SIMULATION OF MASONRY SHEAR WALL BEHAVIOR BY APPLIED ELEMENT METHOD

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1. INTRODUCTION

Masonry structures constitute a large portion of existing buildings in high seismic regions of the world. The construction is still in practice in some of those regions. It is important to be able to estimate their response under lateral loading for the purpose of setting guidelines for new construction and retrofitting of existing ones. In this paper, application of Applied Element Method (AEM) in simulating masonry wall behavior under lateral load is discussed.

Appraisal of AEM to simulate the behavior of RC structures shows the method's capability to capture the complete path of structural response until total degradation [1), 2)]. Its applicability to the structures composed of blocky masonry units is realized by the features (i) Element formulation in AEM to discretize the structure into small virtual elements can trace the exact mapping of masonry unit laying with mortar joint location and (ii) It allows large displacement between elements without loosing numerical accuracy. In masonry walls under lateral loading, damage concentrate in mortar joints [3)] where crack appears since early times of structural response history. To capture this phenomenon, AEM can accommodate large displacement discontinuity in mortar region treating brick units and mortar joints separately.

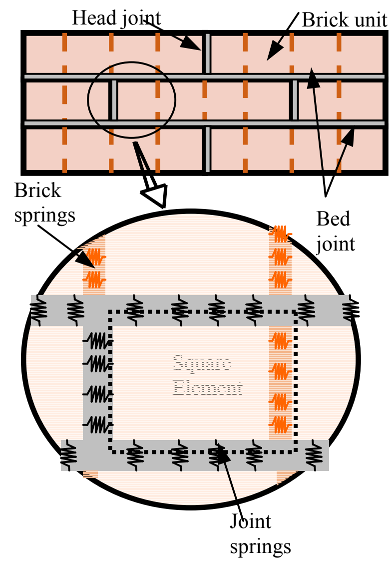

Fig. 1 Mesh generation Scheme of brick masonry

2. ELEMENT FORMULATION

In AEM, structure is assumed to be virtually divided in small square elements each of which is connected by pairs of normal and shear springs set at contact locations with adjacent elements. Stress and strain are defined based on displacement of spring endpoints located along the axis passing thorough corresponding element centroid. Global matrix equation is solved for three degrees of freedom of these elements for 2D problem. Details of element formulation scheme in AEM can be found elsewhere (refer Ref. 1).

To take the account of anisotropy of masonry, which is two-phase material with brick units and mortar joints set in a regular interval, structure is discretized such that each brick unit is represented by a set of square elements where mortar joints lie in their corresponding contact edges. Springs that lie within one unit of brick are termed as 'brick springs' and are assigned to structural properties of brick. Springs those accommodate mortar joints are treated as 'joint springs'. They are defined by equivalent properties based on respective portion of unit and mortar thickness. **Figure 1** shows the configuration of brick units, joints and their representation in this study.

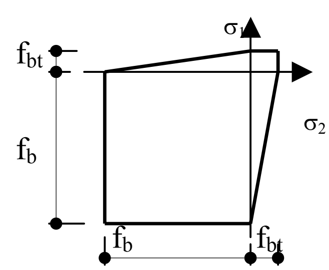

Fig. 2 Brick unit failure criterion

3. MATERIAL MODEL

Both brick springs and joint springs are assumed to have elastic-perfectly plastic stress-strain relationship in normal as well as shear state. A simple failure criterion based on biaxial stress state as shown in **Fig. 2** is used for brick units[4)]. For joint springs, Mohr-Coulomb failure surfaces are used. **Figure 3** illustrates failure surfaces applied to these springs. Vertical tension cut-off model purposed by Lourenco[3)] is adopted to take account of shear action in tensile regime at unit mortar interface. Uniaxial tensile failure of debonding without softening branch is assumed for normal tensile behavior. A Coulomb friction failure envelope is taken for shear sliding failure. In current model, a constant cohesion is used up to first exceed of failure envelope thereafter dropped without residual. Failure modes that come from joint participation of unit and mortar in high compressive stress is considered by modified version of linearized cap model adopted by Sutcliffe[5)] that is derived from original proposal as spherical failure surface by Lourenco[3)] is implemented.

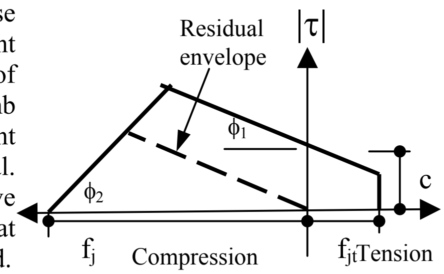

Fig. 3 Joint failure envelope

4. CASE STUDY OF WALL WITH OPENING

Test carried out by Vermeltfoort[6)] on masonry wall with central opening is used to compare the result of the present study with experiment. The wall used to perform the test is shown in **Fig. 4**. It is approximately square with single wyth of brick dimension

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of 204 X 98 X50 mm with 10 mm mortar thickness.

