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3-D ANALYSIS OF COMPOSITE MASONRY WALLS SUBJECTED TO EARTHQUAKE LOADS

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SUMMARY

3-D finite element analysis of a composite masonry wall subjected to vertical and horizontal inplane loads using a linear isoparametric brick element is presented. It is shown that the maximum interface shear stresses in the collar joint occur near the ends of the wall. Their values predicted by a previously developed quasi-3D model are much higher than those calculated in this analysis and may be too conservative in estimating the integrity of a composite wall.

INTRODUCTION

A composite wall, as shown in Fig. 1, consists of one wythe of brick and another of concrete block, with the cavity between the two wythes (called the collar joint) filled with grout. The loads, which may be vertical due to gravity, or horizontal due to wind or earthquake, are generally transmitted only to the block wythe by the floor slab as shown. These loads, nevertheless, are partially transferred to the brick wythe, thus creating shearing stresses in the collar joint as shown in Fig. 2. If the resultant shear stress becomes too large at the brick-grout or block-grout interface, delamination may occur and the load would no longer be transferred to the brick wythe and the wall may experience distress.

The senior author of this paper, and his students have developed a quasi-3D finite element model that is capable of predicting the normal and shear stresses in the collar joint. This model has primarily been utilized to compute collar joint shear stresses due to vertically applied loads on the block wythe [1]. However, the authors have also utilized this model to compute stresses in composite masonry walls subjected to inplane horizontal loads [2]. These studies have indicated that the most critical stresses in a composite wall are the shear stresses in the collar joint.

The authors recently developed a 2-D plane strain finite element model which can predict cracking in the collar joints of composite masonry walls subjected only to vertical loads [3]. This cracking model was later extended for use with the quasi-3D model to analyze walls subjected to vertical as well as horizontal loads [4].

It should be noted that the interface shear stresses predicted by the quasi-3D model may be substantially larger than those computed by a 3-D model.

