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Experimental Study on the Behavior of Plastered Confined Masonry Wall under Cyclic Load

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Abstract

Confined masonry walls are commonly found in non-engineered housings in Indonesia. To better understand their behavior and to find improvement to the current practice, experimental studies have been conducted using full-scale (3m × 3m) wall specimens, which represent simple housing wall panels. In this research, the performance of plastered confined masonry walls in resisting lateral loads was studied experimentally. Three wall specimens were constructed following general construction practice in Indonesia. All specimens were plastered on both sides. Model 1 was constructed without continuous anchorage, Model 2 with two continuous anchorages with 1m spacing, and Model 3 with two continuous anchorages with 0.5m spacing. The specimens were subjected to cyclic in-plane lateral loads. The parameters evaluated were damage pattern and failure mechanism, load capacity, stiffness, ductility, and energy dissipation. The study revealed that adding plaster improved the wall's lateral capacity. The continuous anchorage shows less significant improvement on plastered walls compared to non-plastered walls, but still increased stiffness, ductility, and energy dissipation. The study verifies that having plaster and continuous anchorage improve structural performance while delaying damage. Analytical study reveals that all models have adequate capacity to resist the design seismic load based on the current code.

Keywords: *Confined masonry wall, plastered masonry wall, continuous anchorage, cyclic lateral load, experimental study*

Abstrak

Dinding bata terkekang umum digunakan pada bangunan sederhana di Indonesia. Untuk mempelajari perilaku dinding bata terkekang dan memperbaiki penggunaannya, kajian eksperimental telah banyak dilakukan menggunakan model dinding berskala penuh (3m x 3m), yang mewakili tipikal panel dinding pada bangunan sederhana. Pada riset ini, kinerja dinding bata terkekang berplester dalam menerima beban lateral dikaji secara eksperimental. Tiga spesimen dinding dibangun mengikuti kebiasaan konstruksi di Indonesia. Semua spesimen dinding diplester pada kedua sisinya. Model 1 dibangun tanpa angkur menerus. Model 2 dibangun dengan dua angkur menerus berjarak 1m. Model 3 dibangun dengan dua angkur menerus berjarak 0.5m. Ketiga spesimen diberi beban siklik lateral. Evaluasi meliputi pola kerusakan dan keruntuhan, kapasitas, kekakuan, daktilitas, dan energi disipasi. Kajian menunjukkan adanya plester meningkatkan kapasitas dinding. Angkur menerus lebih tidak berpengaruh pada dinding berplester dibandingkan dinding tidak berplester, tetapi tetap menaikkan kekakuan, daktilitas, dan energi disipasi. Kajian membuktikan bahwa adanya plester dan angkur menerus meningkatkan kinerja struktur dan menunda kerusakan. Analisis menunjukkan bahwa semua model memiliki kapasitas yang memadai untuk menahan beban gempa rencana sesuai peraturan yang berlaku.

Kata kunci: *Dinding bata terkekang, dinding bata berplester, angkur menerus, beban lateral siklik, kajian eksperimental*

Introduction

A vast majority of structures in Indonesia are of one- or two-story residential buildings constructed of confined masonry walls. This type of building is often classified as non-engineered structures, where the structures are typically built with no or minimum appropriate structural design process and commonly following rules of thumb that have been practiced among the builders. Past earthquakes have revealed that these buildings are prone to structural damages or even collapse if not properly constructed (Build Change, 2018). Observations after earthquakes reveal that the failures of confined masonry walls were commonly due to the inadequate detailing of structural elements as well as poor workmanship and low quality of materials (Rildova *et al*., 2024). Thus, improving the seismic behavior of these structures is a necessity to minimize economic losses and casualties. Various guidelines and manuals were developed for non-engineered structures, with the objectives of improving their performance under seismic load (Shrestha *et al*., 2009; Meli *et al*., 2011).

Studies have been conducted to understand the behavior of such structures and how to improve their behavior under earthquake load. Numerous analytical models on masonry walls have been developed to determine the performance of the structures and to obtain overall structural responses to earthquake loads. Several key parameters, such as materials and geometric properties, confined elements, reinforcements, aspect ratio of walls, and gravity loads, were found to be detrimental for seismic response (Borah *et al.,* 2021). However, analytical models of confined masonry walls are strongly influenced by the characteristics of the materials as well as the method of construction. Hence, there are considerable variations between analytical models of masonry walls developed for various locations. More experimental studies are needed to develop more accurate numerical models that consider various accounts of materials and construction practices (Borah *et al.*, 2023).

