Seismic performance of earthquake resistant simple residential confined masonry house structure based on permen PUPR No.5 of 2016 specification

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Abstract. This research focused on seismic performance evaluation of earthquake resistant simple landed house using Confined Masonry (CM) structural system which follows technical specifications set forth in regulation of Appendix 2 of Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat (Permen PUPR) Nomor 5 tahun 2016 (Permen PUPR No. 5 of 2016). The seismic performance evaluation of the structure is performed by conducting strength based analysis using earthquake loading as specified in SNI 1726:2019. Seismic performance evaluation of Unreinforced Masonry (URM) simple landed house was also performed to be compared. Evaluation result shows that CM house prototype which follows the regulation has good seismic performance. Meanwhile, URM house prototype is inadequate to resist earthquake loads particularly on many locations in Indonesia with moderate to high level of seismicity.

1. Introduction
Indonesia is a region with a high level of seismic risk. This is due to its geographical location between the Eurasian plate, the Indo-Australian plate, and Pacific plate. The energy stored due to shifts and collisions between the plates, at a certain level, is released and produces a wave. The wave then propagates to the surface which is felt by humans as an earthquake phenomenon.

The number of residential buildings that were severely damaged, even collapsing and affecting their inhabitants due to earthquake shocks, indicates that there is still a lot of residential construction built by the community has poor structural performance. Inhabitants of buildings affected by collapsed buildings generally do not have sufficient time to save themselves, which shows that their buildings are experiencing brittle damage. The nature of brittle damage to buildings is something that must be avoided because it will experience a sudden collapse shortly after its capacity to resist lateral forces due to earthquakes has been exceeded. An earthquake resistant building may suffer damage due to a large earthquake but must have a ductile behavior so that it can survive when experiencing large deformation without experiencing a total collapse. Thus, the inhabitants will have the opportunity to save themselves when an earthquake occurs.

Commonly people use non-engineered buildings for houses, especially those classified as simple residential houses. Non-engineered buildings can be defined as buildings that are built without
involving construction experts such as Architects and Civil Engineers [1]. This causes many simple residential houses with poor structural seismic performance. For this reason, the Indonesian government conducted a study and development on the specifications of earthquake resistant simple residential house.

The study and development activities carried out by the Indonesian government, assisted by experts, have produced various guidelines and technical specifications for earthquake resistant simple residential houses. The latest version of the guidelines and specifications are listed in regulation of Appendix 2 of Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat (Permen PUPR) Nomor 5 tahun 2016 (Permen PUPR No. 5 of 2016) about Building Permit (known as Izin Mendirikan Bangunan in bahasa).

However, studies and knowledge of potential earthquake hazards also continue to experience development. In 2017, the Indonesian government through the National Earthquake Study Center (Pusat Studi Gempa Nasional or Pusgen) has issued a 2017 Indonesia Earthquake Hazard and Source Map (Peta Sumber dan Bahaya Gempa Indonesia 2017). The presence of the new earthquake map causes the need for adjustments in earthquake resistance design standards that apply in Indonesia so that SNI 1726: 2019 has published. In this study, an analysis and assessment on the seismic performance of simple earthquake resistant house structures with technical specifications according to Permen PUPR No. 5 of 2016 against the technical requirements of SNI 1726: 2019 will be carried out.

2. Development of specifications for earthquake resistant simple residential houses in Indonesia

People in the past established traditional houses as their homes. These traditional houses have different characteristics in each particular areas, and are generally built using materials available in each local area. The most widely used material for building traditional houses in various regions is wood.

Masonry building began to be recognized by Indonesian people since the Dutch colonialism. That kind of building structural system uses masonry wall as load bearing element, with or without reinforcement or confining frame. Types of masonry buildings built by the Dutch colonial at that time commonly had a wall thickness of one to two layers of bricks, and generally had brick pilasters but without reinforced concrete frames as confining element [1]. Such masonry system without reinforcement or confining frame is called as Unreinforced Masonry (URM) system. Materials of masonry buildings (such as bricks and mortars for brick and plaster adhesives) that were built by the Dutch generally used certain specifications which were generally not used in masonry buildings in the period after Dutch colonialism ended.

