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RESEARCH ARTICLE

Micro model analysis of JD6 and JD7 Eindhoven walls with fixed smeared crack model

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Abstract

Micro, simplified micro and macro modelling are used for the numerical modeling of the masonry. In this study, the efficiency of a 3-dimensional fixed smeared crack model in the micro modelling of masonry walls is investigated. For this purpose, the experimental results of the masonry walls called as the JD6 and JD7 Eindhoven walls are selected. The concrete model with three parameters which special case of William Warnke model is used to calculate the nonlinear behavior of mortar and brick regions of this wall. Interface element is not use at between brick and mortar. Predictor-corrector technique used for nonlinear analysis. Numerical and experimental results are compared in terms of the base shear-peak displacement curve and the crack regions obtained in the walls. Good approximation are obtained between experimental and numerical results with regard to ultimate base-shear force obtained. Some differences are determined between experimental and numerical results with regard to threshold displacement value that calculated versus ultimate base-shear force.

Keywords

Masonry walls; Micro modelling; 3-dimensional fixed smeared crack; Eindhoven walls.

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1. Introduction

Masonry walls have been used for constructions of buildings since centuries. These constructional elements are still preferred. Nowadays, masonry walls are generally used in frame structure as filling material except from masonry building construction. It is known that these structural elements provide to positive contributions for earthquake resistance of buildings [1,2]. However, contributions of this element are not generally considered in numerical solutions of the buildings due to require complex analysis.

Three modelling techniques are suggested for analysis of masonry structure under static and

seismic loadings in the literature [3-8]. These modeling techniques are Micro, Simplified micro and Macro modeling. Stone/brick and mortar materials are separately modeled in micro and simplified micro modeling techniques. In the macro modeling technique, stone/brick and mortar materials are homogenized as a continuum domain. Advantage of this technique, less element number according to micro and simplified micro modeling techniques in finite element model are used. Disadvantage of macro modeling technique, it cannot achieve ultimate load capacity and no damage zone geometry are accurately calculated. Large computational time and large computer

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19 Karaton and Çanakçı

memory are required for numerical modelling of masonry buildings by using micro. Masonry walls with small scale can be only analyzed by these modelling techniques. Therefore, development of novel macro modelling techniques are required for accurately computation of load carrying capacity and damage zone geometry of masonry walls. Many researchers have focused on this problem and, have been developed simplified or alternative methodologies for reduce of computational effort in order to engineering practice [3-8]. In these researchers, Adam et al. [9] performed micromechanical modeling by a finite element method for a series of laboratory tests on masonry structures. Mortar and brick were modeled as solid material at the finite element model, and the interface of these two materials modeled with interface elements. The results of the non-linear numerical analysis and the experimental results were compared in terms of load-displacement and bending moment-rotation responses. Mohyeddin et al. [10] obtained analyses of reinforced concrete frames filled with masonry walls using threedimensional discrete finite elements. Ansys finite element program was used in the solutions. In order to validate this model, experimental data in the literature were used. It was observed that the model accurately reflected the effect on the fill frame inplane and out-of-plane loading cases. Caporale et al. [11] used the two-dimensional micro modelling to examine the effect of different masonry patterns and loading conditions on adobe walls. Experimental results showed that adobe bricks and mortars under compressive and tensile loads have different modulus of elasticity. Petracca et al. [12] presented a new damage mechanic model which based continuous domain for the analysis of masonry walls in micro scale. The model was compared with discrete micro modeling methods in the literature.

In this study, the efficiency of a 3-dimensional fixed smeared crack model in the micro analysis of masonry walls was investigated. A lot of researcher are often preferred for numerical modelling of the masonry walls. Therefore, effectiveness of the model should be investigate in micro modelling of

the masonry wall. For this purpose, the experimental results of the masonry walls called as JD6 and JD7 Eindhoven walls were used. Numerical analyses were achieved by using Ansys finite element program [13]. William and Warnke model were selected for yield surface [14]. Numerical and experimental results were compared in terms of the base shear force-peak displacement curve and the crack regions obtained in the walls.

2. Micro, simplified micro and macro modelling techniques for masonry walls

Micro, simplified micro and macro scale modelling techniques are generally used for numerical analysis of masonry [4,15]. One of the finite elements, the discrete element or the finite volume element methods could be preferred for modelling. In the micro modelling technique, brick/stone and mortar are modelled by using different mechanical properties of material. Interface elements are used between these units. Finite element dimensions of brick/stone are extended to middle of mortar unit in the simplified micro modelling technique. In the macro modelling technique, brick/stone and mortar are homogenized by using composite material theories. Effective material properties equivalent to these materials are used (Fig. 1).

