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# Effect of slit geometry on the performance of shear wall for resisting lateral loads

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***Abstract:* -** Reinforced concrete shear walls are normally constructed to resist lateral loads either due to earthquake or wind. Solid shear wall are very rigid structures introduced in multi storeyed structures to resist lateral load. The stiffness of the wall directly contributes to the increase in lateral resistance of RC frame. This phenomenon occurs particularly in multi storey tall framed building. However, flexible structures are recommended when the buildings are subjected to high magnitudes of earthquake. The idea of slit shear wall comes forward in this situation. Slits are introduced in solid walls for dissipating energy and convert them to flexible structures. The present study focuses how the size of slit affects the performance of shear wall when subjected to lateral load

***Keywords:* -** *solid shear wall; slit; dissipating energy; flexible structures*

## I. INTRODUCTION

Reinforced concrete shear walls are widely used in medium high rise building to resist lateral loads. When a shear wall is subjected to lateral load it behaves as a vertical cantilever beam. The maximum flexural moment due to horizontal load occurs at the base of the wall. Hence the plastic hinge is formed at a region nearer to the base and most of the input energy is dissipated in flexure manner at the base. The ductility resources of the most part of the wall remain unused. By some method if the ductility of the shear wall is increased, its performance during earthquake can be improved.

One method to improve the ductility of shear wall is the introduction of slit in the wall. A slit is a narrow opening purposely introduced in a wall which divides the shear wall into two or more narrow sub walls which are inter connected together by shear connectors. It is designed in such a way that under normal lateral loads, the shear connector remains elastic so that the slit shear walls behaves like solid shear wall as if there is no slits, but when subjected to earthquake loads the shear connector yields first and thus the ductility of the walls utilized. Thus shear walls should be transformed from rigid one to flexible one during heavy lateral loads.

## II. BACKGROUND

The concept of slit shear wall was patented by Muto[1]. The effectiveness of the slit shear wall concept was demonstrated in a thirty six storey steel framed building at Tokyo. In that building structural frame works, vertical strips of concrete forming a slit panel are introduced. The contact between the strips is made with plaster, asbestos sheets, synthetic resin or metal plates. The goal of the paper was to create an ideal structure which behaves as rigid one under reduced seismic action and as flexible one under high intensity earthquake. Khan et al [2-4] conducted elastic analysis, elasto-plastic and dynamic analysis of slit shear wall. The study revealed that yielding of connecting beam reduces the deflection response of the slit shear wall structure and the seismic loading induced on it. Lu and Wu [5] and Lu and Jiang [6,7] suggested that performance of the slit wall is improved and compared to ordinary solid shear walls. The introduction of slits in solid walls causes the damages first to occur at the sides of slit and thus reduces the damage at the base of walls. Jiang and Lu (2002) carried out non-linear time history analysis is for a ten storey slit shear wall model. Sabouri and Ziyaeifar [8] compared the performance of solid shear wall, coupled shear wall, slit shear wall and shear wall with upper connection. The parameters like strength, stiffness, lateral displacement and steel weight have been considered and concluded that the performance of coupled shear wall and slit shear wall is better than solid shear wall. The parametric study on the slit size is not being discussed in the literature. This present study addresses this lacuna.

