & Hussain, 2019).

PLB bricks have a simple and flat shape making them easier to organize in storage. The basic materials and methods of burning are the same as ordinary bricks, no special furnace is required, so all brick craftsmen can make them. The volume of material used in the manufacture is less than ordinary bricks. Similar studies with PLB bricks are still few so it is necessary to conduct research that produces applicable and conclusive designs for problems that are also easily mass-produced.

This study aims to determine the effectiveness of mortar post-filling PLB masonry in increasing the shear strength of the wall. The shear strength of the PLB masonry will be compared with the shear strength of the ordinary masonry to determine the contribution of the mortar post.

2 MATERIALS AND METHODS

The test objects used were divided into two groups. The first group is a PLB brick panel and the second group is a regular model brick panel as a control.

2.1 Making Test Specimen

The normal brick panel (N) is made of ordinary masonry measuring 10-centimeter wide, 20-centimeter long, and 3-centimeter thick (see Figure 5). Meanwhile, PLB panels are made of hole bricks of the same size as normal bricks but have a 3-centimeter diameter hole (see Figure 6). The two types of bricks are arranged to form a panel measuring 60x60 cm (see Figure 7-8). The number of test objects is shown in table 1.

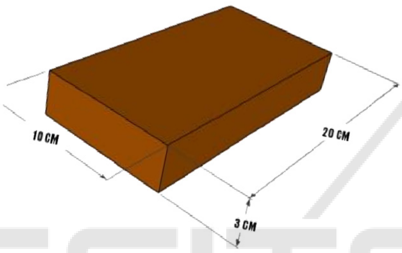

Figure 5: Ordinary bricks.

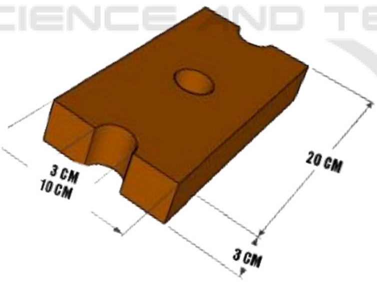

Figure 6: Purus lobang berkait (PLB)Brick.

Figure 7: Manufacture of test specimens.

Figures 8 and 9: show the results of a series of ordinary and PLB brick panels.

a) A series of panels made of ordinary bricks produces the same bed joint and head joint pattern, namely a rectangular area (see Figure 8).
b) The panel series of PLB bricks produces a rectangular bed joint pattern and the head joint hasa cylindrical plane pattern that is connected from the top to the bottom (see Figure 9).
c) The head joint pattern in the PLB is expected to be able to withstand the lateral force (earthquake) in the horizontal direction on the brick series.

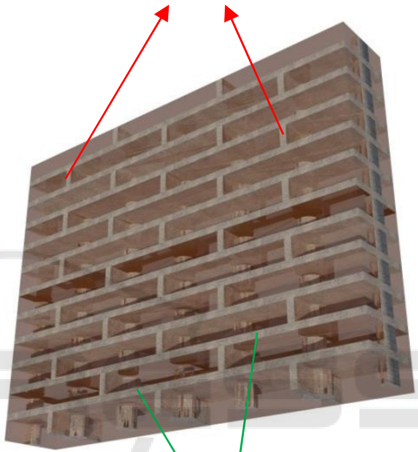

Figure 8: Illustration of bed joint and head joint pattern.

Figure 9: Illustration of bed joint and head joint pattern.

Table 1: Number of the test specimen.

Brick Type	DiagonalShear
Ordinary (N)	3 specimen
Purus LobangBerkait(PLB)	3 specimen

2.2 Testing

Figure 10: Diagonal shear strength test.

The diagonal shear test procedure is as follows. First, the test object is painted white to make it easierto observe the cracks that occur. Then the test object is placed in a diagonal position (see Figure 10) and the end position of the test object must be in a vertical line with the load cell or load jack. Followed by the installation of the dial gauge on the right and left ends. This tool serves as a strain gauge when receiving a force. Loading is done by giving a force that increases regularly. Loading starts from 0 and increases by 50 kgf until it is destroyed or the device is no longer able to read. At every 50 kgf increase, the condition of the specimen was observed and the strain was recorded. Crack development is monitored from the beginning of loading until failure. Then the results of the test are analyzed.

2.3 Shear Stress

Shear Stress calculated according to the Indonesian National Standard formula(SNI O3-4166-1996, 1996).

