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Seismic Behaviour of Multistorey Prefabricated Modular Building

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Abstract : Modular building construction relies on prefabricated modules which are assembled onsite to form complete buildings. The assembly requires modules to be connected at discrete locations and results in the formation of discontinuous diaphragms. Generally, prefab can be categorized into components, panels (2D), modules (3D), hybrids, and unitized whole buildings. On average, greenhouse gas emissions from conventional construction were higher than for modular construction, not discounting some individual discrepancies. The work undertaken is an attempt to understand the fundamentals of prefab modular building, its design & behavior under seismic loading. As, no specific guidelines are available for design of building with modular building in Indian code IS 1893-2016 (Part I). Two types of modular structures are compared one with bracings and another with shear wall in G+20 building.

***IndexTerms* - Prefab Modular Building, Greenhouse, Shear Wall, Bracings, Diaphragm.**

I. Introduction

An emerging trend in the construction of medium-rise structures is modular construction or three-dimensional “pre-fabricated construction systems”. It differs from conventional construction as it involves the prefabrication of individual volumetric units (modules) off-site in factory-controlled settings (off-site manufacture or OSM) which are then assembled on-site, expediting the construction process while maintaining quality and safety standards. The concept of prefabricated modular structures has arisen in recent times as an effective solution to the AEC industry to achieve both speedy constructions as well improved and sustainable quality of the final product. Prefabricated building modules (such as apartments, office spaces, staircases etc.) can be fully constructed with architectural finishes and services inside a quality-controlled factory environment, ready to be delivered and assembled on site to form a safe and stable structure. Most manufacturers will nowadays cater for any architectural design with innovative modular units accordingly. Such building modules are mass produced in factories where the intense labour which would have otherwise been required at a conventional building site is replaced with specialist workmanship and machine handling in a mass production facility.

As more innovative and unconventional designs are generated through modern architecture, prefabricated modules with different shapes and sizes will be demanded.

Modular construction has gained a lot of popularity in the recent few years, and from what is already constructed it is evident that there are various types of prefabricated modules as well as various structural systems that are employed in constructing buildings out of them. This section will systematically categorise the various types of prefabricated modules according to their load transfer mechanisms, structural systems, production type and predominant building materials.

1. Corner supported modules – where loads are transferred from edge beams to the supporting corner columns to the ground or a podium floor

2. Load bearing modules – where the loads are transferred from the side walls of the module to the ground Accordingly, by the review of the researchers on prefabricated modular building the few concerning factors for the structural design of the such buildings are as,

1. Fred Edmond Boafo, Jin-Hee Kim, presented Performance of "Modular Prefabricated Architecture: Case Study-Based Review and Future Pathways", which introduce prefabricated building concept, Components allow for the greatest degree of customization and flexibility within the design and execution phases and Simultaneously, detailed design and offsite fabrication of building components, under controlled factory conditions, using the same materials and designing to the same local building codes.

2. Zhengdao Li.al, Geoffrey Qiping Shen presented "Critical review of the research on the management of prefabricated construction", this study provides a critical overview of the MPC research development, which provides a valuable reference for both scholars and industry practitioners. This study helps scholars gain an indepth understanding of the state-of-the-art of MPC research and allows them to continue from the findings of previous studies. This study can also benefit industry practitioners by providing them with effective methods in prefabricated construction practice.

3. Andrew W Lacey, Wensu Chen, Hong Hao, Kaiming Bi conducted, "Structural Response of Modular Buildings" in this paper Structural connections which is key to overall performance and so a detailed review of connection types is presented. Also define the range of existing modular buildings, a list of multi-storey modular building projects has been compiled based on a review of the literature.

Figure 1. Prefabricated modules made with timber

Figure 2. Prefabricated modules made with concrete

1.1 Advantages of Prefabricated Modular Building

i) Saves Time : An obvious one is that modular construction allows a chunk of the work to be made in a factory while sitework and foundations are simultaneously performed on the site.

ii) No Possible of Weather Delay : Furthermore, by fabricating the modules inside a controlled environment, worries about weather delaying construction of the modular units is virtually eliminated. It also provides workers safer and more comfortable conditions to be more productive and produce a higher quality product.

iii) Lower Volume of Waste : With the environment being a growing concern in the construction industry, modular strategies are becoming more popular to limit the amount of waste on each project. There are even efforts to maximize recycling within factories that put the building portions together.

iv) Lower Labor Cost : An important and potentially controversial advantage involves economics of labor. Skilled labor is in short supply for construction in most places and can be very expensive in cities for a variety of reasons. Without getting into politics, this leads to real challenges when trying to get a building constructed for a given budget and timeline. Modular allows those coveted skilled workers to remain in fixed locations with controlled and safer conditions as mentioned.

1.2 Dis-advantages of Prefabricated Modular Building

i) Mass Production and Limited Variety: First, a modular (think mass production) approach on scale is better the more uniform and repetitive the spaces and products. So naturally, apartment buildings and hotels are likely candidates if each unit can be standardized and stacked. At this stage of technology, trying to create distinct or non-repetitive modules reduces, and potentially defeats, the time and cost advantages for both buyer and supplier parties.

ii) Transport Cost and Risk: Since modules are prefabricated in a factory miles from the job site, they need to be transported either directly to the job site or staged at a place nearby and then set in place. The transporters and riggers must be extremely careful with each module as one mishap during transportation and the entire module could need significant repairs or replacement.

II. OBJECTIVES

1. Identifying the general structural behavior and load transfer mechanisms of a modular structure by analyzing a 3D computer model, under gravity loads as well as earthquake and wind loads.
2. Identifying the contribution of connections in the performance of the lateral load resisting system
3. Providing the theoretical background to the necessary idealizations in preparing global structural models to analyze modular buildings using commercially available software.
4. Evaluating the behavior of connection subjected to a lateral load through a detailed finite element analysis.

III. LITERATURE REVIEW

Satheeskumar Navaratnam, Tuan Ngo, presented the "**Performance Review of Prefabricated Building Systems and Future Research**". In this paper the performance of prefabricated building systems has been reviewed from the available resources. This review shows that prefabricated building systems and construction hold high potential to improve the efficiency and performance of the Australian construction industry in a more sustainable sense. Also given suggestions to increase the market demand and to contribute to the development of prefabricated building systems.

Prajjwal Paudel, Sagar Dulal , presented "**Study on Pre-fabricated Modular and Steel Structures.**", In this paper they studied the quantified benefits of employing prefab technology in light to medium commercial building projects. Also, successfully established the fact that proportion of prefab content has a significant relationship with the cost performance and time performance of the project.

Saidu Ibrahim, Gaetan Rwaburindi, presented "**Comparative Study on Modular Construction with In-situ Construction of Residential Buildings**" , this paper includes present situation of modular construction and the cost effectiveness of construction modular building for residential purposes. Also identifies the difference in the cost of constructing a one storey residential building using the two methods.

Andrew W Lacey, Wensu Chen, Hong Hao, Kaiming Bi conducted, "**Structural Response of Modular Buildings**" in this paper Structural connections which is key to overall performance and so a detailed review of connection types is presented. Also define the range of existing modular buildings, a list of multi-storey modular building projects has been compiled based on a review of the literature. And conclude that the Modular building refers to the application of a variety of structural systems and building materials. Modular buildings perform differently to similar traditional structures owing to the requirements of site interconnection for modular building.

Sriskanthan Srisangeerthanan, M. Javad Hashemi, Pathmanathan Rajeev, Emad Gad, Saman Fernando, presented "**Numerical study on the effects of diaphragm stiffness and strength on the seismic response of multi-story modular buildings**", This study considers modular buildings as those built using prefabricatedfully-completed volumetric units called modules, whichcould be an apartment unit, staircase, structural core component, etc. Such modules are factory manufactured and fit with mechanical connections for assembly on-site, where they would be stacked vertically and scaled horizontally to form complete buildings.

Issa J. Ramaji and Ali M. Memari conducted research on "**Identification of Structural Issues in Design and Construction of Multi-Story Modular Buildings**" This paper initially introduces different types of modular multi-story or high-rise construction systems. The structural systems including gravity and lateral load resisting systems are then discussed. The challenges that structural designers face in addressing load path continuity and gravity and lateral load transfer between adjacent structural components are reviewed. Approaches for system and building modeling needed for structural analysis as well as relevant building code requirements are discussed. Furthermore, the challenges in design and detailing of different structural members and components/systems are evaluated. The paper also provides an overview of any special structural safety issues for design and construction. Finally, the paper outlines the R&D needs for advancing the technology of multi-story modular building design and construction.

IV. METHODOLGY

Although modular technology has been around for decades and established low rise examples have existed for over 20 years, the technology is relatively new in high rise construction and very limited examples exist that have been completed or are under construction. As such, large data set analysis is not currently possible and analysis must be limited to the few dozen projects available for review around the world. In light of this data set, the methodology of research primarily relies upon literature review, interviews, case studies and financial analysis based upon scenarios of available construction data.

1. Seismic Analysis-

In the dynamic analysis procedure, the lateral forces are based on properties of the natural vibration modes of the building, which are determined by the distribution of mass and stiffness over height.In the equivalent lateral force procedure, the magnitude of forces is based on an estimation of the fundamental period and on the distribution of forces as given by a simple formula that is appropriate only for regular buildings. In the preliminary design process, equivalent static seismic forces are used to determine the design internal forces of structural members using linear elastic analyzed structure and, in turn, determine the design member strength demands. Such static seismic forces are simply determined corresponding to the elastic design acceleration spectrum divided by a structural strength reduction factor particularly called the response modification factor.

