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STUDIES IN COMPOSITE ACTION IN WALL-BEAM STRUCTURES : AN ELASTIC APPROACH

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ABSTRACT : This paper presents linear elastic finite element analysis of composite action between masonry wall made from burnt clay solid bricks and RCC supporting beam. Isoparametric four noded rectangular element with two degrees of freedom at each node was used in this analysis. From the analysis it has been found that due to arch action, major portion of the distributed load applied at the top of the wall concentrates on a small portion of the beam near the supports. The stresses in the wall calculated by existing formulae have been found to agree favourably with the present analysis, whereas the bending moment in the supporting beam showed a marked difference.

KEY WORDS: Masonry, RCC Beam, Composite, Arch-Action, Homogeneous, Non-homogeneous, Stress, Concentration.

INTRODUCTION

Masonry wall carrying load on the top and resting on a beam spanning over an opening serves not only as a load transferring media but also acts as a composite part of the supporting beam. The composite action of the wall with the supporting beam produces arching action. The compression of the arch is mostly contained in the masonry wall, while the supporting beam being acted upon mostly by tension. Due to this arching action a major portion of the superimposed load concentrates towards the support providing a great relief of load on the beam at the middle of the span. This results a considerable reduction of bending moment in the supporting beam. Thus the consumption of concrete and reinforcement for such structural element can be reduced if the composite action between the masonry wall and the supporting beam is considered.

Limited number of experimental and analytical works have been published so far by different authors. Some of these investigations (Wood, 1952; Rosenhaupt, 1962, 1964; Coull, 1966; Male and Arbon, 1969 and Saw, 1975) played a key role towards the understanding of the problem and thereby implementing the conception of the composite

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action in the design of wall-beam structures. However, existing design rules for wall-beam structures have two main limitations. One, the types of constituent materials with the possibility of inherent variation of material properties. The other one is the lack of proper knowledge of interaction between wall and supporting element and also between the brick unit and mortar. A project therefore, has been undertaken in the Department of Civil Engineering, BUET, which involved both experimental and theoretical works to study the composite behaviour of wall-beam structures. This paper presents some of the important observations from this study.

FINITE ELEMENT MODEL

A plane stress, four noded isoparametric rectangular element with two degrees of freedom per node and linear dsiplacement function was chosen as the basic element for this study. Initially, the wall was considered as a homogeneous continuum when coarse mesh was used in element discretization. Finally, non-homogeneity of the masonry and concrete was incorporated in the model by discretising the bricks, mortar joints, steel reinforcement and the concrete separately along with their individual material properties. In this case fine mesh was used to discretize the panel with finer meshes near the support where the stress gradient is very high. The model facilitates automatic generation of global co-ordinates of the nodes and element connectivity from the simple data input. Subroutines are provided both for Gausian integration at the sampling points for the computation of element stiffness and also for direct stiffness calculation of the element. The model uses frontal technique for the solution of stiffness equations. Finally, the stress are calculated from the displacements obtained at sampling/nodal points. The average of these stresses are assigned to the centre of the elements. Provision is also provided to calculate the principal stresses of the elements from the above stresses.

APPLICATION OF THE MODEL TO WALL-BEAM INTERACTION

Before going to apply the finite element model for the analysis of wall-beam structures the accuracy of the model needs to be verified. For this purpose,the wall-beam tested by Rosenhaupt, 1962 and investigated by different authors was analysed in this study to compare the findings with previous investigators. Experiments carried out by Wood (1952) Rosenhaupt (1962) and Burhouse (1969), on Wall-beam structure are widely known. Rosenhaupt (1962) in his experimental program furnished the detailed material properties which are suitable to incorporate in the finite element model (see Fig. 1). It shows physical properties of a typical wall-beam structure made of light weight concrete block on reinforced concrete beam. This beam was later analysed by other investigators (variational method of Coull, 1966; finite difference method of Rosenhaupt, 1964; finite element analyses of Male and Arbon, 1969 and Saw (1975) to compare with experimental results of Rosenhaupt (1962). The strains obtained by the present finite element analysis on the same wall-beam are also compared with those investigators (see Fig. 2, Fig. 3 and Fig. 4).

