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BEHAVIOUR OF OPENING IN SHEAR WALL IN HIGH RISE BUILDINGS

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ABSTRACT

Shear walls are a crucial component of lateral load-resisting systems in buildings, providing resistance to seismic and wind forces. The incorporation of openings in shear walls, however, can compromise their structural integrity. This paper delves into the significance of shear walls, their use with openings, and the importance of considering these factors in building design. Shear walls are vertical elements that resist lateral forces, ensuring the stability and safety of structures. Their importance is magnified in high-rise buildings, where wind and seismic forces are more pronounced. The presence of openings in shear walls, such as doors, windows, and service penetrations, can significantly affect their performance. The paper discusses the impact of openings on the shear capacity, stiffness, and ductility of shear walls. It highlights the need for careful consideration of opening sizes, locations, and shapes to minimize their adverse effects. The importance of shear walls in maintaining structural integrity is emphasized, particularly in earthquake-prone regions.

Keywords: RC Shear Wall, High Rise Buildings, Openings, ETABS Software, Behavior.

I. INTRODUCTION

General:

High-rise buildings have become an integral part of modern urban landscapes, symbolizing technological advancements, economic growth, and architectural innovation. These towering structures, typically exceeding 75 feet in height, play a vital role in shaping the skylines of cities worldwide. By maximizing land use in densely populated areas, high-rise buildings serve as hubs for business, commerce, and residential living, driving local economies and fostering innovative design. Moreover, they incorporate green technologies, reduce carbon footprints, and promote eco-friendly practices, making them a crucial aspect of sustainable urban development. However, high-rise buildings also pose unique challenges that must be addressed. Their increased height makes them more vulnerable to seismic activity, requiring robust structural designs to withstand earthquakes. Additionally, they are exposed to high winds, necessitating careful consideration of wind loads during the design process.

Shear wall

In structural engineering, a shear wall is a vertical element of a seismic force resisting system that is designed to resist in-plane lateral forces, typically wind and seismic loads. They are usually provided in tall buildings and have been found to be of immense use to avoid total collapse of the building under seismic forces it is always advisable to incorporate them in buildings built in regions likely to experience earthquake of large intensity or high winds. Shear walls are generally made of concrete or masonry. Initially shear walls were used in reinforced concrete buildings to resist wind forces. These came into general practice only as late as 1940. With the introduction of shear walls, concrete construction can be used for tall buildings also. Earlier, tall buildings were made of steel, as bracing to take lateral wind loads could be easily provided in steel construction.

Classification of Shear walls

a) Simple rectangular type and Flanged walls

The simple rectangular shear walls, under the action of in plane vertical loads and horizontal shear along its length, are subjected to bending and shear. Barbell type of wall are formed when a wall is providing monolithically between two columns. The columns at the two ends are then called the boundary elements. The barbell type walls are stronger and more ductile than the simple rectangular type of uniform section. Also, they never fail in shear but only by yielding of steel in bending. One of the disadvantages of this type of shear walls is

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that as these walls are rigid during an earthquake they attract and dissipate a lot of energy by cracking, which is difficult to repair.

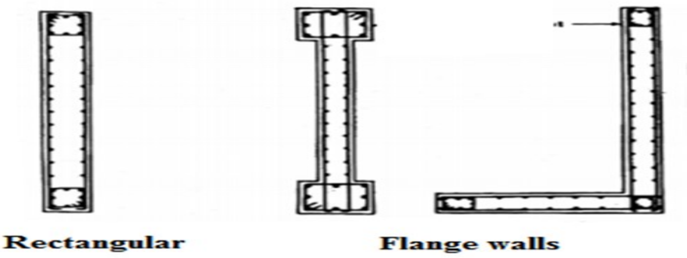
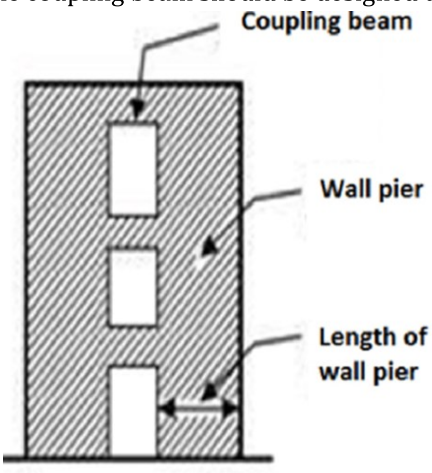


Figure 1.1 Simple rectangular type and Flanged walls

b) Coupled shear walls

If two structural walls are joined together by relatively short spandrel beams, the stiffness of the resultant wall increases; in addition, the structure can dissipate most of the energy by yielding the coupling beams with no structural damage to the main walls. It is easy repair these coupling beams than walls. These walls should satisfy the following two requirements: The system should develop hinges only in the coupling beam before shear failure the coupling beam should be designed to have good energy-dissipation characteristics.



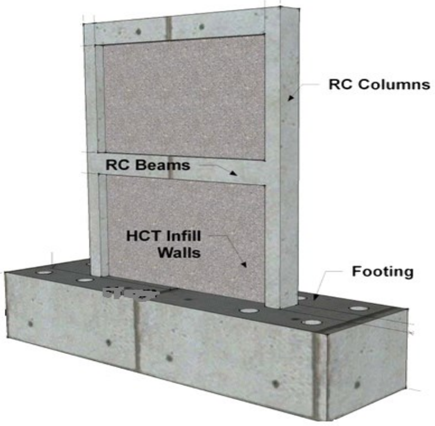


Figure 1.2 Coupled shear wall Figure **Figure 1.3 Framed walls with infill frames**

c) Framed walls with infill frames:

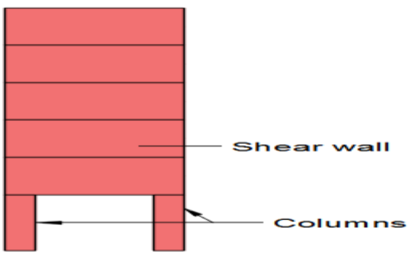
Framed walls are cast monolithically, whereas in filled frames are constructed by casting frames first and in filling it with masonry or concrete block later.

d) Column supported shear walls

For architectural reasons to discontinue shear walls at floor level the wall to carry by widely spaced column. In such column supported shear wall, the discontinuity in geometry that level should be specially taken care of in the design.

e) Core type

In some building, the elevators and other service areas can be grouped in a vertical core which may serve as device to withstand lateral loads.



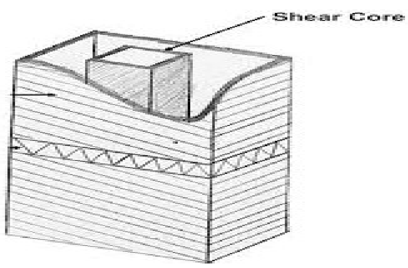


Figure 1.4 Column supported shear wall **Figure 1.5 Core type shear wall**

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II. LITERATURE REVIEW

1. A Comprehensive Study on the Effect of Regular and Staggered Openings on the Seismic Performance of Shear Walls. (Research gate Publications) 2022.

Ahmed Saeed, Hadee Mohammed Najm, Amer Hassan, Shaker Qaidi, Mohanad Muayad Sabri Sabri and Nuha S. Mashaan.

Shear walls have high strength and stiffness, which could be used at the same time to resist large horizontal loads and weight loads, making them pretty beneficial in several structural engineering applications. The shear walls could be included with openings, such as doors and windows, for relevant functional requirements. In the current study, a building of G + 13 stories with RC shear walls with and without openings has been investigated using ETABS Software. The seismic analysis is carried out for the determination of parameters like shear forces, drift, etc.

2. Analysis and Design of Multistorey Building with R.C.C Shear Wall using E Tabs (International Journal for Modern Trends in Science and Technology, December 2022)

In seismic design of multi storied building, shear walls are most common structure adopted to make the structure earthquake resistant. These are constructed to counteract the lateral loads caused by wind load and seismic loads. Shear walls provide adequate stiffness to the structure. So that the lateral drift will be in limits. Generally, shear walls are the vertical cantilever which acts as a Column. After many practical studies it has shown that use of lateral load resisting systems in the building configuration has tremendously improved the performance of the structure in earthquake. Shear walls are mainly flexural members and usually provided in high rise buildings to avoid the total collapse of the high-rise buildings under seismic forces.

3. Effects of Openings in Shear Wall on Seismic Response of Structures (Bangladesh 2022.)

M.A. Rahman, M.J. Islam, A.K. Das

Displacements are almost equal but as soon as story level increases, displacements are increasing or buildings shear wall with opening or door. At topmost story level, displacement or shear wall with opening at middle is little bit less than that of shear wall with openings placed at or right. More the area of opening more the displacements conceded by the building and this trend increases with story level.

Thickening wall around the door openings are more effective than that window opening since displacement is reduced more at top most story level or shear wall with door opening. Opening in shear wall placed in plane of loading is more critical than that of opening inshear wall placed out of plane of loading since there is a significant change in displacement noticed after having opening in shear wall placed in plane of loading.

4. Comparative Study Between Regular Concrete and Lightweight Concrete To Be Used In Concreting Of Shear Wall (International Research Journal of Engineering and Technology (IRJET) Sep 2021) Prashant Pundkar, Amit Gawande

In current study we are comparing regular concrete and light weight concrete from the perception of weight loss (Dead Load Reduction) of different structural elements of buildings specially shear walls. The primary use of light weight concrete from structural point of view is to reduce dead load of concrete structure which allows us to reduce the size of structural members resulting in reduction of earthquake forces on it. In structural engineering a shear wall is basically a vertical element used to resist seismic forces on structure. In this project the attempt is made to predict response of multi storey building with the use of light weight and regular concrete in special member viz. shear wall which helps in resisting seismic forces. To compare the seismic behavior of shear wall made up with regular concrete and light weight concrete provided in G+9 residential building located in zone v. Staad-pro package is being used to analyse the structure.

5. Seismic response on multi-storied building having shear walls with and without openings. (Elsevier Publications) 2020.Authors: V. Naresh Kumar Varma, Uppuluri Praveen Kumar

Medium rise R.C framed apartment buildings with storey ranges from 8 to 10 or 12 are becoming popular in metropolitan areas of India. Medium rise R.C framed are provided with shear walls for the lateral load resistance. Frequently the shear walls are provided with openings thus it is necessary to study the effect of those on the storey drift, storey stiffness, and shear and moments and on the stress within the shear walls. A 3-D analysis is carried out for analysis of the shear wall in the building. This study covers the effects of size and locations of these openings. Detailed results have been obtained and useful conclusions are drawn on the basis of this study which will be of use to the practical engineers.

6. Shear wall layout optimization for conceptual building planning (International Research Journal of Engineering and Technology (IRJET) Sep 2018) Darsh M Patel, Parth G Bhagat, Jasmin B Patel, Hiral Y Patel, Jaldipkumar J Patel

Most of the high-rise structure is collapse due to the earthquake. Shear wall is the most important component of the high-rise structure which can resists the lateral load. Inbuilding planning the location of the shear wall is also important. The effective position of Shear walls in planning the deflection of building due to earthquake is decreases. By providing shear wall we can reduce overall damage of the structure.

