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The Effect of Bracing on Masonry Wall with Opening to Earthquake Response

Claudius Sunami Sanjoyo[1], Sri Murni Dewi[2], Achfas Zacoeb[3]
[1, 2, 3]Departement of Civil Engineering, Brawijaya University, Malang, Indonesia-65145

***Abstract*—** *Indonesia is a country that prone to earthquakes. The weak wall properties toward flexural and shear force is the main weaknesses so often damaged heavily because of earthquake. The bracing addition at the wall able to increase the wall resistance strength in facing the earthquake. The diagonal bracing use often difficult to implement if there is opening for window and doors. In the research, it is used two bracing model, that is knee bracing and inverted v-bracing. The specimen model is by using masonry wall constrained with wall dimension 120 cm × 100 cm, dimension of practical column beam 7 cm × 7 cm and opening dimension 70 cm × 30 cm is modeled single opening at the center of span. Bracing reinforcement material by using steel and bamboo. Based on the research results, the bracing use able to increase the structural resistance strength toward earthquake load compared with the opening wall without bracing when given cyclic load. The wall model with knee bracing from the bamboo reinforcement the strength increase 99% and deformation decrease of 31%. At the wall model with inverted v-bracing from the steel reinforcement the strength increase 297% and deformation decrease 37%. For wall model with inverted v-bracing from bamboo reinforcement the strength increase 128% and deformation decrease 38%. The bracing model differences and the bracing reinforcement material type influence the earthquake resistance strength and deformation decrease.*

***Keywords*—** *Wall with opening, bracing, strength, cyclic load, earthquake response.*

I. INTRODUCTION

Indonesia is a country situated at the meeting point of three big plates in the world, Eurasia plate, Indo-pacific plate and Australia plate, so make Indonesia become prone to earthquake. One of the most vulnerable elements to get heavy damage because of earthquake loading is the wall. The wall which is weak toward flexural and shear is the main weaknesses of the wall so the wall element often get heavy damage because of earthquake force. One of the methods to increase the lateral strength of the wall is using bracing. The diagonal bracing use showed better results compared without bracing in improving the wall strength and stiffness toward earthquake response and improve the wall ductility [1]. The diagonal bracing use sometime difficult to be implemented if there is opening at the wall for doors and windows mounting. It shows the weaknesses side of full diagonal of bracing, even the opening presence at the wall able to decrease the stiffness and lateral strength of the wall [2, 3]. To resolve the problems be used two bracing model, knee bracing and inverted v-bracing as the wall stiffener and using steel material and bamboo for bracing reinforcement. Bamboo materials as alternative because easy to find and cheaper than steel but has strength similar with the steel. The research aimed at knowing the influence of bracing use, bracing type and bracing reinforcement type toward earthquake load resistance and deformation to the masonry wall with opening.

II. LITERATURE REVIEW

Wall is composite material which consisting of bricks and mortar as the adhesive. Wall is important element in building served as structural stiffener so improve the resistance capacity toward lateral forces.

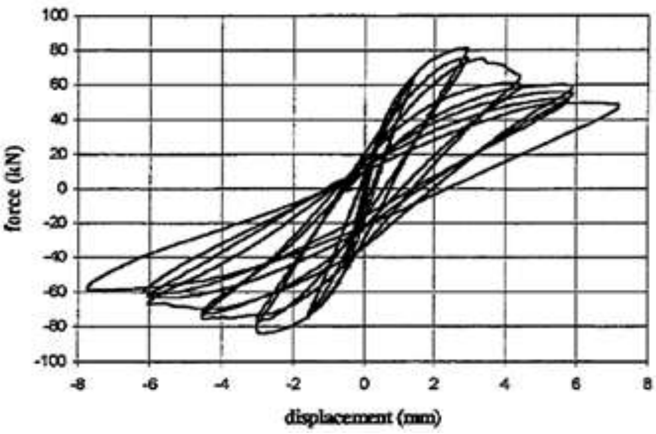

Fig. 1. Hysteretic curve behavior because of diagonal shear crack [4].

Masonry wall has tensile strength of 1.5-2.0% from the compressive strength so easy to crack or damage because of lateral load. The collapse of simple residential house made from masonry wall occurred at the low axial force, it means the collapse occurred especially the low shear strength of the wall structure [5].

