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Out-of-plane Analysis of In-filled Brick Masonry Wall

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In current day, 60% of world's population is living in masonry house[1)]. In addition, the distribution of masonry house is coincident with earthquake occurring areas. Therefore, masonry houses are vulnerable to earthquake and make loss of casualties and property. In this study, the objective is to determine the behavior of out-of-plane failure in brick masonry wall through the static analysis by using FEM, and improve the seismic stability during earthquake due to the protection of masonry structure.

Keywords: *masonry, in-filled, FEM analysis, out-of-plane*

1. Introduction

Masonry structure is composed of walls which use individual brick units. For seismic design and maintenance management, the kind of structures is vulnerable to earthquake and makes lots of casualties. The biggest weakness of the brick walls is the interaction between bricks and mortar. The shear strength of the surface is much lower than brick and mortar. For this cause, it seems to consider severe damage occurs by the reduction of strength.

In this study, the masonry units are arranged in Flanders method[1)]. In construction process this technique is useful because of special arrangement of masonry bricks, some regular interval voids are in the wall. Through filling the holes using concrete with thin steel fiber bars, we discuss about the behavior of out-of-plane during earthquakes. A plan view of brick wall[2)] is shown in Fig.1. The testing sample of brick wall also is shown in Photo.1.

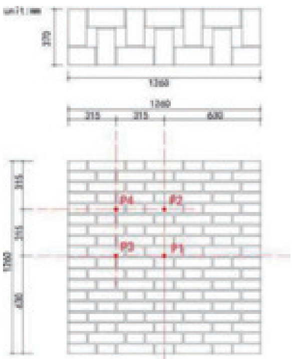

Fig. 1 A Plan View of Brick Wall and Displacement Point on The Surface of Wall

Photo 1 Specimen Sample of Brick Wall

2. Finite Element Models

We use the normal concrete used in Japan with steel fiber bars, which the strength is approximately the same as high-strength concrete in Iran. Analytical parameters of reinforcing material, the mixing ratio of steel fiber bars in concrete is 1.5% (length is 35mm, diameter is 0.6mm, above 600MPa in tensile strength).

The object of this study is to analyze the breaking force values under the compression testing and investigate the relationship between force and displacement. The stress distribution of non-reinforced and reinforced wall models in out-of-plane direction by using the FEM analysis. The brick and mortar are used as one model material, and there are two cases of young modulus[3)] in the wall models. The material parameters[3)] of model are referenced from the unit test in our laboratory. The parameters are shown in the Table 1 and Table 2.

The size is 1,260mm×1,260mm×370mm referenced from the testing sample. There are 76,964 elements in the no-reinforced brick wall model divided by 20mm×20mm×20mm unit. Also in the reinforced brick wall model, there are 76,964 elements with 6 reinforced fiber-concrete models which each 14,619 elements. The models are shown in Fig.2-A and Fig.2-B.

The out-of-plane failure type is common when the main direction of the seismic shake or loading is perpendicular to the masonry walls. In this study, all of the models are simulated under the loading from out-of-plane direction in the center of model by applying average displacement rate of 0.01mm/s while the 4 corners of wall model are fixed condition in both displacement and rotation.

Table 1 Parameters of Case-A Models

CASE A	Brick Wall with Holes		Brick Wall with Reinforcing Material		
	Brick Wall	Fix+Stick(steel)	Brick Wall	Fiber Concrete	Fix+Stick(steel)
Young's Modulus(MPa)	4,000	206,000	4,000	20,000	207,000
Poisson Ratio(-)	0.164	0.2	0.16	0.2	0.27
Yield Stress(MPa)	3.43	245	3.4	27.3	245
Plastic strain(-)	0	0	0	0	0

Table 2 Parameters of Case-B Models

CASE B	Brick Wall with Holes		Brick Wall with Reinforcing Material		
	Brick Wall	Fix+Stick(steel)	Brick Wall	Fiber Concrete	Fix+Stick(steel)
Young's Modulus(MPa)	6,700	206,000	6,700	20,000	207,000
Poisson Ratio(-)	0.164	0.2	0.16	0.2	0.27
Yield Stress(MPa)	3.43	245	3.4	27.3	245
Plastic strain(-)	0	0	0	0	0