## III. PRESENT STUDY

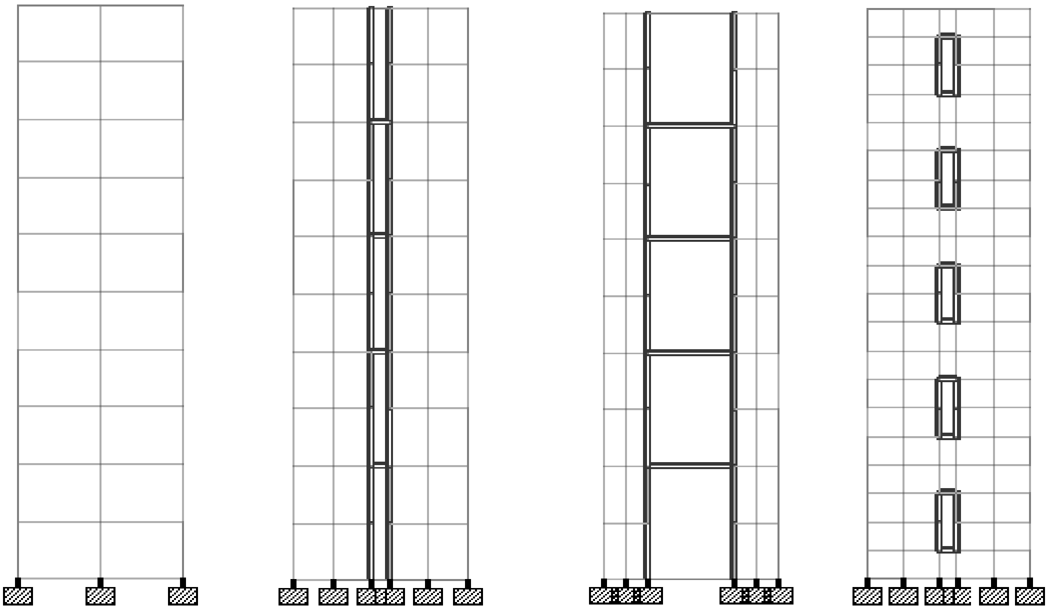
The present study concentrates on the geometry of slits. For that a five storey framed building is considered. The details of frame are given in Table 1. The variables considered are the width and height of the slit in the shear wall. The columns are considered at the edges to simulate the boundary. The various combinations considered in this study are given in Table 2. The finite element model of frames is given in Fig 1. A horizontal load of 100 kN is applied at the roof level of the shear wall for studying the deformation capability.

Table 1 Details of RC frame with shear wall

| Description | Magnitude |
|---|---|
| Bay width (B) | 4m |
| Storey height (H) | 3m |
| Frame height | 5@3m =15m |
| Column size | 0.40m x 0.40m |
| Wall thickness | 150mm |
| Lateral load at roof level | 100kN |

Table 2 The details of slit dimension.

| Frame designation | Width of slit, b (m) | b as a ratio of B , b/B | Height of slit, h (m) | h as the ratio of H, h/H |
|---|---|---|---|---|
| 0.0B x 0.0H* | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.1Bx 1.0H | 0.4 | 0.1 | 3.0 | 1.0 |
| 0.2Bx 1.0H | 0.8 | 0.2 | 3.0 | 1.0 |
| 0.3Bx 1.0H | 1.2 | 0.3 | 3.0 | 1.0 |
| 0.4Bx 1.0H | 1.6 | 0.4 | 3.0 | 1.0 |
| 0.5Bx 1.0H | 2.0 | 0.5 | 3.0 | 1.0 |
| 0.1Bx 0.9H | 0.4 | 0.1 | 2.7 | 0.9 |
| 0.1Bx 0.8H | 0.4 | 0.1 | 2.4 | 0.8 |
| 0.1Bx 0.7H | 0.4 | 0.1 | 2.1 | 0.7 |
| 0.1Bx 0.6H | 0.4 | 0.1 | 1.8 | 0.6 |
| 0.1Bx 0.5H | 0.4 | 0.1 | 1.5 | 0.5 |
| *No slit shear wall | | | | |



(a) 0.0B x 0.0H (b) 0.1Bx 1.0H (c) 0.5Bx 1.0H (d) 0.1Bx 0.5H

Fig 1 STAAD Model of the selected frames

The walls are modeled using plate elements and the columns are modelled using beam elements. The procedures in STAAD modelling are shown in Fig 2.

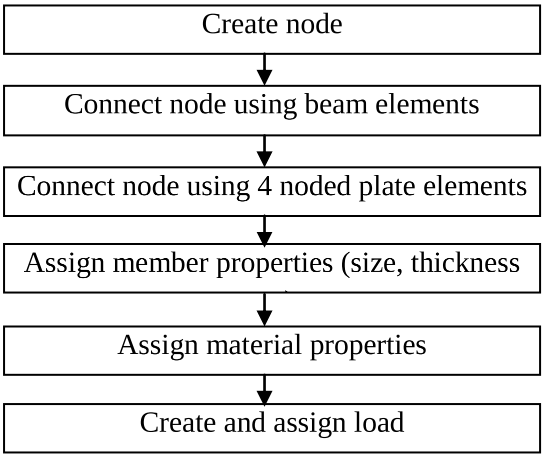


Fig 2 Flow chart for modelling in STAAD

## IV. FINITE ELEMENT ANALYSIS

The walls and end column are analysed using STAAD (2008) software. The linear analysis has been carried out using FEM model. The details for finite element solution techniques are described in this section.

