Behavior of Shear Wall with Base Opening

by

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CERTIFICATE OF APPROVAL

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(Muhammad Masood)

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ABSTRACT

Shear wall, commonly used to provide lateral stiffness of buildings, and is an important element for seismic resistance of a structure. Shear walls are frequently pierced for doors, windows and corridor openings. Also provision of parking at basement or ground level may require opening to be kept at the base of a shear wall. As the entire lateral load acting in a shear wall is transmitted to the ground through the base, it is the most critical section of a shear wall. So openings at that level will affect its overall stiffness as compared to shear wall without opening. In this research work, concentration is given to establish the range of base opening that may be allowed without significantly affecting the strength and stiffness of a structural wall. The behavior of both planar and box type shear wall (core wall) with varying percentages of base opening have been studied.

With the above objective, finite element package ANSYS (2000) has been used for modeling the shear wall and study its behavior in terms of stress pattern and stiffness variation due to incorporation of opening at base. The behavior of shear wall for different opening width have been studied and compared to that of a shear wall without opening. Three parametric ratios such as deflection ratio, maximum shear stress ratio and maximum flexural stress ratio have been studied. The ratios are calculated as the ratio of corresponding values of a shear wall with and without base opening. A set of non-dimensional graphs have been prepared featuring important parameters which will guide the designer to choose appropriate opening width without hampering the lateral stiffness significantly. An investigation is also performed to show how the degradation of stiffness of shear wall with base opening can be compensated using additional portion of the shear wall.

It is observed that these three parametric ratios increase with the increase of percentage of base opening. However, the rate of increase of these ratios has been found to be relatively low up to 60% base opening. Beyond 60% opening, these ratios increase rapidly, meaning strength and stiffness degradations are excessive beyond this limit. It is also observed that, with the introduction of compensating elements, it is feasible to fully compensate the deflection and flexural stress ratios and also bring about significant improvement in the shear stress ratio. Based on the findings of the study, it has been recommended that in high-rise construction a provision of base opening up to 50% of the length of the wall may be considered as a feasible option.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

CHAPTER : 1

INTRODUCTION

1.1 General

Shear walls may be defined as structural elements, which provide strength, stiffness and stability against lateral loads deriving strength and stiffness mainly from its shape. These are vertical stiffness members designed to resist lateral loads due to wind or earthquake. The walls may be either planar open section or closed section around elevator and stair cores. BS 8110 defines a shear wall as a vertical load-bearing member whose length exceeds four times its thickness.

Reinforced concrete shear walls are commonly used to provide lateral stiffness of buildings and are an important element for seismic resistance of a structure. Shear walls are frequently pierced for doors, windows, corridor openings or also for providing parking facility. Provision of parking at basement or ground level requires opening to be kept at the base of a shear wall. Shear wall with opening presents a highly indeterminate frame system with rather more complicated behavior. If the openings are appreciable in size the stiffness of the wall will be reduced and stress distribution in the wall will be greatly affected. If openings are small, their effect on the overall state of stress in a shear wall is minor (Url:1; Samih and Faiq). Large openings have a pronounced effect and, if openings are very large, the resulting system would behave more like a frame.

Openings in shear walls commonly occur in regularly spaced vertical rows throughout the height of the wall, and the connection between the wall sections is provided by either connecting beams (or spandrels), which form a part of the wall, or floor slabs, or a combination of both. If the openings do not line up vertically and/or horizontally, the complexity of the analysis is greatly increased. In most cases when openings occur in a regular fashion, a rigorous analysis of a wall with openings is not required (Url:1). In the design of a wall with openings, the deformations must be visualized in order to establish some approximate method for analyzing the stress distribution of the wall. The major points that must be considered are the lengthening and shortening of the extreme sides (boundaries) due to deep beam action, the stress concentration at the corner junctions of the horizontal and vertical components between openings, and the shear and diagonal tension in both the horizontal and vertical components (Url:1). The design of coupled wall with inter connecting coupling beams in the upper stories are widely covered in the literature (Beck, 1962; Coull, 1967; Park, 1975; Rosman, 1964; Url:2). However, little research has been conducted on the effect of openings at the base of a shear wall, a condition encountered to provide access for vehicular movement at basement or ground floor level.

The base is the most critical section of a shear wall as the entire lateral load acting on a shear wall is transmited to the ground through the base. So openings at that section will affect its overall stiffness as compared to shear wall without opening. Maximum deflection and stresses at base will be higher than that of shear wall without opening. The section will become more critical with the increase in opening width and shear wall height. It is, important to establish the range of base opening that may be allowed without significant loss of strength and stiffness of a structural wall.

1.2 Objectives of the Research

The research reported in this thesis has been conducted with the following objectives:

- To study the behavior of planar and closed shear wall with base openings.
- To study the behavior of shear wall with varying width of opening.
- To investigate governing parameters influencing the behavior of such shear wall.
- To develop recommendations for the allowable opening width in shear wall without significant loss of stiffness.
- To develop recommendations for the analysis of concrete shear wall with varying width of opening.

1.3 Methodology

Finite Element Technique has been used for modeling shear wall with base opening. The general purpose finite element package ANSYS (2000) has been the tool for modeling the shear wall and study its behavior in terms of stress pattern and stiffness variation due to incorporation of opening at base. The behavior of shear wall for different opening width have been studied and compared to that of a shear wall without opening. Linear elastic analysis using three dimensional membrane shell element has been used for suitable meshing. A refined mesh has been used around the opening to capture the likely stress concentration at the juncture.

1.4 Scope

The present research has been undertaken to study the behavior of shear wall with base opening.

1. Necessary finite element models would have been developed for varying opening width and height using finite element package ANSYS (2000).
2. The behavior of plane shear wall and box type shear wall would have been studied in this research.
3. Two types of opening at base would have been modeled for plane shear wall. These are shear wall standing on double legs (central opening) and standing on single leg (edge opening).
4. In box shear wall, opening will be kept in two opposite parallel planes. In this study box type shear walls would have been classified into two types depending on direction of the applied wind load with respect to location of the base openings.
5. Maximum shear stress, maximum flexural stress and deflection at different heights would have been studied. The behavior of shear wall for different opening width would have been studied and compared to that of a shear wall without opening. A set of non-dimensional graphs would have been prepared featuring important parameters which will guide the designer to choose appropriate opening width without hampering the lateral stiffness significantly.
6. An investigation performed for a complete 15 storied frame structure with or without shear wall keeping provision of base opening. The effect of underground basement wall on the stiffness of overall structure would have also been studied.
7. The improvement in stiffness of shear wall with base opening would have been shown by introducing compensatory measure.

1.5 Outline of the Thesis

The research work conducted for achieving the stated objectives is presented in seven chapters of the thesis so that the steps involved in the study may be properly delineated. A brief description of the contents of each chapter is as follows:

The current chapter, Chapter 1, introduces the reader with the background of the thesis work. Application, types and behavior of shear wall, need for opening in shear wall and a review of related analysis are described in Chapter 2. Chapter 3 describes the methodology for model generation, refining mesh and loading considered. The behavior of plane shear wall with base opening and a comparative study between applied uniformly distributed load and wind load, and finally the behavior of plane shear wall with base opening with a compensatory measure are presented in Chapter 4. Chapter 5 deals with the behavior of box type shear wall with base opening. Chapter 6 narrates the behavior of a 15 story shear wall frame structure. Finally, Chapter 7 draws conclusions by summarizing the outcome of the study and proposes new direction for further research and development.

CHAPTER : 2

Literature Review

2.1 Introduction

Lateral forces acting on reinforced concrete structures are resisted by different systems. Frames are commonly used for low-rise construction. Such frames may also rely on the contribution of infill walls and partitions to lateral load resistance, especially if wind is the only lateral force considered. When large lateral loads must be resisted, such as seismic loads or very high wind loads, shear walls often are incorporated in building as a means of lateral load resistance. In such buildings shear walls may be constructed between column lines or may be incorporated into stair walls, elevator shafts, or utility shafts.

2.2 Location of Shear Wall

Fig. 2.1(a) and 2.1(b) show plans of buildings with different layout of shear walls. The structural engineer must locate shear walls to maximize the structural efficiency by making it efficient from functional as well as aesthetic view point. For example, in Fig. 2.1(a), walls located on the outer perimeter of the building provide maximum flexibility for use of floor space: however, they eliminate windows and may reduce the space available for offices and apartments in which exterior views and light arc highly desirable. Shear walls often are placed in elevator or stairway areas so that both structural and user needs are satisfied.

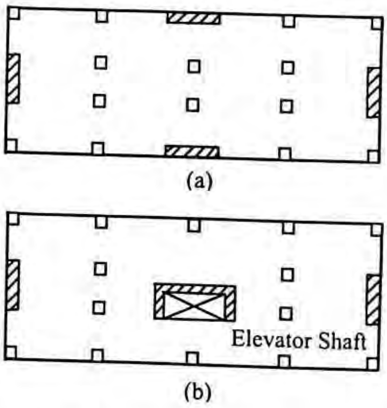


Fig. 2.1: Plans of Structures with Shear Walls. (a) Separate Walls. (b) Incorporated into Elevator Shaft.

Fig. 2.2 illustrates another layout of shear wall. The resultant N-S lateral force is at the center of the long side of the building. In this case, however, shear walls AB and CD, which resist the lateral force in the N-S direction. are located to the left of the center of the building. The distance x between the resultant lateral force and the centroid of the shear wall (the centroid of "shear resistance") produces a torsional moment on the structure. Torsion can result in rotational deformations of the building and create overstresses or excessive deformations in columns farthest from the centroid of the shear walls. Torsion also is produced by loads acting on the short side of the building because wall BD is not colinear with the resultant applied shear force. Such torsional effects should be avoided by carefully locating the walls. In most structures, the lateral stiffness of the columns is much smaller than that of the walls. Therefore, most of the shear is resisted by walls.

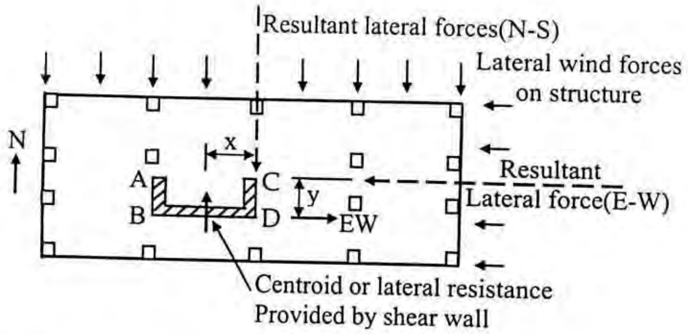
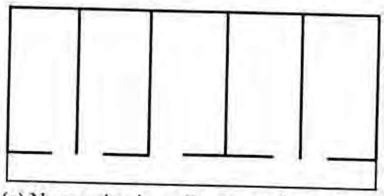


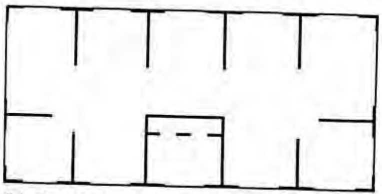
Fig. 2.2: Torsion Owing to Eccentric Shear Wall Location (Ferguson, 1987).

Fig. 2.3 shows various ways of utilizing shear walls in multistory buildings. The scheme of Fig. 2.3(a) has shear walls without openings across the building with access through a gallery running alongside the building. Each wall accepts a share of the lateral load proportional to its stiffness. The calculation of lateral stiffness is simple, and stresses in such shear walls without openings involve simple bending theory only.

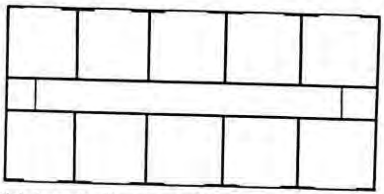
Schemes (b) and (c) of Fig. 2.3 have interior corridors, and, therefore, the shear walls are interrupted by an opening on each floor and they are interconnected either by slabs or beams. Although the major shear walls are usually in the transverse direction of the building, separating the individual apartments, stability in the longitudinal direction is normally provided by elevator shafts or some longitudinal shear walls. Such structural systems as shown in Fig. 2.3 are known as egg-crate or cross-wall buildings; they are extremely rigid in the direction of the shear walls.



(a) No opening in walls: access from outside



(b) Coupled walls



(c) Longitudinal corridor walls

Fig. 2.3: Schematic Layouts of Shear Wall Structures

2.3 Application of Shear Wall

Shear walls are used in apartment, hotel, and other residential buildings where walls are customarily spaced between 15 and 24 ft apart with floor slab thicknesses proportioned according to span. Spans up to 40 ft have been used with prestressed hollow-core concrete slabs (Fintel, 1986).

Shear wall structures are well suited for construction in earthquake prone areas. Buildings of up to 70 stories have been built using shear walls. Feasibility studies for projects up to 200 stories utilizing shear walls have been made and found workable (Fintel, 1986).

2.4 Types of Shear Wall Structures

(A) Coupled Shear Wall Structures

Analysis of walls with opening is often a complex problem. Openings normally occur in vertical rows throughout the height of the wall and the connection between the wall segments is provided by either connecting beams or floor slabs, or a combination of both.

The terms "coupled shear walls," "pierced shear walls," and "shear wall with openings" are commonly used to describe such units as shown in Fig. 2.4.

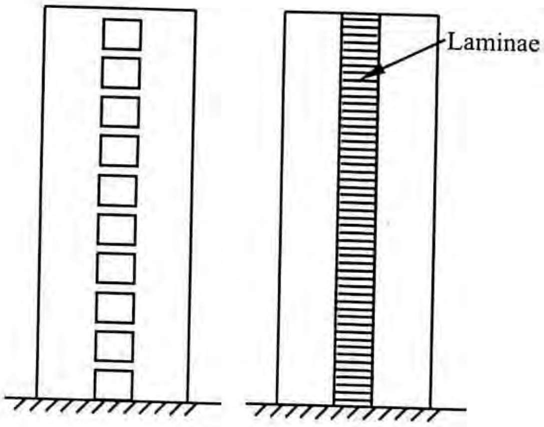


Fig. 2.4: Coupled Shear Wall.

If the openings are very small, their effect on the overall state of stress in a shear wall is minor. Larger openings have a more pronounced effect and, if very large, may result in a system in which typical frame action predominates. The degree of coupling between two walls separated by a row of openings has been conveniently expressed in terms of a geometrical parameters **α** (having a unit 1/length), which gives a measure of the relative stiffness of the connecting beams with respect to that of the walls. The parameter α appears in the basic differential equation of the so-called continuum approach. The studies (Beck, 1962; Pauley,1971; Coull and Choudhury, 1967) indicate that when the dimensionless parameter αH (H being the total height of the walls) exceeds 13, the walls may be analyzed as a single homogeneous cantilever. When $\alpha H < 0.8$, the walls may be treated as two separate cantilevers. For intermediate values of αH (i.e., $0.8 < \alpha H < 13$), the stiffness of the connecting beams should be considered.

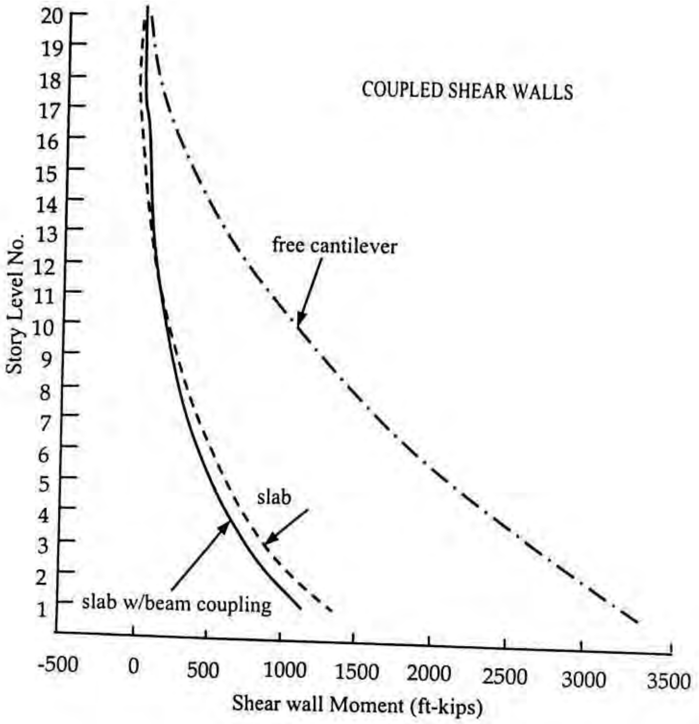


Fig. 2.5: Shear Wall Moments for the Coupled System (Fintel, 1986).

The effectiveness of the coupling of shear walls can be clearly seen from Fig. 2.5, where the cantilever moment of the shear wall acting alone is compared with the moment reduced due to frame action caused by coupling.

A special type of coupled shear wall is shown in Fig. 2.6 where the coupled shear wall is supported on exterior columns only. Parking areas under residential buildings require different spans from the apartments above. For this reason the shear walls must be stopped and supported on exterior columns, thus leaving the entire parking area column-free. The lower portions of such shear walls act as a deep beam spanning between the supporting columns.

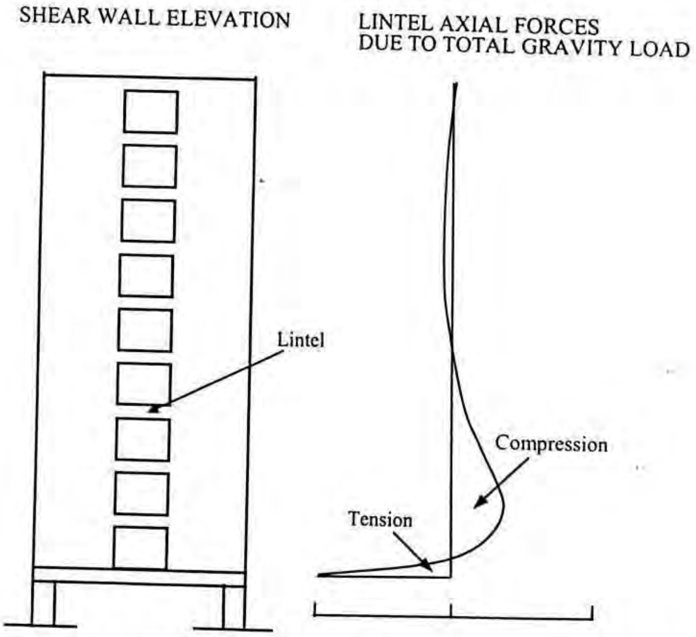


Fig. 2.6: Coupled Shear Walls Supported on Exterior Columns to Accommodate Parking Facilities in the Ground Story (Fintel, 1986).

The majority of shear wall buildings have coupled shear wall systems to accommodate corridors in the middle. A study carried out at the Portland Cement Association showed the feasibility of supporting a coupled shear wall on exterior columns as shown in Fig. 2.6. The computer study showed that the second floor beam (supporting the shear walls) acts like the tension member for the coupled shear wall above. The lintels over the doors for the next five stories act as compression struts: above that level the forces in the lintels are minimal, as can be seen in Fig. 2.6. The study also indicated that the shear wall must be supported during construction only until about the fifth floor is cast; after that the structure is self-supporting (Fintel, 1986).

(B) Shear Wall-Frame Structures

Since the late 1940s, when the first shear walls were introduced in high-rise construction, their use in high-rise buildings to resist lateral loads has been extensive. This was particularly in tall frames which could not be efficiently designed to satisfy lateral load requirements.

The great majority of multistory buildings today are, in fact, shear wall-frame structures, since elevator shafts, stairwells, and central core units of tall buildings are mostly treated as shear walls, in addition to isolated concrete walls (if some are used). Frame structures depend primarily on the rigidity of member connections for their resistance to lateral forces, and they tend to be uneconomical beyond 15 to 20 stories. To improve the rigidity and economy, shear walls are introduced in buildings exceeding 15 to 20 stories in height.

The term shear wall-frame structure is used here to denote any combination of frames and shear walls. This category would include the typical frame structure with shear walls appropriately located about the plan and the so-called hollow-core or framed-tube-with-core structure. The shear wall can have any plan shape and may be linear, angular, rectangular, or circular in plan.

The common assumption to neglect the frame and assume that all the lateral load is resisted by the shear walls may not always be conservative, since, owing to the interactive forces, the frame is usually subjected to forces higher than the exterior applied wind forces in the upper stories (Fintel, 1986). Therefore, distributing the applied wind to the different resisting elements in proportion to their relative stiffness in the case of shear wall-frame interaction can lead to erroneous results (Fintel, 1986).

The main function of a shear wall for the type of structure being considered here is to increase the rigidity for lateral load resistance. Shear walls also resist vertical load, and the difference between a column and a shear wall may not always be distinct. The distinguishing features are the much higher moment of inertia of the shear wall than a column and the width of a shear wall, which is not negligible in comparison with the span of adjacent beams. The moment of inertia of a shear wall would normally be at least 50 times greater than that of a column, and a shear wall would be at least 5 ft wide.

The introduction of shear walls represents a structurally efficient solution to the problem of stiffening a frame system. The frame deflects predominantly in a shear mode shown in Fig. 2.7(a), while the shear wall deflects predominantly in a bending mode as shown in Fig. 2.7(b).

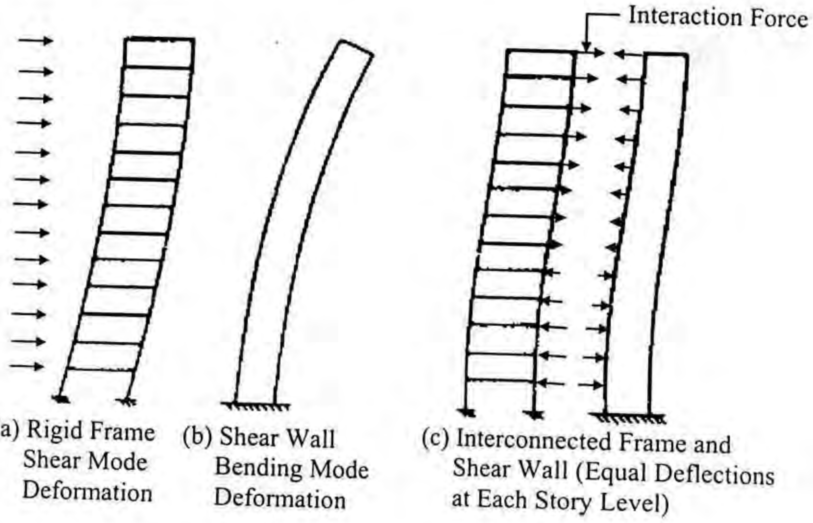


Fig. 2.7: Deformation Mode

In a building, the in-plane rigidity of the floor slabs forces the deflection of the walls and the frames to be identical at each story level. To force the walls and the frame into the same deflected shape, internal forces are generated that equalize the deflected shape of each. Thus, the frame in the upper stories pulls back the wall, while in the lower stories the wall pushes back the frame. These internal interactive forces, shown in Fig. 2.7(c), greatly reduce the deflection of the overall combined system, creating a considerably higher overall stiffness than would be the sum of the individual components, each resisting a portion of the exterior loads. In that distinctive feature of increasing the stiffness through a set of internal forces lies the great advantage of shear wall-frame interactive systems (Fintel, 1986).

2.5 Lateral deflection or drift

Lateral deflection or drift is the magnitude of displacement at the top of a building relative to its base. The ratio of the total lateral deflection to the building height, or the story deflection to the story height, is referred to as the "deflection index." The imposition of a maximum allowable lateral sway (drift) is based on the need to limit the possible adverse effects of lateral sway on the stability of individual columns as well as the structure as a whole, and the integrity of nonstructural partitions, glazing, and mechanical elements in the building. Cracking associated with lateral deflections of nonstructural elements such as partitions, windows, etc., may cause serious maintenance problems (loss of acoustical properties, leakage, etc.). A drift limitation is thus an important parameter to be selected to minimize such cracking.

In the absence of code limitations in the past, buildings were designed for wind loads with arbitrary values of drift index, ranging from about 1/300 to 1/600 depending on the judgment of the engineer. Deflections based on drift limitation of about 1/300 used several decades ago were computed assuming the wind forces to be resisted by the structural frame alone. In reality, as mentioned previously, the heavy masonry partitions and exterior cladding common to building of that period considerably increased the lateral stiffness of such structures. In contrast, in most buildings that have been constructed in recent years, the frame alone resists the lateral forces.

The Uniform Building Code, BOCA, and the National Building Code of Canada, among North American model building codes, specify a maximum value of the deflection index of 1/500, corresponding to the design wind loading. Also, ACI Committee 435 recommends a drift limit of 1/500. In recent years many engineering offices, owing to competitive pressures, have somewhat relaxed the drift criterion by allowing an overall drift of slightly over H/500, with the maximum drift in any one story not to exceed H/400 (Fintel, 1986). Also, in cases where wind tunnel studies indicate wind forces in the building to be smaller than those specified in the code, designers take the liberty of applying the H/500 criterion to the smaller (wind tunnel) wind forces (Fintel, 1986).

Most of the modern tall reinforced concrete buildings containing shear walls have computed deflections ranging between H/800 and H/1200 due to the inherent rigidity of the shear wall-frame interaction (Fintel, 1975).

2.6 Failure Modes of Shear Wall and Design Consideration

Fig. 2.8 shows several possible failure modes for shear walls with large height-to-length ratios (Ferguson, 1987). Fig. 2.8(a) shows a wall with a very low vertical (flexural) reinforcement ratio. As the wall is deformed the tensile steel elongates at the base and only one major flexural crack forms before the steel fractures. Fig. 2.8(b) shows a wall that failed in shear after a large number of flexural cracks formed. The critical crack is a flexural crack that inclines downward at about 45°. At failure, some of the horizontal reinforcement across the critical crack may fracture and lead to an opening of the crack with crushing of the compression zone at the root of the critical crack. Fig. 2.8(c) shows the most common failure mode, that is, one in which considerable yielding of the flexural reinforcement eventually leads to crushing of the concrete at the base. The amount of flexural reinforcement and the area of concrete in compression is important in determining the mode of failure.

