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Analysis of Tall Structure Considering Soft Storey Under Dynamic Loading using ETABS

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ABSTRACT

There has been a steady rise in urbanisation in the last few years which has led to major issues in parking vehicles and made the street busy. Such cases have led engineers to plan parking spaces even on the first floor for the purpose of parking. Structures with RC frames with the open ground floor without infill are subjected to heavy lateral loads and prove to fail in case of heavy earthquake loads. When masonry infill interacts with its surrounding frames, the lateral stiffness and lateral load-carrying capacity of the structure significantly increase. The presence of masonry infill walls affects how the structure behaves overall when subjected to lateral forces. Earthquakes that occurred recently have shown that a large number of existing reinforced concrete buildings especially soft storey building are vulnerable to damage or even collapse during a strong earthquake. The building's first floor exhibited soft behaviour, and the earthquake prevented the columns from offering enough shear strength.

This research is carried out with various building models such as soft storey structure with and without steel bracings. In the second case the steel bracing is provided at the center of the structure. The study uses ETABS software to analyse a soft storey structure using the pushover analysis method, and it must provide the results and analysis's conclusion.

Keywords : Soft Storey Building, Cross Bracings, Strength Factor, Response Reduction Factor.

I. INTRODUCTION

In the most recent earthquakes, several buildings with parking lots or commercial spaces on the first storeys sustained severe structural damage and collapsed. Soft stories and resulting damage are caused by large open spaces, a lack of infill and exterior barriers, and greater floor levels at the bottom level. The lateral load resisting systems in such buildings are far less stiff at such storeys than they are at stories above or below. If there are unusual inter-story drifts between neighbouring stories during an earthquake, the lateral stresses will not be evenly distributed throughout the structure's height. Due to this circumstance, the lateral pressures are focused on the story or stories with the largest displacement (s). Additionally, due to the high level of load deformation (P-Δ), if the local ductility requirements are not met in the design of such a building structure for that storey and the inter-storey drifts are not controlled, a local failure mechanism or, worse yet, a storey failure mechanism could form, which could cause the system to collapse.

Lateral displacements calculated during the elastic design process can also provide very important information regarding the structural behaviour of the device codes outline smooth storey irregularity by stiffness contrast of adjoining floors, displacement-based criteria for such irregularity determination, and so on. If the P-Δ impact is thought to be the primary cause of the dynamic fall apart of building structures during earthquakes, it should be determined that this is the case.

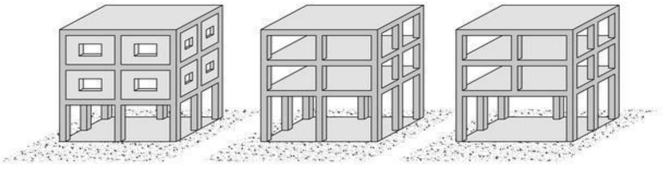
Earthquake is generated in the earth's crust. It will be for a short period of a few seconds or a minute. The main loads which we get through gravity effect are Dead load and Live load. Apart from these two types of loads there is a lateral load which is produced by seismic effect and also known as Earthquake load and wind load. Sometimes Earthquake will cause a large loss to the human beings but sometimes will be a minor attack, inspite of knowing that buildings are destroyed due to seismic effect still the buildings are constructed such that the basements are kept open without any walls or any other strengthening material.

Requirements of Structural Elements in High Rise Building

Wind and seismic forces acting on high-rise buildings become a significant design consideration. Tall building structural systems can be enhanced to regulate dynamic response by employing more appropriate structural elements such as shear walls and tube structures, as well as enhancing material qualities; the maximum height of concrete buildings has risen substantially in recent decades. Shear walls' edges are subjected to severe compressive and tensile stresses as a result of the massive overturning effects induced by horizontal Earthquake forces. Concrete at the wall end areas must be strengthened in a specific way to survive these load reversals without losing strength in order for shear walls to behave ductilely. Boundary elements are wall end sections with enhanced confinement. The boundary elements' specific restricting transverse reinforcement is comparable to that found in reinforced concrete frame columns. The thickness of the shear wall in these boundary elements is sometimes raised as well.

Soft Storey Structure

A soft storey building is typically an apartment or commercial structure with open space on the ground level, which is typically used for parking. A multi-story building with broad doors and commercial rooms on the ground floor is referred to as a soft storey building. a structure where the softest floor is less than 70% as stiff as the floor directly above it or less than 80% as stiff as the three floors above it on average. The storey when the ground storeys are left open is known as a soft storey. These storeys are the weakest storey when compared to the other storey. These ground storeys are meant for parking facility purpose or for shops etc. In soft storey building there are various types of failure. Soft storey at the basement is the main reason for the failure of the building this is also known as soft storey failure.



(a) Stiff and strong upper floors due to masonry infills

(b) The columns in one storey longer than those above

(c) Soft storey caused by discontinuous column

Fig 1 Soft Storey Structure

II. Literature Survey

Mariem M. Abd-Alghany et.al (2021) Using the finite element method, a research report examined the seismic performance of RC buildings with soft storeys. The height of the soft storey, the irregularity in the building plan dimensions, and the placement of the soft storey along the building height were all taken into consideration in this study. An attempt was made to find the optimum location of the soft storey through the building height to minimize its effect. In addition, the impact of applying simple strengthening techniques was investigated to promote structural safety without significant changes in the architectural and functional requirements of the building. The results included the effect of the investigated parameters on stiffness, displacement and storey drifts by using equivalent static load method and modal response spectrum method (MRS). P-Delta effect and cracked stiffness ratio are included in analysis.

Results stated that shear walls are found to be very effective in improving the stiffness irregularity and decreasing the displacement and drift. For example, after adding a shear wall with increasing soft storey height, the displacement decreases by 46%. while the drift decreases by 60% at soft storey height equal to 6 m as compared to MRF system. Despite adding the shear wall, the effect of the soft storey is still present when soft storey height is greater than twice the height of typical floor. Cross bracing is found to be very effective and economical technique for retrofitting building with soft storey and reducing the stiffness irregularity. Determining the position and ratio of bracing is very important to improve the seismic performance of RC building with soft floor. On the other hand, adding the bracing only at soft storey is the best solution to reduce the soft storey irregularity. Adding cross bracing, the effect of soft storey was greatly reduced in most study groups despite increasing displacement and drifts.

Nilesh Bharat Vidhate and G. A. Sayyed (2021) research paper investigated the nonlinear behaviour and design of mid-to-high-rise RCC diagrid structures using ETABS with respect to different parameters such as storey drift, storey displacement, base shear and analyze demand capacity curve of diagrid structure and conventional with pushover analysis. Three G+7, G+11, G+16 diagrid building models for RCC were created and analyzed in ETABs software for different positions of shear wall in zone V with subsoil Type medium -II. To confirm seismic activity with the same storey and storey height, both of the buildings were subjected to the same earthquake packing.