**Theoretical basis of plate elements**

Finite element analysis is found very much useful in the analysis of plates and shells. Surface structures such as walls, slabs, plates and shells can be modelled using either three noded triangular or four noded quadrilateral element. For larger plates meshing is done for accuracy of results. The features of plate bending elements are (i)they have displacement compatibility between the plane stress component and plate bending component which is usually ignored in most flat shell/ plate elements. (ii) It has out of plane rotational stiffness and satisfies patch test absolutely. (iii) These elements have six degrees of freedom and available as triangles and quadrilaterals with corner nodes only. The four noded plate elements and the forces developed in it are shown in Fig 3. The forces can be calculated using the matrix given below.

$$\begin{pmatrix} Mx \\ My \\ Mxy \\ Qx \\ Qy \end{pmatrix} = \begin{pmatrix} 1 & x & y & 0 & 0 & 0 & 0 & 0 & 0 & x2 & xy & 0 & 0 \\ 0 & 0 & 0 & 1 & x & y & 0 & 0 & 0 & 0 & 0 & xy & y2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & x & y & -xy & 0 & 0 & -xy \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & x & y & 0 & -x \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & -y & 0 & x & y \end{pmatrix} \begin{pmatrix} a1 \\ a2 \\ . \\ . \\ a13 \end{pmatrix}$$

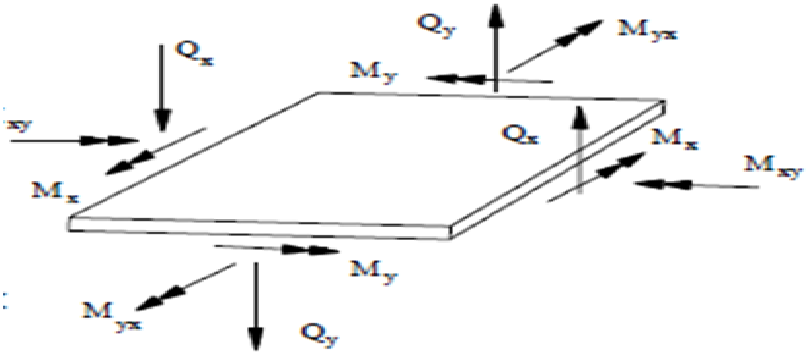


Fig 3 Forces in a four noded plate element

**Theoretical background of space beam element**

A SPACE structure, which is a three dimensional framed structure with loads applied in any plane, is the most general. A space beam element has 6 DOF (three translations and three rotations) at each node, and 12 DOF for each element. The stiffness matrix can be derived by super imposing the axial, bending, and torsion loadings in the XY, XZ and YZ planes. The stiffness matrix in local co- ordinates is given below.

$$K=\begin{bmatrix}
\frac{AE}{L} & 0 & 0 & 0 & 0 & 0 & -\frac{AE}{L} & 0 & 0 & 0 & 0 & 0 \\
0 & \frac{12EI_z}{L^3} & 0 & 0 & 0 & \frac{6EI_z}{L^2} & 0 & -\frac{12EI_z}{L^3} & 0 & 0 & 0 & \frac{6EI_z}{L^2} \\
0 & 0 & \frac{12EI_y}{L^3} & 0 & -\frac{6EI_y}{L^2} & 0 & 0 & 0 & -\frac{12EI_y}{L^3} & 0 & -\frac{6EI_y}{L^2} & 0 \\
0 & 0 & 0 & \frac{GJ}{L} & 0 & 0 & 0 & 0 & 0 & -\frac{GJ}{L} & 0 & 0 \\
0 & 0 & -\frac{6EI_y}{L^2} & 0 & \frac{4EI_y}{L} & 0 & 0 & 0 & \frac{6EI_y}{L^2} & 0 & \frac{2EI_y}{L} & 0 \\
0 & \frac{6EI_z}{L^2} & 0 & 0 & 0 & \frac{4EI_z}{L} & 0 & -\frac{6EI_z}{L^2} & 0 & 0 & 0 & \frac{2EI_z}{L} \\
-\frac{AE}{L} & 0 & 0 & 0 & 0 & 0 & \frac{AE}{L} & 0 & 0 & 0 & 0 & 0 \\
0 & -\frac{12EI_z}{L^3} & 0 & 0 & 0 & -\frac{6EI_z}{L^2} & 0 & \frac{12EI_z}{L^3} & 0 & 0 & 0 & -\frac{6EI_z}{L^2} \\
0 & 0 & -\frac{12EI_y}{L^3} & 0 & \frac{6EI_y}{L^2} & 0 & 0 & 0 & \frac{12EI_y}{L^3} & 0 & \frac{6EI_y}{L^2} & 0 \\
0 & 0 & 0 & -\frac{GJ}{L} & 0 & 0 & 0 & 0 & 0 & \frac{GJ}{L} & 0 & 0 \\
0 & 0 & -\frac{6EI_y}{L^2} & 0 & \frac{2EI_y}{L} & 0 & 0 & 0 & \frac{6EI_y}{L^2} & 0 & \frac{4EI_y}{L} & 0 \\
0 & \frac{6EI_z}{L^2} & 0 & 0 & 0 & \frac{2EI_z}{L} & 0 & -\frac{6EI_z}{L^2} & 0 & 0 & 0 & \frac{4EI_z}{L}
\end{bmatrix}$$

