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PARAMETRIC STUDY OF COMPOSITE ACTION BETWEEN BRICKWALL AND SUPPORTING BEAM

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ABSTRACT : The finite element study of wall-beam structure outlined in this paper is aimed at establishing its critical parameters. Findings of this paper are the result of elastic analysis of wall-beam structure considering non-homogeneity of constituent materials. The analysis confirms the results reported by several previous investigators who assumed masonry as a homogeneous material. In this paper emphasis has been made on the variation of vertical stress concentration and shear stress concentration at the interface level of wall and the supporting beam. The study in this paper includes some additional parameters which were not addressed by previous investigators. They are particularly, the reinforcement in the supporting beam, width of the support, height of the supporting column and the effect of opening in the wall. The study reveals that reinforcement in the supporting beam and the width of support decreases the stress concentrations in the wall. However, the offset opening and the height of the supporting column increases the stress concentrations. It is recommended that inclusion of these important parameters in the design equation will lead to a more rational approach than it is presently practised by the designers.

KEYWORDS : Wall-beam, parameters, non-homogeneous, vertical stress, shear stress, support width, reinforcing steel, supporting column, opening and wall-beam interaction.

INTRODUCTION

Masonry wall supported on reinforced concrete beam or steel beam is a common feature in residential, commercial and factory buildings. Yet the attention of the designers on the wall-beam composite system is very inadequate. Lack of rational analysis and well-defined design procedures, and limited test data are the main reasons

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behind this. As a result this structural component is over designed in most of the cases. During a series of tests carried out by Building Research Station, U. K., very low amount of anticipated stresses have been observed by Mainstone (1960). It is of course in a broader sense evident that the stress reductions were produced as a result of the composite action between the wall and the supporting beam. However, it is necessary to determine how these reductions take place and to what extent.

The wall-beam structure can be categorised as any type of masonry wall that transfers in-plane vertical loads applied on the top of the masonry wall down to the supporting beam. Masonry may be of any combination of materials, e.g. stones, clay bricks, concrete block, line mortar (calcium silicate) block with mortar made from cement sand on any practical proportion (with or without additives). The supporting member may be reinforced concrete or steel beam. The walls are mainly looked upon as space separator or at best a load transferring media. But when the proper interaction between wall and its supporting beam is considered, the material consumption in the supporting beam can be reduced considerably.

BACKGROUND OF RESEARCH

The behaviour of wall-beam structure was first investigated by Wood (1952). Later Rosenhaupt (1962) and Burhouse (1969) carried out similar tests. Recently, Annamalai, et al. (1984) carried out tests on reinforced brick wall thin lintels to study the composite action.

All these investigators observed the concentration of vertical stress near the support that initiated the failure before yielding of supporting beam. They recommended that the moment in the beam supporting the wall was much less than the case where if the load would be uniformly distributed on the span. But these recommendations vary widely from country to country reflecting the empirical nature of the problem. This is possibly due to the size, type and variability in the material properties of the specimens adopted during the experiments.

In the previous years due to the variability in test results the researchers simultaneously worked with the mathematical and computer modelling to model the actual behaviour of wall-beam structure. The analytical works in the field includes the Airy's stress function of Rosenhaupt (1964), variational approach of Coull (1966), the lattice analogy of Colbourne (1969), equivalent stress block of Wood and Simms (1969) and shear lag method of Yettram and Hirst (1974). Ramesh et al. (1970) analysed the problem by expressing the displacement in the form of multiple Fourier series and Green (1972) unlike other analysts considered the wall-beam system as a beam on elastic foundation.

With the advent of electronic computer, finite element method of stress analysis for wall-beam structure was adopted by the researchers Ahmed (1977), Davies and Ahmed (1978), Stafford Smith and Riddington (1977), Yisun et al. (1985) and Kamal (1990) to make a close study of such highly indeterminate structure.

All the analyses performed at that time were hampered due to lack of representative material model for masonry. In most of the cases the masonry was considered as a homogeneous media with the assumption of isotropic linear elastic behaviour for the constituent material. But in wall-beam structure the brickwork consists of brick and mortar joints (bed joints and header joints). The beam consists of concrete and reinforcement. All these components behave differently when loaded. Therefore, the idea of considering the brick wall as a homogeneous material cannot fully represent the actual material of the wall-beam. It is, therefore, important to have a detailed study of parameters those govern the effectiveness of wall-beam structures.

METHODOLOGY

Comprehensive analysis of wall-beam structure has been made using finite element technique. The constituent materials are idealised separately to represent nonhomogeniety.