After Indonesian independence, Indonesian people were accustomed to using brick masonry houses. However, as the cost to build houses increased, the community began to build half-brick thick brick masonry houses, which were initially without reinforcement of reinforced concrete frames. Such masonry houses have brittle behavior that makes it difficult to survive when experiencing shocks due to earthquakes [1].

From the events of building damage caused by the earthquake, a habit arises in the community to add reinforced concrete frames as a confining element of a half-brick masonry houses. These reinforced concrete frames or confining elements are commonly referred to as 'practical columns' and 'practical/perimeter beams'. This structural system is called Confined Masonry (CM). The confined masonry houses show better behavior and better earthquake resistance if built with certain specifications [1].

Technical specifications for confined masonry buildings began to be introduced with the issuance of Minister of Human Settlement and Regional Infrastructure Decree (Keputusan Menteri Permukiman dan Prasarana Wilayah) No. 403 of 2002 (known as Kepmen Kimpraswil 403/2002) concerning Technical Guidelines for the Construction of Healthy Simple Houses (recognized as Rumah Sederhana Sehat). In the scope of structural performance aspect, the regulation provides various prototypes of simple house buildings that are equipped with material specifications and structural topology, including details of reinforcement and connection systems between structural components.
The results of a survey conducted by the Bandung Institute of Technology (ITB) regarding the percentage of the type of typology of residential house structural systems for rural and urban areas with sample loci in the provinces of Yogyakarta, West Java, and West Sumatra are shown in Table 1. Meanwhile, Table 2 shows the data of structural systems usage for residences in DKI Jakarta and Manado City areas based on survey conducted by Puskim, Ministry of Public Works and Public Housings. From Table 1, it is known that URM residential houses are dominantly used in rural areas, while CM residential houses are dominantly used in urban areas. This is supported by the data in Table 2 which shows that in urban areas such as Jakarta and Manado, the CM residential houses had been dominantly used.

Development and refinement of the technical specifications for an earthquake resistant simple residential house is then introduced in Appendix 2 of the Minister of Public Works and Public Housing Regulation No. 5 of 2016 (recognized as Permen PUPR No.5 2016) about Building Permit (known as Izin Mendirikan Bangunan). The technical specifications for simple residential house prototype described in the Permen PUPR was established with the support of structural performance experimental testing results which is conducted in the Laboratory of Building Structure of the Research Institute for Human Settlements (known as Puskim, now Directorate of Technical Development of Human Settlements and Housing) which was conducted in 2010.

### Table 1. Survey results of typology of residential house structural systems in Province Yogyakarta, West Java and West Sumatra

| Area    | % Total |         |         |
|---------|---------|---------|---------|
|         | URM     | CM      | Non     |
| Rural   | 63%     | 8%      | 29%     |
| Urban   | 16%     | 66%     | 18%     |

Source: ITB, BNPB (2012)

### Table 2. Survey results of typology of residential house structural systems in Jakarta and Manado

| City     | % Total |         |         |         |
|----------|---------|---------|---------|---------|
|          | URM     | CM      | IW      | Non     |
| Jakarta  | 7%      | 70%     | 21%     | 1%      |
| Manado   | 20%     | 69%     | 11%     | n/a     |

Source: Puskim

URM : Unreinforced masonry
CM : Confined masonry
IW : Infilled Wall
Non : Non permanent buildings

3. Specifications for earthquake resistant residential houses according to permen PUPR No.5 of 2016

In general, the earthquake resistant simple residential house prototype described in Permen PUPR No.5 of 2016 is a one-story confined masonry building with certain material specifications and several configurations of floor plans. The specifications of concrete material specified in the regulation are determined based on the composition of the mixture of concrete materials that is 1 cement: 2 sand: 3 gravel: 0.5 water. The steel/rebar reinforcements for confining elements are specified using plain (undeformed) bar of diameter 8 and 10 mm. General information about the structural technical specifications for the building prototype is shown in Figure 1.
4. Experimental test method

This research used quantitative and qualitative method. The performance of the residential house prototype structure was tested experimentally through cyclic loading test of a full scale three dimensional (3D) specimens. The results obtained from the cyclic loading test include the hysteresis curve of the lateral displacement ($\Delta$) vs the lateral force ($F$) at the top of the building.

