Shear behavior of interlocking masonry brick wall portal with the substitution of Mount Sinabung volcanic ash against pushover static load

R Karolina*, Syahrizal, M A P Handana and P Ramadhan
Civil Engineering Department, Universitas Sumatera Utara, Medan 20155

*Email: rahmi.karolina@usu.ac.id

Abstract. Earthquake events produce a shear damage effect on the interlocking masonry wall brick in the form of diagonal cracks. This shows that there's an influence of the resistance of the masonry to bear the shear force against the horizontal force in the direction of the wall plane caused by the earthquake. The purpose of this research is to determine the shear strength and crack patterns of walls against static loads and to utilize volcanic ash from Mount Sinabung as one of the constituent materials of interlocking masonry brick because the eruption activity of Mount Sinabung is also one of the most active in the world. The samples are in the form of a 3 m x 3 m wall surrounded by a 0.13 m x 0.13 m beam-column portal filled with interlocking masonry brick of 0.25 m x 0.125 m x 0.1 m with the optimum substitution of Mount Sinabung volcanic ash by 20% as a substitute for sand. Wall portal test was done by giving a pushover static load on the wall joint which refers to ASTM E 564-2003 to get the value of shear strength and crack pattern of the wall. From the static test results of interlocking masonry brick wall portal, the samples are able to accept a pushover load of 63931.2 N which results in an ultimate displacement of 35 mm with a crack thickness of 4 mm. The wall shear strength obtained is 21.31 N / mm. Based on the analysis of the equivalent energy elastic plastic (EEEP) curve, it is obtained that the elastic stiffness of the wall is 5905.88 N / mm and the wall's yield load is 57237.55 N with the deviation of 9.69 mm. Failure of the interlocking masonry brick wall portal is a shear failure characterized by cracking like a ladder pattern on the wall. Based on the crack pattern that occurs, the wall portal is a type of stepped cracks shear failure.

1. Introduction

In recent years, there has been a lot of research and development on wall filler materials that are easier and faster to work with. One of them is interlocking masonry brick wall filler material. The advantage of interlocking masonry bricks over other bricks is that when mounted to a wall, it is possible to not need a bonding specs between bricks because the top and bottom surfaces of the bricks are designed like joints that lock one another.

One of the constituent materials of interlocking masonry brick is fine aggregate. The high level of houses and buildings construction will certainly affect market demands for fine aggregate materials, for example, sand. So an alternative is needed to replace part of the sand composition with other types of fine aggregate but still does not affect the quality of the interlocking masonry brick itself [1]. So, in this research, volcanic ash from the eruption of Mount Sinabung is used as a substitution for fine aggregate of interlocking masonry brick.

The reason for the use of Mount Sinabung volcanic ash substitution is because the ash released by Mount Sinabung tends to cause pollution in the environment and the use of ash that has not been maximized. In addition, volcanic ash contains major elements (Al, Ca, and Si) of 56%, 4% and 18%, so it is very possible to make use of the ash as cement material or cement-based object [2][3]. The utilization of Mount Sinabung volcanic ash will be further studied as an interlocking masonry brick substitution material for wall filler material.
Disaster events of volcanic eruptions in Indonesia often occur so that volcanic ash is very abundant in the surrounding area. Another disaster that often occurs in Indonesia is earthquakes. From some earthquake events in Indonesia, there is a shear damage effect on the masonry wall pairs in the form of diagonal cracks. This shows that there’s an influence of the resistance of the masonry to bear the shear force against the horizontal force in the direction of the wall plane caused by the earthquake. Then it is necessary to know the value of the shear strength and crack pattern of the wall, especially the interlocking masonry brick wall with the substitution of Mount Sinabung volcanic ash [4].

Based on research conducted by Karolina et al [5], the compressive strength test of interlocking masonry brick with a mixture variation of Mount Sinabung volcanic ash of 0%, 10%, 20%, 30%, 40%, and 50%. From the research, the optimum average compressive strength value of the interlocking masonry brick was 12.10 MPa and it was the maximum compressive strength with a mixture variation of 20% volcanic ash and for cube samples, the maximum compressive strength was 23.20 MPa in the variation of 20%. Based on SNI 03-0349-1989, these values are included in the quality classification I with an average compressive strength of 7 MPa for hollow concrete bricks for wall pairs.

This research is a study on the development of interlocking masonry brick with 20% volcanic ash substitution which is concluded as the optimum ash percentage and reaches the maximum compressive strength value at that percentage. The interlock masonry brick has dimensions of (25 x 12.5 x 10) cm and there are two holes each with a diameter of 6 cm. In this research, the interlocking masonry brick was applied as a 1:1 scale wall pair with a wall size of 3 m x 3 m surrounded by a 13 cm x 13 cm of beam-column portal. The samples are tested for its shear strength against pushover static load and analyzing the crack patterns that occur due to the load.