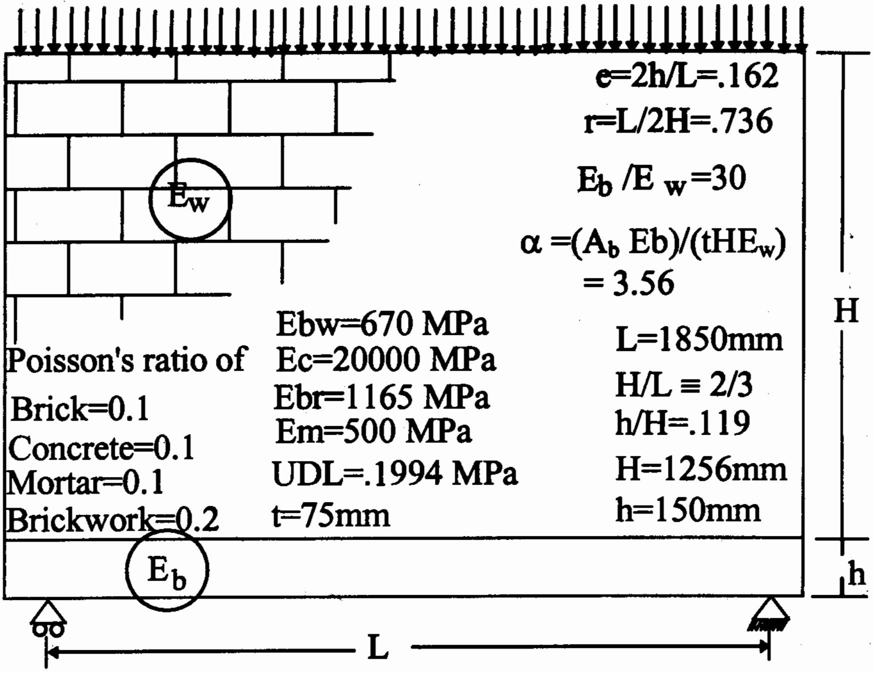


Fig 1. Physical Properties of Wall-beam Tested by Rosenhaupt (1962)

COMPARISON WITH EXPERIMENTAL RESULTS

As mentioned above the wall-beam structure tested by Rosenhaupt (1962) (see Fig. 1) has been taken for the comparison of results of the present finite element analysis. The strain recorded by him was at a level of load such that the wall and the beam remain in the elastic range. These strains are compared with those predicted by the present analysis and Male and Arbon (1969) (see Fig. 2 and Fig. 3). Comparison shows that the analytical horizontal strains at mid vertical section agree quite satisfactorily with those of the experimental values. In case of vertical strain and particularly at sections close to the support the analytical results considering the homogeneity of the masonry does not agree reasonably with experimental values. This may be due to fact that, the panel sections close to the support experience high stress gradient. And for this region the selection of coarse mesh considering homogeneity of brickwork may be inappropriate. But the strains as obtained from the present finite element analysis considering non-homogeneity of brickwork are found to agree favourably with those of the experimental results of Rosenhaupt (1962) (see Fig. 2 and Fig.3)

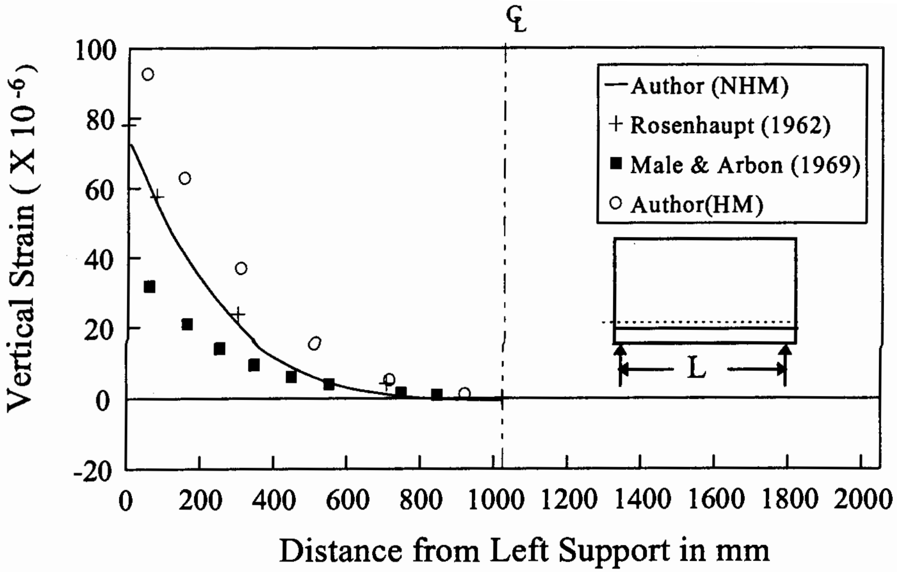


Fig 2. Comparison of Computed Vertical Strains with Experimental Values of Rosenhaupt (1962)