Opening is the weakness of wall structure because able to decrease the wall stiffness, decrease the structure ability to receive load and decrease the collapse load capacity if compared with wall without opening [6]. Based on the previous research showing correlation between strength reduction of wall and the increase of opening height at the wall [3]. It means the bigger opening dimension at the wall the lower strength and stiffness of the masonry wall.

Bracing is structural element made to prevent structure experience big deformation at horizontal direction and make structure become stable. In the previous research bracing use at the wall portal able to increase the lateral resistance and able to increase the resistance stiffness toward earthquake response [1, 7].

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Shear Load and Wall Response

Behaviors before crack showed with the moderate hysteretic curve form and ignore the strength degradation factor or stiffness. The diagonal crack occurrence firstly at the load 90% from the peak load value. Response after peak showed with more hysteresis dissipation and faster strength degradation.

III. RESEARCH METHODOLOGY

In the research will be made 15 specimens of masonry wall with opening with dimension of 1.2 m × 1.0 m by using two different bracing treatments, knee bracing and inverted v-bracing. For opening of 0.3 m × 0.7 m modeled as door.

a. 6 wall specimens with column and beam at both sides by using 6 mm diameter steel reinforcement and 6 mm steel reinforcement bracing with 4 mm diameter stirrup and space distance 5 cm. Each 3 specimens for knee bracing and inverted v-bracing.
b. 6 wall specimens with column and practical beam at both sides by using 6 mm diameter steel reinforcement and 8 mm × 8 mm bamboo reinforcement bracing with 4 mm diameter stirrup and space distance 5 cm. Each 3 specimens for knee bracing and inverted v-bracing.
c. 3 wall specimens with opening without bracing.

Complete specification of the specimen model can be seen in table I. While for specimen model can be seen in Figure 2.

TABLE I. Specimen specification.

Specimen Code	Reinforcement Type				Bracing Model
	Bracing	Beam	Column	Stirrup	
D-0A(1) D-0A(2) D-0A(3)	-	Steel Ø 6 mm	Steel Ø 6 mm	Steel Ø 4 mm	-
D-1A(1) D-1A(2) D-1A(3)	Steel Ø 6 mm	Steel Ø 6 mm	Steel Ø 6 mm	Steel Ø 4 mm	Knee Bracing
D-2B(1) D-2B(2) D-2B(3)	Steel Ø 6 mm	Steel Ø 6 mm	Steel Ø 6 mm	Steel Ø 4 mm	Inverted V-bracing
D-3C(1) D-3C(2) D-3C(3)	Bamboo 8 mm × 8 mm	Steel Ø 6 mm	Steel Ø 6 mm	Steel Ø 4 mm	Knee Bracing
D-4D(1) D-4D(2) D-4D(3)	Bamboo 8 mm × 8 mm	Steel Ø 6 mm	Steel Ø 6 mm	Steel Ø 4 mm	Inverted V-bracing

Loading Stages

In the research, the loading stages planed including monotonic loading to get maximum load and cyclic loading to know deformation, ductility and energy dissipation capacity.

Monotonic test done by giving monotonic shear load once up to the wall fail at five specimen for each different type to know the collapse load so can be planned the cyclic load and the loading cycle.

After obtaining the maximum load data from the monotonic test, then from the monotonic load data is use the cyclic load by divide the load become several load stages. At each loading stage consist of two cycles. The cycle load assumed has behavior as earthquake load by ignoring the period influence (time).