The material model thus adopted in this analysis is "microscopic" in nature with bricks and joints being modelled separately. This is essential if the high stress gradients and localised failure occurring in wall-beam are to be modelled. Four–noded rectangular isoparametric elements have been used to analyse the panel. The finite, element model has been discussed in Hossain et al. (1996) and is not discussed here to avoid repetition. The properties needed to define the material model can be obtained from various simple tests on samples of bricks, mortar joints and small brick masonry specimens. These tests have been reported by the authors in previous paper (1997) and is not included here.

The adequacy of the finite element model used for parametric study has been verified by the authors in previous papers (1996, 1997) and is not included here to avoid repetition.

PARAMETRIC STUDY OF WALL-BEAM STRUCTURE

The wall-beam structure is a highly complex type of composite structure comprising of a number of different materials, each having different material properties. The composite action of masonry wall with the supporting beam depends on many parameters. The main influencing parameters are outlined as follows :

a The wall height to span ratio.

b. The depth of the supporting beam to span ratio.

c. Relative stiffness of masonry wall and its supporting beam.

d. Vertical edge column and top beam.

e. The size and position of opening in the wall.

f. Reinforcement in the supporting beam.

g. Width of the support for beam

h. Height of support column.

The other parameters may include wall thickness, size of brick unit, thickness of mortar, modulus of elasticity and Poisson's ratio of constituent materials, support bearing and end conditions, anchorage of tension reinforcement and bond characteristics of mortar.

Some of the parameters were studied by the authors in a previous paper (1996). They were mostly related to aspect ratio of wall-beam structures and elastic properties of masonry constituents. In this paper the effect of reinforcement in supporting beam, vertical columns at both ends, opening in wall-beam, support width and effect of supporting column height have been studied.

Effect of Reinforcement in Supporting Beam

The relative stiffness of wall and the beam influences the behaviour of wall beam structure considerably. Although this fact was agreed in general by previous researchers, they did not consider the contribution of reinforcing steel in calculating the stiffness of reinforced concrete beam. The structural purpose of supporting beam in a wall-beam structure is to resist tension and bending. The increase of axial stiffness and bending stiffness due to the contribution of embedded reinforcement should therefore be considered. Vertical stress concentration, V_C ($=\sigma_y/w$) and shear stress concentration, Sc ($=\tau_{xy}/w$) along the span are calculated at the interface level of wall and beam. Their variation is shown in Fig. 1(a) and Fig. 1(b). It can be observed from these figures that when the effect of reinforcement is considered in the model, the magnitude of maximum stress concentrations (Vc and Sc) is decreased. It is concluded that modeling of reinforcement in reinforced concrete supporting beam is required to simulate a real wall-beam structure.

