THREE DIMENSIONAL MICRO-MODELING OF MASONRY UNIT USING FINITE ELEMENT METHOD

[1]YASH SHARMA, [2]PR MAITI

[1,2]DoCE,IIT(BHU),Varanasi,India, DoCE,IIT(BHU),Varanasi,India
E-mail: [1]yash.sharma.civ12@iitbhu.ac.in, [2]prm.civ@iitbhu.ac.in

Abstract- Masonry system is an alternate way of constructing low to medium rise building. Masonry structures are popular because of its low cost, thermal and sound insulation, easy availability and good vertical loading resistance. Masonry units are consisting of Mortar and Bricks. In this present study, the strength behavior of masonry components is investigated in the elastic region. A three-dimensional micro-model consisting of discrete elements of brick, closure and mortar are used in the analysis which together formed a 3D masonry wall. Finite element method is used to model the masonry structure. Stress analysis is carried in the masonry single brick wall having discontinuous vertical joints for different vertical load applied at the top of the wall. The stress developed in the lime mortar joint interface elements was found more than in brick element. Homogenization principles of material lead to a smoothing of stresses but in real case the elastic properties of mortar and brick portion are different. Therefore, an adequate safety factor must be adopted to compensate for the underestimation of peak stress values.

Index Terms- FEM, Interface, Micro-Modeling, Masonry Structure

I. INTRODUCTION

Masonry structures are low cost and are widely used for construction in different parts of the world. In past, there has been an interest to study the mechanics of unreinforced masonry structures which has a complex behavior. Mortar joints usually present a lower strength than masonry units, so explaining the existence of plane of weakness along which cracks propagate to failure [1].This makes the modeling of mortar an important requirement for study of failures in masonry. Broadly there are two ways to model masonry micro-modeling and macro-modeling [2]. In the former method the joints and units are described by different elements whereas in the latter the properties of unit and joint are fused together and represented by a continuum material [2].For micro-modeling a number of plasticity-based continuous –interface models were developed to model the tension and shear behavior of masonry –mortar joints [3].

The early attempts for macro-modeling include the approach presented by Pande et al where he suggested an equivalent homogenous orthorhombic elastic material for the brick masonry [4]. The expressions for the elastic properties of the equivalent material were derived in terms of the elastic properties of the brick and mortar together with relative thicknesses. It was called "two-step homogenization". First the units of a single row and the vertical joints were considered and homogenized into a layer. In the second step the horizontal joints between the layers were homogenized with the layers to obtain a continuum material. It had the following shortcomings.

(i) It caused a reduction in the horizontal stiffness as the effect of texture (running bond, stack bond, Flemish bond) is not considered. The effect of offset between the vertical joints of adjacent rows on strength is not considered and lead to error in case of non-linear analysis.
(ii) Different homogenization materials are obtained if the steps of the process are reversed (if horizontal joints and masonry units are homogenized first).

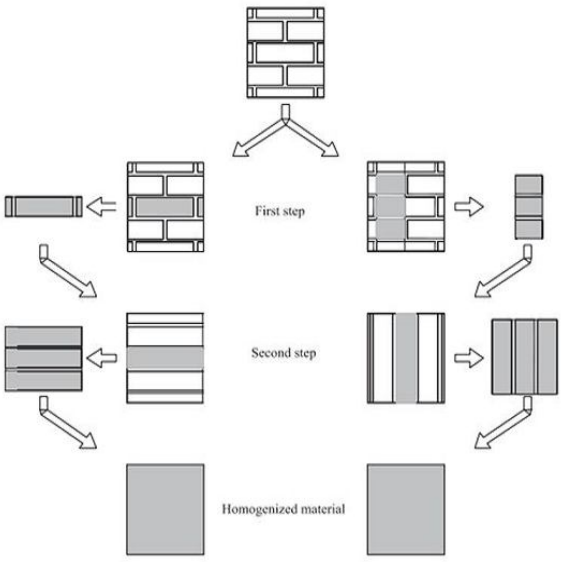


Fig1. Two-step homogenization proposed by Pande et al (1989): (a) horizontal homogenization first; (b) vertical homogenization first