7. Analysis and Design of Shear Wall for an Earthquake Resistant Building using ETABS (International Journal for Innovative Research in Science & Technology| Volume 4 | Issue 5 | October 2017). A. Ravi Kumar, K. Sundar Kumar, Badipati Anup

Shear walls generally used in high earth quake prone areas, as they are highly efficient in taking the loads. Not only the earthquake loads but also wind loads which are quite high in some zones can be taken by these shear walls efficiently and effectively. To determine the solution for shear wall location in multi-storey building based on its both elastic and elasto-plastic behaviors. The earthquake load is to be calculated and applied to a multi-storied building of plan 26mx26m and 10 no. of (G+9) floors with 40meters height. For this model, results are calculated and analysed for the effective location of shear wall. The design above is verified for this same structure using extended three-dimensional analysis of buildings (ETABS) software. The results are compared.

8. Behavior of Shear wall with Base Opening. (International Research Journal of Engineering and Technology (IRJET) 2017. Authors: Muhammad Masood, Ishtiaque Ahmed and Majid Assas

Provision of parking may require an opening to be kept at the base of a shear wall. In this paper, an attempt is made to establish the range of base opening that may be allowed without significantly affecting the strength and stiffness. The behavior of planar and box shear wall with varying percentages of base opening has been studied and compared to that of a shear wall without opening. Finite element package ANSYS has been used for modeling. A set of non-dimensional graphs has been prepared featuring important parameters which will guide the designer to choose an appropriate opening width. It is observed that the rate of decrease of stiffness is relatively low for up to 60% base opening. Beyond this limit, strength and stiffness degradations are excessive. Based on the findings of the study, it has been recommended that in high-rise constructions the provision of a base opening to 50% of the length of the wall may be considered as a feasible option.

III. OBJECTIVES AND PROBLEM STATEMENT

3.1 Objectives

The major objective of this project is to study the overall behaviour of the shear wall structure in comparison with respect to Case-1) Conventional Shear wall Structure, Case-2) Shear wall with opening at central portion, Case-3) Shear wall with staggered openings, with the aid of ETABS 2018 finite element software.

3.2 The objectives of study:

1. To carry out the study and analysis of shear wall with Conventional and Staggered openings using Finite Element Tool.
2. To study the effect of size of opening and its position for seismic loading.
3. To Study the seismic behaviour of shear wall with respect to

Modal mass, Fundamental Natural Time Period, Stiffness, Lateral Displacement, Story Drift

3.3 Problem Statement

Larger openings in shear walls are necessary to accommodate various architectural and functional requirements, including doors and windows for natural light, ventilation, and access, service penetrations for electrical, plumbing, and HVAC systems, and architectural features like arches, recesses, and niches. However, these openings technically reduce the shear wall's stiffness and strength, requiring additional reinforcement, increase the stress concentrations around openings, necessitating careful detailing, and affect the wall's ductility and energy dissipation capacity.

Despite these challenges, larger openings are important as they enhance occupant comfort and experience, improve building aesthetics and functionality, allow for flexibility in space planning and usage, and increase the building's value and marketability.

IV. METHODOLOGY

4.1 Identification of problem

Generally, shear walls are provided at the periphery of the structure to provide stiffness and to avoid torsion in the structure. Sometimes, to provide additional stiffness to the structure, shear walls are provided at the internal portion of the structure too. Providing shear walls at the periphery of a structure without openings can have several disadvantages. One major drawback is the reduction of natural light and ventilation, leading to a dependence on artificial lighting and HVAC systems, which can increase energy costs and negatively impact occupant comfort.

4.2 Problem solution

Advanced analysis, like finite element modeling, can accurately assess the wall's behavior. However, from analysis we can enhance our design as per structural requirement to ensure structural safety and serviceability.

4.3 Modeling software

[1]4.3.1 ETABS 2018 (18.0.2)

ETABS (**E**xtended **T**hree-**D**imensional **A**nalysis of **B**uilding **S**ystem) is an engineering software product that caters to multi-story building analysis and design. Modeling tools and templates, code-based load prescriptions, analysis methods and solution techniques, all coordinate with the grid-like geometry unique to this class of structure. Basic or advanced systems under static or dynamic conditions may be evaluated using ETABS.

4.4 Method of Seismic Analysis:

Seismic analysis is a subset of structural analysis and is the calculation of the response of a building (or non-building) structure to earthquakes. It is part of the process of structural design, earthquake engineering or structural assessment and retrofit (see structural engineering) in regions where earthquakes are prevalent.

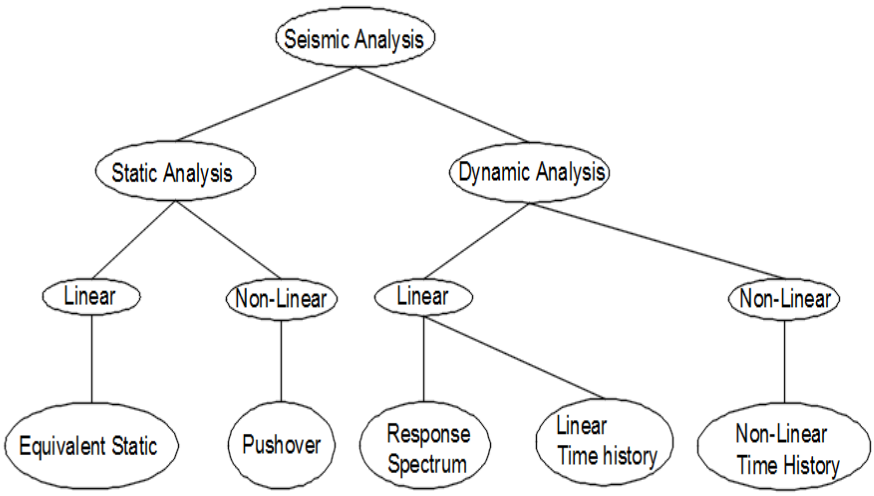

Figure 4.1 Classifications of Seismic Analysis Methods

4.5 Consideration of RC-SW (Reinforced Concrete Shear Wall) structural models:

To observe the overall structural behaviour of shear walls without and with openings, models are made as follows:

4.5.1 Model 1: Shear wall without any openings

RC-SW structural system. All shear walls are starting from foundation level of the building and continues up to building height. 8 shear walls placed at periphery and 2 shear walls in Y direction at internal portion as to stabilize the modal behaviour of the structure is shown.

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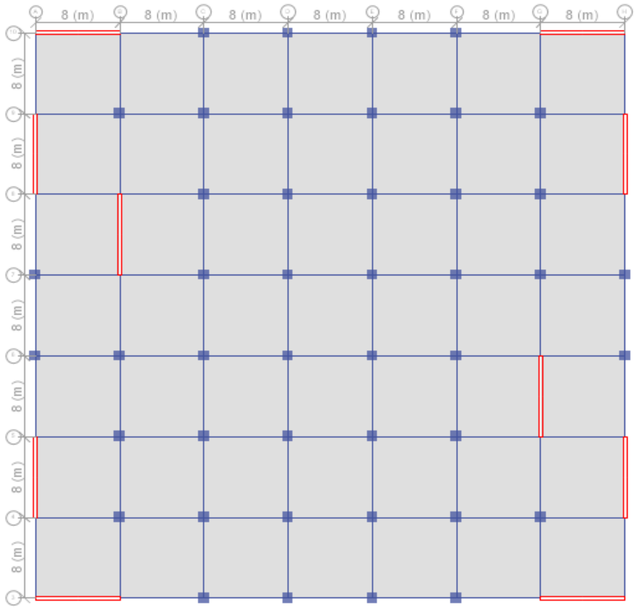

Figure 4.2 Model 1: Shear wall without any openings: PlanFigure

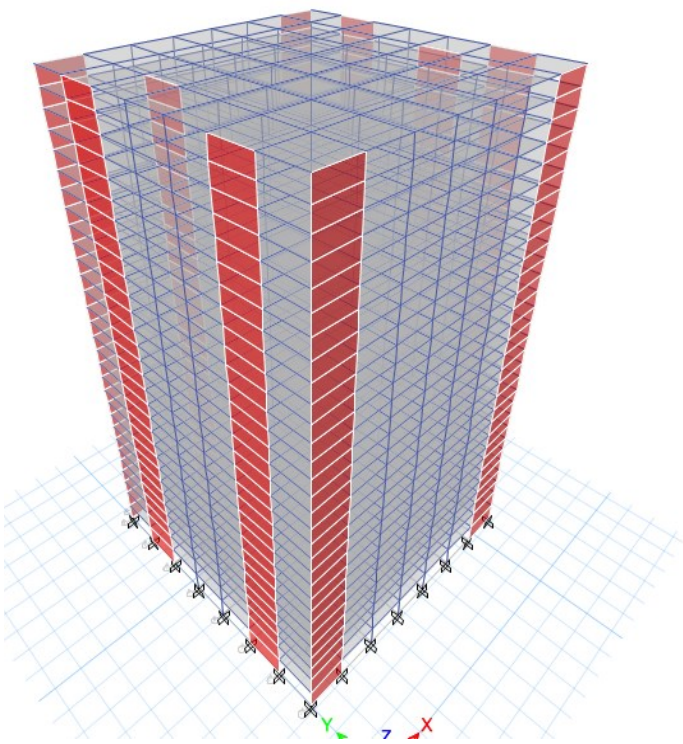

Figure 4.4 Model 1: Shear wall without any openings: 3D view

4.5.2 Model 2: Shear Wall with Opening at Centre (3mx1.4m)

RC-SW structural system. Plan of model 2 is same as that of model 1. All shear walls are throughout, starting from foundation level to building height. However, all periphery shear walls have central opening throughout the building height of opening size 3m x 1.4m (Approximately 20% of wall area).

Note: Internal shear wall does not have any openings.