We can find the transformation matrix for axial, bending, and torsion loading and then use the equation,

$$K_G \quad = T^T \; K \; T$$

Once the global stiffness matrix is obtained we can calculate the load at each node from the relation

$$P = \; K_G \, u.$$

The solution of these equations manually is tedious, time consuming and error prone task particularly for three dimensional stress analysis of solids and shells. Hence we make use of software to analyse such structures. A pre processor creates the finite element model and the results can be displaced as tables and Figs.

## V. RESULTS AND DISCUSSION

In the present study, the performance of slitted shear wall for a given lateral load of 100kN is considered. The slits with widths ranging from 0.1times to 0.5 times the bay width and height ranging from 0.5 times to full height frame height are analysed. The variation of lateral displacement for varying slit width and slit heights 3m and 1.5m is shown in Fig 4 and Fig 5 respectively. It is seen that the lateral displacement is increasing gradually for lesser slit widths and tremendous increase in the value for larger slit widths. The top storey displacement for various slit width is plotted in Fig 6.

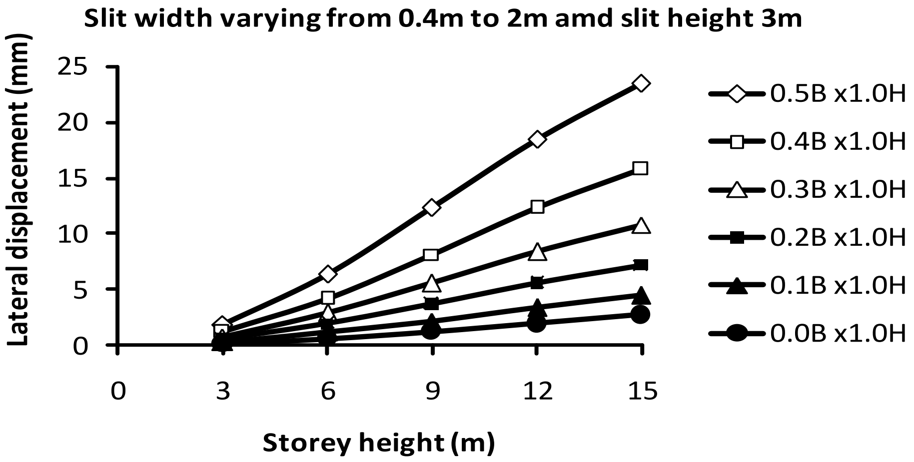


Fig 4 Lateral displacement at different storey level for varying slit width and slit height 3m