De Felicie(1995) and Secci and Sab (2002) proposed an approach where joints were considered as interface[5][3]. It was based on the criteria that masonry units are stiffer than mortar and the thickness of mortar joints are much less as compared to size of masonry. It led to the development of the Homogenized masonry constitutive function by means of the introduction of several parameters that measure smallness:

- ε (Scale parameter) representing the ratio between the size of the cell and the overall panel.
- ξ which is the ratio between the young's modulus of the mortar, E_m, and the young's modulus of the unit, E_u
- φ representing the ratio between the thickness of the joint , e, and the size of the characteristic module a. (φ =e/a)

Where $\xi \to 0$ correspond to the condition when the mortar is infinitely deformable with unit, and $\varphi \to 0$ represents the condition where the joint become an interface.

De Felicie proposed that by assuming the bricks to be stiff analytical formulas of homogenized elastic constants could be used for masonry analysis [5]. The constants would depend only on the geometry of the elemental cells and the geometry of mechanical joint.

In the multi-parameter homogenization study for the two dimensional and three dimensional in plane case, Cecci and Sab removed the stiff masonry assumption [3]. They developed a quasi-analytical formula. A symbolic FE method was adopted and a coarse triangular element was used to discretize the elementary cell. The problems faced by this approach were:

- The reduction of joints to interface led reduction in accuracy of the method for cases where the mortar joint is thick.
- The method could not have been extended for non-linear analysis which would have led to non-negligible errors with respect to the FE approach.
- By considering the units to be elastic the sole use of analytical method was no longer possible and required use of the FE procedures.

The modeling of brick masonry by Lee et al. (1995) incorporated the inelastic stresses of the units and joints [6]. The two step-homogenization approach was utilized for getting the equivalent elastic parameters of the system. The tensile cracking of masonry was based on the elastic-brittle behaviors and was extended into the nonlinear region. Cracking was based on the strength of material at the calculated stresses or strains. This model came to be known as the crack model.

Lorenco used both micro-modeling and macro modeling for analyzing masonry wall [2]. An interface element is used to for the joint. Due to the zero thickness of the interface element the brick element has to be expanded equal to depth of mortar joint in both directions. An elastic relationship was used to represent the behavior of brick. $\sigma = D^e \varepsilon$

Where $\sigma = \{\sigma, \tau\}^T$, D^e ={K_n,K_s} and $\varepsilon = \{\Delta\upsilon_n, \Delta\upsilon_s\}^T$,where n and s denote the normal and shear components, respectively.

The normal and shear stiffness of the expanded brick element are given by:

$$K_n = \frac{E_u.E_m}{h_m(E_u - E_m)} \quad , \; K_s = \frac{G_u.G_m}{h_m(G_u - G_m)}$$

Where E_u and E_m are the young's modules, G_u and G_m are the shear moduli, respectively, for unit and mortar and m h is the actual thickness of the joint.

Advances in homogenization techniques have led to an increased understanding of homogenization system. The variation of equivalent homogenized elastic property with changing thickness and moduli of mortar keeping the parameters of brick units was established (Nitin Kumar 2016)[7].The need for micro-modeling remains to take into account for the geometrical arrangement of units and their internal geometry shown by (G.Mohamad et Al 2016)[8].

II. FEM MODELING

The behavior of a structure in the elastic range is of great interest because of the requirement of the serviceability load condition. In this FEM analysis of masonry the two phases Mortar and Brick are separately discretized and a perfect interface bonding hypothesis is assumed. This type of analysis came to be known as detailed micro-modeling [2]. The codes for the Finite Element program have been written using MATLAB which is powerful software for solving matrix problems. The material properties of brick and mortar necessary to define the model are derived using micro-experiments. These properties are given in table1. The mortar was assumed to be having a mix proportion of 1:1:5 (cement: sand: lime) [9].