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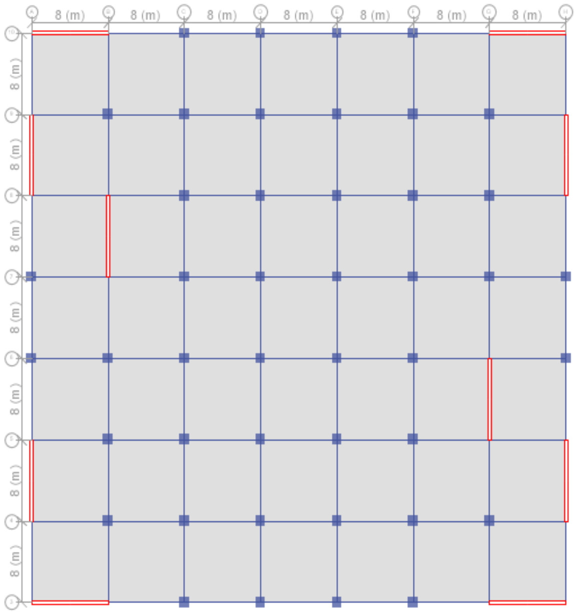

Figure 4.5 Model 2: Shear Wall with Opening at Centre (3mx1.4m): Plan

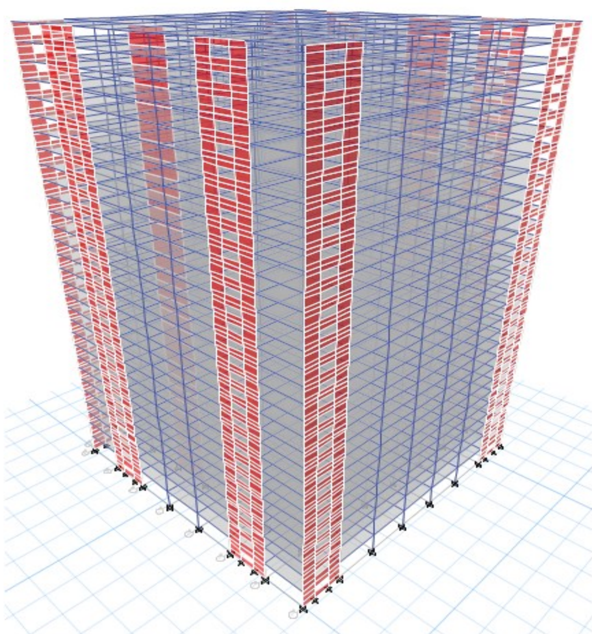

Figure 4.6 Model 2: Shear Wall with Opening at Centre (3mx1.4m): 3D view

4.5.3 Model 3: Shear Wall with Staggered Openings (3mx1.4m)

RC SW structural system. Plan of model 3 is same as that of model 1. All shear walls are throughout, starting from foundation level to building height. However, all periphery shear walls have staggered openings throughout the building height of opening size 3m x 1.4m (Approximately 20% of wall area).

Note: Internal shear wall does not have any openings.

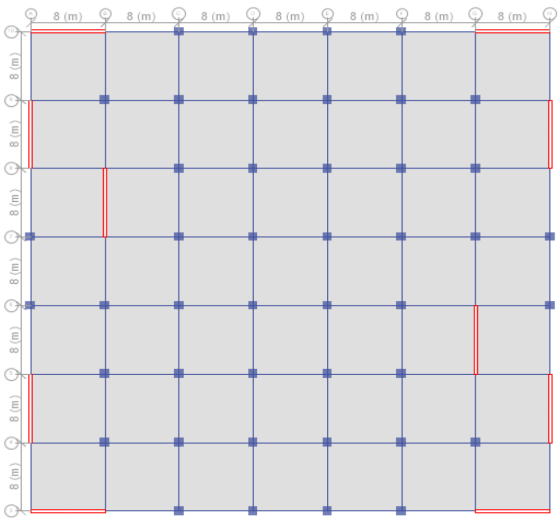

Figure 4.8 Model 3: Shear Wall with Staggered Openings (3mx1.4m): Plan

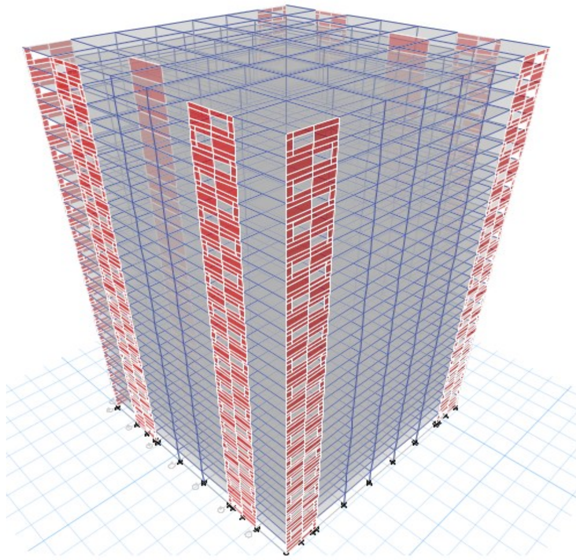

Figure 4.9 Model 3: Shear Wall with Staggered Openings (3mx1.4m): 3D view

4.6 Structural configuration

A simple structure was adopted for the investigation. The salient features of the building are: -

1) Type of structure	:	RC-SW structure. (Office Building)
2) No. of stories	:	Basement+Stilt+28 Floors
3) Length in X-direction	:	56 m
4) Length in Y-direction	:	56 m

5) Height of structure : 92 m
6) Number of bays in each direction : 7
7) c/c distance between each bay : 8 m
8) Typical storey height. : 3 m
9) Materials
Grade of concrete : M40
Grade of steel : Fe500, Fe415
10) Sections considered
: a) Beam (400X800 mm)
: b) Column (1200X1200 mm) and (1000mmX1000mm)
: c) Shear wall Section (400mm)
11) Depth of slab : 225 mm
12) Unit weight of RCC : 25 KN/m3
a) Unit weight of masonry : 10 KN/m3 (AAC Blocks)
13) Loads considered
a) Live : 4 KN/m2 (Parking), 3 KN/m2 (Typical)
b) Floor finish : 1.5 KN/m2
c) External wall : 5.2 KN/m
d) Internal wall : 5.2 KN/m
14) Clear cover to beam : 25 mm
15) Clear cover to Column : 40 m

4.7 Consideration of loading cases:

Following are the loading cases are adopted for the analysis and design of all structural models incorporated in this project are given as follows:

Table 1. Load Combinations used for design

1. 1.5DL	20. 0.9DL - 1.5EXN
2. 1.5DL + 1.5LL	21. 0.9DL + 1.5EYP
3. 1.2DL + 1.2LL + 1.2EXN	22. 0.9DL - 1.5EYP
4. 1.2DL + 1.2LL - 1.2EXN	23. 0.9DL + 1.5EXP
5. 1.2DL + 1.2LL + 1.2EYP	24. 0.9DL - 1.5EXP
6. 1.2DL + 1.2LL - 1.2EYP	25. 0.9DL + 1.5EYN
7. 1.2DL + 1.2LL + 1.2EXP	26. 0.9DL - 1.5EYN
8. 1.2DL + 1.2LL - 1.2EXP	27. 1.2DL + 1.2LL + 1.2RSX
9. 1.2DL + 1.2LL + 1.2EYN	28. 1.2DL + 1.2LL + 1.2RSY
10. 1.2DL + 1.2LL - 1.2EYN	29. 1.2DL + 1.2LL - 1.2RSX
11. 1.5DL + 1.5EXN	30. 1.2DL + 1.2LL - 1.2RSY
12. 1.5DL - 1.5EXN	31. 1.5DL + 1.5RSX
13. 1.5DL + 1.5EYP	32. 1.5DL + 1.5RSY
14. 1.5DL - 1.5EYP	33. 1.5DL - 1.5RSX
15. 1.5DL + 1.5EXP	34. 1.5DL - 1.5RSY
16. 1.5DL - 1.5EXP	35. 0.9DL + 1.5RSX
17. 1.5DL + 1.5EYN	36. 0.9DL + 1.5RSY
18. 1.5DL - 1.5EYN	37. 0.9DL - 1.5RSX
19. 0.9DL + 1.5EXN	38. 0.9DL - 1.5RSY

4.8 Process followed for this project

[2]4.8.1 Modeling of RC-SW structure in ETABS 2018.

For the analysis purpose three models are created by using ETABS software, to compare the behavior shear wall structure for

a) No Opening in Shear Wall
b) Opening at Central Portion in Shear Wall (3m X 1.4m)
c) Staggered Openings in Shear Wall (3m X 1.4m)

Note: In all the models section size for slab, beams, columns and shear walls and the loading applied on the structure are kept identical for comparison purpose.

- **Model 1: No Opening in Shear Wall:** The structure is RC-SW (Reinforced Concrete Shear Wall) structure. Length and width of structure is 56m. Height of structure is 92m. Section size for slab is 225mm and for beams 400x800mm. As per the requirement of design column size from foundation level to 5th floor is 1200mm X 1200mm. However, from 6th floor to terrace 1000mm X 1000mm. Shear walls are provided of thickness 400mm. Thickness and distribution/ placing of shear wall is kept as per fig. 4.2 in order to control modal behavior, lateral displacement, storey drift and stiffness of the structure. **In this case all shear walls (periphery as well as internal) are solid without any openings.**
- **Model 2: Opening at Central Portion in Shear Wall (3m X 1.4m):** All the parameters described in Model-1 are kept identical except all periphery shear walls having opening at central portion of size 3m X 1.4m (approximately 20% of wall area)

Note: No openings are provided in internal shear walls, which are in Y-direction.

- **Model 3: Staggered Openings in Shear Wall (3m X 1.4m):** All the parameters described in Model-1 are kept identical except all periphery shear walls having staggered opening of size 3m X 1.4m (approximately 20% of wall area)

Note: No openings are provided in internal shear walls, which are in Y-direction.

4.9 Application of loading, load combinations and analysis of the structure.

In the ETABS model gravity loads such as dead and superimposed loads will be applied as per IS 875 part-1 and 2. Seismic parameters will be applied according to IS 1893:2016 and load combinations will be applied as per table no 1.1.

4.10 Obtaining results and post processing.

- As per our objective to study the behavior of conventional and staggered opening, these type of opening is added in the different model and their behavior is to be checked.
- The behavior of the structure is checked by the parameters such as:

a) Modal mass
b) Fundamental Natural Time Period
c) Stiffness
d) Lateral Displacement
e) Story Drift

4.11 Modeling process

[3]4.11.1 Plan (Model-1, Model-2 and Model-3)

Plan dimension of model is 56X56 m. In each direction there are 7 numbers of bays, each bay is having centre to centre distance of 8 m in both horizontal directions.

[4]4.11.2 Elevation

In the elevation, total height of structure is 92 m and typical storey height is 3 m and at bottom from basement to stilt i.e. for 2 storey heights are 4m.

[5]4.11.3 Defining material properties

M40 grade of concrete is used for all concrete members such as columns, beams, slab and shear wall. For steel material Fe500 and Fe415 grade of steel is used in model 1, 2 and 3.

[6] 4.11.4 Defining section properties

1. Column section:

a) Ordinary column section	:	1000mmX1000 mm (6th Floor to Terrace)
b) Ordinary column section	:	1200mmX1200mm (Basement to 5th Floor)
2. Beam section	:	400X800 mm
3. Slab thickness	:	225 mm
4. Shear wall sections	:	400 mm

[7] 4.11.5 Support condition

In this project, fixed supports are provided at the base of the columns and shear walls. In other words, they are restrained at base against translation and rotation. moment.

