Paper No. 96. Bulletin of the Indian Society of Earthquake Technology, Vol. VII. No. 3, pp. 147-152, Sep, 1970

BEHAVIOUR OF LOAD BEARING BRICK SHEAR WALLS WITH OPENINGS

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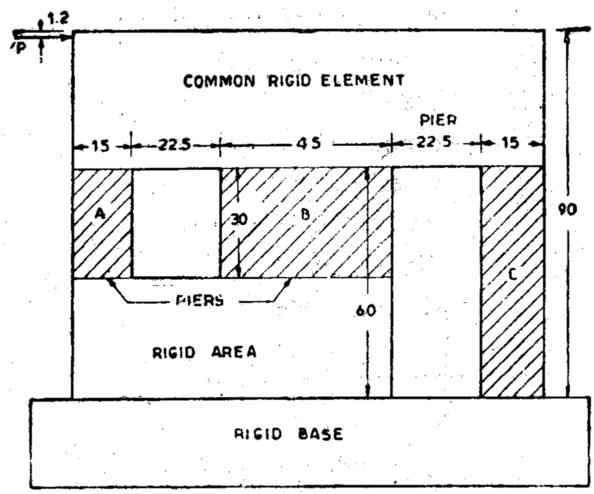
INTRODUCTION

Shear wall in brick buildings forms the most important structural element in resisting lateral forces. It has, therefore, been the endeavour to study the behaviour of such walls through theoretical and experimental models. The problem becomes quite complicated if the wall has openings. Also, for functional requirements openings must be present in walls. Theoretical and experimental studies[1] indicate that strength of a shear wall is latgely influenced by the size and position of openings. It is found that sections along jambs of openings are the critical sections in a wall panel. It would therefore be necessary to reinforce these sections in order to strengthen it against lateral forces. It was with this objective that studies[3,4] were carried out to investigate the behaviour of brick walls with and without reinforcement. In these studies lateral load tests were performed on models of walls. The results of these provide useful data in studying qualitatively the effectiveness of different strengthening methods. However, in order to have a quantitive idea, it is necessary to develop theoretical solution of the problem so that answer could be given for any case without going in for a model test every time. But before attempting such a solution, it will be essential to know as to how the walls with openings behave under vertical and lateral forces.

An approximate solution is suggested by Portland Cement Association[6]. The method treats the wall as series of piers and the portion of wall above openings is considered as a rigid element (Fig. 1). Under the action of lateral load, all the piers are assumed to undergo the same horizontal deflection($\triangle$). Since piers have considerable depth compared to its height, $\triangle$ includes shear deformations also in addition to bending deformations. The lateral forces are resisted by the piers in proportion to their rigidities ($1/\triangle$ values). This shear in the pier causes bending stresses. In order to work out the stresses in piers due to overturning moment of lateral force, it in assumed that the wall bends as a vertical cantilever having a neutral axis at the centre of gravity of pier areas. Overturning stress is calculated in proportion to distance of piers from this centre of gravity. This assumption is not consistent with the wall behaviour assumed for calculating shear in pier analysis. Also, the analysis does not give any importance to stresses at points other than at sections through openings. Some cantilever action is definitely present in wall of the type shown in Fig. 1 and must be taken into acco-



(*a*) Details of Shear wall Mode
(All dimension in cm)

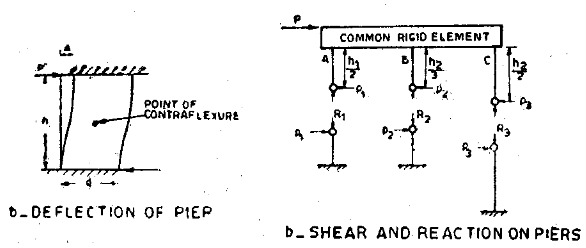


Fig. 1. Behaviour of Shear wall as assumed in P C.A. Method.

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unt. It is with this idea that a detailed numerical analysis is carried out for the wall shown in Fig. 1. The analysis is explained here.