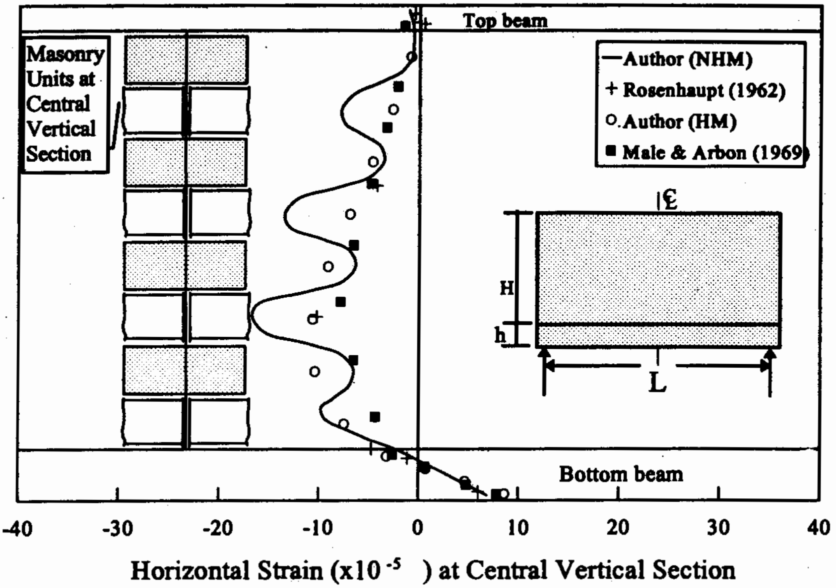


Fig 3. Comparison of Computed Horizontal Strains with Experimental Values of Rosenhaupt (1962)

COMPARISON WITH ANALYTICAL RESULTS

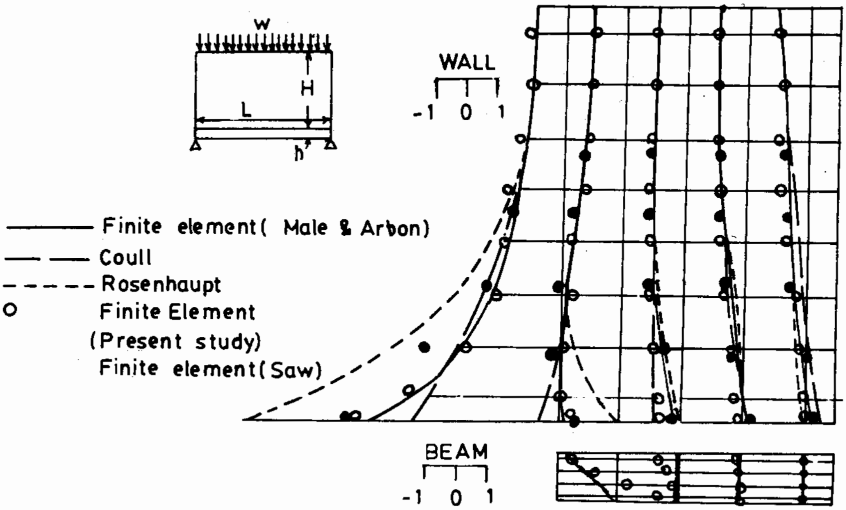
Most of the previous authors considered brickwork in wall-beam structure as homogeneous material. In this section (the result of the analysis considering brickwork as a homogeneous material) was *compared with* those of previous investigators (Male and Arbon, 1969; Saw, 1974, 1975). The element discretization adopted in the present study and by other authors are shown in Fig. A l of Appendix I.