[8] 4.11.6 Loading Assignment

Dead loads:

Dead loads shall include weight of all structural components. Self-weight of the materials shall be calculated based on unit weights given in IS 875:1975 part -I.

a) Self-weight of RCC : 25 kN/m3
b) Unit weight of AAC blocks : 10 kN/m3
c) Floor Finish : 1.5 kN/m2
d) Water proofing load : 1.5 kN/m2

Live loads:

The office building and other areas needs to be designed for live loads as per IS 875:1987 (part-II)

a) Terrace : 2.0 kN/m2
b) Typical floor : 3.0 kN/m2
c) Parking load : 4.0 kN/m2

Seismic Forces data

For the analysis purpose of structural models we have assumed the seismic data as follows:

As per IS 1893-2016 (Part 1) (Fifth Revision) the following factors to be considered for designs.

a) Seismic Zone: IV (Annexure E): IS 1893 (Part-1): 2016
b) Seismic Zone factor, Z: 0.24 (Table 2): IS 1893 (Part-1): 2016
c) Soil profile: Type II (Medium soil sites)
d) Occupancy of building: Office building.
e) Design horizontal seismic coefficient (Ah):

(Ah) = (Z/2) *(Sa/g) *(I/R).

f) Importance factor (I): 1.2 (Ref Table 6-IS: 1893-2016)
g) Response reduction Factor (R): 4 (Only Shear wall are considered as Ductile)
h) Damping in Structure: 5%

Time Period calculation for Structure (Ta)

As the height of building exceeds 50m (in our case it is 92m), we have referred latest revision of tall building code i.e., IS 16700:2023 for calculation of Fundamental Natural Period.
(Clause no 6.3.4, page no. 7 of IS 16700:2023.)
Ta = 0.0672*H0.75 (For all other concrete structural system)
Therefore,

Ta = 0.0672*(92) 0.75 = 2 sec.

This value of time period is used for analysis purpose in X and Y direction as well.

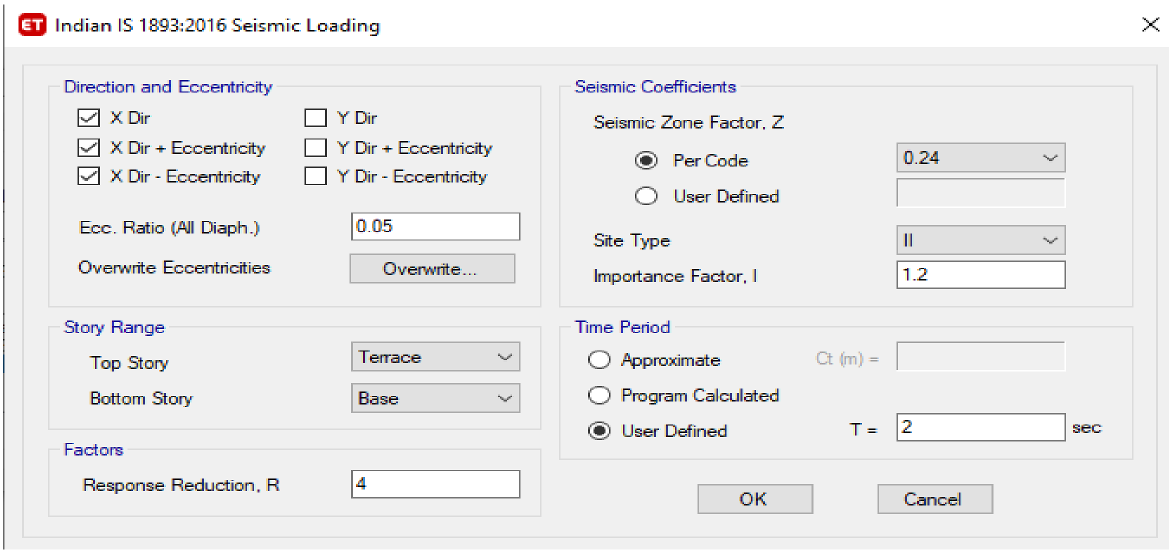

Figure 4.11 Application of Seismic parameters and time period in ETABS (X-Dir.)

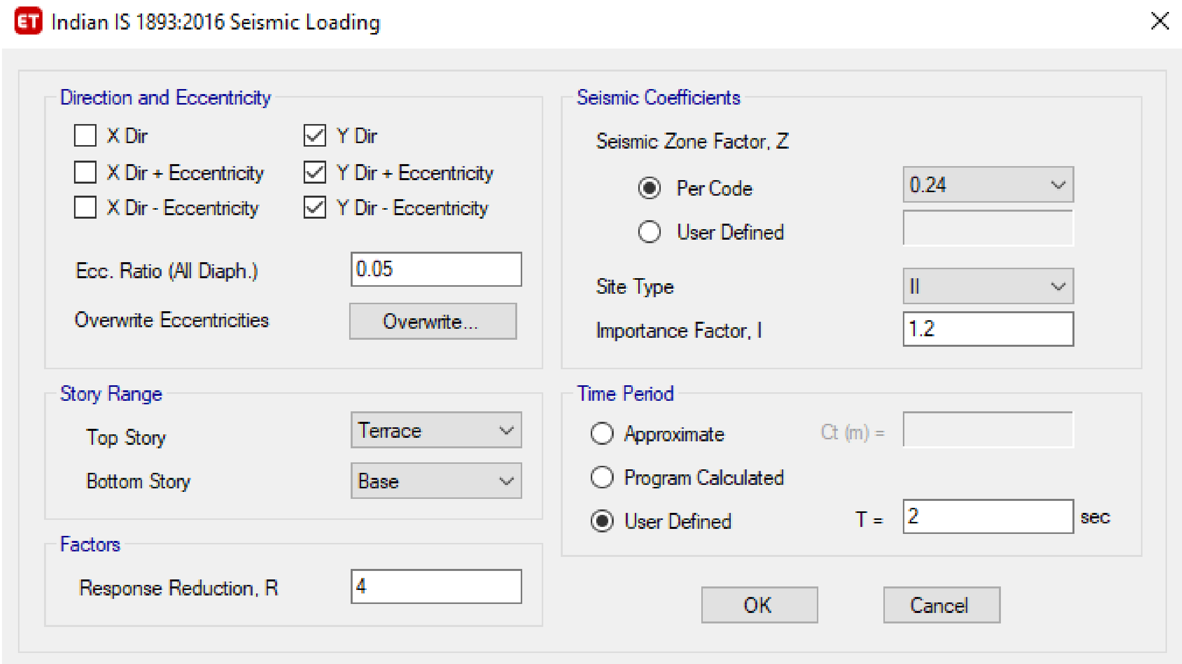

Figure 4.12 Application of Seismic parameters and time period in ETABS (Y-Dir.)

4.11.7 Application of Cracked section properties to slab, beams, columns and shear walls

As per clause no 7.3.6 and Table no 5 of IS 16700:2023 section properties are as follows:

Table 5 Cracked Section Properties of RC members

(*Clauses* 5.5.2,7.3.6, 8.1.3.2.1 *and* 7.2)

Sl No.	Structural Element	Serviceability Design		Strength Design	
		Cross-Sectional Area	Moment of Inertia	Cross-Sectional Area	Moment of Inertia
(1)	(2)	(3)	(4)	(5)	(6)
i)	Slabs	$1.0A_g$	$0.35I_g$	$1.00A_g$	$0.25\ I_g$
ii)	Beams	$1.0\ A_g$	$0.7\ I_g$	$1.00\ A_g$	$0.35\ I_g$
iii)	Columns	$1.0\ A_g$	$0.9\ I_g$	$1.00\ A_g$	$0.70\ I_g$
iv)	Walls	$1.0\ A_g$	$0.9\ I_g$	$1.00\ A_g$	$0.70\ I_g$

Figure 4.13 Cracked Section Properties IS 16700:2023

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Following are the proof of applying cracked section properties to the members like slab, beam, column and shear walls while creating actual 3D model of structural system as per IS 16700:2023.