The analysis concluded that the diagrid structure was more economical than normal structures up to the 11th floor, but G+16 less economical than the G+7 and G+11 structures. The diagrid structure has a greater capacity resisting force than the normal structure.

Objectives of the research

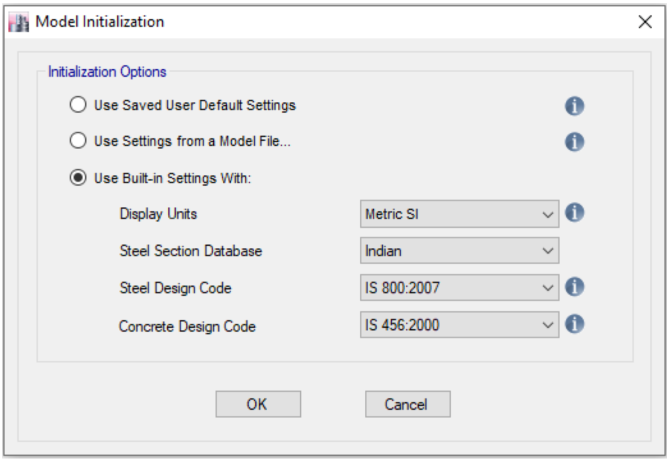
The primary objectives of the research are stated below

- to investigate the behaviour of different forms of open-storey buildings that have the ground and first floors in seismically active areas.
- to design an IS 1893:2002 compliant 3D G+10 storey Ordinary Moment Resisting Frame construction with various combinations (Soft storey structure without Bracing and Soft Storey Structure with Bracing at centre).
- Analyse the different model by using Etabs software.
- Perform Equivalent Static Analysis Method.
- Results are discussed in terms of lateral forces, storey displacements, storey drifts, storey shear, and overturning moment and storey stiffness.
- Comparison of the parametric results of different types of models are done.

Steps of Analysis

Step 1: Soft storey is visible in structures in order to create open space in form of parking or some commercial area in structures. First step of any research demand review of such similar research in order to identify the scope of the research. While reviewing different research on similar stream, it was identified that their a need of further research on identifying the behaviour of soft storey structures when subjected to earthquake loading.

Step 2: ETABS is a component of engineering software that handles the analysis and design of multi-story buildings. The grid-like geometry specific to this form of construction is taken into account via modelling tools and templates, code-based load prescriptions, analysis techniques, and solution approaches. Choosing a scale for model initialization is the first stage in the modelling process. Here the display units are considered in Metric SI, steel design code is considered as per IS 800:2007 and concrete design code as per IS 456:2000.


Model Initialization

Initialization Options

○ Use Saved User Default Settings

○ Use Settings from a Model File...

● Use Built-in Settings With:

Display Units: Metric SI

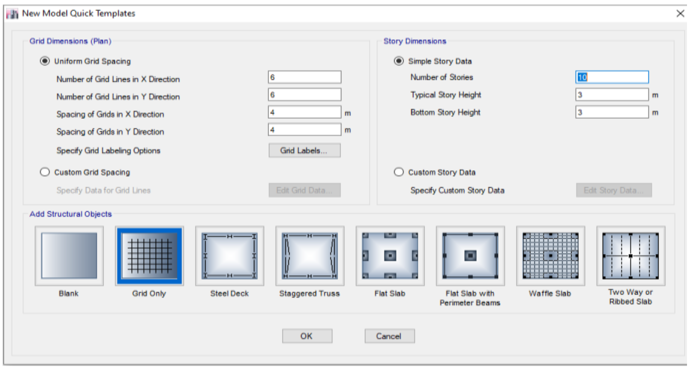
Steel Section Database: Indian

Steel Design Code: IS 800:2007

Concrete Design Code: IS 456:2000

Fig 2 Model Initialization

Step 3: ETABS provide an option of quick template where the grid system is defined as per the structure requirements and further it can be customised as per the needs. The grids are defined in X and Y direction and the storey height is considered in Z direction.


New Model Quick Templates

Grid Dimensions (Plan)

● Uniform Grid Spacing

Number of Grid Lines in X Direction: 6

Number of Grid Lines in Y Direction: 6

Spacing of Grids in X Direction: 4 m

Spacing of Grids in Y Direction: 4 m

○ Custom Grid Spacing

Story Dimensions

● Simple Story Data

Number of Stories: 10

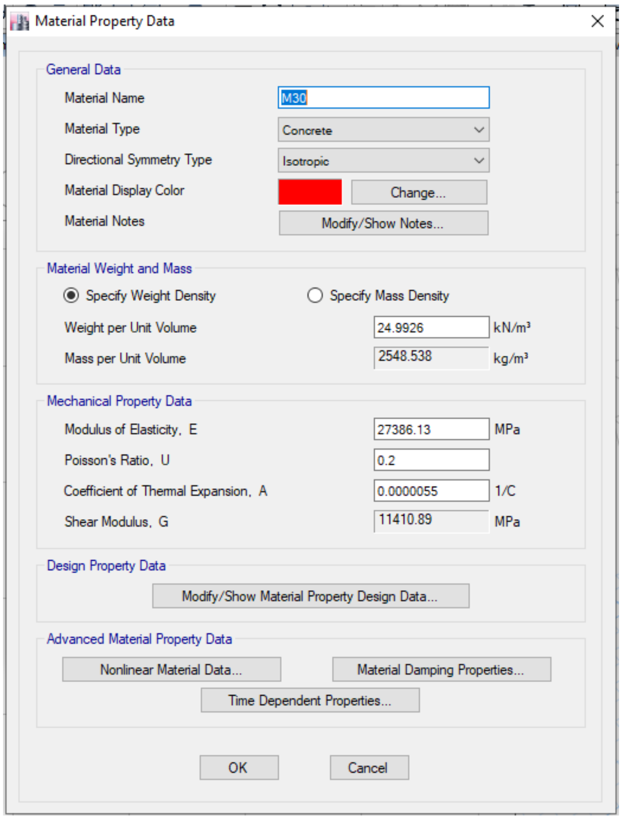
Typical Story Height: 3 m

Bottom Story Height: 3 m

○ Custom Story Data

Fig 3 Model Templates

Step 4: Defining material properties for steel and concrete. ETABS provide predefined data for the material properties as per Indian standard. Here M30 concrete is considered where the material properties are mentioned in the figure below.