Diagonal shear strength formula:

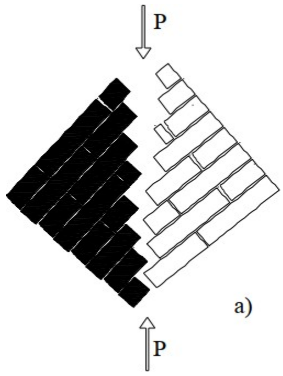

Figure 11: Diagonal shear crack pattern(Borri et al., 2015).

$$f_{vd} = \frac{0{,}707Pu+W}{A} x(1-\mu) \quad (1)$$

$$A = h\, x\, b \quad (1.2)$$

Where:
Pu = Maximum test load in N
W = Mass of internal aids N
b = Brick width in mm
h = The length of the shear plane of the brick in mm
μ = Friction coefficient 0.3
A =Shear cross-sectional area (hxb) in mm2

The formula above shows that the diagonal shear strength value is the ability of the magnitude of the force in cutting across the diagonal area with the length of the diagonal of the panel as h and the thickness of the panel as b. This formula will be effective if the crack of the test specimen has a diagonal pattern so that the crack length is assumed to be equal to the diagonal (as h). However, if the crack pattern is not diagonal, then the proposed conversion value (h) is derived from the length a of the crack or the conversion of the magnitude of the force if the crack pattern is in the diagonal direction.

3 RESULTS AND DISCUSSION

Masonry walls are made of bricks and mortar that form a homogeneous whole. The bricks function as filler and mortar as an adhesive for the bed joint and head joint. Some researchers state that the wall is a homogeneous series of marble and bricks in resisting forces (Chopra, 2012; Francisco J. Crisafulli, 1997a; Gambarotta & Lagomarsino, 1997; Miha Timocevic, 2006; Pauly, 2010).

The pattern of cracks/collapse that occurs between ordinary panels and PLB panels has its characteristics. The crack pattern starts from the area that resists the force to the weak area. Weak areas are found in the joints between mortar and bricks (Cavaleri & Di Trapani, 2015; Lucchesi M, 2008; Tomaževič, 2009). Pola ini sangat menarik untuk diobservasi dan analisis.

The brick panels that receive a diagonal force have a diagonal crack pattern that passes through the head joint and bed joint (see Figure 11).

There are crack patterns that are produced in the laboratory, starting from the top and some starting from the bottom of the test object (as shown in Figures 12 and 13).

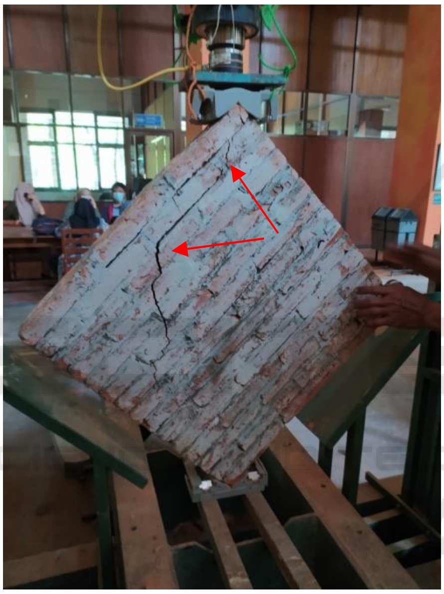

Figure 12: Ordinary brick crack pattern.

Figure 13: Ordinary brick crack pattern.

The pattern of cracks/failure of normal brickstends to be lateral which is not following theoretical estimates. The pattern of cracks that occurs predominantly in the horizontal direction may be caused by the placement of the corners of the test specimens not being perfect at the ends of the brick panels so that during the loading process the panels move slightly (see Figure 14). This movement causesthe position of the panel to shift slightly which resultsin the force not being in a perfect diagonal direction and causing some of the crack patterns to be horizontal.

Figure 14: The placement of the corners is not perfect.

The crack pattern of diagonal compression test results on purus lobang berkaitbrick specimens.

Figure 15: PLB brick crack pattern.

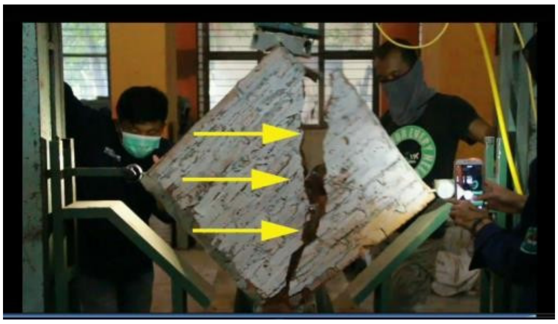

Figure 16: PLB brick crack pattern.