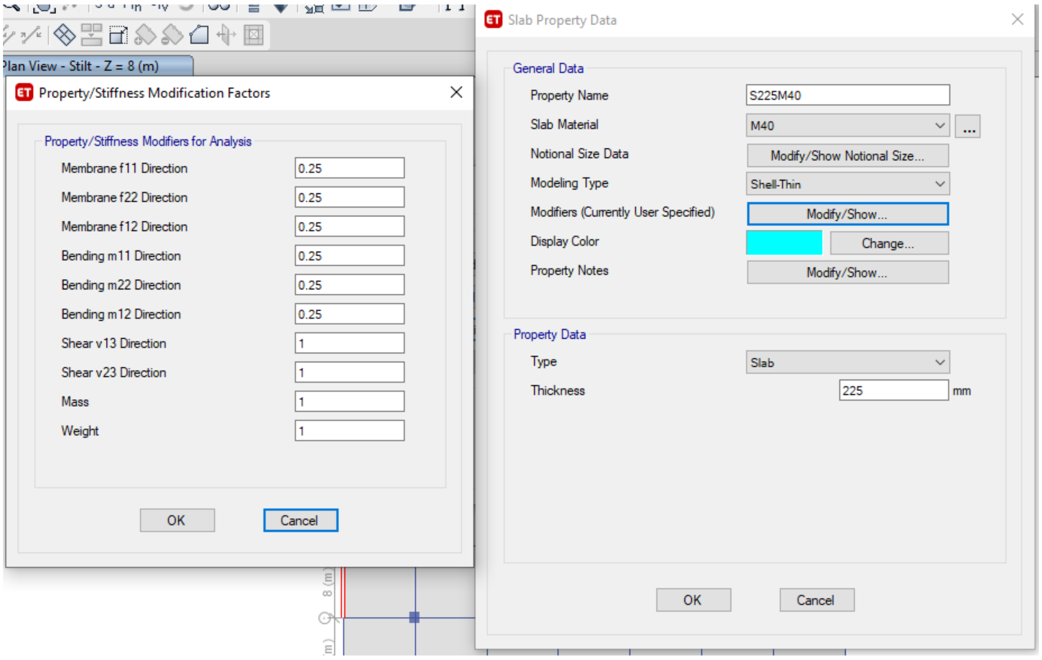


Figure 4.14 Cracked Section Properties for Slab

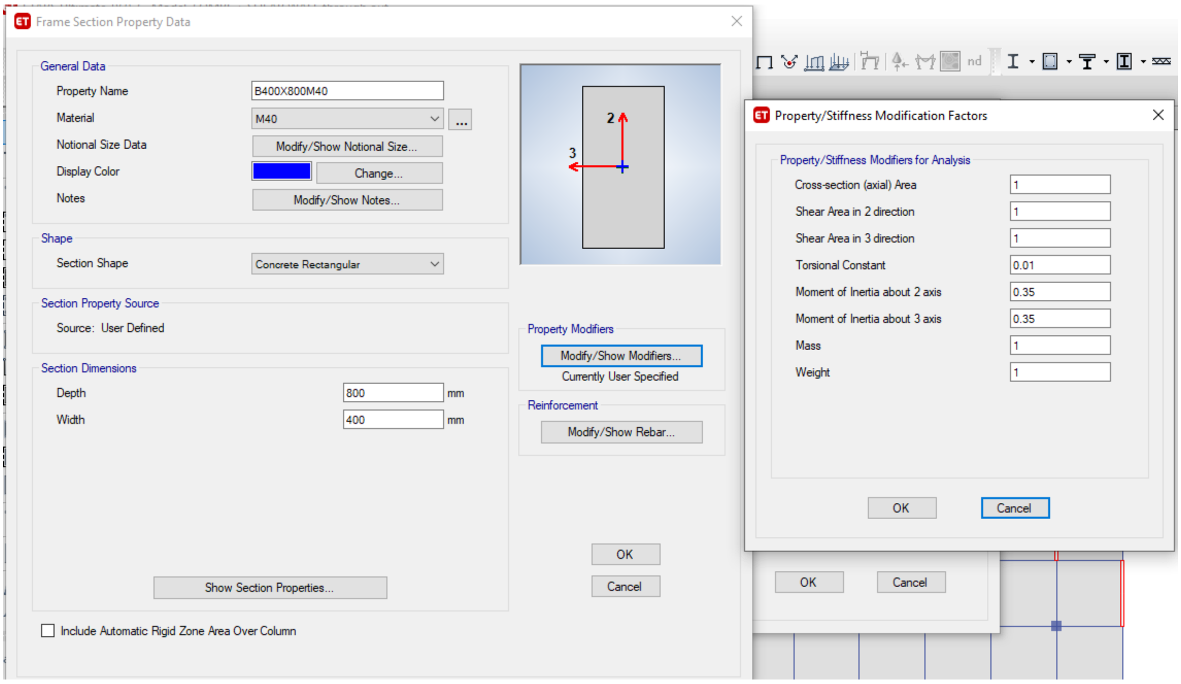


Figure 4.15 Cracked Section Properties for Beams

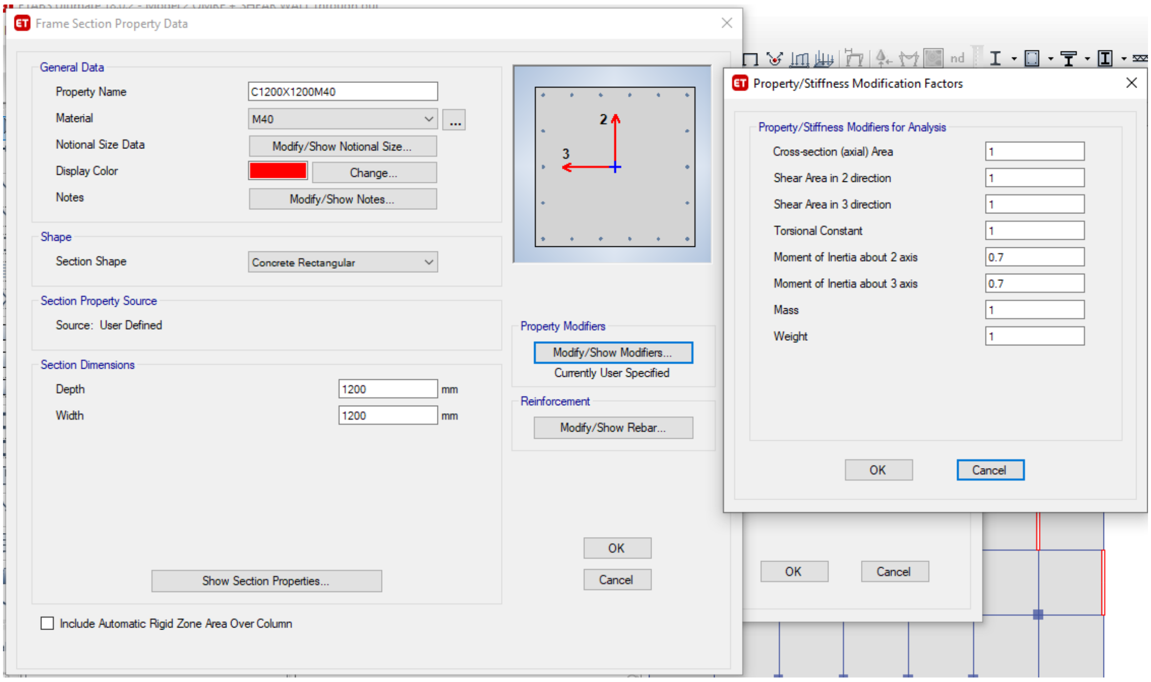


Figure 4.16 Cracked Section Properties for Columns

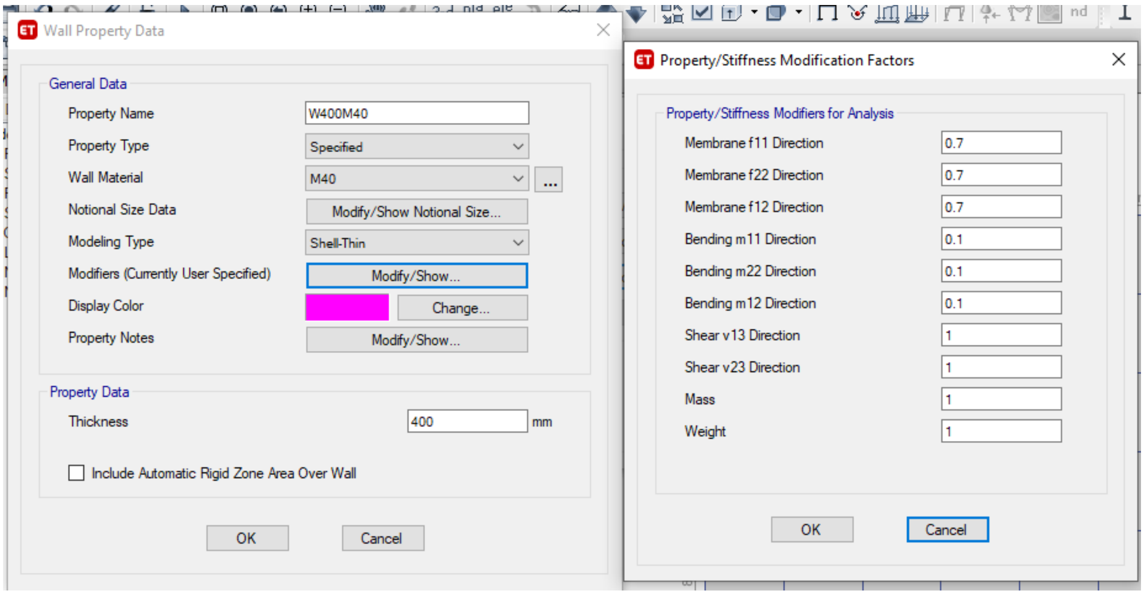


Figure 4.17 Cracked Section Properties for Shear Walls

V. RESULTS AND DISCUSSION

5.1 Modal Participating Mass Ratios:

Modal mass is a crucial concept in structural analysis, representing the amount of mass participating in a particular mode of vibration. Its significance lies in its impact on a structure's dynamic response to external loads, such as earthquakes or wind, influencing the calculation of modal frequencies and mode shapes. Modal mass affects the structure's energy absorption and dissipation capabilities, making it a vital factor in seismic design and analysis, where it affects the structure's ability to resist seismic forces. Additionally, modal mass is essential for calculating the effective mass of a structure, which is critical for vibration analysis and control. By identifying the most critical modes of vibration, engineers can optimize structural design, ensuring safety, efficiency, and resilience. Overall, modal mass plays a fundamental role in understanding and predicting a structure's dynamic behaviour, making it a vital parameter in structural analysis.

In our case we will observe the Modal participating mass ratios for all 3 selected cases are as follows:

a) Case 1: No Opening in Shear Wall

b) Case 2: Opening at Central Portion in Shear Wall (3m X 1.4m)

c) Case 3: Staggered Openings in Shear Wall (3m X 1.4m)

5.2 Modal participating mass ratios:

5.2.1 Case 1: No Opening in Shear Wall

Table 2. Case-1: No Opening in Shear Wall

Modal Participating Mass Ratios							
Mode	**Period**	**UX**	**UY**	**SumUX**	**SumUY**	**RZ**	**% Time Diff.**
	sec						
1	4.889	0.736	0.0005	0.736	0.0005	0.0008	
2	4.319	0.0006	0.7269	0.7367	0.7274	0.0027	11.65
3	3.636	0.0007	0.0027	0.7373	0.7301	0.708	15.81
4	1.385	0.1174	0.00003666	0.8547	0.7302	0.000008778	
5	1.209	0.00003956	0.121	0.8547	0.8512	0.0001	
6	1.135	0.00004119	0.001	0.8548	0.8522	0.0002	
7	0.971	0.00001837	0.0001	0.8548	0.8523	0.1324	
8	0.673	0.0526	0.000004551	0.9074	0.8523	0	
9	0.576	0.00000315	0.0545	0.9075	0.9068	0.000002798	
10	0.439	0	0.000004466	0.9075	0.9068	0.059	
11	0.397	0.0293	0.000001105	0.9367	0.9068	0.000004409	
12	0.336	5.332E-07	0.0301	0.9367	0.9368	0	

Case 2: Opening at Central Portion in Shear Wall (3m X 1.4m)

Table 3. Case-2: Opening at Central Portion in Shear Wall (3m X 1.4m)

Modal Participating Mass Ratios							
Mode	**Period**	**UX**	**UY**	**SumUX**	**SumUY**	**RZ**	**% Time Diff.**
	sec						
1	4.989	0.744	0.0006	0.744	0.0006	0.0009	
2	4.385	0.0007	0.7314	0.7447	0.732	0.003	12.10
3	3.691	0.0007	0.003	0.7454	0.7351	0.7156	15.82
4	1.447	0.1176	0.00003821	0.863	0.7351	0.00000893	
5	1.246	0.00003256	0.1222	0.8631	0.8572	0.0001	
6	1.014	0.00002221	0.0001	0.8631	0.8573	0.1322	
7	0.733	0.0495	0.000004743	0.9126	0.8573	0	
8	0.611	0.000003286	0.0525	0.9126	0.9098	0.000007497	
9	0.481	0.0000114	0.00000915	0.9126	0.9098	0.0561	
10	0.456	0.026	0.000001133	0.9386	0.9098	0.00004973	
11	0.369	5.721E-07	0.0281	0.9386	0.9379	9.938E-07	
12	0.319	0.0156	0	0.9542	0.9379	0.00001435	

5.2.3 Case 3: Staggered Openings in Shear Wall (3m X 1.4m)

Table 4. Case-3: Staggered Openings in Shear Wall (3m X 1.4m)

Modal Participating Mass Ratios							
Mode	**Period**	**UX**	**UY**	**SumUX**	**SumUY**	**RZ**	**% Time Diff.**
	sec						
1	5.097	0.7446	0.0007	0.7446	0.0007	0.001	
2	4.459	0.0008	0.7314	0.7454	0.7321	0.004	12.51
3	3.792	0.0008	0.004	0.7462	0.7362	0.7173	14.95
4	1.481	0.1138	0.00004156	0.86	0.7362	0.000004021	
5	1.27	0.0000352	0.1192	0.86	0.8554	0.0001	
6	1.047	0.00001578	0.0001	0.86	0.8555	0.1259	
7	0.743	0.05	0.000005516	0.9101	0.8555	0.000001696	
8	0.619	0.000003904	0.0529	0.9101	0.9083	0.000007694	
9	0.491	0.00000701	0.00001139	0.9101	0.9084	0.057	
10	0.45	0.028	0.000001264	0.9381	0.9084	0.00002613	
11	0.368	7.048E-07	0.0293	0.9381	0.9377	0.000001319	
12	0.305	0.0171	0	0.9552	0.9377	0.00002354	

5.2.4 Observations:

As per the above displayed results of modal participating mass ratios or simply modal results we can observe that,

a) The regular modes of oscillations as per the table no. 6 [(vii).a] of IS1893:2016. In all the three models, we can observe that first and second modes are translational, and are oscillating in firstly in X-direction and then in Y. However, third mode of oscillation is rotational. All the three modes are contributing more than 65% individually, so we can say that with reference to codal provision's structure is having regular modes of oscillations.

b) In all the three models, the percentage difference between the fundamental lateral natural time periods are found more than 10% as per the table no. 6 [(vii). b] of IS1893:2016. However, which confirms the all the three structures are having regular modes of oscillations.