2. Method

2.1. Materials

Interlocking masonry bricks are concrete bricks which its top and bottom surfaces as well as the sides of the bricks are designed like joints that lock one another. Interlocking masonry brick is possible to not need mortar as a binder between bricks. So that mounting bricks into a wall pair will be faster and more effective than the conventional one. The constituent materials of interlocking masonry brick are cement, sand, rock ash, volcanic ash and water.

Volcanic Ash

Volcanic ash is a type of natural pozzolan where it is a natural material resulting from sedimentation from volcanic ash or lava that contains active silica elements. If volcanic ash is mixed with lime, a cement-like process will occur. Natural pozzolan has different shapes, colors, and qualities from one eruption to another. So that volcanic ash material can be used as an alternative to fine aggregate.

The volcanic ash used in this research was taken at a location of approximately 5 km from the eruption point of Mount Sinabung.

| Table 1. Oxide element contents of mount sinabung volcanic ash. |
|---------------|---------------|-----------|--------|
| No. | Parameter | Result | Unit | Method |
| 1 | Silica, SiO₂ | 85.6 | % | Gravimetric |
| 2 | Aluminium, Al₂O₃ | 0.95 | % | Calculation |
| 3 | Calcium, CAO | 4.78 | % | Gravimetric |
| 4 | Magnesium, MgO | 4.48 | % | Gravimetric |
| 5 | Water Content | 1.43 | % | Gravimetric |

From the examination results of the chemical contents of Mount Sinabung volcanic ash above, it is very possible to do the utilization of ash as sand and cement material that can be used in the manufacture of interlocking masonry brick.
From SEM test of volcanic ash samples, it can be seen the morphology view of irregular samples with varying sizes. And the magnitude of volcanic ash particles distribution from the eruption of Mount Sinabung is 13.49 - 45.56μm.

![SEM test of volcanic ash samples](image)

**Figure 1.** a) Magnification of volcanic ash in SEM Test, and b) interlocking masonry brick

2.2. *Interlocking masonry brick samples*

The making of interlocking masonry brick in one stirring produces 20 samples according to the planned mix design.

| Number of Samples | Volcanic Ash Substitution | Cement (gr) | Rock Ash (gr) | Sand (gr) | Volcanic Ash (gr) |
|-------------------|---------------------------|-------------|---------------|-----------|------------------|
| 20                | 20%                       | 42244.86    | 14081.62      | 45061.184 | 11265.296        |

**Table 2.** The requirements of material in one stirring.

2.3. *Wall portal samples*

This research examines the shear strength of a 1: 1 scale of interlocking masonry brick wall portal with dimensions of 3 m x 3 m placed on top the foundation according to the design so as not to be lifted during testing. The process of making a test wall is by casting a 130 mm x 130 mm column first. Then arrange the bricks into a ½ brick arrangement that is given a stirring on the vertical brick hole. Then ended with a casting of 130 mm x 130 mm beam when all bricks have been mounted.

![Interlocking masonry brick wall portal](image)

**Figure 2.** Interlocking masonry brick wall portal.
2.4. Static test of wall portal

Adjustment (setting) of static test equipment is done by installing a hydraulic jack on the elbows on the wall placed parallel to the wall in-plane. While the front side of the hydraulic jack is mounted with a dial indicator to determine lateral displacement caused by pushover loads.

Static test of interlocking masonry brick wall portal refers to ASTM E 564 - 2003 regulations to obtain parameters of elastic stiffness (Ke), shear strength (Su), yield load (Pyield), yield deviation, ductility and equivalent energy elastic plastic (EEEP) curve.

Elastic Stiffness, \( (Ke) = \frac{0.4P_{peak}}{\Delta 0.4P_{peak}} \)  \hspace{1cm} (1)

Shear strength, \( (Su) = \frac{P_u}{b} \)  \hspace{1cm} (2)

Yield load, \( (Pyield) = \left( \Delta u - \sqrt{\Delta u^2 - \frac{2A}{Ke}} \right) Ke \)  \hspace{1cm} (3)

Yield deviation, \( (\Delta yield) = \frac{Pyield}{Ke} \)  \hspace{1cm} (4)

Ductility, \( (\mu) = \frac{\Delta u}{\Delta yield} \)  \hspace{1cm} (5)

2.5. Equivalent energy elastic – plastic (EEEP) curve

The EEEP curve is an approximation of approach of the original deviation load curve or envelope curve which is influenced by the ultimate deviation and the deviation on its axis [6]. Part of the EEEP curve can consist of the same slope as the original slope which is the elastic stiffness (Ke) while the plastic conditions are indicated by a horizontal line with a yield load (Pyield). The area of plastic elastic curve is obtained by the principle of balancing the extent of the deviation load curve that is connected to the peak. The part of the curve that has a line with the same slope is the elastic-plastic shear stiffness at a load of 0.4Ppeak and deviation of \( \Delta 0.4P_{peak} \). The collapse load is 0.8 Ppeak while the failure limit state value tells that the point where the relation between the load and the deviation to the last data point with a time load is or greater than 0.8 Ppeak.

