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EJENS

European Journal of Engineering and Natural Sciences

DergiPark AKADEMİK

CODEN: EJENS

Macro and Micro Modeling of the Unreinforced Masonry Shear Walls

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Abstract

Masonry structures are constructed by joining masonry units (brick, stone, marble etc.) with mortar. Various methods are used for modeling of masonry walls of the structures. Micro modeling and Macro modeling are two diverse modeling techniques. In this study, these two modeling strategies are analyzed on a solid unreinforced masonry shear wall numerically. The models are implemented in ANSYS software to simulate the structural behavior of a tested wall in literature. The homogenization technique is applied to obtain the material parameters used in the macro model. Brick and mortar are modelled separately in the micro model. Stresses occurring in the walls under the effect of in-plane loads are investigated. The propagations of the cracks on the walls are analyzed numerically. The results obtained in the micro modeling and macro modeling are in consistent with the experimental study in the literature. However, macro modeling and micro modeling represent strictly disparate behavior in the material identification, and crack propagations.

Key words

Crack, Macro, Masonry, Micro

1. INTRODUCTION

Masonry structures are the first structures of the history and have a significant place among all the structures. There are many masonry monumental structures in the world such as buildings, palaces, bridges and towers. Modeling of the masonry structures has become a significant requirement to evaluate the strengths of existing masonry structures and to build modern masonry structures. Modeling of the masonry walls is a challenging issue because of their composite structures. There are several modeling techniques for modeling of walls constituting the masonry structures. Macro modeling and micro modeling are two different technique for modeling of masonry structures. In this study, the macro modeling and micro modeling techniques are investigated on the masonry walls. Masonry walls are modelled and analyzed to determine the fracture mechanisms of the walls. In-plane behaviors of unreinforced masonry walls are analyzed numerically.

Engineers and architects have worked to determine the in-plane effects on the masonry walls throughout the history. The effects of tension, pressure and shear on the masonry walls have been investigated by many scientists. The researchers used macro and micro modeling techniques to model the masonry walls. Masonry units and mortar are modelled as a single material in the macro modeling technique. The macro modeling technique was studied in [1] and [2]. Masonry units, mortar and interfaces are modelled separately in the micro modeling technique. The micro modeling technique was used in studies [3] and [4]. Lourenço made extensive work on modeling masonry structures using micro and macro modeling techniques [5], [6]. Oller were studied on the numerical modeling of masonry walls [7]. Many scientists have continued to model masonry walls.

2. MACRO AND MICRO MODELİNG

The main goal in modeling is to produce a model that behaves close to the real structure. The modeling of the masonry walls requires more care than other constructions because of the different characteristic of the masonry units and mortar. Various methods are used in the modeling of masonry structures. Masonry structures can be generally modelled as heterogeneous and homogeneous models. Detailed micro and simplified micro models are heterogeneous models. Macro modeling technique is known as homogeneous modeling technique. The modeling techniques diagram is shown in Figure 1.

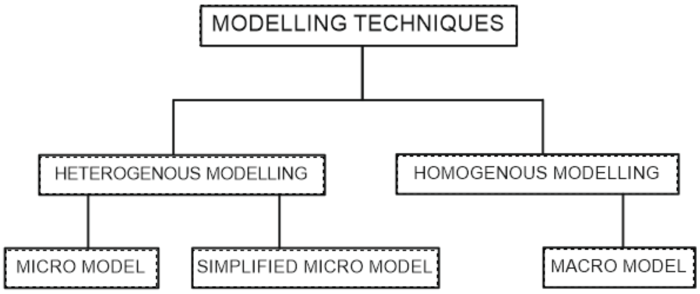

Figure 1. Modeling techniques for masonry walls

2.1. Macro Modeling

In macro modeling technique, masonry units (bricks, stone units), and the mortar between them are modelled as a single material. Application of the macro modeling technique is shown in Figure 2. Masonry walls are composite structures that can be homogenized using advanced techniques according to the macro modeling technique. It is beneficial to use elementary masonry wall parts which periodically repeat themselves on the wall in order to model the masonry walls by homogenization.