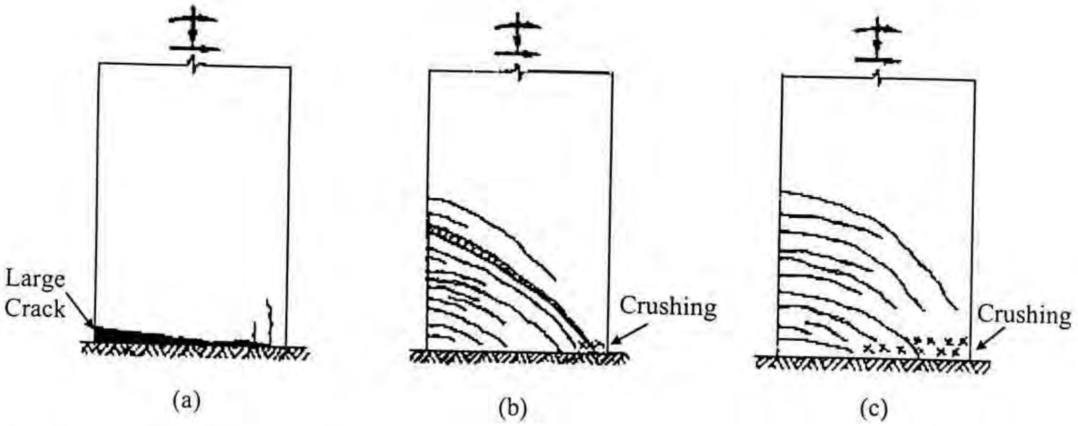


Fig. 2.8: Failure Modes: High-rise Walls. (a) Fracture of Steel. (b) Flexure-Shear Failure. (c) Failure by Concrete Crushing (Ferguson, 1987).

From the preceding discussion, it can be seen that shear walls act as cantilever beams fixed at the base to transfer load to the foundation. The forces that must be considered in the design of the wall include

a. Varying shear that is maximum at the base.
b. Varying flexure that is maximum at the base and produces compression on one end of the wall and tension on the opposite end.
c. Gravity loads that produce compression on the wall.

The forces and the deformed shape of the wall are shown in Fig. 2.9. In addition, the foundation must be designed to resist the shear and moment at the base of the wall. The reinforcement at the base must be carefully detailed so that the forces can be transferred from the wall to the foundation. The critical detail is anchorage of bars into the foundation and splicing bars in the wall at or near the base.

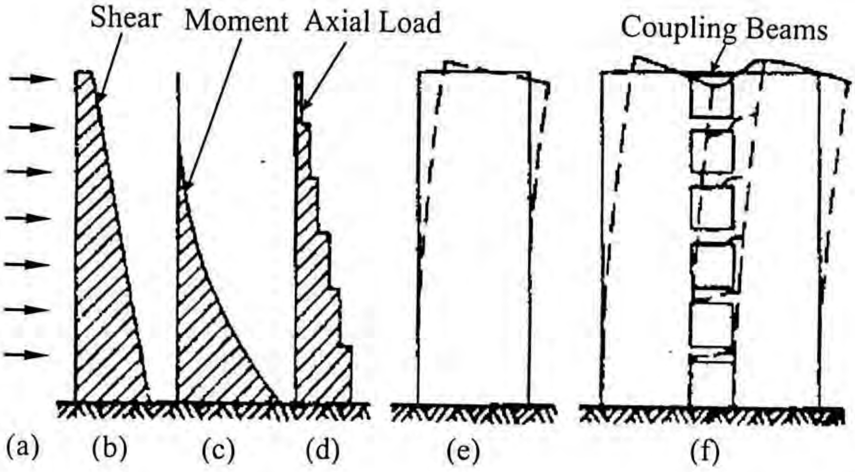


Fig. 2.9: (a) Lateral Loads. (b) Shear Diagram. (c) Moment Diagram. (d) Axial Loads. (e) Isolated Wall. (f) Coupled Wall (Ferguson, 1987).

2.7 Shear Wall with Base Opening

Opening is kept at the base of a shear wall mainly for provision of parking at basement. If the openings are appreciable in size the stiffness of the wall will be reduced and stress distribution in the wall will be greatly affected. If openings are small, their effect on the overall state of stress in a shear wall is minor (Url: 1, Samih and Faiq). Bryan Stafford Smith and Alex Coull have been studied shear wall with base opening in the book "Tall Building Structures: Analysis and Design". To discuss the different types of force interactions, two extreme cases of discontinuity have been considered. In Case 1 the inner pair of walls have openings in the ground story, which leave each wall standing, in effect, on a pair of edge columns shown in Fig. 2.10. In Case 2, the inner walls are cut back in the ground story to leave each wall supported on a much shorter central wall shown in Fig. 2.11.

For Case 1 the equivalent half-structure planar model has been considered, as shown Fig. 2.10(b). When the structure is subjected to horizontal loading, the flexibility of the columns supporting the right-hand wall causes the ground story of that wall to be very much less transversely stiff than that of the left-hand wall. The flexural stiffness of the right-hand wall, however, has been reduced by a proportionately much lesser amount because of the edge location of the columns. The resulting effect in Case 1, therefore, is a heavy transfer of shear from the discontinuous wall (wall with base opening) to the continuous wall, with a relatively smaller transfer of moment. As an approximate illustration, the resulting forces on the walls are shown in Fig. 2.10(c).

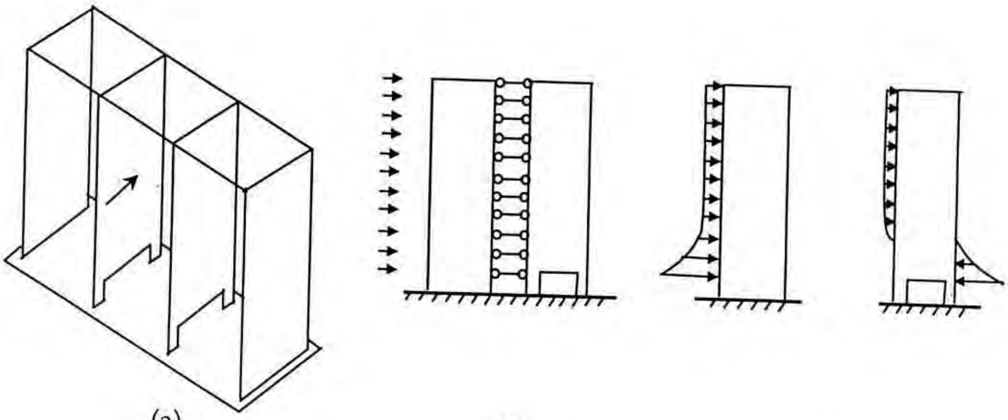


Fig. 2.10: (a) Walls with Openings at Base; (b) Half-structure Planar Model; (c) Resulting Loadings (Smith and Coull, 1991).

On the other hand, for Case 2 the equivalent planar model has been shown in Fig 2.11(b). It has been observed that the flexural rigidity of the cut-back wall is very much reduced in the ground story, whereas its transverse rigidity has suffered by a proportionately lesser amount. Consequently, there is a very large transfer of moment from the cut-back wall to the continuous wall in the levels just above the ground story, with correspondingly large horizontal interactions between the walls, and high forward and reverse shears (Smith and Coull, 1991).

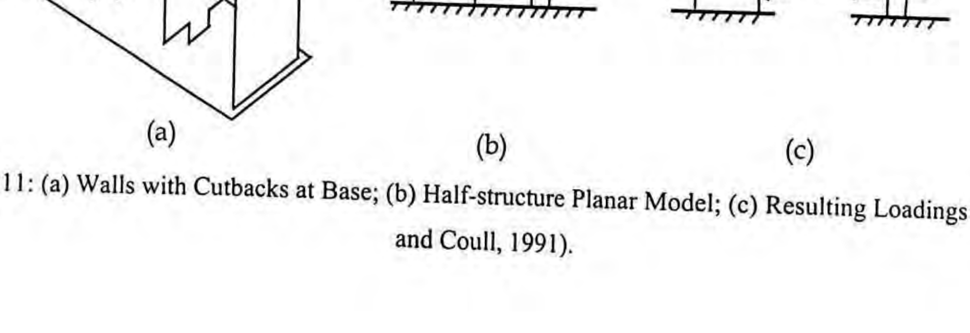


Fig. 2.11: (a) Walls with Cutbacks at Base; (b) Half-structure Planar Model; (c) Resulting Loadings (Smith and Coull, 1991).

As an approximate illustration, the forces on the walls are as in Fig. 2.11(c). It is quite possible, in Case 2-type structures with severe reductions in length of certain walls, for the remaining walls to be subjected to a shear of twice, or more than twice, the total external shear on the structure (Smith and Coull, 1991).

This discussion of the effects of discontinuities is intended mainly to explain the modes of the resulting actions, and to serve notice about their potential significance. The desirability of a detailed analysis in such a case, rather than an approximate intuitive estimate of the forces, is evident.

CHAPTER : 3

FINITE ELEMENT MODELING OF SHEAR WALL

3.1 Introduction

With the availability of sophisticated numerical tools for analysis like the finite element method, it has become possible to model the complex behavior of reinforced concrete structures. To achieve good result using finite element for the responses of any structural problem, reliable model is essential. The ultimate purpose of a finite element analysis is to recreate mathematically the behavior of an actual engineering system. In the broad sense, this model comprises all the nodes, elements, material properties, real constants, boundary conditions and other features that are used to represent a physical system. This chapter portrays the modeling technique and procedures to idealize the problems. Elastic finite element analyses (FEA) have been performed and the results of the analyses have been compared with the those obtained using conventional formula as well as with the results of a linear FEA which was verified with experimental results.

3.2 The Finite Element Packages

A good number of finite element analysis computer packages are now available such as STAAD Pro, SAP 90, ADINA, FEMSKI, ANSYS, DIANA, ABAQUS etc. They vary in degree of complexity, usability and versatility. Among these available packages, ANSYS-5.6 (2000) has been used in this study for its relative ease of use, detailed documentation, flexibility and vastness of its capabilities.

3.3 Finite Element Modeling of Shear Wall

The present thesis work is aimed at studying the linear behavior of reinforced concrete shear wall with base opening. SHELL63 element from ANSYS element library has been selected for the modeling of the reinforced concrete shear wall.

SHELL63 has both bending and membrane capabilities (Fig. 3.1). Both in-plane and normal loads are permitted with this element. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes. Stress stiffening and large deflection capabilities are included. A consistent tangent stiffness matrix option is available for use in large deflection (finite rotation) analyses.

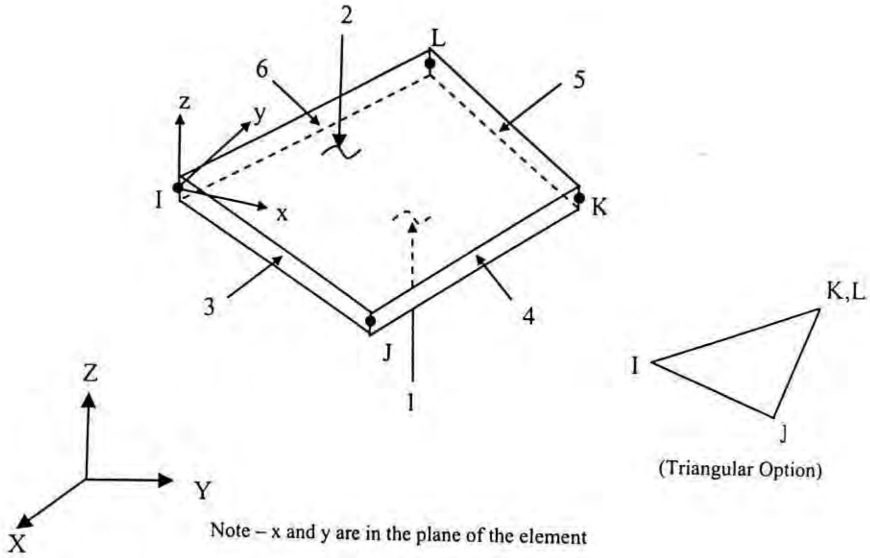


Fig. 3.1: SHELL63 Elastic Shell

3.4 Developing the Finite Element Mesh

The procedure for generating a mesh of nodes and elements consists of three main steps:

- Setting the element attributes.
- Setting mesh controls. ANSYS offers a large number of mesh controls. For the purpose of this thesis the feature called SmartSize has been used.
- Generation the mesh.

Before meshing the model, and even before building the model, it is important to think about whether a free mesh or a mapped mesh is appropriate for the analysis. A free mesh has no restrictions in terms of element shapes, and has no specified pattern applied to it. Compared to a free mesh, a mapped mesh is restricted in terms of the element shape it contains and the pattern of the mesh. A mapped area mesh contains either only quadrilateral or only triangular elements, while a mapped volume mesh contains only hexahedron elements. Mapped mesh is a time consuming feature. So in this study free meshing feature has been used.

Smart element sizing (SmartSizing) is a meshing feature that creates initial element sizes for free meshing operations. SmartSizing gives a better chance of creating reasonabe shaped elements during automatic mesh generation. The SmartSizing algorithm first computes estimated element edge lengths for all lines in the areas or volumes being meshed. The edge lengths on these lines are then refined for curvature and proximity of features in the geometry. This feature provides a range of settings from coarse to fine mesh. It has an integer value from 1 (fine mesh) to 10 (course mesh).

A comparative study is done on a model of double legged plane shear wall (see Section 4.2) with 60% base opening, to choose a reasonable value of SmartSize for meshing. This model is meshed by applying different SmartSize value. It is observed that the required time to run the solution increases with the decrease in SmartSize value. Fig. 3.2 presents the effect of mesh refinement on 3 different study parameter ratios (discussed in Section 4.4) for SmartSize value 1 to 6. The figure indicates very few significant effect on study parameter ratios for SmartSize value from 1 to 4. So the SmartSize value of 3 appeared to work reasonably and therefore, considered for the analysis performed in this study.

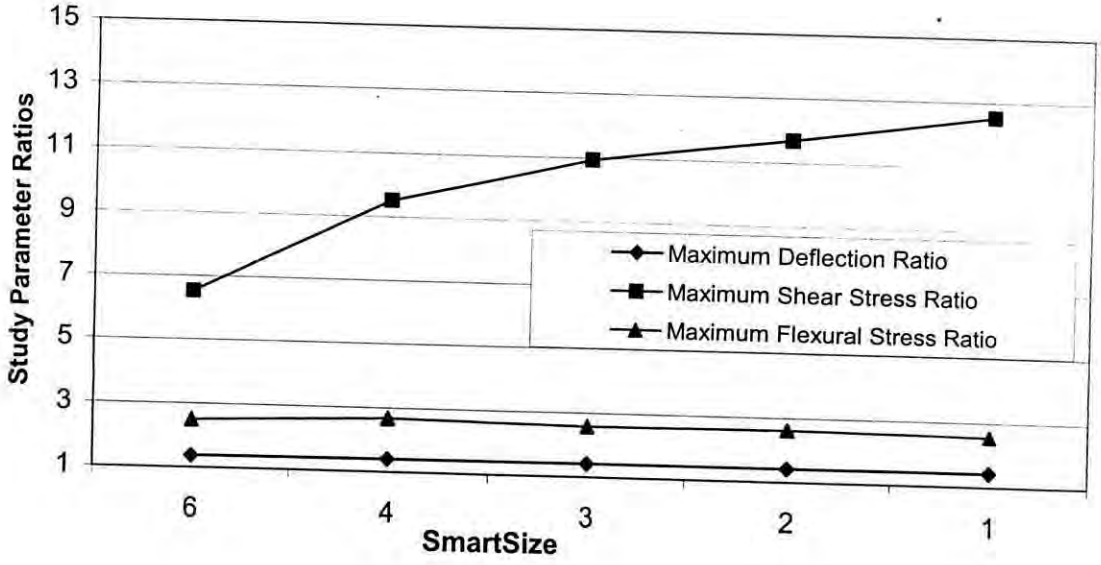


Fig. 3.2: Effect of Mesh Refinement on 3 Study Parameter Ratios for Different SmartSize Value.

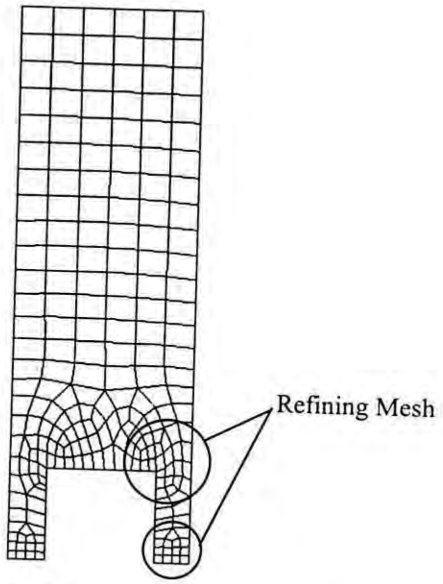


Fig. 3.3: Developing the Finite Element Mesh.

After meshing the whole model, it is needed to have more refined mesh in some specific region. There are generally two situations in which we may want to refine a mesh in a local region. These are: 1) a meshed model has been developed and it is intended to have a finer mesh in specific regions of the model, or 2) an analysis has been completed and, based on the results, it is necessary to have a more detailed solution in a region of interest. For all area meshes the ANSYS program allows to refine the mesh locally around specified nodes, elements, keypoints, lines, or areas. In this study, the specific area where stress concentration occurs has been refined. In the present shear wall model, meshes near the support and the corner of base opening are refined which is shown in Fig. 3.3.

3.5 Loading Considered

Lateral load comes on building mainly from earthquake and wind pressure. Since the structural response of the static earthquake or wind load is identical, in the present investigation, consideration is given only to wind induced lateral load. The minimum design wind load on buildings and components thereof have been determined based on the velocity of wind, the shape and size of the building and the terrain exposure condition of the site as set forth by the provisions of Bangladesh National Building Code (BNBC, 1993). The design wind load shall include the effects of the sustained wind velocity component and the fluctuating component due to gusts.

To calculate design wind load, a typical plan of a building has been assumed (as shown in Fig. 3.4) with its location in Dhaka, i.e. the taken basic wind speed is $V_b = 210$ Km/h. Table 3.1 shows the calculated design wind load along the height.

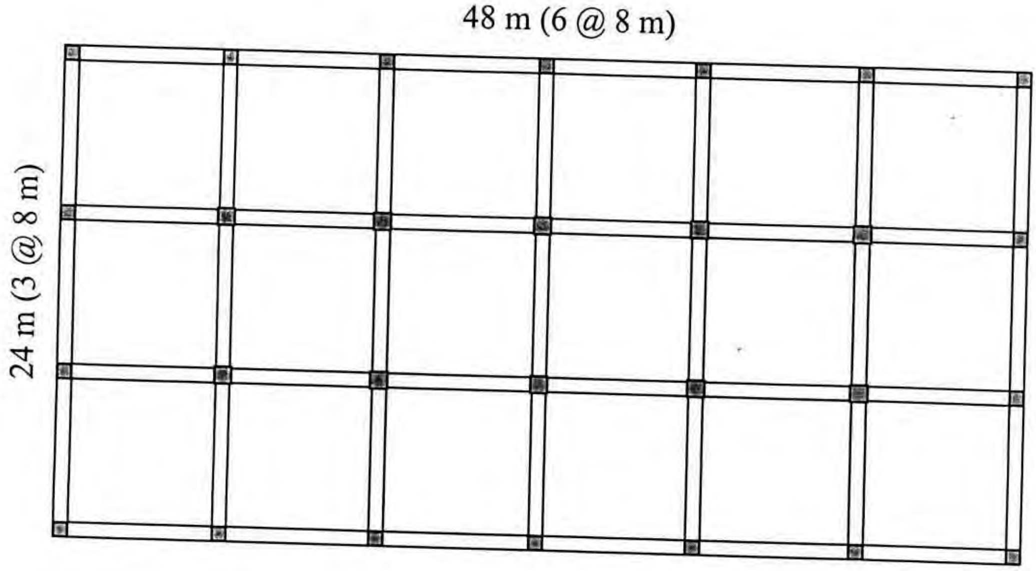


Fig. 3.4: Plan of the Building Used for Calculating Design Wind Load.

Table 3.1: Design Wind Pressure for a 15 Story Building.

HEIGHT IN METER	DESIGN WIND PRESSURE IN kN/m^2
4.5	1.8
6.0	2.0
9.0	2.3
12.0	2.5
15.0	2.7
18.0	2.9
21.0	3.0
24.0	3.1
27.0	3.3
30.0	3.4
35.0	3.6
40.0	3.7
45.0	3.9

However, since the present study is concerned with the investigation of the strength and stiffness characteristics of shear wall with base opening, detail variation in the application of loading is not considered to have a significant influence. Instead, an uniform average value of 3.0 kN/m^2 has been assumed. Assuming a panel width of 5 meter, uniformly distributed load along height comes to be (3.0x5 =) 15 kN/m.

A comparative study is presented in Chapter 4, by applying the calculated design wind pressure and the average uniformly distributed load separately. The purpose of this comparison is to identify whether variation in wind pressure distribution makes any material difference in the context of present study.

CHAPTER : 4

BEHAVIOR OF PLANE SHEAR WALL WITH BASE OPENING

4.1 Introduction

This chapter aims at studying the behavior of isolated shear wall with or without base opening subjected to uniformly distributed lateral loading. A set of finite element models have been developed by varying opening width and height. The effects of base opening on shear stress, flexural stress and deflection at different heights have been studied. The behavior of shear wall for different opening width have been studied and compared to that of a shear wall without opening. A set of non-dimensional graphs have been prepared featuring important parameters.

4.2 Parametric Study

In this chapter two types of shear walls are studied. One is double legged (Type-1), another is single legged (Type-2) as shown in Fig 4.1. In each case height of shear wall is H and width is B. Width of opening is b. Curves for each case are presented in non-dimensional form. The parameters involved in the curves are the base opening ratio (b/B), height/width ratio (H/B) and the thickness of shear wall (T). The general idea of parametric study for a number of independent parameters embodies the fact that at a single instance only one variable should be allowed to vary while other parameters are fixed at some standard value within its range. If two or more parameters are varied at the same time, it would cause confusion in the results. The various study parameters are described next.

Base opening ratio (b/B):

It is the ratio between total width of opening and total width of shear wall. When there is no base opening in a shear wall i.e. with 0% base opening (i.e. solid shear wall), the value of b/B comes 0. Similarly for 60% opening b/B = 0.6. The percentage base opening and corresponding values of b/B, which have been used for various building model, are shown in Table 4.1.

Table 4.1: Base Opening Ratios Used for Building Model.

b/B	% base opening
0	0%
0.2	20%
0.4	40%
0.6	60%
0.8	80%
0.9	90%

Height/Width ratio (H/B):

It is the ratio between height (H) and width (B) of shear wall. The values of H/B we take for parametric study are H/B=1, H/B=3.75, H/B=6.

4.3 Assumptions of Parametric Study

SHELL63 element from ANSYS element library has been selected for the modeling of the reinforced concrete shear wall. The Young's Modulus of elasticity (Ex) of concrete is taken as 3.0×10^6 psi. i.e. 20.693×10^6 kN/meter^2. The Shear Modulus = 9380736 kN/meter^2 and Poisson ratio = 0.1 have been taken. Preliminarily the width of shear wall B has been taken to be 8 meter, height of opening h = 3 meter and the thickness T = 250 mm. Applied load (as discussed in Section 3.5) is 15 kN/meter, uniformly distributed as shown in Fig. 4.1.

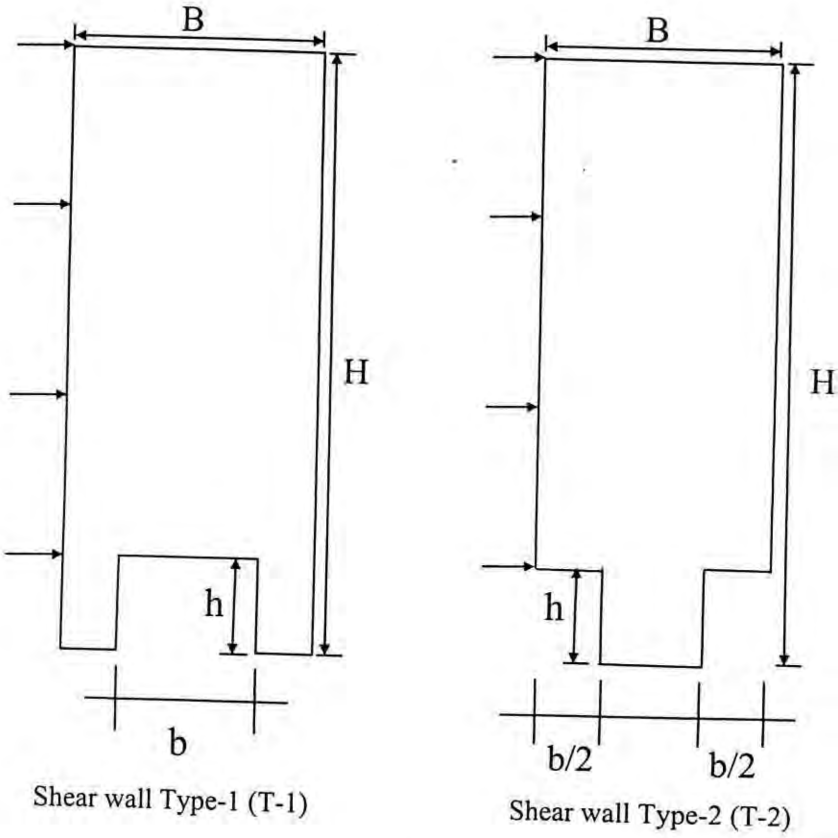


Fig. 4.1: Types of Shear Wall with Base Opening.

4.4 Study Parameters

The parameters described in Section 4.2 have great influence on the deflection and stresses (shear stress and flexural stress) of shear wall. In this study the deflection ratio, maximum shear stress ratio and maximum flexural stress ratio for varying b/B, H/B and T have been studied. The results are calculated with respect to shear wall without base opening. The various ratios used in the subsequent presentations are described next.

Deflection ratio:

Deflections at three locations have been studied. These are the top (maximum) deflection, deflection at mid height and at 3 meter above base. At a particular height of shear wall and with a particular percentage of base opening, deflection ratio is the ratio between deflection of the shear wall with base opening and deflection of an identical shear wall without base opening. Similarly, the other two deflection ratios are also calculated.

Maximum shear stress ratio:

With a particular percentage of base opening, maximum shear stress ratio is the ratio between maximum shear stress at base of the shear wall with base opening and maximum shear stress of an identical shear wall without base opening.