To better understand structural behavior and to verify numerical models, experimental studies have been conducted on confined masonry walls. The size of confined elements as well as longitudinal reinforcement ratio were found to have significant effect on the strength and stiffness, ductility, crack pattern, and collapse mechanism of the confined masonry walls (Ibrar, *et al,* 2022). The collapse mechanism of confined masonry thin walls was further studied experimentally, and flexural failure was observed with concrete crushing at columns and diagonal cracks developed on masonry walls (Varela-Rivera *et al.,* 2019). The effects of confinement with various detailing on typical Indonesian masonry walls have also been evaluated, especially related to wall-frame connections (Wijaya *et al*., 2011). Variations of specimens include size of confinement portal, confinement detailing, as well as detailing of confinement to walls such as anchorage, lintel beam, shear key, or haunches on beam column connections. The study revealed that continuous anchorage reinforcement was considered as the best solution to improve the performance of the masonry wall, due to increase in structural capacity without reducing ductility. This solution is also quite easy to implement.

The use of joint reinforcement was also studied experimentally, and results show that while the reinforcement increases lateral strength and reduces stiffness degradation, it also reduces lateral ductility and may not be feasible for rehabilitation of damaged existing walls (Cruz, A, and Perez-Gavilan, J.J, 2021). Research on the effects of openings on walls have also been conducted, from small openings to large ones (Muhammad, 2011; Prasetyo, 2012, Putra, 2024). The study shows that large openings have significant effects on structural performance, as openings reduce both strength and ductility. Monical and Pujol (2024) studied the effect of infill walls on reinforced concrete frames and found that the cross-sectional area of masonry infill walls affects the damage on the structure.

An experimental study of confined masonry walls rehabilitated with various techniques (mortar reinforced with welded wire mesh, mortar reinforced with synthetic or steel fibers, or installation of buckling restrained braces) was conducted, and the rehabilitation was found to increase structural strength and stiffness (Lubin, *et.al*. 2023). Alternative retrofitting techniques and strategies were also evaluated for typical confined masonry walls in Indonesia (Boen, 2014). The addition of continuous anchorage on typical Indonesian masonry walls was studied by varying the location of the anchorage (Apriani, 2013), revealing that anchorage prevented the development of cracks on walls. Installing ferrocement or wing wall also proved to be able to improve the structural performance for these walls (Firdaus, 2023). Retrofitting projects utilizing some of the above strategies have also been conducted locally to improve the performance of existing structures (Kusumastuti *et al*., 2008; Kusumastuti *et al*., 2024).

Very few studies have been conducted to solely understand the effect of plaster on confined masonry walls. Considering that many masonry wall structures in Indonesia are plastered on both sides, it is crucial to evaluate the effect of plaster on the masonry wall based on typical wall construction in Indonesia.

The installation of plaster to confined masonry walls adds connection of the frame elements to the wall, as well as structural strength and stiffness. Moreover, the plaster protects brick masonry walls from various external elements. Conversely, the plaster may also change the damage pattern and collapse mechanism of the structure. It should be noted that local materials and construction practices significantly affect structural behavior. Therefore, the effect of plaster on typical confined masonry walls in Indonesia needs to be quantified and better understood.

This research aims to better understand the effect of plaster on confined masonry walls, and to observe the structural behavior structure under lateral load, especially related to the typical wall construction in Indonesia. The experimental results also will be used to develop numerical model for typical plastered confined masonry walls in Indonesia,

Methodology

Experimental models

This research evaluates the use of plaster on both sides of walls, as well as the use of reinforcement anchorage to improve the behavior of confined masonry walls. Three full-scale (3x3m) plastered confined masonry walls were used as specimens in the experimental study (Fig. 1).

