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The Material Behavior Of Plastered-Bamboo Wall Towards Lateral Loads

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Abstract
This study determined the lateral resistance capacity of the plastered-bamboo wall. The test was carried out on three pieces of plastered-bamboo wall. The first was plastered-bamboo wall without bracing (DP-TB), second was plastered-bamboo wall using bamboo bracing (DP-BB), and the last is a plastered-bamboo wall which uses wiremesh bracing (DP-BK). The static load (monotonic) test method was used to determine the correlation between the lateral resistance and the deflection of plastered-bamboo wall. The monotonic testing was only conducted until the load has experience 20% decrease from peak load. The test results showed that the plastered-bamboo wall using wiremesh bracing had the peak load capacity, energy dissipation, and higher ductility than the plastered-bamboo wall using bamboo bracing. Elastic stiffness of the plastered-bamboo wall using bamboo bracing was 1.27 greater than plastered-bamboo wall using wiremesh bracing. The ultimate load resulted from the experiment of the plastered-bamboo wall with either bamboo or additional wiremeshbracingwas 25.52 kN and 26.37 kN or two times greater than the results of an analysis of the flexural failure based on Subedi method (1991) which was 14.39 kN.

Keywords: plastered-bamboo, bracing, lateral load

I. INTRODUCTION

Earthquake is a natural phenomenonwhich always hits settlements, kills a number of people, as well as damaging numerous infrastructures. Although the frequency of casualties caused by the earthquake may be relatively smaller than the other natural disasters, the disaster remainsasa natural phenomenon which is feared by humans because of devastating impact that lasts only in a blink of an eye, unexpectedly.

Given that Maluku province, especially Ambon Island, is an area prone to earthquakes which is located in Seismic Zone V of Indonesian Earthquake Zone Map, then in the planning of building a simple house, it should receive special attention.

Based on the above condition, it will encourage the community needs towards the disaster-friendly house, particularly a house which has a big endurance to earthquake.

The concept of disaster-friendly houseis a simple house that can provide protection to the occupants from the disaster, as well as to minimize the devastations and losses it caused.

The concept of a simple house using woven bamboo and then plastered, or it is known as plastered-bamboo wall in Maluku, Ambon island particularly, is not something new because it had already been built since the Dutch colonial period until the eighties. This system is often found in many homes of local residential population of both rural and urban areas. In fact, until now these buildings are still in good condition.

This study is to determine whether the plastered-bamboo wallcan be used as the construction for simple house which is safe against the earthquakes, while taking into account the following parameters: the load when it is cracking, melting, at peak and ultimate, energy dissipation, ductility, and the ratio displacementas well as to know the bracing effect of using bamboo and wire against the resistance capacity due to earthquake loads.

There are several studies on the composite structure of plastered-bamboo structure and shear walls that have been conducted by several researchers, for instance Dewi Sri Murni (2005). She conducted a study on the mechanical behavior of layered composite plate structure gedek-spesitowardsthebending loads and in-plane loads, Hidayat (2010) conducted a research about shear panel composite of woven bamboo shear testing of composite panels of woven bamboo using concrete waste as an aggregate material with the shear connectorspacing variation and mix aggregate, Awaludin A. (2011) conducted a study of the predictive power of the wood paneling, C. Ash *et.al* (2004) conducted a study on *ReversedCyclicIn-PlaneTestsOf Load-Bearing*

*PlasteredStrawBale**Walls,***Saneinejad, A., Hobbs, B. (1995)conducted a research on the *Inelastic Infilled Design of Frames,*Madan, et al. (1997) conducted a research on *Modeling of Masonry Infill Panels for Structural Analysis,*Subedi (1991) conducted a study on *RC-Coupled Shear Wall Structures.*
From the existing researches above, the method proposed by Subedi (1991) is the most suitable method to be the basis for the theoretical analysis to calculate the strength and stiffness of shear wall against flexure failureand modes of shear failure. In his paper, it is shown that the method gives predictions which iscloser to the experimental results.

