SIMPLIFIED EVALUATION METHOD BASED ON WALL RATIO OF BRICK MASONRY BUILDINGS

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ABSTRACT:

This paper verifies the simplified evaluation method for the seismic performance base on wall ratio of masonry structure. Load bearing wall such as shear wall which are the main lateral earthquake resistant element in masonry buildings. Therefore, the wall ratio is one of parameters of seismic performance. Based on seismic calculation method for ultimate strength Route 1 in Japanese guideline, Simplified evaluation method based on wall ratio of brick masonry as Un-Reinforced Masonry and Confined Masonry in developing countries is proposed. In some countries, a preliminary computation usually used in the design phase is procedure known as wall density ratio which consists in finding the ratio between walls area and story area. The purpose of investigate is getting the potential of seismic performance of ordinary buildings based on the experimental data, and which can compare with minimum requirement. Cyclic loading test are conducted to investigate shear strength of masonry wall like Un-Reinforced Masonry and Confined Masonry in each countries (Present study is in Indonesia).

KEYWORDS: Masonry structure, Evaluation method, Wall ratio, Non-engineered construction Confined masonry, Disaster mitigation, Cyclic loading test

1. INTRODUCTION

Most of the loss of life in past earthquakes has occurred due to the collapse of buildings which are constructed using brick masonry. Those were not particularly engineered for being earthquake resistant is called "Non-Engineered Construction", which are widely constructed in the seismic prone area. For the disaster mitigation, it is essential to develop Simplified Evaluation Method which is possible to use by many people. Structural walls, which are the basic resisting element to seismic loads, Load bearing wall such as shear wall which are the main lateral earthquake resistant element in masonry buildings. Therefore, the wall ratio is one of parameters of seismic performance. Simplified evaluation method based on wall ratio of brick masonry as Un-Reinforced Masonry and Confined Masonry in developing countries is proposed.

2. SIMPLIFIED EVALUATION METHOD

2.1. Japanese Building Code, Earthquake Resistant Design for Buildings 2001

The calculations of ultimate strength are used to confirm safety against earthquake. There are three calculation procedures (rules), which varies according to differences of the building types in Japanese building code. One of three calculation procedures is Route 1, which is used for relatively small buildings other than specified buildings.

Route 1 for RC structures

$$\sum 2.5Aw + \sum 0.7Ac \geq ZWAi \Rightarrow \tau wAw + \tau cAc \geq cw \sum Af$$

"Route 1" signifies "the shear strength of walls + shear strength of columns $\geq$ Required Seismic force."

where, Aw = Total cross section area of walls, Ac = Total cross section area of columns, Z = Zone factor, W= Combination of Load, Ai= A value of a vertical distribution of seismic story shear coefficients in i-th story, c=Base shear coefficient, w=Weight per unit floor Area (kg), Af=Area of floor.

Shear coefficient was decided experimental data, and on the basis of the records of the earthquake disaster survey shown in Figure 1.

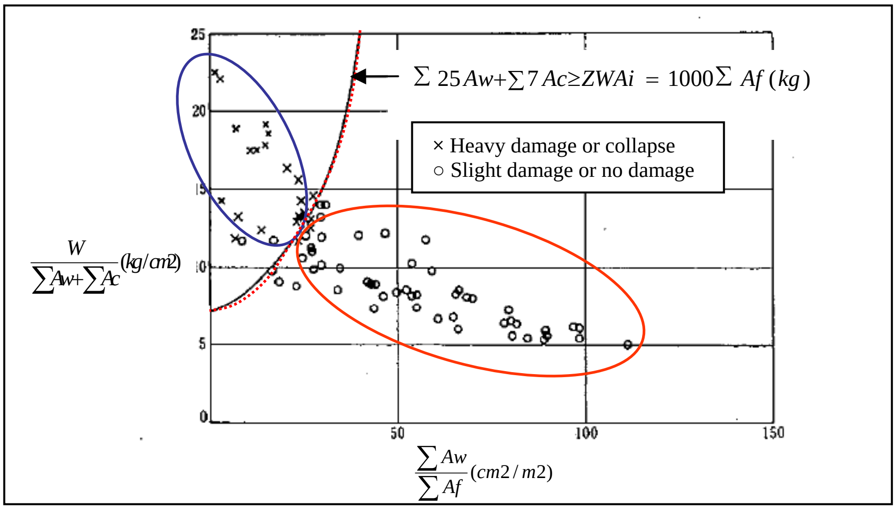

Figure1. Relationship Route 1 to Field Research by Dr. Shiga after Miyagiken oki earthquake 1978

2.2. Instance a Case of Wall Ratio, Masonry Construction Guide by CISMID, PERU (Photo 1)

Quoted a document, 5. How do you know if walls amount is enough?