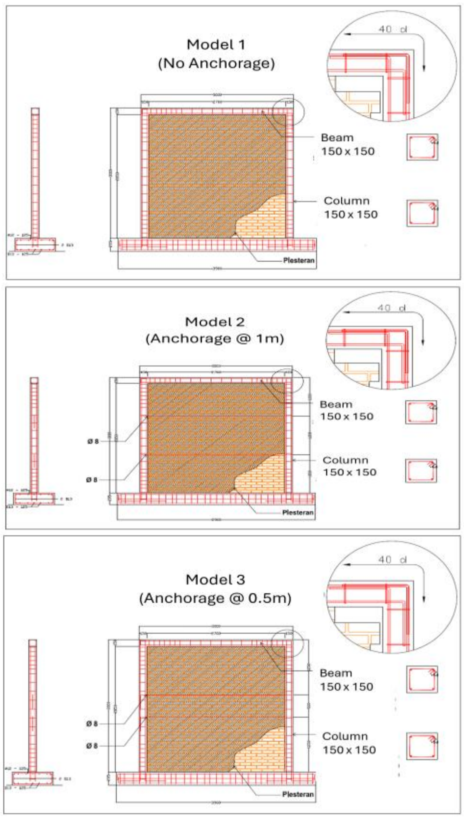


Figure 1. Test specimens

The specifications of each specimen are as follows: Model 1, plastered confined masonry wall without horizontal continuous anchorage, Model 2, plastered confined masonry wall with two horizontal continuous anchorages with 1 m spacing Model 3, plastered confined masonry wall with two horizontal continuous anchorages with 0.5 m spacing. The variations of continuous anchorage were made to observe their effect on the walls' performance. The locations were selected to obtain optimal anchorage locations to avoid wall-frame separation. Thus, Model 2 was constructed with equal spacing of anchorage, while Model 3 was constructed with anchorage concentrated near the mid height of the wall. The three models were constructed with stages of typical practice in Indonesia, i.e., reinforcement bars assembling, concrete foundation pouring, brick masonry layering, concrete frame pouring, and wall plastering. No special attentions for code compliance were applied since the specimens were expected to mimic the actual confined masonry wall panels in typical Indonesian houses.

Material characteristics

The masonry walls were of local quality bricks, with the size of 50mm x 100mm x 200 mm. The mortar space between the bricks was 15mm, made of cement and sand with volume ratio of 1:5, and the same volume of water as cement. The plaster was applied on both sides of the walls, 15 mm thick, with similar mixing composition ratio as the mortar.

The beams and columns were of reinforced concrete members with dimensions of 150 mm x 150 mm. The concrete mixture used a 1:2:3 volume ratio of cement, sand, and coarse aggregate, respectively, with water content equal to the cement volume. The longitudinal rebars were of 4ϕ10 plain rebars, while the transverse rebars were of 7ϕ8-100, 8ϕ8-200, 7ϕ8-100, along the length of the beams.

Prior to conducting the experiment, materials were assessed to determine their properties. Compression tests were conducted on brick masonry unit, mortar, and concrete materials. Bond shear strength between brick masonry unit and mortar was also tested. The tensile tests were conducted for reinforcement bars. Table 1 presents the summary obtained from material tests.

Table 1. Cracks on masonry walls

Material properties		Test results (MPa)
Concrete compressive strength	f_c'	18.02
Mortar compressive strength	f_m	6.37
Masonry compressive strength	f_b	6.63
Bond shear strength of brick-mortar	f_s	0.095
Rebar Ø8 tensile strength	f_y	315
Rebar Ø10 tensile strength	f_y	337

Material tests reveal that the compressive strength of brick masonry unit was 6.63 MPa. According to SII.0021-78, this brick masonry was characterized between classes 50 and 100. The mortar compressive test result was 6.37 MPa. This result complies with the Indonesia Earthquake Study (min. 3 MPa), and the recommendation of Eurocode (min. 5 MPa). The bond shear strength between mortar and brick material was found to be weak (only 0.095 MPa). The test on concrete material reveals that the compressive strength was 18.02 MPa, thus meets SNI 2847-2020 minimum requirement. The materials of plain reinforcement bars of diameters 8 mm and 10 mm were BJTP 30, with the nominal yield strength of 300 MPa. The tensile test verified that the rebars satisfied the requirements for BJTP 30.

Test setup

To simulate seismic loading, a loading history of quasi static lateral cyclic load was used to obtain structural performance. The lateral load was applied on the top of the specimen with a displacement control mechanism. The test was conducted for the specimen until the capacity reduction reaches 50% (collapse condition) or the drift reaches 5%, whichever came first. Strain gauges and Linear Variable Displacement Transducers (LVDT) were installed to measure responses of the specimen. Strain gauges were placed on longitudinal rebars for beams and columns near the beam column joints and at mid span, while LVDTs were placed to monitor the displacement of the specimen. Figure 2 illustrates the test setup and locations of LVDTs used in this study.

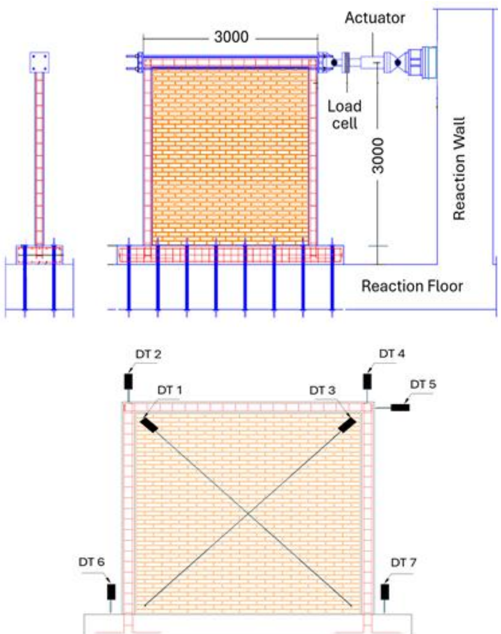


Figure 2. Test setup and LVDT locations

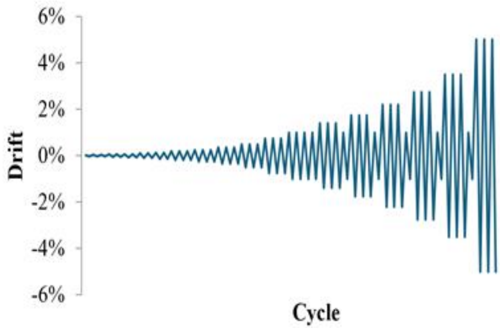


Figure 3. Loading history

As illustrated, the lateral load was applied in-plane of the wall. Figure 3 presents the loading history for the cyclic load in this study. The loading history follows the recommendation from ACI 374.1-05(19) (ACI, 2019).