The PLB crack/failure pattern is dominant in the vertical direction with the crack pattern crossing the bed joint and brick area. The cracks produced by PLB bricks have a diagonal tendency. Figure 15 destruction of the panel above the second branch because at the time of failure, the end of the panel received a collision from the auxiliary tool so that the crack direction pattern was in the same direction as the bed joint. Figure 16 shows the failure of the top plane not right at the end because the placement is not perfect at an angle.

The results of the diagonal panel shear test in this study showed a pattern of cracks through the bed joint, head joint, and bricks. This pattern occurs in both types of bricks. This test is very precise to determine the diagonal shear strength of wall panels from homogeneous mortar and brick bonds. Meanwhile, to determine the shear strength of the bed joint and head joint, a horizontal shear test is carried out.

A lateral load-deformation diagram resulting from laboratory tests.

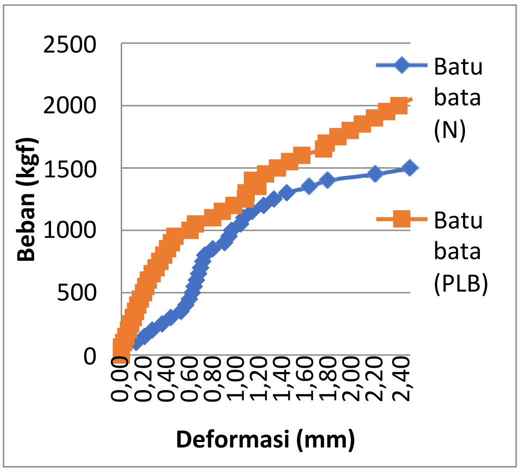

Figure 17: Load-deformation diagram.

This diagram shows that at the beginning of loading shows a linear strength increases in proportion to the deformation up to a certain point. After that, the increase is not consistent with thedeformation and makes the non-linear direction untilthe total collapse.

Figure 17 shows that ordinary bricks (N) after linear conditions increase in stiffness. This condition is possible because the position of the elbow at the end is still loose and unstable. At the time of loading from the beginning to the end, the linear elbow at the end experiences a movement that affects the stiffness value. Then after that, the condition is stable which increases the stiffness of the panel.

Normal bricks are in linear condition at a force of 0-450 kgf with deformation of 0.00 – 0.59 mm. Non-linear conditions at 450-1550 kgf with deformation 0.59 – 2.73 mm, failure at 1300-1550 kgf. PLB bricks are in linear condition at a force of 0-1000 kgf with deformation of 0.00 – 0.64 mm. Non-linear conditions at 1000-2150 kgf with deformation 0.64 – 2.79 mm, failure at 2000 -2200 kgf.

The results of the calculation of the diagonal shear strength are summarized as follows:

Table 2: The results of the calculation of the shear strength of the diagonal panel.

Types ofbricks	Earlycrack (MPa)	Maximumshear strength(MPa)	Average (MPa)
OrdinaryN 1	0,028	0,088	0,110
OrdinaryN 2	0,040	0,138	
OrdinaryN 3	0,034	0,105	
LobangPLB 1	0,062	0,130	0,125
LobangPLB 2	0,056	0,118	
LobangPLB 3	0,059	0,128	

The results of the calculation of this study are following the calculations carried out by Joyklad, with the results of 0.096 - 2.183 MPa (Joyklad & Hussain, 2019).

Figure 18: PLB brick-shaped mortar pegs.

One of the reasons for increasing the strength of PLB bricks is the formation of a cylindrical mortar post in a vertical direction as shown in Figure 18. As a validation, it is necessary to ensure the horizontal shear test.

4 CONCLUSIONS

This research opens new insight that the strength of masonry wall panels is influenced by the design of the bricks that increase the function of the mortar. PLB brick peg mortar increased the diagonal shear strength of the panel by 13.64% compared to ordinary bricks (N).

Tests in the laboratory showed that not all of the crack patterns were following the theory. In future research, more attention is paid to the setup of the test object according to the standard to get results that are closer to events in the field. In addition, numerical studies are also needed as controls.

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