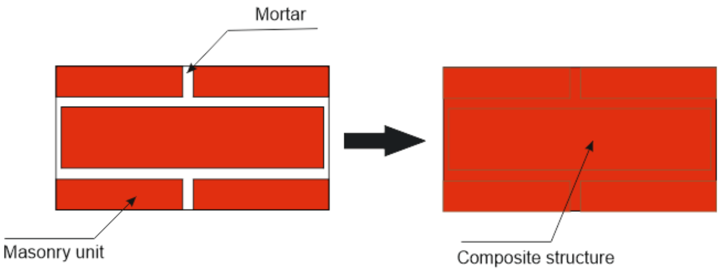

Figure 2. Macro modeling procedure

2.2. Micro Modeling

In micro technique, masonry units (brick, stone, etc.) and the mortar are modelled separately. Interfaces in the joining areas of these elements can be also included in the model. The micro modeling is shown in Figure 3. Although modeling of structures with micro modeling technique is a detailed process, local behavior of the structures can be investigated wit this technique.

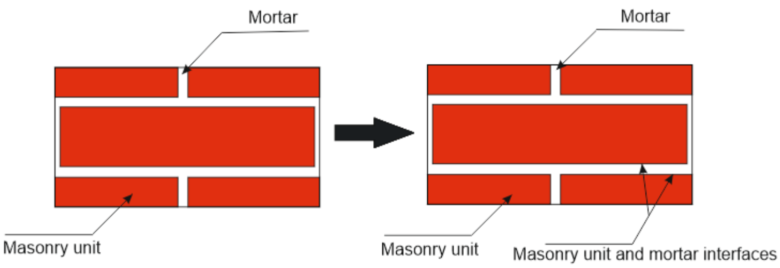

Figure 3. Micro modeling procedure

3. FINITE ELEMENT MODELS OF MASONRY WALLS

In this study, finite element analysis was performed by using micro and macro modeling techniques on unreinforced masonry walls. Experimental study was used in the literature for numerical analysis [8]. The geometry of the masonry wall and the masonry unit using at the wall are shown in Figure 4. The wall is loaded in two steps. In the first load step, the wall was loaded with a vertical pressure of 0.3 MPa to top nodes of the wall. In the second load step, horizontal displacement is given to the top nodes of the walls. The first load step is implemented by dividing by 10 equal sub-steps. The second load step is divided into 40 sub-steps.

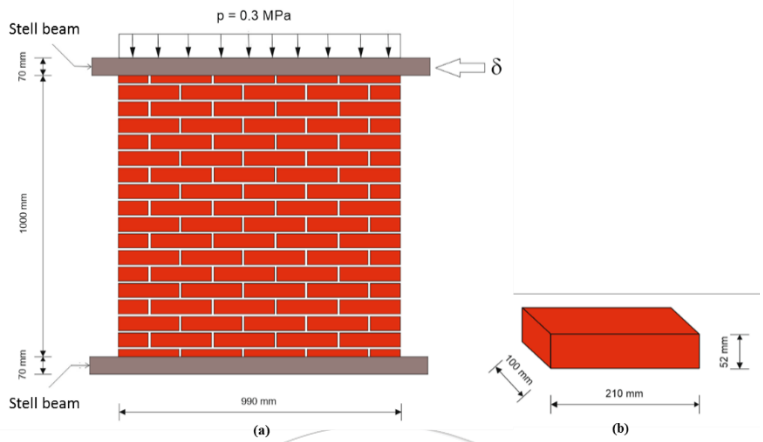

Figure 4. (a) Masonry wall geometry (b) masonry unit used in the wall

SOLID 65 finite elements in the ANSYS software was used for the finite element analysis. This element has 8 node points and each node point has 3 displacement degree of freedom in x, y and z directions. It can show collapse mechanisms both tensile and compression. Brittle materials can be modelled such as rock, stone, brick, concrete etc. This element is suitable for modeling of nonlinear behavior of structures and cracks can be determined in the structure. The structure of the SOLID 65 element is shown in Figure 5.

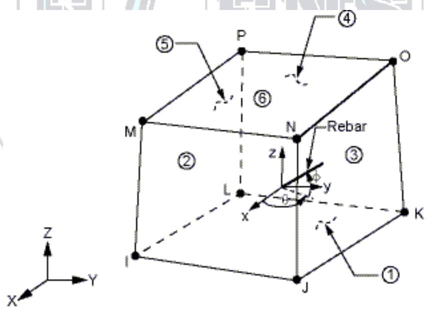

Figure 5. SOLID 65 element

Concrete material is used for the nonlinear analysis on the masonry walls. Typical Stress-strain curve of the concrete material is shown in Figure 6. Crack distribution on the wall under in-plane loading can be determined with this material model.