Wall is subjected to vertical constant pressure of 0.3 Mpa from the top. Horizontal displacement *d* is monotonically applied at the top layer that is clamped in steel beam. Material properties derived from micro-test results as reported in reference 3 are shown in **Table 1**. Angle to define the cap mode, ϕ_2, is selected as 40^0 as the application range suggested by Sutcliffie[5] is 20^0-70^0. A reasonable value compressive strength of brick unit (f_b) is assumed.

Table 1. Material property

Material	E (Mpa)	f_b (Mpa)	f_{bt} (Mpa)	c (Mpa)	ϕ_1 (deg)	ϕ_2 (deg)
Brick	1.67×10^4	20.0	2.0	-	-	-
Joint	0.79×10^3	10.5	0.25	0.35	36.5	40.0

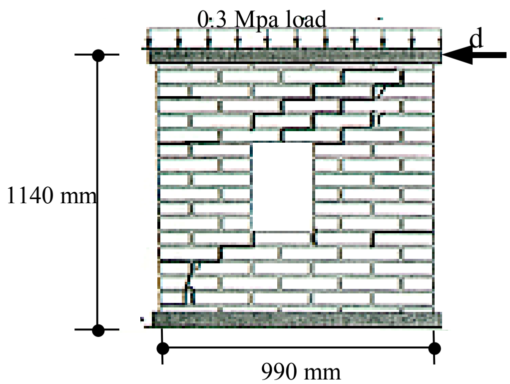

Fig. 4 Experimental crack pattern

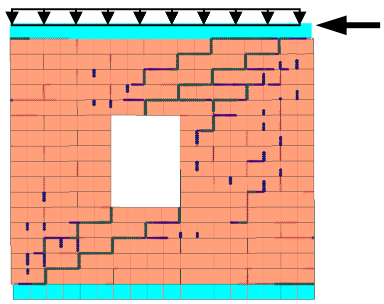

Fig. 5 Crack pattern from numerical analysis

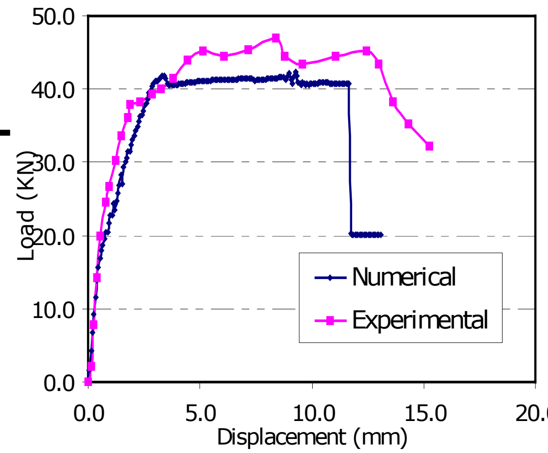

Fig. 6 Load – Displacement diagram

5. RESULTS AND DISCUSSION

Experimental and numerical crack patterns are shown in **Figs. 4** and **5** respectively. Damage concentration in loaded diagonal corners as observed in test is well captured in simulation. Cracks in opposite corners of opening seen in **Fig. 4** are not evident in numerical result. However, break of springs in early stage of loading was observed but cracks were not opened further. This is because mode of global response of wall turned to sliding of upper triangle of wall over stepped cracked surface once the major crack had breakthrough along wall diagonal. All the response, then, was localized in this zone only. The plateau in load–displacement diagram as shown in **Fig. 6** represents this phenomenon.

Comparison of load displacement diagrams obtained from experiment and numerical analysis is made in **Fig. 6**. From the figure, it can be observed that initial pre-peak behavior is well predicted with reasonable estimate of peak load. Flat plateau observed in analysis corresponds to state of shear in residual envelope in **Fig. 3** with perfectly plastic stiffness and constant load carrying capacity. As the current model of interface does not incorporate softening branch for constitutive relation in shear and normal load, post peak degradation could not be captured. Sudden drop in load at 12mm displacement is due to complete separation of some springs in cracked zone leaving no residual forces. Material model that includes strain softening will be incorporated and result will be presented in JSCE conference.

6. SUMMARY

Simulation of masonry wall under monotonic lateral loading is discussed. From the study, it is found that masonry behavior can be well predicted by AEM. Result could be further improved if material model that can define the post peak damage in constitutive relation is implemented.

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