Material Property Data

General Data

Material Name: M30

Material Type: Concrete

Directional Symmetry Type: Isotropic

Material Display Color: 🟥

Material Weight and Mass

● Specify Weight Density ○ Specify Mass Density

Weight per Unit Volume: 24.9926 kN/m³

Mass per Unit Volume: 2548.538 kg/m³

Mechanical Property Data

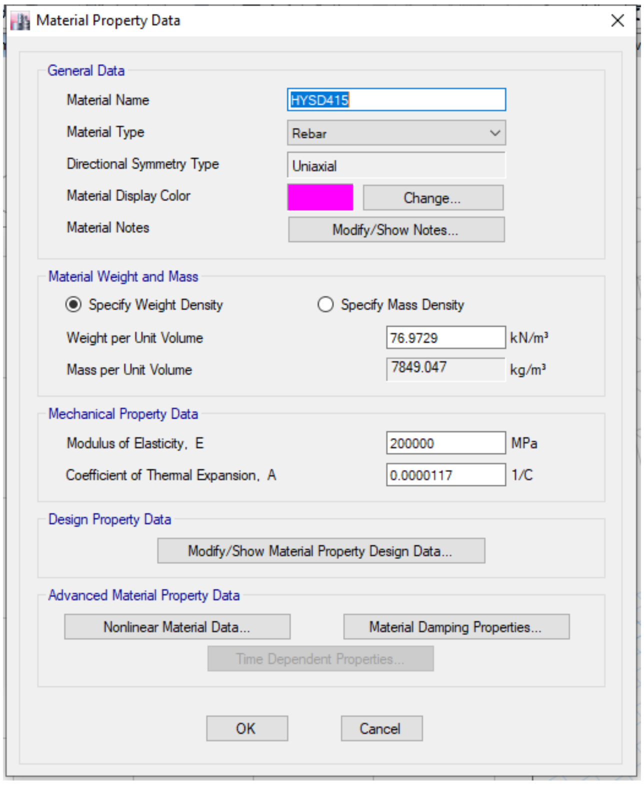
Modulus of Elasticity, E: 27386.13 MPa

Poisson's Ratio, U: 0.2

Coefficient of Thermal Expansion, A: 0.0000055 1/C

Shear Modulus, G: 11410.89 MPa

Fig 4 Defining properties of concrete


Material Property Data

General Data
Material Name: HYSD415
Material Type: Rebar
Directional Symmetry Type: Uniaxial
Material Display Color: 🟪 Change...
Material Notes: Modify/Show Notes...

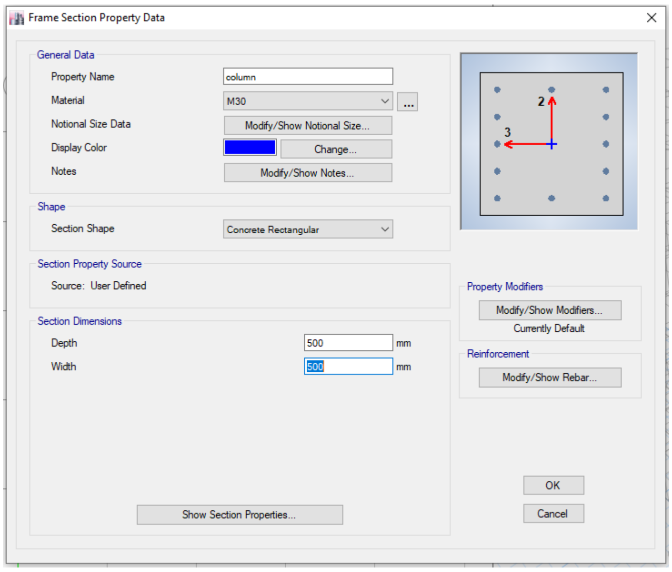
Material Weight and Mass
● Specify Weight Density ○ Specify Mass Density
Weight per Unit Volume: 76.9729 kN/m³
Mass per Unit Volume: 7849.047 kg/m³

Mechanical Property Data
Modulus of Elasticity, E: 200000 MPa
Coefficient of Thermal Expansion, A: 0.0000117 1/C

Design Property Data

Fig 5 Defining material properties of Rebar

Step 5: This step involved defining section properties for column, beam and slab and as bracing system are installed in a soft storey structure so the properties of bracing system section are further defined.


Frame Section Property Data

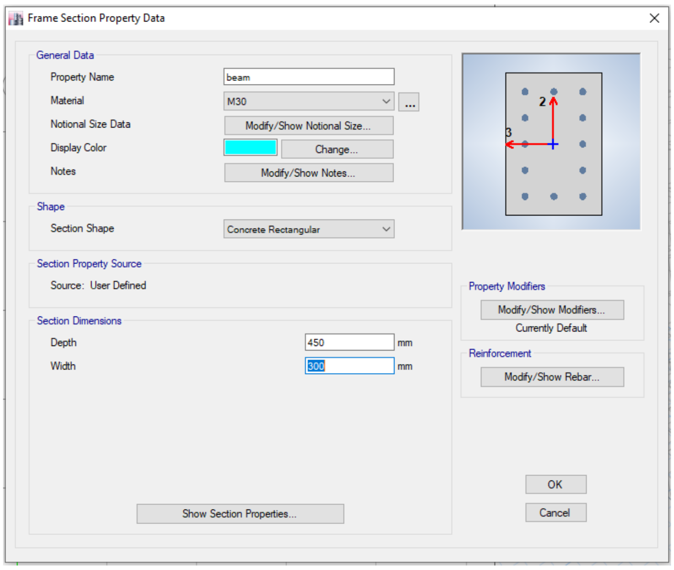
General Data
Property Name: column
Material: M30
Notional Size Data: Modify/Show Notional Size...
Display Color: 🟦 Change...
Notes: Modify/Show Notes...

Shape
Section Shape: Concrete Rectangular

Section Property Source
Source: User Defined

Section Dimensions
Depth: 500 mm
Width: 500 mm

Fig 6 Defining section properties for column


Frame Section Property Data

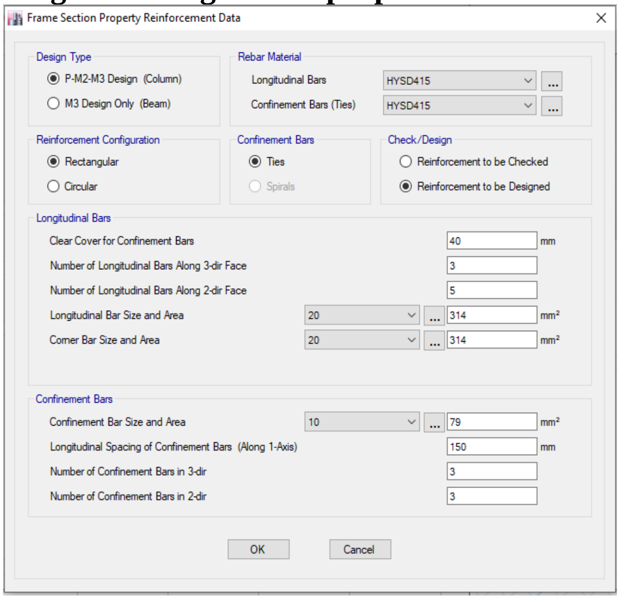
General Data
Property Name: beam
Material: M30
Notional Size Data: Modify/Show Notional Size...
Display Color: Change...
Notes: Modify/Show Notes...