THE METHOD OF ANALYSIS

The shear wall is analysed by treating it as a two-dimensional elastic plate, using grid analogy. The wall is divided into a number of rectangular elements and these elements are replaced by grid member. Properties of these grid members are worked out using Grinter formula[2]. Accordingly, the width (b) and depth (d) of the members are given by following relationship.

$$b = t\sqrt{1+\mu} \quad \text{and} \quad d = \frac{1}{\sqrt{1+\mu}}$$

where L is the uniform spacing of grid in the direction of members, t is the thickness of the plate and μ is the poison ratio of plate material. Three unknown deformations at each joint are the horizontal displacement ($\triangle$) the vertical deflection (δ) and rotation (θ). Forces and moments in grid members are expressed in terms of these deformations and equilibrium equations are formulated at each joint. These equations are solved to obtain $\triangle$, δ and θ at various joints and hence the forces.

THE MODEL

In model chosen for analysis[6] is a wall with a door and a window. This has been shown in Fig. 2 with the corresponding equivalent grid. The properties of grid members are calculated by assuming μ to be zero for brick masonry. The grid spacing is L horizontally and 2L vertically. The area of cross-section and moment of inertia of vertical members is A and $AL^2/12$ respectively, where $A = L^2$. These values for horizontal members are 2A and $8AL^2/12$ respectively.

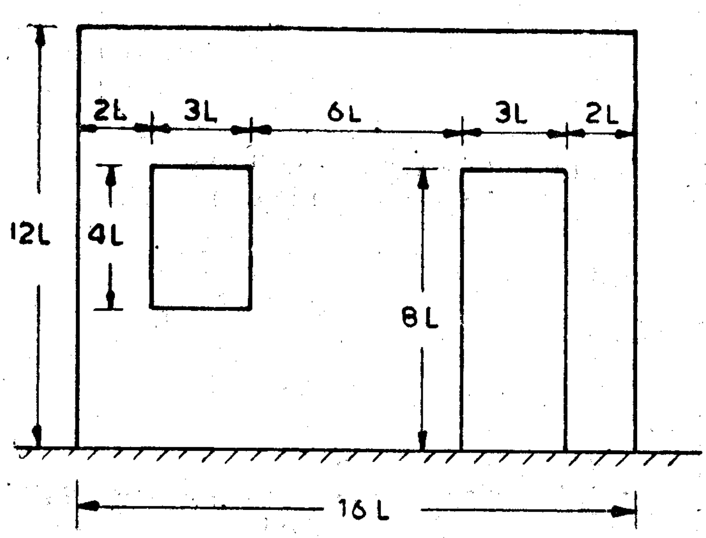


Fig. 2 (a)—Dimensions of Shear Wall Model Used in Numerical Analysis.

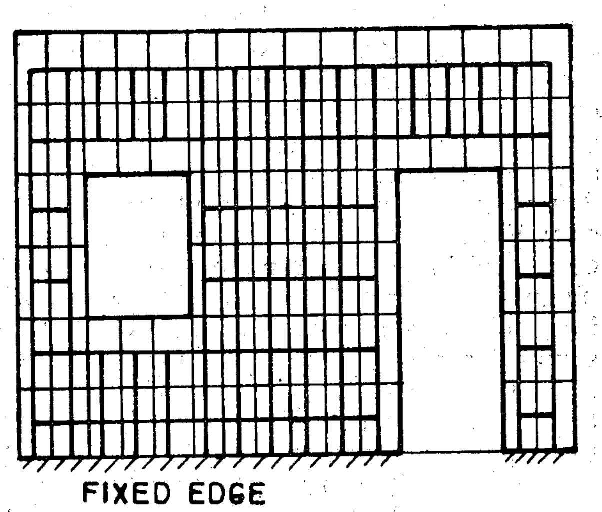


Fig. 2 (b)—The Equivalent Grid

SIGN CONVENTIONS

Fig. 3 shows the sign convention adopted for describing various quantities. Clockwise rotations and moments are designated as positive. Horizontal displacements are considered positive towards right hand side of original configuration while vertical displacements are positive if measured downwards.

