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Numerical Evaluation of the Elastic Properties of Brick-Mortar Prisms: The Effect of Varying Thickness of Mortar Joint

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ABSTRACT

This paper is a presentation of the numerical evaluation of stress in a brick-mortar prisms considering it's various mortar joint thickness which is a basic physical property of brickwork. The brick-mortar prism here serves as a meaningful substitute for a brick-wall structure. A powerful analytical tool in the finite element method would be used for the analysis. An overview of the steps to determine the element stiffness matrix for a plane stress problem is also presented. In this work but a homogenous and a heterogeneous (composite) model is use for our investigation. The results obtained in this work shows a gradual decrease in compressive stress and strain as the mortar joint thickness increases and this result compares favorably with results from experimental and analytical works, but the basic observation in this work is that there is no significant difference in the values obtained through the use of the two kinds of structural model. Hence, the assumption of a homogenized material in numerical analysis of a composite material like the brick work structure is very appropriate

Keywords: *Brick, mortar joint, compressive strength.*

1. INTRODUCTION

Masonry is a composite material made up of bricks as its building unit and mortar as the binding unit. The compressive strength of a masonry unit is important as higher strength value provides better durability under severe weathering and loading condition. Practical and aesthetic consideration have resulted in the thickness of mortar joints standardized of 10mm. However, workmanship and construction tolerances do sometimes lead to noticeable variations in joint thickness. The effect of mortar joint thickness on the compressive strength of grouted hollow brick prisms have been studied by [1], where the effect is reduced due to the continuity of the grout. Also the effect of mortar joint thickness express in terms of the ratio of unit height to joint thickness have been studied [2]. From the test on clay brick prisms it is apparent that lower strength corresponds to smaller ratios of brick height to mortar thickness and the result in line with the expected failure mechanisms [3,4,5], hence the unit height to mortar joint thickness ratio affects the compressive strength of the assemblage.

Only a few experimental studies worldwide have proposed analytical relationships to plot the stress-strain distribution in test prisms. However, these relationships are not easy to use because of the requirement of large amount of input data. Limited experimental research has been carried out to determine the stress-strain curves of masonry [6,7]. In this present study, extensive experimental testing of brick masonry prisms in performed considering the varying thickness of the mortar region. This experimental study will be validated using suitable numerical method.

The compression testing was performed according to ASTM specifications [8] also similar to that given in [9]. Stress-strain values will be obtained from experimental test on brick-mortar prisms. A powerful numerical method using the finite element approach would be use to model this typical prisms. The basic modelling strategy will be the micro-modelling technique which involves constant strain triangular elements utilizing the displacement approach. The mechanical property of the brick-mortar composite material would also be replaced with an equivalent mechanical property, considering it to be an isotropic material. The values of stress and strain obtain would be compared with values obtained from the analysis on the real composite material.

2. FINITE ELEMENT ANALYSIS

This investigation shall be carried out using the constant strain three node triangular elements. Hence the brick and mortar couplet continuum shall be divided into constant strain triangular elements which shall include elements in the mortar joints. By the use of this method the distribution of stress in the brick-mortar continuum can be obtained easily, and with the result obtained, areas of critical stress states will be obvious.

The basic principle of this method is that the continuum is divided into a finite number of elements interconnected at node points situated on their boundaries. The structure thus idealized can be analysed by any of the standard method of structural analysis. The development and application of the finite element method are well published.

For the purpose of this brick-mortar analysis, the formulation used will be the displacement approach. In using this method the nodal displacements are the basic unknown, while the stresses and strains are assumed constant for each element.

The basic concept of the finite element method of analysis is that the structure can be considered to be an assemblage of individual structural elements. Hence the idea of the finite element method is the use of two and there dimensional elements for the idealization of a continuum, where accuracy of the solution increases with the number of elements considered.

The element stiffness matrix [K^e] would be a 6 x 6 matrix for this plane elasticity triangle and the force vector [F^e] represented as follows

$$\{F^e\} = [K^e]\{\delta^e\} \tag{1}$$

where [K^e] the element stiffness matrix and $\{\delta^o\}$ is the displacement vector for a typical contain strain element.