Table.1 Elastic properties for bricks and joints [9]

Brick		Joint	
E (N/mm^2)	ν	E (N/mm^2)	ν
37000	0.1	20000	0.25

A linear brick (solid) element is chosen for both the brick and mortar. The element is appropriate for representation of elastic solid phases in 3D space. Also the element's geometry and ease of handling in codes

make it a suitable choice for the program. The modulus of elasticity and poisson's ratio are the material parameters for this element. An advantage of using MATLAB or any other programming language is that the user can exhibit greater control over the mesh, element and element definition as compared to FE software. Once the dimensions of the element are decided the finite element Eq.1 is used to get its stiffness matrix.

$$[k] = \iiint_v [B]'[C][B]dxdydz$$

Eq.1

Where [k] is element stiffness matrix, [B] is strain-displacement matrix; [C] is constitutive matrix. MATLAB tools are very useful for assembling of individual stiffness matrices to form the global stiffness matrix based on the geometry.

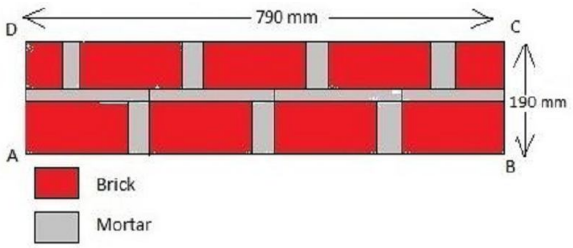


Fig. 2 Model of Lime Mortar brick Masonry

III. MICRO MODEL OF BRICK UNITS

A simple masonry consisting of two courses is considered for analysis. The thickness of bed joints and head joints is taken as 10mm.The dimensions of the brick are 190mm X 90mm X 90mm (length X width X depth). The two closures at the top are required for overlapping of masonry and make the head joints (vertical joints) discontinuous. The front view of masonry is as in fig2. In 3D each part (joint, brick, closure) would have a depth of 90mm into the plane of paper. The bottom face AB and sides DA and CB are restrained against any movement and analysis is done with increasing uniformly distributed load on the face DC.

Fig.3 gives the variation of σ_{yy} with increasing uniformly distributed load on face DC for Head Joint, Brick Element and Closure. The elements were chosen were those which experience maximum stress in their category. All the elements show a linear variation of stress with uniformly distributed load which is typical of an elastic system. The head joint experiences considerably higher levels of stresses as compared to other elements. Since the compressive strength of mortar is also generally less than brick, so it is a critical component for failure in compression under such kind of loading. The brick and closure elements experience lesser compression stresses which is due to the smoothing out of large uneven stresses over their larger size.

Fig. 4 gives the variation of various stresses at the center of elements on the top course with their distance from the left edge. The stresses are very much symmetric about X= 400m with an exception of σ_{yy} and σ_{xy} which deviate slightly from symmetry. The vertical axial stress σ_{yy} has an oscillating nature owing to the presence of alternate vertical joints and brick units. All the other stresses have a smooth and symmetric profile along the X axis of the structure.

It can be seen from fig. 5 that tensile axial stress has developed both in brick and mortar. The peak tensile stress for the brick element is much less as compared to joint element.

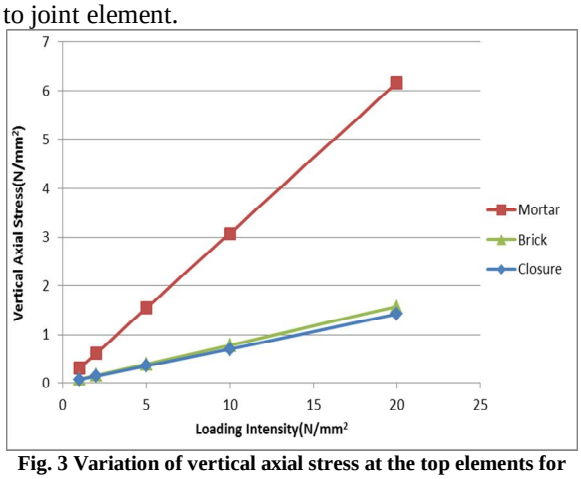


Fig. 3 Variation of vertical axial stress at the top elements for different loading