Maximum flexural stress ratio:

With a particular percentage of base opening, maximum flexural stress ratio is the ratio between maximum flexural stress at base of the shear wall with base opening and maximum flexural stress of an identical shear wall without base opening.

4.5 Results of Parametric Study

In this section, the effects of the variation in the input parameter (as mentioned in Section 4.2) on the selected study parameters (as discussed in Section 4.4) are presented.

(a) Behavior of Double Legged (Type-1) Shear wall

Deflection ratios at three different floor levels for varying opening size (b/B), are presented in Fig. 4.2(a), Fig. 4.2(b) and Fig. 4.2(c). It is observed that deflection increases with the increase of % base opening. However, the rate of increase of deflection is very low up to 60% base opening. Beyond 60% opening wall stiffness decreases significantly. Maximum deflection of shear wall with base opening 90% and H/B = 1 is 67 times than that of solid shear wall whereas in the case of shear wall with base opening 60% it is only 3 times. The influence of height of shear wall (i.e. H/B) in its stiffness is also observed here. For all values of H/B with 0 to 60% base opening, the effect is insignificant but for base opening higher than 60% it is very high. This is may be due to reduction of moment of inertia. It is observed that, beyond 60% opening moment of inertia of the wall is significantly reduced. For example, due to opening, reduction of moment of inertia for 40% opening is 6.4%, for 60% opening is 21.6% and for 80% opening is 52%.

For very stiff wall (i.e. H/B=1) the loss of stiffness due to base opening is quite significant whereas for relatively slender walls (H/B=3.75) the reduction in stiffness only moderate. For example with 90% base opening top deflection ratio of shear wall with H/B = 1 is 67 and it is only 4.7 for shear wall with H/B = 3.75.

Comparisons of deflections at lower levels (i.e. at mid height and 3 meter height) are shown in Fig. 4.2(b) and Fig. 4.2(c). The general tendency of stiffness degradation due to base opening, as reflected in the computed deflection ratios, remains the same as in the case of maximum deflection ratios. However, deflection ratios at lower levels are higher than the maximum deflection ratio at top of the wall. With 90% base opening the mid deflection ratio (for H/B=1) is 112 and the deflection ratio at 3 meter height stands at 153. Both figures being significantly higher than the corresponding maximum deflection (at top) ratio of 67. Still with 60% or lesser base opening, deflection ratios at lower levels are insignificant (close to 1.0).

Maximum shear stress and maximum flexural stress ratio for varying base opening (b/B) are presented in Fig. 4.3 and Fig. 4.4 respectively. Identical to the deflection pattern similar behavior is observed in the stress pattern. It is seen that up to 60% base opening; rate of increase of these ratios are low. But for more than 60% opening the stress ratios increase rapidly. The increase in shear stress ratios for 60% opening appears to 5 to 10 times in section at 3 meter height (shown in Fig. 4.3). This high concentration of shear stress needs to be addressed carefully from design point of view and is dealt with in section. Whereas in the case of flexural stress ratios for 60% opening appears to 2 to 3 times (shown in Fig. 4.4). It is seen from Fig. 4.3 and Fig. 4.4 that shear stress is more affected than flexural stress due to the introduction of base opening in shear wall. For same % of opening, shear stress ratio is more than flexural stress ratio. For example with 60% opening & H/B = 3.75 the flexural stress ratio is 2.3 when shear stress ratio is 7.3.

(b) Behavior of Single Legged (Type-2) Shear wall

Similar set of curves (from Fig. 4.5 to Fig. 4.7) are drawn for single legged shear wall (Type-2). It has been observed that stress (flexural and shear) ratios increase with the increase of shear wall height when on the other hand in Type-1 these stress ratios decrease with the increase of shear wall height. Apart from this, all curves show almost similar behavior to the behavior of double legged shear wall (Type-1). Although general behaviors of Type-1 and Type-2 are similar, the absolute values of the ratios are quite high in the case of Type-2.

To observe the comparative view of these three parameter ratios; curves from Fig. 4.8 to Fig. 4.10 are drawn for both type shear walls. It is clearly observed that all ratios of Type-2 shear wall are very high than that of Type-1 shear wall. For example with 90% base opening (though it is not practical) & H/B = 3.75, top deflection ratio of Type-2 is 366 when it is only 4.7 for Type-1. This is may be due to excessive reduction of moment of inertia for Type-2. For example, for 60% opening the reduction of moment of inertia of Type-1 is 21.6%, whereas it is 94% for Type-2. A summery of the various ratios is presented in tabular form, in Table 4.2.

Deflections/Total Height ratios (also called Drift) along the height of the wall for various combinations of H/B and % base opening are presented in Fig. 4.11 for both types shear wall. ACI Committee 435 recommends a drift limit of 1/500 (Fintel, 1986). It is observed that, shear wall (Type-1 with H/B=6) with 90% base opening exceeds the limit.

Table 4.2: Various Ratios for Varying % Opening and H/B of Both Type of Shear Wall.

% Base opening	Type of shear wall	Top Deflection ratio		Maximum Flexural stress ratio		Maximum Shear stress ratio	
		H/B=3.75	H/B=6	H/B=3.75	H/B=6	H/B=3.75	H/B=6
90% base opening (b/B=0.05)	Type-1	4.7	2.4	20	14.4	51.5	37
	Type-2	366	253	86	92	215	233
80% base opening (b/B=0.1)	Type-1	2.2	1.7	7.6	4.6	15.2	5.6
	Type-2	45	30	20	22	100	116
60% base opening (b/B=0.2)	Type-1	1.16	1.1	2.3	2	7.3	5.5
	Type-2	7	5.2	5.1	5.4	17.6	20.6
40% base opening (b/B=0.3)	Type-1	1.1	1.06	1.85	1.2	5.1	3.8
20% base opening (b/B=0.4)	Type-1	1.03	1.0	1.4	1.2	2.8	1.6

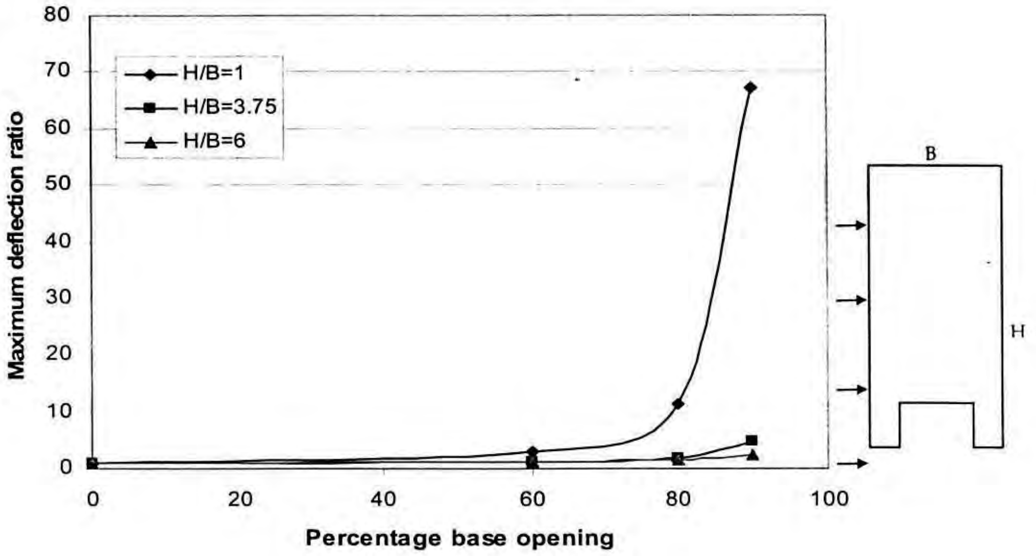


Fig. 4.2(a): Effect of Opening Size on Maximum Deflection Ratios for Varying Ratios of H/B.

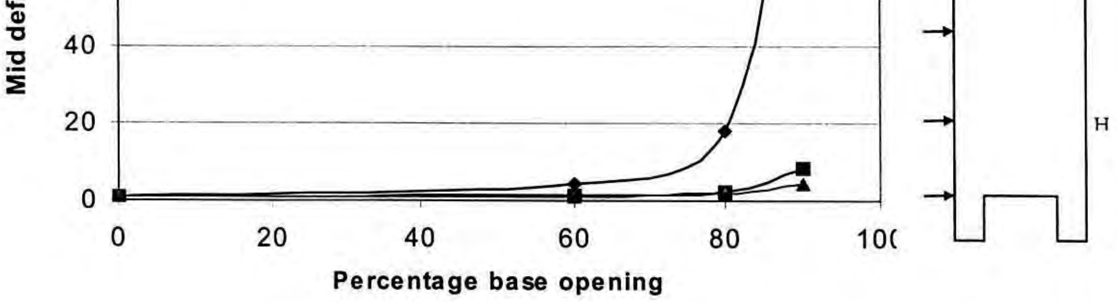


Fig. 4.2(b): Effect of Opening Size on Mid Deflection Ratios for Varying Ratios of H/B.

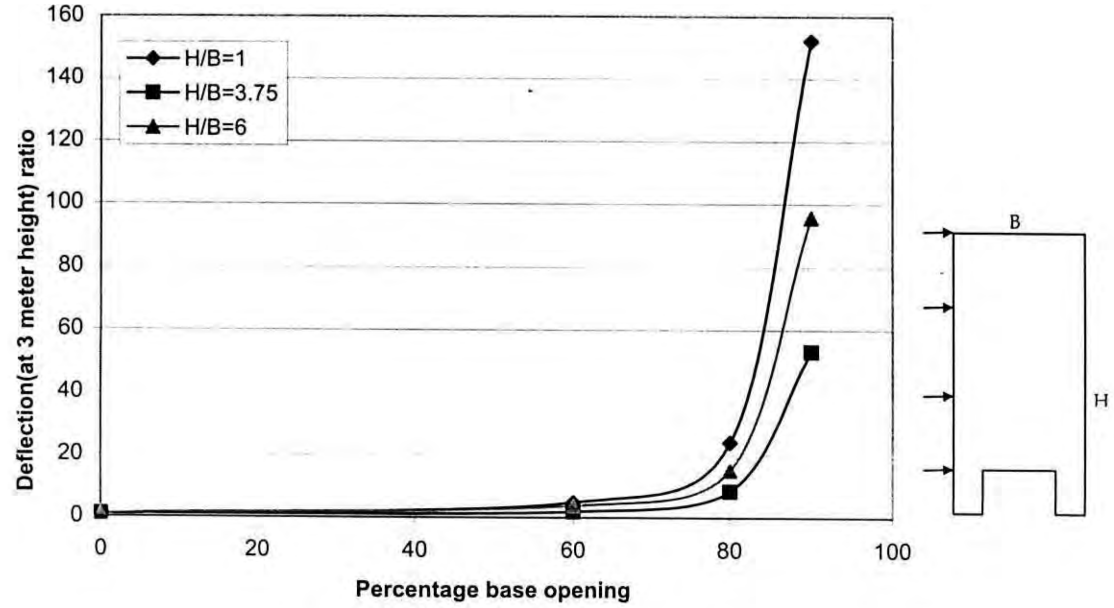


Fig. 4.2(c): Effect of Opening Size on Deflection (at 3 meter height) Ratios for Varying Ratios of H/B.

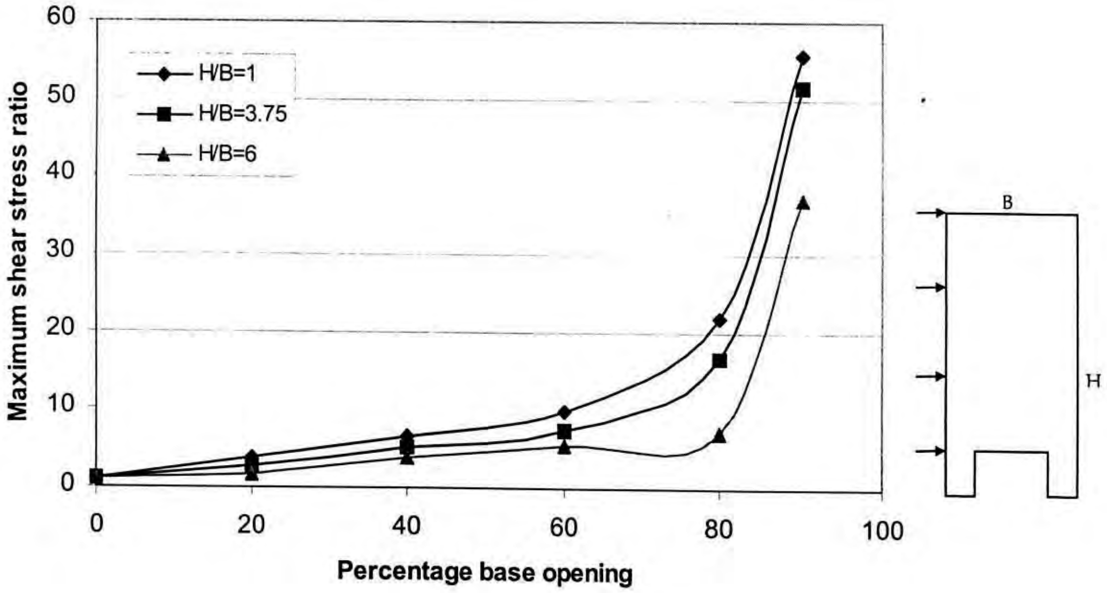


Fig. 4.3: Effect of Opening Size on Maximum Shear Stress Ratios for Varying Ratios of H/B.

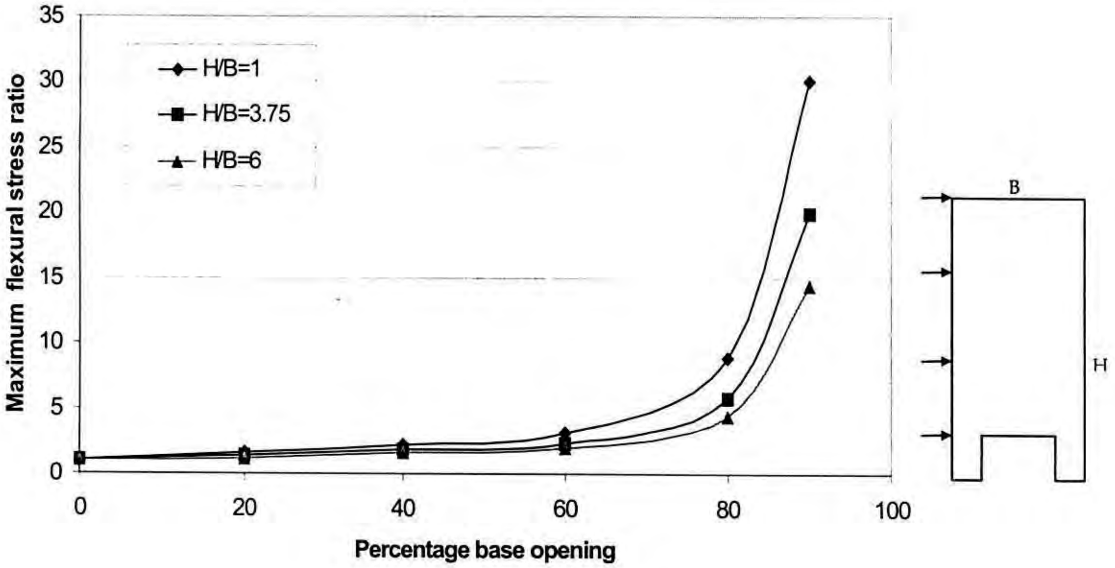


Fig. 4.4: Effect of Opening Size on Maximum Flexural Stress Ratios for Varying Ratios of H/B.

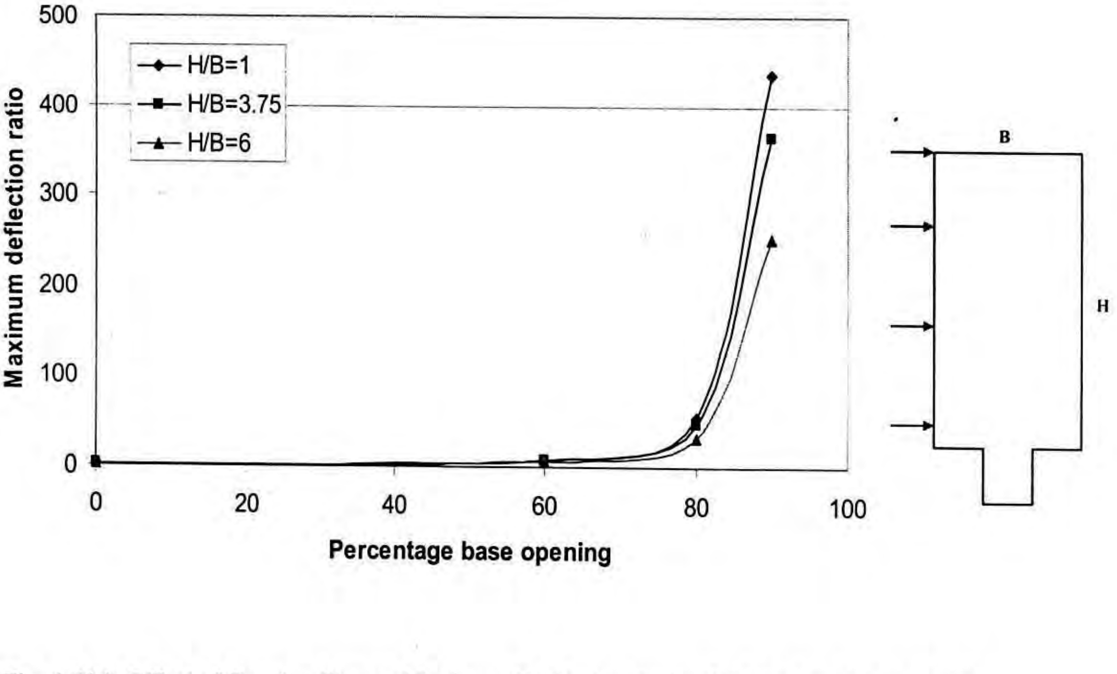


Fig. 4.5(a): Effect of Opening Size on Maximum Deflection Ratios for Varying Ratios of H/B.

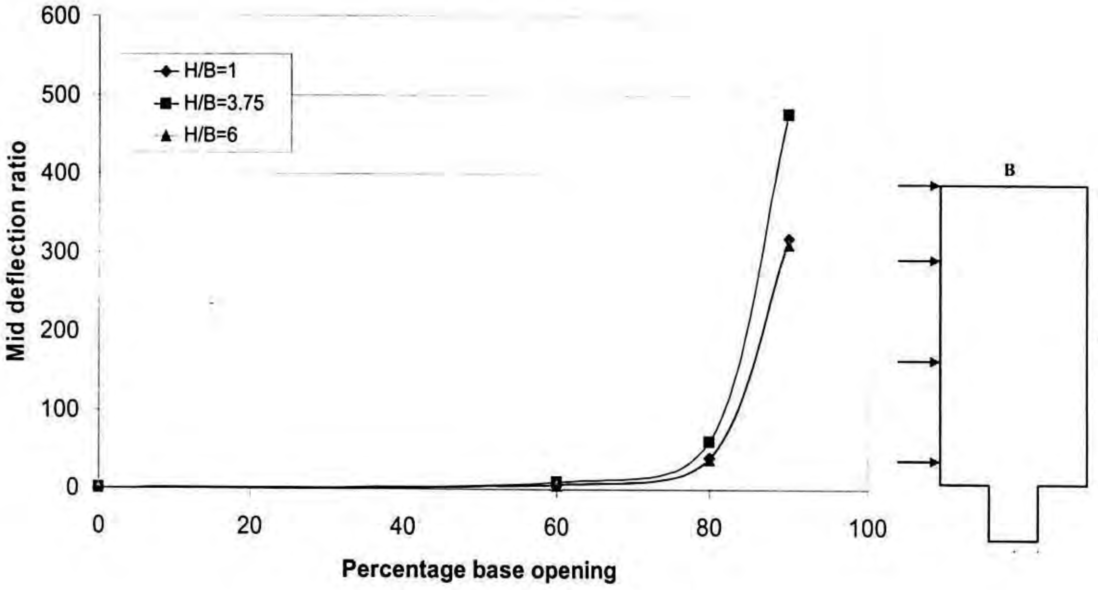


Fig. 4.5(b): Effect of Opening Size on Mid Deflection Ratios for Varying Ratios of H/B.

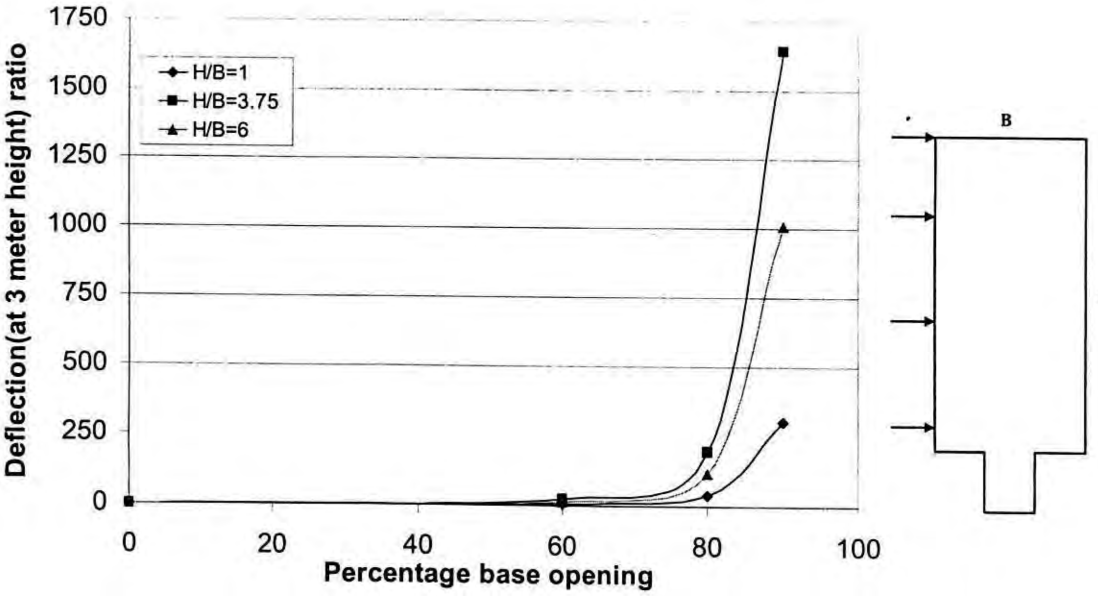


Fig. 4.5(c): Effect of Opening Size on Deflection (at 3 meter height) Ratios for Varying Ratios of H/B.

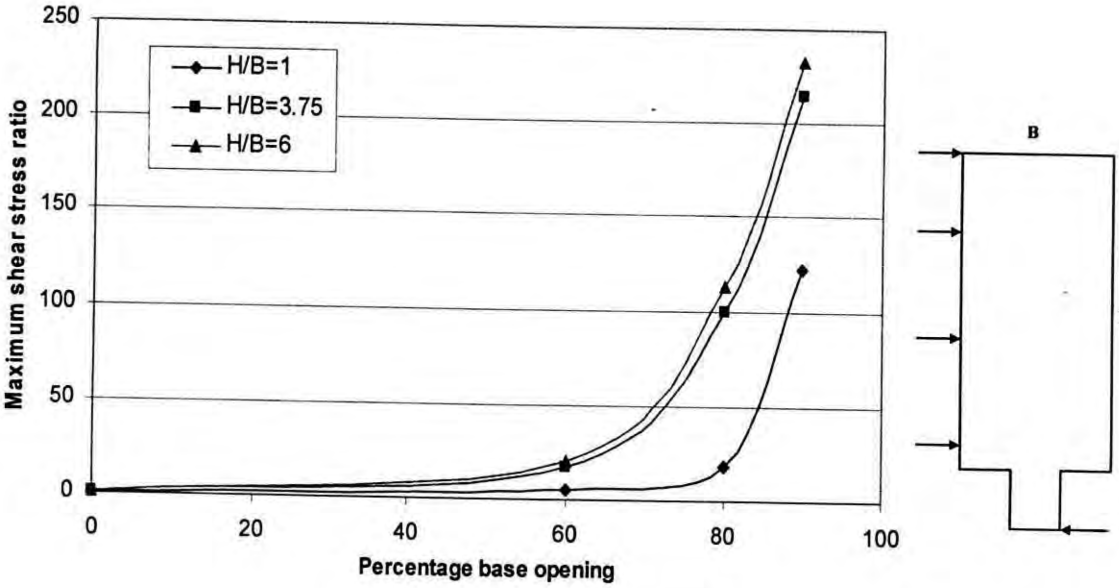


Fig. 4.6: Effect of Opening Size on Maximum Shear Stress Ratios for Varying Ratios of H/B.

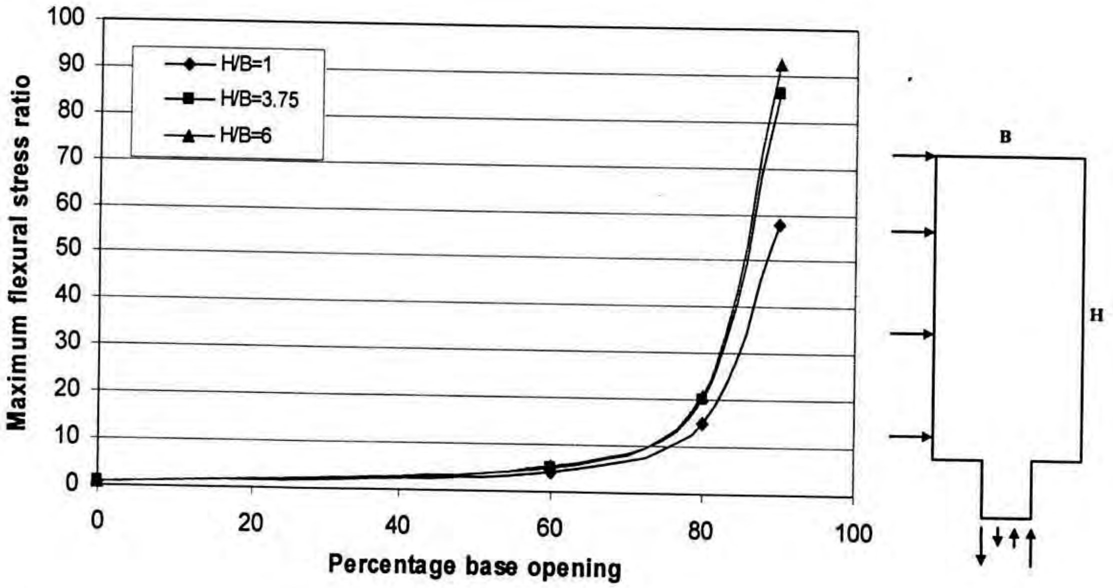


Fig. 4.7: Effect of Opening Size on Maximum Flexural Stress Ratios for Varying Ratios of H/B.