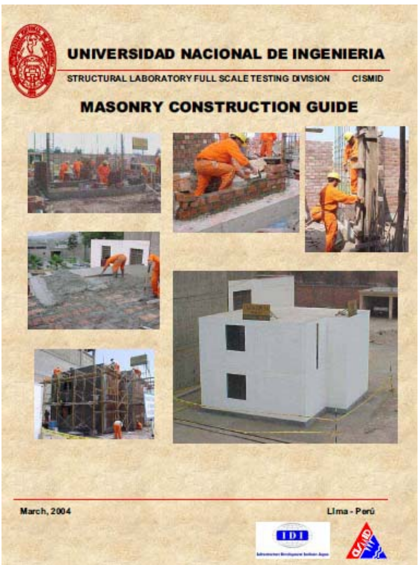

Photo 1. Masonry construction guide

A preliminary computation usually used in the design phase of the project is the procedure known as wall density ratio. This procedure is very simple and consists in finding the ratio between walls area and story area. The ratio should be examined on each floor. It should also be examined severally in the vertical direction and in the horizontal direction. A wall whose length is under 30cm, shouldn't be counted because it isn't effective enough. As a result value the ratio must be compare with a threshold value proposed by the Peruvian committee of masonry standards, which are as follow:

Soil Type	Zone-3	Zone-2	Zone-1
S1	4%	3%	1%
S2	4%	3%	2%
S3	5%	4%	2%

Table 1. Minimum wall density in Peru

Here the minimum wall density ratio is presented as a percent and is given for each soil type and each earthquake zone in Peru shown in table 1.

3. EXPERIMENTAL STUDY ON CONFINED MASORY IN YOGYAKARTA, INDONESIA.

3.1. Wall Specimens and Material Properties

A total of three Reinforced Concrete wall and Confined Masonry wall specimens listed Table.2 and specimens shown Figure.2 and Figure.3, were designed and constructed in Gadahmada University in Yogyakarta. Material test are also conducted in Gadahmada University shown in Table.3 and Table.4.