A suitable displacement function is chosen to define the displacement at any point in the element. This is simply represented by two linear polynomials functions containing six unknown coefficients $(\alpha_1, \alpha_2 \cdots \alpha_6)$ representing the six degrees of freedom in the case of a plane triangular element.

$$\left.\begin{aligned} u &= \alpha_1 + \alpha_2 x + \alpha_3 y \\ v &= \alpha_4 + \alpha_5 x + \alpha_6 y \end{aligned}\right\} \tag{2}$$

For plane elasticity problems the [D] matrix which represent the contribution of modulus of elasticity E and poisons ratio v can be expressed as

$$[D] = \begin{bmatrix} d_{11} & d_{12} & 0 \\ d_{21} & d_{22} & 0 \\ 0 & 0 & d_{33} \end{bmatrix}$$

where for plane stress problem

$$d_{11} = d_{22} = E/(1-v^2)$$

$$d_{12} = d_{21} = vE/(1-v^2)$$

$$d_{33} = d_{22} = E/2(1+v)$$

Though rigorous calculation the statically equivalent nodal forces {F^e} related to the nodal displacements $\{\delta^e\}$ and hence the element stiffness matrix [K^e] can be obtained as

$$\{F^e\} = \left[\int [B]^T[D][B]d(vol)\right]\{\delta^e\} \tag{3}$$

where matrices [B] and [D] contain only constant terms.

Hence, suitable computer programme code will aid this analysis, in order to take care of the rigorous calculation that would arise as a result of several elements.

3. STRUCTURAL MODEL

The analytical brick-mortar model consists of the full size brick and mortar prisms. The prisms consists of four brick panels of average dimensions 215mm x 103mm x 70mm, fabricated from high quality perforated bricks of standard dimensions.

These would be two sets of models. The first model would consist of a homogenized material while the second would represent an idea composite material. In both models the basic idea is to investigate compressive stress at varying thickness of the mortar joint. The mortar joint thickness would varying as 7mm, 10mm, 12.5mm, 15mm and 17.5mm. Hence by considering a three node triangular elements, each model would be divided into a finite number of triangular elements. The idealization of the models would be such that the elements within the mortar joints are made smaller so as to take care of the critical stress nature of the brick-mortar interface.

The loading condition of the structural model in order to carry out the finite element analysis shall consist of a unit of uniformly distributed load which represents a vertical compressive force figure 1. The support condition for the structural model would consist of a pin and roller supports at separate ends to ensure a determinate structure.

4. ANALYTICAL MODEL

In this research, two types of models (homogenized and composite) will be use to analysis the stress state of a brick work structure considering varying thickness of the mortar joint region which is a physical property.