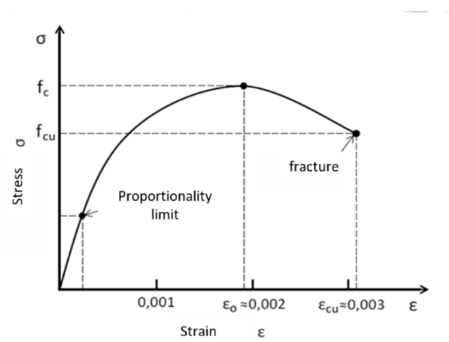

Figure 6. Typical stress-strain diagram of the Concrete material

Material parameters used in the models are shown in Table 1. Brick and mortar material parameters were implemented to micro finite element model. But, wall material parameters were obtained with homogenization of the masonry wall and were implemented to the macro finite element model.

Table 1. Material properties

Material	Modulus of Elasticity [MPa]	Poisson's Ratio	Tensile Strength [MPa]	Compressive Strength [MPa]
Brick (Micro)	16700	0,15	2	10,5
Mortar (Micro)	780	0,15	0,25	3
Wall (Macro)	3655	0,15	0,25	9

In the numerical analysis, the Willam-Warnke fracture hypothesis is used for nonlinear behavior of the masonry wall. Three-dimensional fracture surface and two-dimensional fracture surface for Willam-Warnke hypothesis is shown in Figure 7. Willam-Warnke hypothesis is a suitable hypothesis for materials having different compressive strength and tensile strength such as masonry materials. Masonry materials usually have high compressive strength and low tensile strength.

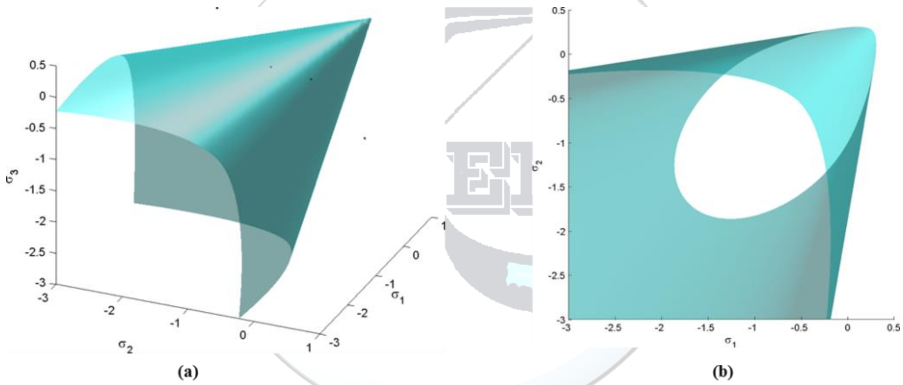

Figure 7. Willam-Warnke fracture surfaces: (a) Three dimensional space (b) Two dimensional plane

3.1. Macro Finite Element Model

In ANSYS software the geometry of the masonry wall was created by using the macro modeling technique. Masonry units and mortar were produced as a single material. Figure 8 shows the geometry and the finite element mesh of the masonry macro model. Refined mesh distribution was used in the models to investigate the crack distributions well.

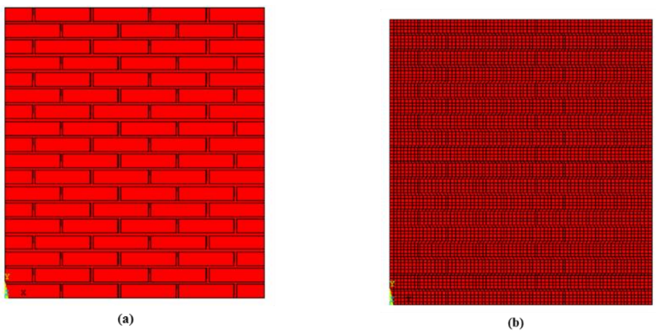

Figure 8. (a) Geometry of the wall (b) finite element mesh of the masonry macro model

Total displacement at the end of the 1. load step, minimum principal stresses at the end of the 1. load step, minimum principal stresses at δ=1, total displacement at δ=1mm and shear stresses at δ=1mm are shown in Figure 9. Continuous stress distribution is determined between the bricks and mortar.