The categorization can be summarised as follows:

- Linear static analysis
- Nonlinear static analysis
- Linear dynamic analysis
- Nonlinear dynamic analysis

While the earthquake analysis methods have a wide variety, earthquakes themselves differ from each other by a number of parameters, namely:

- Intensity
- Depth
- Duration
- Peak Ground Acceleration (PGA)
- Peak Ground Velocity (PGV)
- Peak Ground Displacement (PGD)
- Energy Released
- Damage Caused

Several scales are used in practice around the world to categorise earthquakes according to their ‘magnitude’ which is a measure of the intensity of an earthquake and the energy released during the event. Such scales used to estimate the magnitude are:

- Richter Intensity Scale (ML)
- Moment Magnitude Scale (MW/MMS)
- Mercalli Intensity Scale and Modified Mercalli Intensity Scale (MMI)

2. Basic Principles of Earthquake Analysis and Design

The seismic response of a building depends on dominant modes of vibration of the building which are defined through its mass and stiffness, the ground motion at the foundation, and the mode of soil structure interaction. The motion of a very stiff building is more similar to the ground motion whereas that of a very flexible building can be quite different. The response will be based on criteria such as the natural frequency, the damping ratio of the structure, the behaviour of the foundation, the ductility of the structure, the duration of the earthquake etc. As discussed previously earthquake analysis procedures for buildings can take the form of either force-based design or performance-based design.

3. Force Based Methods of Earthquake Analysis

The effects of an earthquake on a structure can be evaluated in many ways. Design codes that are used around the world for Engineering practice categorise these analysis techniques into two main types namely, static and dynamic analyses. There are many different ways to analyse the response of a structure to earthquake loads that are applied according to these two main categories and some of the common methods are as follows;

a. Linear Static Analysis

1.1.1 Linear static analysis is carried out with equivalent static forces to simulate the dynamic action of an earthquake on the structure. Structural Engineers continue to use static analysis procedures for earthquake designs based on the notion that buildings designed this way have performed well in the past during earthquakes. Equivalent static load (ESL) method: All seismic design must consider the dynamic nature of the load. However, for simple regular structures, analysis by equivalent linear static methods is often sufficient.

1.1.2 **Equivalent static load (ESL) method**:

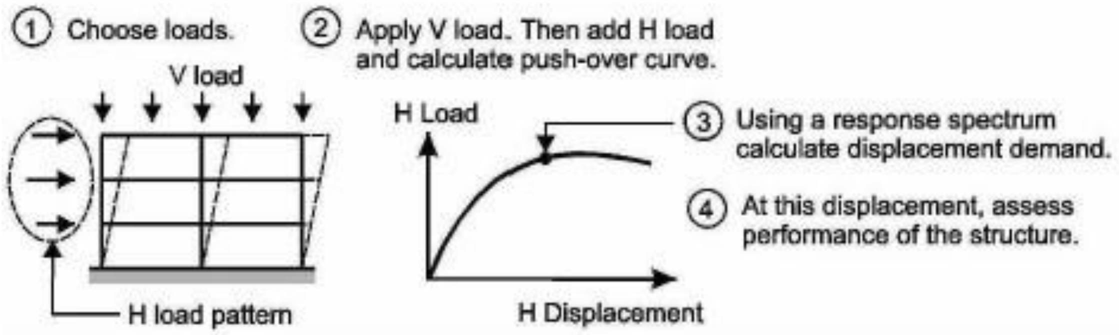
All seismic design must consider the dynamic nature of the load. However, for simple regular structures, analysis by equivalent linear static methods is often sufficient. This is permitted in most codes of practice for regular, low- to medium-rise buildings.

b. Nonlinear Static Analysis

Certain static analysis techniques are widely used in checking structures for their nonlinear behaviour against larger lateral loads. These analysis techniques are discussed below:

1.1.3 Nonlinear Static Pushover Analysis

As a static nonlinear analysis, pushover analysis is one of the most used and popular methods in earthquake engineering as this method follows after a response spectrum analysis. This analysis technique provides a load versus deformation relationship of the structure, starting from a state of rest and continuing onto the ultimate failure of the structure. A horizontal load, that is representative of the equivalent static load of a particular mode of vibration of a structure, which may be conveniently taken as the total base shear of the structure, is applied to push the structure from rest to failure. Similarly, the deformation may be obtained for any storey of a building but is commonly taken at the top storey as it would usually produce the worst deformation.

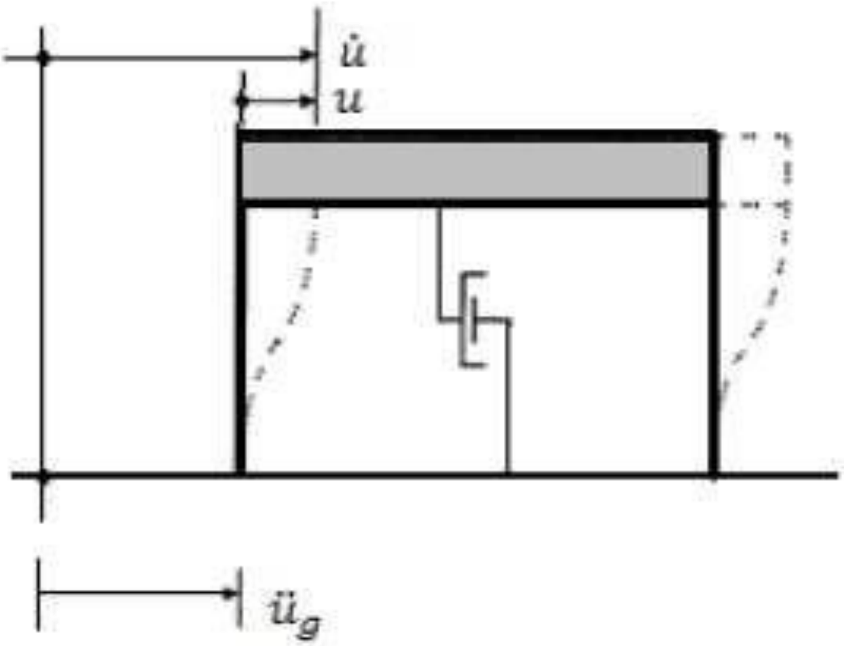


c. Linear Dynamic Analysis

Under the linear dynamic procedure, design seismic forces and the corresponding internal forces and displacements of the structure are determined using a linear elastic dynamic analysis. Most earthquake design codes provide similar methods for this type of analysis.

1.1.4 Response spectrum (RS) method:

Static procedures are appropriate when higher mode effects are not significant. This is generally true for short, regular buildings. Therefore, for tall buildings, buildings with torsion irregularities, or non-orthogonal systems, a dynamic procedure is required. In the linear dynamic procedure, the building is modelled as a multi-degree-of-freedom (MDOF) system with a linear elastic stiffness matrix and an equivalent viscous damping matrix. The seismic input is modelled using either modal spectral analysis or time history analysis but, in both cases.



1.1.5
1.1.6
1.1.7

1.1.8 Modal Analysis and Modal Combination Methods

Modal analysis is one of the most commonly adopted methods of designing structures for earthquakes in order to obtain estimates of structural response, both in terms of design forces and displacements. The first step of the procedure is to perform an eigen-value analysis of the structure with a given seismic mass and elastic stiffness in order to identify its modal characteristics. The characteristics of particular importance are the modal periods an modal shapes. The natural frequencies, are calculated from the solution of the following determinant:
The modal combinations and directional combinations can be carried out using various methods such as:

- SRSS method (Square Root of Sum of Squares)
- CQC method (Complete Quadratic Quotients)
- Absolute Sum method
- General Modal Combination method (GMC)
- 10 Percent Method of Nuclear Regulatory Commission (NRC 10%)

d. Nonlinear Dynamic Analysis

The non-linear dynamic procedure involves a time-history dynamic analysis to directly calculate the seismic responses. The equation of motion here is for an elastic multi-degree of freedom (MDOF) structure and is written in a similar form to the equation for an elastic SDOF system

1.1.9 Time history analysis:

Time-history analysis is a step-by-step analysis of the dynamical response of a structure to a specified loading that may vary with time. The analysis may be linear or nonlinear.
Nonlinear time-history analysis is the most reliable method at present for determining or verifying the response of a designed structure to the design level of intensity, and the number of records to be used for the analysis is defined by many codes.

There are three methods for obtaining spectrum compatible accelerograms as follows:

- Amplitude scaling of acceleration records from real earthquakes to provide a best fit to the design spectrum over the period range of interest

- Generating artificial spectrum compatible records using special purpose programs
- Manipulating existing real records to match the design spectrum over the full range of periods.

4. Wind analysis-

4.1 Static method

Basic wind speed- Basic wind speed map of India, as applicable to 10 m height above mean ground level for different zones of the country.
Design wind speed (Vz) –The basic wind speed (Vb) for any site shall be modified to include the following effects to get design wind speed, Vz at any height ‘z’ for chosen structure.

4.2 Dynamic method

Design wind pressure is calculated by static method. In general, following guidelines may be used for examining the problems of wind induced oscillation.

- Building and closed structures with a height to minimum lateral dimension ratio of more than 5.0,or
- Building and structures whose natural frequency in the first mode is less than 1.0 Hz. Any building or structure which satisfies either of the above two criteria can be examined for dynamic effect of wind.

The values of Gust Factor for the building in different terrain categories were obtained. The wind loads at various levels along the height have been obtained for the chosen building in all the four terrain categories by Mean Wind Approach- Gust Factor Method along with base shear and base moments.
The procedure followed for computing wind load is same as laid down in IS 875(Part 3)-1987.