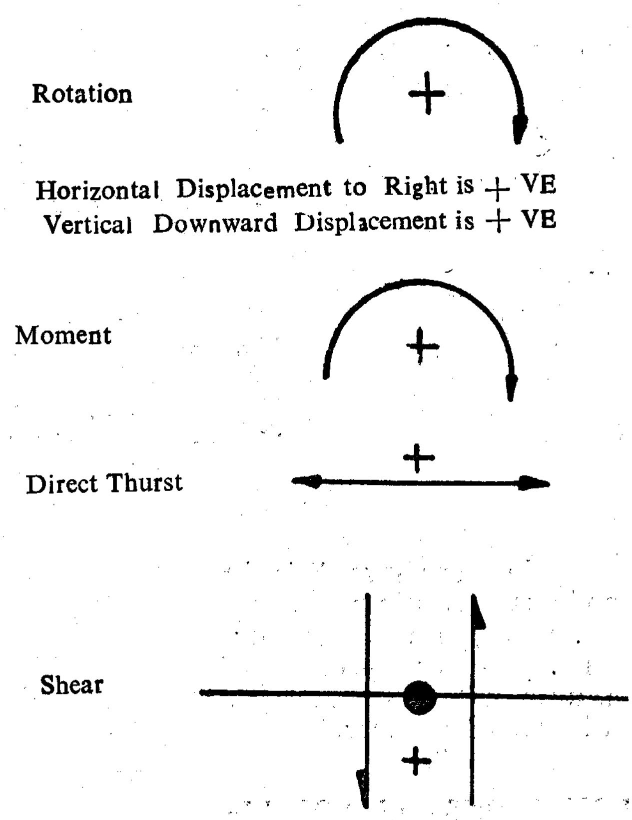


Fig. 3. Sign Convention Used.

FORCES IN MEMBERS

Fig. 4 shows the equivalent grid of the model with the joints numbered. Fig. 5 shows a typical node 0 where four members meet. These members are designated 01, 02, 03 and 04. Forces in members are expressed in terms of member properties and joint deformation. Appropriate subscripts are used to identify various quantities.

(a) *Thrust*

$$T_{01} = \frac{EA_{01}}{L_{01}} (\triangle_1 - \triangle_0)$$

$$T_{02} = \frac{EA_{02}}{L_{02}} (\delta_2 - \delta_0) \text{ etc.} \qquad (2)$$

(b) *Shear due to deflections*

$$S'_{01} = \frac{12\, EI_{01}}{L^3_{01}} (\delta_0 - \delta_1)$$

$$S'_{02} = \frac{12\, EI_{02}}{L^3_{02}} (\triangle_2 - \triangle_0) \qquad (3)$$

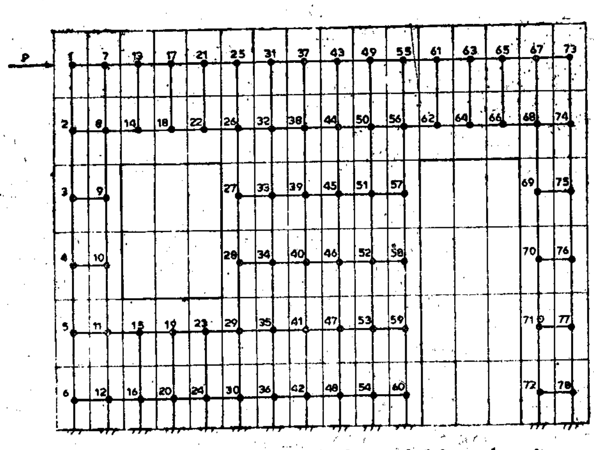


Fig. 4. Equivalent Grid and Numbering of Grid Joints.

