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Numerical analysis of triplet shear test on brickwork masonry

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Abstract. Shear failure is often found for masonry structure when subjected to complex loading. This paper presents the numerical analysis of shear strength test on triplet masonry specimens under different normal compressive stresses. Two different models were produced using a commercially available finite element analysis package ANSYS. The first model is a continuum model with the brick unit modeled as linear elastic material, while the mortar joints are modeled using a Drucker-Prager (DP) material or a concrete material. In the second model, the mortar joints as well as the brick/mortar interfaces were represented by a series of contact elements, and the Mohr-Coulomb failure surface was employed by these contact elements. Comparisons with the experimental results show that both models give satisfactory predictions for the maximum failure load, while the finite element model with interfaces has a better performance in terms of the load displacement response.

Introduction

Unreinforced masonry shear walls are often used as the main structural component of masonry buildings responsible for carrying lateral loading. The shear strength of masonry structures has been of great concerns for design and assessment purposes.

In general, there are two main approaches adopted for masonry modeling: macro-modeling and micro-modeling [1]. The macro-modeling approach does not make a distinction between individual brick units and joints but only treats masonry as a homogeneous anisotropic composite. The micro modeling technique treats each component of masonry material separately with its own specific constitutive law and failure criteria. The micro modeling is often used for the detail analysis of small structures where the stress and strain states are of great interests. On the other hand, macro-modelling is suitable for the global analysis of structure with sufficient size where the interaction between brick and mortar joints is negligible.

Two finite element models were produced for the analysis of a shear strength test on triplet masonry specimens under different normal compressive stress levels. Comparisons have been made on the modeling results between these two models, and they are also compared with the experimental testing that carried out by Wang et al [2].

Continuum model

A continuum model was produced for the triplet shear tests and aimed to predict maximum failure load. As learned from the experimental tests, shear failure always occurred at the brick-mortar interfaces or across the mortar joints [2]. The brick unit is assumed as an elastic isotropic material, while the mortar joints were modeled using two different material models: the Drucker-Prager (DP) model [3] and a concrete model [4]. The finite element model (as shown in Fig. 1) consists of 4400 elements and 5313 nodes. The material properties used for the DP and concrete material are listed in Table 1 and 2 respectively. For the concrete material model, β and β_c are the shear transfer coefficient for open and close cracks, while f_t and f_c are the uniaxial tensile and compressive strength of the mortar joints. T_c is a multiplier for amount of tensile stress relaxation (defaults to 0.6) [5].

The whole analysis was completed in four steps. Firstly, the bottom surface of bottom brick were fixed in all the three directions, and the influence of self-weight were considered by introducing the gravity. The normal compressive stress was applied on the top surface as a pressure load in the second step. Then the right side surface of the top and bottom brick were fixed horizontally, and the movement in Z direction was also constrained. A small horizontal displacement load was divided into small sub steps and gradually applied on the surface of the central brick (see Fig .2).

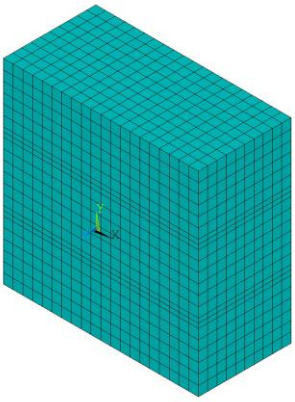

Fig.1 Finite element mesh for triplet shear model

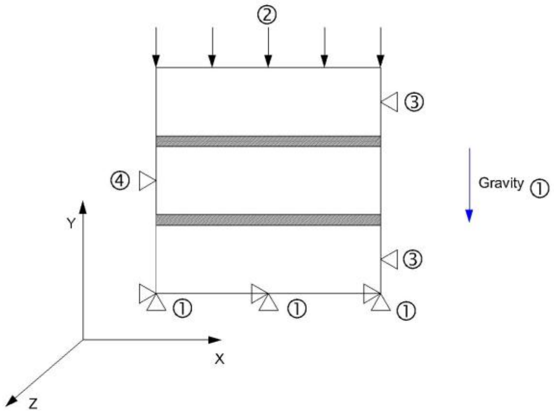

Fig.2 Boundary conditions

Table 1Material properties for continuum model [2,6,9]