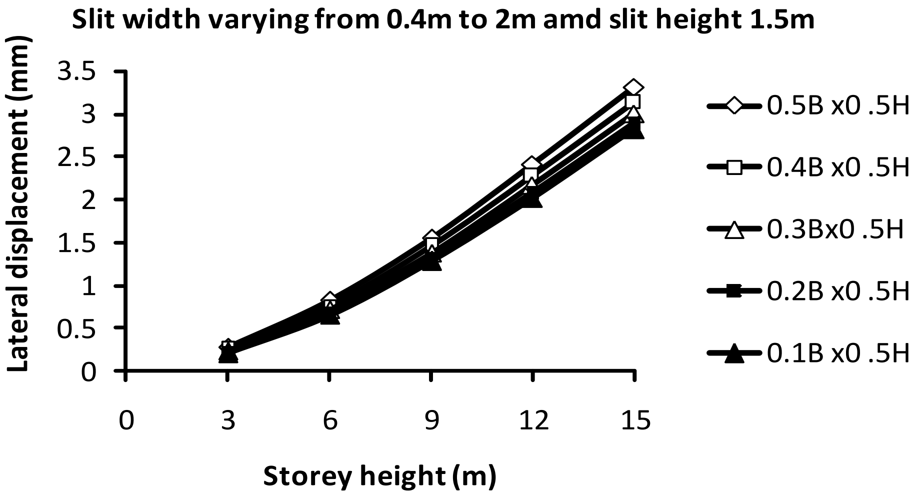


Fig5. Lateral displacement at different storey level for varying slit width and slit height 1.5m

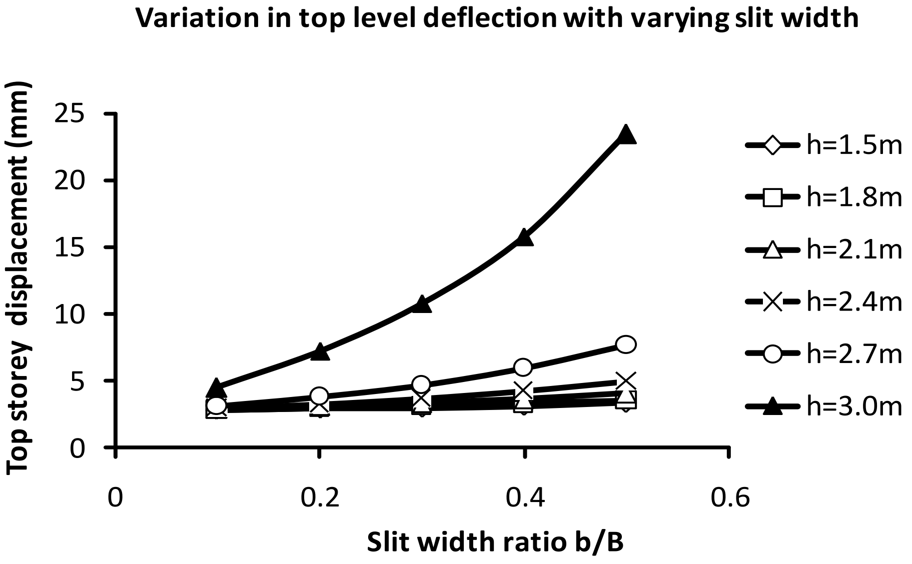


Fig 6. Top storey displacement for different slit width

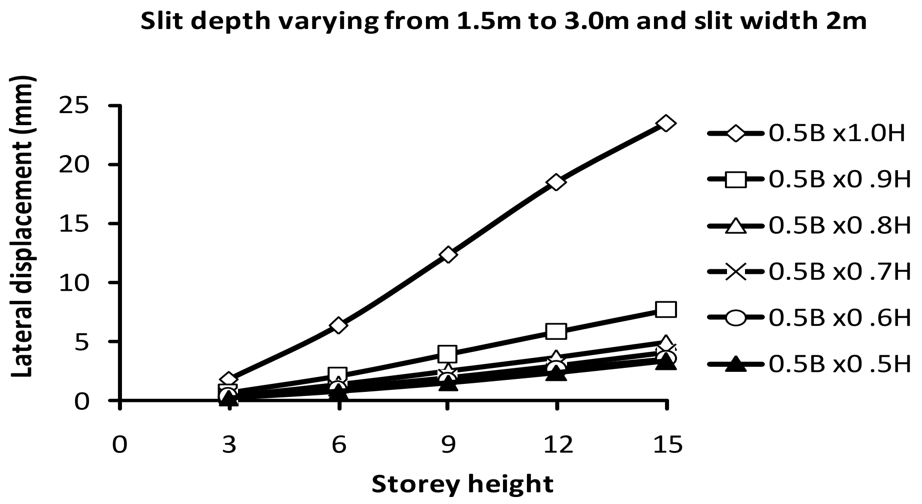


Fig7. Lateral displacement at different storey level for varying slit height and slit height 2m