The concentration of vertical stress is given by σ_y / w, where w is average vertical stress applied on the top of the wall and σ_y is the vertical stress developed at any level due to composite action.The comparison of concentration of vertical stress in the wall, obtained by other authors (Rosenhaupt, 1964; Coull, 1966; Male and Arbon, 1969 and Saw, 1975) and the present analysis can be seen from Fig. 4(a). The agreement is reasonable except the ends of the beam in case of Rosenhaupt, 1964. He assumed that the vertical forces at wall-beam interface are concentrated near the support.

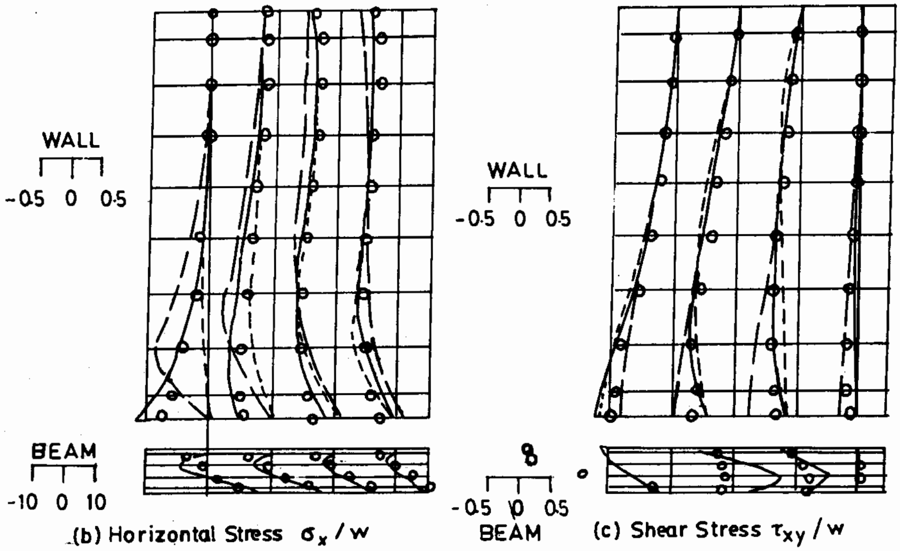
The concentration of horizontal stress is given by, σ_x / w where, σ_x is the horizontal stress developed at any level due to composite action. Fig. 4(b) shows the distribution of concentration of horizontal stress in the panel and indicates reasonable agreement between the present finite element analysis and that of Male and Arbon,(1969). While the agreement between the present finite element analysis and those of Coull (1966) and Rosenhaupt (1964) is not reasonable. This fact however seems to posses doubt to accept the assumption made by Coull (1966) that the stresses can be expressed as a power series with coefficients being function of height only. Limitation due to Rosenhaupt's assumption mentioned before is also a cause of deviation of horizontal stress. The stress distribution in the beam as shown in Fig. 4(b) indicates that the supporting beam cannot always be assumed to act as a tension tie as it is mentioned by Rosenhaupt (1964). It is also clear from the stress distribution along the length of the beam that the maximum stress in the beam does not occur at the middle of the span but close to the support.

The concentration of shear stress is given by τ_{xy} /w where, τ_{xy} is the shear stress developed at any level due to composite action. From Fig. 4(c) it can be seen that the distribution of shear stress concentration in the wall agrees favourably with the results of previous investigators (Rosenhaupt, 1964; Coull, 1966; Male and Arbon, 1969 and Saw, 1975). This figure also indicates that the shear stress at wall-beam interface concentrates near the end. The cause of variation of horizontal stress and shear stress in the supporting beam with those of Male and Arbon (1969), is possibly due to triangular finite element discretization adopted in his study.

The agreement between the results of the present analysis and the analyses made by other authors (Stafford Smith and Riddignton, 1977 and Davies and Ahmed,1978) regarding maximum vertical stress concentration in the wall for a wide range of wall height and beam depth can be found elsewhere (Hossain et al., 1993).