Loading Pattern

ii) Apart from the self-weight, the building is subjected to various type of loading. The major loads acting on the building are:

iii) Dead Load (DL): - The dead load, include self-weight of the structure itself, and immovable fixtures. Dead loads are also known as permanent loads. The dead load of the beams and columns are automatically considered by the model. The loads from the slabs are distributed as triangular or trapezoidal line loads on the supporting beam as per IS 456:2000.

iv) Live Load (LL) or Imposed Load (IL): - Live loads, or imposed loads are temporary, of short duration or moving. These dynamic loads involve considerations such as impact, momentum, vibration, fatigue, etc. Apart from the self-weight, the building is subjected to live loads. The load distribution pattern of the live load from the slabs to the supporting beams is similar as that in case of the DL.

v) Seismic Loading: - Seismic loading is one of the basic concepts of earthquake engineering which means application of an earthquake-generated agitation to the structure. It happens at contact surfaces of a structure either with the ground, or with adjacent structures, or with gravity waves from tsunami. The seismic load is calculated as per the provisions given in IS: 1893 (Part l)-2016.

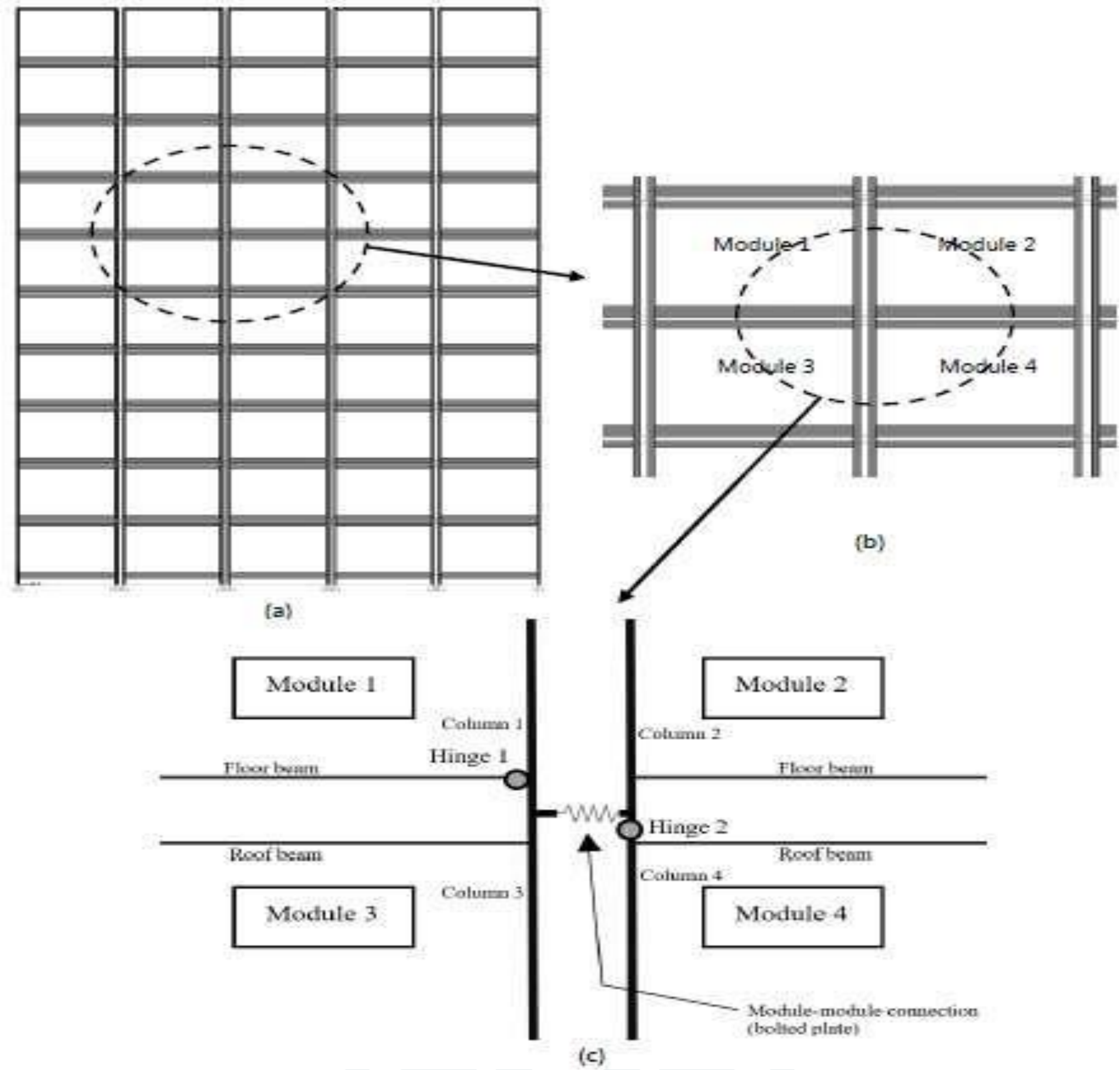
Basic Assumptions in Modeling

The following are the main modelling assumptions used in this study:

- Fixed Base: The columns of buildings are assumed to be fixed at their base on rigid foundation No soil-structure interaction effect is considered in present study.
- Lumped Mass at Floor Level: The masses and the mass rotational moments of inertia of the building are assumed to be lumped at the floor levels.
- Rigid Diaphragm: Each floor has been assigned as rigid diaphragm.

Expected Structural Behaviour

- The gravity loads in the form of dead loads, live loads and super imposed loads (finishes, services etc.) that are imposed on the floors and roofs of each module will be transferred to the supporting corner columns through the floor and roof beams. The corner columns will transfer the gravity loads straight to the foundation. However, the transfer of lateral loads occur following a different mechanism.
- A cross section of the module-module connection which transfers loads both vertically and horizontally, is sketched in Figure 4. The possible pinned connections are not shown in order to prevent confusion with the possible hinge locations shown in the diagram. One such connection would connect four supporting corner columns from four adjoining modules.



An illustration of the module-module connection and possible hinge locations via (a) the view from the front elevation of the modular building, (b) a close-up of the elevation view of neighbouring modules and (c) the module-module connection

V. Modelling and Analysis

In this project one regular and two different irregular models are taken. Two irregular model is with two different irregularities viz. soft storey and torsional irregularity. Following are material properties, sizes of elements (beams, columns, shear wall), seismic and wind parameters, load combinations considered this project.

Material Properties:
Concrete:
grade: M25,Steel grade:HYSD500

Trial Sizes of elements:
Beam- 450X600 MM,300X600 MM
Column- 600X900 MM
Slab thickness- 250 MM

Load combinations:

a) Strength load combinations-

1.5 (DL + L.L)	*1.2 (DL + LL ± EQX)*
1.5 (DL ± EQX)	*1.2 (DL + LL ± EQY)*
1.5 (DL ± EQY)	*1.2 (DL + LL ± WLX)*
1.5 (DL ± WLX)	*1.2 (DL + LL ± WLY)*
1.5 (DL ± WLY)	*0.9 DL ± 1.5 WLX*
0.9 DL ± 1.5 EQX	*0.9 DL ± 1.5 WLY*
0.9 DL ± 1.5 EQY	

b) Service load combinations-

1 (DL + LL)	*0.8 DL + 0.8 LL ± 0.8 EQX*
1 (DL ± EQX)	*0.8 DL + 0.8 LL ± 0.8 EQY*
1 (DL ± EQY)	*0.8 DL + 0.8 LL ± 0.8 WLX*
1 (DL ± WLX)	*0.8 DL + 0.8 LL ± 0.8 WLY*
1 (DL ± WLX)	

Load Calculations:

I. Dead load and live load calculation on slab (As Per is 875-2015 Part-1&Part-2 clause 3.1 Table 1):

Dead load calculation (from IS 875 part-1):

Dead Load = DL of tiles +DL of mortar + DL of filler material

= 0.2 + (density of mortar x thickness) + (density of filler x thickness)

Assuming,

Thickness of mortar=25mm

Thickness of filler material=75mm

Filler material=sand

Dead Load = 0.2 + (20.40 x 0.020) + (17.00 x 0.050)

= 0.2 + 1.258 = 1.458 KN/m2 □ 1.5 KN/m2

Dead Load = Light weight filling material + Floor Finish

= 0.15 x 10 + 1.5

= 3.0 KN/m2

Table.1 Load on slab

Sr. No.	Slab type	Dead Load (kN/m^2)	Live Load (kN/m^2)
1	Habitual slab	1.5	2
2	Lobby area	1.5	3
3	Sunken slab	3	2
4	Terrace slab	3	2
5	Staircase slab	3	3

