Modeling Masonry Structures using the Applied Element Method

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1. Introduction

Masonry is a construction material widely used around the world. Although its poor behavior under seismic loads has been extensively reported, masonry is used in earthquake prone areas mainly due to its relatively low cost. In order to improve the seismic performance of this type of structures, it is important to understand the pre and post peak behavior of masonry under seismic loads. In this context, both experimental and numerical approaches are needed.

Masonry is a composite material made of bricks and mortar. Due to large number of influence factors, such as anisotropy of bricks, dimension of bricks, joint width, material properties, arrangement of joints and quality of workmanship, the behavior of masonry is very variable and this makes modeling difficult. Several attempts have been done to model masonry subjected to in-plane loads [1,2,3]. However, the results are so far limited. This paper reports the initial results of a masonry model using the Applied Element Method (AEM) [4].

2. Numerical tool

This is the first application of the AEM to the solution of a brittle composite material such as masonry. Due to the brittle behavior of unreinforced masonry, the modeling of this material is particularly challenging.

In the AEM, the structure is virtually divided in elements connected through couples of normal and shear springs. Mass and damping properties are lumped at the elements and the springs have normal and shear stiffness. For modeling unreinforced masonry, two types of springs were considered. The first connects discrete elements within bricks, i.e. links elements with identical characteristics, and its properties are calculated as described in [4]. A new type of spring is defined for the modeling of the mortar joints as shown in **Fig. 1**. For this case, equivalent normal and shear springs, Kn_{eq} and Ks_{eq}, are defined as:

$$\frac{1}{Kn_{eq}}=\frac{(L-th)\times n}{E_b\times t\times L}+\frac{th\times n}{E_m\times t\times L},\quad \frac{1}{Ks_{eq}}=\frac{(L-th)\times n}{G_b\times t\times L}+\frac{th\times n}{G_m\times t\times L} \qquad (1)$$

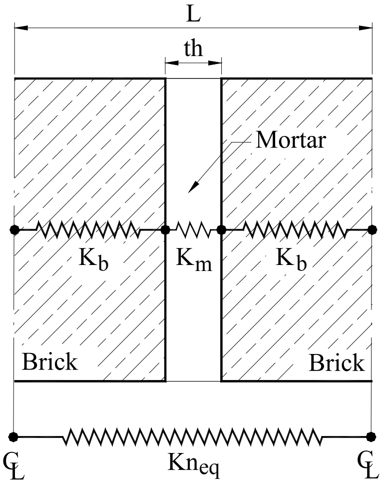

Fig. 1 Equivalent normal spring introduced in the AEM

where n is the number of springs per element side, t is the element thickness, E_b and G_b are the Young's and Shear modulus of brick and similarly E_m and G_m for the mortar. Other variables are defined in **Fig. 1**.

3. Material modeling and failure criteria

To this extend, mortar and brick are both considered linear elastic up to cracking and all the masonry inelastic behavior occurs at the interface. This assumption is based on experimental evidence, which confirms that unreinforced masonry tends to behave linearly almost up to cracking.

The linear behavior of the constitutive materials is changed as soon as the spring forces reach the initial failure surface, which for the present analysis is described by the "cap model" shown in **Fig. 2**. After initial failure surface is exceeded, a residual failure surface is defined and the forces at the springs are mapped back to it.

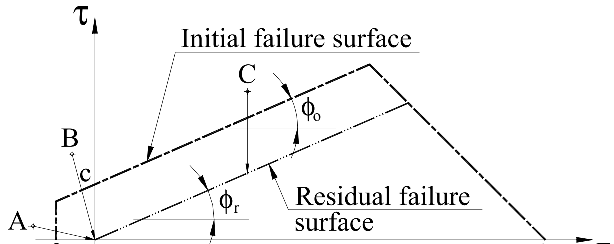

Fig. 2 "Cap model" and return mapping of trials A, B and C (f_t: mortar tensile strength; f'_m: masonry compression strength; c: interface cohesion; ϕ_o and ϕ_r: initial and residual interface friction angle)

Key Words: Masonry, Applied Element Method, earthquake, numerical simulation, cap model, interface
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4. Preliminary results

In order to test the stability of the model two analyses (Case 1 and 2) were carried out. The masonry wall shown in **Fig. 3** was subjected to a vertical uniformly distributed load equal to 30kN/m and then subjected to a horizontal displacement of 2mm. Vertical displacements of the upper course were constrained following the experimental conditions described in [5]. The material properties used for the analysis are summarized in **Table 1**.