(a) Vertical Stress σ_v/w



(b) Horizontal Stress σ_x / w

(c) Shear Stress τ_{xy} / w

Fig 4. Wall beam Interaction

PRINCIPAL STRESSES

To determine the distribution of principal stresses in the wall-beam structure the beam shown in Fig. 1 was analysed using coarse mesh and homogeneous material properties. The principal stress obtained was expressed in terms of intensity of applied load, w (at the top of the wall) and is shown in Fig. 5(a). Therefore, this plot shows the concentration of principal stresses throughout the wall with magnitude and directions. From this figure it can be seen that the stresses within the panel concentrate towards the ends of the supporting beam leaving negligible stress in the middle of the span at the level of wall/beam interface. It is also seen that the stresses in the wall are mainly compressive and those in the beam are mainly tensile, both together acting in a manner of tied arch. This phenomenon clearly indicates the arch action within wall-beam structure where the supporting beam takes the tension of the arch and resists its spread. Thus the arching effect results stress concentration near the support while the middle portion of the supporting element is relieved from the action of the vertical load applied on the top of the wall. As a result the bending moment in the supporting beam will be reduced substantially. As an additional illustration of arching action in wall-beam structure the principal stress

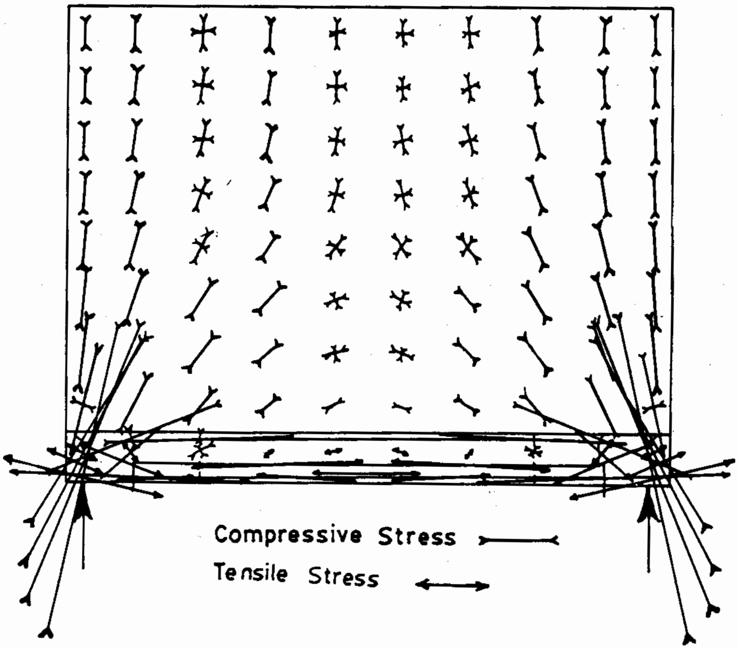
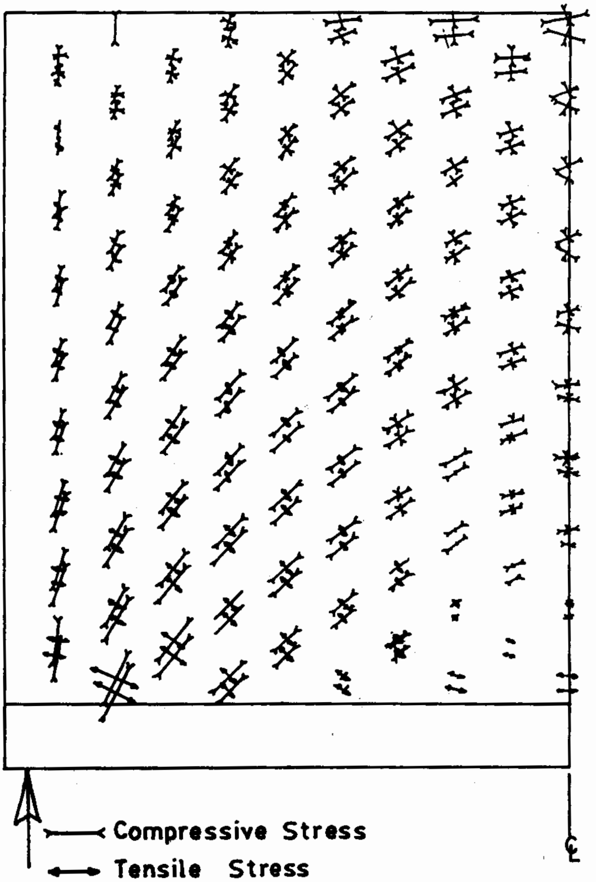


Fig 5(a). Principal Stress Trajectories (Homogeneous case) trajectories for vertical joints of a wall-beam structure is shown in Fig. 5(b). This was obtained from non-homogeneous analysis of a wall-beam structure using fine mesh. The wall was tested and analysed by the author as a part of his research.