Shape
Section Shape: Concrete Rectangular

Section Property Source
Source: User Defined

Section Dimensions
Depth: 450 mm
Width: 300 mm

Fig 7 Defining section properties for beam


Frame Section Property Reinforcement Data

Design Type
● P-M2-M3 Design (Column)
○ M3 Design Only (Beam)

Rebar Material
Longitudinal Bars: HYSD415
Confinement Bars (Ties): HYSD415

Reinforcement Configuration
● Rectangular
○ Circular

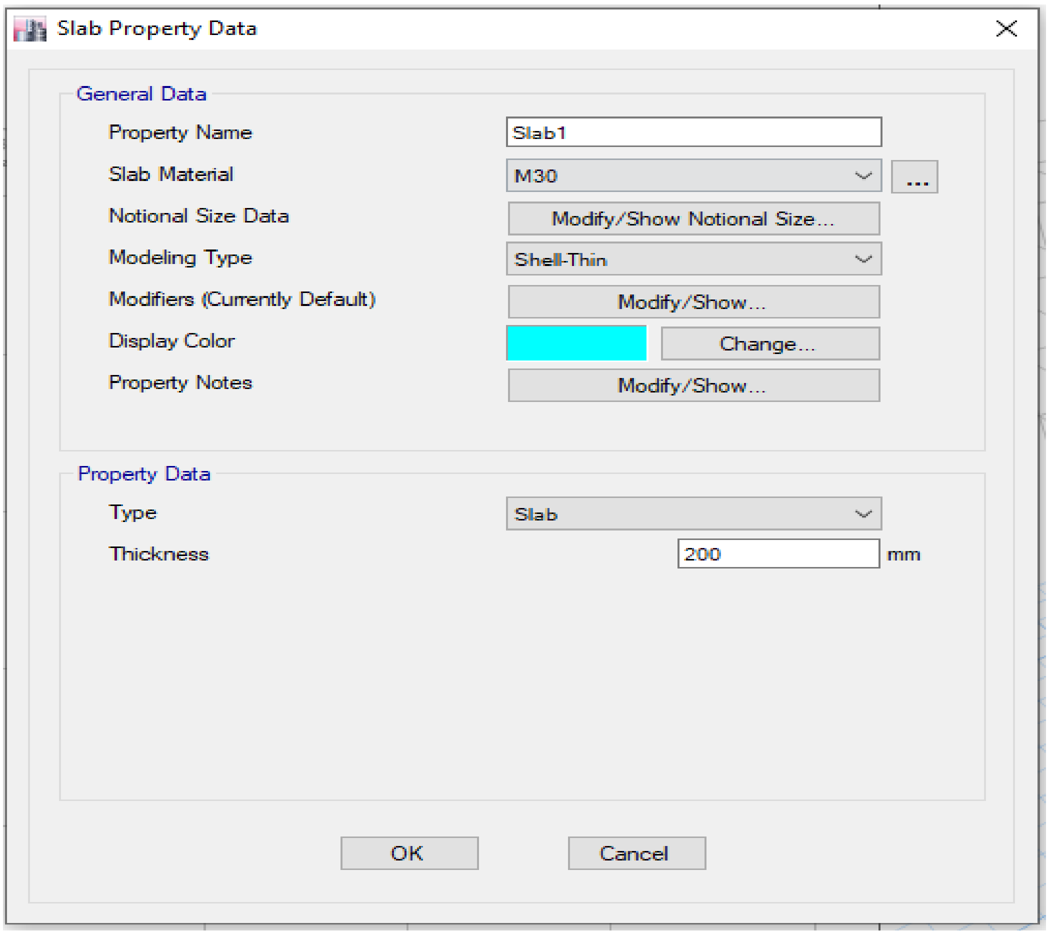
Confinement Bars
● Ties
○ Spirals

Check/Design
○ Reinforcement to be Checked
● Reinforcement to be Designed

Longitudinal Bars
Clear Cover for Confinement Bars: 40 mm
Number of Longitudinal Bars Along 3-dir Face: 3
Number of Longitudinal Bars Along 2-dir Face: 5
Longitudinal Bar Size and Area: 20, 314 mm²
Corner Bar Size and Area: 20, 314 mm²

Confinement Bars
Confinement Bar Size and Area: 10, 79 mm²
Longitudinal Spacing of Confinement Bars (Along 1-Axis): 150 mm
Number of Confinement Bars in 3-dir: 3
Number of Confinement Bars in 2-dir: 3