The results from the experiments were then obtained and evaluated. Comparisons with results from previous studies were also conducted for complete analysis.

Experimental Results

Crack patterns

Due to lateral load, the specimens experienced damage. Cracks were developed on the specimens and propagated as the load increased. All models revealed that cracks began on the frames and then developed into the masonry walls. Separation of brick-walls and confining-frames were observed. Yields of the reinforcement were also obtained. Table 2 and 3 present the observed drifts when the first cracks occurred and reinforcement yielded on the models.

Table 2. Cracks on masonry walls

Model	Drift at first crack (%)	Crack pattern
1	0.100	Strut diagonal
2	0.133	Strut diagonal
3	0.133	Strut diagonal
B	0.067	Diagonal compression
F	0.050	Diagonal compression

Note: B and F are from previous study (Wijaya, 2011)

Table 3. Damage on frames

Model	Drift at first Crack (%)	Drift at first yield of rebar (%)
1	0.050	0.200
2	0.067	0.350
3	0.067	0.350
B	0.250	0.250
F	0.250	0.500

Note: B and F are from previous study (Wijaya, 2011)

Comparisons were made to the previous study for completeness, with Model B is a confined masonry wall without plaster and without anchorage, and Model F is a confined masonry wall without plaster but with continuous anchorage (Wijaya, 2011). As Model B and Model F were constructed without plaster on the masonry walls, the effect of adding plaster to the wall panel could be evaluated.

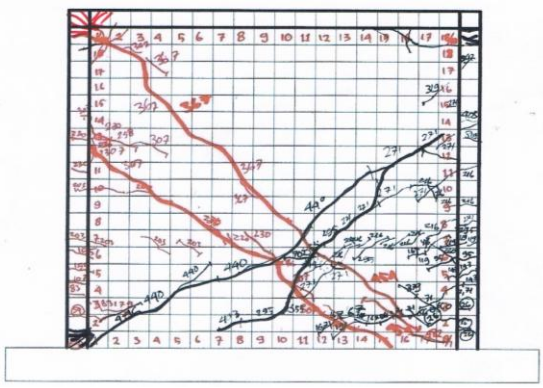
Model 1 shows first crack between brick wall and frames occurred at 0.5% drift, and at 1% drift has spread along the brick-wall and frame bonding area and caused separation. At 1.75% drift, failure was observed at approximately two-thirds of the column height, and the beam column connection. Due to the failure of the connection, the cyclic lateral load could not be continued, and the experiment was terminated at this drift. Model 2 and Model 3 showed no separation between frame and brick wall until the final drift, i.e., 5% drift. However, cracks were observed along the anchorage for these specimens. on 5% drift for Model 2, and on 1.4% drift for Model 3. Both models showed less damage above the anchorage compared to Model 1. Figure 4 presents the crack patterns for all models.

The experiment shows that adding plaster on both sides of the wall caused cracks on the confining frames at an earlier stage. This is due to the increase in wall-to-frame stiffness ratio; thus, frame elements became the critical members for the plastered confined masonry models. However, the cracks on walls were delayed for the plastered models compared to non-plastered models, as the plaster provided additional protection for the walls. The test results also show that the addition of horizontal continuous anchorage could delay onset of damage on walls, and the strut diagonal mechanism could be achieved.

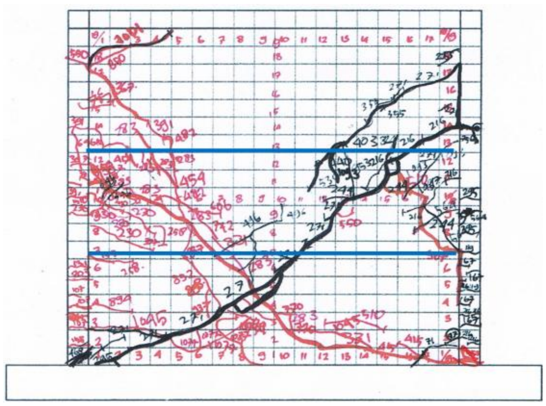
Modes of failures

The specimens were tested until the failure mechanism or the 5% drift limit was obtained. All models showed that cracks were developed on the columns and then propagated to the plastered masonry walls. Next, the strut diagonal cracks were developed on the masonry walls. The models showed severe damage at the completion of the experiment. Figure 5 presents the condition of the specimens at the final stage.