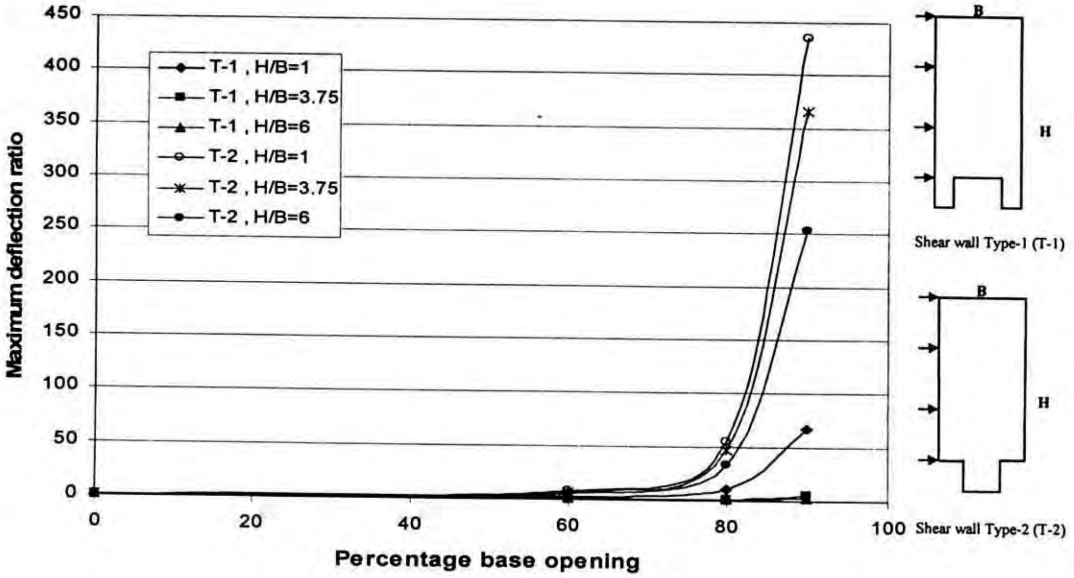


Fig. 4.8(a): Effect of Opening Size on Maximum Deflection Ratios for Varying Ratios of H/B.

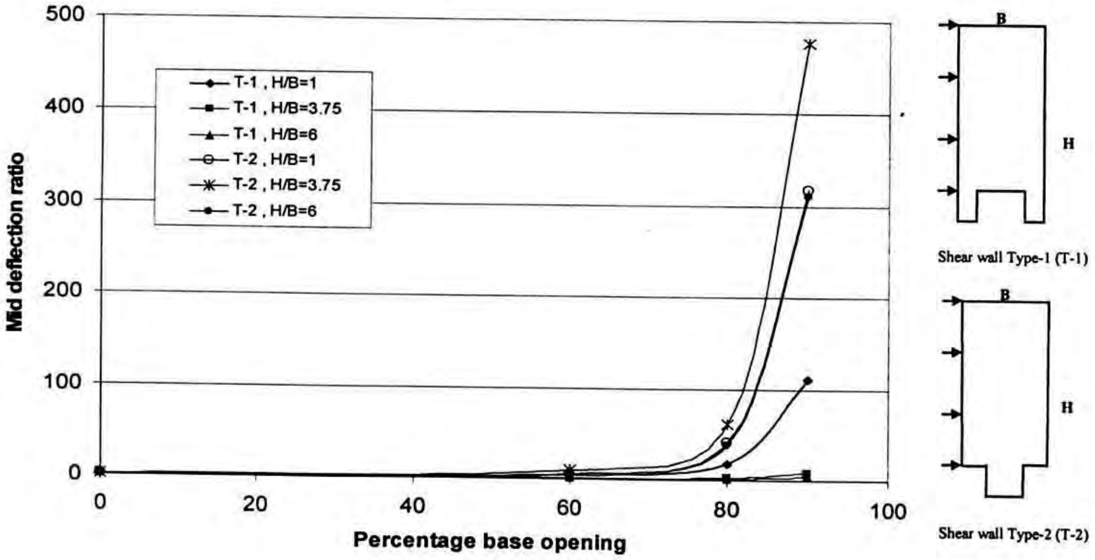


Fig. 4.8(b): Effect of Opening Size on Mid Deflection Ratios for Varying Ratios of H/B.

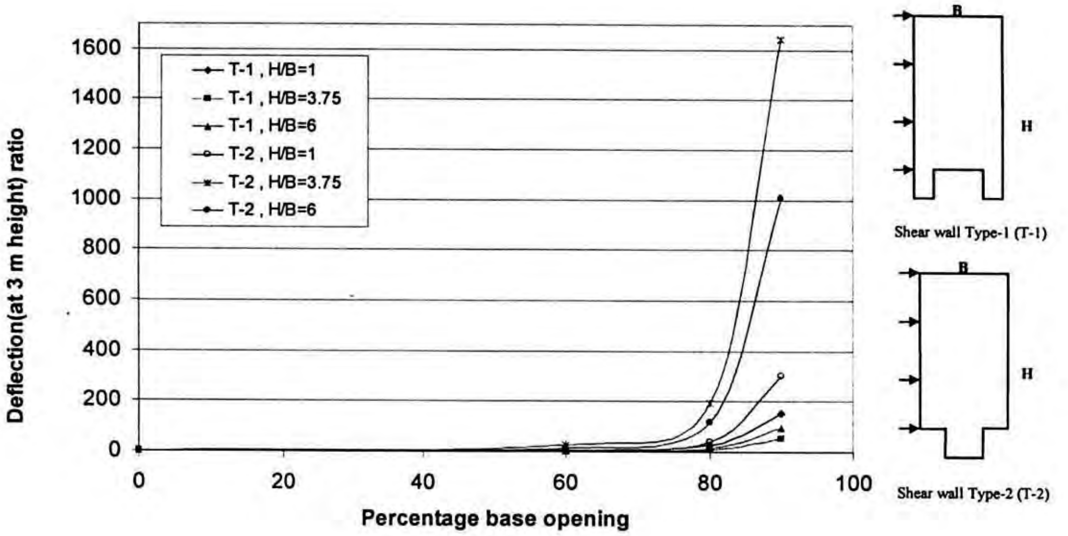


Fig. 4.8(c): Effect of Opening Size on Deflection (at 3 meter height) Ratios for Varying Ratios of H/B.

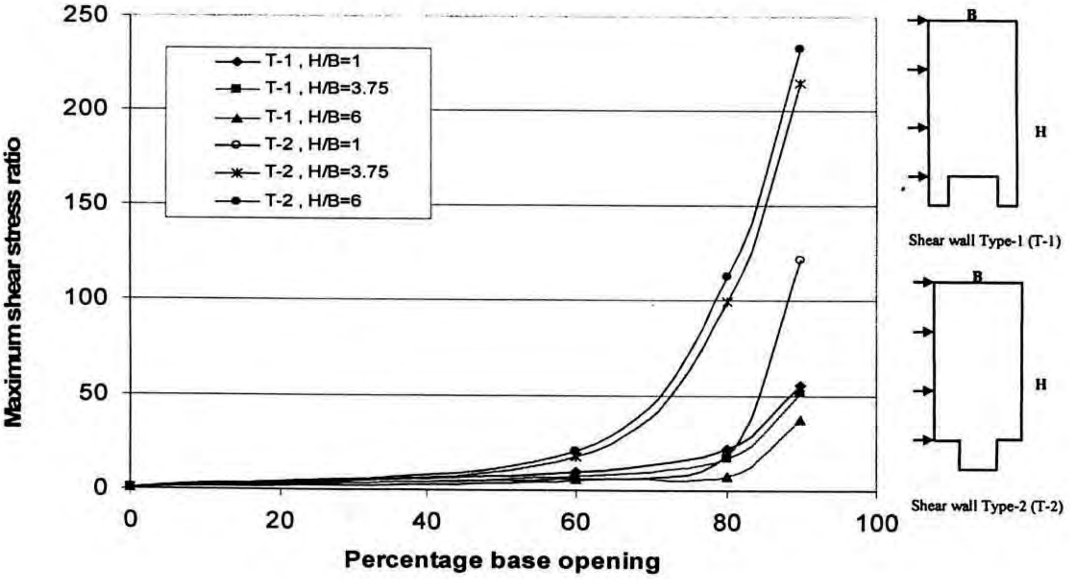


Fig. 4.9: Effect of Opening Size on Maximum Shear Stress Ratios for Varying Ratios of H/B

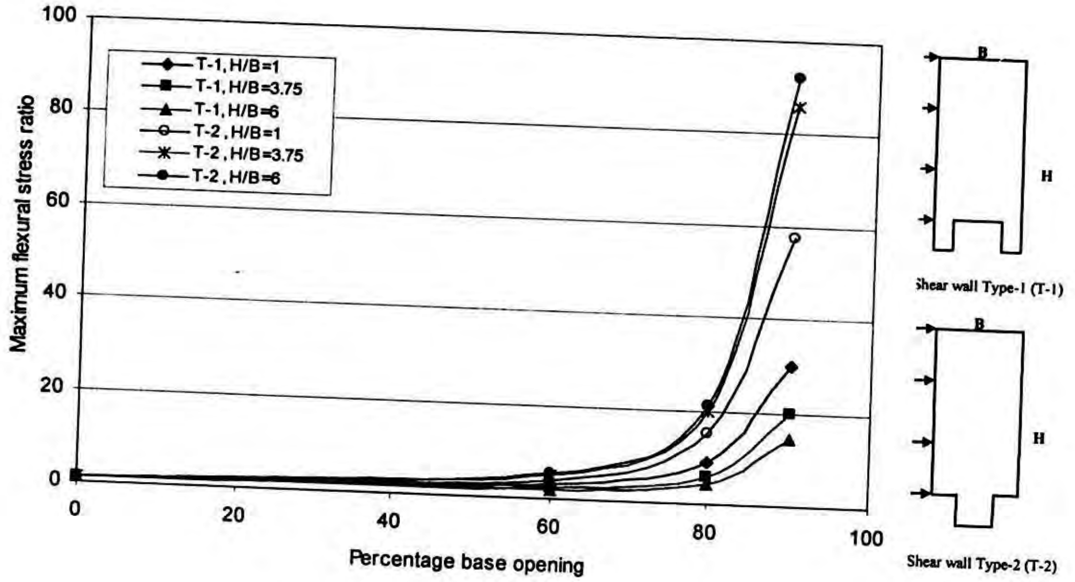


Fig. 4.10: Effect of Opening Size on Maximum Flexural Stress Ratios for Varying Ratios of H/B.

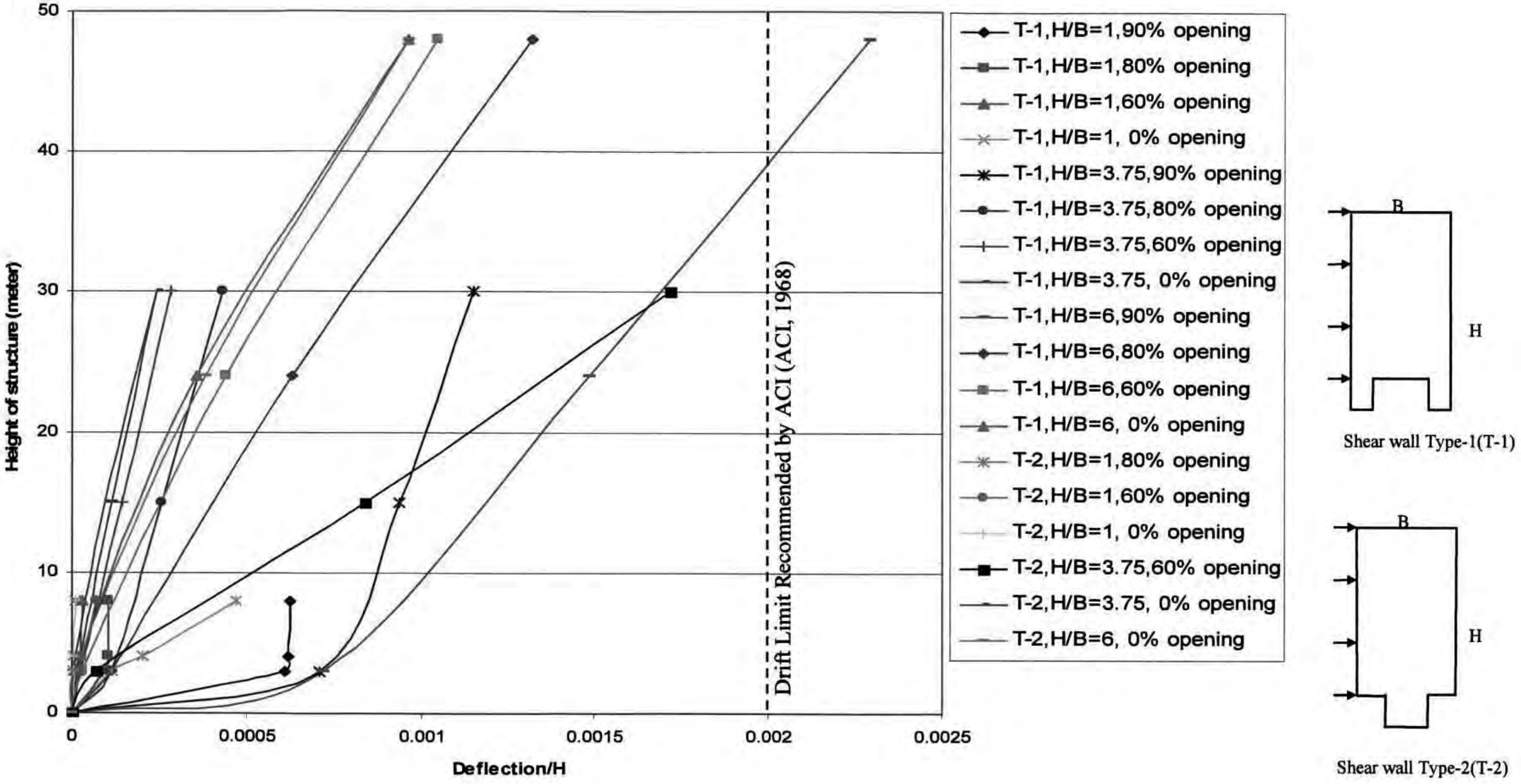


Fig. 4.11: Ratios of Deflection/H at Different Height for Varying Ratios of H/B and Opening Size for Both Type-1 and Type-2 Shear Wall.

4.6 Effect of Loading Type

In a structure, lateral load comes mainly from wind pressure and earthquake. In the present study earthquake load has not been considered. According to BNBC (1993), the calculated wind load has been discussed in Section 3.5. To avoid complexity, in overall study, an uniform load has been applied of value close to the average value of the design wind load. In this section both types of load have been considered. The objective of this study is to observe the comparative effect of loading on different study parameter ratios.

4.6.1 Parametric Study

Two types of lateral load distribution have been considered here. One is uniformly distributed load (UDL) throughout the height of shear wall and other is linearly varying wind load (WL), which is calculated according to BNBC (shown in Table 3.3). These loads are applied in shear walls of two different heights; 6 story i.e. H/B = 2.25 and 10 story i.e. H/B = 3.75. The applied uniformly distributed load has been chosen to be equivalent to the wind load; that means both types of load, if applied separately, would produce same moment at base. To ensure that, uniformly distributed load, 2.533 KN/m^2 is applied for 6 story and 2.868 KN/m^2 is applied for 10 story high shear walls. Double-legged shear wall (Type-1) has been chosen for present study. All other parameters are kept same as mentioned in Section 4.2 & 4.3.

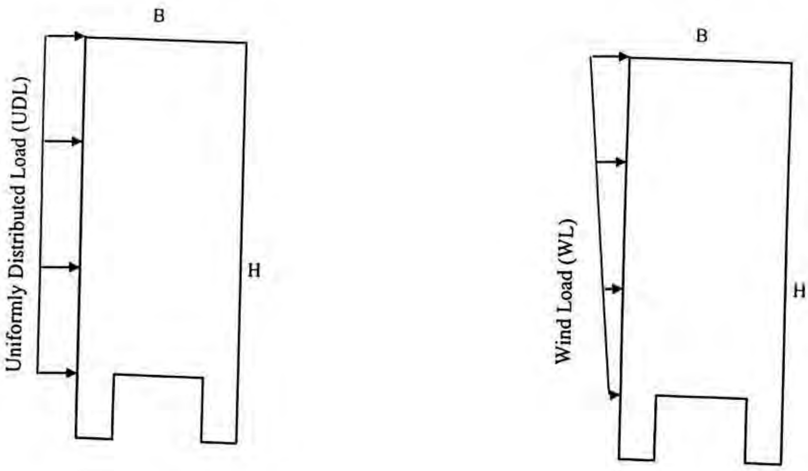


Fig. 4.12: Two Types of Lateral Load Applied in Double Legged Plane Shear Wall.

4.6.2 Parameters Considered

The study parameters have already been described in Section 4.4. The various ratios found from current study are presented in Table: 4.3 for both types of loading.

Table 4.3: Parameter Ratios for Different Loading Type

		Maximum deflection ratio			Maximum flexural stress ratio			Maximum shear stress ratio		
	% base opening	60%	40%	0%	60%	40%	0%	60%	40%	0%
6 story (H/B=2.25)	UDL	1.4	1.1	1.0	2.6	1.6	1.0	10.9	6.8	1.0
	WL	1.4	1.1	1.0	2.5	1.6	1.0	10.4	6.5	1.0
10 story (H/B=3.75)	UDL	1.2	1.0	1.0	2.1	1.5	1.0	6.0	4.1	1.0
	WL	1.2	1.0	1.0	2.0	1.4	1.0	5.4	3.7	1.0

4.6.3 Result and Discussion

The effects of loading type on the three parameter ratios are presented below.

Maximum Deflection ratio:

The ratios are found same for both type of loading.

Maximum Flexural stress ratio:

It is observed that the effect on the ratio is very little. For 6 story with 60% base opening this ratio is 2.6 for UDL whereas in the case of WL it is 2.5. It can be said that the impact on this ratio is insignificant.

Maximum Shear stress ratio:

It is observed that there is a little impact on this ratio comparative to other two parameter ratio. For 10 story with 60% base opening this ratio is 6.0 for UDL while it is 5.4 for WL. Ratio for WL is less than that for UDL.

After overall observation of this study, it can be concluded that there is insignificant impact of loading type on these study parameter ratios. So, for the whole study, uniformly distributed load can be applied instead of wind load.

4.7 Plane Shear wall with Base Opening with Compensating Measure

This section is aimed at studying the behavior of shear wall with base opening with compensatory measure. Two alternative compensatory measures have been taken for present study. First, the thickness of two legs of shear wall have been increased and in the second alternative, two compensatory elements have been introduced which are placed perpendicular to shear wall at the two edges (Fig. 4.13 and Fig. 4.14). Total area of compensatory element is taken such that the resultant cross-sectional area of the pierced shear wall remains same as that of the solid shear wall (i.e. without opening). That means, total cut area for base opening is equally distributed at the two edges/legs of shear wall. In this section, an attempt has been made to show the improvement of stiffness that might occur with introducing compensatory measures. Three parameter ratios (as defined in Section 4.4) of the shear wall for different opening width have been calculated and compared to that of shear wall without compensatory measures.

4.7.1 Parametric Study

Double legged shear wall (Type-1) with H/B=3.75, has been chosen for present study. Geometric parameters such as height, width, thickness are kept same as mentioned in Section 4.2 except in first alternative leg thickness is varied with the varying opening width and assumptions as mentioned in Section 4.3 are also kept same. Finite element models of shear wall with three different percentage of base opening (60%, 40% and 20%) have been developed for current study.

4.7.2 Study Parameters

Study parameters have already been described in Section 4.4. These parametric ratios found from current study for different base opening width are presented in Table: 4.4 for 1st alternative and in Table: 4.5 for 2nd alternative. Fig. 4.15 shows the graphical presentation of the data of Table 4.5.

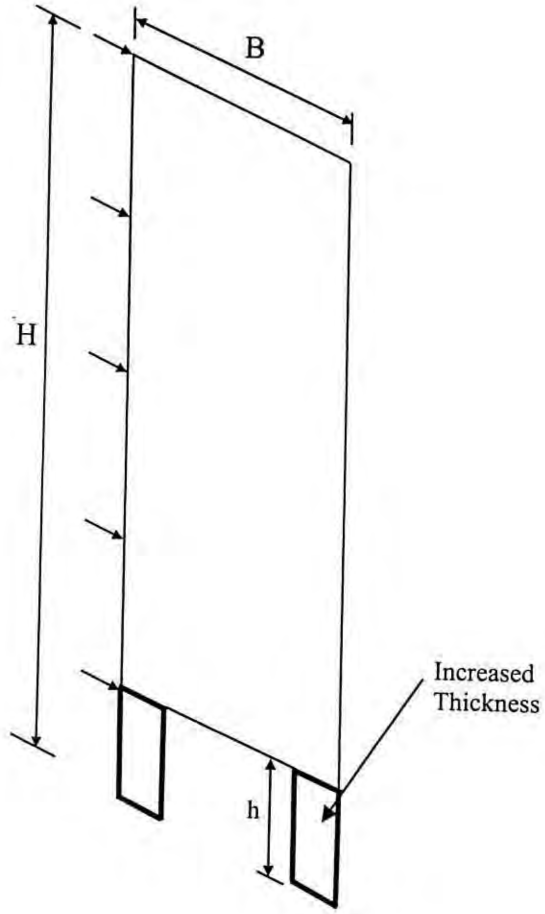


Fig. 4.13: Shear Wall with Compensatory Measure (1st Alternative).

Table 4.4: Study Parameter Ratios for Varying % Base Opening of Both Type of Shear Wall (H/B=3.75) for 1st Alternative Measure.

% of base opening	Type of shear wall	Maximum deflection ratio	Maximum flexural stress ratio	Maximum shear stress ratio
60% base opening	Without compensating measure	1.16	2.11	5.34
	With compensating measure	0.88	0.74	4.27
40% base opening	Without compensating measure	1.05	1.44	3.54
	With compensating measure	0.90	0.87	3.14
20% base opening	Without compensating measure	1.01	1.18	2.25
	With compensating measure	0.94	0.92	2.10

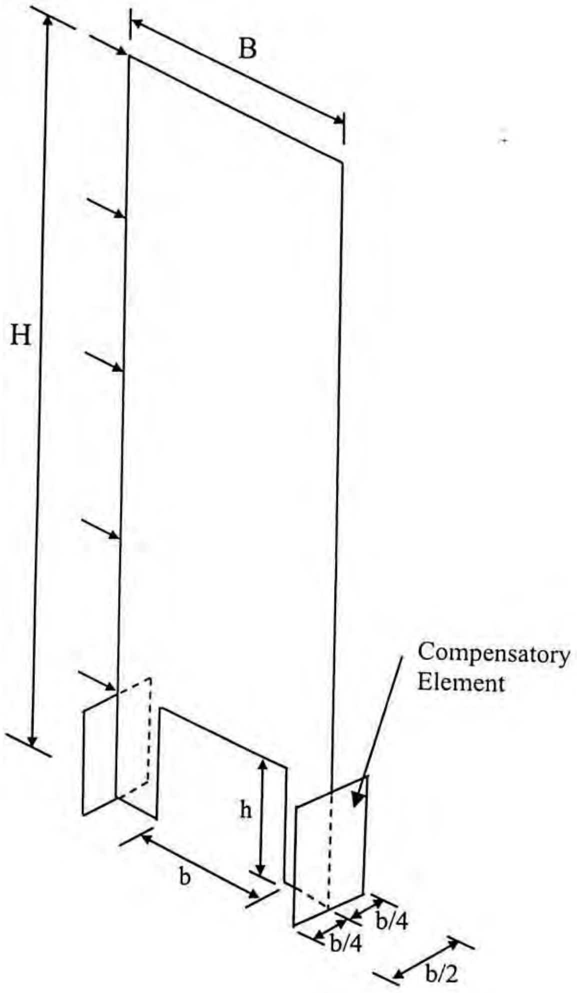
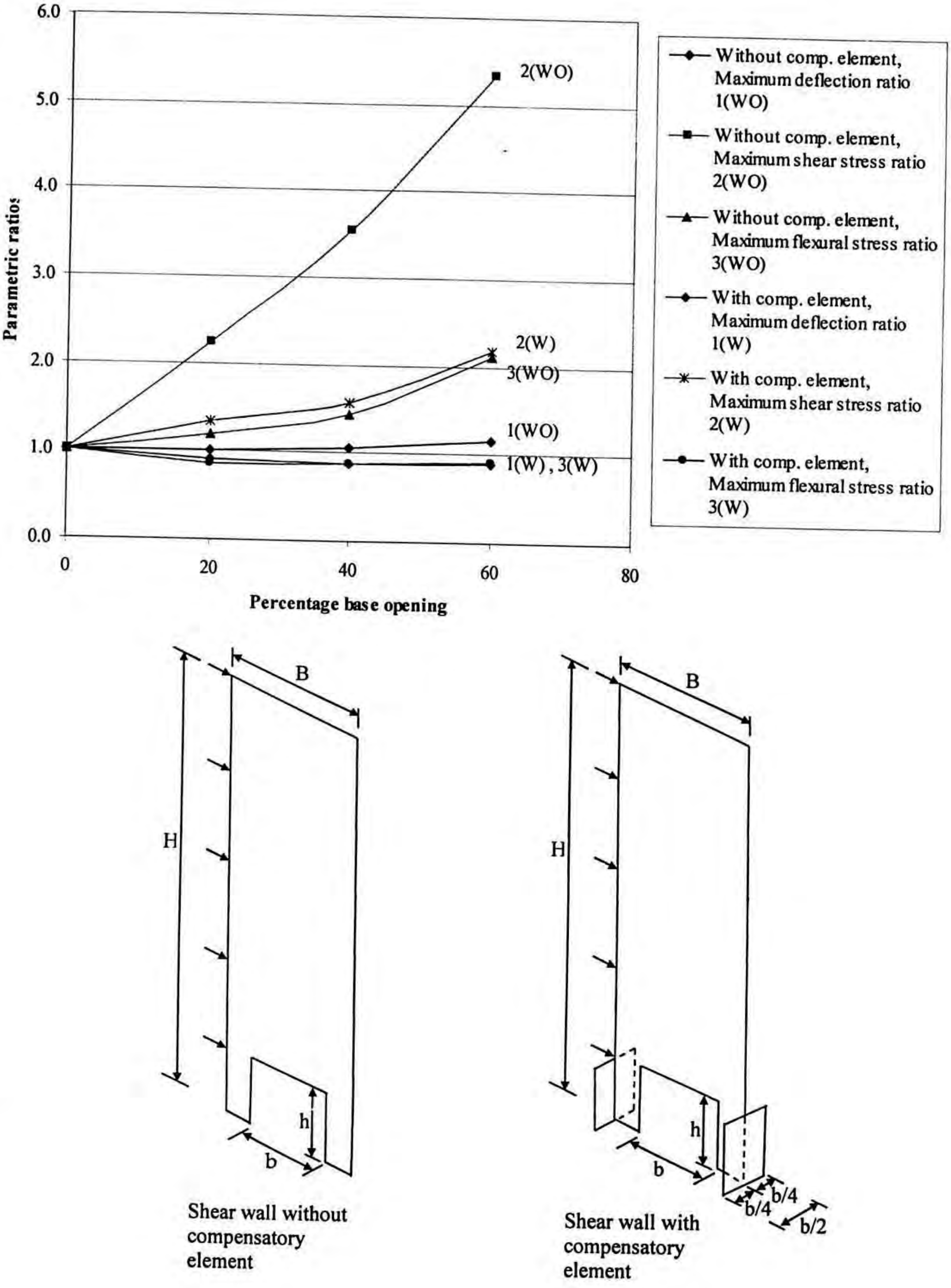


Fig. 4.14: Shear Wall with Compensatory Element (2nd Alternative).