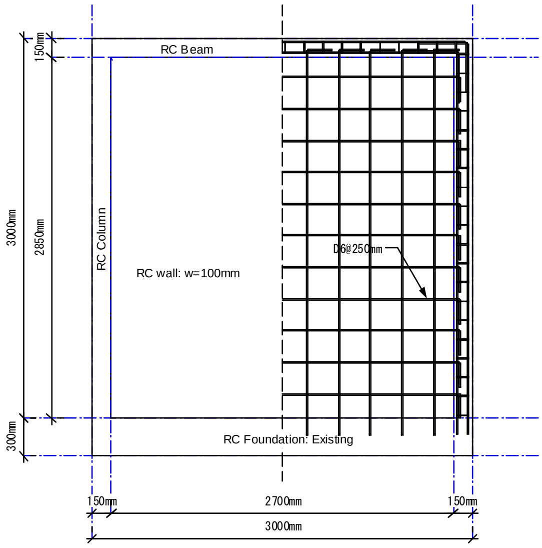

Figure.2 Specimen RC1

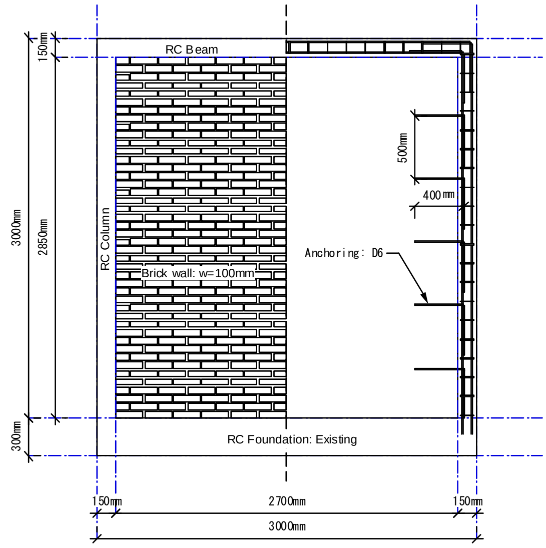

Figure.3 Specimen CMD10 and CMD12

Specimen	Method	Column		Beam		Wall		Anchoring
		Longitudinal	Hoop	Horizontal	Stirrup	Longitudinal	Horizontal	Column to wall
RC1	RC	4-D8	D6@150	4-D8	D6@150	D6@250	D6@250	Nil
CMD10	CM	4-D10	D8@150	4-D10	D8@150	Nil	Nil	D6@500
CMD12	CM	4-D12	D8@150	4-D12	D8@150	Nil	Nil	D6@500

Table.2 List of test specimens

Material	Compressive Strength (MPa)	Date	Others
Concrete	16.91	28days	1cement : 2sand : 3aggrigate
Mortal	11.45	28days	1cemen : 4sand
Brick	1.45	14days	Brick Prism

Table.3 List of material test of Compressive strength

Shear Strength of Brick masonry	0.15MPa	14days
Tensile Strength of Brick Masonry	0.102MPa	7days

Table.4 List of material test of Shear and Tensile strength

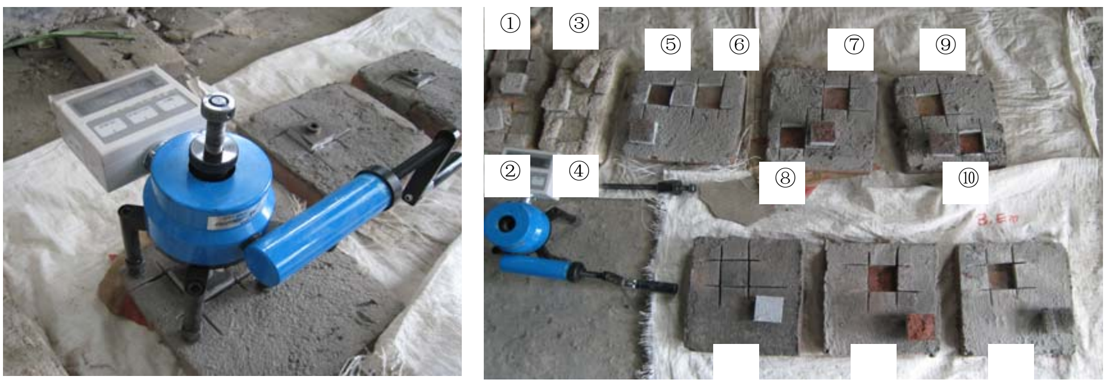

Photo.2 Tensile strength test by BRI method

3.2. Laboratory Test

Full scale Reinforced Concrete specimen and Confined Masonry specimens were quasi statically tested under revered cyclic displacement controlled environment which are shown in Photo.3, Photo.4 and Photo.5. The lateral load-lateral deformation relationship test result of each wall is shown in Figure.4, Figure.5 and Figure.6. The crack and crack propagation during the test were monitored and recorded by marking the cracks at loading while the specimen was held at the maximum displacement, although crack widths were not filed. The cracks were partially closed with load reversal.