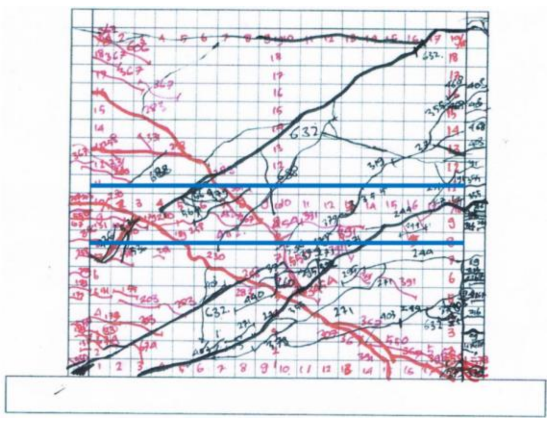
For Model 1, as larger cracks were developed on the masonry wall, bulging occurred on the columns. Separation of the plastered masonry wall and confining columns increased as the experiment progressed. Eventually, failure of confining column occurred at approximately two-thirds of the column height. Beam column connection failure was also observed on this model. The failure was estimated due to insufficiency of development length of longitudinal rebars. The connection failure terminated the experiment.



(a) Model 1



(b) Model 2

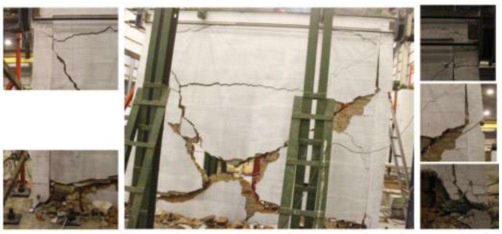


(c) Model 3

Figure 4. Crack patterns at final stage

Failures were observed on columns of Model 2 and Model 3. This was due to the lateral anchorages that stiffened and strengthened the upper frames; hence the column supports became the critical areas and experienced damage. For Model 2, damage was also observed at approximately two-thirds of the column height, due to location of the upper anchorage and overlays of concrete pouring. The observation shows that Model 2 and Model 3 developed failures at the column supports. The shear capacity of the support was estimated to be less than the shear force applied at the specimens. It should be noted that the maximum shear forces applied to the specimens were higher than the actual shear force developed on typical confined masonry walls of real structures.

(a) Model 1



(b) Model 2

(c) Model 3

Figure 5. Conditions of test specimens at final stage

Installing continuous anchorage on plastered masonry wall seems to have less effect than expected. All specimens developed almost similar capacity, albeit Model 1 has the least capacity. However, the maximum displacement and ductility were very much different, with continuous anchorage was successful in delaying cracks and improving bonding between columns and walls. Observation also reveals that the variation of locations of the anchorage does not yield additional benefit to the wall's performance as expected, since cracks did not develop through the anchorage.

Structural performances

Hysteretic curves and lateral capacity.

Based on the experiment, hysteretic curves were developed for all wall specimens. Figure 6 presents the envelope of the hysteretic curves for Model 1, Model 2, and Model 3. All models develop similar hysteretic behavior with a slight increase in capacities of continuous anchorage models. However, there are significant differences observed in stiffnesses degradation and structural ductility. Models 2 and 3 with continuous anchorage show larger displacement capacities as well as less strength reductions after ultimate strength capacities were achieved.

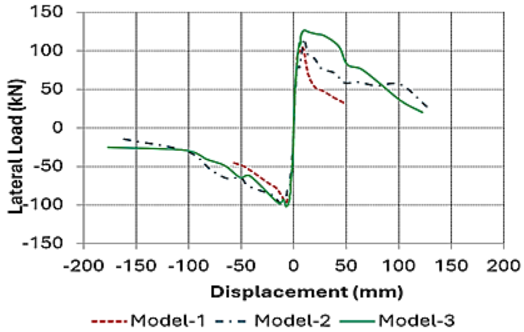


Figure 6. Envelopes of Hysteretic Curves

Table 4. Lateral Capacity of Specimens

Model	Lateral capacity (kN)
1	90.8
2	100.9
3	102.0
B	50.9
F	67.0

Note: B and F are from previous study (Wijaya, 2011)

Table 4 presents the lateral capacity of the models. The study reveals that adding plaster to both sides significantly increased the capacity of confined masonry walls, by 50 to 80 percents. The effect of plaster is larger for models without anchorage. Although the compressive strength of mortar for plaster was smaller than that of concrete, the installation of plaster increased the cross-sectional area of the wall, thus increasing the capacity accordingly. Moreover, the models with continuous anchorage have approximately 10 percent increased capacity compared to the one without anchorage. Results show that cracks on the plastered walls were observed at larger displacements compared to cracks on the non-plastered model. The addition of plaster appears to enhance the masonry walls' confinement, effectively delaying the onset of the initial crack. This results in improved structural performance for the specimens.