	Density kg/m^3	E N/mm^2	Poisson's ratio	Cohesion N/mm^2	Friction angle	Dilatation angle
Brick unit	2200	2.5×10^4	0.15			
Mortar joint	1850	700	0.1	0.12	34 °	0 °

Table 2 Material properties for concrete model [2,7,8]

β	β_c	f_t N/mm^2	f_c N/mm^2	T_c
0.5	0.9	0.4	1.1	0.6

The maximum failure load for the model with DP material was determined when the specimen experienced plastic deformation, which can be seen from the load displacement curves. The specimen under different normal stress showed quite similar behaviour. The failure of the specimen with a concrete material is defined as when majority cracks (represented by the small dots) were found in the mortar joints as shown in Fig. 3.

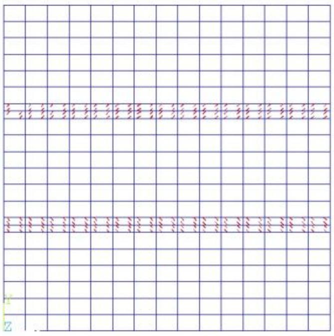

Fig.3 Finite element model shows mortar cracking failure

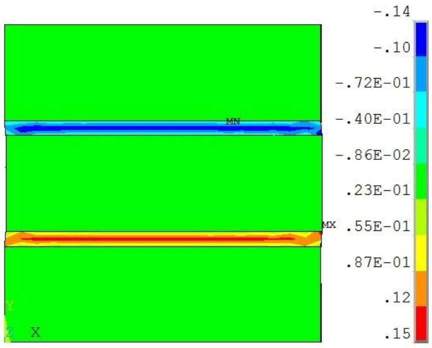

Fig.4 XY plane shear plastic

Table 3 Predicted failure load and comparisons with experimental results

	Experimental [kN]	DP Model [kN]	Concrete Model [kN]
0.2 N/mm^2	8.6	12.4	13.8
0.6 N/mm^2	20.5	25.5	23.7
1 N/mm^2	33.2	36.5	35.4

The contour plot for the shear plastic strain in the XY plane (for the maximum horizontal deformation) is shown in Fig. 4. It is learned that the largest plastic shear occurred at the middle of both mortar joint. The whole mortar experienced relatively larger shear deformation, indicating the interface delamination, and this is consistent with experimental results. As can be seen from Table 3, the predictions of both material models show good agreements with experimental tests under high normal stress levels. They give an overestimated strength when the normal compressive stress is lower. The concrete model gives more accuracy predictions than the DP material model under high stress levels (0.6 N/mm^2, 1.0 N/mm^2), but not for the lower stress level.

Interface model

In this section, it describes the modelling work by introducing interfaces between brick and mortar joints. Unlike the previous models, it mainly focuses on the load displacement relationship rather than the failure load. The simplified micro modelling approach was employed. The mortar joints as well as the brick/mortar interfaces were represented by a series of contact elements. The brick units was expanded to keep the original geometry and assigned with an average property of the masonry assembly. As no cracking was found in the brick, the new 'brick' unit is still assumed as an isotropic elastic material, and the failure is caused by the separations at the interface.

For the contact elements, the basic Coulomb friction model with slight modification was used. Two contacting surfaces can carry shear stresses up to a certain magnitude across their interface before they start sliding relative to each other. The Coulomb friction model defines an equivalent shear stress τ, at which sliding on the surface begins as a fraction of the contact pressure p. The relationship between them can be expressed by Eq. 1:

$$\tau=\mu p + c \qquad (1)$$

Where μ is the friction coefficient and c specifies the cohesion sliding resistance. A maximum contact friction stress is introduced in the friction model. The sliding between two surfaces will occur once the friction stress reaches in this value, regardless of the magnitude of normal contact pressure.