3. William and Warnke model

The model is called as three parameters model which a special case of five parameters model of William and Warnke [16]. Zeinkiewicz and Taylor [17] were stated that the model can be used for the brittle materials. This model is effectively used when macro modeling of the masonry structures [9,10,17,18]. This model is a similar to cone with convex cross-section as seen in Fig. 2.a [14]. In this figure, are principal stresses. fc and ft are uniaxial compressive and tensile strengths of the material, respectively. Softening behavior of the material under the tensile stress is given in Fig.2.b. In where, Tc is reduction coefficient of the tensile strength which after cracking initiation. ε_{ck} is threshold cracking strain and $6\epsilon_{ck}$ is also taken for ultimate strain in the Ansys software.

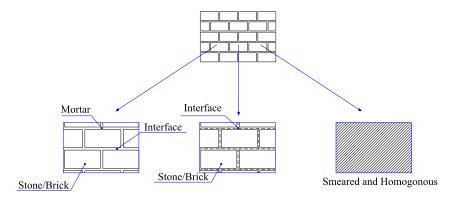


Fig. 1. Modelling techniques of masonry unit; a) micro, b) simplified micro and c) macro modelling [4,15]

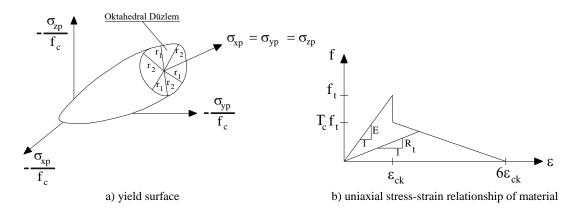


Fig. 2. Three parameters model [16].

4. Micro model analysis of JD6 and JD7 walls

In the numerical application, Eindhoven walls called as JD6 and JD7 were selected. Dimensions of JD4 wall are 990×1000×100 mm. It was constructed by using brick with 210×52×100 mm dimensions and mortar with 10 mm thickness. Lower side surface of the wall was supported on the rigid surface. 120 kN and 210 kN preloading loads in vertical direction were applied to upper surface of JD6 and JD7 walls, respectively. Displacement controlled loading in the horizontal direction were applied at the upper side of walls as seen in Fig. 3 [20].

In this paper, experimental results of JD6 and JD7 walls were used for the numerical comparison. Numerical solutions of the two walls were obtained with "Micro modelling technique" by using finite element method. ANSYS finite element program was used for numerical analysis of the walls. Three

dimensional solid concrete element of ANSYS (Solid 65) was selected. 33600 nodes and 21978 solid elements were used in finite element model in Micro Model of JD6 and JD7 walls (Fig.4). Interface element is not use at between brick and mortar. Boundary condition in direction of horizontal and vertical were applied to bottom of steel elements. Boundary conditions in direction of vertical were performed at upper side of top steel elements. In the solutions, self-weight for dead loading of walls and 120 kN and 210 kN for preloading were applied to wall in first loading stage. In second stage, loading based on displacement was applied to node in the upper side of the wall. Predictor-corrector technique used for nonlinear analysis. Material properties of brick and mortar used in the analyses were given in Table 1 and 2. ft and fc are shear retention factor in opening and closing case of a crack region, respectively.

Karaton and Çanakçı

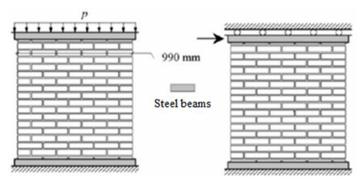


Fig. 3. Geometric properties, loading case and boundary conditions of JD6 and JD7 Eindhoven walls [20].



Fig. 4. Geometric properties, loading case and boundary conditions of JD6 and JD7 Eindhoven Wall.

Table 1. Material properties of JD6 wall

Malerial type	E (MPa)	ν	ρ (t/m ³)	f _t (MPa)	f _c (MPa)	β_{t}	β_{c}
Brick	9000	0.15	2.2	1.20	30.00	0.05	0.90
Mortar	2000	0.20	2.3	0.50	10.00	0.05	0.90

Table 2. Material properties of JD7 wall

]	Malerial type	E (MPa)	ν	ρ (t/m ³)	f _t (MPa)	f _c (MPa)	β_t	β_{c}
	Brick	16500	0.15	2.2	2.20	55.00	0.05	0.90
	Mortar	2000	0.20	2.3	0.50	10.00	0.05	0.90