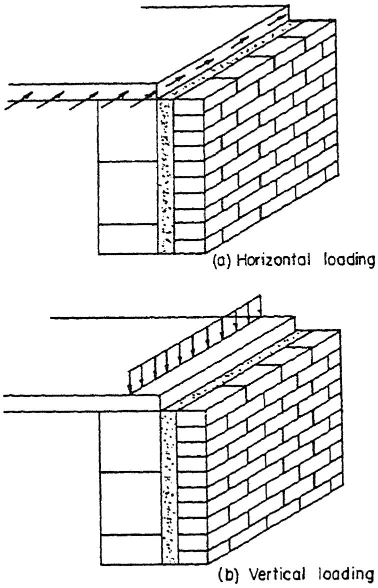

Fig. 1 Composite Wall and Loads

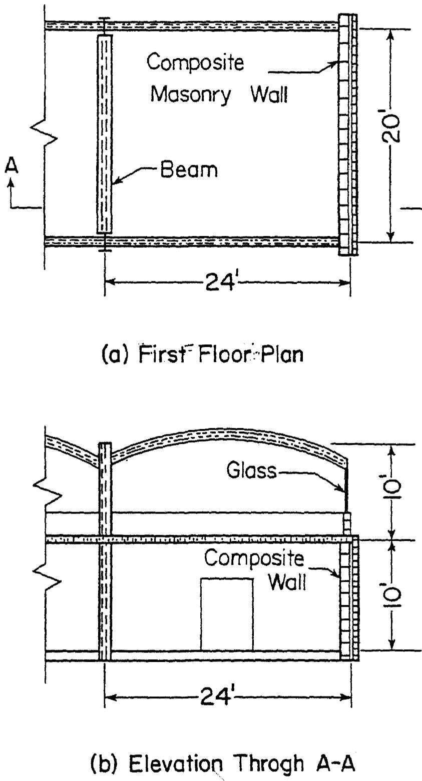

Fig. 3 Building with Composite Wall

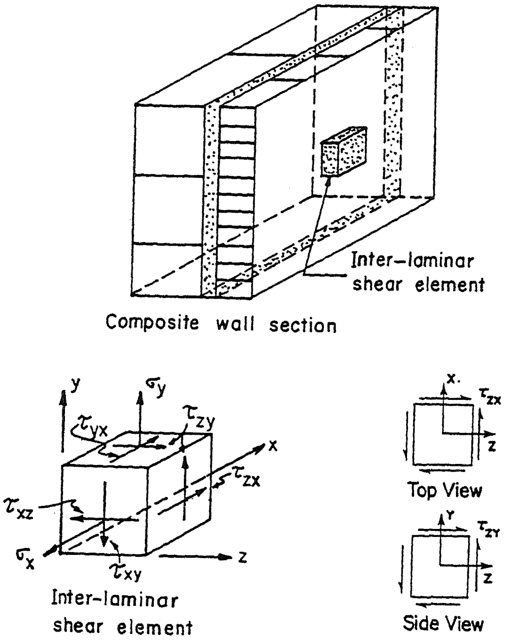

Fig. 2 Shear Stresses in Collar Joint

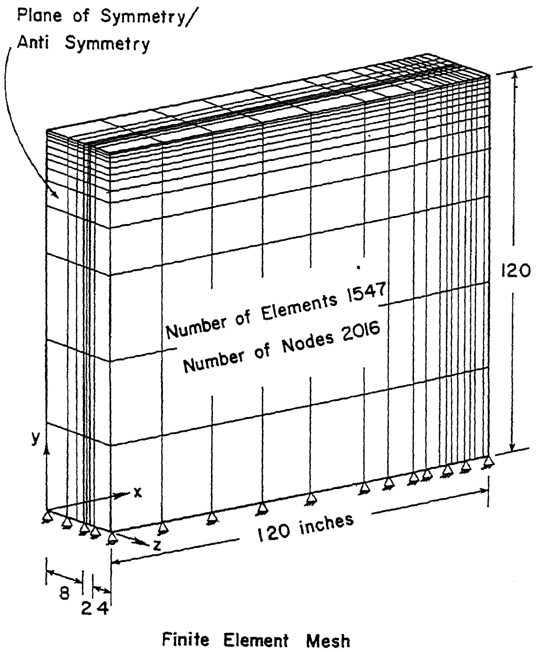

Fig. 4 Finite Element Model

This increased prediction of shear stresses in the former model subjected to vertical loads was first reported in Ref. [5]. A better estimate of safe vertical and horizontal loads on composite walls can, thus, be made by performing three dimensional failure analyses. This paper presents shear stress distributions in the collar joint of a composite masonry wall subjected to vertical as well as horizontal earthquake loads using a 3-D finite element analysis. No crack propagation has been considered in this preliminary study.

PROBLEM DEFINITION

A 10 ft high x 20 ft long composite masonry wall subjected to vertical and horizontal loads acting on the block wythe is analyzed. The wall consists of an 8 in concrete block wythe, a 4 in brick wythe, and a 2 in thick grouted-collar joint. The wall could be considered as an external load bearing wall of a system shown in Fig. 3.

The properties for the various materials are computed based on their laboratory compressive strengths. It is assumed that the materials behave linear-elastically. The elastic moduli for the concrete block wythe, brick wythe, and grout are 1,040 ksi, 2,000 ksi, and 1,600 ksi, respectively. The corresponding values for the Poisson's ratio are 0.25, 0.25 and 0.20.

The detailed calculations to compute vertical and horizontal inplane loads for the wall have been given in Ref. [2] The resulting vertical and horizontal uniform loads on the block wythe are 2.70 klf and 1.58 klf, respectively.

The wall is represented by the finite element mesh shown in Fig. 4. Only one half of the wall length is modelled by exploiting the symmetry and antisymmetry conditions. Symmetry about y-z plane exists for the vertical loads and antisymmetry for the horizontal loads. 8-noded linear solid isoparametric elements are utilized and the top and end of the wall are modelled using a refined grid. This refinement is based upon the experience gained during previous analyses [2,4] which showed high stress concentrations in these regions. A total of 1547 elements with 2016 nodes have been utilized.