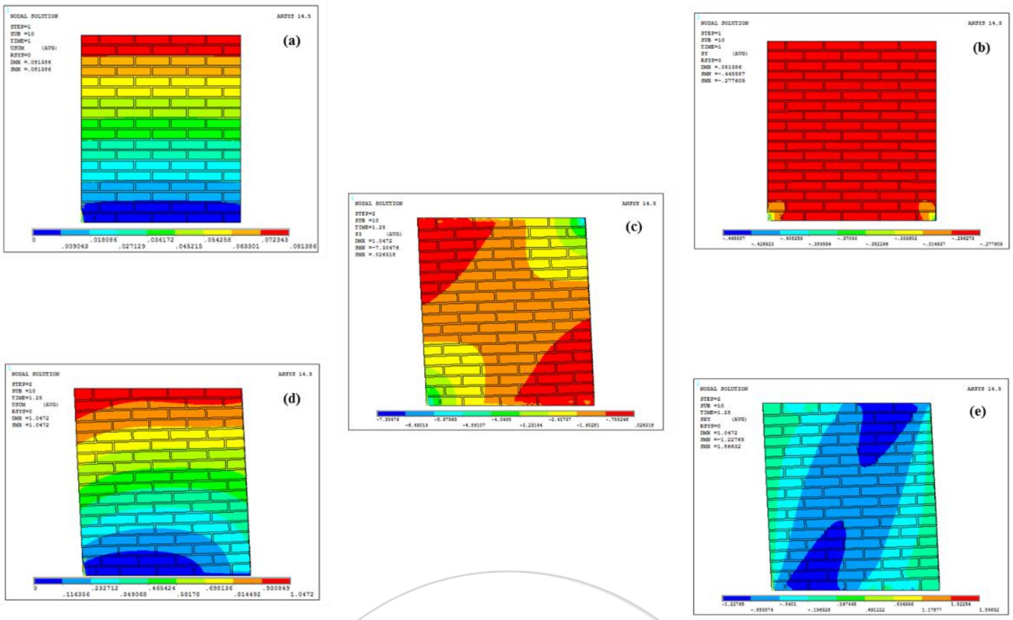

Figure 9. Macro model: (a) total displacement at the end of the 1. Load step, (b) minimum principal stresses at the end of the 1. Load step, (c) minimum principal stresses at δ=1, (d) total displacement at δ=1mm, (d) shear stresses at δ=1mm

The crack distribution of the unreinforced masonry wall from δ=0.1 mm to δ=1 mm is given in Figure 10. Continuous cracks are obtained with the macro modeling technique according to finite element analysis.

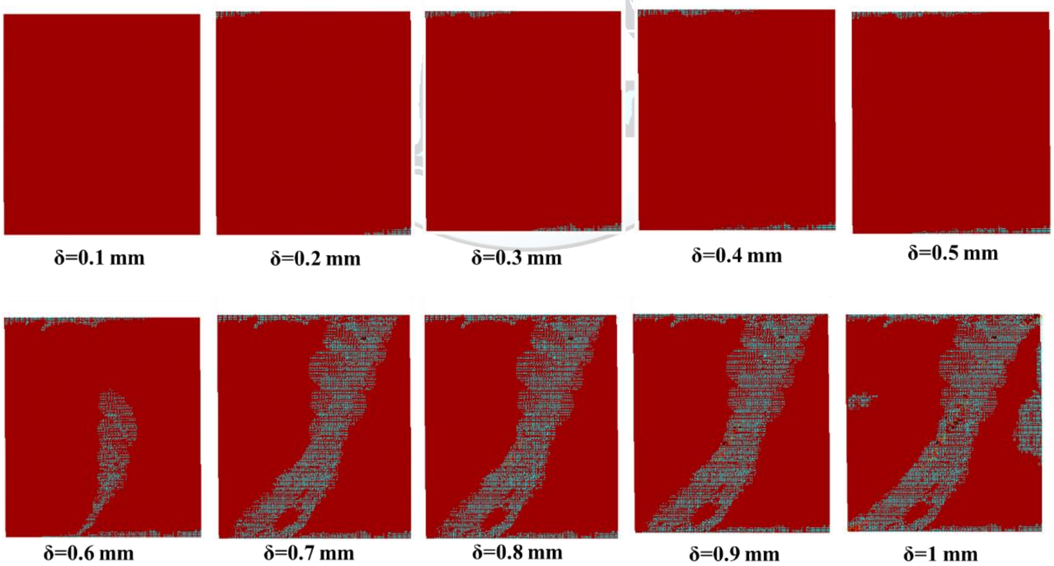

Figure 10. Crack distribution at the end of the macro modeling

It is seen that the cracks first started from the upper left and lower right corners of the wall. Next, diagonal cracks occur on the wall.