BENDING MOMENT

The bending moment in the supporting beam of Fig. 1 as determined by different authors (Colbourne, 1969; Coull, 1966; Pildish et. al., 1955; Rosenhaupt, 1964; Saw, 1975 and Yettram and Hirst, 1971) along with the



Note:- Principal Stress Trajectories for Beam are Similar to Fig. 5(a).

Fig 5(b). Principal Stress Trajectories for Elements of Vertical Mortar (Non-homogeneous case) by Fine Mesh Discretization present analysis is shown in Fig. 6. The figure clearly illustrates very large reduction of bending moment in the supporting beam (in comparison to the moment, $wL^2/8$). This reduction is the most important contribution of the composite action of wall-beam structure. The variation of moment as obtained by different authors and by present analysis is noteworthy. Bending moment in the beam as proposed by Wood (1952), is based on experimental results. He proposed a maximum moment of $0.01\ wL^2$ for the wall-beam having no opening at the end. This moment coefficient is used for the design of composite wall-beam system. The bending moment at the middle section of the supporting beam as

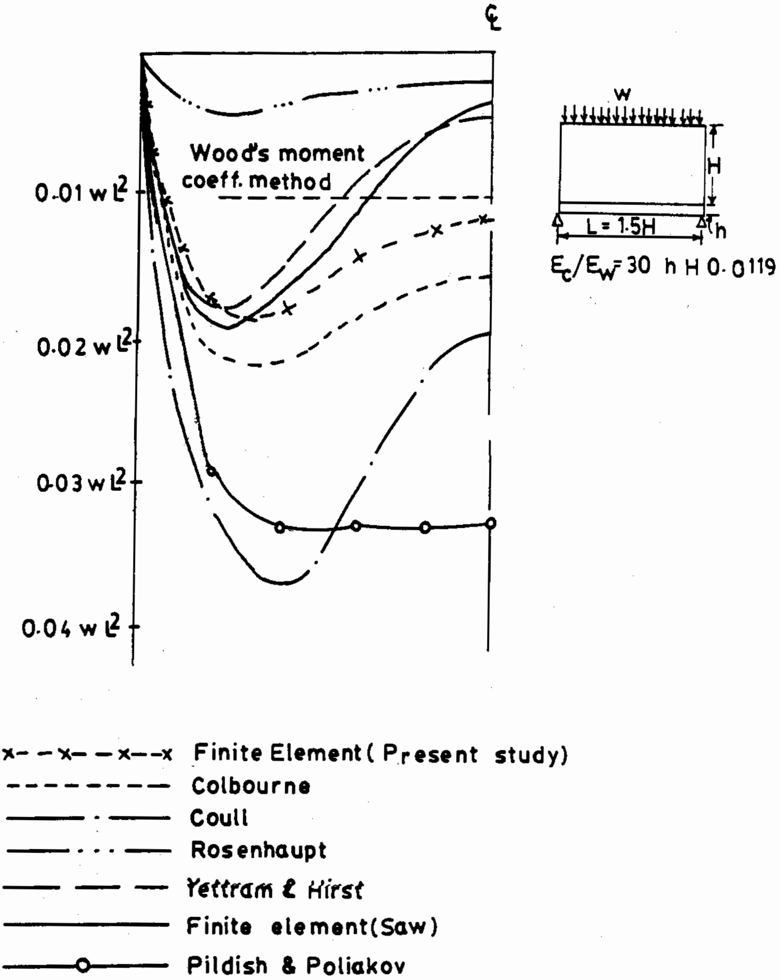


Fig 6. Bending Moment in Supporting Beam

obtained from the present analysis agrees favourably with that of the value experimentally obtained by Wood (1952). The bending moment at the sections near the ends of the supporting beam as obtained from present analysis agrees favourably with that of the value obtained by finite element method of Saw (1975) and shear lag method of Yettram and Hirst (1971). Therefore, the moments obtained by the present finite element analysis at different sections are reasonable on conservative side. Although the load on the top of wall is uniformly distributed over the entire span, due to composite action the maximum moment in the supporting beam does not occur at the middle of the span (see Fig. 6). This change in location of maximum bending moment is also observed by previous investigators. In the present analysis the maximum moment in the supporting beam is $0.018wL^2$ and is found to occur at a distance of 0.14L from the end of the support.