The model had a mesh density with 20, 10 and 6 divisions in the X, Z and Y directions respectively for the 'unit' and consists of 4400 elements. The main material properties used during the analysis for both the unit and contact elements are listed in Table 4.

Table 4 Material properties for interface model [2,5,10]

	Unit		Contact
Density [kg/m^3]	2200	Cohesion c [N/mm^2]	0.09
Elastic Modulus E [N/mm^2]	2500	Friction coeffcient μ	0.6
Poission's Ratio	0.3	Normal stiffness [N/mm^3]	1
		Tangential stiffness [N/mm^3]	0.5

The elastic modulus used for the unit is determined from the compressive strength test on masonry assembly [2]. The value of Poisson’s ratio comes from the experimental tests by Mahmoud [5] on similar materials. The cohesion, friction coefficient properties and tangential stiffness for the contact element were determined according to the initial shear strength under different normal stress levels [2].

There is generally a lack of information on the contact normal stiffness, a reference value used by Claxton et al. [10] on their numerical analysis of retaining walls was adopted here.

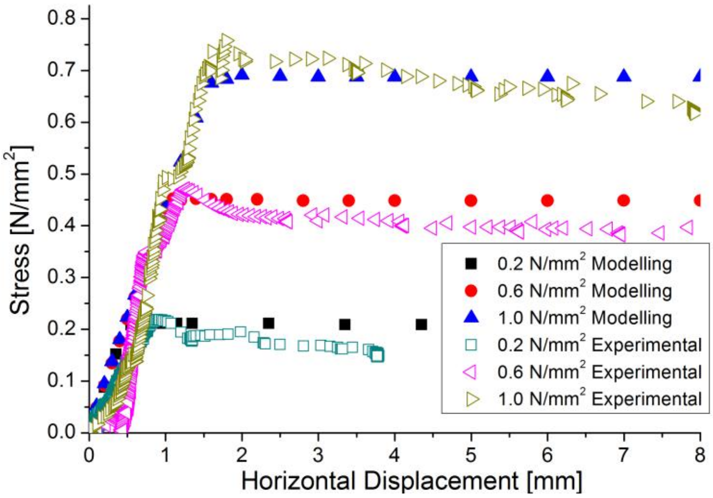

Fig.5 Load displacement relationships for interface model

The modelling work mainly focuses on load displacement response. The same boundary conditions as described in previous section were used here. A 10mm displacement load was applied by dividing into 100 increments, and the reaction force was recorded and plotted in Fig.5.

The maximum loads obtained from finite element analysis are 9.7 kN, 19.7 kN and 30.2 kN respectively for the three normal compressive stress levels. The numerical model with contact elements has good prediction for all the specimens under different stress levels. Similar to the DP model, it gives a slightly higher failure load for the specimen under 0.2 N/mm^2 normal stress. However, for the specimens with 0.6 N/mm^2 and 1.0 N/mm^2 normal stresses, lower values were obtained for the maximum load, and they are 4% and 9% smaller than the experimental results. It is also noticed from the load displacement curves that the corresponding displacement when the maximum load was reached shows good agreement with the experimental tests.

Conclusions

The shear strength of brickwork masonry specimens under different normal compressive stresses was studied by the finite element analysis using two different types of models. Both the continuum and interface model proposed in the paper show great accuracy for the prediction of maximum failure load. There is an increasing trend of the accuracy of both models as the increase of the normal compressive stress. The interface model has a better performance in terms of the load displacement response and the prediction of failure load at a low stress level. The contact elements with Mohr-Coulomb failure surface are suitable for the modeling of shear failure at interface, especially for specimen with relatively high normal compressive stress level.

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