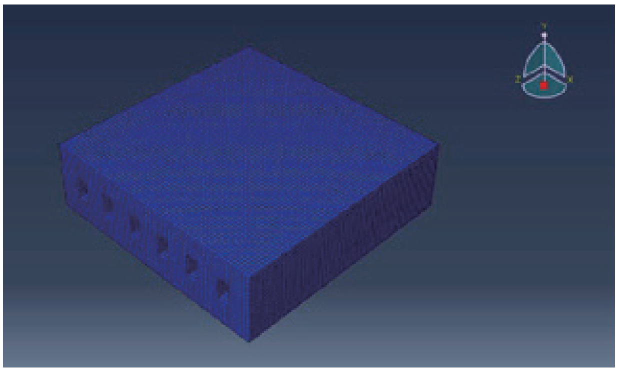

Fig. 2-A No-reinforced Brick Wall Model

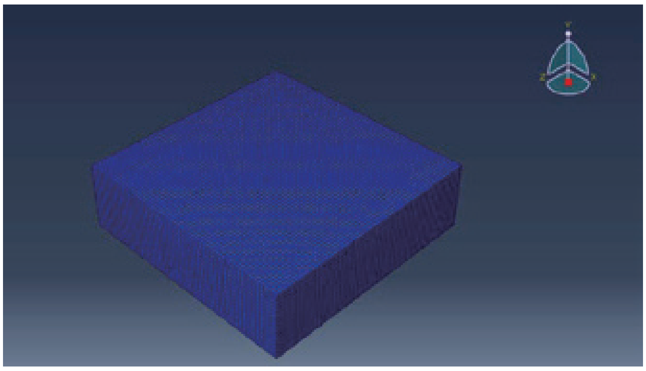

Fig. 2-B Reinforced Brick Wall Model

3. Analytical Results

The analytical results indicate that the failure load of no-reinforced brick wall model in young's modulus 4,000MPa (i.e., Case A) is 368kN, and the failure load of reinforced brick wall model is 731kN. Meanwhile, the failure load of no-reinforced brick wall model in young's modulus 6,700MPa (i.e., Case B) is 383kN, and the failure load of reinforced brick wall model is 743kN.

The stress distributions of models are shown in Fig.3-A and Fig.3-B. The figures show that the reinforced model can decrease shear stress around the holes better than the no-reinforced model. The stress of no-reinforced model is large near the loading point. However, the stress is not uniformly along the holes direction. The stress of reinforced model is not large around the loading point.

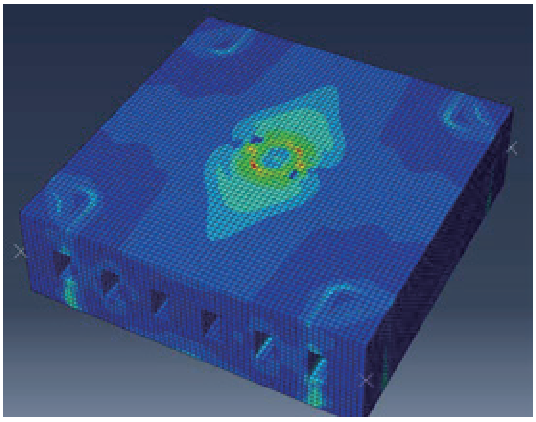

Fig. 3-A Analytical Result of No-reinforced Brick Wall Model

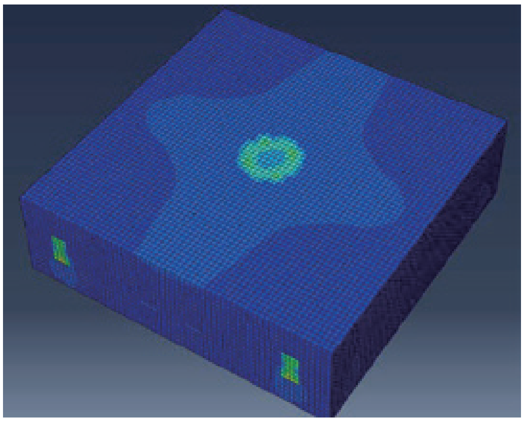

Fig. 3-B Analytical Result of Reinforced Brick Wall Model

Based on the Fig.4 and Fig.5 we can see that the relationship between force and displacement of 4 analytical points (each analytical point referenced Fig.1). These figures show that the maximum displacement at the center point (P1) of no-reinforced brick wall model in young's modulus 4,000MPa (i.e., Case A) is 2.2mm, and the maximum displacement of P4 is 0.38mm. The maximum displacement at the center point (P1) of reinforced model in young's modulus 4,000MPa (i.e., Case A) is 3.4mm, the maximum displacement of P4 is 0.8mm. In addition, the maximum displacement at the center point (P1) of no-reinforced model in young's modulus 6,700MPa (i.e., Case B) is 1.8mm, and the maximum vertical displacement of P4 is 0.25mm. The maximum displacement at the center point (P1) of reinforced model in young's modulus 6,700MPa (i.e., Case B) is 3.8mm, the maximum displacement of P4 is 0.74mm. The displacement values of each analytical point are shown in Table 3.