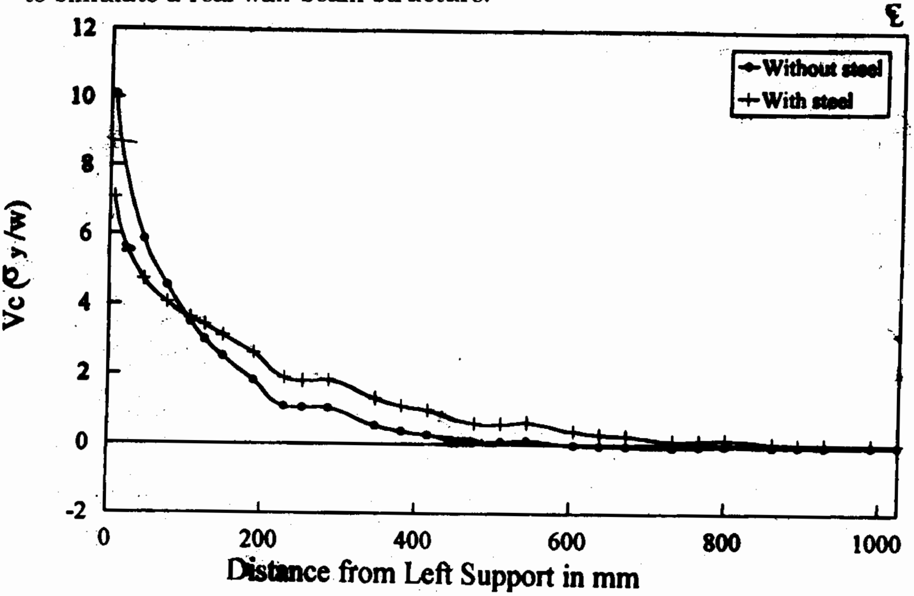

Fig 1 (a). The Influence of Beam Reinforcement on Vc

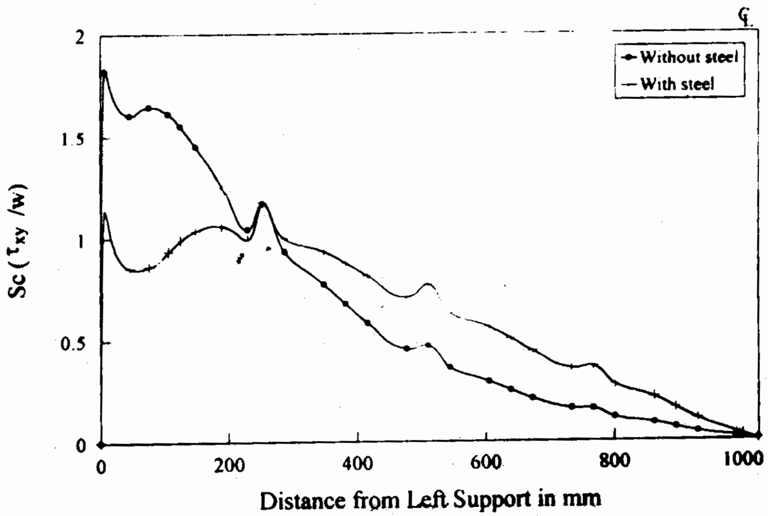

Fig 1 (b). The Influence of Beam Reinforcement on Sc

Effect of Vertical Columns at Edges

The wall-beam interaction exists in brick infilled beam-column frame system. Possible practical arrangements may be (1) the masonry wall supported by beam at the bottom and having columns at vertical edges, (abbreviated as 'BCOL'), (2) the masonry wall supported by beam at the bottom, having columns at vertical edges and slab or beam at the top (abbreviated as 'FRM') and (3) the plane wall-beam structure i.e., the wall supported by beam at the bottom (abbreviated as 'WBM'). These arrangements are shown in Fig. 2(a). The above three systems were analysed. The distribution of vertical stress and shear stress along the span expressed by Vc and Sc are plotted in Fig. 2(a) and Fig. 2(b), respectively. The comparison shows that the 'BCOL' and 'RRM' systems behave almost in identical manner. In both the cases, maximum vertical stress concentration and maximum shear stress concentration are found to be reduced considerably within the masonry part of the wall-beam. Therefore 'FRM' and 'BCOL' type of wall-beam structure will effectively enable the panel to resist against crushing of bottom corner. For bricks having lower compressive strength such technique will be more effective. To investigate the effect of above three systems on the reinforcement of the supporting beam, the variation of tension (σ_x) at bottom reinforcement, expressed as tensile stress concentration, Tc (= σ_x/w) is shown in Fig. 2(c). It is seen that for all the three type of wall-beam structures ('WBM', 'FRM' and 'BCOL') tension in the bottom reinforcement is practically unaltered.