1.1. Theoretical Analysis of Shear Wall Capacity

Analysis of shear wall capacity is calculated based on the method Subedi (1991) to compare the test results experiment.

a. Flexure Failure Mode

Flexure failure, which occurred due to bending, can be seen in Figure 1, where the cracks caused of bending would increase the press area, so that the concrete would be crushed in the press area.

The ultimate load on the flexural capacity can be expressed in:

$$P_{u1} = \frac{2h'}{a} A_{st} f_y \quad (1)$$

Where:

P_{u1} = ultimate load due to bending
A_{st} = bamboo area of longitudinal reinforcement is reduced by 0.9 to account for the lack of consistency,imperfectness, extensive reinforcement attached with mortar.
f_{tb} = tensile strength of bamboo is average with and without vertebra
a = height of the wall
h ' = the distance between the longitudinal reinforcement bamboo

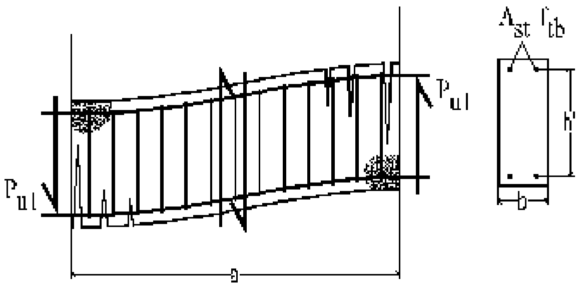


Figure1. Changes in shape due to bending (Subedi, 1991)

b. Shear Failure

Shear forces could be calculated by considering the half-triangle force system of walls and can be seen in Figure 2.

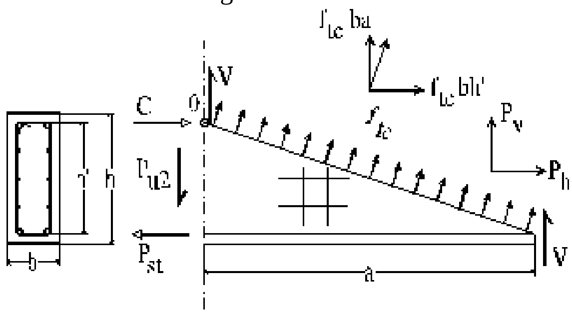


Figure 2.Idealisationofforce equilibrium diagram of half triangle (Subedi, 1991)

- Vertical force equilibrium :

$$P_{u2} = 2V + f_{tc}ba + P_v \quad (2)$$

- Horizontal force equilibrium :

$$P_{st} = f_{tc}bh' + P_h + C \quad (3)$$

- Moment of equilibrium :

$$P_{st}h' = Va + f_{tc}\frac{b(h'^2 + a^2)}{2} + P_h\frac{h'}{2} + P_v\frac{a}{2} \quad (4)$$

Where: (to equation 2-5)

P_{u2} = ultimate load at failure of the sliding mode
a = height of the wall
b = thickness of wall
h = width of wall
f_{tc} = limit tensile stress in the concrete
V = shear force at an angle of press
P_{st} = tensile force in reinforcement at edge pedestal
C = shattered voltage on the concrete block
P_h and P_v = contribution of the reinforcement body

Ultimate load can be expressed in:

$$P_{u2} = (f_{tc}bh' + 2C + P_h)\frac{h'}{a} \quad (5)$$

Where the value of C can be expressed in:

$0{,}85 f'_c b \frac{(h-h')}{2}$(For cylinder compressive strength)

$0{,}67 f'_c b \frac{(h-h')}{2}$*(For the cube compressive strength)*

1.2. Testing Procedure and Analysis

The testing procedures were conducted using monotonic method. Monotonic testing is conducted by providing a one-way static system load on the test object until it collapses. The monotonic testing on the composite wall panels was conducted until it was 20% decline from the maximum load. The calculation results of monotonic tests in the laboratory were analyzed based on ASTM E564 and ASTM E2126.

a. *Equivalent Energy Elastic-Plastic (EEEP) Curve*

The idealization of elastic-plastic curve is an approximation of the extent of load curve displacement or the original *envelope* curve as shown in Figure 3. It is influenced by the *ultimate*displacement and displacement on its axis. Part of the curve *EEEP* may consist of the same slope with the original curve slope is the elastic stiffness(k_e).The plastic condition is indicated by a horizontal line, with the yield load (P_{yield}).