Photo.3 Specimen of RC1

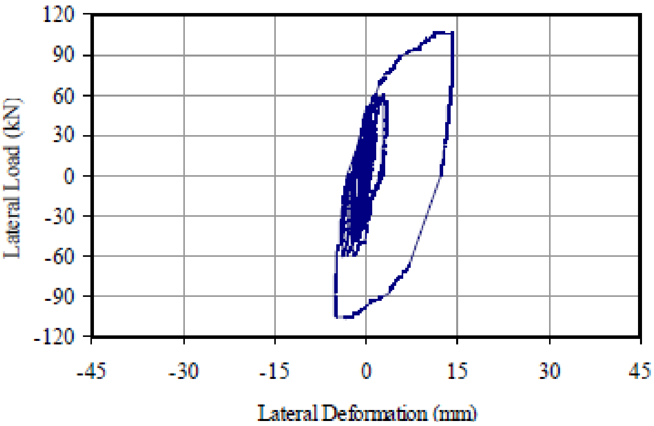

Figure.4 Hysteretic loop for RC1

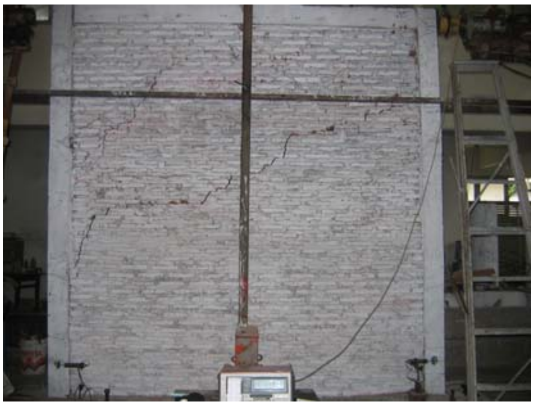

Photo.4 Specimen of CMD10

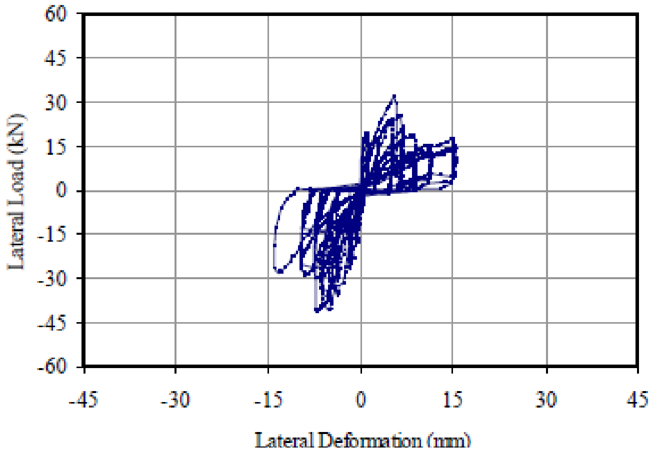

Figure.5 Hysteretic loop for CMD10

Photo.5 Specimen of CMD12

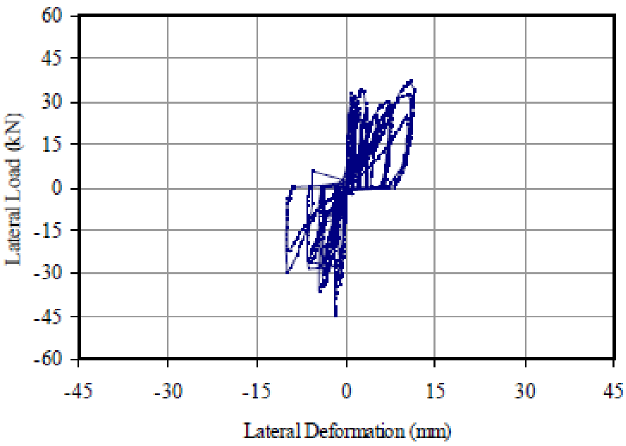

Figure.6 Hysteretic loop for CMD12

3.3. Crack Patterns

The final crack patterns were developed in the specimens of Confined Masonry wall are Figure.7 and Figure. 8.