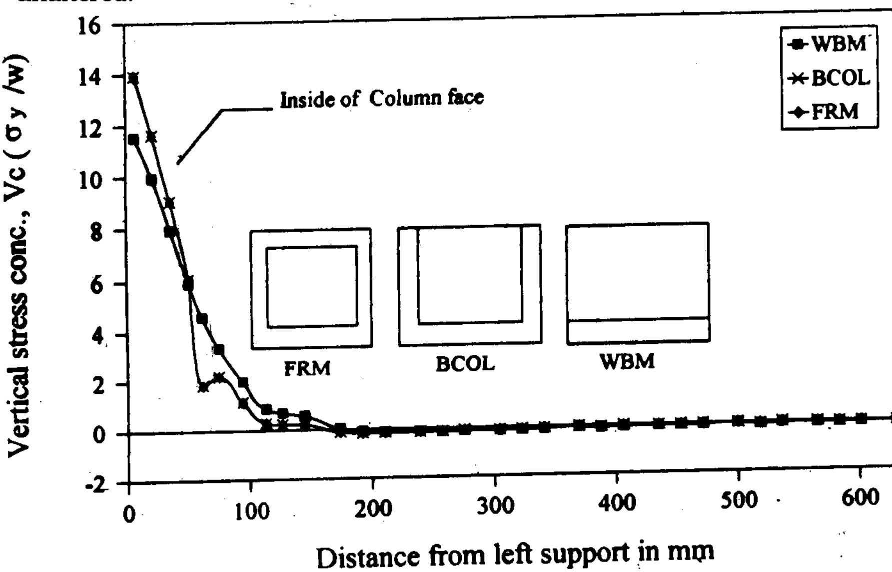

Fig 2 (a). Influence of Lateral Confinements on Vc

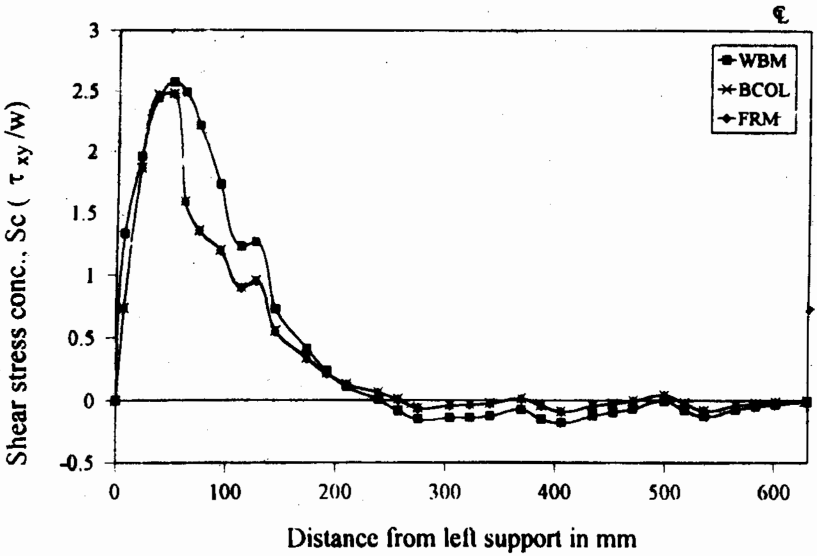

Fig 2 (b). Influence of Lateral Confinements on Sc

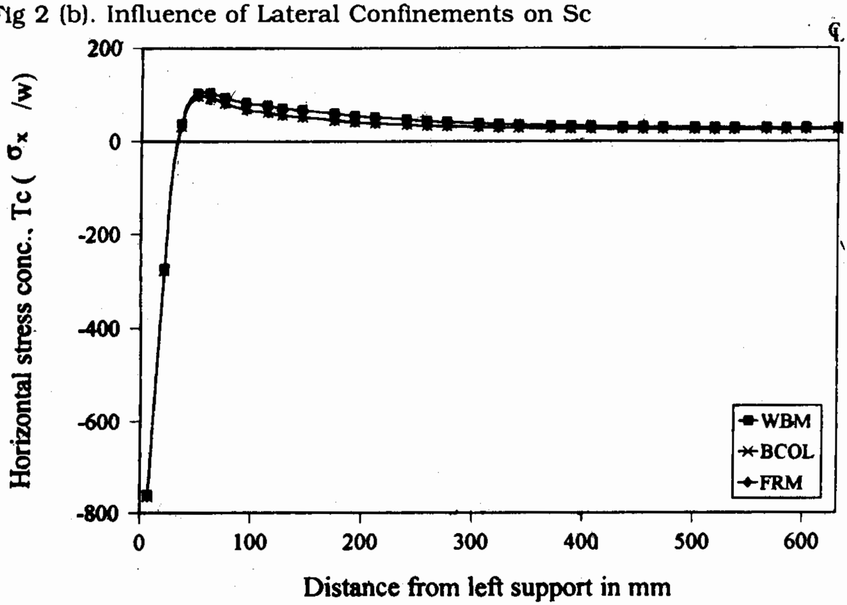

Fig 2 (c). Influence of Lateral Confinements on Stress in Beam Steel

Effect of Opening in Wall-beam

Masonry wall is often found to have door and window openings. When these occur in a wall-beam structure where composite action is considered, the stress distribution becomes complicated and their magnitude changes abruptly. A comparison of vertical and shear stresses at interface level of wall-beam and the tensile stress at the bottom rod of supporting beam have been studied for different size and position of openings. A window at the central position is abbreviated as 'WMID' and a door at the end of the span is abbreviated as 'DEND'. It is seen from Fig. 3 (a) that the door opening at the end of the span produces very high compressive stress at the support and also high tensile stress at the bottom corner of the opening near the end of the span. Vertical tensile stress of lower intensity is also produced at wall-beam interface near the mid span. Opening at the end also produce maximum shear stress at mid span (see Fig. 3 (b) which is more than that of a wall-beam without opening. Comparatively large tensile stress is encountered in reinforcement due to offset opening (see Fig. 3 (c). It is observed from Fig. (3(a-c) that the position of safest opening in the wall-beam structure is at the middle ('WMID'), while the door at the end ('DEND') is observed to be the most dangerous opening. Since the normal opening at the central position does not materially change the interaction behaviour it can be designed like a solid wall-beam structure. For the design of wall-beam structure with offset opening, elaborate analytical and experimental study should be carried out.