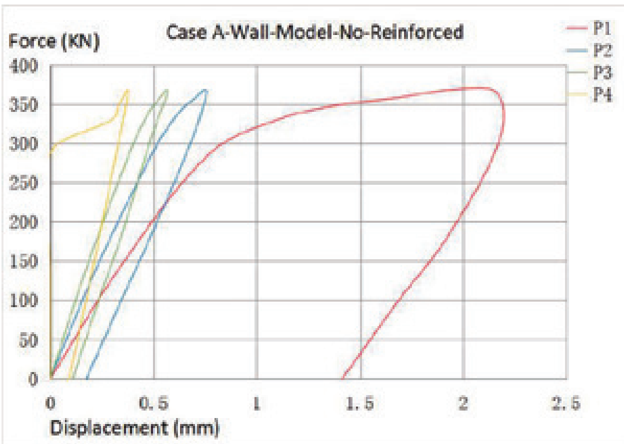

Fig. 4-A Force-Displacement Relationship of No-reinforced Model in Case A

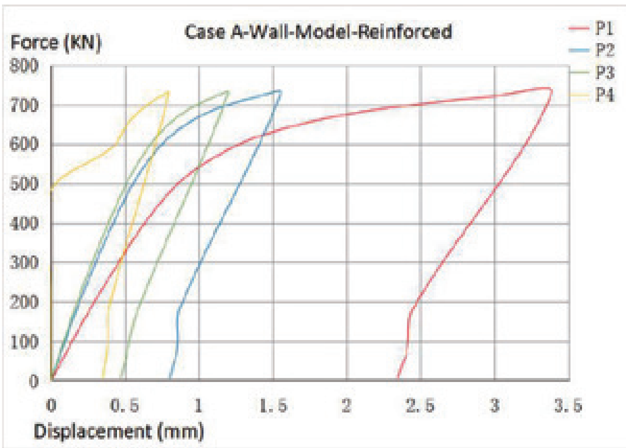

Fig. 4-B Force-Displacement Relationship of Reinforced Model in Case A

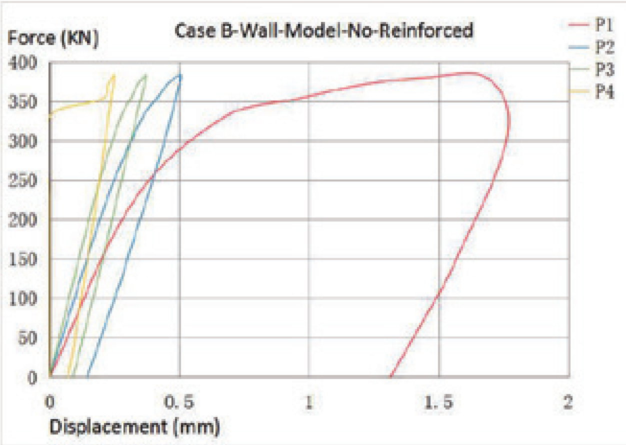

Fig. 5-A Force-Displacement Relationship of No-reinforced Model in Case B

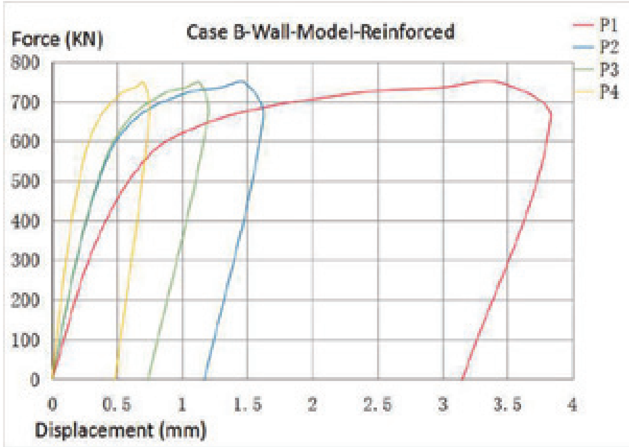

Fig. 5-B Force-Displacement Relationship of Reinforced Model in Case B

Table 3 The Displacement Values of Each Analytical Point

	Case A				Case B			
	No-reinforced Model		Reinforced Model		No-reinforced Model		Reinforced Model	
	P1	P4	P1	P4	P1	P4	P1	P4
Displacement(mm)	2.2	0.38	3.4	0.8	1.8	0.25	3.8	0.74

4. Conclusion

From the relationship between loading force and measured displacement at the points, the stress distribution of brick wall models can investigate for the out-of-plane loading by using FEM. In the aspect of strength, the value of reinforced model with fiber concrete is increased about 2 times in comparison with no-reinforced model. The maximum displacement of reinforced model at the center point increase about 55% to 111%. The stress of reinforced model is uniformly small around the loading point, and stress value decrease around the holes in case of reinforced model. This reinforcing method of brick wall is considered to improve the strength obviously.

Acknowledgment

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