3.2. Micro Finite Element Model

Geometry of the model and finite element mesh were produced with the micro modeling technique. In this technique bricks and mortar are modelled separately. The same mesh distribution was used with the macro model. Figure 11 indicates the geometry and the finite element mesh of the micro model.

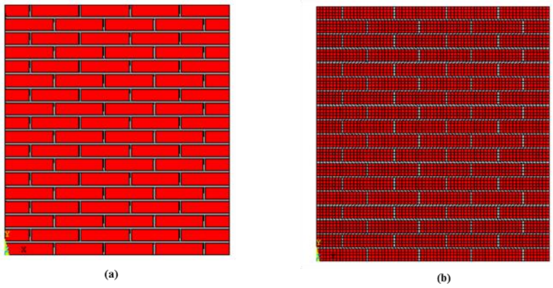

Figure 11. (a) Geometry of the wall (b) finite element mesh of the masonry micro model

Total displacement at the end of the 1. load step, minimum principal stresses at the end of the 1. load step, minimum principal stresses at δ=1, total displacement at δ=1mm and shear stresses at δ=1mm according to finite element analysis are shown in Figure 12.

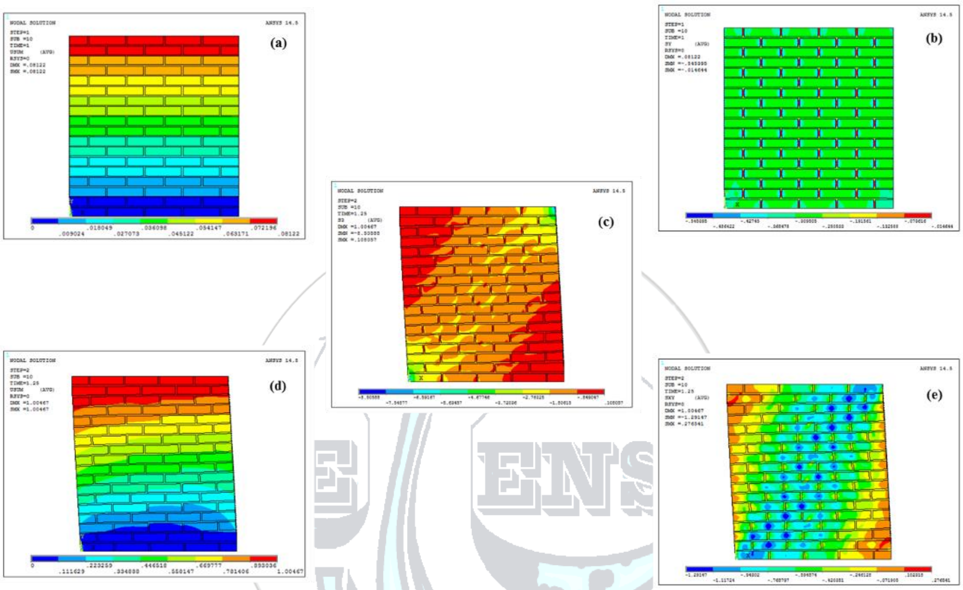

Figure 12. Micro model: (a) total displacement at the end of the 1. Load step, (b) minimum principal stresses at the end of the 1. Load step, (c) minimum principal stresses at δ=1, (d) total displacement at δ=1mm, (d) shear stresses at δ=1mm

The crack distributions of the unreinforced masonry wall are given from δ=0.1 mm to δ=1 mm in Figure 13.