PRACTICAL APPLICATION

With the increasing use of brickwork and the greater possibility of adopting wall-beam structures, for example, in transfer system near the base of framed building, lintel and in-filled system, it is important to recognise accurately the arching effects in the wall-beam structure and to incorporate them into design method.

The most significant effects which result from the arching behaviour have been discussed in this paper and finally design coefficient for moment in the supporting beam has been given. The considerable reduction in bending moment in the beam supporting the masonry wall is a point of interest in selecting wall-beam structure. Due to composite action the moment in the beam supporting the wall which carries uniformly distributed load on its top is much lower than would be the case if the same load is applied on the beam surface. The maximum moment in a simply supported beam due to uniformly distributed load is given by $\frac{wL^2}{8}$ (= $0.125wL^2$) which occurs at the middle of the span. But, if composite action of wall and supporting beam is considered the moment at middle section of the supporting beam is obtained as $0.012wL^2$ (see Fig. 6) which is about 1/10th of the value obtained from conventional formula. The maximum moment in this case is obtained as $0.018wL^2$ whcih occurs at 0.14 times the span from the support (see Fig. 6).

To illustrate the reduction of bending moment in the supporting beam of wall-beam system the wall-beam of Fig. 7 is considered. It is important that the height of the wall-beam must not be less than 0.6 times the span of the beam opening to ensure shear transfer at wall/beam interface and thus to ensure composite action. Similar finding was also observed by Wood (1952) and other researchers (Burhouse, 1969; Riddington and Stafford Smith, 1978).

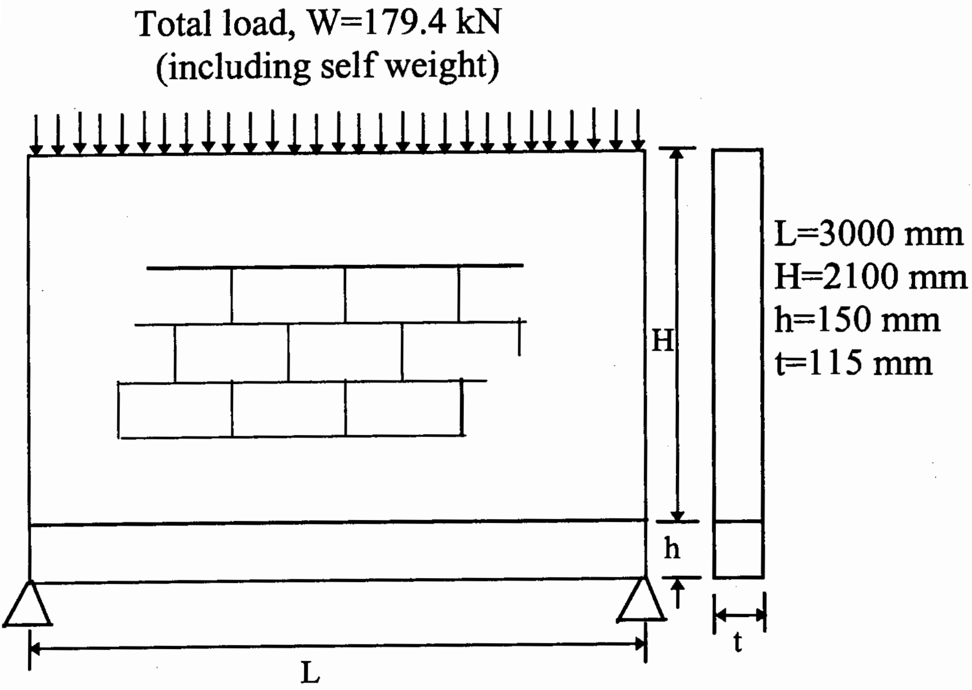


Fig 7. Design Details for a Wall-beam Panel

Maximum bending moment by present study =9.7 KN-M
Maximum bending moment by Wood (1952) = 5.38 KN-M
Maximum bending moment by conventional formula =67.2 KN-M

For detailed calculation see Appendix II. The section and reinforcing steel corresponding to moment will have to be selected according to the code usually adopted.