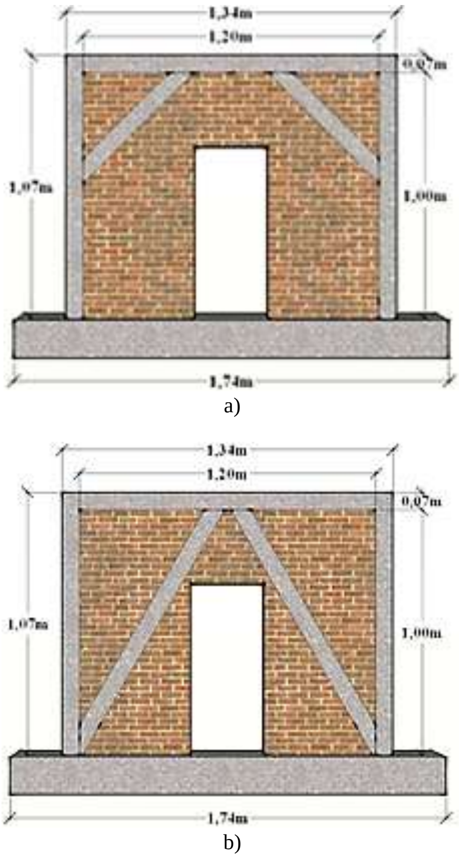

Fig. 2. Specimen model a) Knee bracing b) Inverted v-bracing.

IV. RESULTS AND DISCUSSION

Monotonic test done at each specimen model to get the maximum load value and maximum deformation as given in table II.

Based on the monotonic test results at the wall obtained that the wall without bracing has the lowest load resistance of 518 kg but has big deformation, it is caused by wall stiffness without bracing lower so the deformation capacity greater.

TABLE II. Monotonic load test results.

No	Specimen Models	Results	Units
1	Wall Without Bracing		
	Maximum Load	518	kg
	Maximum Deformation	25,75	mm
2	Wall with Steel Knee Bracing		
	Maximum Load	1358	kg
	Maximum Deformation	24,75	mm
3	Wall with Bamboo Knee Bracing		
	Maximum Load	976,5	kg
	Maximum Deformation	17,795	mm
4	Wall with Steel Inverted V Bracing		
	Maximum Load	1818	kg
	Maximum Deformation	21,35	mm
5	Wall with Bamboo Inverted V Bracing		
	Maximum Load	1202	kg
	Maximum Deformation	13,12	mm

At the wall model with knee bracing from the steel reinforcement the strength increase 162% and deformation decrease 4%. For wall model with knee bracing with bamboo reinforcement the strength increase 89% and deformation

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decrease 31%, it is caused by bamboo elasticity lower than steel. For wall model with inverted v-bracing from the steel reinforcement the strength increase 251% and deformation decrease 17%. At the wall model with inverted v-bracing from the bamboo reinforcement the strength increase 132% and deformation decrease 49%. Relationship graph of load transfer because of monotonic load can be seen in Figure 3. From the graph showed that the bracing addition at the wall able to increase the resistance strength, but the wall capacity to deform decrease. It is caused by wall with bracing addition become stiffer. Steel reinforcement material at bracing give better deformation capacity than bamboo reinforcement material, because steel more ductile and elastic than bamboo.

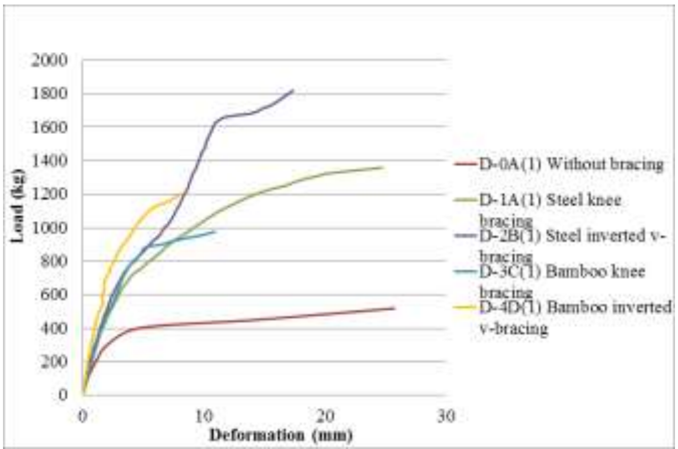

Fig. 3. Load-deformation relationship of wall monotonic test.

From the cyclic test done show the bracing addition at the wall able to increase the significant lateral load resistance can be seen in table III.

TABLE III. The shear cyclic loading test results.