Table 4.5: Study Parameter Ratios for Varying % Base Opening of Both Type of Shear Wall (H/B=3.75) for 2nd Alternative Measure.

% of base opening	Type of shear wall	Maximum deflection ratio	Maximum flexural stress ratio	Maximum shear stress ratio
60% base opening	Without compensating element	1.16	2.11	5.34
	With compensating element	0.89	0.9	2.18
40% base opening	Without compensating element	1.05	1.44	3.54
	With compensating element	0.87	0.88	1.57
20% base opening	Without compensating element	1.01	1.18	2.25
	With compensating element	0.9	0.86	1.33



Shear wall without compensatory element

Shear wall with compensatory element

Fig. 4.15: Effect of Compensatory Element (2^{nd} Alternative) on Parametric Ratios for Varying Percentage of Base Opening.

4.7.3 Results and Discussions

The effects of introducing compensatory measure on three parametric ratios have been presented in Table 4.4 and Table 4.5. These are further discussed below.

Maximum Deflection ratio:

The ratio decreases as compared to that of shear wall without compensatory element. For example, with 60% base opening the ratio is 1.16 and with compensatory measure it is 0.88 for 1st alternative; 0.89 for 2nd alternative - indicating an improvement over the stiffness of the shear wall without base opening.

Maximum Flexural stress ratio:

Maximum flexural stress ratio is also reduced with the introducing compensatory measure. For shear wall with 60% base opening this ratio is 2.11 whereas in the case of shear wall with compensatory measure it is only 0.74 (for 1st alternative) and is 0.90 (for 2nd alternative). It can be said that the use of compensatory elements, in cross-sectional area as that of opening, can be beneficial in offsetting the adverse effect of introducing base opening.

Maximum Shear stress ratio:

It is observed that the ratio is significantly improved. With the introduction of compensatory element shear stress is decreased to almost half. With 60% base opening this ratio is decreased from 5.34 to 4.27 (for 1st alternative) and to 2.18 (for 2nd alternative). It is noticed that shear stress ratio, the most adversely affected parameter due to introduction of the base opening, can be improved significantly if compensatory elements are added.

After this study, it is observed that there is significant impact of introducing compensatory measure on these parametric ratios. So, it can be concluded that introduction of the compensating measure would fully compensate the deflection and flexural stress ratios and also bring about significant improvement in the shear stress ratio. It is also observed that 2nd alternative measure is more efficient than 1st one to compensate the adverse effect of introducing base opening. However, the overall planning need of the ground story would dictate the choice between the two.

4.8 Stress Contour

Stress contours for plane shear wall (H/B=3.75) with or without base opening are shown from Fig. 4.16 to Fig. 4.25. The contours of flexural stress and shear stress for shear wall without base opening are shown in Fig. 4.16 and Fig. 4.17. For 20% and 60% base openings, corresponding stress contours are presented form Fig. 4.18 to Fig. 4.21. And finally, stress contours for shear wall with compensatory elements (2nd alternative) with base opening are shown from Fig. 4.22 to Fig. 4.25 as this measure is more efficient than 1st one.

It is observed that, maximum flexural stress is located in extreme edge at base of shear wall. On the other hand, maximum shear stress is located in around the upper corner edge of opening. It is also observed that, with introducing compensatory elements, location of maximum flexural stress is understandably shifted from base to the just top of compensatory element.

With the introduction of base opening in the shear wall, concentration in the shear stress has been observed at top corners of the opening. Depending on the size of the opening the multiplication of the stress concentration can be as high as 5.34 for 60% base opening as against 3.54 for 40% base opening. The stress concentration can be significantly alleviated with the introduction of compensatory elements. However special attention needs to be given so that this problem can be dealt with by proper detailing of the juncture.

4.9 Summary of Findings

Behavior of isolated plane shear wall with or without base opening subjected to uniformly distributed lateral loading, have been studied in this chapter. The effects of base opening on shear stress, flexural stress and deflection at different height of a plane shear wall have been presented. In the case of double legged plane shear wall, it is observed that, beyond 60% base opening wall stiffness decreases significantly. This may be due to excessive reduction of moment of inertia beyond 60% base opening. The effect on shear stress is more than that on flexural stress and deflection due to introduction of base opening. In the case of single legged plane shear wall, almost same behavior is observed. But due to introduction of base opening, the increase in stresses and deflection

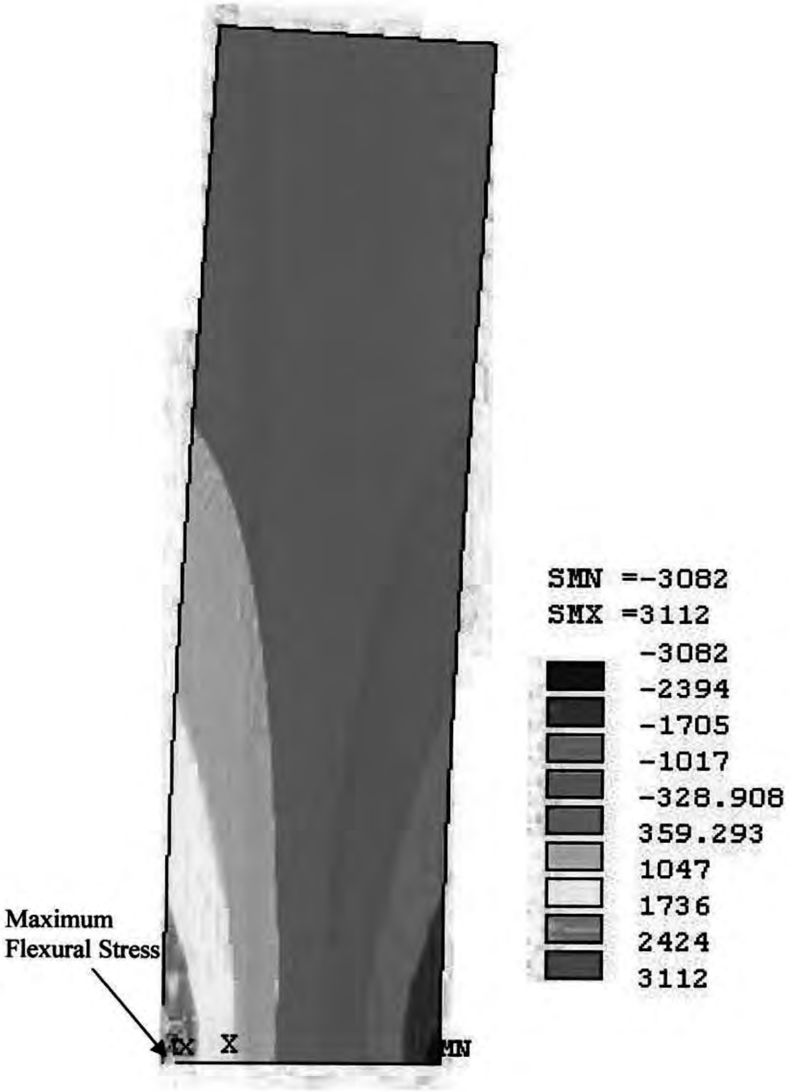


Fig. 4.16: Contour of Flexural Stress (Unit: kN/m^2) with Deflected Shape for Shear Wall without Base Opening.

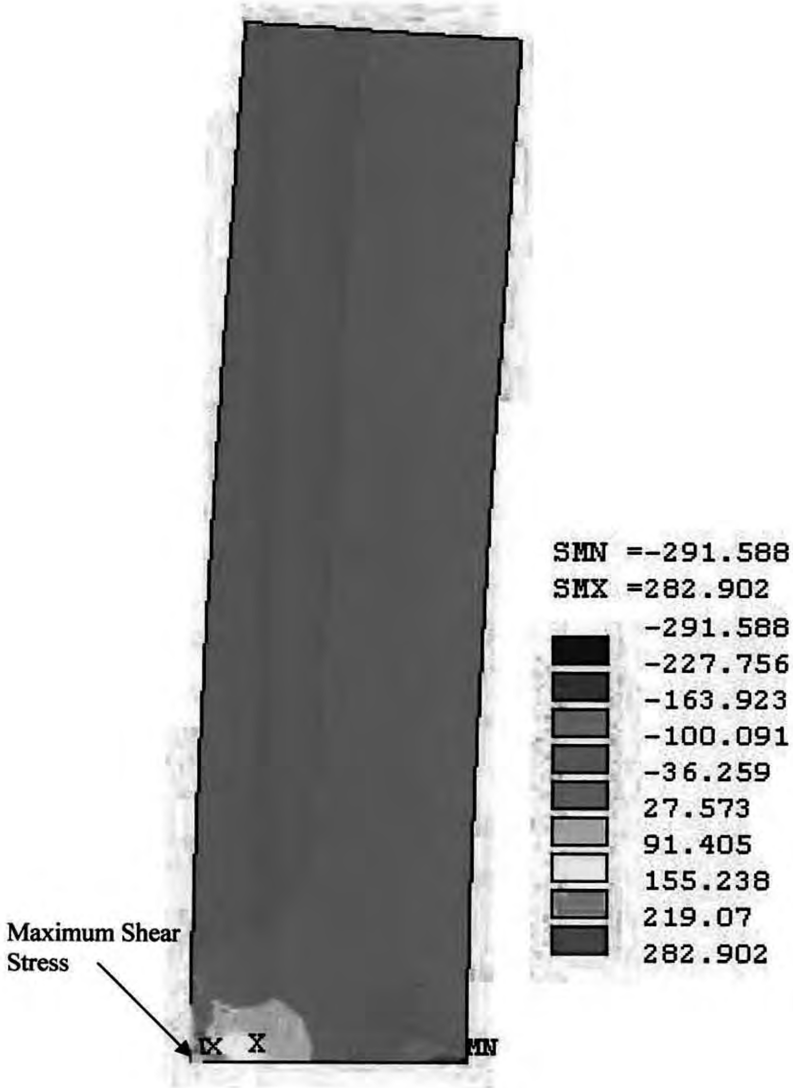
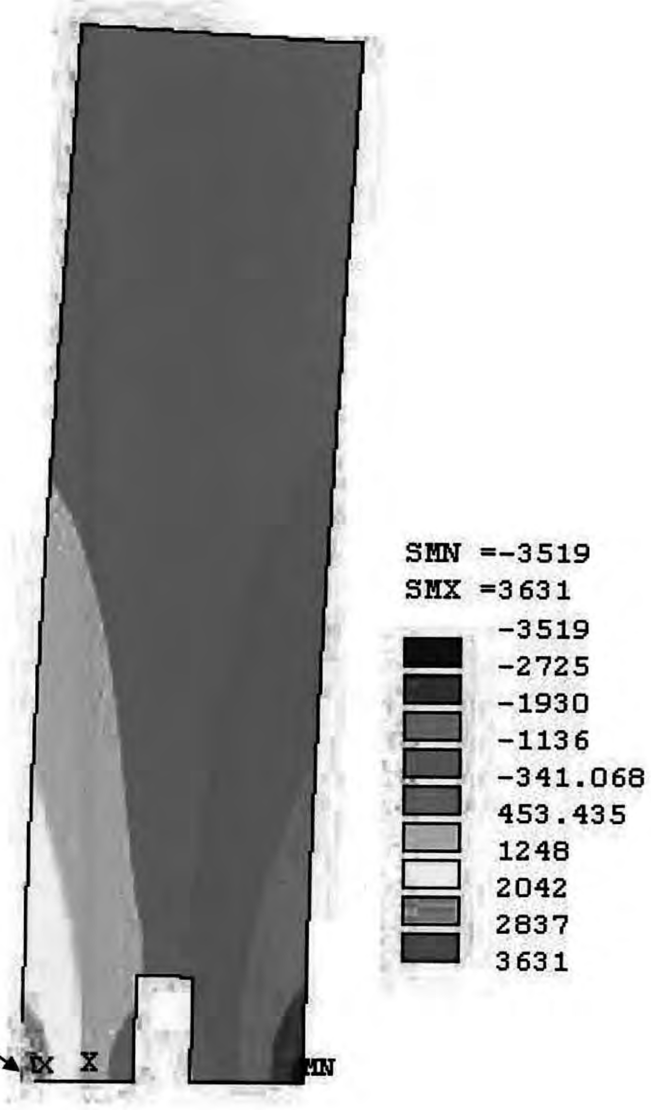


Fig. 4.17: Contour of Shear Stress (Unit: kN/m^2) with Deflected Shape for Shear Wall without Base Opening.



Maximum
Flexural Stress

Fig. 4.18: Contour of Flexural Stress (Unit: kN/m^2) with Deflected Shape for Shear Wall with 20% Base Opening.

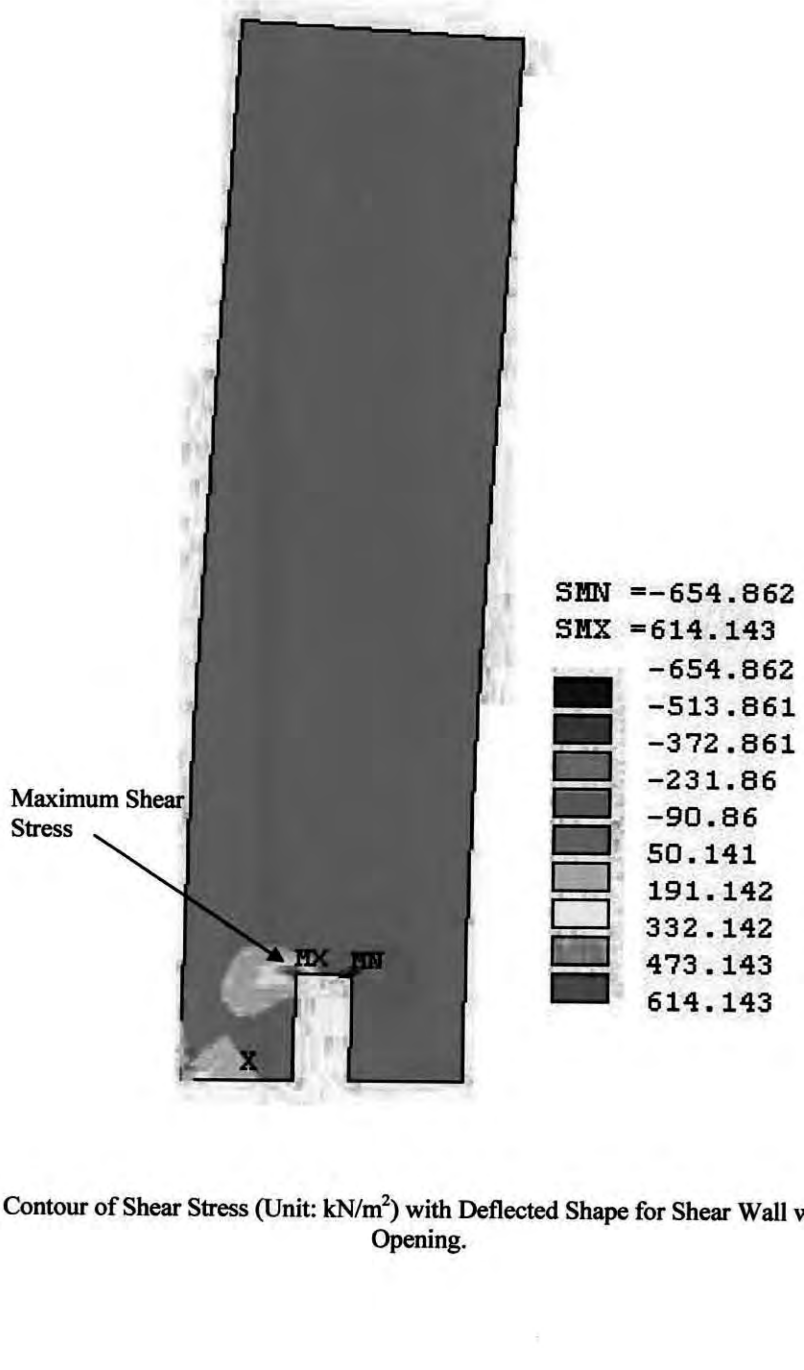


Fig. 4.19: Contour of Shear Stress (Unit: kN/m^2) with Deflected Shape for Shear Wall with 20% Base Opening.

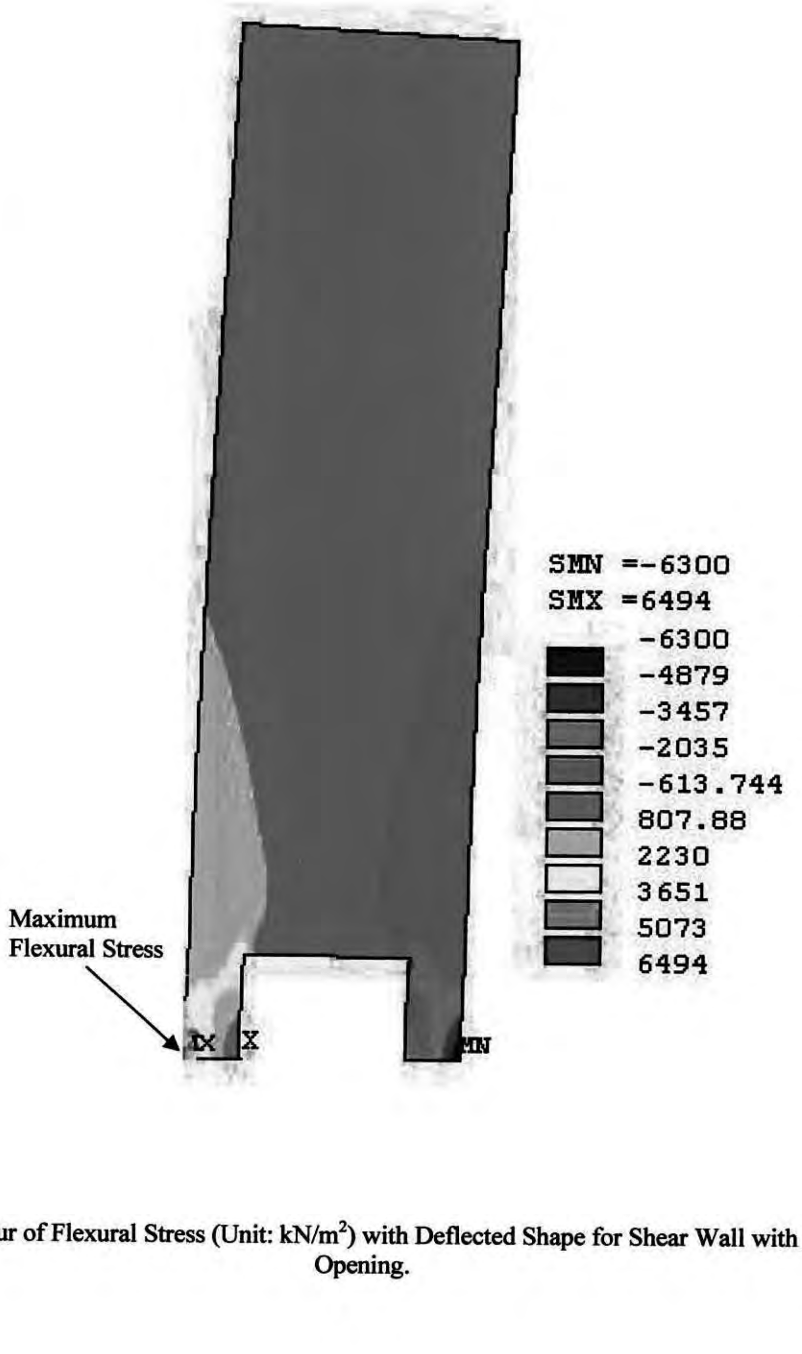


Fig. 4.20: Contour of Flexural Stress (Unit: kN/m^2) with Deflected Shape for Shear Wall with 60% Base Opening.

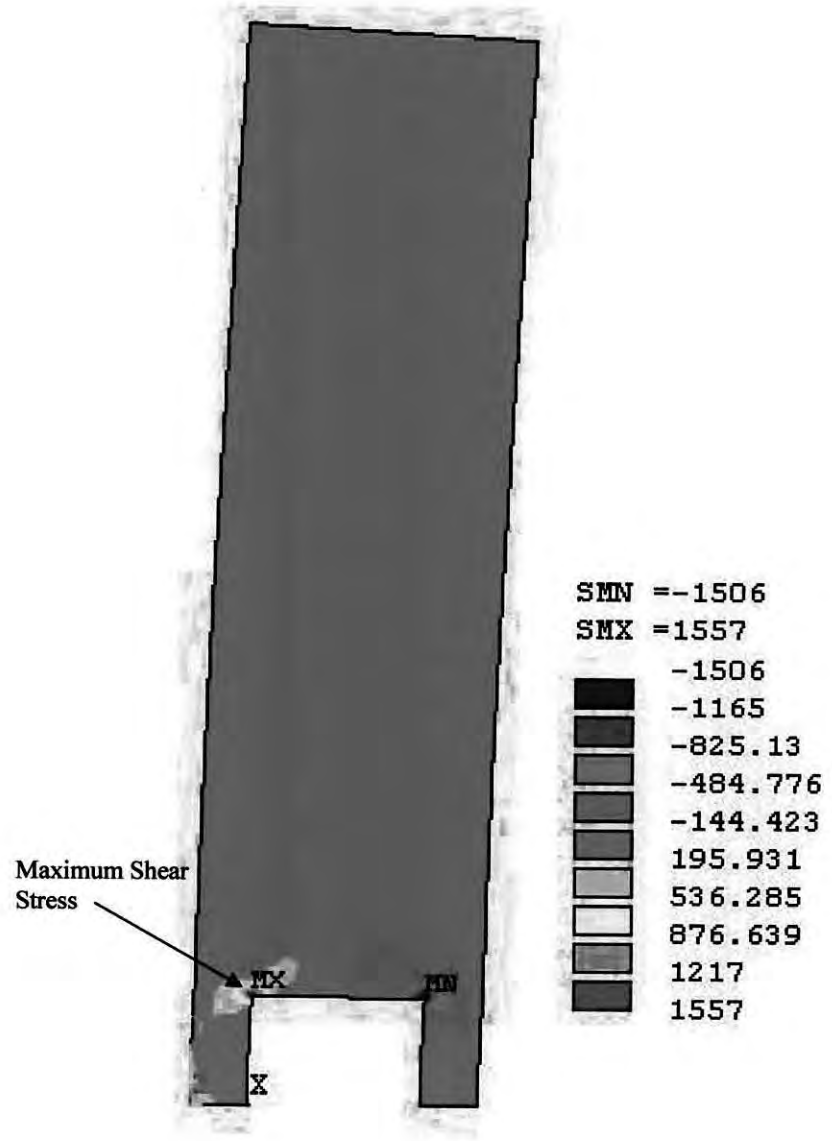


Fig. 4.21: Contour of Shear Stress (Unit: kN/m^2) with Deflected Shape for Shear Wall with 60% Base Opening.