RESULTS AND DISCUSSION

The CPU time required to analyze the model for one load case on a VAX 8600 is approximately 16 minutes. This large amount of computer time required is due to over 6000 degrees of freedom that need to be solved during an analysis.

Only shear stresses, τ_{zy}, and τ_{zx}, and the resulting shear stress, τ_R, in the collar joint are primarily of interest as far as the integrity of the composite action in a wall is concerned. Accordingly, these are plotted due to the vertical as well as horizontal and combined loads. The stresses considered are at the centroids of collar joint elements closest to the block wythe.

<u>Stresses due to Vertical Load</u> The distribution of the vertical shear stress, τ_{zy}, along the block wythe-collar joint interface at various points along the length of the wall is shown in Fig. 5 due to the vertical load. It can be noted that near the top of the wall the shear stress has same value. For most of the wall height, however, the magnitude of shear stresses reduces in value from the end of the wall towards its center. This can be attributed to out-of-plane displacements in the wall which appear to have insignificant influence near the top.

τ_{zy} is maximum near the top and its magnitude reduces sharply within the top 10 in as the load transfer to the brick wythe takes place in this region.

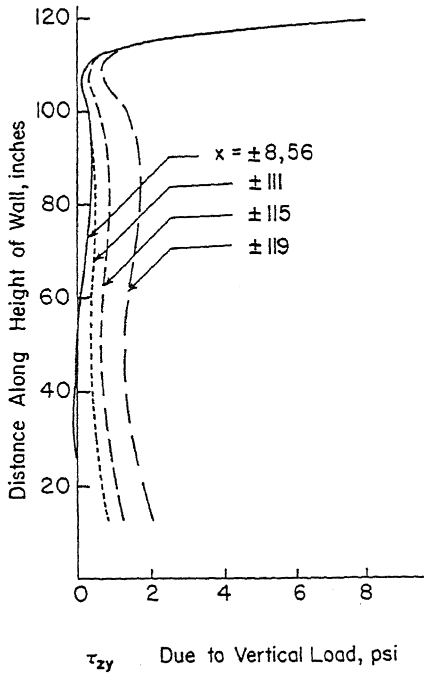

Fig. 5 τ_{zy} due to Vertical Load

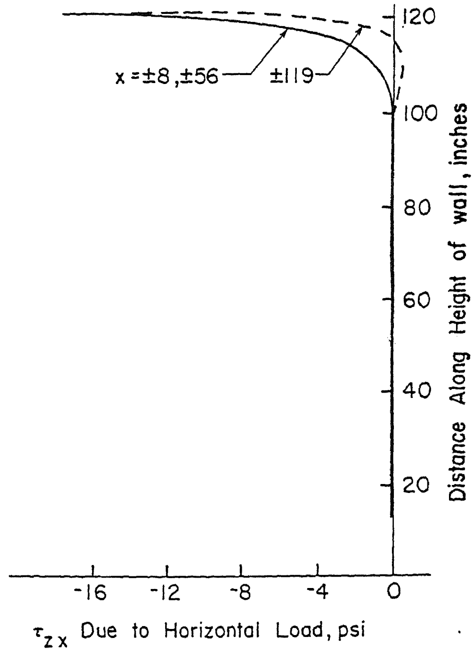

Fig. 6 τ_{zx} due to Horizontal Load

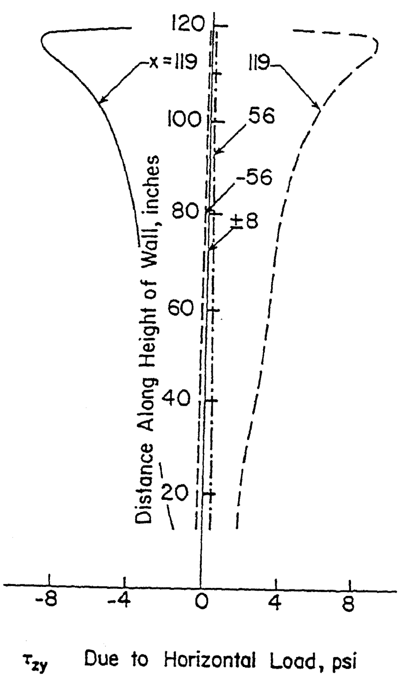

Fig. 7 τ_{zy} due to Horizontal Load

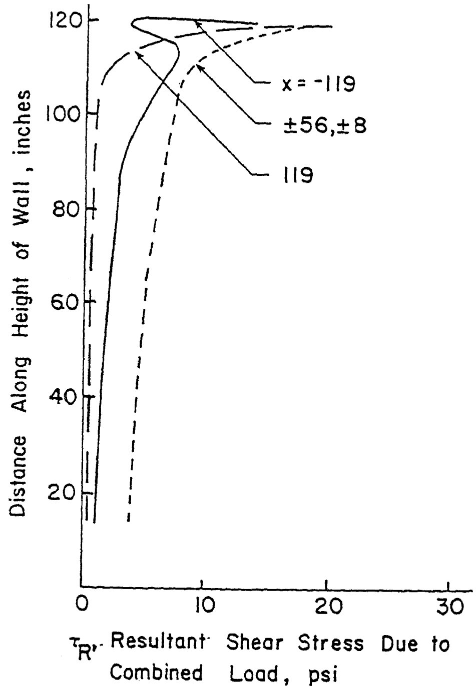

Fig. 8 τ_R due to Combined Load

This phenomenon has also been observed previously with the plane strain cross-sectional model. The maximum shear stress from Fig. 5 is 8.0 psi whereas the corresponding values form the cross-sectional model [6] and the quasi-3D model [2] are 6.1 psi and 27.0 psi, respectively. It is obvious that the quasi-3D model, the so called longitudinal model, over predicts the stresses substantially.

The vertical load also produces the horizontal shear stress, τ_{zx}, at the interface; however, its magnitude is insignificant and need not be considered.