No	Specimen Models	Results
1	Wall Without Bracing	
	Average Maximum Load	507,5 kg
	Average Maximum Deformation	20,903 mm
	Average Maximum Load Stage	113% Maximum Load
2	Wall with Steel Knee Bracing	
	Average Maximum Load	1154 kg
	Average Maximum Deformation	24,810 mm
	Average Maximum Load Stage	87% Maximum Load
3	Wall with Bamboo Knee Bracing	
	Average Maximum Load	1007,5 kg
	Average Maximum Deformation	14,375 mm
	Average Maximum Load Stage	113% Maximum Load
4	Wall with Steel Inverted V Bracing	
	Average Maximum Load	2015,5 kg
	Average Maximum Deformation	13,130 mm
	Average Maximum Load Stage	100% Maximum Load
5	Wall with Bamboo Inverted V Bracing	
	Average Maximum Load	1155 kg
	Average Maximum Deformation	12,978 mm
	Average Maximum Load Stage	102% Maximum Load

At the model with knee bracing from the steel reinforcement the strength increase 127% and deformation increase 19%. For wall model with knee bracing from the bamboo reinforcement the strength increase 99% and deformation decrease 31%, it caused by bamboo elasticity lower than steel. For wall model with inverted v-bracing from steel reinforcement the strength increase 297% and deformation decrease 37%. It showed the wall model with inverted v-bracing from the steel reinforcement has big stiffness so the resistance strength toward lateral loads increase. At the wall model with inverted v-bracing from bamboo reinforcement the strength increase 128% and deformation increase 38%. From the test for each wall model with bracing from bamboo reinforcement showed the lateral loading resistant results and the deformation capacity decrease lower than the wall model with bamboo bracing lower than steel so the behavior of stress-strain of bamboo and steel different. The steel material more ductile and has better resistance in sustaining load either in non-elastic phase. Even bamboo is brittle, so after pass the elastic phase the bamboo ability to sustain the load decrease heavily.

Based on the test results and Figure 4, 5, 6, 7, 8 then the bracing model as the wall stiffener influence the resistance strength toward earthquake load and the deformation change. It showed that by using bracing at the wall able to increase stiffness of the wall element. The stiffer wall element the higher strength but inversely with the deformation capacity.

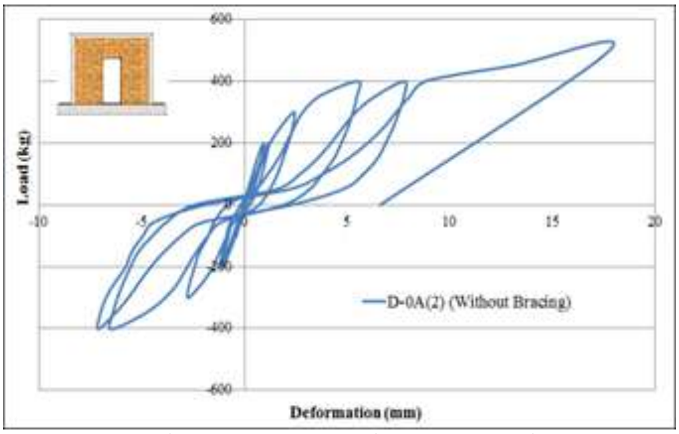

Fig. 4. Load-deformation relationship of cyclic load test of wall without bracing.

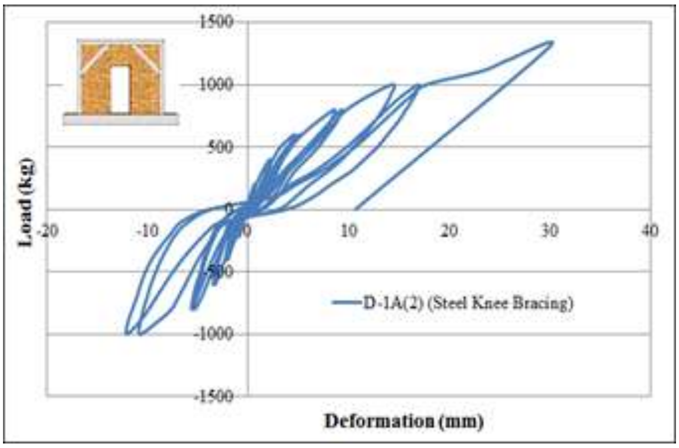

Fig. 5. Load-deformation relationship of cyclic load test of wall with steel knee bracing.