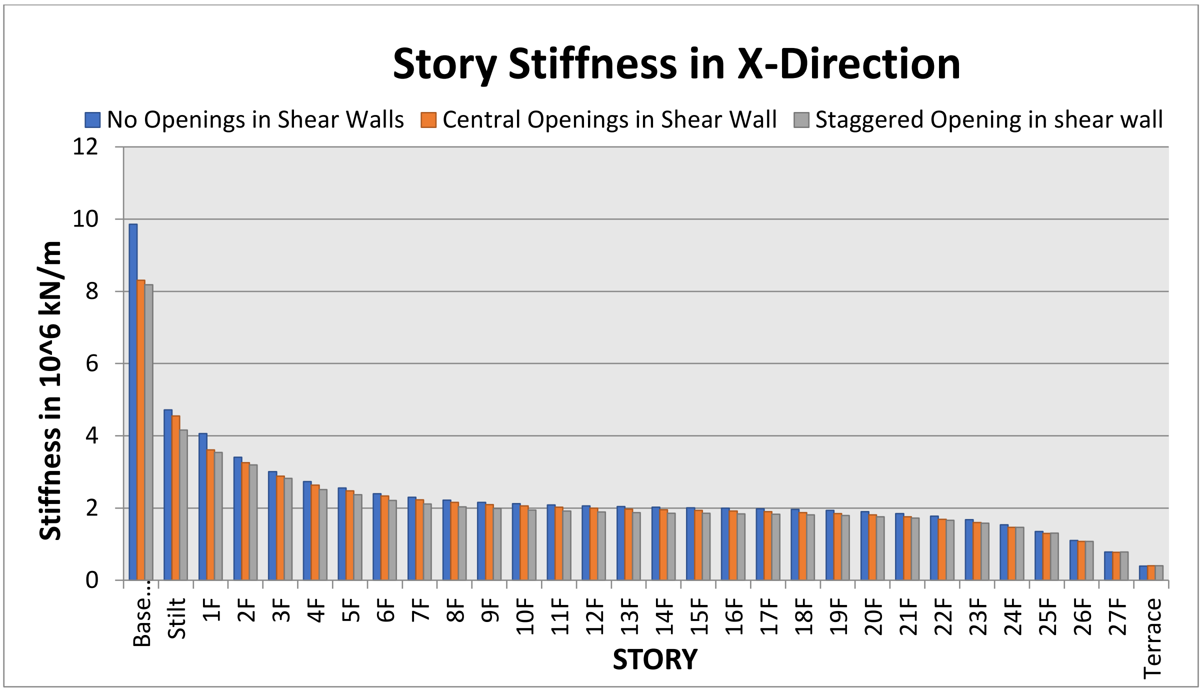
c) As per the above results mentioned in table, we can observe that, all the three models are following same pattern in terms of modal behavior but, in case-1, Shear wall with no openings time periods in first and second mode are the smallest (4.889 and 4.319 seconds). In case-2, Shear wall with central opening time period values are little bit increased to 4.989 and 4.385 seconds. However, in case-3, staggered openings in shear walls time period values are found maximum i.e. 5.097 and 4.459 seconds.

5.3 Storey Stiffness:

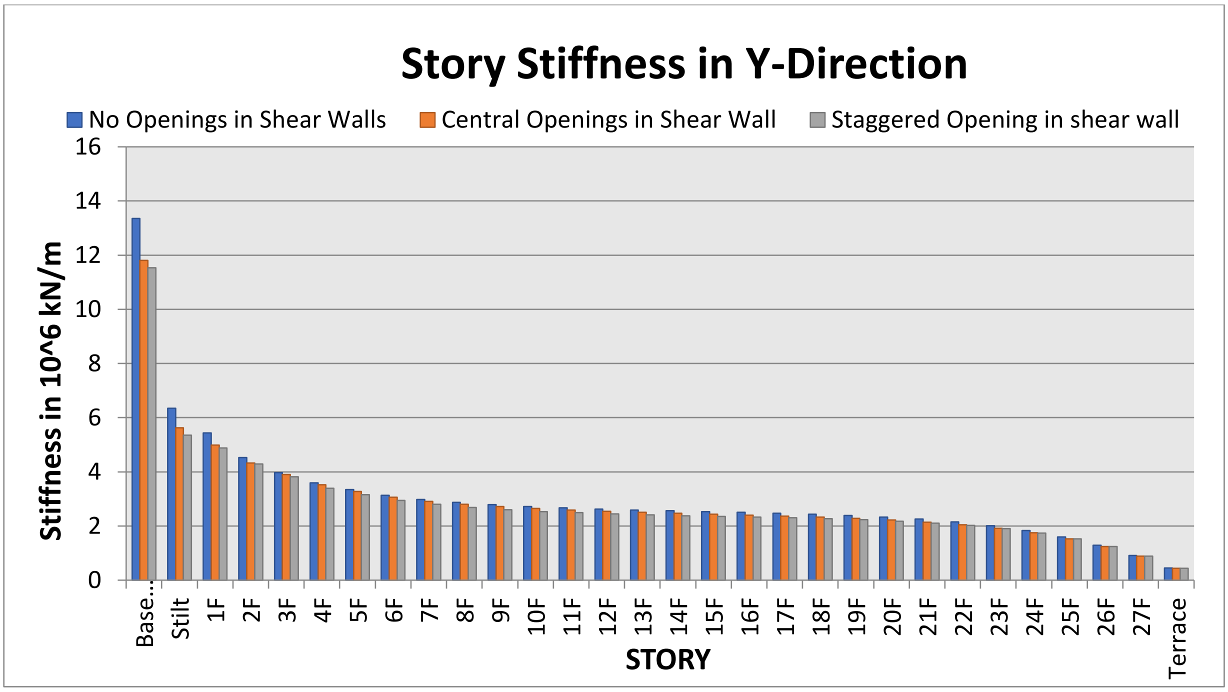
Storey stiffness is a crucial aspect of a structure's design, as it plays a vital role in resisting lateral loads like wind and seismic forces, thereby ensuring the structure's stability. It also influences the structure's natural frequencies and mode shapes, affecting its vibration response, and limits lateral drift to prevent excessive deformation and damage. Moreover, storey stiffness affects the distribution of loads between storeys, preventing any single storey from being overloaded, and maintains the structural integrity of the building to prevent collapse or significant damage. Adequate storey stiffness also ensures occupant comfort by minimizing excessive vibrations and movements. Furthermore, it is essential for optimizing structural design, material usage, and cost-effectiveness. In seismic design, storey stiffness is critical, as it affects the structure's ability to withstand earthquake forces. By ensuring adequate storey stiffness, engineers can design structures that are safer, more comfortable, and more resilient to various loads and hazards.

Table 5. Story Stiffness for all Cases

Story Stiffness							
		X-Direction			Y-Direction		
Story	Elevation	Case-1	Case-2	Case-3	Case-1	Case-2	Case-3
	m	kN/m	kN/m	kN/m	kN/m	kN/m	kN/m
Terrace	92	393427	397473	400345	450539	438293	438196
27F	89	782718	777570	779065	907494	886928	886020
26F	86	1103811	1073910	1078226	1291889	1246351	1245250
25F	83	1351552	1299473	1302304	1597136	1530163	1525808
24F	80	1537672	1468807	1462361	1834336	1749748	1737137
23F	77	1674713	1594754	1581047	2015488	1918340	1899610
22F	74	1774213	1687993	1660721	2152434	2047298	2017289
21F	71	1845751	1756936	1722663	2255472	2146087	2109930
20F	68	1896886	1808058	1759872	2333080	2222273	2174377
19F	65	1933442	1846298	1793458	2392041	2281836	2229268
18F	62	1959873	1875444	1809326	2437727	2329495	2265636
17F	59	1979617	1898444	1830317	2474407	2369024	2302295
16F	56	1995380	1917651	1836666	2505536	2403505	2325954
15F	53	2009370	1935015	1851914	2534001	2435552	2356806
14F	50	2023492	1952241	1858668	2562334	2467497	2378113
13F	47	2039498	1970915	1874934	2592895	2501551	2412024
12F	44	2059137	1992627	1889417	2628055	2539972	2442641
11F	41	2084303	2019094	1915885	2670380	2587938	2490281
10F	38	2117208	2054786	1942751	2722866	2645838	2533907
9F	35	2160611	2097215	1984757	2789235	2714117	2605274
8F	32	2218151	2152408	2028717	2874356	2800885	2679738
7F	29	2295101	2224518	2112045	2985394	2912041	2797675
6F	26	2395442	2332257	2206431	3128217	3066356	2940174
5F	23	2559197	2477329	2368535	3346987	3275006	3162255
4F	20	2735788	2638922	2511653	3596666	3527227	3398158
3F	17	3004444	2881015	2817078	3969756	3907223	3816691
2F	14	3408157	3255512	3194154	4526809	4322711	4285762
1F	11	4063183	3609295	3537428	5432058	4993420	4886299
Stilt	8	4719463	4549088	4156628	6348585	5622201	5357872
Basement	4	9856365	8308510	8186923	13349990	11804258	11533016



Graph 1. Stiffness in X-direction



Graph 2. Stiffness in Y-direction

5.3.1 Observations:

As per the above displayed results of story stiffness we can observe that,

a) For all the cases, stiffness's values are maximum at the base and as elevation increases storey stiffness compared to below storey is getting reduced. However, we can confirm form the tables and graph as well that, "No Weak or Soft storey is encountered" in all three case.

b) As the graph is showing comparisons of stiffness plots of all three cases as mentioned earlier, in case-1, Shear wall with no openings stiffness is found maximum. In case-2, Shear wall with central opening stiffness is quite reduced compared to case-1. As we can expect that introduction of opening (3m X 1.4m) in case-2 has significant effect on stiffness parameter.

c) In case-3 staggered openings in shear walls (3m X 1.4m), even though size of opening are kept same per storey, just pattern of placing of opening changed i.e. staggered pattern has reduced stiffness significantly in the lower stories.

d) As elevation height is getting increased, we can observe that there is very little variation in the story stiffness's in all 3 cases i.e. no much variation in the stiffness are found in all 3 models as storey height increasing.