The cyclic loading tests follows the provisions in FEMA 450 using displacement controlled method. Figure 2 shows the cyclic loading sequence according to FEMA 450. Testing is carried out in the Laboratory of Building Structure of Research Institute of Human Settlements. Testing of Confined Masonry (CM) prototype specimen was carried out in September 2010. Meanwhile the testing of Unreinforced Masonry (URM) prototype specimen was carried out in April 2015 to determine the strength and behavior of the URM system as well as comparing it with CM system performance.

4.1. Specifications of specimens

In this research, two specimens had been tested. The first specimen is a one story house (without roof construction) of 36m$^2$ of plan area with specifications following the provisions from Appendix 2 of Permen PUPR No.5 of 2016, which represents a confined masonry (CM) structural system. The second specimen is a similar house but without practical columns and beams (confining elements). The second specimen represents the unreinforced masonry (URM) structural system. In this paper, each specimen will be referred to as CM specimen and URM specimen respectively. The
configurations of the specimens are shown in Figure 3. In general, the cyclic loading tests setup are shown in Figure 4 and Figure 5. The material specifications of the CM and URM specimen are obtained through direct testing of material samples as shown in Table 3 and Table 4.

![Image of specimen plans](image1)

**Figure 3. Plans of Specimens**

![Image of testing setup](image2)

**Figure 4. Photograph of the 3D full scale testing setup**

| Materials                        | (MPa) | Table 3. Technical specification of CM specimen materials |
|----------------------------------|-------|--------------------------------------------------------|
| Compressive strength of bricks   | 3.84  |
| Compressive strength of mortar   | 17.55 |
| Compressive strength of concrete | 19.00 |
| Yield strength of rebar          | 335.75|

| Materials                        | (MPa) | Table 4. Technical specification of URM specimen materials |
|----------------------------------|-------|--------------------------------------------------------|
| Compressive strength of bricks   | 8.31  |
| Compressive strength of mortar   | 8.68  |
| Compressive strength of concrete | 23.27 |
| Yield strength of rebar          | 262.50|

4.2. **Testing setup and instrumentation**

The cyclic loading test was carried out on the reaction wall and reaction floor platforms. Lateral cyclic load is provided through a 150 tonf capacity hydraulic jack which is placed at the top of the specimens and controlled by a hydraulic pump. The lateral loading from the hydraulic jack is monitored by a load cell, while the lateral displacements of the specimens are monitored using LVDTs or transducers placed at the loading point and top of each side of the wall parallel to the direction of cyclic loading. In addition, transducers are also placed at several points of the specimens to monitor its deformation during test. Specimens setup for both CM and URM systems are shown in Figure 4 to Figure 6.
4.3. Analysis Method
The hysteresis curve of the cyclic test results can be processed to determine the maximum lateral capacity of specimens. Lateral displacement of the specimens used for analysis is the average lateral displacements of the north side wall (Δ1), interior wall (Δ2), and the south side wall (Δ3) as shown in Figure 6. The specimens performance are evaluated using strength based analysis method, where the lateral load capacity of the specimens (as strength supply) are compared to the static equivalent earthquake force at some locations in Indonesia (as strength demand) according to the provisions of SNI 1726: 2019.

It's necessary to note that the CM specimen was laterally loaded on its weak axis direction, where the number of segments in-plane shear resisting wall in the loading direction is smaller than its perpendicular direction. On the other side, the URM specimen was laterally loaded on its strong direction, where the number of segments in-plane shear resisting wall in the loading direction is larger than its perpendicular direction. Thus, this research was intended to gain the minimum lateral load capacity of CM specimen and the maximum capacity of URM specimen.

In addition, the experimental test results will also provide qualitative data such as visual data of structural failure modes and damage patterns of the specimens. Furthermore, the stress distribution of the lateral load to the load bearing elements of the specimens can be interpreted from the failure modes photograph.
5. Result and discussion

5.1. Strength based analysis of the specimens

The results of the cyclic loading tests of the CM and URM specimens are shown in Figure 7 and Figure 8. The cyclic hysteresis curve is shown with a light gray line. The peak values of each cycle are presented with a thick blue line. The minimum drift ratio limit that must be conducted in a cyclic test (hereinafter referred as target drift ratio) which is calculated in equation (1) according to FEMA 450 provisions is indicated by a red dotted line. For CM and URM specimens, with wall height \( h_w \) and wall length \( l_w \) of 3000 mm, a target drift ratio of 1.17% is obtained.