Fig 8 Frame Section Reinforcement Data



Property Name Slab1

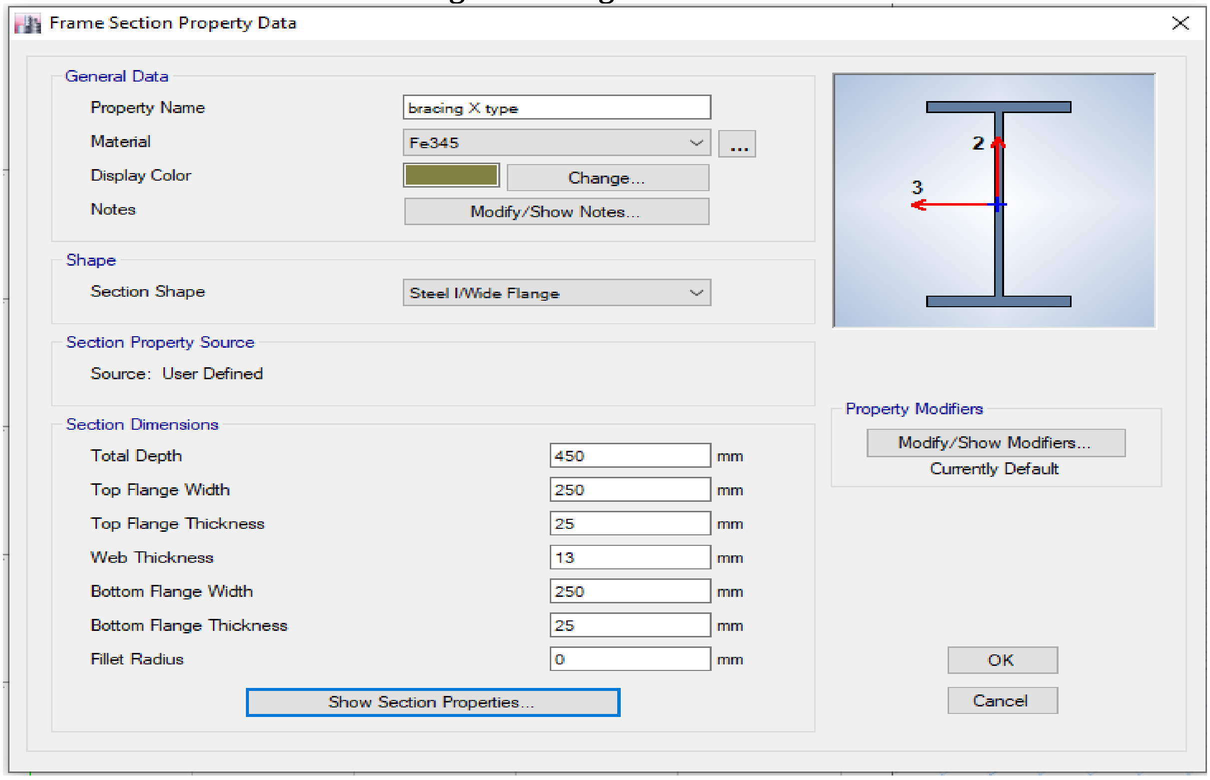
Slab Material M30

Modeling Type Shell-Thin

Type Slab

Thickness 200 mm

Fig 9 Defining Slab Section



Property Name bracing X type

Material Fe345

Section Shape Steel I/Wide Flange

Source: User Defined

Total Depth 450 mm

Top Flange Width 250 mm

Top Flange Thickness 25 mm

Web Thickness 13 mm

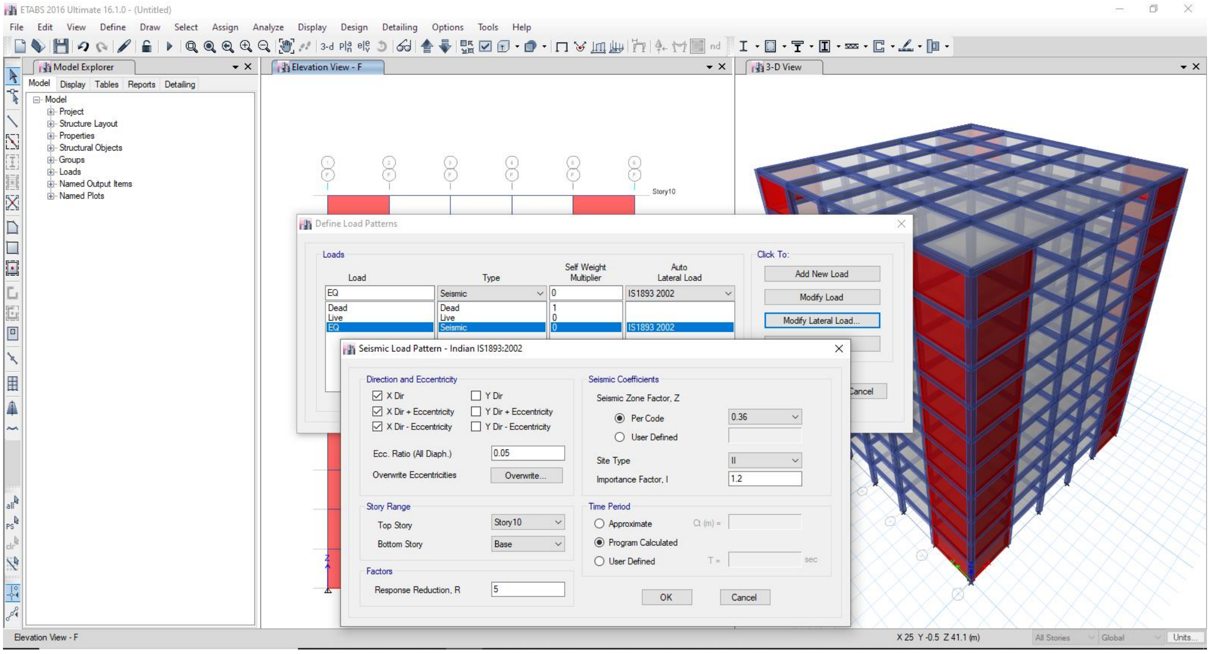
Bottom Flange Width 250 mm

Bottom Flange Thickness 25 mm

Fillet Radius 0 mm

Fig 10 Defining Frame Section for X Bracing

Step 6 Defining load pattern for dead, live load and seismic load.



Define Load Patterns

Loads

Load	Type	Self Weight Multiplier	Auto Lateral Load
EQ	Seismic	0	IS1893 2002
Dead	Dead	1	
Live	Live	0	
EQ	Seismic	0	IS1893 2002

Seismic Load Pattern - Indian IS1893:2002

Direction and Eccentricity

☑ X Dir ☐ Y Dir
☑ X Dir + Eccentricity ☐ Y Dir + Eccentricity
☑ X Dir - Eccentricity ☐ Y Dir - Eccentricity

Ecc. Ratio (All Diaph.) 0.05

Overwrite Eccentricities Overwrite...

Story Range

Top Story Story10
Bottom Story Base

Factors

Response Reduction, R 5

Seismic Coefficients

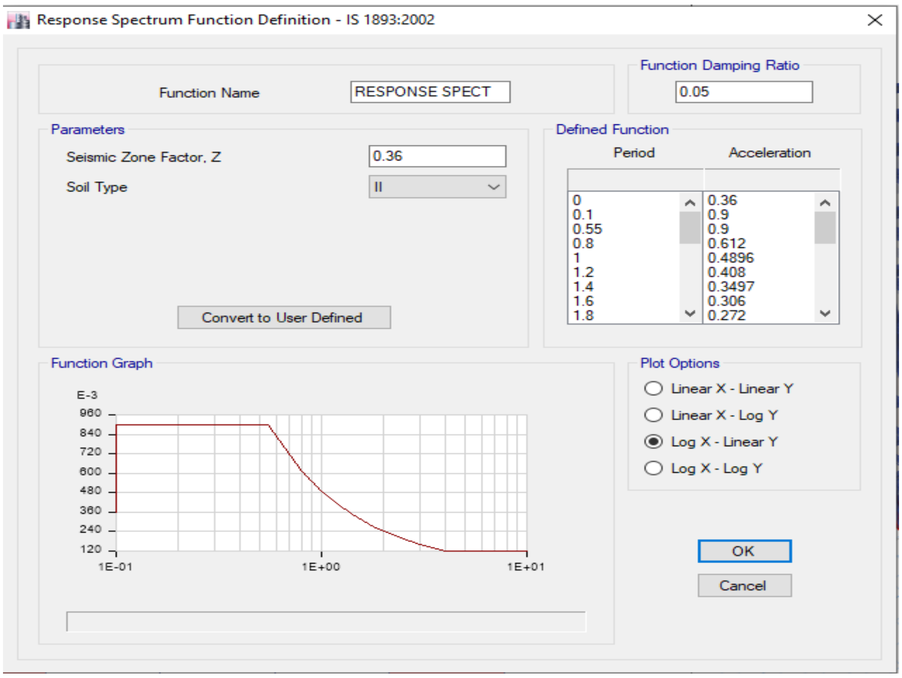
Seismic Zone Factor, Z
● Per Code 0.36
○ User Defined