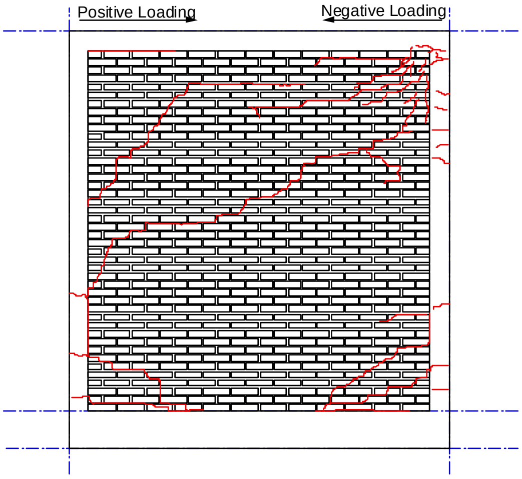

Figure.7 Final Crack Pattern of CMD10

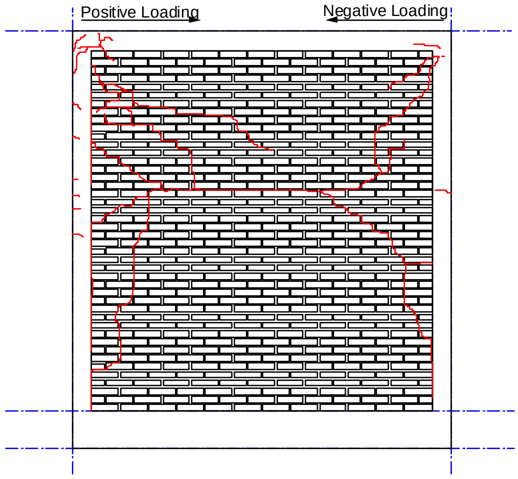

Figure.8 Final Crack Pattern of CMD12

3.4. Test Results and Discussions

- The Reinforcement concrete wall in which the reinforcement quantity of confining element is the same as the one of practical tradition or standard with 8mm longitudinal reinforcement diameter and 6mm stirrup diameter (Specimen RC1 in Table.2) has the highest ultimate strength which is 102kN. The cracks were concentrated on bottom of column and wall, the crack were observed mostly along the horizontal joint of bottom of the wall, which failed in flexural failure mode
- The ultimate strength of the Confined Masonry walls were 33.1kN for 10mm longitudinal reinforcement diameter (Specimen CDM10 in Table.2) and 36.6kN for 12mm longitudinal reinforcement diameter (Specimen CMD12 in Table.2). The cracks were concentrated along the diagonals, which failed in shear failure mode.
- The comparison of two specimens of Confined Masonry wall (CMD10 and CMD12), the increment of lateral load resistant due to the increasing of longitudinal bar diameter is only small difference as a margin of construction error.

4. COMPARISON OF ULTIMATE SHEAR STRENGTHES USING EXSISTING EQUATIONS

The result by the experiment were compared with ultimate strength for the specimen were calculated by the existing equations for Confined Masonry wall, discussed below,

4.1. Existing equation for ultimate shear strength

EQUATION1: Miha Tomazevic, Earthquake-Resistant Design of Masonry Buildings [1]

The ultimate shear strengths of the Un-Reinforced Masonry wall and Confined Masonry wall were culculate

$$H_{s,w} = \frac{f_t A_w}{C_I b}\left[1+\sqrt{C_I^2\left(1+\frac{N_w}{f_t A_w}\right)+1}\right] \text{ -- (URM Wall) (4.1.1)}$$

$$H_{s,c} = \frac{f_t A_w}{C_I b}\left[1+\sqrt{C_I^2\left(1+\frac{N_w}{f_t A_w}\right)+1}\right] + n0.806 d_{rv}^2 \sqrt{f_{cm} f_y} \text{ -- (CM Wall) (4.1.2)}$$

where, b = h/l = the shear stress distribution factor, Aw = d*t, d =width of wall, t = thickness of wall, $C_I = 2\alpha\, bl/h$ = interaction coefficient, α = 5/4 = the parameter of shape and distribution of interaction forces, Nw = imposed vertical load carried by masonry wall panel, ft = tensile strength of wall, n = the number of reinforcing bars in the confining elements, d_{rv} = diameter of bar, f_{cm} = compression strength of concrete, f_y = yield strength of steel.

EQUATION2: T.Paulay and M.J.N.Priestley, Seismic Design of Reinforced Concrete and Masonry [2]
Maximum shear resistance is minimum of Vf (sliding shear failure) and Vc (diagonal compression failure).