5.4 Maximum Storey Displacement:

Displacement values need to be controlled in seismic analysis because excessive displacements can compromise structural integrity, leading to damage, collapse, or instability. Large displacements can also cause damage to non-structural elements, such as partitions, ceilings, and equipment, and exceed building code-specified drift limits, which are essential for ensuring occupant safety and preventing damage. Furthermore, uncontrolled displacements can trigger P-Delta effects, leading to structural instability and collapse. Controlling displacements is crucial for ensuring that structures meet seismic performance objectives, such as life safety and collapse prevention, and maintaining occupant comfort while minimizing the risk of injury during earthquakes. Ultimately, limiting displacements helps prevent significant economic losses due to damage, downtime, and repair costs, making it a critical aspect of seismic analysis and structural design.

Table 6. Maximum Story Displacement for all Cases

Maximum Storey Displacement							
		X-Direction			Y-Direction		
Story	**Elevation**	**Case-1**	**Case-2**	**Case-3**	**Case-1**	**Case-2**	**Case-3**
	m	mm	mm	mm	mm	mm	mm
Terrace	92	331	342	354	267	276	284
27F	89	324	335	348	261	270	279
26F	86	317	328	341	255	264	272
25F	83	310	321	334	248	257	266
24F	80	302	313	326	241	250	259
23F	77	293	304	317	234	243	252
22F	74	284	295	308	226	235	244
21F	71	274	285	298	218	227	235
20F	68	264	275	287	210	218	226
19F	65	253	263	276	200	209	217
18F	62	241	252	264	191	199	207
17F	59	229	239	251	181	189	196
16F	56	217	226	238	171	178	186
15F	53	204	213	224	160	167	174
14F	50	190	199	210	149	156	163
13F	47	176	185	195	138	145	151
12F	44	162	171	180	127	133	139
11F	41	148	156	164	115	121	127
10F	38	133	141	149	104	110	114
9F	35	119	127	133	92	98	102
8F	32	105	112	117	81	86	90
7F	29	90	97	102	70	74	77

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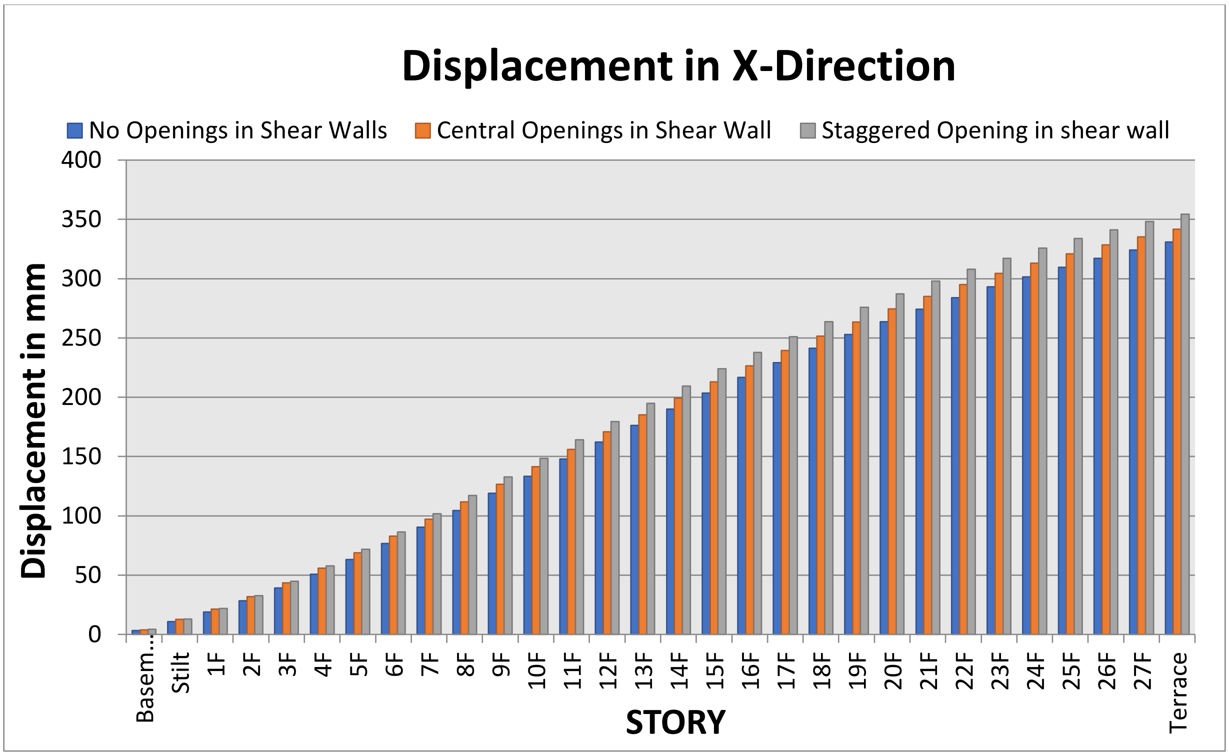
6F	26	77	83	87	59	63	66
5F	23	63	69	72	49	52	54
4F	20	51	56	58	39	42	44
3F	17	39	43	45	30	32	33
2F	14	28	32	33	22	24	24
1F	11	19	21	22	14	16	16
Stilt	8	11	13	13	8	9	10
Basement	4	3	4	4	2	3	4

Maximum Displacement limit for Seismic loading = Building Height (H)/250

Therefore,

Building Height = 92000mm / 250 = 368mm



Graph 3. Displacement in X-direction

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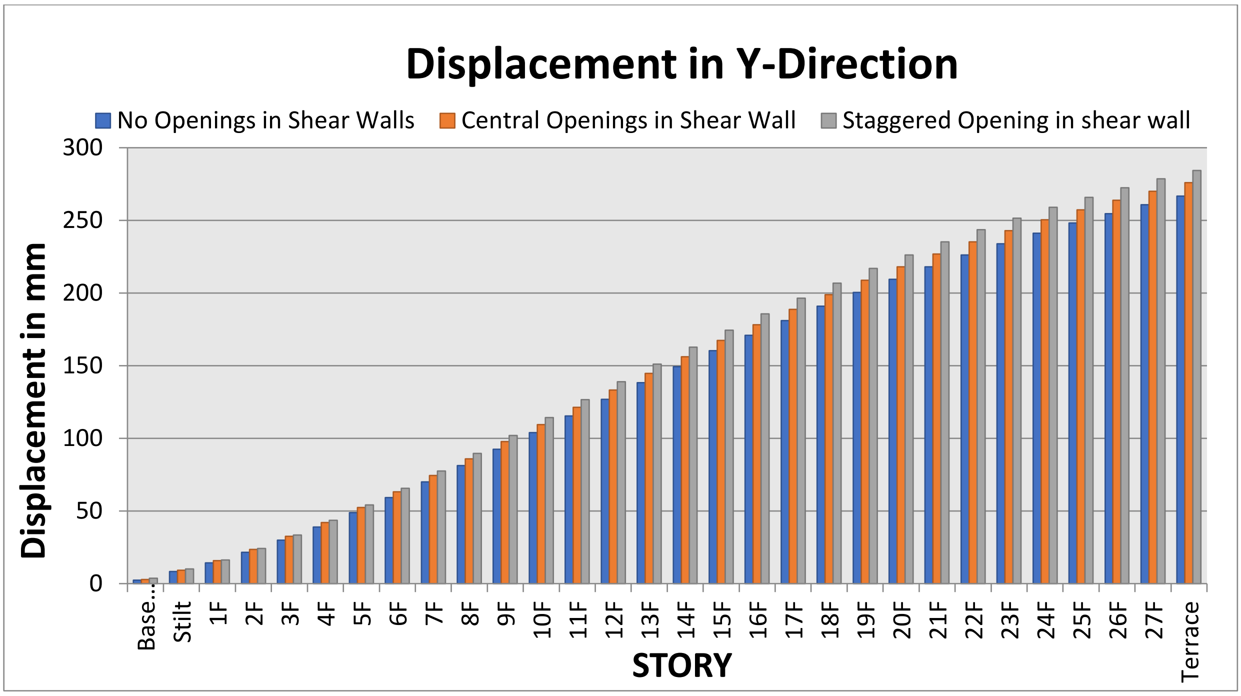

Graph 4. Displacement in Y-direction

5.4.1 Observations:

As per the above displayed results of maximum story displacement, we can observe that:

a) Case-1 having no openings in shear wall, it shows minimum displacement value among all the three cases analysed.

b) In the Case-2 as we introduced, opening in shear wall at the central portion displacement is little bit more compared to case-1 but less than case-3.

c) In the Case-3, openings are arranged in staggered manner with same size. However, displacement values found maximum for this case.

d) Displacement values of all the cases are within limit as specified i.e. H/250.

5.5 Maximum Storey Drift:

Storey drift control is crucial in seismic analysis because it directly impacts the structural integrity, safety, and performance of a building during earthquakes. Excessive storey drift can lead to significant damage to structural and non-structural elements, and even cause progressive collapse, where failure of one storey leads to subsequent failures, resulting in catastrophic collapse. Moreover, uncontrolled storey drift compromises occupant safety, as it can lead to injury or entrapment due to falling debris, collapsing walls, or structural failure. Building codes specify storey drift limits, typically 1-2% of storey height, to ensure structural integrity and occupant safety. Large storey drift can also trigger P-Delta effects, causing structural instability and potential collapse. By controlling storey drift, engineers can design structures that meet seismic performance objectives, such as life safety and collapse prevention, ultimately protecting lives and property, and minimizing economic losses due to damage, downtime, and repair costs.