Site Type II
Importance Factor, I 1.2

Time Period

○ Approximate Ct (m) =
● Program Calculated
○ User Defined T = sec

Fig 11 Defining seismic load pattern as per IS 1893 part I 2016


Response Spectrum Function Definition - IS 1893:2002

Function Name RESPONSE SPECT

Function Damping Ratio 0.05

Parameters

Seismic Zone Factor, Z 0.36
Soil Type II

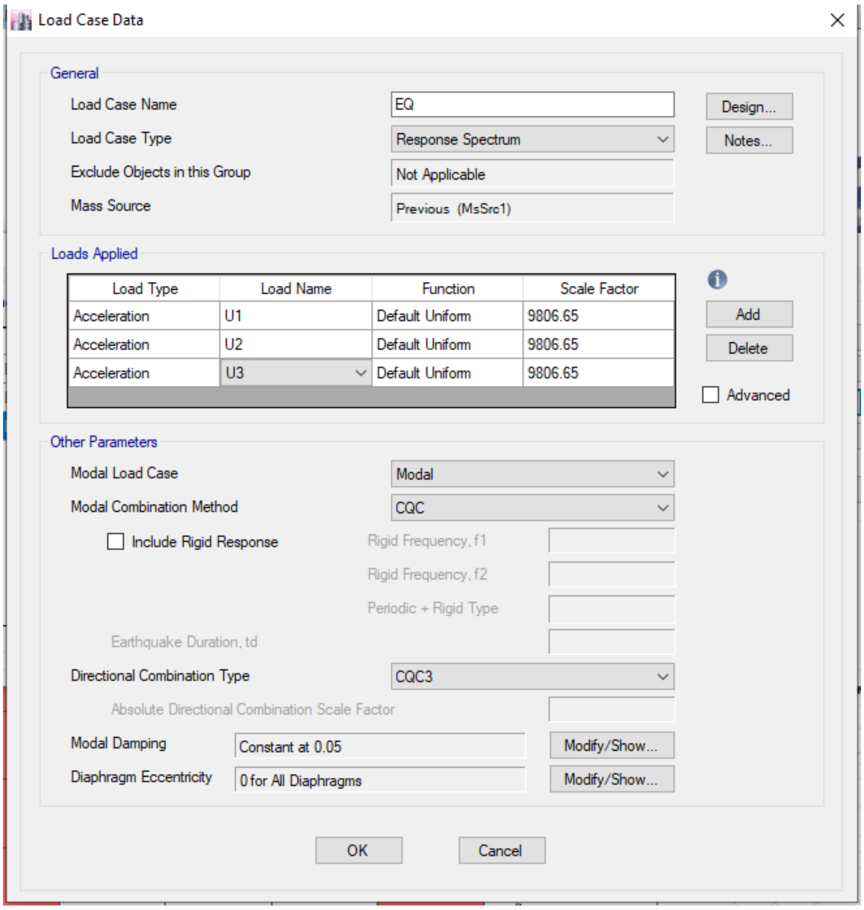
Defined Function

Period	Acceleration
0	0.36
0.1	0.9
0.55	0.9
0.8	0.612
1	0.4896
1.2	0.408
1.4	0.3497
1.6	0.306
1.8	0.272

Plot Options

○ Linear X - Linear Y
○ Linear X - Log Y
● Log X - Linear Y
○ Log X - Log Y

Fig 12 Defining response spectrum function



General

Load Case Name: EQ

Load Case Type: Response Spectrum

Exclude Objects in this Group: Not Applicable

Mass Source: Previous (MsSrc1)

Loads Applied

Load Type	Load Name	Function	Scale Factor
Acceleration	U1	Default Uniform	9806.65
Acceleration	U2	Default Uniform	9806.65
Acceleration	U3	Default Uniform	9806.65

☐ Advanced

Other Parameters

Modal Load Case: Modal

Modal Combination Method: CQC

☐ Include Rigid Response

Rigid Frequency, f1

Rigid Frequency, f2

Periodic + Rigid Type

Earthquake Duration, td

Directional Combination Type: CQC3

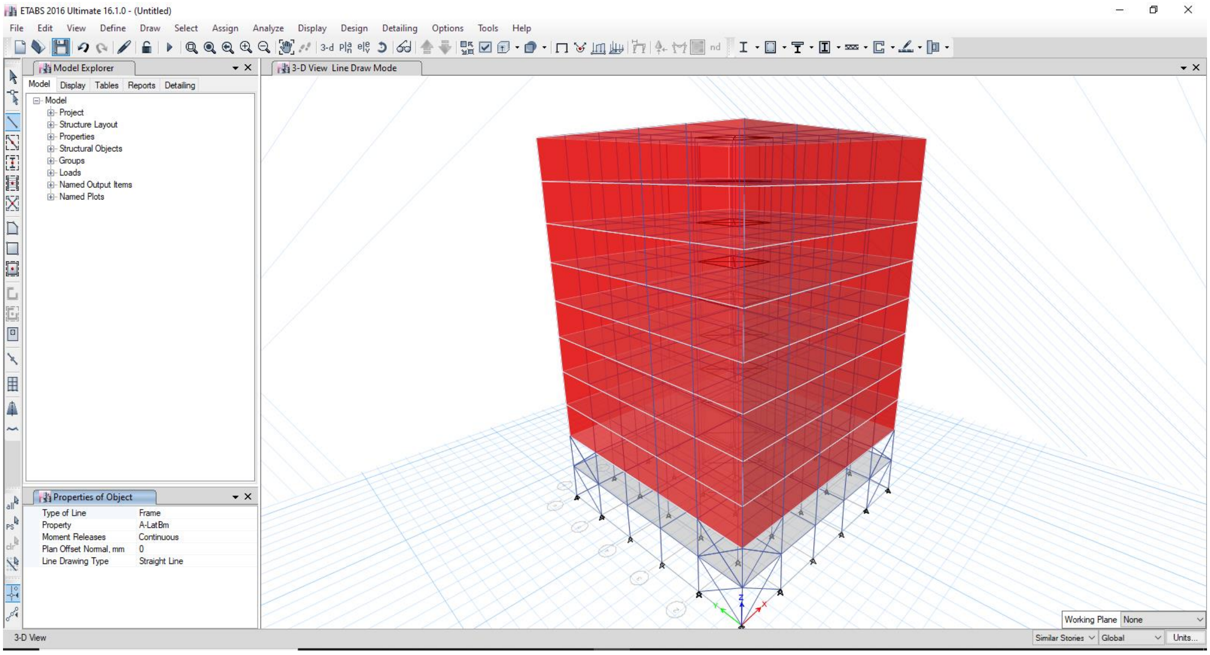
Absolute Directional Combination Scale Factor