The cyclic test was carried out until the maximum lateral load capacity \( V_{\text{max}} \) of the specimens is exceeded and still continue until the remaining lateral load capacity of the specimens are 80% of \( V_{\text{max}} \). From Figure 7, it is known that maximum lateral load capacity of the CM specimen for positive direction (push) and negative direction (pull) \( [V_{\text{max}}(+) \text{ and } V_{\text{max}}(-)] \) are 426.11 kN and 492.61 kN respectively. In positive lateral loading condition, \( V_{\text{max}} \) was reached shortly before the target drift ratio limit, while in the negative lateral loading condition \( V_{\text{max}} \) was reached after the target drift ratio limit. Meanwhile, from Figure 8, it is known that the maximum lateral load capacity of the URM specimen for positive and negative lateral loading \( [V_{\text{max}}(+) \text{ and } V_{\text{max}}(-)] \) are 273.62 kN and -235.86 kN respectively. The maximum lateral load capacity \( V_{\text{max}} \) of the URM specimen for both positive and negative lateral load conditions were reached before the target drift limit.

The remaining lateral load capacity (80% of the \( V_{\text{max}} \)) of the CM specimen was reached at a drift ratio of 2.75% for both positive and negative lateral loading conditions. Meanwhile, the remaining lateral load capacity (80% of the \( V_{\text{max}} \)) of the URM specimen was reached at a drift ratio of 0.50% for positive lateral loading conditions and 0.65% for negative lateral loading conditions. Thus, it is known that CM building specimen has a much better maximum lateral load capacity and ductility compared to URM building specimen.

The value of lateral force and lateral displacement at the end of the test then marked as ultimate lateral force \( V_{\text{ult}} \) and ultimate lateral displacement \( \Delta_{\text{ult}} \). Lateral force and the lateral displacement at maximum and ultimate conditions of the specimen testing are shown in Table 5 and Table 6.

Target drift limit according to FEMA 450:

\[
0.80 \leq 0.67 \left( \frac{h_w}{l_w} \right) + 0.5 \leq 2.5
\]

\[
0.80 \leq 0.67 \left( \frac{3000 \text{ mm}}{3000 \text{ mm}} \right) + 0.5 \leq 2.5
\]

\[
\therefore \text{ Target drift} = 1.17\%
\]
Figure 7. Cyclic loading test result of CM specimen

Figure 8. Cyclic loading test result of URM specimen
Table 5. Maximum lateral load capacity (Vmax) of CM specimen

| Testing result of CM specimen (loaded on weak axis) | Maximum Condition | Ultimate Condition |
|-----------------------------------------------------|--------------------|-------------------|
|                                                     | V\(_{\text{max}}\) (kN) | \(\Delta_{\text{max}}\) (mm) | V\(_{\text{ult}}\) (kN) | \(\Delta_{\text{ult}}\) (mm) |
| Positive/Push loading (+)                          | 426.11             | 28.81             | 254.39             | 83.41 |
| Negative/Pull loading (-)                          | 492.61             | 63.98             | 322.94             | 84.09 |
| ∴ V\(_{\text{max}}\)                                | 426.11             |                  |                  |      |

Table 6. Maximum lateral load capacity (Vmax) of URM specimen

| Testing result of URM specimen (loaded on strong axis) | Maximum Condition | Ultimate Condition |
|--------------------------------------------------------|--------------------|-------------------|
|                                                       | V\(_{\text{max}}\) (kN) | \(\Delta_{\text{max}}\) (mm) | V\(_{\text{ult}}\) (kN) | \(\Delta_{\text{ult}}\) (mm) |
| Positive/Push loading (+)                             | 273.62             | 5.34              | 210.26             | 15.38 |
| Negative/Pull loading (-)                             | 235.86             | 4.90              | 185.74             | 19.09 |
| ∴ V\(_{\text{max}}\)                                | 235.86             |                  |                  |      |