The extent of elastic-plastic curve was obtained by the principle of balancing the load curve area displacementand its associated peaks. Part of the has elastic-plasticcurve which has similar slope line which is the elastic-plastic shear stiffness *(equivalent elastic shear stiffness*) when the load is 0.4 during P_{peak}anddisplacement Δ0, 4 P_{peak}.Thefailure load is 0.8 P_{peak}, while the failure limit statestating a point where the correlation between the load displacementtowards the last data point with a load time of equal or greater than 0.8 P_{peak}.

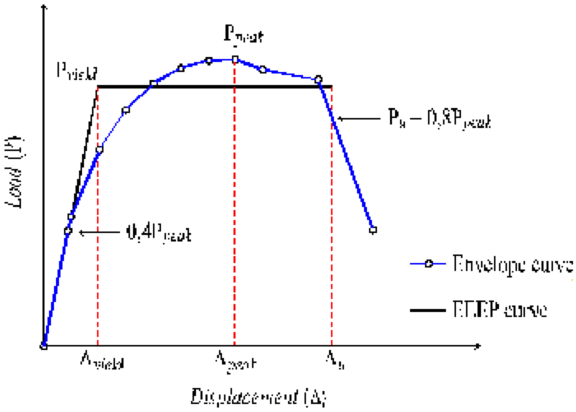


Figure3.*Equivalent energy elastic plasticcurve*
(Minjuan dkk, 2012)

b. Elastic Stifness (k_e)

According to ASTM E2126 07, the elastic stiffness (k_e),is defined as the slope of load curve or envelopecurveat 0.4 P_{peak} load. Elastic stiffness can be calculated with the following equation:

$$k_e = \frac{0{,}4\ P_{peak}}{\Delta_{0{,}4P_{peak}}} \quad (6)$$

Where :
k_e = Elastic stiffness (KN/mm)
0,40 P_{peak} = Load at 0,40 P_{peak} (KN)
$\Delta_{0,40\ Ppeak}$ = Displacement when load is 0,40 P_{peak} (mm)

c. Yield load (P_{yield}) dan yield displacment(Δ_{yield})

According to ASTM E2126 02a (ASTM 2003), the load at the yielding condition (P_{yield}) can be calculated by the following equation:

$$P_{yield} = \left(\Delta_u - \sqrt{\Delta_u^2 - \frac{2A}{k_e}}\right) k_e \quad (7)$$

Where :
P_{yield} = the load at yieldingconditions (kN)
A = the area (kN.mm) corresponding load-displacement or wide curve observed or envelope curve ranging from zero to ultimatedisplacement(Δ_u)
k_e = *elastic shear stiffness* (kN/mm) was obtained from the slope of the load curve or curve-displacement envelope at 0.4 P peak load.

Yielding displacement(Δ_{yield}) can be calculated using the following equation:

$$\Delta_{yield} = \frac{P_{yield}}{k_e} \quad (8)$$

Where :
Δ_{yield} = yield displacement (mm)
P_{yield} = yield load (KN)
k_e = elastic stiffness (KN/mm)

d. Ductility (μ)

According to ASTM E2126, ductility is the ability of a structure or structural component to deform beyond the elastic limit, which is expressed by first yield, without a decrease in strength and excessive stiffness. Ductility can be calculated by the following equation:

$$\mu_s = \frac{\Delta_u}{\Delta_{yield}} (9)$$

Where :

μ = Ductility
$\Delta_{ultimit}$ = Displacement when the load is at 0,80 P_{peak}(mm)
Δ_{yield} = Displacement when the load is at first yield (mm)

II. RESEARCH METHODOLOGY

The specification of plastered-wall with and without bracing, which is shown in figure 4.