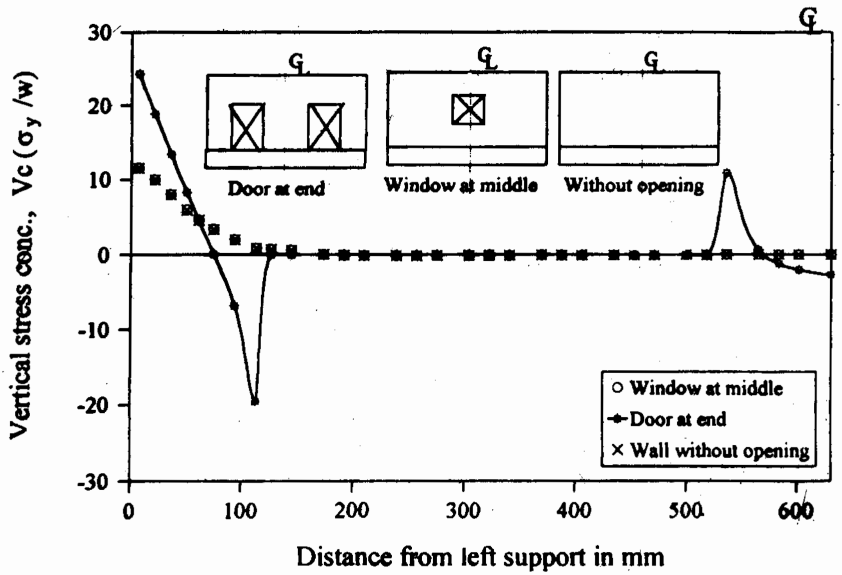

Fig 3 (a). Influence of Openings on Vc

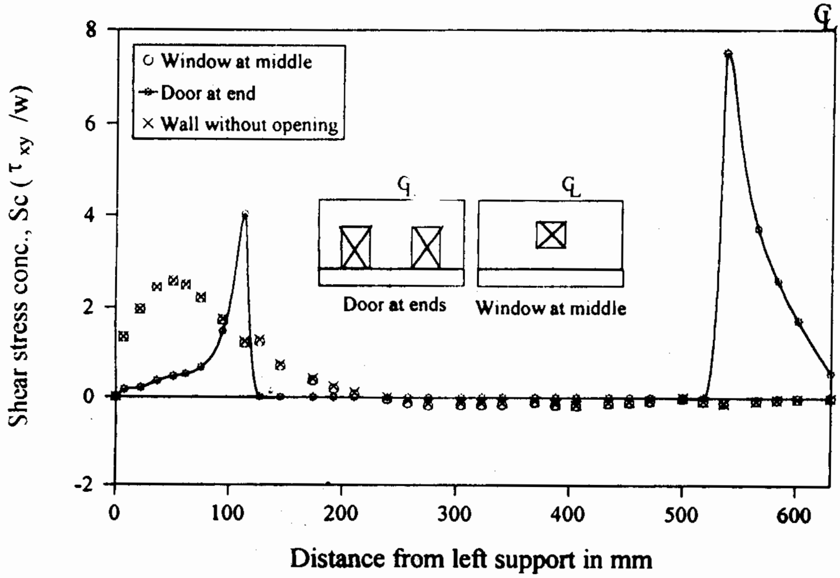

Fig 3 (b). Influence of Openings on Sc

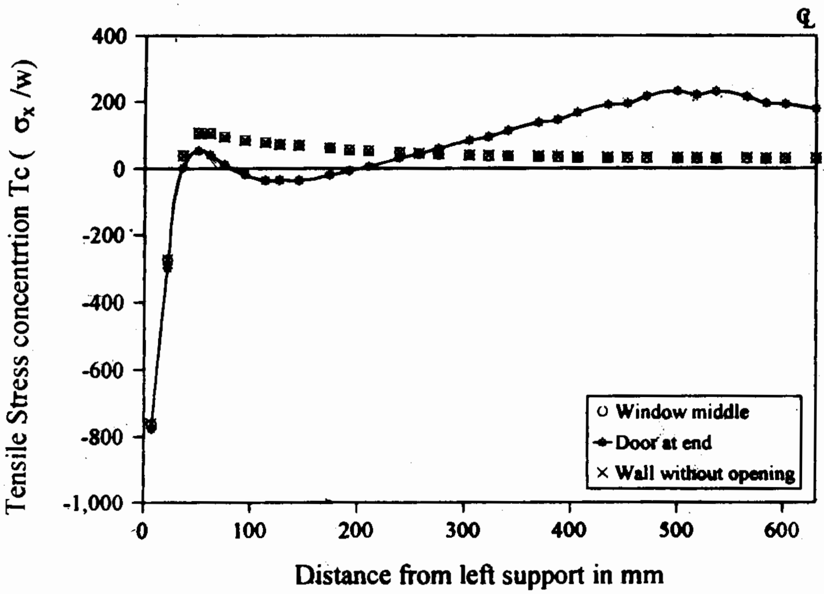

Fig 3 (c). Influence of Openings on Steel in Beam

Effect of Support Width

In practical cases supports always occupy some place. This parameter is studied to know the extent and nature of the effect of bearing area of support on the behaviour of wall-beam structure. For this purpose supports of contact length 0.05L, 0.025L and end bearing support were considered at each end of the span. The variations of vertical stress concentration, shear stress concentration at wall-beam interface level and the tensile stress concentration in the bottom reinforcement of the supporting beam are shown in Fig. 4(a), Fig. 4(b) and Fig. 4(c) respectively. It is clear from these figures that the support contact length has great influence on distribution of stress near the bottom corner of wall. With the increase of contact length of support, vertical and shear stress concentration are found to decrease considerably. Due to the increase of contact length of support tensile stress in the reinforcement also decreases along with shifting of location of maximum stress. It is therefore concluded that, if support width in the direction of span is duly considered stress concentration can be reduced quite significantly.