Modal Damping: Constant at 0.05

Diaphragm Eccentricity: 0 for All Diaphragms

Fig 13 Defining Load case data for Response Spectrum

Step 6 Analyzing the structure for displacement, drift and shear force



Type of Line	Frame
Property	A-LatBm
Moment Releases	Continuous
Plan Offset Normal, mm	0
Line Drawing Type	Straight Line

Fig 14 Analysis of Structure

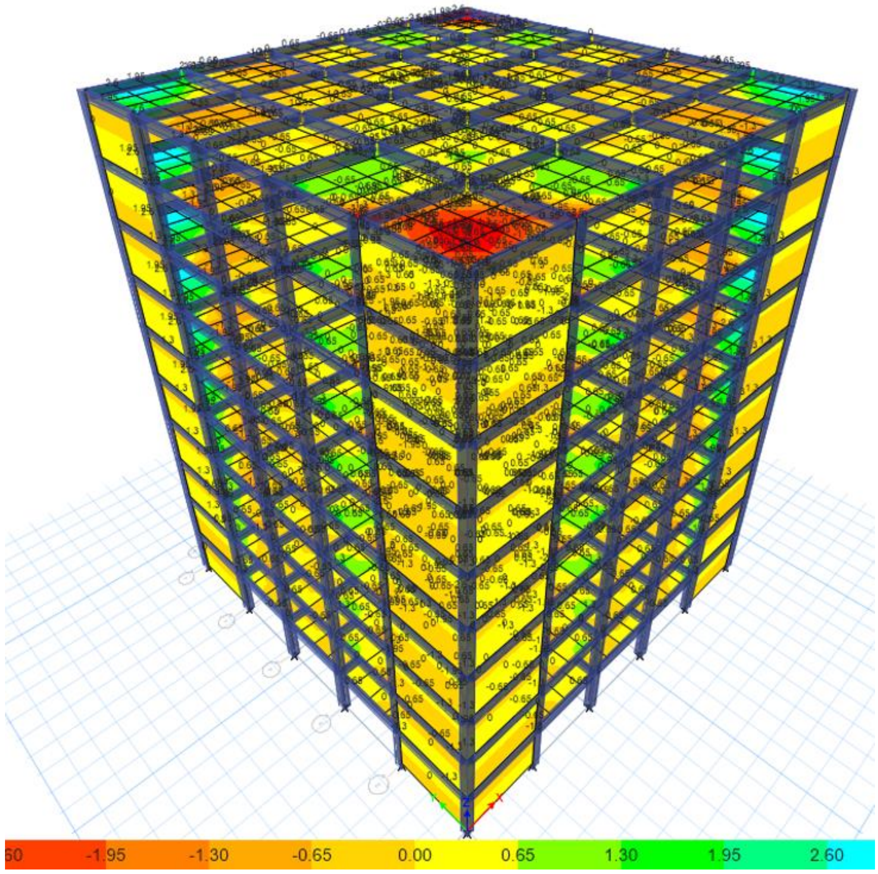
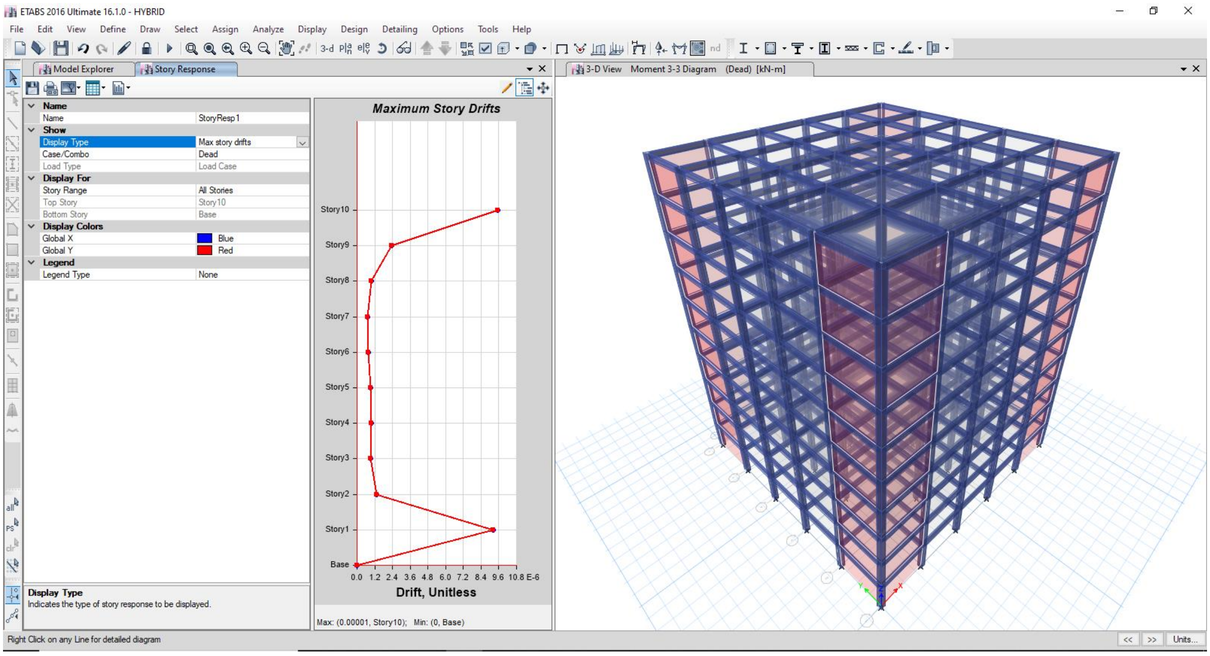