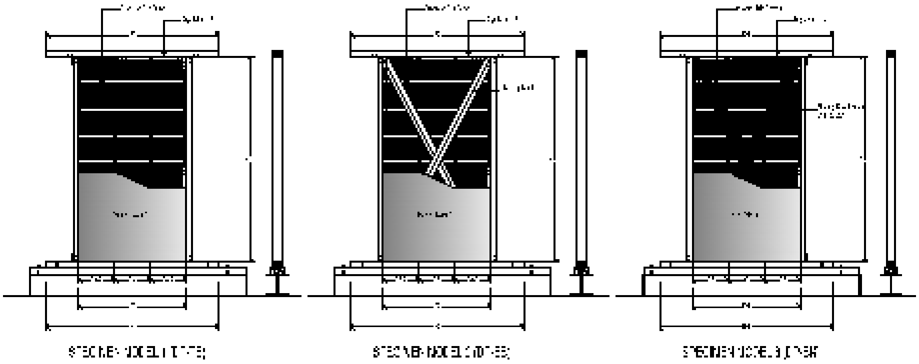


Figure 4 The plaster bamboo wall specimen models

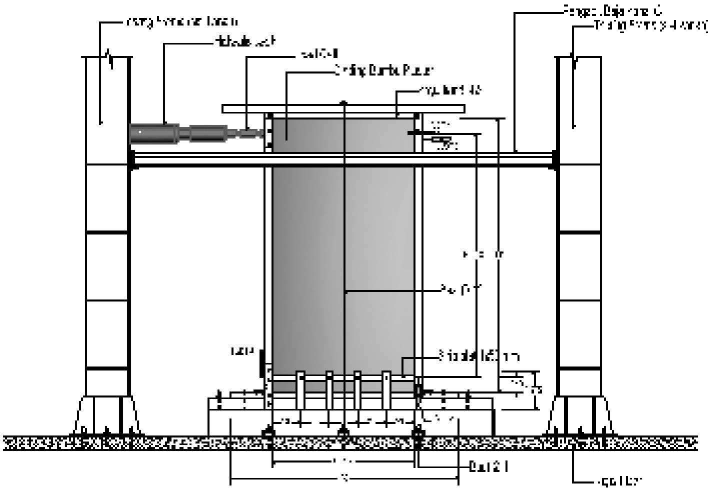


Figure 5. The Setting Up sketch of the experiment

The research stages of this study is shown at Figure 6.

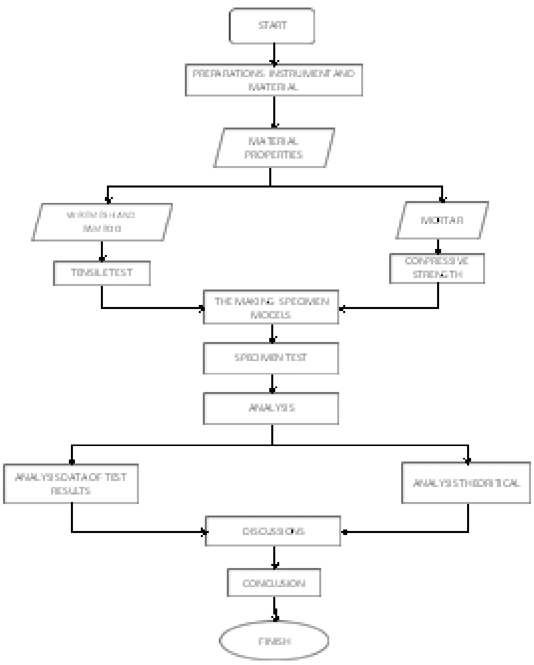


Figure 6. Research Flow Chart

III. RESULT AND DISCUSSION

a. Material Testing

The test result of bamboo tensile strength, is, on average, amounted to 228.937-313 MPa, tensile strength 100 MPa for samples with no roads and 61.116-123 MPa, 327 MPa for samples with Internodes. The result of tensile testing wire mesh on average, amounted to 755.82 MPa for the yield stress (σ_y) and 832.80 MPa for ultimate stress (σ_u). The result of plaster-compressive strength test results of 5.17 MPa.

b. The testing of plastered-bamboo wall

1. The result of Monotonic Plastered-Bamboo Wall using Monotonic testing in the laboratorium, analyzed based on the rule from ASTM E564 serta ASTM E2126.