II. Load on beams:

i. Wall load =c/s area x density of wall

= 0.15 x (3-0.60) x 10 = 3.6 KN/m

ii. Balcony & parapet wall load = 1.5 KN/m

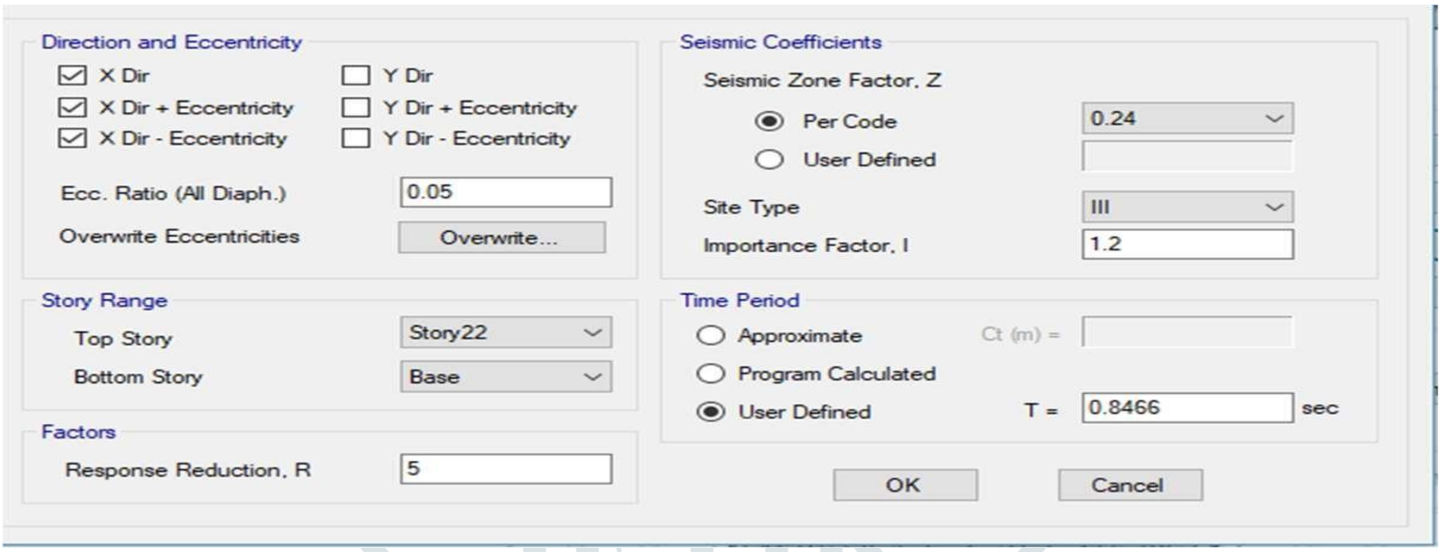
III. Earthquake Load (IS 1893-Part:1-2016) : Seismic parameters:

The residential building located where seismic is Zone IV with factor 0.24. Since it is a residential building, which is having importance factor 1.2. Dual system is considered as a lateral load resisting system in which ductile RC shear walls with RC SMRF with response reduction factor (R) 5 is taken. Project building is located on type B medium stiff soil site.

Design lateral force = Vb = Ah x W (As per 1893-2016 part 1 clause 7.2.1) Where,
Ah= Design horizontal acceleration spectrum value as per using the fundamental Natural period Time period Time Period, (Considering Building with infilled wall Panel) (clause 7.6.2) At X direction = 0.09h/√dx

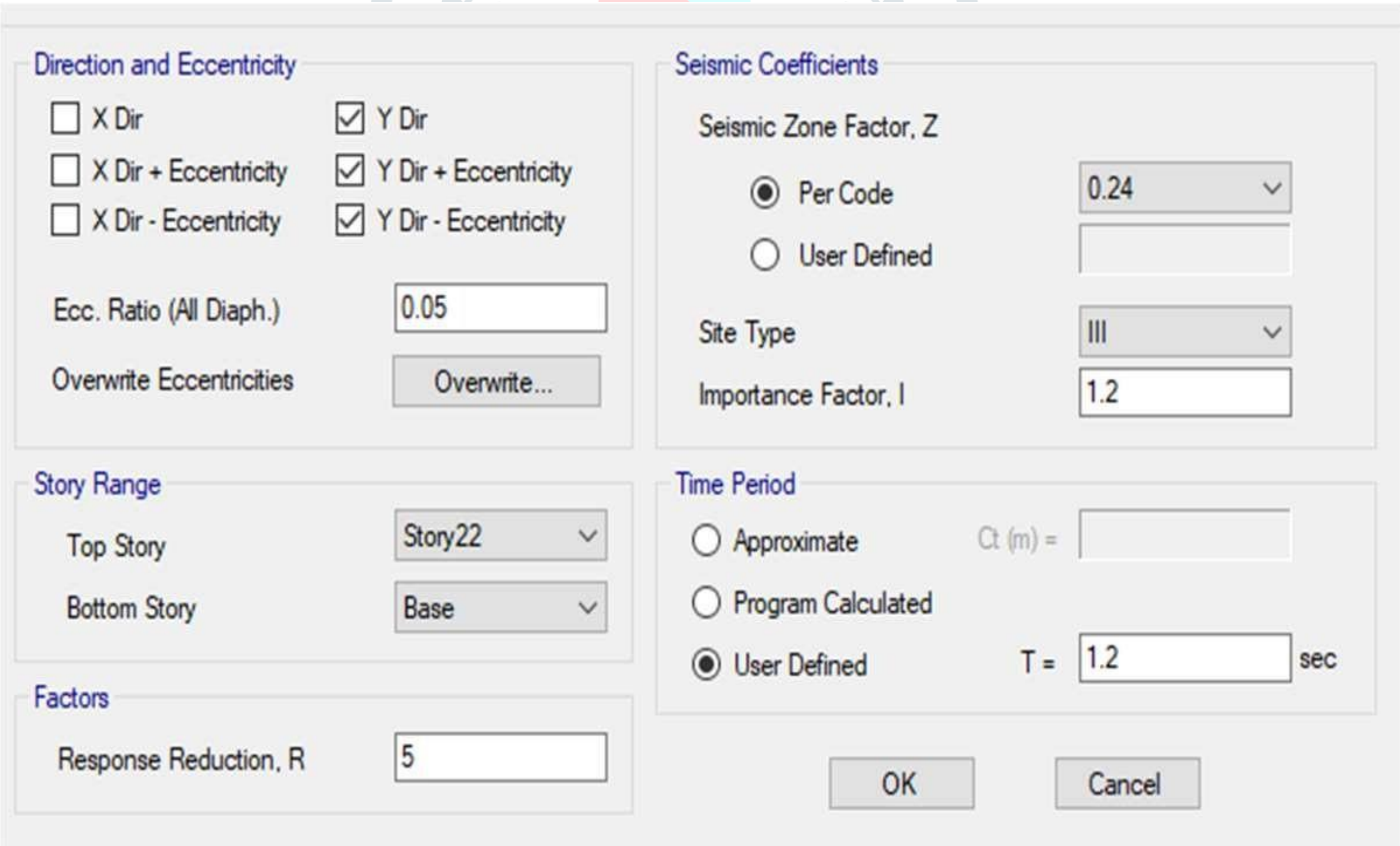
= 0.09 x 70.4/ √56

= 0.84 Sec



Earthquake Parameters in X-Direction

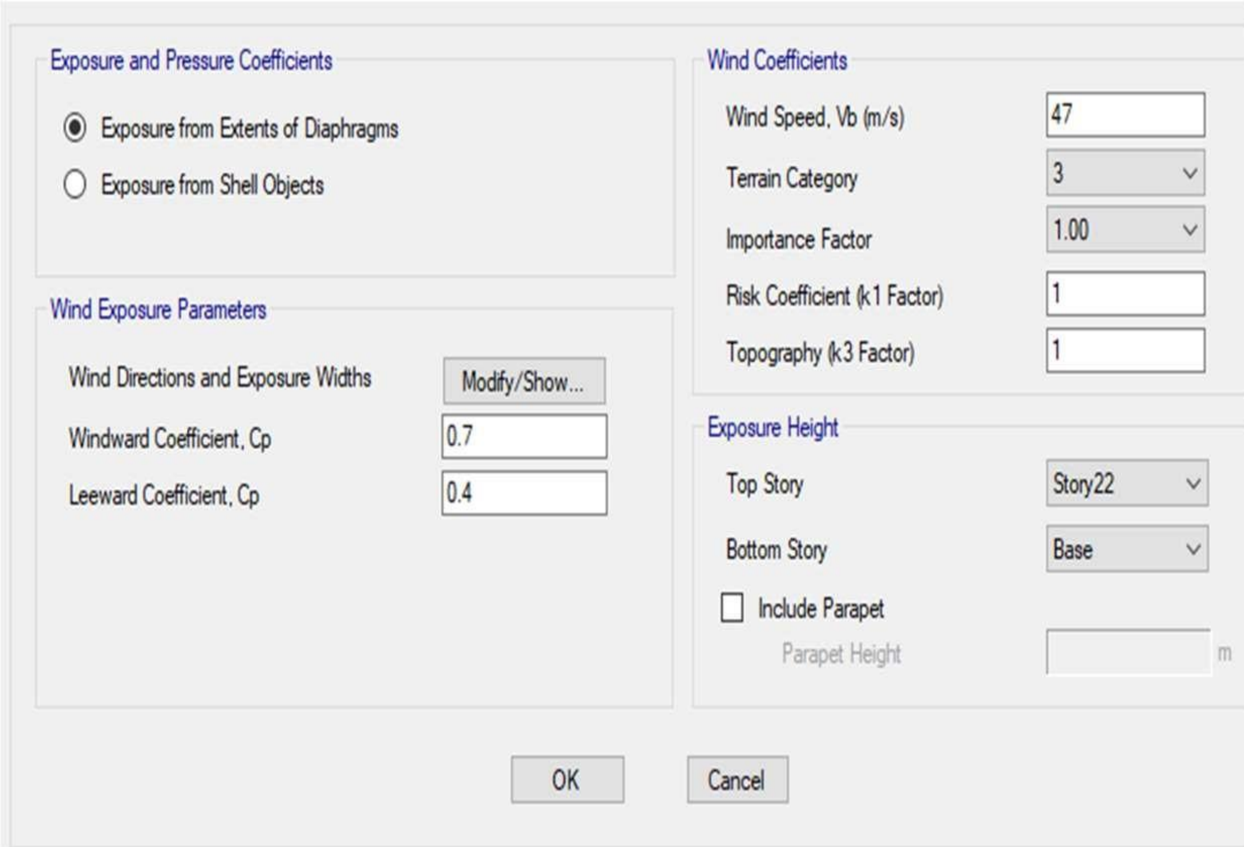
At Y Direction = 0.09h/√dy= 0.09 x 70.4/ √32 = 1.2 Sec