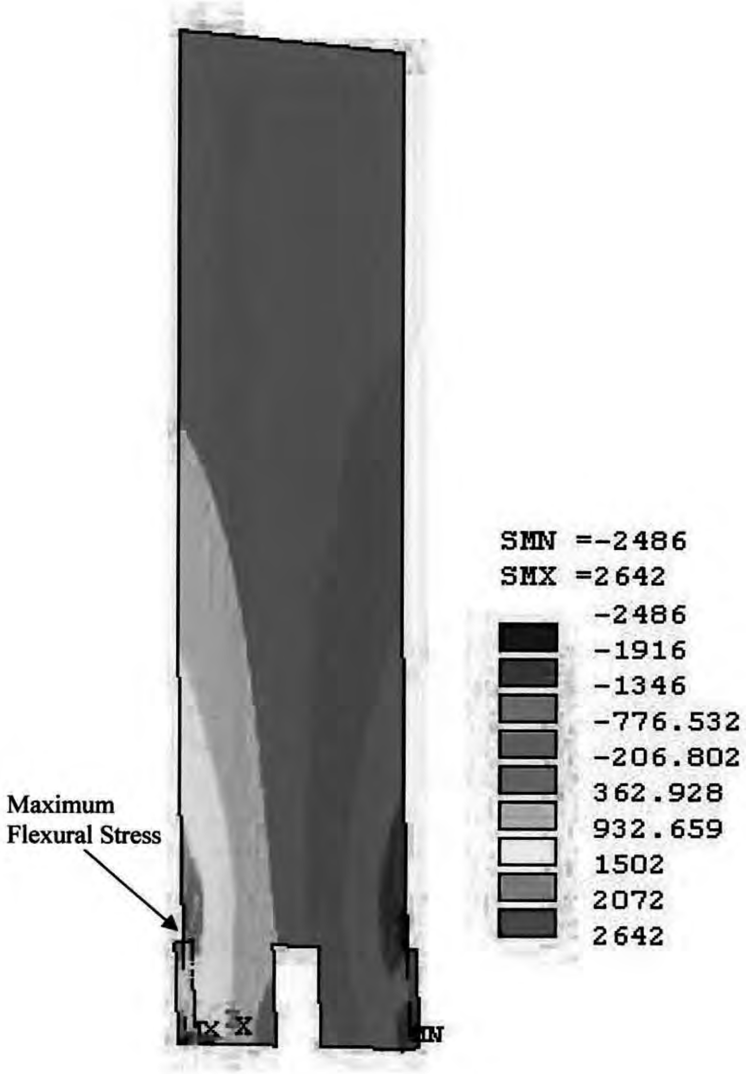

Maximum Flexural Stress

Fig. 4.22: Contour of Flexural Stress (Unit: kN/m^2) with Deflected Shape for Shear Wall with 20% Base Opening with Compensatory Elements (2nd Alternative).

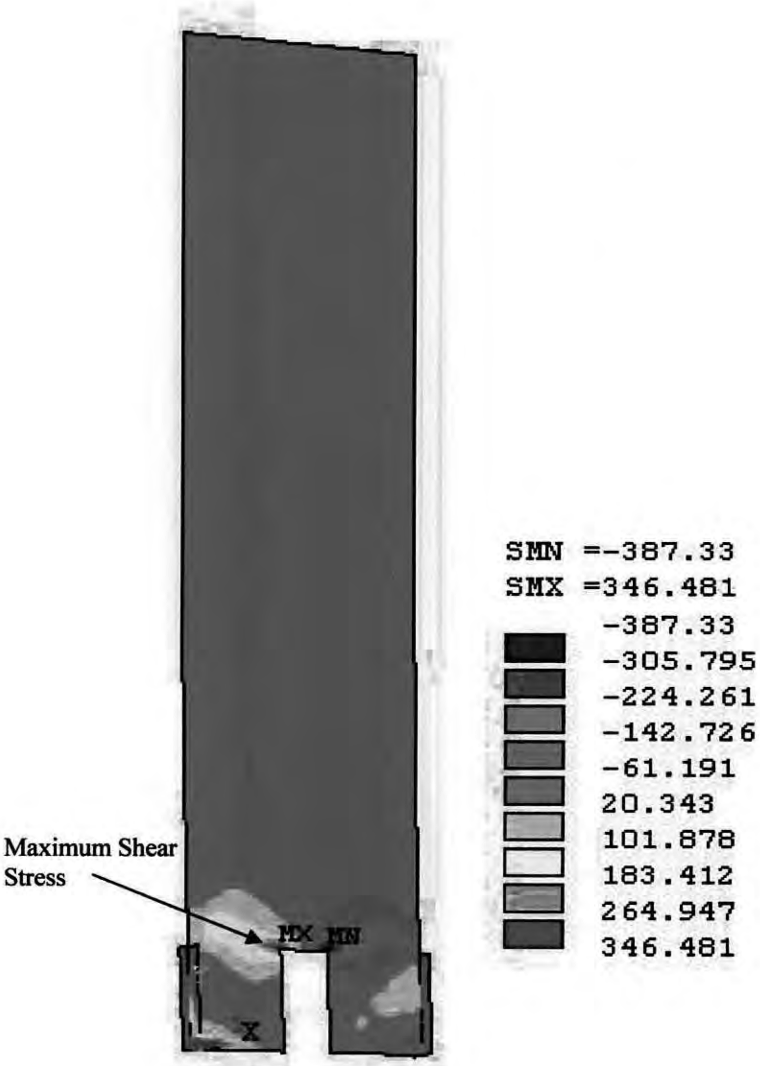


Fig. 4.23: Contour of Shear Stress (Unit: kN/m^2) with Deflected Shape for Shear Wall with 20% Base Opening with Compensatory Elements (2nd Alternative).

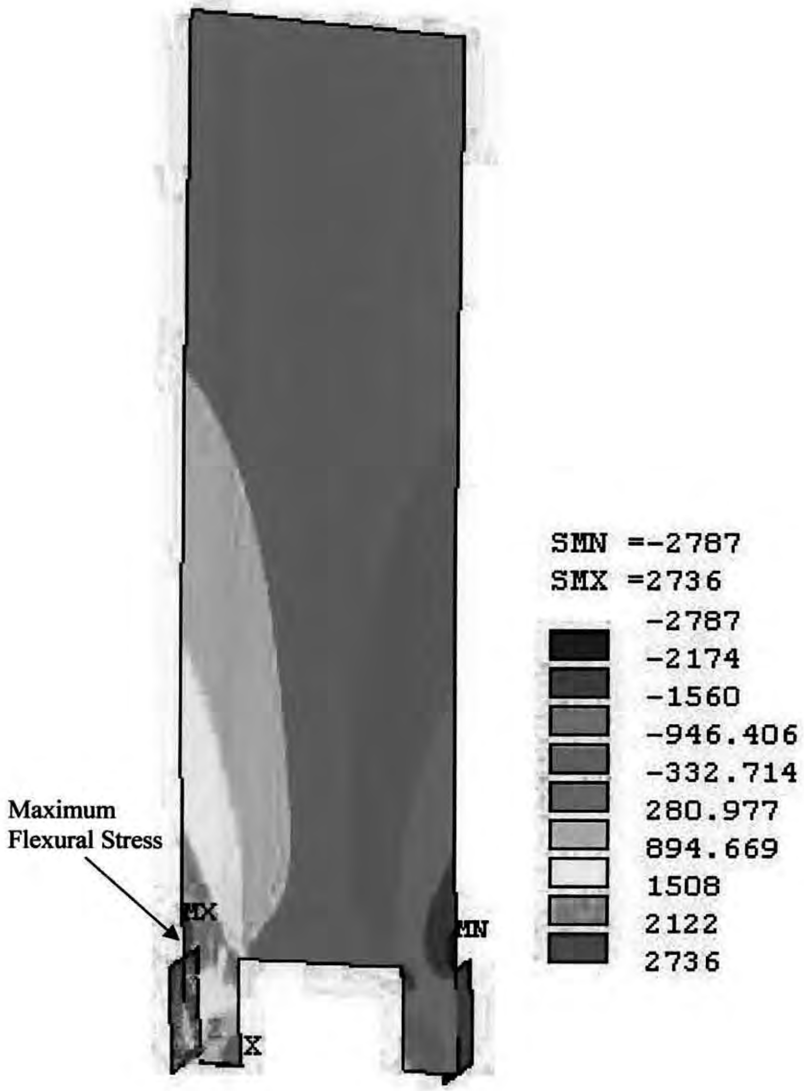


Fig. 4.24: Contour of Flexural Stress (Unit: kN/m^2) with Deflected Shape for Shear Wall with 60% Base Opening with Compensatory Elements (2nd Alternative).

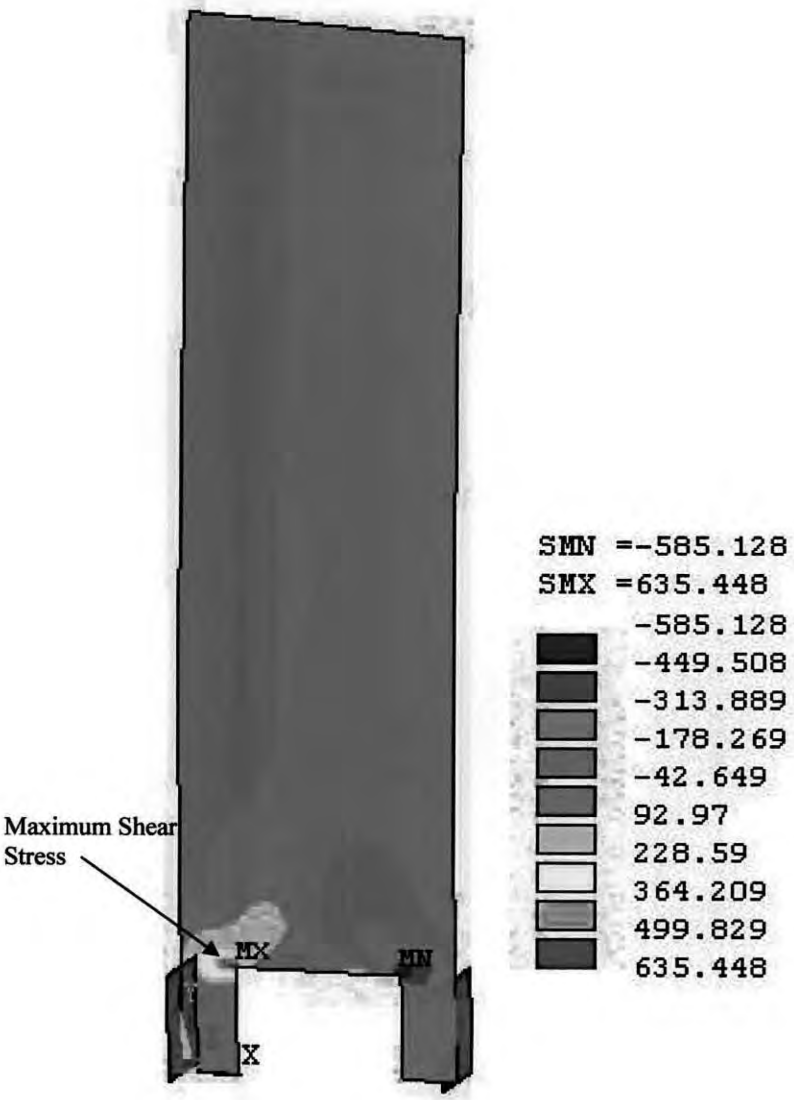


Fig. 4.25: Contour of Shear Stress (Unit: kN/m^2) with Deflected Shape for Shear Wall with 60% Base Opening with Compensatory Elements (2nd Alternative).

of this later type shear wall become excessive than that of double legged shear wall. It is, therefore, rational to recognize that any attempt to keep base opening in this type of shear wall could be detrimental and as such considered as not feasible.

A comparative study on different parameter ratios due to wind load and uniformly distributed lateral load has also been presented in this chapter. There is insignificant effect of loading type on these parameter ratios.

An attempt has been made to show the improvement of stiffness that might occur with introduction of compensatory measure, in the case of double legged plane shear wall with base opening. Two alternative compensatory measures have been taken. It is observed that the stiffness of the shear wall significantly improves due to this compensating measure.

Finally, the location of maximum stresses is observed in the stress contour. The location of maximum flexural stress is in the extreme edge at base while maximum shear stress is located around the upper corner edge of opening. It is also observed that, with introduction of compensatory elements, location of maximum flexural stress is expectedly shifted from base to the top of compensatory element.

CHAPTER : 5

BEHAVIOR OF BOX SHEAR WALL WITH BASE OPENING

5.1 Introduction

Box type shear wall is frequently used as a lift core in structure. It is also known as core walls. In Chapter 4, an investigation for various parametric conditions is performed for plane shear wall. This chapter presents results of investigation of the behavior of box shear wall with or without base opening subjected to uniformly distributed lateral loading. A set of finite element models have been developed for varying opening width and height. Shear stress, flexural stress and deflection at different heights have been studied. The behavior of box shear wall for different opening width have been studied and compared to that of a box shear wall without opening at base. A set of non-dimensional graphs have been prepared featuring important parameters which influence behavior of such wall.

5.2 Parametric Study

A frame structure with a box shear wall is selected for the study. The plan of the structure is shown in Fig. 5.1. In box shear wall, opening is kept in two opposite parallel plane of the box (XY plane) as shown in Fig. 5.2. Here box shear walls have been classified into two types depending on the direction of applied load. In Type-l, load is applied along X axis on the YZ plane. On the other hand in Type-2, load is applied along negative Z axis on the XY plane where opening is kept. In either case cross-section of box shear wall has been considered to be square with length of each side B and height of shear wall H. Three different equivalent heights of box shear walls have been considered for study: 6 story, 10 story and 15 story. Width of base opening is b as shown in Fig. 5.2. Results for each case are presented in non-dimensional form. The parameters involved in the graphical presentation are same as discussed in Section 4.2.

Base opening ratio (b/B):

It is the ratio between width of base opening (b) and the width of a side (B) of box shear wall. The percentage base opening and corresponding values of b/B, which have been used for model generation, are shown in Table 5.1.

Table 5.1: Base Opening Ratios Used for Box Type Shear Wall.

b/B	% base opening
0	0%
0.4	40%
0.6	60%
0.8	80%

5.3 Assumptions of Parametric Study

SHELL63 element from ANSYS element library has been selected for the modeling of the reinforced concrete box shear wall. Same material properties are set as in the previous chapter. It has been assumed that the length of each side B = 6 meter and the wall thickness T = 250 mm. Applied load is 1.5 kN/meter^2, uniformly distributed on the wall plane for the two cases as shown in Fig. 5.2.

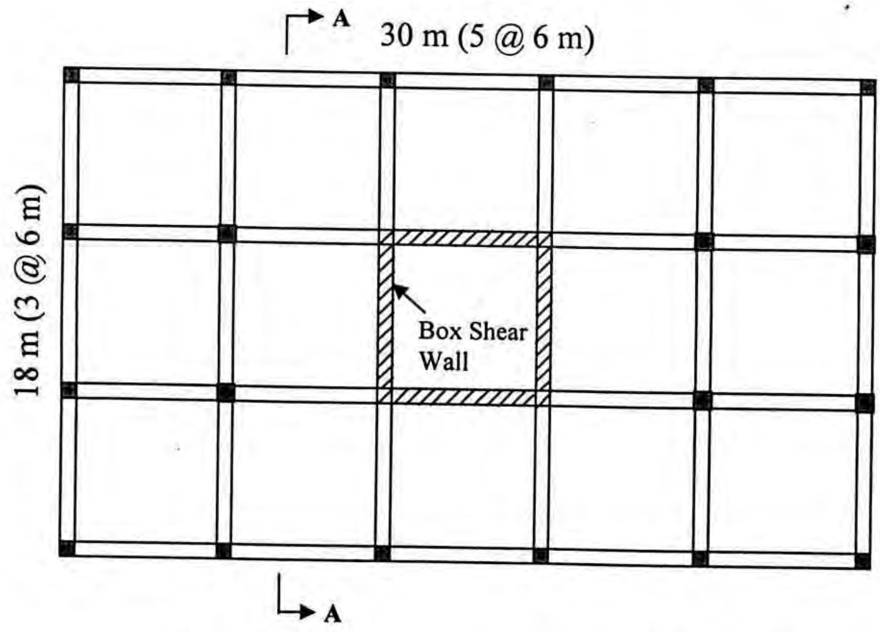
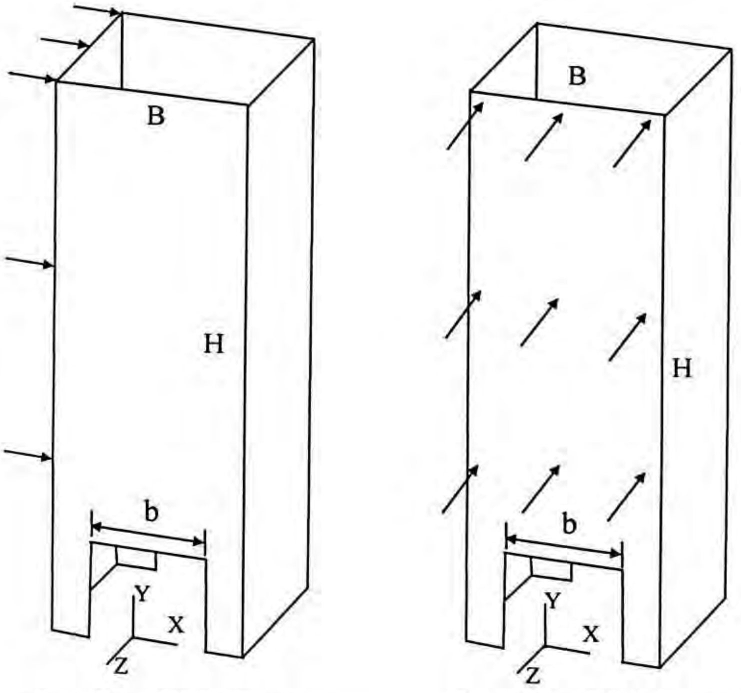


Fig. 5.1: Plan of Selected Frame Structure with Box Shear Wall.



Box Shear Wall (Type-1) Box Shear Wall (Type-2)

Fig. 5.2: Two Distinct Loading Types (Depending on the Loading Direction) of Box Shear Wall with Base Opening Considered.

5.4 Parameters Considered

Three observing parameters as described earlier in Section 4.3 have also been studied in this analysis. Maximum deflection ratio, maximum flexural stress ratio and maximum shear stress ratio for varying percentage of base opening and story height have been calculated. The ratios are calculated with respect to box shear wall without base opening and are reported next.

Maximum Deflection ratio:

For the purpose of presentation of result only top deflection is considered. At a particular box shear wall and with a given percentage of base opening, maximum deflection ratio is the ratio between maximum deflection of the shear wall with base opening and maximum deflection of an identical shear wall without base opening.

Maximum shear stress ratio:

With a particular percentage of base opening, maximum shear stress ratio is the ratio between maximum shear stress of the shear wall with base opening and maximum shear stress of an identical shear wall without base opening.

Maximum flexural stress ratio:

With a particular percentage of base opening, maximum flexural stress ratio is the ratio between maximum flexural stress of the shear wall with base opening and maximum flexural stress of an identical shear wall without base opening.

5.5 Results of Parametric Study

In this section, the effects of input parameters (as mentioned in Section 5.2) on the selected parameters (as discussed in Section 5.4) are presented.

Maximum deflection ratios for varying percentage of base opening is presented for both types of box shear wall, in Table 5.2 and at Fig. 5.3. The deflections reported in this section refer to the relevant deflection at the wall rather than the deflection of the frame. It is observed that ratio increases with the increase of percentage base opening. However, the effect of base opening on deflection is insignificant. The influence of shear wall height in its stiffness is also observed here. The deflection ratios are reported to an accuracy of there decimal places. For both types of box shear wall, ratio decreases with the increasing story height. For example, with 80% base opening maximum deflection ratio of 6 storied Type-1 shear wall is 1.2 and it is 1.0 for 15 storied shear wall. Another interesting feature is that the deflection ratio is virtually not affected for less than 60% base opening.

Table 5.2 Maximum Deflection Ratios for Both Types of Box Shear Wall With Varying Opening Ratios.

Percentage Base opening	Type of Box shear wall	Maximum Deflection Ratio		
		6 story	10 story	15 story
80% base opening	Type-1	1.225	1.061	1.027
	Type-2	1.062	1.050	1.057
60% base opening	Type-1	1.080	1.025	1.010
	Type-2	1.036	1.029	1.034
40% base opening	Type-1	1.036	1.012	1.005
	Type-2	1.019	1.016	1.018

Maximum shear stress and maximum flexural stress ratios for varying percentage of base opening are presented in Fig. 5.4 and Fig. 5.5 respectively for both types of box shear wall. For Type-1, the increase in shear stress ratios for 60% opening appears to be 1.2 to 1.3 times at top of the box shear wall (shown in Fig. 5.4). Whereas in the case of Type-1, the flexural stress ratios for 60% opening appear to 1.5 to 2.6 times (shown in Fig. 5.5). On the other hand, for Type-2 shear wall, all curves are almost similar to those of Type-1. Although general behaviors of Type-1 and Type-2 are similar, the absolute values of the ratios are low in the case of Type-2. For example, in the case of 15 storied Type-1 shear wall with 60% base opening, maximum flexural stress ratio is 2.6 when it is only 1.6 for Type-2. Type-2 box shear wall is stiffer than Type-1. It is observed that shear stress ratios for Type-2 shear wall are 1.0 that means effect of base opening on shear stress is insignificant for Type-2 shear wall.

It is seen from Fig. 5.4 and Fig. 5.5 that flexural stress is more affected than the shear stress due to the introduction of base opening in box shear wall. For same % of opening, shear stress ratio is less than flexural stress ratio. For example with 60% opening & 15 storied Type-1 shear wall, the flexural stress ratio is 2.6 when shear stress ratio is 1.2. A summery is presented in tabular form, which is shown in Table 5.3.

Table 5.3: Stress Ratios for Varying % of Opening and Story Height for Both Types of Box Shear Wall.

Percentage Base opening	Type of Box shear wall	Flexural Stress Ratio			Shear Stress Ratio		
		6 story	10 story	15 story	6 story	10 story	15 story
80% base opening	Type-1	2.1	2.2	2.6	1.5	1.2	1.2
	Type-2	1.7	1.8	1.9	1.0	1.0	1.0
60% base opening	Type-1	1.5	1.8	2.6	1.3	1.0	1.2
	Type-2	1.4	1.7	1.6	1.0	1.0	1.0
40% base opening	Type-1	1.3	1.5	2.6	1.3	1.0	1.2
	Type-2	1.1	1.4	1.3	1.0	1.0	1.0

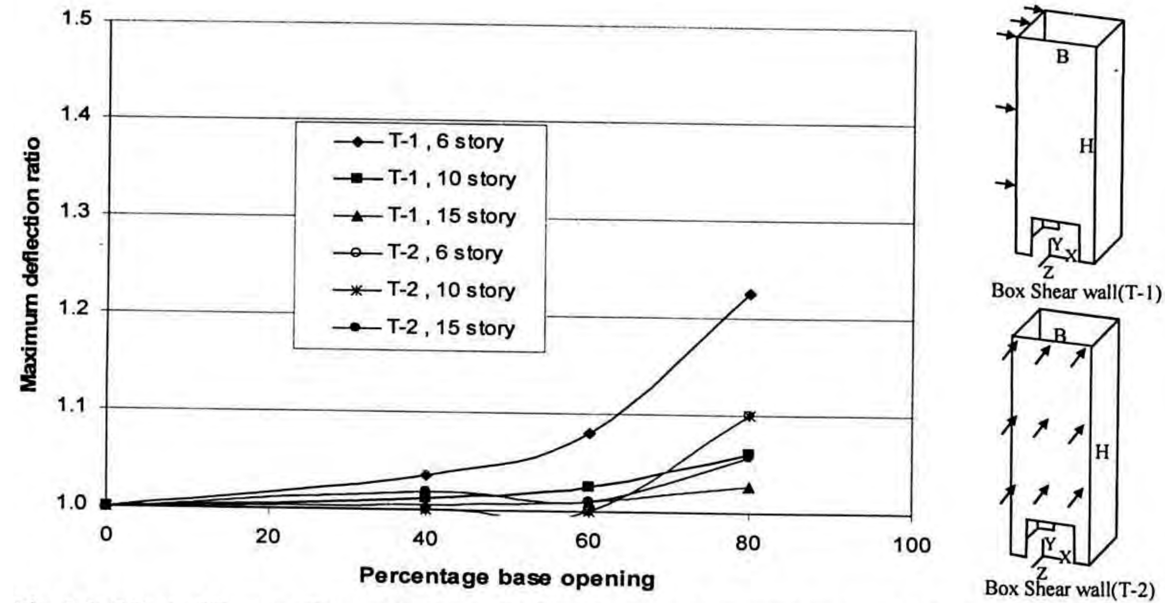


Fig. 5.3: Effect of Opening Size on Maximum Deflection Ratios for Box Shear Wall with Varying Story Height

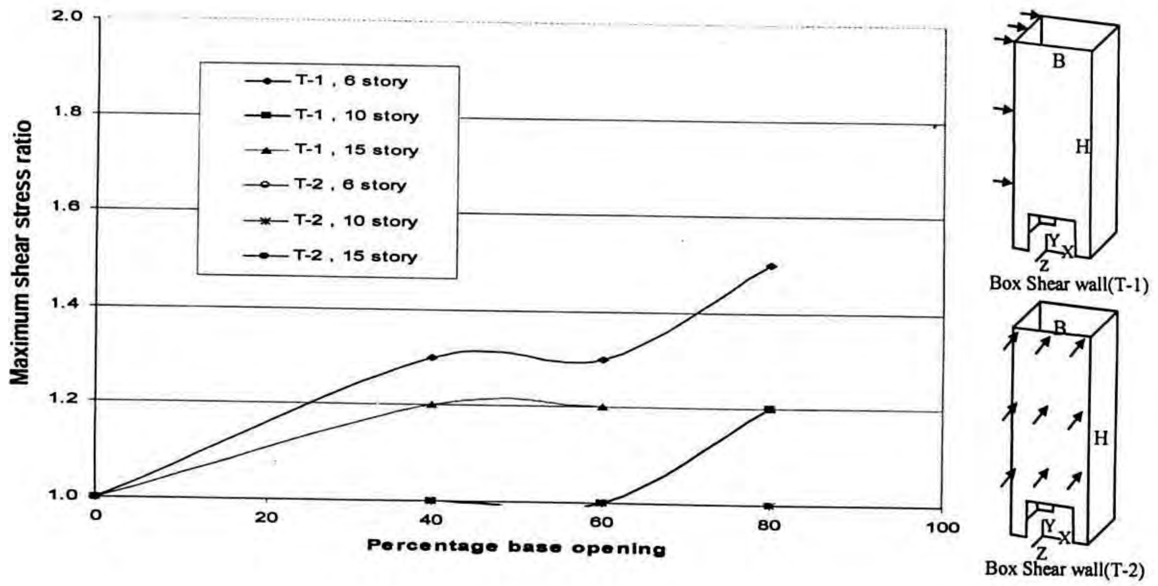


Fig. 5.4: Effect of Opening Size on Maximum Shear Stress Ratios for Box Shear Wall with Varying Story Height.