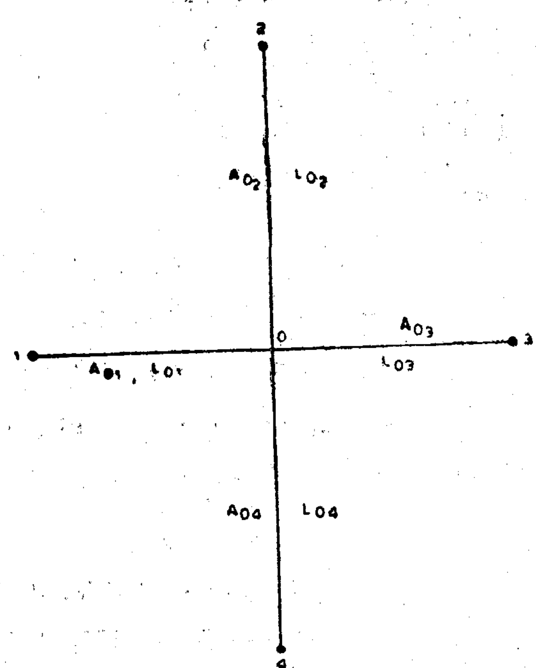


Fig. 5. Properties of Grid Members

(c) Shear due to rotation

$$S''_{01} = \frac{6\,EI_{01}}{L^2_{01}}(\theta_0+\theta_1)$$

$$S''_{02} = \frac{6\,EI_{02}}{L^2_{02}}(\theta_0+\theta_2) \tag{4}$$

(d) Moments

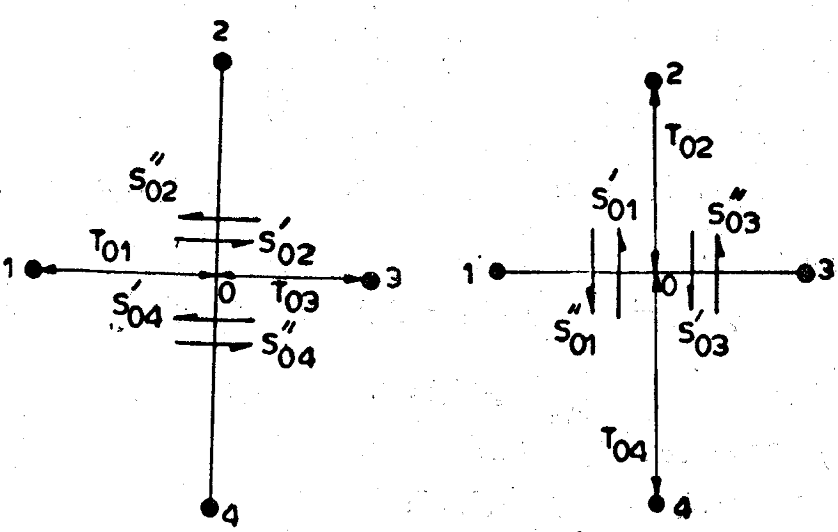
$$M_{01} = \frac{2EI_{01}}{L_1}\left(2\theta_0+\theta_1-\frac{3\delta_0}{L_{01}}+\frac{3\delta_1}{L_{01}}\right)$$

$$M_{02} = \frac{2EI_{02}}{L_{02}}\left((2\theta_0+\theta_2+\frac{3\Delta_0}{L_{02}}-\frac{3\Delta_2}{L_{02}}\right) \text{ etc.} \tag{5}$$

In the above, E is the modulus of elasticity of material, L is length of member, A is area of cross-section of member and I is the moment of inertia of member.

EQUATIONS OF EQUILIBRIUM

Horizontal forces are shown in Fig. 6 (a). If P_0 is external joint load acting rightwards at 0, then for equilibrium in horizontal direction.



(a) $\Sigma H = 0$ (b) $\Sigma V = 0$

Fig. 6. Equilibrium of Horizontal and Vertical Forces in the Grid.

$$\Sigma H = T_{01} - T_{03} + S'_{02} - S''_{02} - S'_{04} + S''_{04} + P_0 = 0 \tag{6}$$

Similarly, referring to Fig. 6 (b) and considering a vertical joint load V_0 at 0,

$$\Sigma V = T_{02} - T_{04} - S'_{01} + S_{01}'' + S'_{03} - S''_{03} + V_0 = 0 \tag{7}$$

and
$$\Sigma M = M_{01} + M_{02} + M_{03} + M_{04} = 0 \tag{8}$$

For the shear wall with a concentrated horizontal load as shown in Fig. 2, equations 6–8 are formulated. Using equations 2–5 and calling Δ/L as α and δ/L as β, equations 6–8 for joint 1 (say) look as follows :

$$\begin{aligned} -17\alpha_1 + \alpha_2 + 16\alpha_7 + \theta_1 + \theta_2 &= -8P/EA \\ -8\theta_1 - 8\theta_7 - 17\beta_7 + \beta_2 + 16\beta_7 &= -2W/EA \\ -3\alpha_1 + 3\alpha_2 + 68\theta_1 + 2\theta_2 + 32\theta_7 + 96\beta_1 - 96\beta_7 &= 0 \end{aligned} \tag{9}$$

where W is the vertical load intensity on top of wall, if any.

Similar equations are written for all the joints. This results in a set of 234 simultaneous equations which must be solved in order to understand wall behaviour. A digital computer IBM 1620 was used to solve these equations.

RESULTS AND DISCUSSIONS

Figs. 7 & 8 show the deflected shape of wall under vertical loads and horizontal loads acting in its own plane. It may be clearly seen from Fig. 8 that there is cantilever action present alongwith the shear type of behaviour. It is observed that for sections near the top and bottom of opening, the shear stresses are very high. Also, it is found that the maximum value of this shear stress does not occur at the centre of the width as would be expected is ordinary cases. The peak shifts towards the corners of openings. Stress concentration in observed at sections near the base of shear wall also.