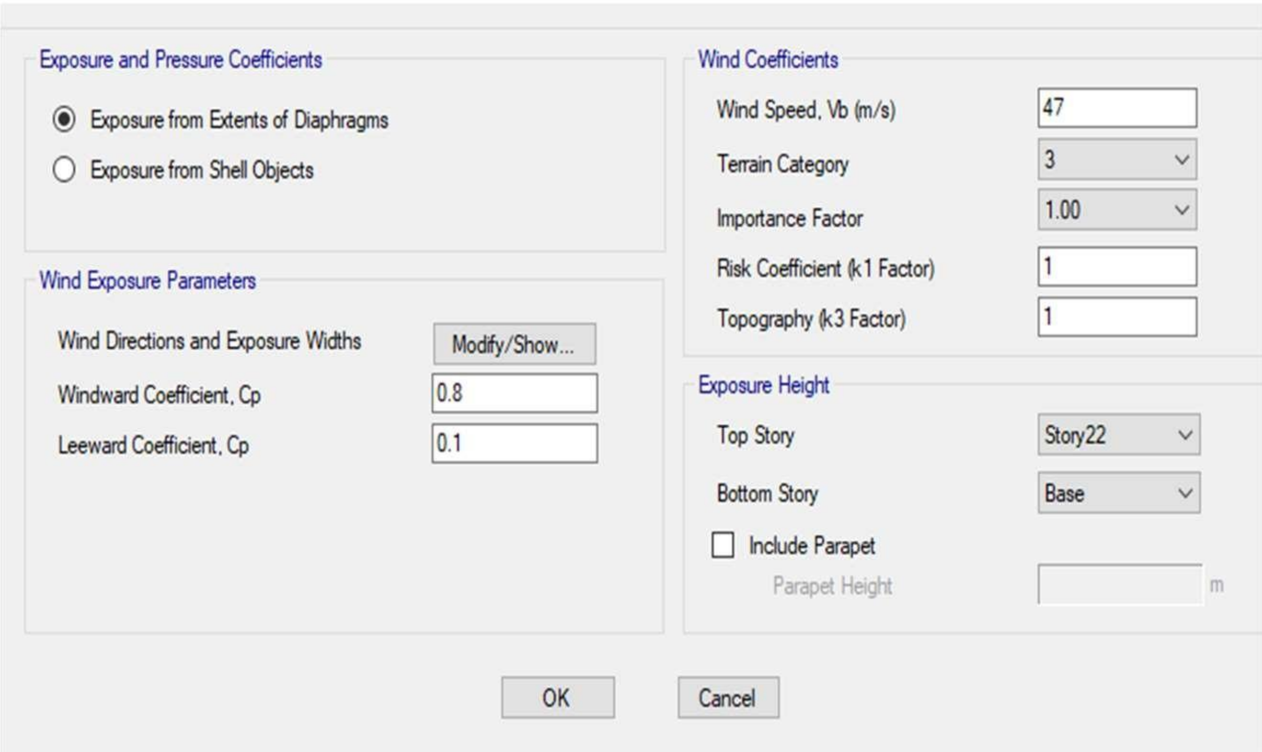
Earthquake Parameters in Y-Direction Percentage of imposed load to be considered in seismic weight calculation

25% for live load up to 3 KN/m2 (As per 1893 part 1 clause 7.3.1 table 10)

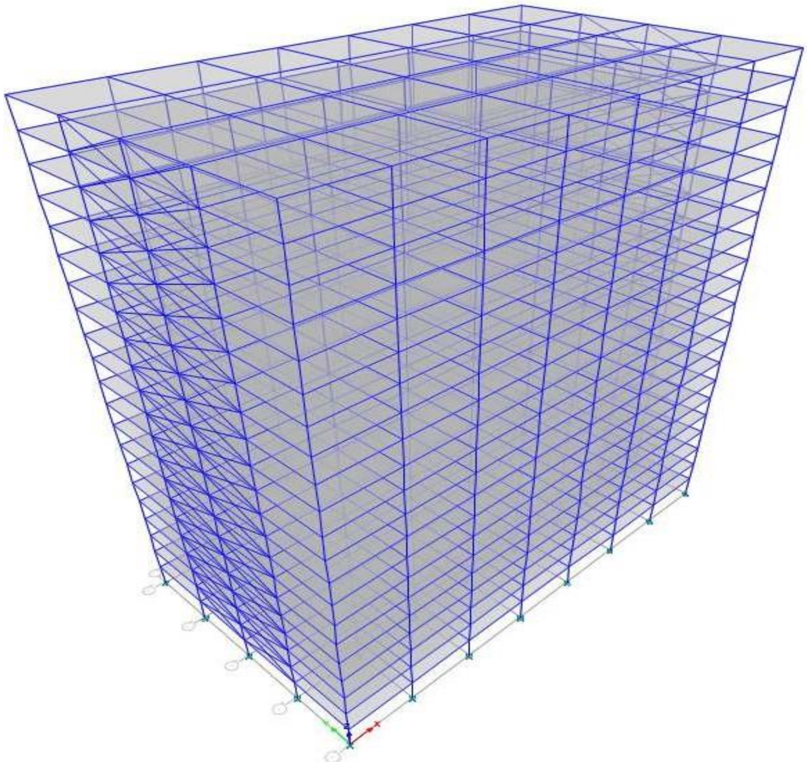
For time history analysis, Fast Nonlinear Analysis Method is used to get accurate results. San Francisco earthquake of 1989, also called Loma Prieta earthquake, major earthquake that struck the San Francisco Bay Area, California, U.S., on October 17, 1989, and caused 63 deaths, nearly 3,800 injuries, and an estimated $6 billion in property damage. It was the strongest earthquake to hit the area since the San Francisco earthquake of 1906. The earthquake was triggered by a slip along the San Andreas Fault. Its epicentre was in the Forest of Nisene Marks State Park, near Loma Prieta peak in the Santa Cruz mountains, northeast of Santa Cruz and approximately 60 miles (100 km) south of San Francisco. Ground motion data of Loma Prieta earthquake is taken which is having earthquake magnitude of 6.9 Mw a maximum Modified Mercalli intensity of IX



Wind Parameters in X-Direction



Wind Parameters in Y-Direction



MODULAR STRUCTURE WITH BRACINGS :

Structure Data

This chapter provides model geometry information, including items such as story levels, point coordinates, and element connectivity.

1.1 Story Data

Tower	Name	Height m	Master Story	Similar To	Splice Story	Splice Height m	Color
T1	Story22	3.2	Yes	None	No		Gray8Dark
T1	Story20	3.2	No	Story22	No		Red
T1	Story19	3.2	No	Story22	No		Yellow
T1	Story18	3.2	No	Story22	No		Blue
T1	Story17	3.2	No	Story22	No		Cyan
T1	Story16	3.2	No	Story22	No		Magenta
T1	Story15	3.2	No	Story22	No		Gray8Dark
T1	Story14	3.2	No	Story22	No		Green
T1	Story13	3.2	No	Story22	No		Red
T1	Story12	3.2	No	Story22	No		Yellow
T1	Story11	3.2	No	Story22	No		Blue
T1	Story10	3.2	No	Story22	No		Cyan
T1	Story9	3.2	No	Story22	No		Magenta
T1	Story8	3.2	No	Story22	No		Gray8Dark
T1	Story7	3.2	No	Story22	No		Green
T1	Story6	3.2	No	Story22	No		Red
T1	Story5	3.2	No	Story22	No		Yellow
T1	Story4	3.2	No	Story22	No		Blue
T1	Story3	3.2	No	Story22	No		Cyan
T1	Story2	3.2	No	Story22	No		Magenta
T1	Story1	3.2	No	Story22	No		Gray8Dark

Table 1.1 - Story Definition

Loads

This chapter provides loading information as applied to the model.