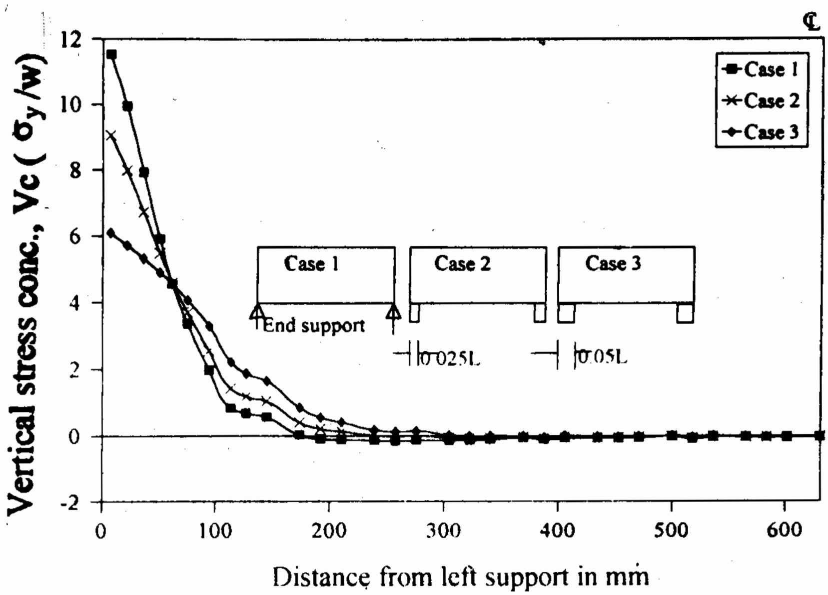

Fig 4 (a). Influence of Width of Support on Vc

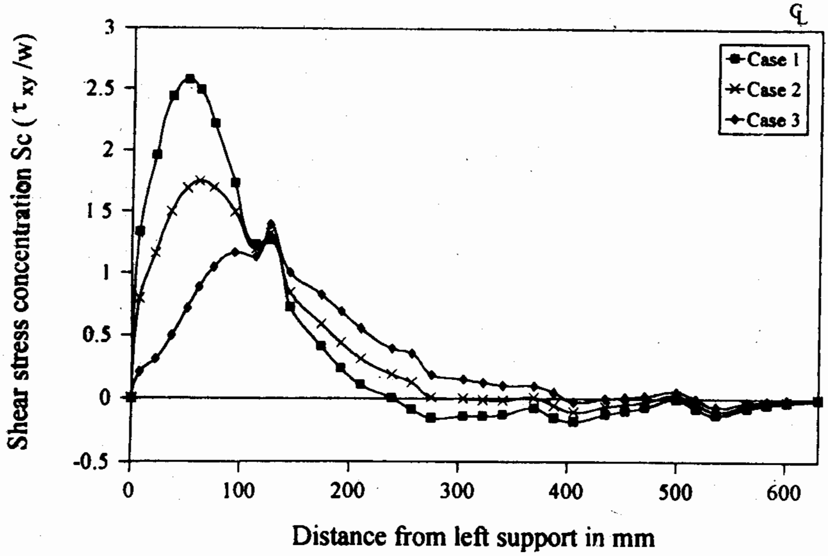

Fig 4. (b) Influence of Width of Support on Sc

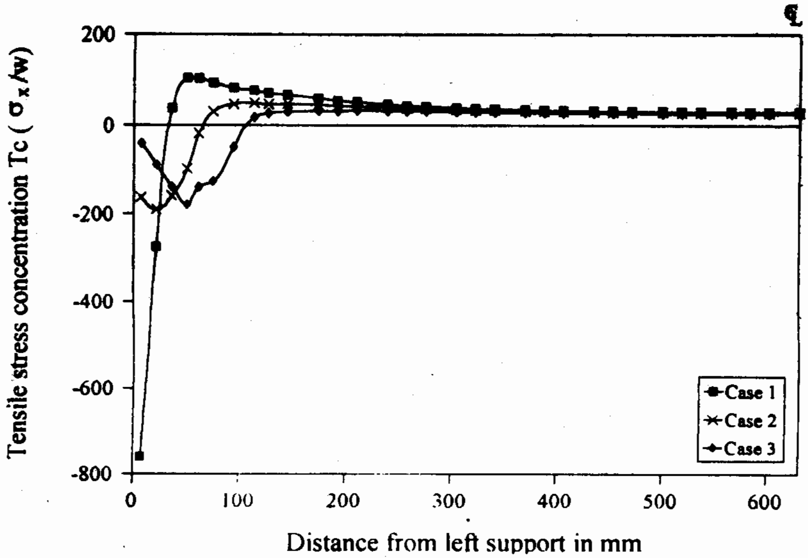

Fig. 4. (c) Influence of Width of Support on Steel in Beam

Effect of Column Height

When supporting beam of a single span wall-beam is connected at its ends with columns, the height of the column will influence on interaction behaviour of wall-beam structure. Unlike other researchers, this height of the column was taken as a parameter in this study. For this purpose wall-beam with varying height of columns (0 mm, 100 mm, 300 mm, 600 mm, 900 mm, 1200 mm) were analysed. The column cross-section was kept constant which provided a constant bearing length of 0.077L. The nodes at the interface of beam and column are assumed to have perfect bond. Simply supported condition at the ends of the column was assumed as before (i.e. the nodes at the support are restrained only in vertical direction). The variation of vertical stress concentration and shear stress concentration at wall-beam interface and the tensile stress of the bottom reinforcement of the supporting beam in terms of 'W' are shown in Fig. 5(a), Fig. 5(b) and in Fig. 5(c) respectively. It is seen from Fig. 5(a) that the maximum vertical stress concentration increases with the increase of column height up to a certain limit. These figures also show that with columns having greater length there is no appreciable change in this increase. Fig. 5(b) shows that effect of column height on the shear stress concentration is not significant. From Fig. 5(c) it is seen that with the change of column height the tensile stress concentration, Tc in the bottom reinforcement changes. This change is very sharp for wall-beam with column of smal height in comparison to that of wall-beam without column.