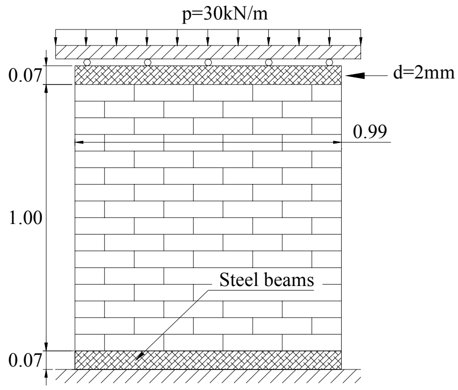

Fig. 3 Test setup (dimensions in m)

Table 1. Material properties used in the analyses

E_b (kN/m^2)	E_m (kN/m^2)	f_m (kN/m^2)	f_t (kN/m^2)	c (kN/m^2)	tan(ϕ_o)	tan(ϕ_r)
1.67×10^7	7.8×10^5	1050	250	350	0.75	0.75

In Case 1, the structure was divided in square elements 31mm side. Each brick consisted of 7×2 elements. For Case 2, the wall was modeled with square elements 62mm side and each brick consisted of 4×1 elements. Although the aspect ratio of each brick varied by approximately 15%, the overall dimensions of the wall were kept. **Figures 4, 5 and 6** show the deformed configuration of the masonry wall after application of the prescribed displacement as obtained experimentally and analytically. The crack pattern is consistent for the both cases analyzed and agrees well with the one observed in the experiments. Furthermore, the model captures the cracking sequence, which is characterized by horizontal tension cracks at the bottom and top of the wall at early loading stages followed by diagonal cracks.

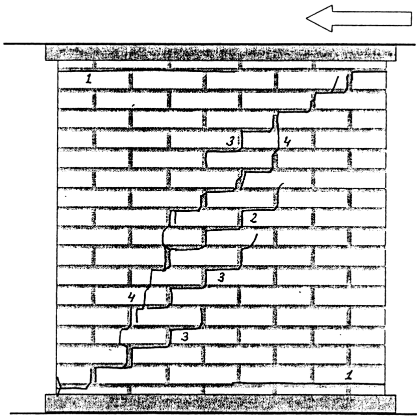

Fig. 4 Experimental results [5]

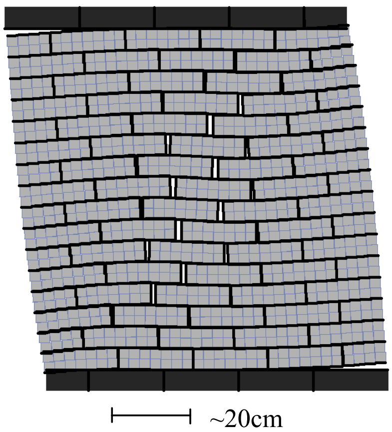

Fig. 5 Deformed shape for Case 1

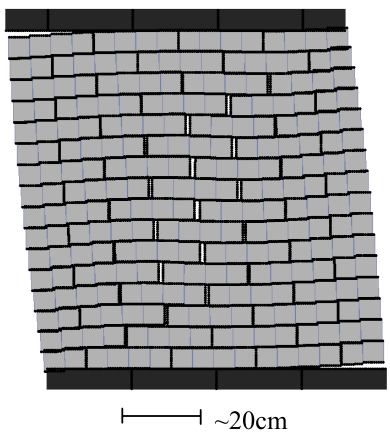

Fig. 6 Deformed shape for Case 2

5. Discussion

The model was able to predict the cracking pattern and sequence observed during the experiments. However, a quantitative discussion of the results is still not possible. The material constitutive models as well as the handling of the sudden drop between the initial and residual failure surfaces need to be refined in order to get better quantitative results. In spite of this, the analysis of masonry structures using the AEM looks promising.

References

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