Qy= min "$V_f = \dfrac{\tau_o t l_m}{(1-\mu \tan\theta)}$" and "Vc = Ztf'$_m$cos θ "------------------------------------- (URM+CM Wall) (4.2.1)

$$f'_m = \frac{f'_{cb}(f'_{tb}+\alpha f'_j)}{U_u(f'_{tb}+\alpha f'_{cb})},\quad \alpha = \frac{j}{4.1h_b},\quad \lambda = \frac{E_m t \sin 2\theta}{4E_c I_g h_m}$$

Where, τ_o = cohesive capacity of the mortar beds = 0.04 f'$_m$, μ = sliding friction coefficient along the bed joint =0.3 to 1.2, θ = Angle subtended by diagonal strut to horizontal plane, f'm = compression strength of the masonry prism, f'$_{cb}$ = compressive strength of the brick, f'$_{tb}$ = tensile strength of the brick= 0.1 f'$_{cb}$, f'$_j$ = strength of the mortar, j = the mortar joint thickness, h_b = the height of masonry unit, Uu = Stress non-uniformity coefficient=1.5, Z= equivalent strut width=0.175$(\lambda h)^{-0.4}d_m$ (FEMA356:2000), E_m = modulus of elasticity of infill masonry=550 f'$_m$ (FEMA 356:2000), t = thickness of infill masonry , E_c = modulus of elasticity of concrete = 4730$(f'c)^{0.5}$ (ACI318-1995), I_g = moment of inertia of column, h_m = height of infill masonry/

EQUATION3: Former Chinese Standards (GBJ11-89) [4]

$$V_{su1} = \left(f_v \frac{1}{1.2}\sqrt{1+0.45\frac{\sigma_0}{f_v}} \right) A_w$$ --- (URM Wall) (4.3.1)

where, Vsu = ultimate lateral shear strength, fv = 0.125$\sqrt{}$Fz = ultimate shear stress with axial load(in the present case 0.15 by experimental data), Fz = compressive strength of joint mortal, σ_0 = constant vertical axial stress, Aw = horizontal cross-sectional area of masonry wall.

EQUATION4: Matsumura, A., Shear Strength of Reinforced Masonry walls [9]
The shear strengths of Confined Masonry wall were calculated from the following equation recommended by Matsumura [9], Eqn.4.4.1 is actually for shear crack strengths, Eqn.4.4.2 is actually for reinforced hollow concrete masonry wall.

$$V_{sc} = \left\{ k_c \frac{1}{(h/d)+2}\sqrt{F_m} + 0.3\cdot \alpha \cdot \sigma_0 \right\} t \cdot j \cdot 10^3$$ ---------------------------------- (Shear crack strength) (4.4.1)

$$V_{su2} = \left\{ k_u k_p \left[\frac{0.76}{(h/d+0.7)} + 0.012 \right]\sqrt{F_m} + 0.18\gamma\delta\sqrt{P_h \cdot {}_h\sigma_y \cdot F_m} + 0.2\sigma_0 \right\} t \cdot j \cdot 10^3$$ ----- (RHC Wall) (4.4.2)

where, Vsc = shear crack strength, Vsu2 = ultimate lateral shear strength, kc, ku = reduction factor, kp = $1.16p_t^{0.3}$ (pt=at(td) in %), h = height of the masonry wall, d = distance between the compression extreme fiber in masonry wall and tension bar in the confining columns (=l$_0$-t/2), Fm = compressive strength of prism, γ = strength reduction factor due to the presence of mortal joints, δ = factor concerning loading method equal to 1.0, Ph = horizontal steel reinforcement ratio, ${}_h\sigma_y$ = yield strength of horizontal reinforcing steel bar, σ_0 = vertical axial stress, t = thickness of the masonry wall, l_0 = length of wall, j = distance between the forces of compression and tension.

4.2. Calculation results and Discussion

Specimens	Experimental Value(Qmax) (kN)	Shear strength Qmax/Aw (Mpa)	Theoretical Value (kN)					
			Equation 1		Equation 2	Equation 3	Equation 4	
			Eqn. 4.1.1	Eqn. 4.1.2	Eqn. 4.2.1	Eqn. 4.3.1	Eqn. 4.4.1	Eqn. 4.4.2
CMD10	33.1	0.11	38.55	62.99	71.84	33.75	42.15	67.39
CMD12	36.6	0.12	38.55	73.75	71.84	33.75	42.15	67.39

Table.5 Comparison of shear strength value

As a result, the theoretical value of Confined Masonry is larger than experimental value for Indonesian masonry model. Especially, Equation 4.1.2 and Equation4.4.2 are excessively value for confining element. The calculation value of Equation 4.1.1 and Equation 4.3.1 for Un-Reinforcement Masonry wall correspond approximately to experimental value.