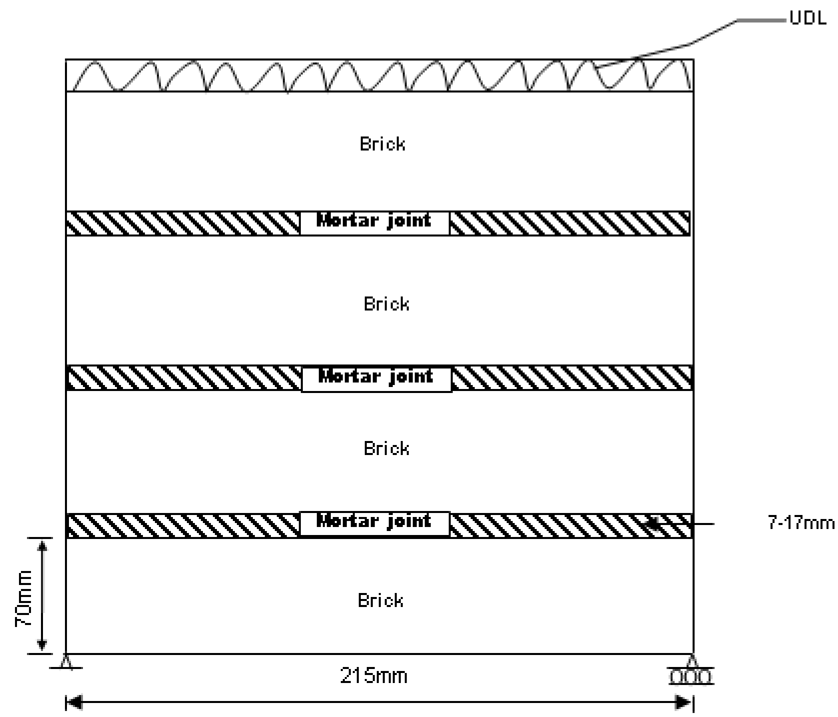

Figure 2: Typical representation of a brick-mortar prisms under uniform loading

4.1 Homogenized Model

In this model, brickwork is assumed to be made of a single kind of material, that is a real isotropic material. Hence there is uniform mechanical property throughout the brickwork. This kind of model is assumed by many researchers in this area. Equivalent mechanical properties can be obtained through experimental test on sets of brick-mortar prisms which can be very expensive to carry out. Values for mechanical properties, that is the modulus of elasticity or poisons ratio have been obtained by different researchers, but for the purpose of this work we shall assume a modulus of elasticity value of 6.83 x 10^3N/mm^2 and a Poisson's ratio of 0.25 for brickwork hence using the material property and a visual basic computer programme code, the finite element analysis of the model is carried out varying the thickness of the mortar joints. From the result maximum compressive stress and strain has been obtained as shown in Table 1.

Table 1: Finite element analysis results for the homogenized model

Mortar joint thickness (mm)	Maximum compressive stress (N/mm^2)	Maximum compressive strain
7mm	7.01	0.00348
10mm	6.90	0.00390
12.5mm	6.73	0.00381
15mm	6.51	0.00369
17.5mm	6.20	0.00398

4.2 Composite Model

A composite material is considered by assuming the real nature of brickwork. Hence the mechanical properties of the two different materials that make up brickwork, namely brick and mortar is used for the analysis. The mechanical properties with reference to previous work [10] can be taken as follows:

Modulus of elasticity of clay brick = 8.83 x 10^3N/mm^2

Modulus of elasticity of mortar 3.45 x 10^3N/mm^2

Poisons ratio for brick = 0.10

Poisons ratio for mortar = 0.18

**Note that the water cement ratio for mortar joint varies with the actual water-cement ratio in the mix proportion, due to absorption by brick and may influence the mechanical property of the mortar region.*

The discretization of the model is done in such a using that a separate layer made of smaller size elements are represented in the mortar region.

Utilizing the material properties, the two dimensional finite element analysis was carried, using the same visual basic code and the maximum value of vertical compressive stresses and strains is as shown in table 2.

Table 2: Finite element analysis results for the composite model

Mortar joint thickness (mm)	Maximum compressive stress (N/mm^2)	Maximum compressive strain
7mm	6.80	0.00333
10mm	6.72	0.00360
12.5mm	6.53	0.00373
15mm	6.38	0.00385
17.5mm	6.03	0.00393

4.3 Experimental Data

The result of experimental work carried out at the Rivers State University of Science and Technology, Port Harcourt, Rivers State, Nigeria is tabulated in Table 3.

Table 3: Experimental values obtained by author

Mortar joint thickness (mm)	Maximum compressive stress (N/mm^2)	Maximum compressive strain
7mm	9.72	0.00537
10mm	9.38	0.00526
12.5mm	8.95	0.00514
15mm	8.79	0.00494
17.5mm	8.60	0.00473

5. DISCUSSION OF RESULTS

A study of the results from finite element analysis of the both models considered in this work shows that higher values of compressive stress are obtained using the homogenized model and as a result tends to be closer to the experimental values, it should be observed that the finite element results in this work are as a result of a fixed number of constant strain triangular element and it can be deduced that with increase in the number of finite elements, the results will tend closer to the experimental value.

Again the mortar joint having lower value of elastic property than the brick units in a composite model will result to a decrease in the maximum compressive stress. Hence the usual consideration of a homogenized model by researchers in this field, even if the reason is to simplify analysis can still be recommended. Hence results from a homogenized model can be factored to obtain values consistent with modeling an idea nature of brickwork.

The compressive stress and strain curves plotted from values obtained from the finite element analysis of the two models for different mortar thickness, shown in figures 2 and 3 shows that the values of compressive stress generally decreases with increase in the thickness of the mortar joint which is a physical property. The result in this work favours the recommendation of the BS 5628 of an average thickness of 10mm for the mortar joint region.

The finite element results also compared favourably with experiment works by [10,11]. In the final analysis, a comparison of the numerical values are lower than the values gotten from experiment test on sets of brick-mortar prisons. The variation in values can easily with attributed to the boundary and support condition assumed in the structural model. An increase in the number of finite constant strain triangular elements may be recommended to obtain more precise results.