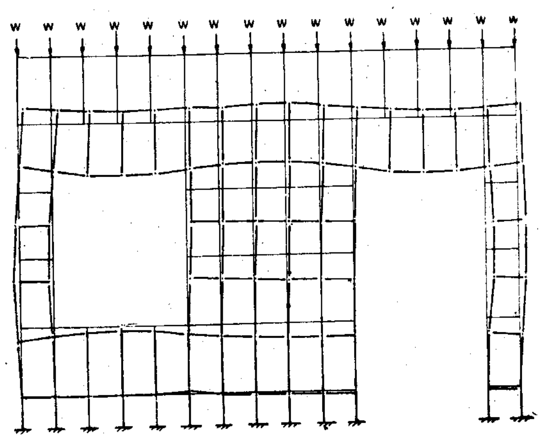


Fig. 7. Deflected shape of the Grid Lines Under Uniformly Distributed Superimposed Load.

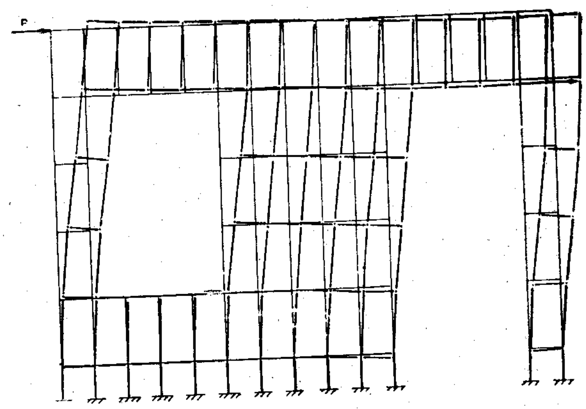


Fig. 8. Deflected Shape of Grid Lines Under Horizontal Load.

Critical sections for normal stress exist near base of the wall. Near the corner of openings, both types of stresses have high values making them vulnerable sections.

EXPERIMENTAL INVESTIGATIONS

Brick wall having the same dimensions as used in theoretical analysis were constructed in 1 : 6 cement mortar. These were tested under vertical and horizontal forces[4,5]. Fig. 9 shows cracks in the wall model (one typical case) resulting from the application of vertical and horizontal loads. These cracks appear exactly at the places indicated by the above analysis. This verifies the theoretical approach presented in this paper.

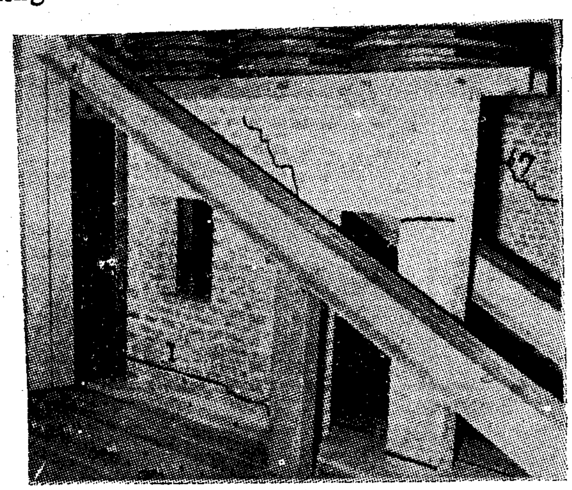


Fig. 9. Shawing a typical failure of wall model under vertical and lateral forces.

CONCLUSIONS

Analysis presented in this paper compares well with the observation during experiments and is therefore recommended for estimating strength and stiffness of wall penels subjected to lateral loads. Results indicate that the wall behaves as combination of bending and shear structure Pier analysis. which assumes absence of cantilever action of wall is, therefore, subject to errors resulting from such an action. Stiffness of wall obtained from pier analysis is therefore on higher side. Necessary corrections in computation of strength and stiffness of wall should be made based on the numerical analysis.

ACKNOWLEDGEMENTS

Authors thank Saravashri Kuldeep Singh and R.K. Vaish of Structural Engineering Research Centre, Roorkee, for their help in solving the large number of simultaneous equation on the IBM 1620 computer.

This paper is being published with the permission of the Director, School of Research and Training in Earthquake Engineering, University of Roorkee, Roorkee.

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