1.1.10Load Patterns

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
~LLRF	Yes	Other	0	
Dead	No	Dead	1	
EQX	No	Seismic	0	IS1893 2002
EQX(1/3)	Yes	Seismic	0	IS1893 2002
EQX(2/3)	Yes	Seismic	0	IS1893 2002
EQX(3/3)	Yes	Seismic	0	IS1893 2002
EQY	No	Seismic	0	IS1893 2002
EQY(1/3)	Yes	Seismic	0	IS1893 2002
EQY(2/3)	Yes	Seismic	0	IS1893 2002
EQY(3/3)	Yes	Seismic	0	IS1893 2002
Live	No	Live	0	
Wind X	No	Wind	0	Indian IS 875:2015

Table : load patterns

1.1 Calculated Base Shear

Direction	Period Used (sec)	W (kN)	V_b (kN)
X	0.847	458091.0805	26024.5082
X + Ecc. Y	0.847	458091.0805	26024.5082
X - Ecc. Y	0.847	458091.0805	26024.5082

Table : calculated base shear

1.2 applied Story Forces

Story	Elevation	X-Dir	Y-Dir
	m	kN	kN
Story22	67.2	3325.4325	0
Story20	64	3163.642	0
Story19	60.8	2855.1869	0
Story18	57.6	2562.5501	0
Story17	54.4	2285.7314	0
Story16	51.2	2024.7309	0
Story15	48	1779.5487	0
Story14	44.8	1550.1846	0
Story13	41.6	1336.6388	0
Story12	38.4	1138.9111	0
Story11	35.2	957.0017	0
Story10	32	790.9105	0
Story9	28.8	640.6375	0
Story8	25.6	506.1827	0
Story7	22.4	387.5462	0
Story6	19.2	284.7278	0
Story5	16	197.7276	0
Story4	12.8	126.5457	0
Story3	9.6	71.1819	0
Story2	6.4	31.6364	0
Story1	3.2	7.853	0
Base	0	0	0

Table : applied storey forces

1.3 Modal Results

Case	Mode	Period sec	Frequency cyc/sec	CircFreq rad/sec	Eigenvalue rad2/sec2
Modal	1	2.856	0.35	2.1999	4.8394
Modal	2	2.398	0.417	2.6201	6.8648
Modal	3	1.739	0.575	3.6126	13.0506
Modal	4	0.938	1.066	6.6999	44.8889
Modal	5	0.758	1.319	8.2899	68.7232
Modal	6	0.551	1.815	11.401	129.9828
Modal	7	0.544	1.839	11.5537	133.4877
Modal	8	0.41	2.438	15.3215	234.7478
Modal	9	0.377	2.655	16.6791	278.194
Modal	10	0.297	3.366	21.1517	447.3951
Modal	11	0.284	3.516	22.0907	487.998
Modal	12	0.282	3.542	22.2553	495.3001

Modal Periods And Frequencies

1.4 Modal Participating Mass Ratios

Case	Mode	Period sec	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ	SumRX
Modal	1	2.856	0.7975	0.0001	0	0.7975	0.0001	0	2.105E-05	0.1984	0.0003	2.105E-05
Modal	2	2.398	0.0001	0.7467	0	0.7976	0.7467	0	0.2136	3.316E-05	0.0326	0.2136
Modal	3	1.739	0.0002	0.032	0	0.7978	0.7787	0	0.0095	3.724E-05	0.7528	0.2231
Modal	4	0.938	0.0972	7.447E-06	0	0.8951	0.7787	0	2.93E-05	0.5223	0.0001	0.2231
Modal	5	0.758	9.055E-06	0.1389	0	0.8951	0.9176	0	0.5245	4.993E-05	0.0058	0.7477
Modal	6	0.551	0	0.0056	0	0.8951	0.9232	0	0.0215	9.256E-06	0.1389	0.7692
Modal	7	0.544	0.0348	5.643E-06	0	0.9299	0.9233	0	1.853E-05	0.0597	3.912E-05	0.7692
Modal	8	0.41	0	0.0371	0	0.9299	0.9604	0	0.0915	0	0.0012	0.8607
Modal	9	0.377	0.0187	0	0	0.9486	0.9604	0	0	0.0714	0	0.8607
Case	Mode	Period sec	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ	SumRX
Modal	10	0.297	2.662E-06	0.0008	0	0.9486	0.9611	0	0.0016	7.915E-06	0.0371	0.8623
Modal	11	0.284	8.496E-06	0.0147	0	0.9486	0.9758	0	0.0575	1.703E-05	3.54E-05	0.9198
Modal	12	0.282	0.0119	7.348E-06	0	0.9605	0.9759	0	3.393E-05	0.0272	3.377E-05	0.9198

Modal Participating Mass Ratios

SumRY	SumRZ
0.1984	0.0003
0.1984	0.0328
0.1985	0.7856
0.7208	0.7856
0.7208	0.7914
0.7208	0.9304
0.7805	0.9304
0.7805	0.9316
0.852	0.9316
0.852	0.9687
0.852	0.9688
0.8792	0.9688

Modal Load Participation Ratios

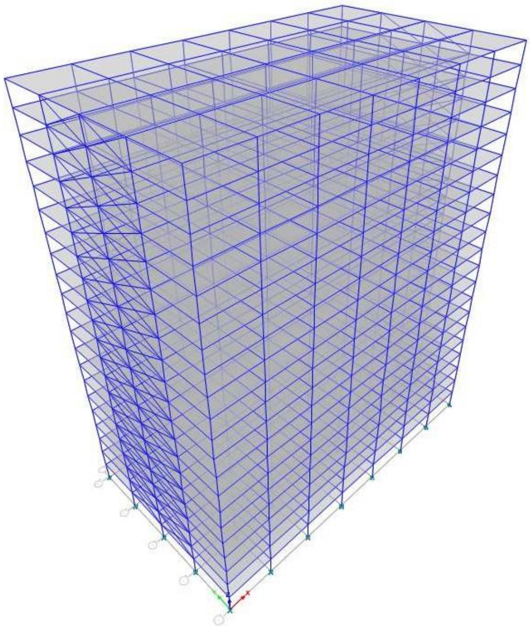
Case	ItemType	Item	Static %	Dynamic %
Modal	Acceleration	UX	99.99	96.05
Modal	Acceleration	UY	99.99	97.59
Modal	Acceleration	UZ	0	0

Modal Direction Factors

Case	Mode	Period sec	UX	UY	UZ	RZ
Modal	1	2.856	1	0	0	0
Modal	2	2.398	0	0.959	0	0.041
Modal	3	1.739	0	0.041	0	0.958
Modal	4	0.938	1	0	0	0
Modal	5	0.758	0	0.959	0	0.041
Modal	6	0.551	0.001	0.042	0	0.957
Modal	7	0.544	0.999	0	0	0.001
Modal	8	0.41	0	0.965	0	0.035
Modal	9	0.377	1	0	0	0
Modal	10	0.297	0.001	0.043	0	0.955
Modal	11	0.284	0.001	0.969	0	0.03
Modal	12	0.282	0.998	0.001	0	0.001

ETABS® version 18

MODULAR BUILDING WITH SHEAR WALLS :



Structure Data

This chapter provides model geometry information, including items such as story levels, point coordinates, and element connectivity.

1.1. Story Data

Tower	Name	Height m	Master Story	Similar To	Splice Story	Splice Height m	Color
T1	Story22	3.2	Yes	None	No		Gray8Dark
T1	Story20	3.2	No	Story22	No		Red
T1	Story19	3.2	No	Story22	No		Yellow
T1	Story18	3.2	No	Story22	No		Blue
T1	Story17	3.2	No	Story22	No		Cyan
T1	Story16	3.2	No	Story22	No		Magenta
T1	Story15	3.2	No	Story22	No		Gray8Dark
T1	Story14	3.2	No	Story22	No		Green
T1	Story13	3.2	No	Story22	No		Red
T1	Story12	3.2	No	Story22	No		Yellow
T1	Story11	3.2	No	Story22	No		Blue
T1	Story10	3.2	No	Story22	No		Cyan
T1	Story9	3.2	No	Story22	No		Magenta
T1	Story8	3.2	No	Story22	No		Gray8Dark
T1	Story7	3.2	No	Story22	No		Green
T1	Story6	3.2	No	Story22	No		Red
T1	Story5	3.2	No	Story22	No		Yellow
T1	Story4	3.2	No	Story22	No		Blue
T1	Story3	3.2	No	Story22	No		Cyan
T1	Story2	3.2	No	Story22	No		Magenta
T1	Story1	3.2	No	Story22	No		Gray8Dark

Table : Story Definations

1 Loads

This chapter provides loading information as applied to the model.

1.1 Load Patterns

IS1893 2002 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQX according to IS1893 2002, as calculated by ETABS.

Direction and Eccentricity

Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
~LLRF	Yes	Other	0	
Dead	No	Dead	1	
EQX	No	Seismic	0	IS1893 2002
EQX(1/3)	Yes	Seismic	0	IS1893 2002
EQX(2/3)	Yes	Seismic	0	IS1893 2002
EQX(3/3)	Yes	Seismic	0	IS1893 2002

1.1 Calculated Base Shear

IS1893 2002 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQY according to IS1893 2002, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
EQY	No	Seismic	0	IS1893 2002
EQY(1/3)	Yes	Seismic	0	IS1893 2002
EQY(2/3)	Yes	Seismic	0	IS1893 2002
EQY(3/3)	Yes	Seismic	0	IS1893 2002
Live	No	Live	0	
Wind X	No	Wind	0	Indian IS 875:2015
Wind Y	No	Wind	0	Indian IS 875:2015

Direction	Period Used (sec)	W (kN)	V_b (kN)
X + Ecc. Y	0.847	429233.201	24385.06988
X - Ecc. Y	0.847	429233.201	24385.06988

Direction	Period Used (sec)	W (kN)	Vb (kN)
X	0.847	429233.2018	24385.0698

1.2 Applied Story Forces

Story	Elevation	X-Dir	Y-Dir
	m	kN	kN
Story22	67.2	3084.2833	0
Story20	64	2968.7507	0
Story19	60.8	2679.2975	0
Story18	57.6	2404.6881	0
Story17	54.4	2144.9224	0
Story16	51.2	1900.0005	0
Story15	48	1669.9223	0
Story14	44.8	1454.6879	0
Story13	41.6	1254.2972	0
Story12	38.4	1068.7503	0
Story11	35.2	898.0471	0
Story10	32	742.1877	0
Story9	28.8	601.172	0
Story8	25.6	475.0001	0
Story7	22.4	363.672	0
Story6	19.2	267.1876	0
Story5	16	185.5469	0
Story4	12.8	118.75	0
Story3	9.6	66.7969	0
Story2	6.4	29.6875	0