Force-displacement graphs and fracture zones of the wall were obtained from nonlinear analyzes of the walls. Force-displacement graphs of the walls obtained from numerical analyses were compared with experimental results as seen in Fig. 5. Value of ultimate load capacity obtained from experimental test of JD6 wall was obtained as 74.87 kN. This value was calculated as 72.46 kN (Fig.5.a) Thus, load capacity obtained from numerical solutions were computed as 3.32% smaller according to experimental test result. Value of ultimate load

capacity obtained from experimental test of JD7 wall was obtained as 100.17 kN. This value was calculated as 99.62 kN in the numerical analysis (Fig.5.b). Therefore, the load capacity obtained from numerical solutions were calculated as 0.55% smaller according to experimental test result. Threshold displacement values versus the ultimate load capacity of JD6 and JD7 walls were also determined as 1.22 mm and 1.56 mm from experimental results, respectively.

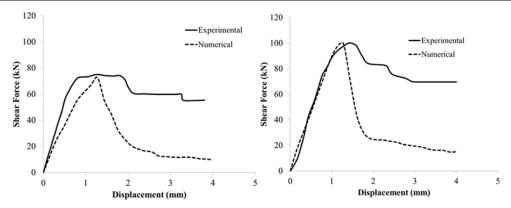


Fig. 5. Force-displacement graphs of JD6 and JD7 walls

The displacement versus the ultimate load capacity of both walls obtained from numerical solutions was 1.28 mm. Differences between experimental and numerical displacement values for JD6 and JD7 walls were defined as 4.92% and 17.95%, respectively. It is assumed that these differences are occurred due to boundary of softening region of the concrete model is fixed ($6\epsilon_{ck}$) and, due to uncertainty in shear stress calculating by reason of cracking effect in element.

Crack regions obtained from numerical (for different top displacement values) and experimental results of the JD6 and JD7 walls were given in Fig.6 and 7. Crack regions of both walls were occurred 3 zones. First zone was started right top corner of the wall and extended to left side of the wall in the horizontal direction. Second zone was started left bottom corner of the wall and extended to right side of the wall in the horizontal direction. An additional cracking zone was also obtained between left top corner and right bottom corner as a diagonal form. Cracking zones obtained from experimental and numerical results are initially similar. But, in later loading phases, distributions were seem in cracking zones obtained from the numerical solutions.

5. Results

In this study, the efficiency of a 3-dimensional fixed smeared crack model in the micro analysis of masonry walls is investigated. For this purpose, the experimental results of the masonry walls called as the JD6 and JD7 Eindhoven walls are selected. In order to calculate the nonlinear behavior of the mortar and brick materials of this walls, fixed smeared crack model is used. Numerical and experimental results are compared in terms of the base shear force-peak displacement curves and the crack regions. Obtained results are given in following,

- Differences between experimental results and ultimate base-shear force obtained from numerical analysis of JD6 and JD7 walls are determined as 3.32% and 0.55% ratio, respectively.
- Differences between displacement values versus ultimate base-shear force obtained from numerical analyses of the JD6 and JD7 walls are determined as 4.92% and 17.95%, respectively. It is assumed that these differences are occurred due to boundary of softening region of the concrete model is fixed (6□ck). It should be changed according to finite element mesh size in the software.
- Crack regions of both walls are occurred 3 zones. First zone is started right top corner of the wall and extended to left side of the wall in the horizontal direction. Second zone is started left bottom corner of the wall and extended to right side of the wall in the horizontal direction. An additional cracking zone is also obtained between left top corner and right bottom corner as a diagonal form. Cracking zones obtained from experimental and numerical results are initially similar. But, in later loading phases, distributions were shown in cracking zones obtained from the numerical solutions.

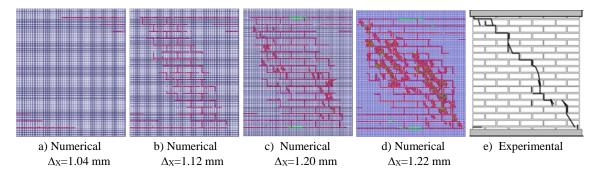


Fig. 6. Crack regions of Eindhoven JD6 wall.

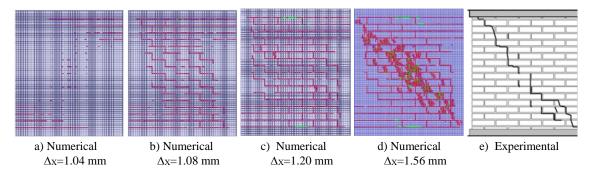


Fig. 7. Crack regions of Eindhoven JD7 wall.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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