Furthermore, the maximum lateral load capacity of each specimen is taken from the smallest value of the maximum lateral load capacity under positive or negative lateral loading, as shown in Table 5 and Table 6. Since the system of the test object structure is an ordinary plain masonry shear wall (OPMSW) with an overstrength factor (\(\Omega_0\)) of 2.5 [2], then the lateral loads design capacity (V\(_d\)) of the specimens can be calculated as follows:

CM specimen:

\[
V_d = \frac{V_{\text{max}}}{\Omega_0} = \frac{426.11}{2.5} = 170.44 \text{ kN}
\]  

(2)

URM specimen:

\[
V_d = \frac{V_{\text{max}}}{\Omega_0} = \frac{235.86}{2.5} = 94.34 \text{ kN}
\]  

(3)

5.2. Failure modes and damage patterns

The damage patterns of CM and URM specimens are shown in Figure 9 and Figure 10. In addition, the crack patterns of CM and URM specimens are shown in Figure 11 and Figure 12. From the figures, it’s known that damage patterns of CM specimen are dominated by diagonal crack through the masonry wall components, which indicate that the wall components work optimally in resisting lateral forces through shear mechanism. The confining elements (reinforced concrete beams and columns) were distributing lateral forces and confining the wall effectively so that the walls could optimally contribute their shear capacity. The photographs of specimens after test shows that confining elements are also damaged in the form of cracks and concrete crushing due to the large deformations.

Meanwhile, the damage patterns occurred in the URM specimen is dominated by horizontal crack at the bottom of masonry wall and some vertical crack at the edges of wall. Horizontal cracking at the lowest part of the wall indicates sliding shear failure which suffered by mortar bed joint. There were no diagonal crack patterns found in the wall components parallel to the direction of the cyclic loading, indicating that the masonry wall components did not optimally contribute to resist lateral load since the damage were occurred at the interface between masonry wall and tie beam/ foundation. This failure mode results the low capacity of lateral loads and ductility of the URM specimen.
Figure 9. Damage patterns of CM specimen

Figure 10. Damage patterns of URM specimen

Figure 11. Crack patterns of CM specimen
5.3. Evaluation on lateral load capacity

The performance evaluation of the specimens are conducted by strength based analysis method, where the lateral load design capacity obtained from the testing result (V_d) of the structure is compared to the static equivalent base shear (V) which is calculated according to the provisions in SNI 1729: 2019. In this study, the base shear forces (V) were taken from 18 cities in Indonesia, including locations with low, medium and high seismicity level. Calculation of the base shear (V) used a seismic coefficient (Cs) calculated based on the Response Modification Coefficient (R) of 1.5 (for the ordinary plain masonry shear wall structural system), the Importance Factor (Ie) of 1 [2], and the seismic weight (W) of each of the two test specimens of 250 kN.

Figure 13 shows the comparison of V_d versus V values for the Site Class D (stiff soil) and Site Class E (soft clay soil). The evaluation result shows that CM specimen has lateral load design capacity (V_d) that is greater than the base shear forces (V) of all samples of cities taken. Meanwhile, URM specimen generally has insufficient lateral load design capacity (V_d) to withstand the base shear forces (V) of most samples of cities taken. URM specimen is only sufficient to withstand the base shear forces (V) of a few locations such as Balikpapan, Makassar, Palembang and Pontianak.

**Figure 13.** Evaluation of lateral loads design capacity (V_d) of the specimens against the base shear forces (V)
6. Conclusion
The result of strength based analysis in this research shows that the prototype of the Confined Masonry (CM) Simple Residential House with specifications according to Appendix 2 of Permen PUPR No. 5 of 2016 has good structural seismic performance. The evaluation carried out in this study follows the provisions of the latest earthquake load in Indonesia, that is SNI 1726: 2019.

The results of full-scale three dimensional (3D) cyclic loading tests on CM and URM specimens show that CM house system has better lateral load capacity and ductility than URM house system. In addition, the results of this research also showed that the Unreinforced Masonry (URM) house system is inadequate to resist earthquake loads in many locations of Indonesia. Considering that regions in Indonesia mostly have high earthquake hazards, the Simple Residential Houses with the URM system is not recommended to be used, especially in areas with high level of seismicity.

Further development of earthquake resistant residential house system is necessary to deal with the increasing trend of earthquake hazards. The target of the residential house system development also should consider construction cost aspect so that it can be widely applied in the community.

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