Table 7. Maximum Story Drift for all Cases

Maximum Story Drift							
		X-Direction			Y-Direction		
Story	**Elevation**	**Case-1**	**Case-2**	**Case-3**	**Case-1**	**Case-2**	**Case-3**
Terrace	92	0.002233	0.002104	0.002091	0.001973	0.001931	0.001920
27F	89	0.002372	0.002299	0.002296	0.002071	0.002060	0.002059

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26F	86	0.002506	0.002479	0.002454	0.002168	0.002180	0.002171
25F	83	0.002669	0.002673	0.002653	0.002289	0.002317	0.002313
24F	80	0.002852	0.002879	0.002864	0.002425	0.002466	0.002468
23F	77	0.003047	0.003091	0.003099	0.002570	0.002622	0.002636
22F	74	0.003248	0.003305	0.003327	0.002719	0.002781	0.002806
21F	71	0.003451	0.003518	0.003570	0.002870	0.002940	0.002980
20F	68	0.003652	0.003726	0.003795	0.003018	0.003095	0.003148
19F	65	0.003846	0.003925	0.004028	0.003161	0.003243	0.003314
18F	62	0.004030	0.004114	0.004233	0.003296	0.003383	0.003467
17F	59	0.004201	0.004289	0.004442	0.003421	0.003512	0.003613
16F	56	0.004357	0.004448	0.004617	0.003533	0.003628	0.003743
15F	53	0.004495	0.004590	0.004792	0.003630	0.003729	0.003860
14F	50	0.004612	0.004711	0.004925	0.003711	0.003813	0.003956
13F	47	0.004706	0.004810	0.005056	0.003773	0.003879	0.004036
12F	44	0.004774	0.004883	0.005137	0.003813	0.003923	0.004090
11F	41	0.004812	0.004929	0.005211	0.003830	0.003945	0.004123
10F	38	0.004818	0.004945	0.005228	0.003822	0.003942	0.004124
9F	35	0.004787	0.004927	0.005229	0.003784	0.003911	0.004099
8F	32	0.004716	0.004871	0.005164	0.003715	0.003848	0.004036
7F	29	0.004599	0.004771	0.005072	0.003609	0.003751	0.003936
6F	26	0.004436	0.004625	0.004910	0.003469	0.003618	0.003797
5F	23	0.004175	0.004370	0.004638	0.003260	0.003410	0.003574
4F	20	0.003917	0.004147	0.004378	0.003043	0.003207	0.003353
3F	17	0.003573	0.003842	0.004026	0.002762	0.002939	0.003058
2F	14	0.003151	0.003453	0.003571	0.002423	0.002608	0.002695
1F	11	0.002640	0.002953	0.003020	0.002017	0.002199	0.002255
Stilt	8	0.001929	0.002203	0.002249	0.001455	0.001612	0.001652
Basement	4	0.000810	0.000954	0.000973	0.000608	0.000695	0.000712

Maximum Story Drift limit for Seismic loading 1/250 = 0.004 (IS 16700:2023)

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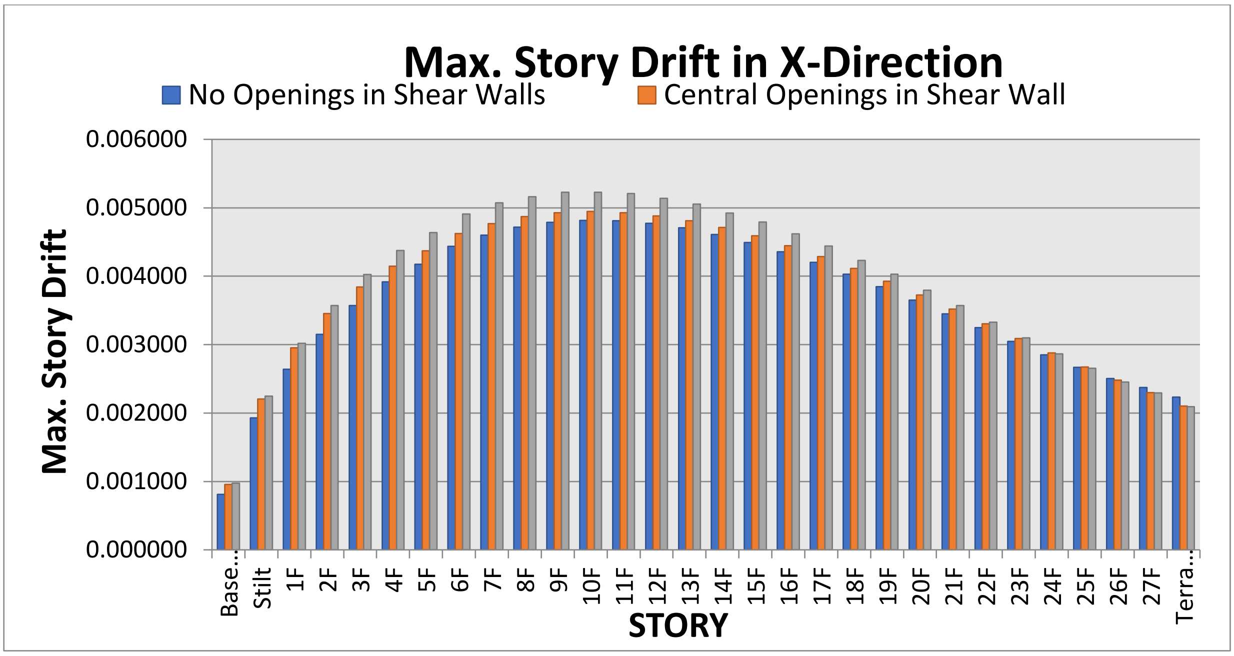
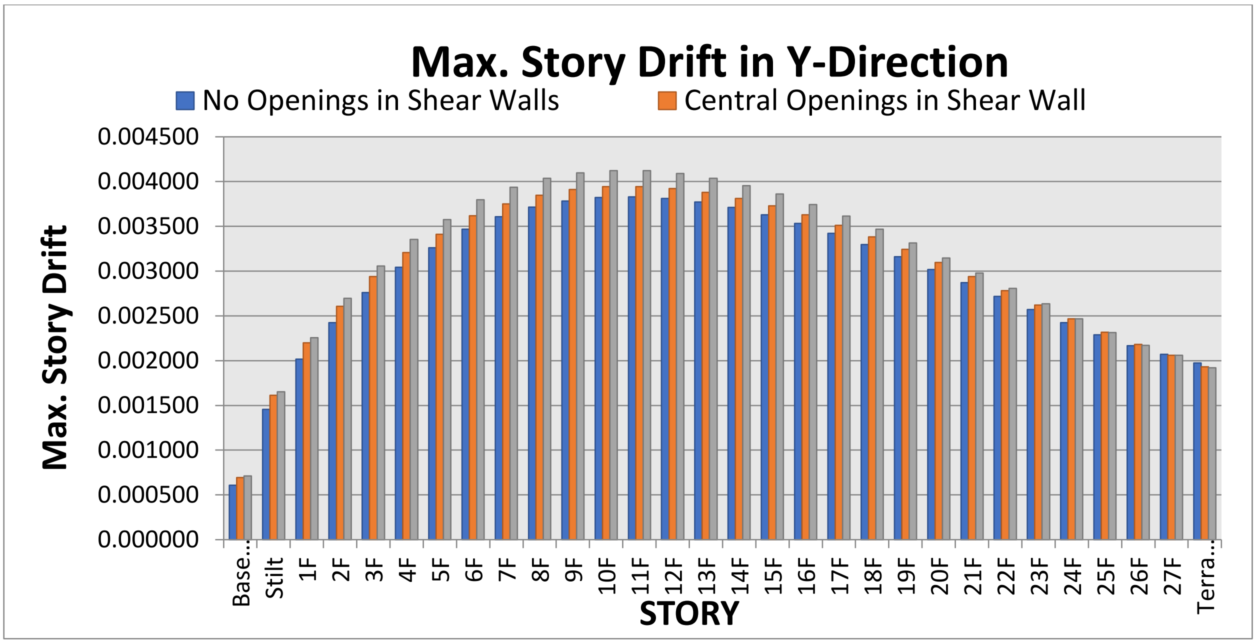


Graph 5. Max. Story Drift in X-direction



Graph 6. Max. Story Drift in Y-direction

5.5.1 Observations:

As per the above displayed results of maximum story displacement, we can observe that:

a) Case-1 having no openings in shear wall, it shows drift value 0.004818 and 0.003830 at 11th floor in X and in Y-direction. As our drift limit for earthquake case is 1/250 as per Cl. 5.4.1 of IS 16700:2023, drift value in X-direction needs to be kept within limit.

b) In the Case-2 as we introduced, opening in shear wall at the central portion drift value found to be 0.004945 at 10th floor in X-direction and 0.003945 at 11th floor in Y-direction.

c) In the Case-3, openings are arranged in staggered manner with same size. However, drift values found maximum among all cases and are 0.005229 at 10th floor in X-direction and 0.004124 at 11th floor in Y-direction.

d) Drift values of all the cases in X-direction exceeded limit as specified by IS code i.e. 1/250.

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5.6 Result and Discussion

In this project we have made 3 models for 3 different cases to observe the effect of openings in shear wall. Cases are mentioned are as follows:

a) Case-1: No openings in shear wall

b) Case-2: Central openings in shear wall

c) Case-3: Staggered openings in shear wall

We will discuss the results one by one.

1. **Modal mass participation ratios:** Aspect ratios, slenderness ratio, section sizes of the elements of all the three models were approximately same. In case-2 and case-3 only we have introduced the openings of size (3m X 1.4m) at central portion and in staggered manner respectively. As the overall geometry of all the models were same. However, we haven't observed much more difference in modal behavior of the structure in all three cases. Therefore, geometry of structure plays important role in the modal behavior even though openings are added in the structure.

Introduction of openings is indirectly related to reducing the stiffness of the element. As a result of this it is observed that increase in time period in the models with openings compared to model without opening.

2. **Lateral Stiffness:** Lateral stiffness is the strength of the elements which are resisting lateral loads. In our case as Response reduction factor is taken as 4, it indicated that the columns and beams are the ordinary element and only shear wall in the structure are ductile. As per model we have made opening in the shear walls, approximately 20% of wall area, eventually we have reduced the stiffness of the wall element. As a result of this we have observed the reduction in the stiffness in walls with openings compared to wall without openings.
3. **Maximum Story Displacement and Drift:** Increased in maximum lateral drift and displacement are observed in walls with openings compared walls without openings. The reasons for these kinds of results are reduction in stiffness as openings are introduced in the shear wall with different patterns, as walls are the only lateral load resisting elements in our case.

VI. CONCLUSION

From the results of this project following conclusions are drawn:

1. Geometry of structure plays an important role in the behavior of the structure like modal behavior of the structure.
2. Sizes, pattern of openings have effects on the fundamental natural period if the structure. Irregular pattern leads to increase in the natural time period of the structure.
3. Sizes, pattern of openings are also responsible for the stiffness contribution of the structure. Irregularity in the opening pattern makes structure more flexible than regular or conventional openings. Irregular openings reduce structural stiffness more vigorously.
4. Less size of openings causes less drift and displacement in the structure, ensuring the structural safety and serviceability.
5. Irregular pattern of openings along with more opening size causes increased in the drift and displacement of the structure.
6. Generally, shear walls are placed at outer periphery and at the corner of the structure. Openings provided near the edge of shear wall makes the overall structure more flexible and vulnerable local failure. However, it further leads to increase in drift, displacement and reduction in stiffness.

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