Structural stiffness

Figure 7 presents specimens' stiffnesses for each cycle. At the initial drift, Model 3 has the highest stiffness. Model 1 has a higher stiffness than Model

2 at the initial cycle but shows higher degradation at 0.25 drift. The is due to the significant crack between the wall and the frame of Model 1 at this drift and it gradually decayed until the end of the cycle. Hence, Model 2 continued to have a higher stiffness than Model 1 until the end of the cycle. The additional anchorages prevent the separation between wall and frame which decreased the frame confinement and reduced the overall structural stiffness.

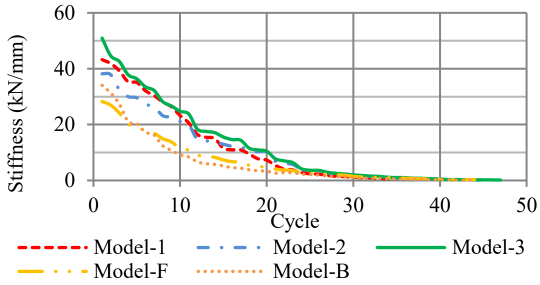


Figure 7. Stiffness of the specimens

Figure 7 also reveals that additional plastered on both sides improved the stiffness significantly. This is because additional plasters not only increased the inertia but also the confinement for the masonry panels.

Ductility

Although testing was conducted until failure, the analysis of structural ductility focused on the stage where strength degradation reached 20% of the ultimate strength, following FEMA failure criteria (FEMA 450, 2003). Table 5 presents the structural ductility of the specimens that were obtained in this study. The result shows that there was no increase in ductility due to the addition of plaster. Further analysis reveals that the plastered masonry walls had greater capacities than non-plastered ones. Therefore, the frames of plastered walls carried more load than non-plastered walls, thus at the beginning of the test the maximum structure capacities increased.

Table 5. Ductility of specimens

Model	Ductility
1	3.55
2	4.34
3	9.36
B	4.14
F	6.68

Note: B and F are from previous study (Wijaya, 2011)

The confining frames, however, have weak areas at the connections which are often neglected. Therefore, when the specimens were subjected to larger forces, the weak areas would be damaged. In this study, the beam-column connection area is suspected to have inadequate distribution of stress due to insufficient development length of longitudinal rebars. Therefore, the joint strength was less than required to convey forces between structural members. Next, the column support was considered to have less capacity than the actual shear force due to noncompliance with the code. Hence, these areas became the weakest links of the wall specimens. It can be seen during the experiment that damage to the support area and the connections occurred early, and the damage was quite severe. With the damage on the connection area due to insufficient anchorage length and damage on the support area due to insufficient shear capacity, there is considerable capacity degradation in the wall specimen. This degradation causes the ductility of the wall specimens to be relatively small. Nevertheless, the failure mode of Model 3 with no damage on column assisted prolonged ductility for the specimen.

Cumulative input and dissipated energy

Figure 8 and Figure 9 present the cumulative input energy and the cumulative dissipated energy for each specimen. Model 1 with no continuous anchorage shows the least cumulative input and dissipated energies, which is due to lowest drift failure of the specimen. The figures also show that the highest input energy was obtained for Model 2. This was due to the lowest stiffness degradation for Model 2, which can be seen from the total reduction from the initial to the final drifts. The spacing of 1 m for additional continuous anchorage was somewhat more effective in improving the dissipated energy compared to the spacing of 0.5 m of Model 3. Table 6 presents the comparison of cumulative input and dissipated energies for all specimens, including from previous study. The continuous anchorage significantly improves the amount of cumulative input energy and cumulative dissipated energy for both plastered and non-plastered confined masonry walls. The continuous anchorage allows the wall specimens to increase the maximum drifts and ductility, and to improve the structural performance in general.