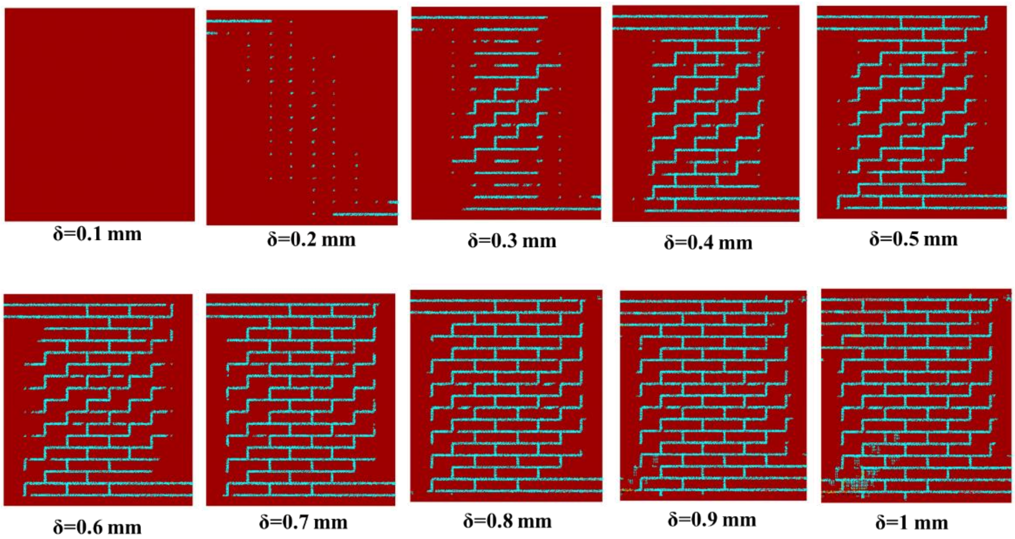

Figure 13. Crack distribution at the end of the micro modeling

It is seen that the cracks first started from the upper left and lower right corners of the wall. Next, cracks in the mortar areas spread all over the wall because of low tensile strength of the mortar areas.

4. RESULTS AND DISCUSSION

In this study, an unreinforced masonry wall was modelled and analyzed using finite element method. Stresses and strains on the wall were determined after the analysis. In addition, the cracks were investigated step by step. The reason of the cracks can be explained in terms of internal effects. Figure 14 shows the reasons of the cracks on the unreinforced masonry wall. Firstly, horizontal cracks that occur in the upper left and lower right parts of the wall shown with number (1) are tensile or shear cracks. Secondly, the cracks that occur in the upper right and lower left parts of the wall shown with number (2) are compressive cracks. Next, the diagonal cracks that occur in the middle region of the wall are represented by number (3) are caused by multiple influences.

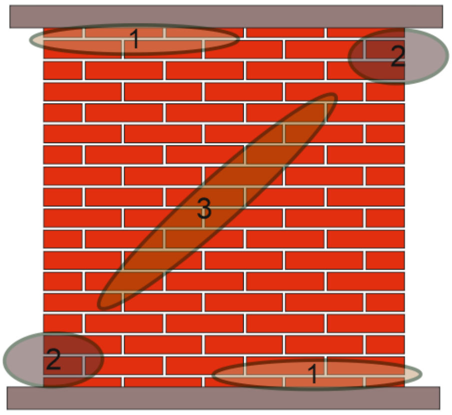

Figure 14. The reasons of the cracks on the masonry

Horizontal displacement of the top of the wall and horizontal reaction force of the wall diagram is shown in Figure 15. There are four different diagrams in the figure. Two of them shows numerical analysis and the other two diagrams shows the experimental results in the literature. It is seen that, the models have similar behavior until reaching the wall collapse state but the concrete material suddenly lost its strength in numerical analysis.

Figure 15. Load – displacement curves of the wall after the analysis

5. CONCLUSION

In micro modeling technique, masonry unit and mortar material properties are added to each model separately. However, single material parameters are used as an average property for masonry unit and mortar in macro modeling technique. In addition, the walls modelled by macro and micro methods represent consistent results with the experimental work, but does not fully reflect the post-peak behavior due to the concrete material property. While the micro modeling technique is suitable for small scale structures, the macro modeling technique is suitable for large-scale structures. Because the micro modeling technique requires more time, effort and computer capacity. Discrete cracks occur with using micro modeling technique. However, continuous cracks can be investigated with using macro modeling technique. Studies have been continued to model and analyze masonry walls.

ACKNOWLEDGMENT

This research has been supported financially by the ITU scientific research projects unit.

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