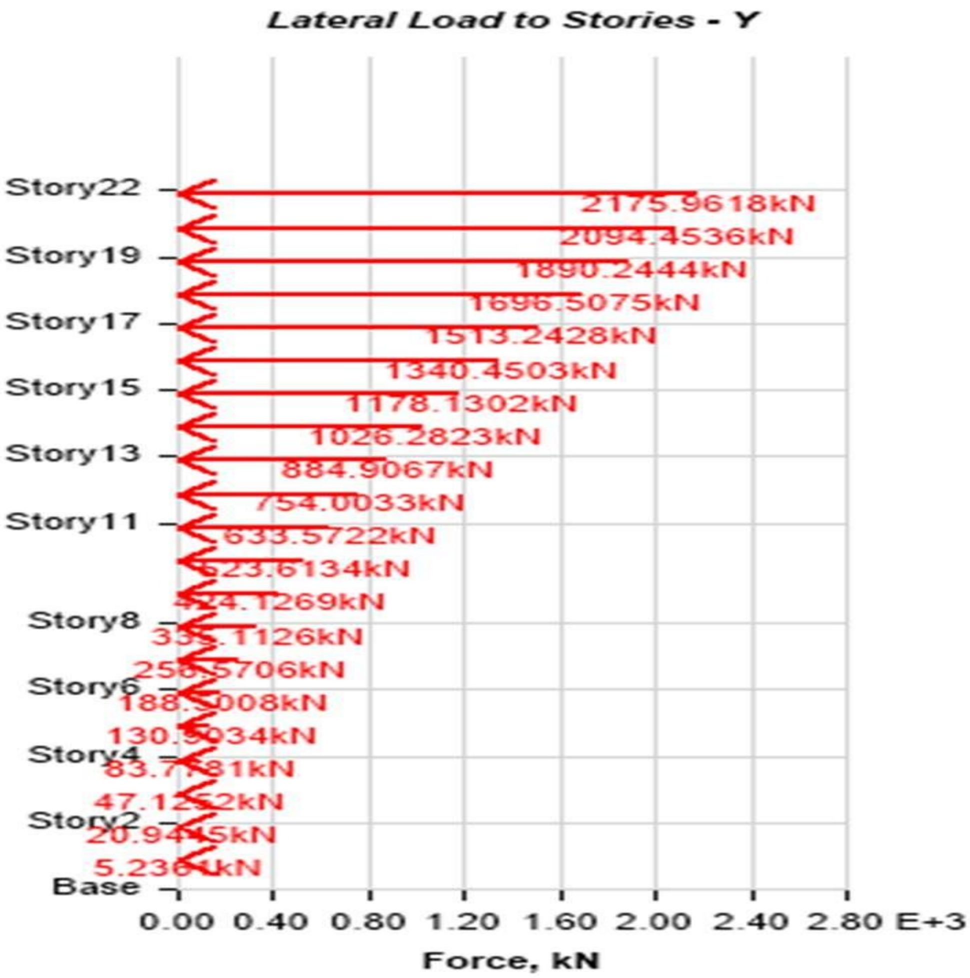
Story	Elevation	X-Dir	Y-Dir
	m	kN	kN
Story1	3.2	7.4219	0
Base	0	0	0

1.3 Calculated Base Shear

Direction	Period Used (sec)	W (kN)	V_b (kN)
Y	1.2	429233.2018	17203.6667
Y + Ecc. X	1.2	429233.2018	17203.6667
Y - Ecc. X	1.2	429233.201	17203.6667 8

1.4 Applied Story Forces

Story	Elevation	X-Dir	Y-Dir
	m	kN	kN
Story22	67.2	0	2175.9618
Story20	64	0	2094.4536
Story19	60.8	0	1890.2444
Story18	57.6	0	1696.5075
Story17	54.4	0	1513.2428
Story16	51.2	0	1340.4503
Story15	48	0	1178.1302
Story14	44.8	0	1026.2823
Story13	41.6	0	884.9067
Story12	38.4	0	754.0033
Story11	35.2	0	633.5722
Story10	32	0	523.6134
Story9	28.8	0	424.1269
Story8	25.6	0	335.1126
Story7	22.4	0	256.5706
Story6	19.2	0	188.5008
Story5	16	0	130.9034
Story4	12.8	0	83.7781
Story3	9.6	0	47.1252
Story2	6.4	0	20.9445
Story1	3.2	0	5.2361
Base	0	0	0



VI. Results and Discussions

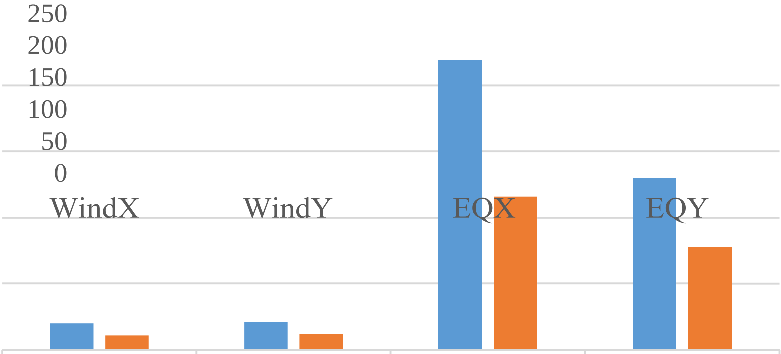
5.1 Results

5.1.1 Displacement:

Lateral displacement or sway is usually found when lateral load is applied to structure.
The lateral load may be seismic or wind load. Figure shows maximum displacement for earthquake zone V and wind speed 50 m/s. As per IS 1893:2016 and IS 875:2015
Part III, maximum allowable displacement for earthquake is H/250.

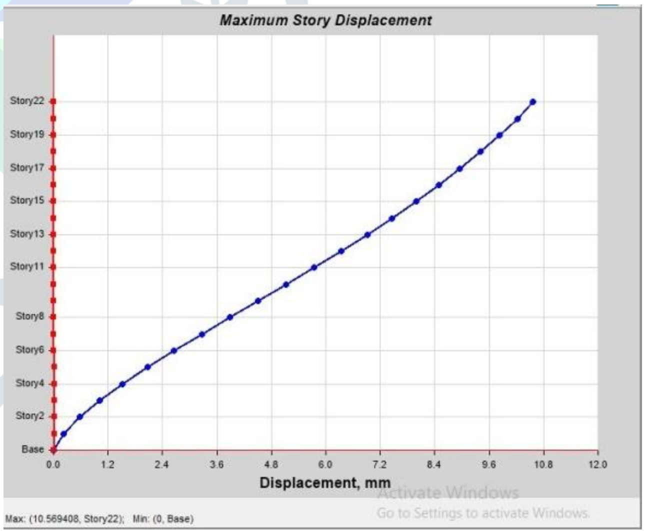
The maximum allowable displacement for G+20 building, in earthquake it will be 264.8mm and in wind 132mm. Figure shows the maximum displacement for dynamic analysis i.e. response spectrum analysis, modular building with bracings shows maximum displacement which is 218.91mm and 129.76mm in EQ-X and EQ-Y respectively. Maximum values in bracing modular building shows ductility and flexibility in building. Also, in case of wind forces, modular building with bracing shows maximum displacement which is around 35% more than the building with shear wall.

Above result shows that the behaviour of becomes more flexible when bracing system installed. Which absorbs more amount of energy as compare to normal system.



	WindX	WindY	EQX	EQY
Bracings Modular Structure	19.97	20.81	218.91	129.76
Shear Wall Modular Structure	**10.57**	**11.74**	**115.88**	**77.99**

Maximum horizontal displacement due to lateral force



5.1.2 Drift-

According to storey drift limitation given in IS 1893 (Part I): 2016 each storey drifts must be limited to 0.004 times the storey height. In case of building with base isolation system shows maximum drift at base of the structure but as height of building increases it shows reduction in drift values. For both X and Y direction earthquake, base isolator gives maximum drift at base, as shown in below graph, reduction in drift values can be observed. Also in below table, values of drift can be determining and observe the difference in drift values as storey increases.

Storey	Building with bracings		Building with shear wall	
	EQ-X	EQ-Y	EQ-X	EQ-Y
Terrace	0.0010	0.0014	0.0009	0.001
20	0.001	0.0021	0.0012	0.002

	6			
19	0.0021	0.0027	0.0016	0.002
18	0.0025	0.0032	0.0019	0.003
17	0.0029	0.0037	0.0022	0.003
16	0.0032	0.0040	0.0025	0.003
15	0.0035	0.0043	0.0028	0.004
14	0.0037	0.0046	0.0030	0.004
13	0.0039	0.0049	0.0032	0.004
12	0.0041	0.0051	0.0035	0.005
11	0.0043	0.0053	0.0036	0.005
10	0.0045	0.0056	0.0038	0.005
09	0.0047	0.0058	0.0040	0.005
08	0.0049	0.0059	0.0041	0.006
07	0.0050	0.0061	0.0043	0.006
06	0.0051	0.0063	0.0044	0.006
05	0.0053	0.0064	0.0046	0.006
04	0.0054	0.0066	0.0047	0.006
03	0.0056	0.0068	0.0049	0.007
02	0.0061	0.0073	0.0055	0.007
01	0.0068	0.0078	0.0076	0.010
Base	0.0023	0.0027	0.0092	0.011

5.1.3 Overturning Moment-

Overturning moment is the force on the structure which causes overturning of the whole structure. Torsion is induced due to high overturning moment. Overturning moment causes chances of failure of structure. Hence during lateral force applied on structure, a structural engineer should concern about the torsion caused by overturning. To avoid sudden collapse or failure of structure, IS code provided some criteria like modal mass participation, first three modes criteria, etc.