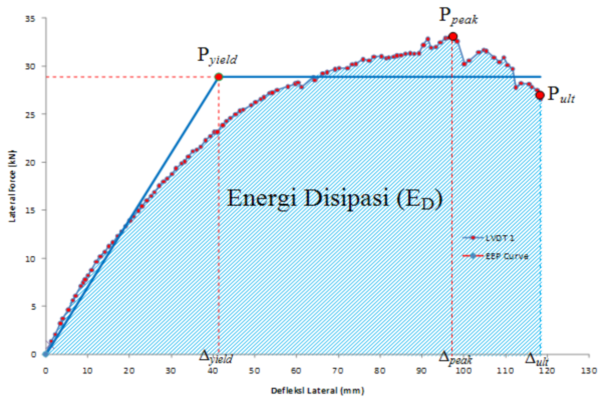


Figure 7.The chart of plastered-bamboo wall testing

P peak (kN)	Δ peak (mm)	P yield (kN)	Δ yield (mm)	P ult (kN)	Δ ult (mm)	E_D (kN.mm)	*ke* (kN/mm)	μ
33,22	97,40	28,86	41,22	26,57	118,42	2819,81	0,70	2,87

Table1. The calculation result of monotonic testing towards plastered-bamboo wall with wiremesh.

The test results of each plastered-bamboo wall caused of the monotonic load is shown in Figure 8that shows the correlation curve between lateral load and deflection.

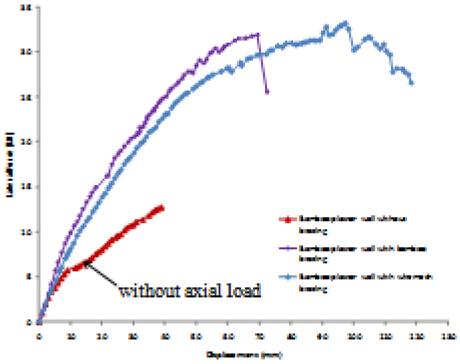


Figure8.The correlation chart between lateral load and displacement

Table 2. The calculation result of the monotonic testing from each plastered-bamboo wall

Tipe	P peak (kN)	Δ peak (mm)	P yield (kN)	Δ yield (mm)	P ult (kN)	Δ ult (mm)	E_D (kNmm)	ke (kN/mm)	μ
DP-TB	12,77	39,08	9,60	14,33	12,77	39,08	306,19	0,67	2,73
DP-BB	31,48	69,48	26,83	30,14	25,52	72,47	1539,43	0,89	2,40
DP-BK	33,22	97,40	28,86	41,22	26,57	118,42	2819,81	0,70	2,87

Table 2 shows that the DP-BK has a peak load capacity, energy dissipation, and higher ductility compared to the test objectofDP-BB.

Nevertheless, the DP-BB panel had the elastic stiffness of 1.27 greater than DP-BK, it occurred due to the vast areas of bamboo bracing used to hold the compression and tensile is much larger than the wiremesh one.

2. Failure Mechanism

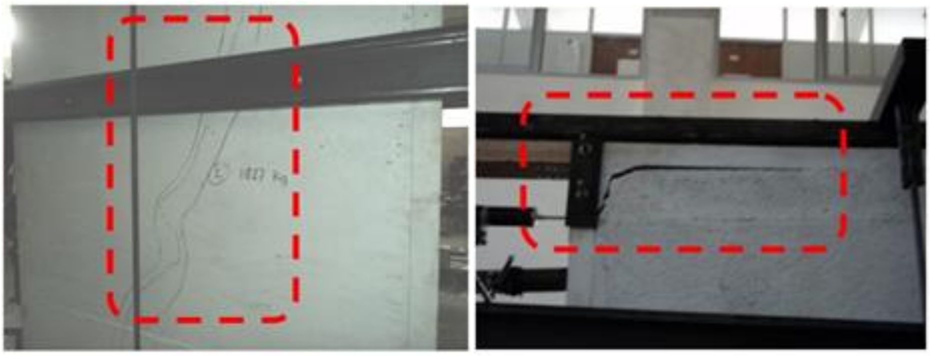
Failure mechanism that occured for each plastered-bamboo wall isas follows:

- Failure mechanisms that occured in the DP-TP panel is shown in Figure 9.
- Failure mechanisms that occured on the panel DP-BB is a shear and bending failure mechanism *(flexural failure)*which is shown in Figure 10.
- Failure mechanisms that occured in DP-BK panel is bending failure mechanisms *(flexural failure)*which is shown in Figure 11.

a. The upper right joint was almost dislodged (panel without bracing)

b. Flexural crackoccurred in the lower right corner in the plastered-bamboo wall with bamboo bracing

Figure 9a and b. Material behavior of the plastered-bamboo wall without *bracing*



a. Diagonal shear crack in the plastered-bamboo wall with bamboo bracing

b. Flexural failure that occurred in plastered-bamboo wall without bracing

Figure 10. Material behavior of the plastered-bamboo wall with bamboo bracing

a.Flexural crack which occurred in the plastered-bamboo wall with wiremesh bracing

b. The plastered-bamboo wall with wiremesh bracing was broken on the field of contact, at the upper right corner

Figure 11. The material behavior of the plastered-bamboo wall with wiremesh bracing

C. Theoretical and Experimental Comparison

Perbandingan beban ultimit yang terjadi pada komponen elemen dinding geser berdasarkan hasil pengujian, sedangkan hasil analisis teoritis berdasarkan metodeSubedi (1991) disajikanpadaTabel 3.

The comparison of ultimate load which was applied to the component of shear wall based on the test results, while the results of theoretical analysis based on Subedi method (1991) is presented in Table 3.

Table 3. The Comparison between Test Result and Analysis

Wall Type	Test Results		Analysis result				Ratio
	fc' (N/mm^2)	*P ult* (kN)	f_{tc} (N/mm^2)	Flexural failure P_{u1} (kN)	Sear failure P_{u2} (kN)	P_u analysis (kN)	
DP-TB	5.17	12.77	0.31	*	*	*	*
DP-BB	5.17	25.52	0.31	14.39	39.09	14.39	0.56
DP-BK	5.17	26.37	0.31	14.39	39.09	14.39	0.54

Description : *not to be used as a comparison

Table 3 shows that the ultimate load capacity of the component of plastered-bamboo wall was based on the specific theoretical analysis to the flexural failure which was 0.5 smaller than the plastered-bamboo wall with bracing, this shows that the addition of wall bracing either by bamboo or wiremesh can increase the endurance of the ultimate load capacity of the wall.

d. The Performanceof Plastered-Bamboo Wall

The performancecalculation of the plastered-bamboo wall based on the seismic zone 5 are presented in Table 4.

Table 4. The Performance Calculation of the Plastered-Bamboo Wall

Type Panel	Number of Walls (m)		Load/1 panel			V_n total > V	
	Floor-1	Floor-2	V_y** (kN)	$V_n = V_y/1,6$ (kN)	V_n total (kN)	V***	Check
DP-TB*	18	9	9.60	6.00	161.92	108.75	Ok
DP-BB	6	3	26.83	16.77	150.91	108.75	Ok
DP-BK	6	3	28.86	18.04	162.23	108.75	Ok

Description :* not to be used as a comparison
** test result
*** horizontal shear force towards earthquake

Table 4 shows that the lateral force that occured on plastered-bamboo wall with additional bracingbetween 1.39 to 1.49 was greater than the acceptable lateral force. It means that the plastered-bamboo wall can be applied to simple two-story house in the seimic Zone V of Indonesian Earthquake area.

IV. CONCLUSION

Plastered-wall bamboo using wiremesh bracing has a peak load capacity, energy dissipation, and higher ductility than the test object using bamboo bracing.However, the elastic stiffness for the latter is1.27 greater than plastered-bamboo walls with wiremesh bracing.

The ultimate load resulted from the experiment of plastered-bamboo wall either using bamboo or wiremesh bracing respectively resulted in 25.52 kN and 26.37 kN or two times greater than the result of an analysis of flexural failure based on Subedi method (1991) which was 14.39 kN.

In this study, the plastered-bamboo wall with bracing can be used as one of the components of simple two-story house in the seismic Zone V of Indonesian Earthquake area.

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