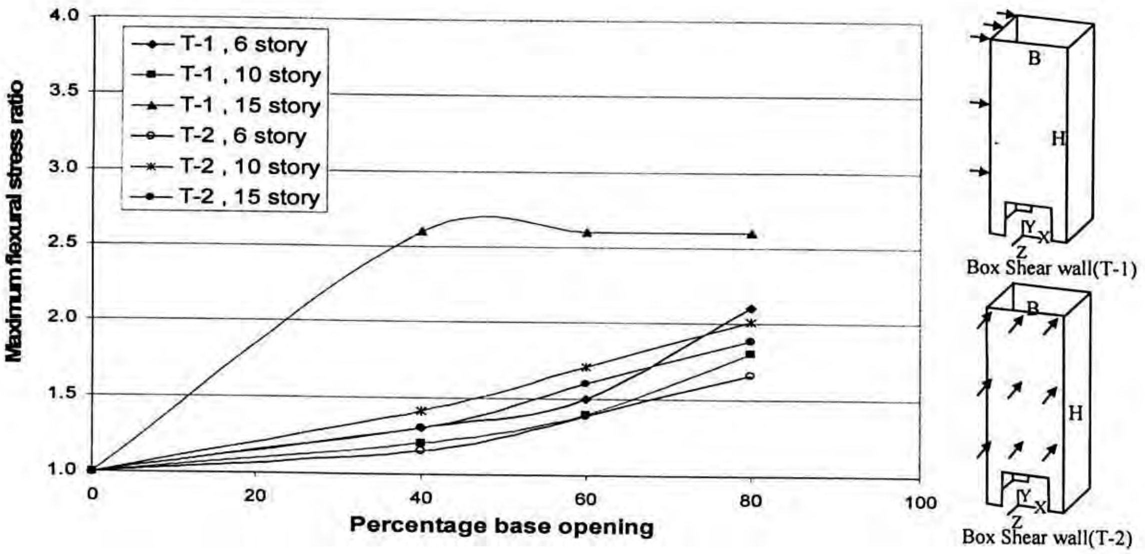


Fig. 5.5: Effect of Opening Size on Maximum Flexural Stress Ratios for Box Shear Wall with Varying Story Height

5.6 Stress Contour

Stress contours for box shear wall (10 storied) with or without base opening are shown from Fig. 5.6 to Fig. 5.11. Flexural stress contour and shear stress contour for box shear wall without base opening are shown in Fig. 5.6 and Fig. 5.7 respectively. The corresponding stress contours for both types (1 and 2) with 60% base opening are presented form Fig. 5.8 to Fig. 5.11.

It is observed that, maximum flexural stress is located at base of shear wall. On the other hand, maximum shear stress is located at top of shear wall. This is due to phenomenon called “Shear lag”. In thin-walled structures the large shearing strains cause the plane of the section to distort. As the maximum warped cross-section occurring in top (see deflected shape in Fig. 5.11), the location of maximum shear stress is in that section.

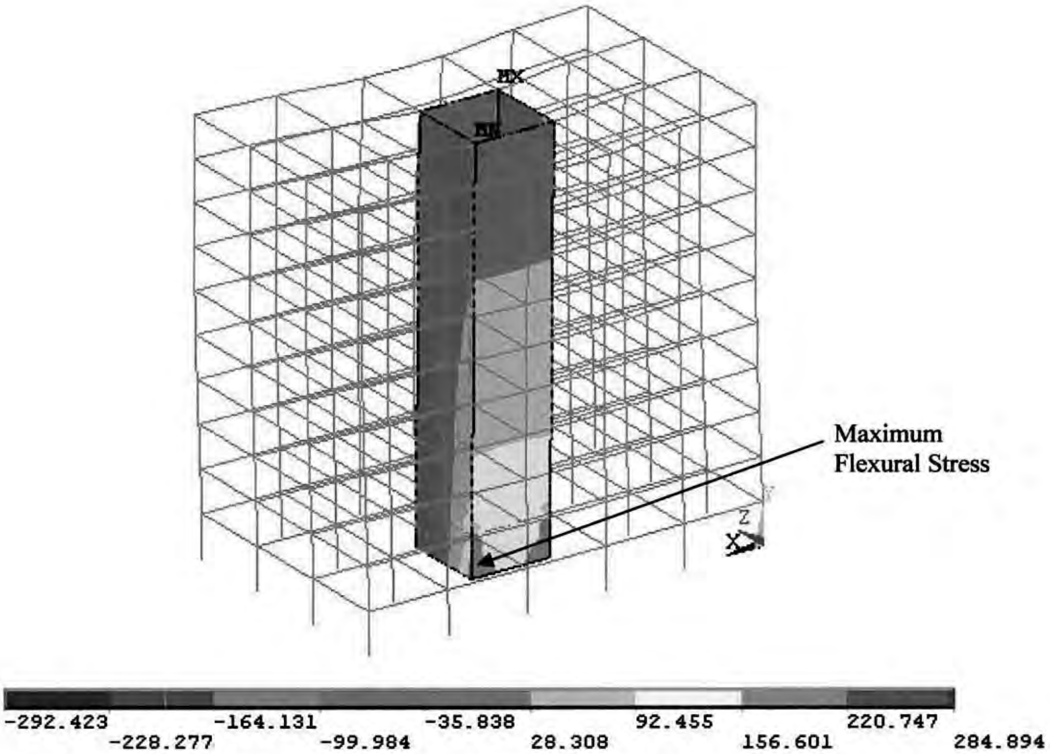


Fig. 5.6: Contour of Flexural Stress (kN/m^2) with Deflected Shape for Box Shear Wall without Base Opening.

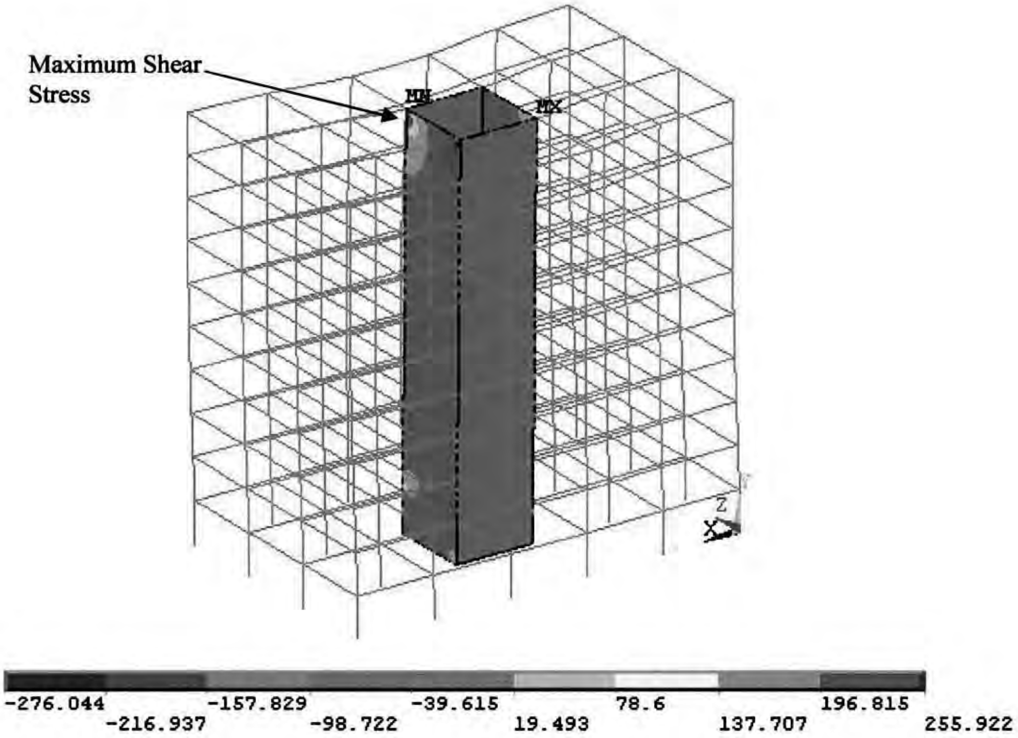


Fig. 5.7: Contour of Shear Stress (kN/m^2) with Deflected Shape for Box Shear Wall without Base Opening.

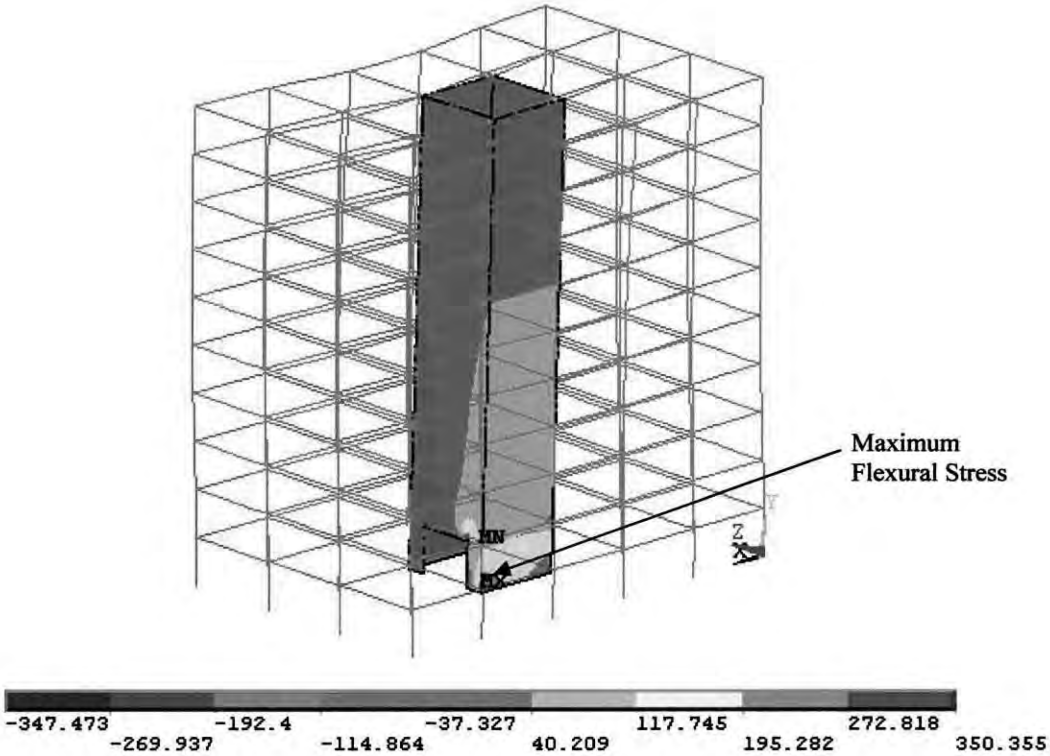


Fig. 5.8: Contour of Flexural Stress (kN/m^2) with Deflected Shape for Box Shear Wall (Type-1) with 60% Base Opening.

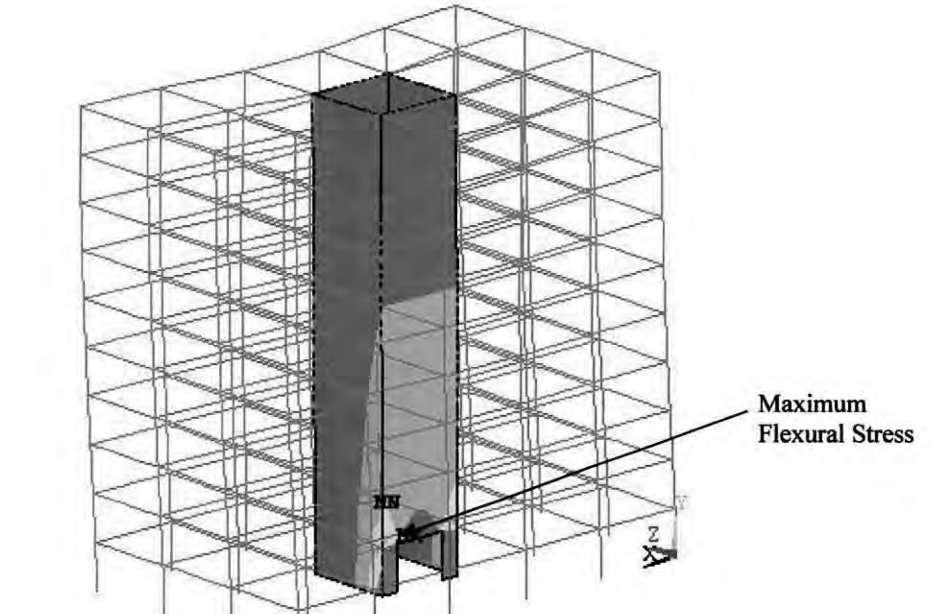


Fig. 5.9: Contour of Flexural Stress (kN/m^2) with Deflected Shape for Box Shear Wall (Type-2) with 60% Base Opening.

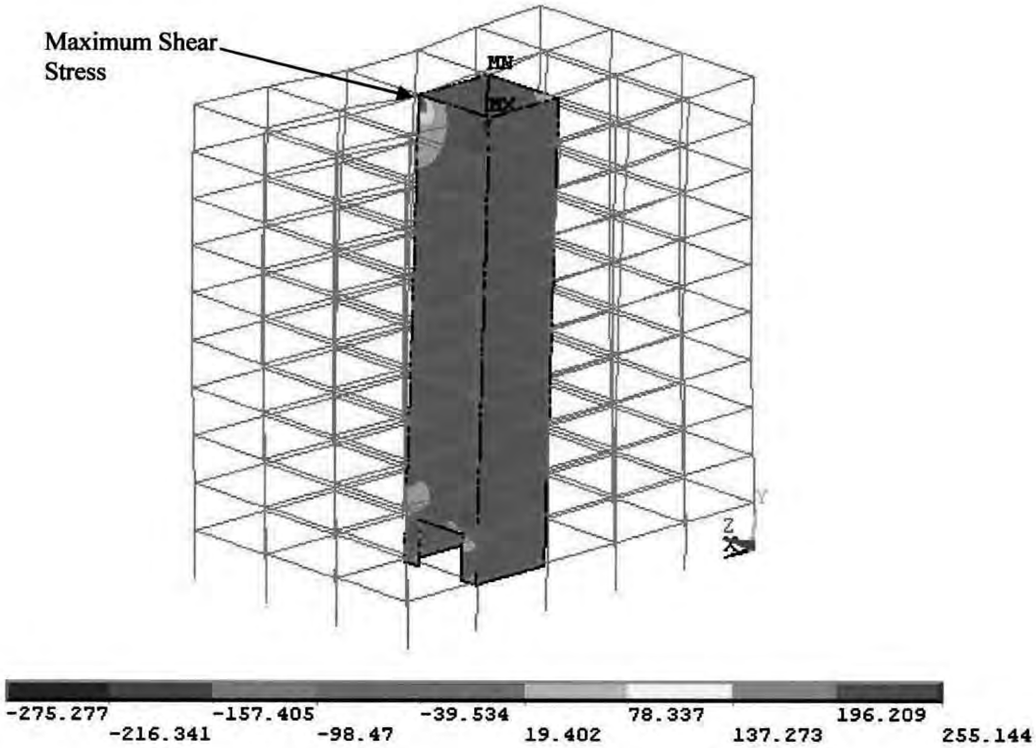


Fig. 5.10: Contour of Shear Stress (kN/m^2) with Deflected Shape for Box Shear Wall (Type-1) with 60% Base Opening.

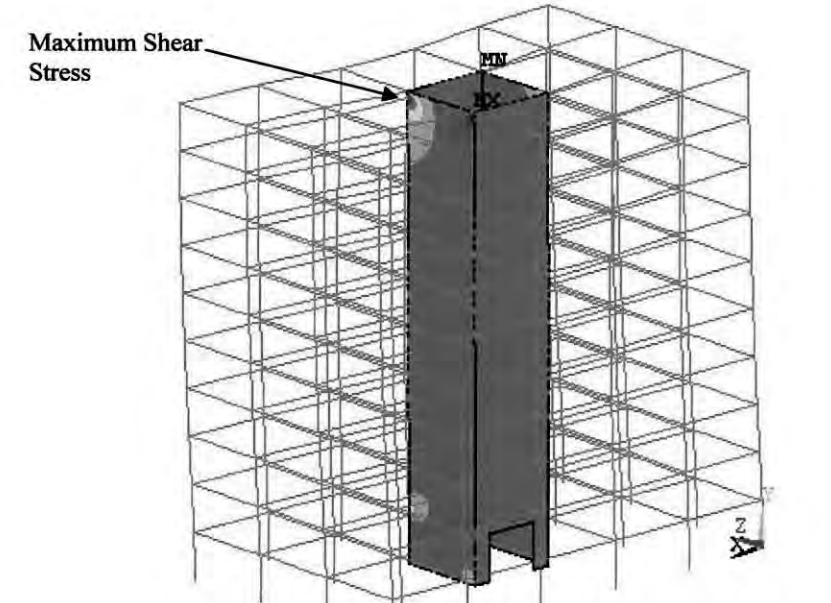


Fig. 5.11: Contour of Shear Stress (kN/m^2) with Deflected Shape for Box Shear Wall (Type-2) with 60% Base Opening.

5.7 Summery of Findings

Behavior of box shear wall with or without base opening subjected to uniformly distributed lateral loading, have been studied in this chapter. Depending on direction of the applied load, shear walls have been classified into two types. The effects of base opening on shear stress, flexural stress and deflection of box shear wall have been presented.

Maximum shear stress and maximum flexural stress ratios for varying base opening (b/B) have been presented. It is seen that flexural stress is affected more than the shear stress due to the introduction of base opening in shear wall. It is also observed that effect of base opening on shear stress is insignificant for Type-2 shear wall.

It is also observed that, in the case of box shear wall, direction of applied load with respect to the position of opening is an important factor.

Finally, the location of maximum stresses has been observed in the stress contour. It is observed that, the maximum flexural stress is located at base of the box shear wall while on the other hand maximum shear stress is located at top of the box shear wall. For the range of structures considered in the study, it is seen that up to 40% base opening the stress ratios reached up to 2.6 for Type-1 and up to 1.4 for Type-2 Shear wall. This can lead to practical conclusion that with proper design and detail, it is feasible to have box shear wall to have base opening up to 40%.

CHAPTER : 6

BEHAVIOR OF A 15 STORY SHEAR WALL FRAME STRUCTURE

6.1 Introduction

The behavior of isolated shear wall (both plain and box type shear wall) with and without base opening have been studied in the previous chapters. This chapter presents results of an investigation performed for a complete frame structure with or without shear wall. The effect of the presence of underground basement wall on the stiffness of overall structure has also been studied. The main purpose of this chapter is to demonstrate how the additional stiffness due to the underground basement wall, if present, may compensate the effect of any base openings in the shear walls.

6.2 Parametric Study

A 15 storied frame structure is selected for the study. The plan of the structure is shown in Fig. 6.1. Design wind load as calculated in Table 3.3 is applied on the structure. Assuming a residential building, live load is chosen as recommended by BNBC (1993) and then slab, beam and column sections are designed. For exterior and interior columns, two different cross sections are chosen. In each case, square cross section is selected and sections are reduced in upper levels. Base opening in shear wall is provided as 50%. Selected slab, shear wall, beam and column dimensions are shown in Table 6.1.

SHELL63 element from ANSYS element library is selected for modeling slab, basement wall and shear wall; BEAM4 element for column and BEAM44 element is selected for modeling beam. Basic properties such as Young's modulus of elasticity, shear modulus, Poisson's ratio are kept same as mentioned in Section 4.3. Both BEAM4 and BEAM44 are uniaxial element with tension, compression, torsion, and bending capabilities and have six degrees of freedom at each node. But element BEAM44 allows a different unsymmetrical geometry at each end and permits the end nodes to be offset from the centroidal axis of the beam. Detailed elementary description of BEAM4 and BEAM44 are available in ANSYS Manual (2000).

Table 6.1: Dimensions of the Selected Slab, Beam and Column.

	Column cross section	
	Exterior	Interior
Ground floor to 5th floor	30"x30"	40"x40"
5th floor to 10th floor	24"x24"	30"x30"
10th floor to top floor	16"x16"	24"x24"
Beam cross section	12"x 24"	
Slab thickness	7"	
Shear wall thickness	10"	
Basement wall thickness	10"	

Underground basement wall is the wall constructed through the peripheral line of a structure to resist the soil pressure. It also increases the stiffness of the structure. In this chapter, stiffness contribution for basement wall with or without shear wall, is also studied. Basement wall is constructed on two floors below ground and thickness is kept same as shear wall.

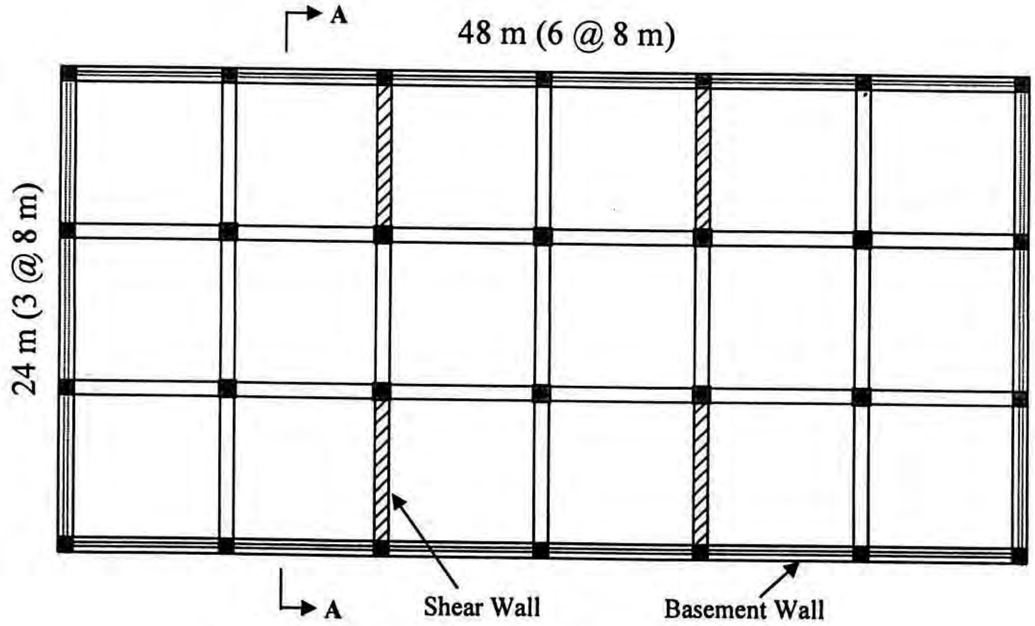


Fig. 6.1: Plan of Selected 15 Storied Frame Structure.

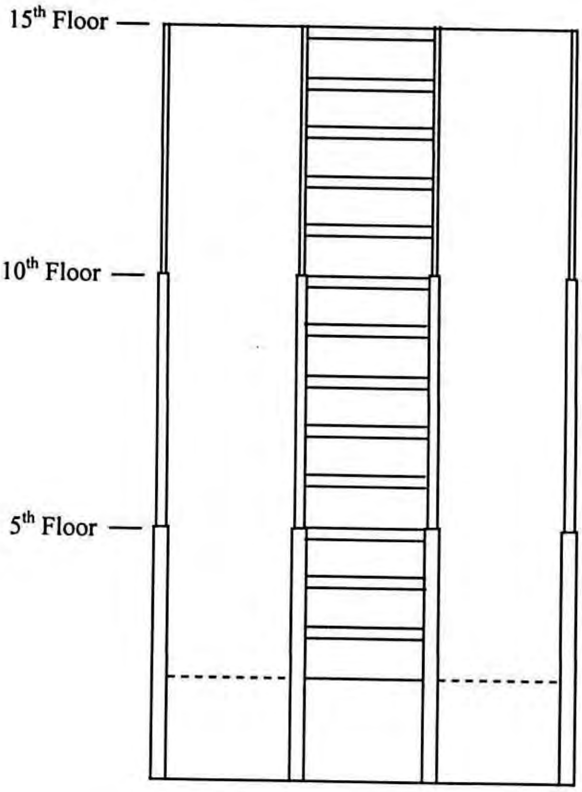


Fig. 6.2: Cross-section A-A of the Structure Shown in Fig. 6.1.

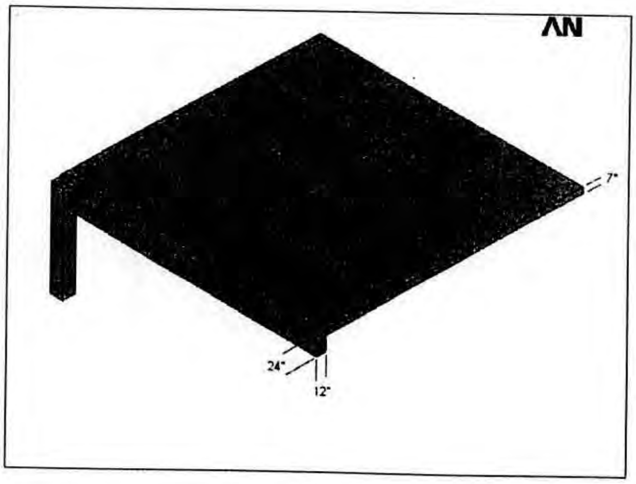


Fig. 6.3: Modeling of Beam, Column and Slab.

6.3 Parameters Considered

For different combination of shear wall with or without base opening and basement wall, six types of structures are considered for study which are shown in Table 6.2.

Table 6.2: Six Types of Structures Considered for the Study.

Type	Shear wall	Base opening	Basement wall
Type-1	-	-	-
Type-2	Yes	-	-
Type-3	Yes	Yes	-
Type-4	Yes	-	Yes
Type-5	Yes	Yes	Yes
Type-6	-	-	Yes

Partial 3-D views of these six types of structures are shown in Fig. 6.4 to Fig. 6.9.