CONCLUSIONS

1. A finite element analysis for wall-beam structures which treats bricks, mortar joints, concrete and steel separately is more realistic, since it reflects the influence of the varying stiffness of the constituent materials.
2. The arching action in the wall-beam structure produces heavy concentration of stress in the wall close to the support and may cause failure of the wall by crushing the brick unit in this region.
3. Composite action of the wall-beam structure reduces the bending moment in the supporting beam quite significantly.

NOTATIONS

FE = Finite element analysis

HM= Homogeneous analysis

H = Height of the brick wall

h = Heigh of the supporting beam

NP = Height of the supporting beam

L = Length of the wall-beam

NHM = Non-homogeneous analysis

t = Thickness of the wall-beam

W = Intensity of uniformly distributed load on top of wall-beam

W = Total load in the panel

σ_y = Vertical stress

σ_x = Horizontal stress

τ_{xy} = Shear stress

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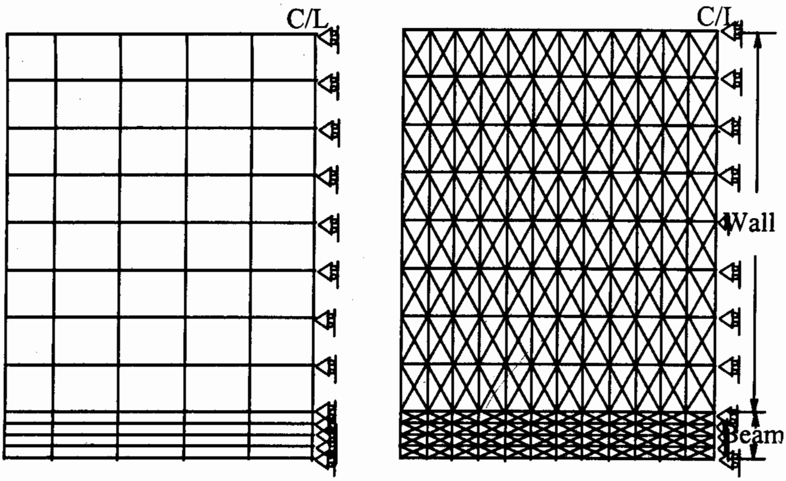
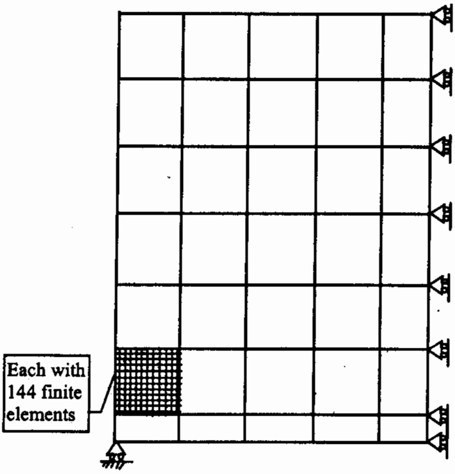
APPENDIX I



(a) Present study

(b) Male and Arbon (1971)



(c) Saw (1974)

Fig A 1. Finite Element Discretization of wall-beam tested by Rosenhanut 1962

APPENDIX II

Considering composite action :

1. Maximum bending moment proposed by Wood (1952) = 0.01WL
2. Maximum bending moment proposed in present study = 0.018wL

By conventional method :

Maximum bending moment = 0.125WL

where,

W = Total load acting on the top of the wall-beam including self weight and L = Span of the panel

Refer to Fig. 7

Total load = 179.4 KN. and L = 3 M with these values and using the above equations maximum moment in supporting beam of the wall-beam panel shown in Fig. 7 are as follows :

- Maximum bending moment proposed by Wood (1952)

  = 0.01WL = .01 X 179.4 X 3 = 5.38 KN-M

- Maximum bending moment proposed in present study

  = 0.018WL = .018 X 179.4 X 3 = 9.7 KN-M

- Maximum bending moment by conventional method

  = 0.125WL = .125 X 179.4 X 3 = 67.2KN-M.