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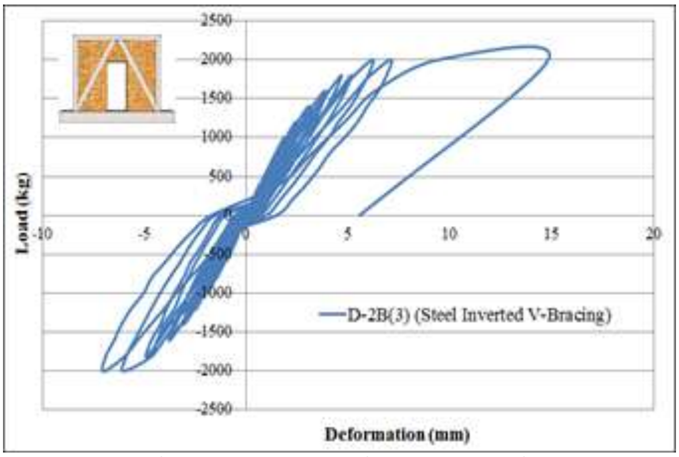

Fig. 6. Load-deformation relationship of cyclic load test of wall with steel inverted v-bracing.

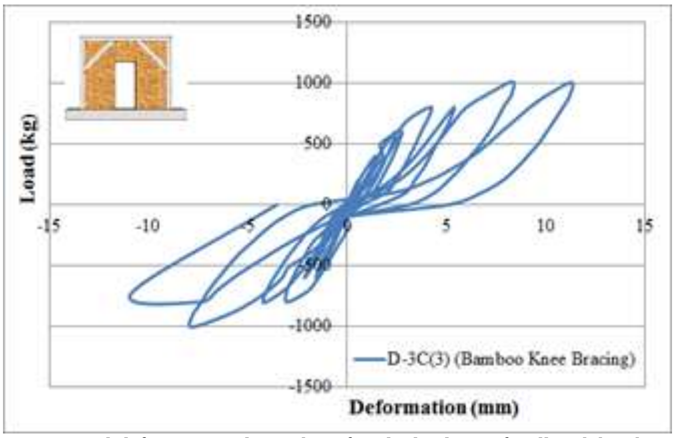

Fig. 7. Load-deformation relationship of cyclic load test of wall with bamboo knee bracing.

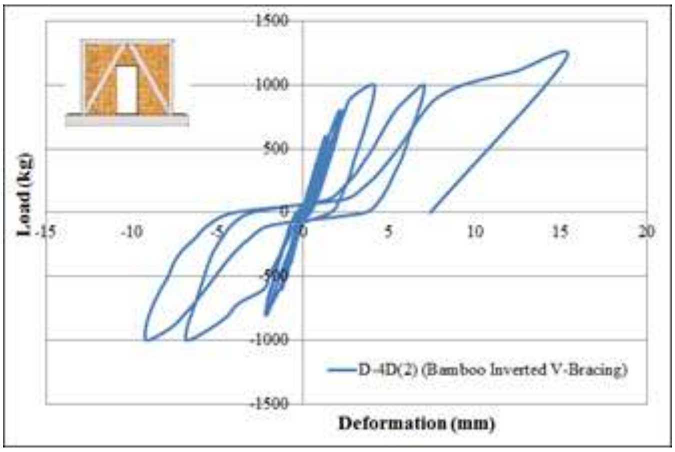

Fig. 8. Load-deformation relationship of cyclic load test of wall with bamboo inverted v-bracing.

V. CONCLUSION

Bracing addition at the masonry wall with opening able to improve the wall stiffness toward earthquake response. It occurred because bracing give strength in defends the tensile force because of the earthquake load. Masonry wall almost similar with the concrete the compressive strength higher than the tensile strength. The wall weakness can be covered with the bracing.

The wall model with inverted v-bracing has highest capability to resist the earthquake for each reinforcement type. It is caused by the inverted v-bracing has bigger stiffness, but the deformation value decrease because the stiffness increase.

The use of bamboo reinforcement at the bracing effectively to replace the steel reinforcement although the earthquake resistance strength lower and the deformation decrease higher. It is caused by the bamboo and steel different in stress-strain. Steel more ductile and has good resistance in resist the load either in non-elastic phase. While bamboo more brittle and the ability to resist load in non-elastic phase decrease heavily.

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