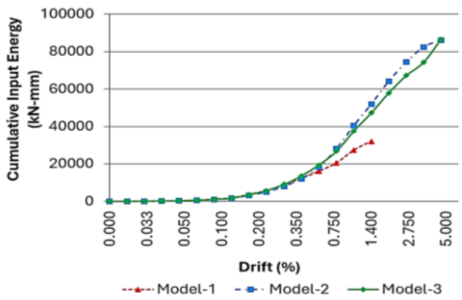


Figure 8. Cumulative input energy

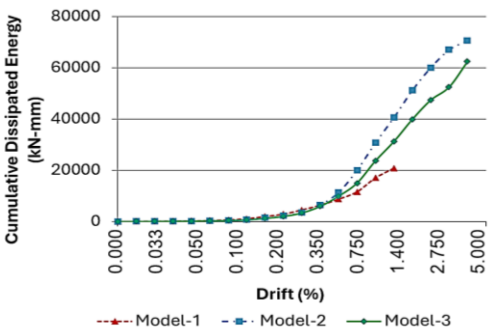


Figure 9. Cumulative dissipated energy

Table 6. Cumulative input energy and cumulative dissipated energy of specimens

Model	Drift (%)	Cumulative input energy (kN mm)	Cumulative dissipated energy (kN mm)	Percentage of dissipation (%)
1	1.75	27,223	16,985	62
2	1.75	40,502	30,709	76
	5.00	86,268	70,598	82
3	1.75	37,560	23,686	63
	5.00	86,640	62,371	72
B	1.40	19,475	13,786	62
F	3.50	66,488	51,529	78

Note: B and F are from previous study (Wijaya, 2011)

The additional plaster on both sides of the confined masonry walls also improves the cumulative input energy and the cumulative dissipated energy for approximately 30 percent than non-plastered one. The study shows that combining the addition of plaster and continuous anchorage significantly increased the ability of the wall panels to dissipate energy.

Numerical model for infill masonry wall

Numerical models for the masonry walls were developed based on experimental results. Beam elements were used for confining members, which allow plastic hinges mechanism developed on the members. The masonry wall was assumed cracked and formed diagonal strut, hence it was modeled as a nonlinear link element.

Madan, et.al (1997) developed an analytical model for the masonry elements as two equivalent diagonal compression struts that work alternately from both sides when lateral loads act from behind the direction of the compressive force. The relationship between shear strength and displacement of the strut was assumed to be a smooth curve which can be simplified as a bilinear curve, with an elastic stiffness (K_0) until it reaches the yield point (V_y) and undergoes stiffness degradation to the ultimate point (V_m). Mostafaei and Kabeyasawa (2004) further developed the strut parameters for post peak residual shear strength of infill masonry wall panels. The equivalent link element model can be developed for infill masonry walls, and Figure 10 illustrates the load-displacement model developed for such element.

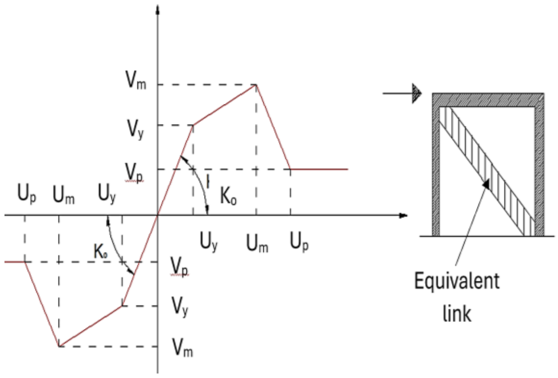


Figure 10. Load displacement model of link element

The yield shear (V_y) can be calculated as Eq.1. While the yield displacement (U_y) can be determined as Eq.2.

$$V_y = \frac{V_m - \alpha K_o U_m}{1-\alpha} \quad (1)$$

$$U_y = \frac{V_y}{K_o} \quad (2)$$

Where K_0 is the initial stiffness and α is ratio of the stiffness after yielding to the initial stiffness, and is taken as 2 and 0.2, respectively. The failure shear capacity (V_p), can be assumed as follows:

$$V_p = 0.3V_m \quad (3)$$

While the failure displacement (Up) can be calculated with the following equation:

$$U_p = 3.5(0.01h_m - U_m) \quad (4)$$

Previous study shows that continuous anchorage increased frame confinement. A widely used analytical model was developed by Mander, et.al. (1988). Assuming that the masonry wall with anchorage was fully confined, the compressive stress of the wall can be derived with the next equation:

$$f_{mc}' = f_m'\left(2.254\sqrt{1+\frac{7.94f_l'}{f_m'}} - \frac{2f_l'}{f_m'} - 1.254\right) \quad (5)$$

Where

$$f_l' = K_e f_l = K_e\left(\frac{2f_{yh}A_{sp}}{d_s s_h}\right) \quad (6)$$

$$\varepsilon_{mc} = 0.002\left(1+5\left(\frac{f_{mc}'}{f_c'}\right)\right) \quad (7)$$

With f_{mc}' is compressive strength - masonry wall (MPa), f_m' is compressive strength - masonry units

(MPa), f_l' is effective lateral stress (MPa), K_e is confinement coefficient, d_s is= specimen width, s_h is clear distance of lateral reinforcement , ε_{mc} is confinement concrete strain

Using the above equations and following the envelopes of the hysteretic curves, f_{mc}' and ε_{mc} for all specimens were then calculated. The values of f_{mc}' and ε_{mc} for Model 1 were found to be 3.26 MPa and 0.0018, while the values for Models 2 and 3 were 3.47 MPa and 0.0027. These values were then applied to Equation (1) to (4) to develop the load displacement strut models. Table 7 presents the strut parameters for all models.