3. Results dan discussion

3.1. Static test results of interlocking masonry brick wall portal

From the static test results, it is obtained the relation of load - deviation of the interlocking masonry brick wall portal as follows:

![Figure 3. Static test results of interlocking masonry brick wall portal.](image-url)
From the graph above, it can be clearly seen that the line which initially linear becomes non-linear after 0.4 Ppeak because ideally at 0.4Ppeak is the limit of the elastic stiffness of the wall so that the endurance of the wall to hold the load decreases. Lateral load-deviation data which has been generated from this test based on ASTM E 564-2003 can be obtained values of elastic stiffness, shear strength, yield load, yield deviation, ductility and EEEP curve. Here are the results of the calculations:

**Table 3.** Static test calculation results of interlocking masonry brick wall portal.

| Pyield (N)   | ∆yield (mm) | Ppeak (N) | Pu (N) | ∆u (mm) | Area of envelope curve, A (Nmm) | Elastic stiffness, Ke (N/mm) | Shear strength, Su (N/mm) | Ductility, μ |
|--------------|-------------|-----------|--------|---------|--------------------------------|-----------------------------|--------------------------|-------------|
| 57237.55     | 9.69        | 63931.2   | 50472  | 35      | 1725957.3                       | 5905.88                     | 21.31                    | 3.61         |

3.2. **Crack pattern of interlocking masonry brick wall portal**

The crack pattern that occurred during the test was observed when wall was cracked at the first time at a pressure of 60 bar or 25236 N. At that time the cracking began to occur due to bending of the wall with a crack width of 1 mm. Cracks occurred in the middle diagonal section of the wall that is loaded because the top of the wall experiences a lateral deviation of 4.27 mm so that the middle diagonal section of the wall is lifted.

The wall is said to collapse when the wall experienced a 4 mm crack width so the testing will be stopped [7]. The wall received a maximum load of 63931.2 N with lateral deviation reaching 35 mm (figure 4).

![Figure 4](image)

**Figure 4.** (a) Crack pattern sketch of interlocking masonry brickwall portal, (b) the wall portal after static load test.

Crack pattern that occur along the side of the brick is like a staircase pattern and a slight crack on the brick due to shear failure of the interlocking masonry brick wall portal and it can be categorized as a type of stepped cracks shear failure [8] because there is no mortar specs given on the right and left sides of the brick so that the bond between the bricks is only at the upper and lower sides of the brick and mortar stir in the brick hole that interlocks one another.
4. Conclusions

Based on the test results that have been carried out on the interlocking masonry brick properties and giving static pushover load test on the interlocking masonry brick wall with volcanic ash of Mount Sinabung substitution, the following conclusions are obtained:

1. From the results of the static pushover load test, the interlocking masonry brick wall is capable of receiving a maximum load of 63931.2 N and an ultimate deviation of 35 mm with a crack width of 4 mm.
2. The shear strength of the interlocking masonry brick wall is 21.22 N/mm where each wall width of 1 mm can withstand a static pushover load of 21.22 N.
3. The analysis results of elastic stiffness of the interlocking masonry brick wall obtained is 5905.88 N/mm and a yield load of 57237.55 N with a deviation of 9.69 mm.
4. Based on the crack pattern that occurred, interlocking masonry brick wall portal is a stepped cracks shear failure type.
5. The less the wall stiffness, the less the wall strength to withstand lateral loads that will make it easy to experience failure.

Acknowledgments

The authors gratefully acknowledge that the present research is supported by Ministry of Research and Technology and Higher Education Republic of Indonesia. The support is under the research grant BP-PTN USU of Year 2018 Contract Number XXX/XXX.

References

[1]. American Standard Testing and Material 2003 ASTM E 564 – 2003 Standart Practical for Static Load Test for Shear Resistance of Framed Walls for Building Designation vol 405.
[2]. Badan Standarisasi Nasional 1989 SNI 03-0949-1989: Bata Beton Untuk Pasangan dinding.
[3]. Francisco C J 1997 Seismic Behaviour of Reinforced Concrete Structures with Masonry Infills (New Zealand: University of Canterbury) pp 130-142.
[4]. Minjuan H and Zeng L 2012 Journal of Timber Engineering.
[5]. Pan C L and Ming Y S 2011 Journal of Thin-Walled Structures 49 363.
[6]. Prayuda H 2015 Jurnal Ilmiah Semesta Teknika 18 130.
[7]. Karolina R, Putra M A and Prasetyo T A 2015 Procedia Engineering 125 pp 669-674.
[8]. Karolina R, Syahrizal I, Handana M A P and Hasibuan D Y 2018 International Conference on Computing, Engineering, and Design (ICCED) pp 99-103.