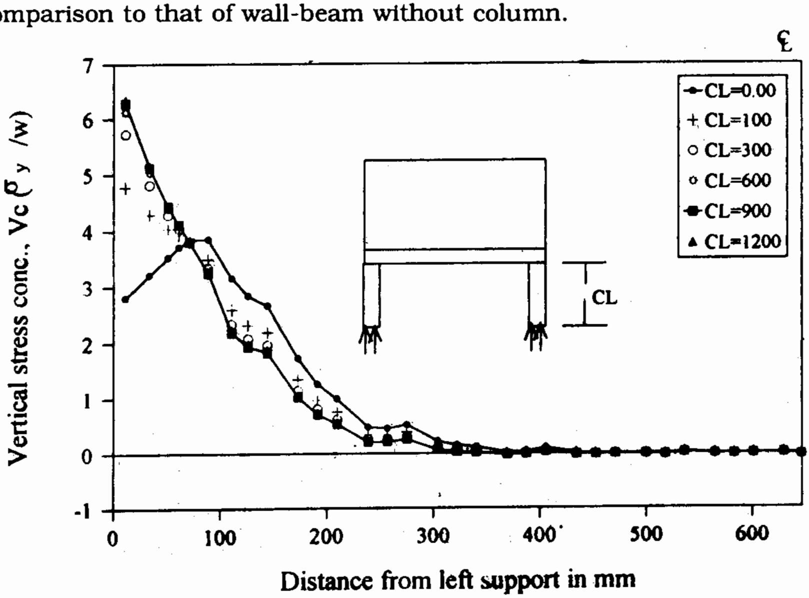

Fig 5 (a). The Influence of Column Height on Vc

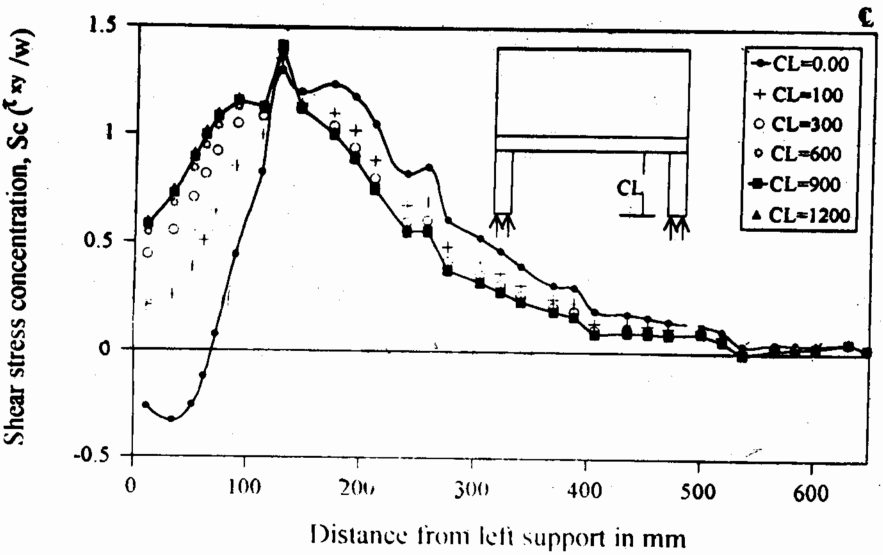

Fig 5 (b). The Influence of Column Height on Sc

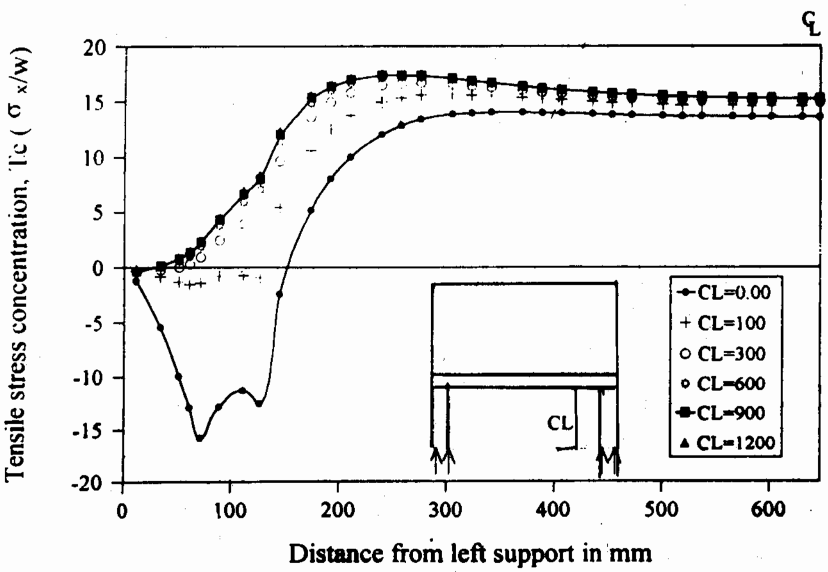

Fig 5 (c). The Influence of Column Height on Steel in Beam

It seems from above discussion that when the ends of supporting beam of wall-beam structure are monolithic with column the degree of framing action occurring between wall-beam system and the column reduces with the increase of column length from zero to normal height. The length of the column reduces the stiffness of the column and the wall-beam system. It is observed that wall-beam with column of normal length produces high vertical stress concentration at the ends.

CONCLUSIONS

In this paper study of important parameters of wall-beam structure has been made by using linear elastic finite element model. From this parametric study the following conclusions can be drawn.

1. The reinforcement in supporting beam increases its stiffness and thus reduces stress concentrations near the bottom corner of the masonry panel. Therefore, the reinforcement in the supporting beam should be incorporated in analytical models for appropriate simulation of a real wall-beam structure.
2. The vertical column of brick in-filled beam column frame panel shares the maximum stresses and thus relieves the stresses in the masonry at bottom corner of the panel. This effect will enable the wall-beam to carry higher load in the case where failure is mainly due to crushing of softer brick unit near the corner.
3. Safest position of opening in a wall-beam structure is at the middle span. The door openings at the ends of the wall-beam produce high compressive and shear stresses in the panel.
4. The stress concentrations in the masonry wall and in the reinforcement of supporting beam of a wall-beam structure decrease with the increase of width of support. Greater width of support will increase the load carrying capacity of the wall-beam panel.
5. The vertical stress at wall-beam interface and the tensile stress in the reinforcement of the supporting beam increases with the increase of height of the supporting column.

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NOTATIONS

Vc	Vertical stress concentration
Sc	Shear stress concentration
w	Uniformly distributed load on beam per unit length
σ_y	Vertical stress
τ_{xy}	Shear stress
σx	Horizontal stress