Table 7. Parameters for link elements in local axis for specimens

Parameter	Model 1	Model 2 and 3
V_y (N)	105468	111627
U_y (mm)	5.60	8.24
V_m (N)	140625	148836
U_m (mm)	14.93	21.98
V_p (N)	42187	44651
U_p (mm)	92.66	92.66

These parameters were used for developing nonlinear models for masonry infilled walls to be used in numerical analysis.

Seismic load analysis

To fully understand the actual condition of plastered confined masonry walls in a typical housing structure, a numerical analysis was conducted to determine the maximum shear force developed in such structure. In this study, a Type-36 house was analyzed using the static equivalent lateral procedure. The structure was assumed located in a seismic prone region in Indonesia. Figure 11 shows the layout of the structure, based on an experimental study on a full-scale house model subjected to lateral load (Hwie, 2011; Kusumastuti, 2012).

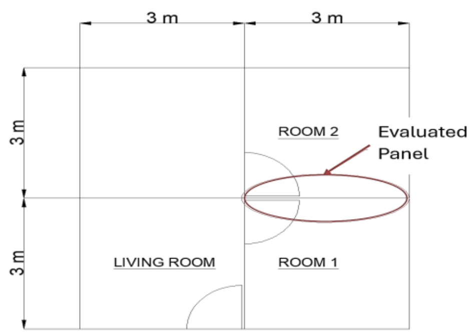


Figure 11. Type-36 house plan view

The reinforced concrete frames were modeled as beams and columns, allowing plastic hinge mechanism developed on these elements. The dimensions were similar to the real dimensions from the experiment. Material properties were obtained from the material testing in this study. The walls were assumed to have the characteristics of the specimens used in this study. The non-linear link elements for Model 1 were used for walls, with strut parameters obtained from numerical approach in the previous section.

The design seismic load was determined based on the current building code, i.e., SNI 1726-2019 (Badan Standarisasi Nasional, 2019). The importance factor (I) was assumed to be 1.0 for regular housing, and the reduction factor (R) was taken as 3.5, to consider limited ductility. The spectral acceleration parameter for short period SDS for the site was assumed to be 0.81 g for site class SD. The seismic self-weight (W) was calculated as 41.6 kN. The structural analysis was then conducted using static equivalent lateral load procedure to determine the design base shear for the structure, as well as the shear force for the evaluated wall panel.

The structural analysis reveals that the period of the structure was 0.15 sec. From the analysis, the design lateral force of the evaluated panel (V) was found to be 10.61 kN. Comparing the design lateral force with the plastered confined masonry walls capacity obtained in this study (see Table 3), this design seismic load of 10.61 kN was significantly less than the actual capacity of the walls. Therefore, the study shows that installing both seismic improvements (plaster and continuous anchorages) on confined masonry walls are effective to prevent the failure of the wall panels due to the design seismic load from the current building code.

Concluding remarks

This experimental study aims to better understand the effect of plaster on typical Indonesian confined masonry walls. Improvement on the walls in terms of installing continuous anchorage was also evaluated. Three full-scale (3x3m) plastered confined masonry walls with variation of continuous anchorages were tested with cyclic in-plane lateral loads, and structural responses were evaluated. Based on the experimental results, the conclusions are as follows.

Installing plasters on confined masonry walls significantly increases the lateral load carrying capacity of the walls, predicted due to increase in cross sectional area. The experiments indicate that the maximum lateral capacity experienced an increase of around 1.5 to 1.8 times. Providing plasters on confined masonry walls prevents premature cracks developed on the walls. In addition, the diagonal strut crack mechanism was developed compared to non-plastered models that may develop sliding shear mechanisms. Continuous anchorages seem to have less effect on the maximum capacity on plastered walls compared to non-plastered walls, but for both plastered and non-plastered, the anchorage improves the confinement of the structure and prevents the separation between frames and infill walls. Hence, the overall structure stiffness can be increased. By combining the continuous anchorage with plaster for the confined masonry walls, the maximum displacement and the structural ductility of the walls can be increased, thus the cumulative input energy and cumulative dissipated energy are also increased. Using the static equivalent load based on the current code, the plastered confined masonry walls in this study can be expected to have adequate capacity and able to resist the design seismic load.

Further analyses are necessary to have a thorough understanding of the effect of plaster on the behavior of confined masonry walls. Installing retrofitting materials such as ferrocement to the walls may affect the behavior even further. Also, the effect of plaster for axial load of walls and out-of-plane lateral force needs to be further studied.

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