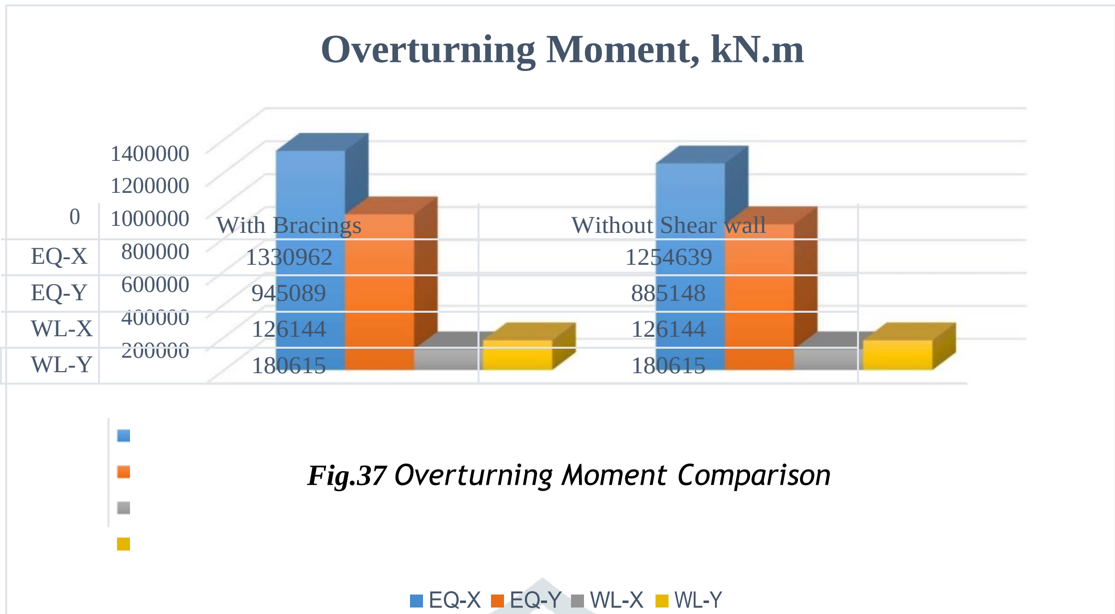


Fig.37 Overturning Moment Comparison

The location of center of mass and center of stiffness in the structure is very important in overturning moment. As the center of mass and center of stiffness far from each other, maximum will be the overturning moment so as torsional moment in the structure. To avoid higher torsional moment in the structure IS 1893:2016 (Part-I) has given certain calculation in clause 7.8. As per this clause, eccentricity between center of mass and center of stiffness shall be maintained. Also, some types of vertical irregularities also cause overturning moment in the structure.

5.1.4 Time Period and Modal Mass Participation-

Mode Number	With Bracings				With Shear wall			
	Time Period	UX	UY	RZ	Time Period	UX	UY	RZ
1	2.856	0.7975	0.0001	0.0003	1.953	0.1308	0.1567	0.4913
2	2.398	0.0001	0.7467	0.0326	1.896	0.5814	0.044	0.0995
3	1.739	0.0002	0.032	0.7528	1.574	0.0006	0.4922	0.2224

Time period play important role in earthquake resisting building design. It is the most important factor affecting seismic performance of building frame. Time period is nothing but the time taken by any structure to complete one cycle of motion. Time period is depending upon mass and stiffness of structure in which time period is directly proportional to mass and inversely proportional to the stiffness. Fundamental time period which is calculated by IS 1893-2016 and analytical time period calculated by any FEM based software, both shall be close enough to get the proper behavior of any structure. Modal mass is the total amount of mass participated in the earthquake activity.

5.1.5 Base shear:

Then, from base shear plots that were obtained after analysis for MRF building frame, modular buildings with bracings and shear wall, Base shear is the maximum lateral force at the base of the structure due to seismic/wind activities. Based on base shear value, behavior or responses of building can be determined. When base shear value is very high then the structure is either very heavy or very stiff. Based on some formulation, base shear which is earthquake force attracted by any structure can be calculated. Building weight, stiffness plays vital role in base shear and also in overall behavior of structure. Base shear of structure is directly proportional to the weight of the structure.

Percentage of earthquake force attracts by both buildings.

	With Bracings	With Shear wall
Base shear EQX (kN)	26024.5082	24385.0698
Base shear EQY (kN)	18360.2905	17203.6667
Dead Load (kN)	440138.8255	412943.2528
Live Load (kN)	75264	69888
% of earthquake (EQX)	5.6	5.313
% of earthquake (EQY)	4.0	3.75
	With Bracing	With Shear wall
Base shear WLX (kN)	3399.6438	3399.6438
Base shear WLY (kN)	4867.6718	4867.6718

table: base shear in Structure Due to Wind

From table, it is observed that the earthquake percentage is reducing due to shear wall hance the reduction in base shear, as explained above if the value of base shear is less then the structure is more flexible, ductile. Also, more flexible building causes proper behavior of building during any lateral force application. From above table, it is observed that around 10 to 15% earthquake get reduced. Base shear due to wind forces does not show any variation, hence for wind forces, it can be assumed that the base isolation system will become more effective as the building height get increased.

5.2 *Discussion*

After carrying out the dynamic analysis for modular structure with shear wall and bracings, the results obtained are compared & discussed here.

i. One of the main criteria for modular structure with bracings is that the time period of structure should be at least three times higher than that of a shear wall modular building.

ii. From the results available in Table 7.1 we can clearly see that the time period for a bracing modular structure is higher than that of a shear wall modular structure.

IS 1893-2002 Part I specifies that the number of modes to be used in the analysis should be such that the sum total of modal masses of all the modes considered is at least 90 % of the total seismic mass and missing mass correction beyond 33 %.

In Table 7.2 we can see that the mass participation of 90 % as per IS -1893 takes part in the 7th mode in modular building with bracings but modular building with shear wall 90% model mass is participating in 9th mode.

Mode	Period	UX	UY	SumUX	SumUY	RZ
	sec					
1	1.953	0.1308	0.1567	0.1308	0.1567	0.4913
2	1.896	0.5814	0.044	0.7122	0.2007	0.0995
3	1.574	0.0006	0.4922	0.7127	0.6929	0.2224
4	0.638	0.001	0.0187	0.7138	0.7116	0.0773
5	0.526	0.1523	0.0003	0.8661	0.7118	0.0006
6	0.423	0.000006045	0.1538	0.8661	0.8656	0.02
7	0.384	0.0002	0.0148	0.8663	0.8804	0.0238
8	0.278	0	0.0007	0.8663	0.8811	0.0168
9	0.258	0.0581	0.00002854	0.9243	0.8811	0.00003307
10	0.219	0.00001673	0.0142	0.9244	0.8953	0.0049

Modal Mass Participation for Modular Building with Shear wall

Displacement in modular building with bracings and shear wall has drastic difference. Modular building with bracings shows maximum displacement at the top which shows the ductile and flexible behavior of building. If observe displacement table it is clear that the 30 to 35% displacement increased in building with bracings as compared to building with shear wall.

Flexible and ductile behavior of building can also be observed by values of time period in both the structures. There is increase in time period in bracing modular building, which makes building flexible and ductile, also might reduce the reinforcement requirement in structure. Since, the bracings absorbed most of lateral forces, building shows appropriate modes with good mass participation.

From observation of drift table, it can said that at the base of structure with bracings drift values are maximum but as the storey increased in structure drift shows declination, which shows that bracings absorbs lateral forces at the base and behaves accordingly, but transfer less forces at top. From drift table, around 25-35% drift reduced at top storey of structure.

Base shear and overturning moment in both the structure shows drastic difference. In case of earthquake force, base shear is reduced about 10-15% but in case of wind force base shear reduction is negligible which is due to application of wind load is from ground of structure. From table of base shear, it is observed that the values of earthquake percentage getting reduced when shear wall is applied to the structure.

Overturning moment is the factor which plays important role in inducing torsion in the building. When shear wall is applied to the structure, torsion in the structure is reduced which can be observed in table of modal mass participation values. Since, the building is regular and almost symmetric, values of torsion reduction doesn’t shows much variation. Still around 15- 20% reduction in overturning moment is shown due to shear wall application.

VII. CONCLUSIONS

On the basis of present study and reviewed literature the following conclusions can be drawn:

1. Around 30 to 35% displacement increased in building with bracings as compared to building with shear wall. Flexible and ductile behavior of building can also be observed by values of time period in both the structures. Building with bracings show more ductile and flexible behavior than the building with shear wall. The ductility of the corner columns is also a critical criterion to maintain in order to achieve a better performance under high seismic loads. Although yielding may occur, high ductile columns may still prevent collapse and assist the horizontal members to redistribute the loads.
2. At base of structure with bracings drift values are maximum but as the storey increased in structure drift shows declination, which shows that bracings absorb lateral forces at the base and behaves accordingly, but transfer less forces at top.
3. Modular building with bracings shows better lateral resistance and ductility than the building with shear wall.
4. Bracings act as the key connections in which the columns are vertically connected. Therefore, these connections need to be designed to take the full shear force of the lateral loads.
5. Base shear and overturning moment in both the structure shows drastic difference. In case of earthquake force, base shear is reduced about 10-15% but in case of wind force base shear reduction is negligible which is due to application of wind load is from ground of structure.
6. Finally, it is concluded that the modular buildings with bracings and shear wall has their own advantages but the bracings modular building found to be more stable in case of earthquake resistance.

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