Stresses due to Horizontal Load The horizontal shear stress, τ_{zx}, at the interface due to the horizontal inplane earthquake loads is shown in Fig. 6. Once again, it can be seen that the maximum shear stress occurs near the top as in the case of the vertical load. The stresses near the wall end have a slightly different distribution due to the out-of-plane displacements. The maximum value of τ_{zx} is computed as 18.5 psi, which is smaller than 24.0 psi predicted by the quasi-3D model [2].

Horizontal load is also instrumental in producing vertical shear stress, τ_{zy}, at the interface. Its distribution is shown in Fig. 7 with the maximum values occurring near the top at the wall ends. The largest τ_{zx} is this case is 8.5 psi whereas the largest corresponding value from the quasi-3D model is 2.5 psi.

Stresses due to Combined Loads The resultant shear stress, τ_R, is equal to $(\tau_{zy}^2 + \tau_{zx}^2)^{1/2}$ which is plotted in Fig. 8. Its value varies along the wall height and wall length with the maximum of 23.0 psi occurring near the top at the wall end. It is surmised, therefore, that the failure due to earthquake loads will initiate near the wall end. The maximum resultant shear stress obtained using the quasi-3D model is equal to 37.8 psi [2].

CONCLUSIONS & RECOMMENDATIONS

The maximum shear stress value of 23.0 psi calculated in this analysis is less than 36.0 psi measured as the average failure shear stress in collar joints of composite wall specimens subjected to cyclic loads. Consequently, this wall would safely withstand inplane earthquake loads prescribed for Zone II. Nevertheless, its safe performance for higher earthquake zones is not guaranteed.

As the maximum shear stress predicted by the quasi-3D model is much higher, it is recommended that, whenever possible, only 3-D analyses of composite walls be carried out to assess their integrity. Future analyses should include failure and crack propagation criteria along with capabilities to incorporate nonlinear behavior of the constituent materials. In addition, more experimental data is required to validate the numerical results presented in this study.

ACKNOWLEDGMENTS

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