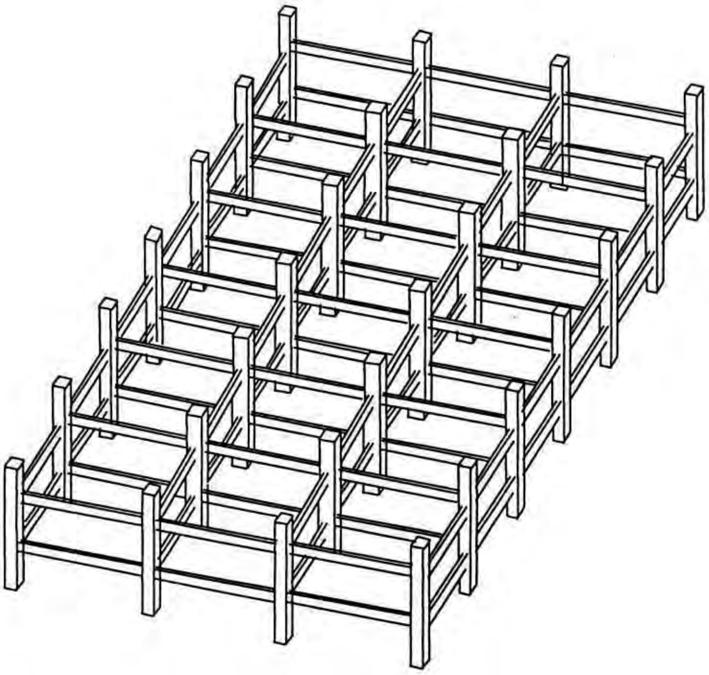


Fig. 6.4: Partial View of the Type-1 (Frame Only).

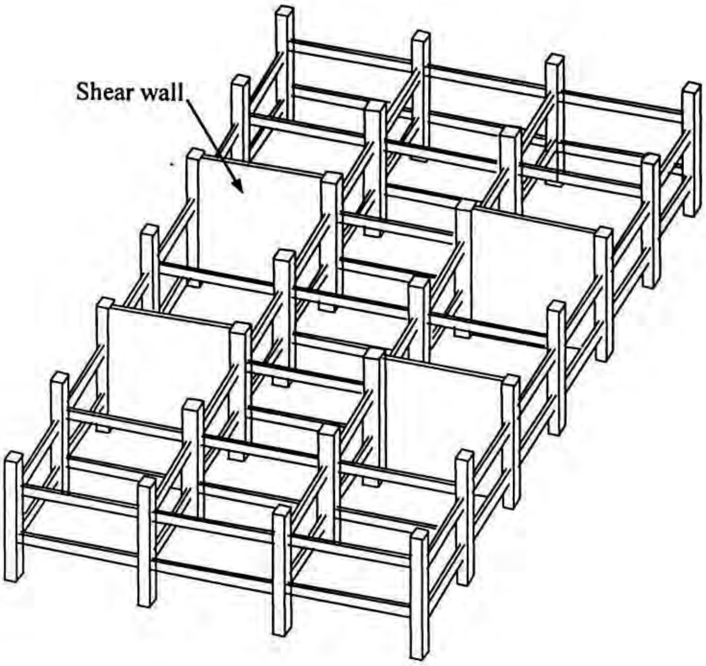


Fig. 6.5: Partial View of the Type-2 (Frame + Shear Wall).

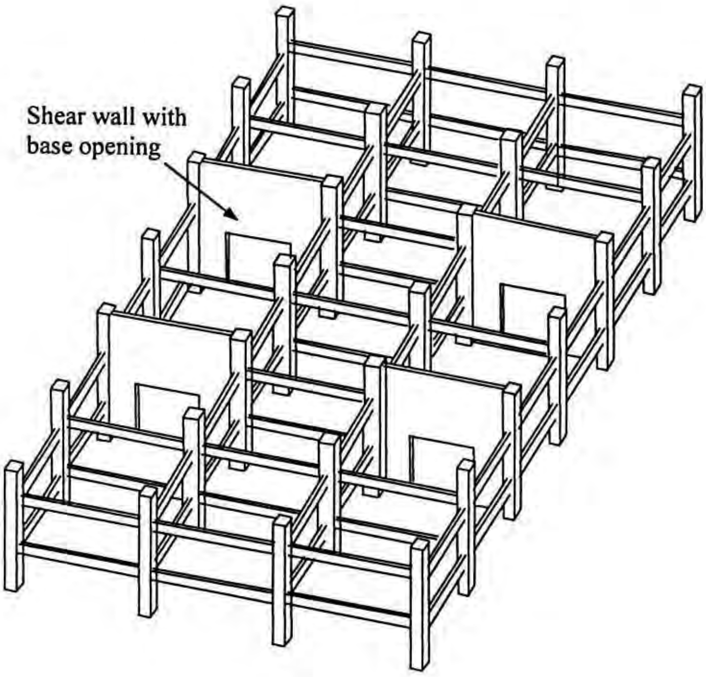


Fig. 6.6: Partial View of the Type-3 (Frame + Shear Wall + Base Opening).

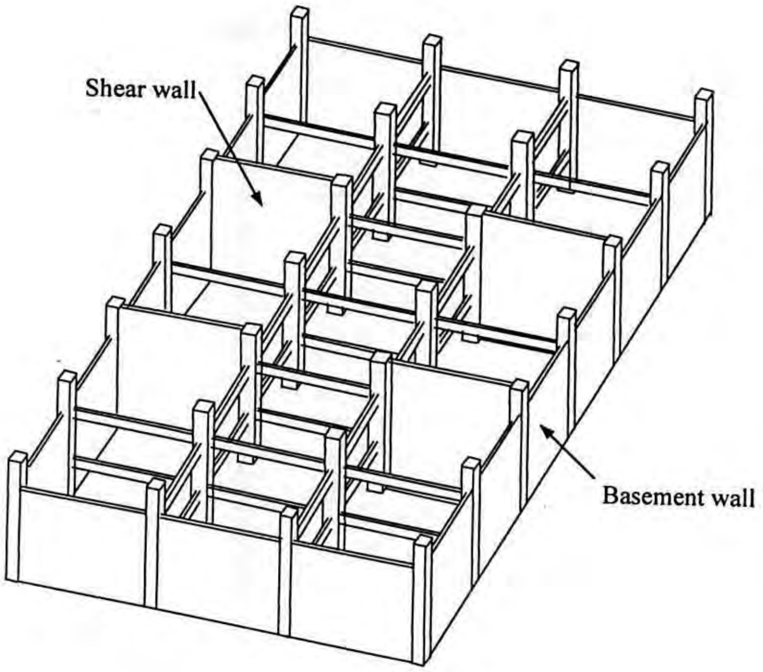


Fig. 6.7: Partial View of the Type-4 (Frame + Shear Wall + Basement Wall).

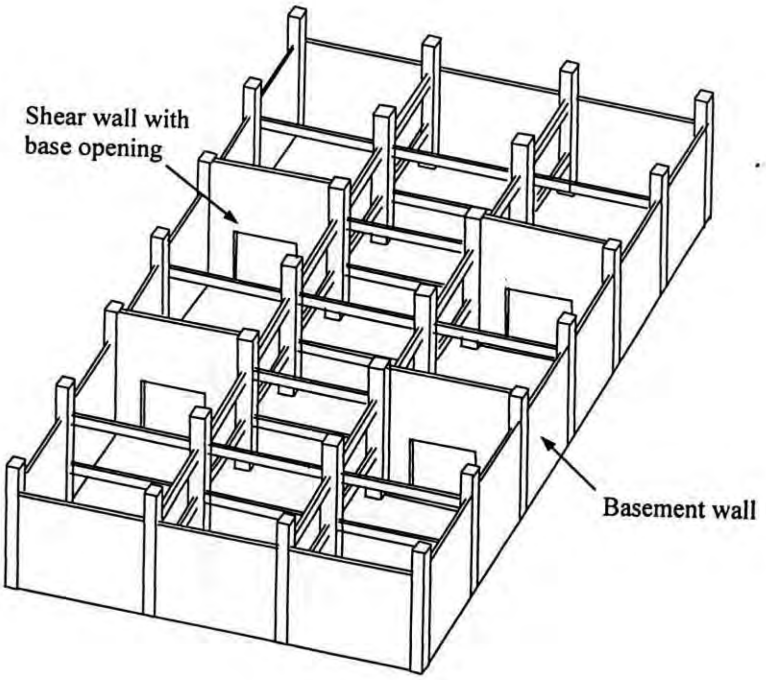


Fig. 6.8: Partial View of the Type-5 (Frame + Shear Wall +Base Opening+ Basement Wall).

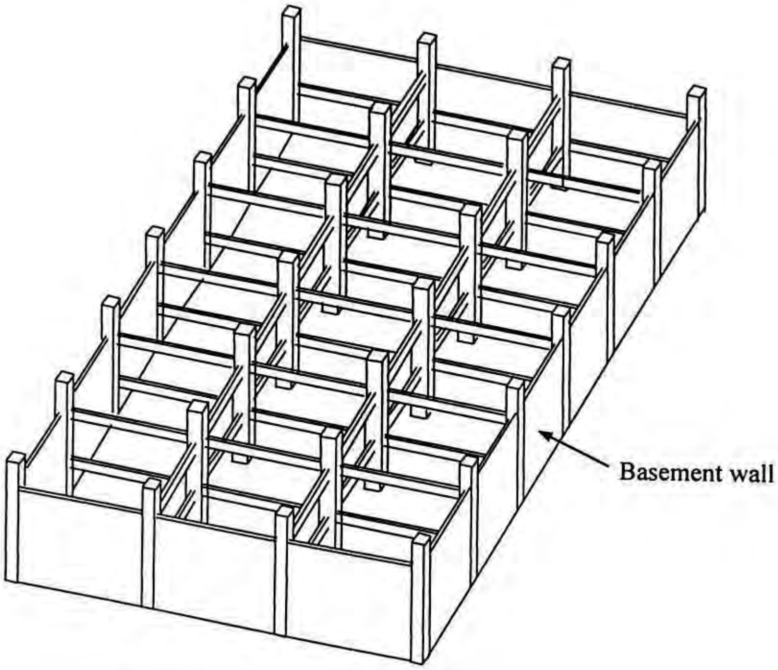


Fig. 6.9: Partial View of the Type-6 (Frame + Basement Wall).

6.4 Results of the Study

Deflections and the drift ratios (Deflections/Total Height ratios) at different floor levels are calculated which is shown in Table 6.3. A graphical representation of drift ratio against height is plotted in Fig. 6.10.

Table 6.3: Deflection/Height Ratio at Different Height for Different Types of Structures.

Type / Height (m)	Type-1 (Frame only) x 10^{-3}	Type-2 (Frame + Shear wall) x 10^{-3}	Type-3 (Frame + Shear wall + Base opening) x 10^{-3}	Type-4 (Frame + Shear wall + Base wall) x 10^{-3}	Type-5 (Frame + Shear wall + Base opening + Base wall) x 10^{-3}	Type-6 (Frame + Base wall) x 10^{-3}
45	2.401	0.529	0.539	0.465	0.467	1.998
30	1.873	0.312	0.321	0.265	0.267	1.476
15	0.897	0.109	0.117	0.083	0.085	0.526
6	0.242	0.026	0.033	0.016	0.018	0.044
3	0.074	0.008	0.014	0.005	0.006	0.005

It is observed from the Fig. 6.10, drift ratio of Type-1, is the highest. After introducing basement wall, i.e. Type-6, stiffness of the structure is increased. On the other hand for Type-2, Type-3, Type-4 and Type-5, stiffness is considerably increased by introducing shear wall. For example drift ratio of Type-1 is 2.401×10^{-3} whereas it is only 0.529×10^{-3} for Type-2. There is no difference between Type-2 and Type-3, except provision of 50% base opening in Type-3 (see Fig. 5.5 and Fig 5.6). Similar provision is kept in Type-5 in comparison to Type-4 (see Fig. 5.7 and Fig 5.8). It is observed that, increase in drift ratio due to provision of 50% base opening is insignificant. For example drift ratio of Type-2 is 0.529×10^{-3} whereas it is 0.539×10^{-3} for Type-3. The Uniform Building Code, BOCA, and the National Building Code of Canada, among North American model building codes, specify a maximum value of the deflection index of 1/500, corresponding to the design wind loading (Fintel, 1986). Also, ACI Committee 435 recommends a drift limit of 1/500 (Fintel, 1986). It is observed that, Type-1 structure exceeds the limit and Type-6 structure touches the limit. With introduction of shear wall in high-rise structure (Type-2, Type-3, Type-4 and Type-5), stiffness can be increased as well as drift criteria can be satisfied. The improvement in the stiffness due to the presence of shear wall and/or basement wall remain virtually unaffected due to presence of any base opening in the shear wall.

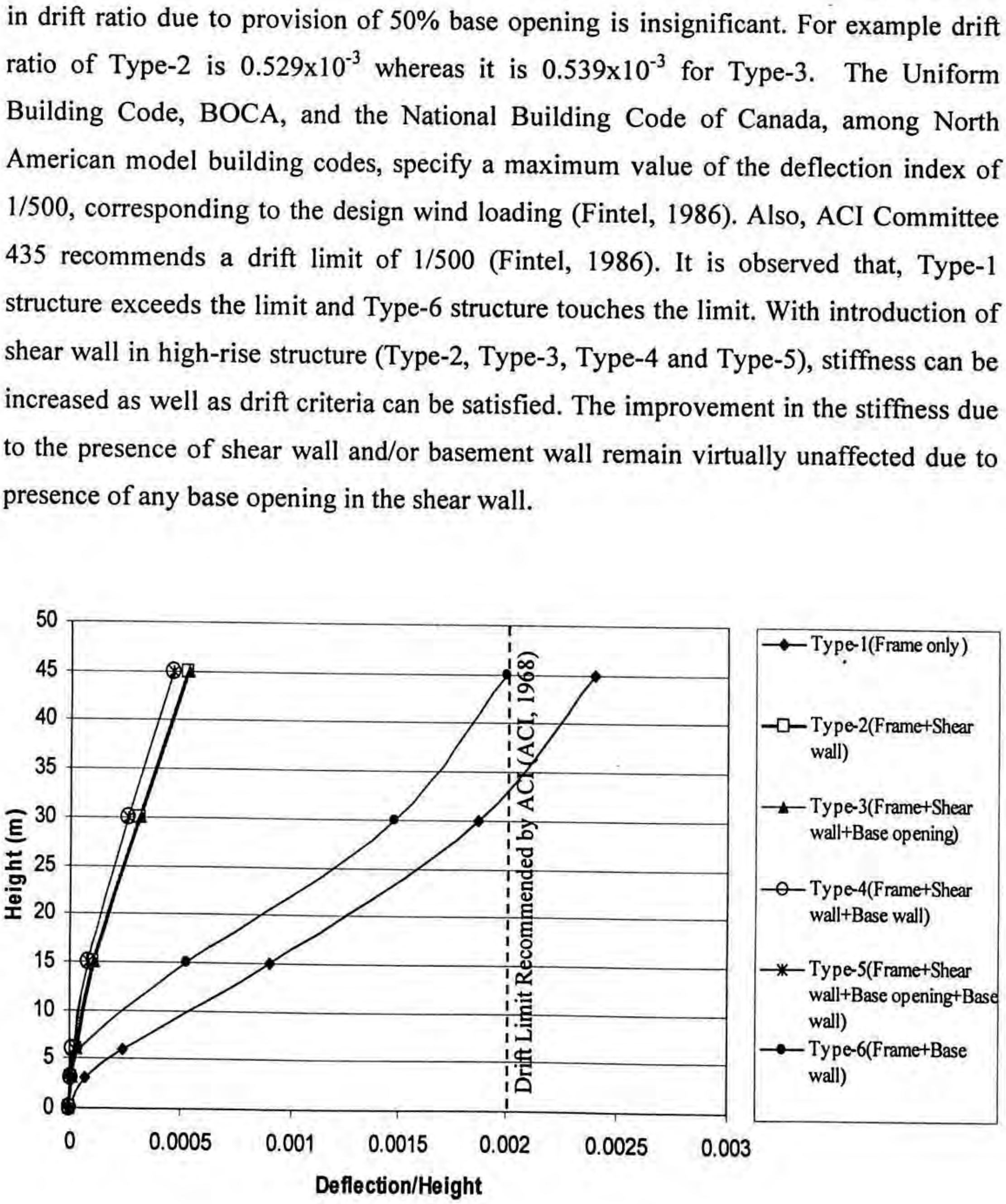


Fig. 6.10: Deflection/Height Ratio at Different Height for Different Types of Structures.

Table 6.4: Maximum Stresses and Maximum Column Axial Force for Different Types of Structures.

Type	Maximum Flexural Stress in Shear Wall (kN/m^2)	Maximum Shear Stress in Shear Wall (kN/m^2)	Maximum Column Axial Force (kN)
Type-2 (Frame + Shear wall)	4212	348	3647
Type-3 (Frame + Shear wall + Base opening)	4918	422	3787
Type-4 (Frame + Shear wall + Base wall)	3323	294	2942
Type-5 (Frame + Shear wall + Base opening + Base wall)	3323	312	3021

Maximum flexural stresses and maximum shear stresses in the shear walls and maximum axial forces in the columns are also calculated which are shown in Table 6.4. It is observed that, increase in stresses due to provision of base opening, is not significant. For example, maximum flexural stress for Type-3 is increased by 17% from value 4212 kN/m^2 to 4918 kN/m^2. Whereas maximum shear stress for Type-3 is increased by 21% from value 348 kN/m^2 to 422 kN/m^2 and maximum column axial force is increased by 4% from value 3647 kN to 3787 kN. On the other hand, effect of introducing base opening in Type-5 is very insignificant. It is also observed that stresses can be reduced by introducing basement wall. Flexural stress is more affected than shear stress. For example, flexural stress is reduced by 21% from value 4212 kN/m^2 to 3323 kN/m^2; on the other hand shear stress is reduced by 15.5% from value 348 kN/m^2 to 294 kN/m$^{2.}$

CHAPTER : 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 General

The main objectives of this research work were to study the behavior of shear wall with base opening. Shear walls are frequently pierced for doors, windows, corridor openings or also for providing parking facility. Provision of parking at basement or ground level requires opening to be kept at the base of a shear wall. As the entire lateral load acting in a shear wall is transmitted to the ground through the base, the base is the most critical section of a shear wall. So openings at that section will affect its overall stiffness as compared to shear wall without opening. In this research work, attempts have been made to establish the range of base opening that may be allowed without significant loss of strength and stiffness of a structural wall. The behavior of both planar and box type shear wall with varying percentages of base opening have been studied. Finite Element Technique has been used for modeling shear wall with base opening. The present chapter draws conclusions by summarizing the outcome of the thesis and proposes new direction for further research in the field.

7.2 Conclusions

Within the limited scope of the study, the following conclusions may be drawn. These conclusions are grouped under sub-heading and listed below:

Behavior of plane shear wall with base opening

Two types of plane shear walls such as double legged and single legged with varying base opening are studied in Chapter 4. From this study the following conclusions can be made:

1. In the case of double legged plane shear wall, it is observed that deflection increases with the increase of % base opening. However, the rate of increase of deflection is relatively low up to 60% base opening. Beyond 60% opening wall stiffness decreases significantly.

2. The influence of height of shear wall (i.e. H/B) in its stiffness is also observed. For all values of H/B ranging from 1 to 6, with 0 to 60% base opening, the effect is insignificant but for base opening higher than 60% the effect of base opening becomes detrimental. For very stiff wall (i.e. H/B=1) the loss of stiffness due to base opening is quite significant whereas for relatively slender walls (H/B=3.75) the reduction in stiffness is only moderate.

3. Deflections at lower levels (i.e. at mid height and at 3 meter height) are also observed. The general tendency of stiffness degradation due to base opening, as reflected in the computed deflection ratios, remains the same as in the case of maximum deflection ratios. However; deflection ratios at lower levels are higher than the maximum deflection ratio at top of the wall.

4. It is seen that up to 60% base opening; rate of increase of flexural and shear stress ratios are low. But for more than 60% opening the stress ratios increase rapidly. The increase in shear stress ratios for 60% opening have been found to be 5 to 10 times in section at 3 meter height. Whereas the flexural stress ratios for 60% opening appear to be in the range of 2 to 3. It is seen that shear stress is more adversely affected than flexural stress due to the introduction of base opening in shear wall.

5. On the other hand, for single legged shear wall, it has been observed that stress (flexural and shear) ratios increase with the increase of shear wall height when in Type- 1 these stress ratios decrease with the increase of shear wall height. Apart from this, almost similar behavior is observed for single legged shear wall and double legged shear wall. Although general behaviors of both types are similar, the absolute values of the ratios are quite high in the case of single legged shear wall making it not feasible for consideration of base opening.

6. In Section 4.6, an attempt has been made to observe the comparative effect of loading on different study parameter ratios. Two types of lateral load distribution have been considered here. One is uniformly distributed load (UDL) throughout the height of shear wall and the other is linearly varying wind load (WL), which is calculated according to BNBC. It has been observed that, the effect of loading

type on these study parameter ratios is very insignificant. So, for the whole study, uniformly distributed load has been applied instead of varying load.

7. In Section 4.7, an attempt has been made in the case of double legged plane shear wall with base opening, to show the improvement of stiffness that might occur with introduction of compensatory measure. Two alternative compensatory measures have been taken for study. First, the thickness of two legs of shear wall have been increased and in the second alternative, two compensatory element have been introduced which are placed perpendicular to shear wall at the two edges. It is observed that, introduction of the compensating measure would fully compensate the deflection and flexural stress ratios and also bring about significant improvement in the shear stress ratio. It is also observed that, 2nd alternative measure is more efficient than 1st one to compensate the adverse effect of introducing base opening.

8. The location of maximum stress has been observed in the stress contour. It is observed that, the location of maximum flexural stress is in the extreme edge at base while maximum shear stress is located around the upper corner edge of opening. Depending on the size of the opening the multiplication of the stress concentration can be as high as 5.34 for 60% base opening as against 3.54 for 40% base opening. The stress concentration can be significantly alleviated with the introduction of compensatory elements. It is also observed that, with introduction of compensatory elements, location of maximum flexural stress is understandably shifted from base to the just top of compensatory element.

9. For plane shear wall with central opening at base, provision of base opening up to 50% of the wall width may be considered as a feasible option. It has been shown that for this level of opening, stiffness degradation is minimal. However, the flexural stress and shear stress would be magnified in the range of 2.0 to 2.5 and 5.0 to 7.0 respectively. These must be carefully taken care of by the designer with special reinforcement detailing. In extreme cases of stress concentration, compensatory walls would be helpful to alleviate stresses.

Behavior of box shear wall with base opening

Behavior of box type shear wall with or without base opening at uniformly distributed lateral loading, have been studied in Chapter 5. In box type shear wall, opening is kept in two opposite parallel planes. Depending on the direction of applied load, box shear walls have been classified into two types. In Type-1, load is applied in the flange wall while the opening is in web walls and in Type-2; openings are in the two parallel flange walls with load being applied on one of the flange walls (see Fig. 5.2). From this study the following conclusions can be made:

1. Maximum deflection increases with the increase of percentage base opening. However, the effect of base opening on deflection is insignificant. The influence of shear wall height in its stiffness is also observed. For both types of box shear wall, deflection ratio decreases with the increasing story height. For example, with 80% base opening maximum deflection ratio of 6 storied Type-1 shear wall is 1.2 and it is 1.0 for 15 storied shear wall. Another interesting feature is that the deflection ratio is not at all affected for less than 60% base opening.

2. Maximum shear stress and maximum flexural stress ratio for varying base opening (b/B) are determined for both types of box shear wall. For Type-1, the increase in shear stress ratios for 60% opening appears to be 1.2 to 1.3 times at top of the box shear wall. Whereas in the case of flexural stress ratios of Type-1 for 60% opening appears to 1.5 to 2.6 times. For Type-2 shear wall, behavior identical to Type-1 shear wall has been observed.

3. Although general behaviors of Type-1 and Type-2 are similar, the absolute values of the ratios are low in the case of Type-2. For example, in the case of 15 storied Type-1 shear wall with 60% base opening, maximum flexural stress ratio is 2.6 when it is only 1.6 for Type-2. Type-2 box shear wall is stiffer than Type-1. It is also observed that shear stress ratios for Type-2 shear wall are 1.0 that means effect of base opening on shear stress is insignificant for Type-2 shear wall.

4. For the range of structures considered in the study, it is seen that up to 40% base opening the stress ratios reached up to 2.6 for Type-1 and up to 1.4 for Type-2

Shear wall. This can lead to practical conclusion that with proper design and detail, it is feasible to have box shear wall to have base opening up to 40%.

Behavior of a multi storied shear wall frame structure

Behavior of a 15 storied frame structure with or without shear wall has been studied in Chapter 6. The effect of the presence of underground basement wall on the stiffness of overall structure has also been studied. For different combination of shear wall and basement wall, six types of structures are considered for study. Provision of 50% base opening is kept in Type-3 and Type-5. From this study the following conclusions can be made:

1. Increase in drift ratio due to provision of 50% base opening is insignificant. It is observed that, stiffness degradation of structure is also insignificant. Increase of stresses due to provision of 50% base opening is not significant. For example, maximum flexural stress for Type-3 is increased by 17%. Whereas maximum shear stress is increased by 21% and maximum column axial force is increased by 4%.

2. With introduction of basement wall, stiffness of the structure is significantly increased. It is observed that, maximum stresses are significantly reduced by keeping provision of basement wall.

3. The change in the stiffness due to the presence of shear wall and/or basement wall remains virtually unaffected due to presence of any base opening in the shear wall.

7.3 Recommendations for Future Studies

The following recommendations are made for future investigations.

1. Shear walls may be planer, but are often of L-, T-, or U-shaped section to better suit the planning and to increase their flexural stiffness (Smith and Coull, 1991). In this thesis only symmetrical planer and box type shear wall has been studied. Different types unsymmetrical shaped shear wall with base opening can be studied in future.

2. Shear wall with varying stiffness throughout their height with base opening can be studied.

3. In this thesis, height of base opening has been kept constant. Behavior of shear wall with varying percentage of base opening as well as with varying height of base opening can be studied in future.

4. Shear wall with base opening subjected to static load as well as dynamic load such as earthquake load, can be studied.

5. Different opening shape, particularly triangular or trapezoidal shaped base opening may be studied in future.

6. In this thesis, for box shear wall, opening is kept in two opposite parallel planes. So study can be carried on box shear wall with base opening in two consecutive planes.

7. With introducing compensatory elements, an attempt has been made to show the improvement of stiffness of shear wall. Behavior of shear wall with other alternative options may be studied in future.

8. A realistic 3D model with reinforcement detailing, can be modeled to find an efficient solution to tackle the concentration of stresses.

9. Design of shear wall with base opening, can be proposed based on the findings of the research.

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