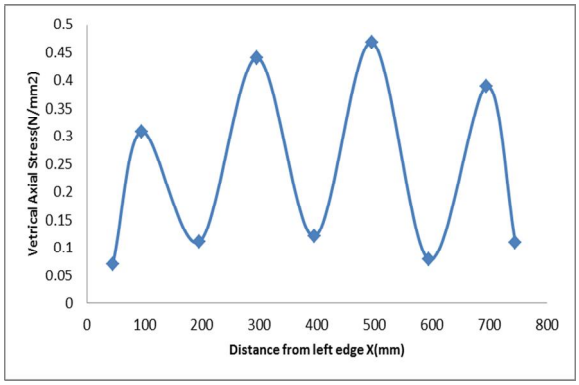


Fig. 4 Variation of Vertical Axial Stress with distance from edge

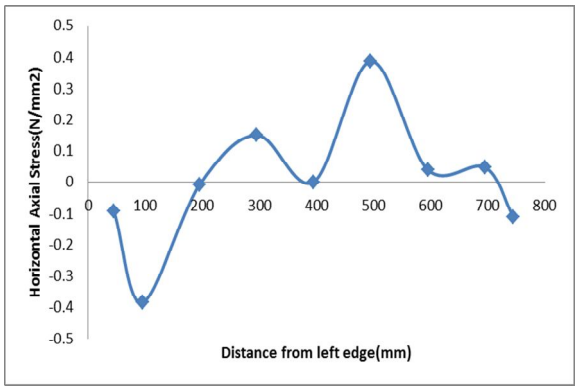


Fig. 5 Variation of Horizontal Axial Stress with. distance from edge

CONCLUSION

The use of MATLAB for finite element modeling of a composite such as masonry offer the advantage that the meshing can be done as the user wants.
It allows a better choice of elements at desired locations. The greater complexity comes at a higher computing and processing loads. As the earlier literatures suggest the variation of stresses horizontally has uneven nature and is smoothened out in case if large equivalent area is considered.

The Homogenization of masonry in elastic range may hold good for observing the response of structure with different load conditions in the elastic range but is a poor choice for observing the change of stresses across the components of masonry.

The stress peaks are smoothened out leading to an underestimation of maximum stress developed. The study also helped to establish the advantage of using detailed micro-modeling.

REFERENCES

[1]. Mohammed, M.S., 2010. Finite Element Analysis of Unreinforced Masonry Walls. A1-Rafidain Engineering, 18(4), pp.55-68.

[2]. Lourenco, P.B. and Rots, J.G., 1994. Analysis of masonry structures with interface elements. Rep. No. 03-21-22-0, 1.

[3]. Cecchi, A. and Sab, K., 2002.A multi-parameter homogenization study for modeling elastic masonry. European Journal of Mechanics-A/Solids, 21(2), pp.249-268.

[4]. Pande, G.N., Liang, J.X. and Middleton, J., 1989. Equivalent elastic moduli for brick masonry. Computers and Geotechnics, 8(3), pp.243-265.

[5]. de Felice, G. 1995, Methods of homogenization for regular systems of bodies.In Proceedings of the XII AIMETA Congress.Naples, Italy, 3-6 October 1995.University of Naples, Naples, Italy. Pp 453-479. [In Italian]

[6]. Lee, J.S., Pande, G.N., Middleton, J. and Kralj, B., 1996. Numerical modeling of brick masonry panels subject to lateral loadings.Computers & Structures, 61(4), pp.735-745.

[7]. Kumar, Nitin, et al. "Homogenization of Periodic Masonry using Self-Consistent Scheme and Finite Element Method." International Journal for Computational Methods in Engineering Science and Mechanics just-accepted (2016): 1-37.

[8]. Mohamad, Gihad, et al. "Numerical Analysis of the Influence of Geometry of Ceramic Units (Blocks) on Structural Walls." Journal of Civil Engineering and Architecture 10 (2016) 44-52 doi: 10.17265/1934-7359/2016.01.005

[9]. Bakhteri, J., Makhtar, A.M. and Sambasivam, S., 2012. Finite element modeling of structural clay brick masonry subjected to axial compression. Jurnal Teknologi, 41(1), pp.57-68.

★★★