5. CASE STUDY MODEL FOR INDONESIAN TYPE

Photo.6 Standard design in Indonesia

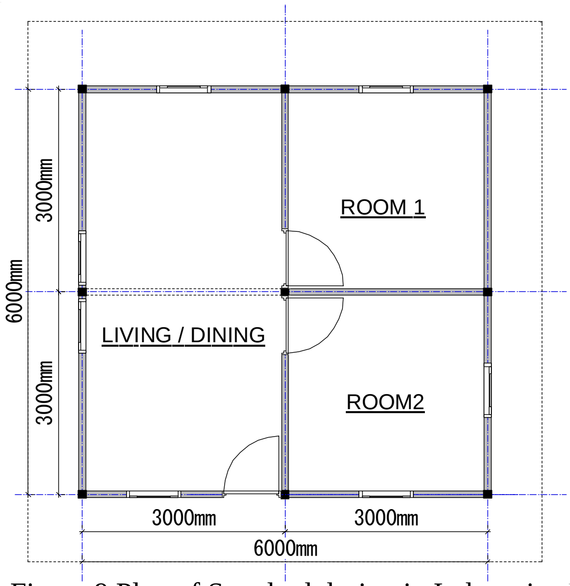

Figure.9 Plan of Standard design in Indonesia

Total area	Total cross section area				
	direction	with openings	ratio	without openings	ratio
36m2	X	1.5m2	4.16%	1.0m2	2.77%
	Y	1.8m2	5.00%	1.3m2	3.61%

Table.6 Area of model structure,

Roof	8.5kN
Brick wall	138.8kN
Column	18.8kN
Beam	33.8kN

Table.7 Weight of model structure

5.1. Evaluation by wall ratio

Simplified evaluation method was applied to estimate the seismic safety of this model. As mention before, Japanese building code Route1.

$$\sum 2.5Aw + \sum 0.7Ac \ge ZWAi \Rightarrow \tau wAw + \tau cAc \ge cw\sum Af \ .$$

Note that the coefficient of left side of the equation is derived from the shear strength from experimental value 0.11(MPa) as shown in table.4. Since the weight for i-th story was estimated as W=104.2kN. The right side of the equation was calculated as ZWAi. (in the present case Z = 1.0, Ai = 1.0) = 104.2kN as requirement value.

・Direction X : 0.11 x 1.0m2 = 110kN > 104kN -----OK
・Direction Y : 0.11 x 1.3m2 = 143kN > 104kN -----OK

In case of this study, this evaluation effected by some assumptions such as following situation which are taking into account this horizontal capacity of opening strengthening and lightweight roof material. This evaluation indicates this model have minimum wall ratio against the seismic loads.

6. CONCLUSIONS

The following conclusions have been drawn from the observations during cyclic loading tests and material tests and analysis of data.

- Confined Masonry of Indonesian type, which thin wall and small dimension of confining element, are seen that the increment of lateral load is more significantly increased by increasing the brick wall strength than by increasing of the dimensions and reinforcement quantity of the confining elements.
- The calculation value of Equation 4.1.1 and Equation 4.3.1 for Un-Reinforcement Masonry wall correspond approximately to experimental value for the prediction of ultimate shear strength for Indonesian confined masonry wall. Equation 4.1.1is based on tensile strength, and Equation 4.3.1 is based on shear strength of the bed joint. In brief of supposable cause, the confining elements contributed to the confinement effect. In the case of this study, the increasing of dimensions and reinforcement quantity above a regular level of the confining elements is not effect significant variation.
- The uniformity of the Confined Masonry wall is very important. The anchoring (the connecting bar) between column and brick wall enhanced confinement effect.
- In case of this study, by taking into account this horizontal capacity of opening strengthening, the relationship of inequality Route 1, which indicates the structure of 1st floor would be have minimum wall ratio against the seismic loads.

This evaluation method is based on wall ratio of each direction, which signifies lateral earthquake resistant element of buildings. However, the out of plane failure of masonry structure is highly visible after earthquake. In the case of Indonesia requirement, the maximum size of confining wall is 9m2. The evaluation method as wall ratio can be applicable to the field by following those rules. For the disaster mitigation, appropriate construction and unerring knowledge is needed.

6. ACKNOWLEDGMENT

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