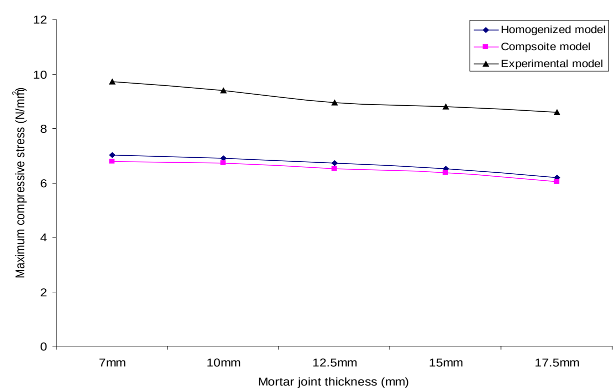

Figure 2: Graph of maximum compressive strength of brick-mortar prism against varying mortar joint thickness

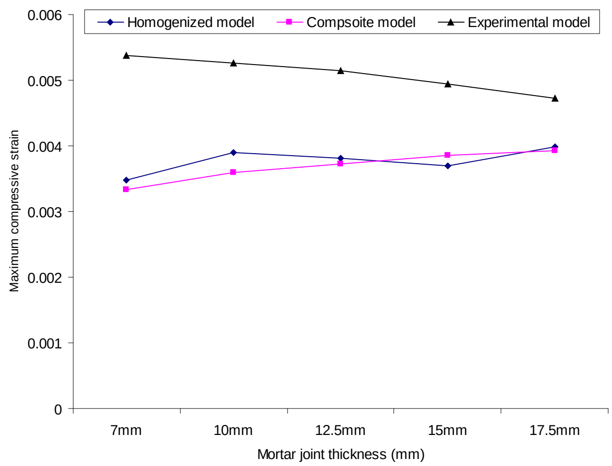

Figure 3: Graph of maximum compressive strain of brick-mortar prism against varying mortar joint thickness

6. CONCLUSION

Numerical and experimental analysis shows that there is no significant difference in the value obtained through the two structural models investigated. Hence a homogenized structural model is very appropriate for simplified analysis. Study of the stress-strain curves also shows decrease in strength of brickwork for increase in the thickness of mortar joint region.

The comparison of the results from this present study with that of the experimental investigation carried out by the author showed that there is significant difference in many cases; hence an appropriate factor of safety should be applied to results from finite element analysis for design purposes.

REFERENCES

[1] R. Brown and A. Whitlock, (1982) "Compressive Strength of Grouted Hollow Brick Prisms, Masonry: Materials, Properties and Performance," J.G. Borchelt, Ed., ASTM STP 728, ASTM, Philadelphia, PA.

[2] A. W. Hendry, (1981) Structural Brickwork, Macmillan, London.

[3] H. K. Hilsdorf, (1969) Investigation into the Failure Mechanism of Brick Masonry under Axial Compression, in Designing, Engineering and Construction with Masonry Products, F. B. Johnson, Ed., Gulf Publishing, Houston, TX, pp. 34-41.

[4] A.A. Hamid and R. G. Drysdale, (1979), Suggested Failure Criteria for Grouted Concrete Masonry Under Axial Compression, *ACI Journal*, Vol. 76, No. 10, pp. 1047-1062.

[5] A. Hamid and A. Chukwunenye, (1986), The Compression Behaviour of Concrete Masonry Prisms," *Journal of the Structural Division, Proceedings of ASCE*, vol. 112, No. 3, pp.605-614.

[6] Sarangapani, G., Venkatarama Reddy, B. V. and Jagadish. K. S., (2002), Structural characteristics of bricks, mortar and masonry. J. Struct. Eng. (India), 29, 101-107.

[7] Naraine, K. and Sinha, S. N., (1989), Behaviour of brick masonry under cyclic compressive loading. *J. Consir. Eng. Manage*, 115, 1432-1445.

[8] ASTM C 1314-00a, (2001), Standard teat method for compressive strength of masonry prisms. *In Masonry Test Methods and Specifications for the Building Industry, American Society for Testing and Materials(ASTM*). Pennsylvania., 4th edn.

[9] IS: 1905—1987, (1998), Indian standard code of practice for structural use of unreinforeed masonry. In Bureau of Indian Standards, New Delhi, 3rd revision, 1987.

[10] Nwofor, T.C. (2012), Experimental determination of mechanical properties of brick-mortar masonry. *Canadian Journal on Environmental Construction and Civil Engineering*, vol. 3, No. 3, pp 127-145

[11] Bakhteri, J. and S. Sambasivam (2003), Mechanical Behaviour of Structural Brick Masonry, An Experimental Evaluation. *Proceeding of 5th Asia-pacific Structural Engineering and Construction Conference, Malaysia*. 305-317.