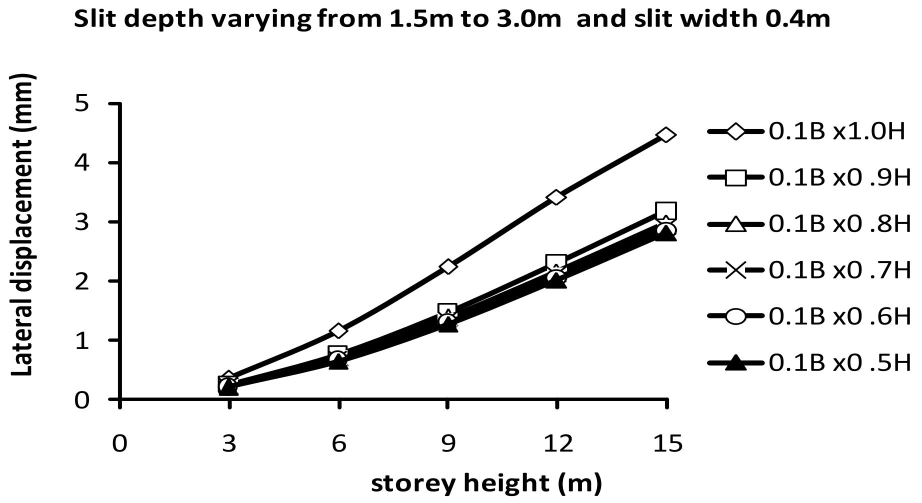


Fig 8. Lateral displacement at different storey level for varying slit height and slit height 0.4m

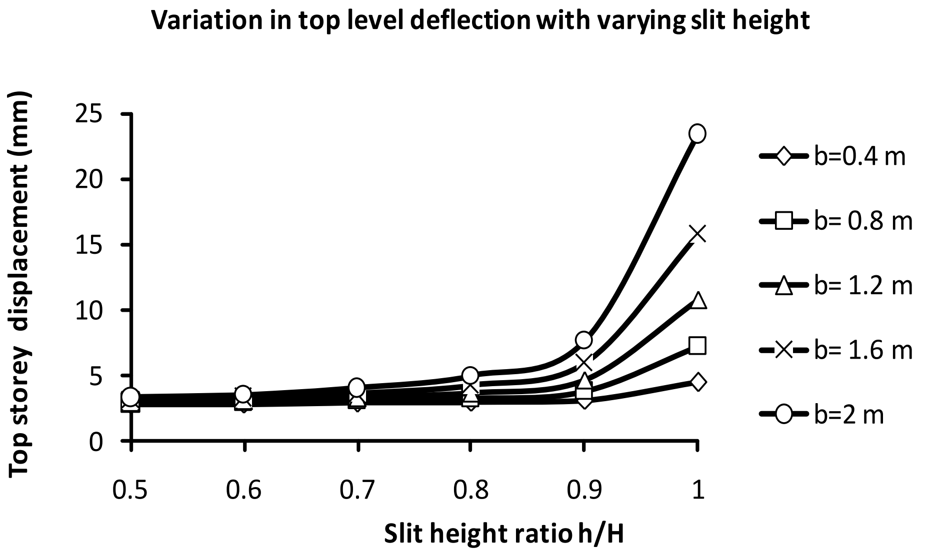


Fig 9. Top storey displacement for different slit depth

The effects of varying slit depths are plotted in the Fig 7, Fig 8 and Fig 9. It is seen that there is a jump in the lateral displacement values for higher slit heights.

## VI. CONCLUSIONS

Based on the analytical study carried out following conclusions are arrived at

i. The slit geometry greatly influences the static deformation characteristics of the shear wall structure.

ii. The increase in the deformation of the shear wall structure is found to be greater with the increase in width of slit rather than the height of the slit. The 2m wide slits shown larger deformations compared to all other slits.

However, more rigorous analysis is required incorporating non-linearity, realistic load conditions etc to arrive at the optimum slit geometry.

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