Fig 15 Analyzing stress



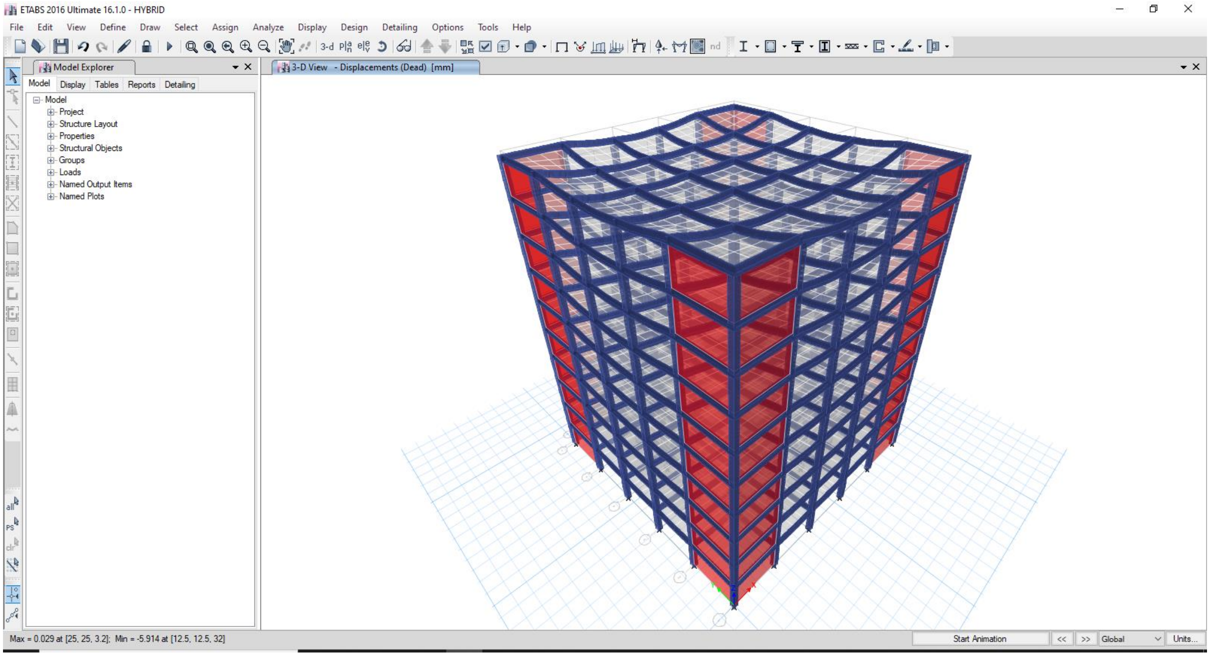
Name	
Name	StoryResp1
Show	
Display Type	Max story drifts
Case/Combo	Dead
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Story10
Bottom Story	Base
Display Colors	
Global X	Blue
Global Y	Red
Legend	
Legend Type	None

Display Type
Indicates the type of story response to be displayed.

Max: (0.00001, Story10); Min: (0, Base)

Right Click on any Line for detailed diagram

Fig 16 Storey Drift



```
Max = 0.029 at [25, 25, 3.2];  Min = -5.914 at [12.5, 12.5, 32]
```

Fig 17 Analysis of Displacement

Table 1 Geometrical Description of the structure

Geometrical Description of Building	
Length in X-direction	25m
Length in Y-direction	25m
Floor to Floor Height	3m
Total Height of Building	30m
Slab Thickness	200mm
Wall Thickness	230mm
Shear wall Thickness	200mm
Column Size	500X500mm
Beam Size	450X300mm
Number of Grid in X Direction	6
Number of Grid in Y Direction	6
Spacing of Grid in X Direction	4m
Spacing of Grid in Y Direction	4m
Number of Stories	10
Typical Storey Height	3m

ANALYSIS RESULTS

Table 2 Storey Displacement in mm

Maximum Storey Displacement in mm		
Storey	Case I	CaseII
Storey 10	90.959	66.49
Storey 9	83.66	52.04
Storey 8	70.8	44.42
Storey 7	62.57	40.27
Storey 6	54.84	33.73
Storey 5	40.66	28.87
Storey 4	33.51	24.07
Storey 3	21.8	12.16
Storey 2	18.17	8.07
Storey 1	11.76	5.67
Plinth	1.73	0.77

Table 3 Maximum Storey Drift

Maximum Storey Drift		
Storey	Case I	Case II
Strorey 10	6.78	6.22
Storey 9	7.21	6.02
Storey 8	7.99	5.87
Storey 7	8.24	5.24
Storey 6	10.94	4.99
Storey 5	11.75	4.62
Storey 4	12.87	3.78
Storey 3	12.03	3.18
Storey 2	10.87	2.92
Storey 1	8.21	2.12
Plinth	0	0

Table 4 Maximum Storey Shear in kN

Maximum Storey Shear in kN		
Storey	Case I	Case II
Stroey 10	1298.098	2098.92
Storey 9	1345.987	3892.267
Storey 8	1428.983	4892.09
Storey 7	1532.986	6644.982
Storey 6	1672.098	7102.983
Storey 5	1738.291	7983.921
Storey 4	1892.21	8329.09
Storey 3	1992.982	9862.01
Storey 2	2021.87	10998.32
Storey 1	2287.1	11276.98
Plinth	2288.709	11875.108

Table 5 Maximum Storey Stiffness

Maximum Storey Stiffness in kN-m		
Storey	Case I	Case II
Stroey 10	216943	229041
Storey 9	447073	459171
Storey 8	598177	610275
Storey 7	887077	899175
Storey 6	987068	999166
Storey 5	999445	1011543
Storey 4	1197773	1209871
Storey 3	1456234	1468332
Storey 2	1678428	1690526
Storey 1	1764684	1776782
Plinth	1800736	1812834

III. Conclusion

This research is carried out with various building models such as soft storey structure with and without steel bracings. In the second case the steel bracing is provided at the center of the structure The study includes the analysis of soft storey building with ETABS software by pushover analysis method and the results and conclusion of the analysis is to be included.

Storey Displacement

For seismic design it is important to estimate, maximum lateral displacement of the structures due to sever earthquake for several reasons.storey displacement is the absolute value of displacement of a storey with respect to ground, under the action of lateral forces. The results obtained for storey displacement stated that maximum displacement was seen at the top storey soft storey structure which is 14 % higher and this can be retained with use of bracing system done in the other case.

Storey Drift

It is the difference between the roof and floor displacements of any given storey as the building sways during the earthquake, normalized by the storey height. Maximum drift was visible in Case I and particularly at 4th storey in case I and Case II showed the reductio in storey drift proving to be far more viable.

Storey Shear

Storey shear factor is the ratio of the story shear force when story collapse occurs to the story shear force when total collapse occurs. Here the storey shear was minimum with structure with X bracing in comparison to a normal soft storey structure.

Storey Stiffness

It refers to the rigidity of a structural element.this means the extent to which the element is able to resist deformation or deflection under the action of applied force. Storey stiffness was 2% on higher side in Case II when compared to Case II and similar differences were seen from First storey to 10th sorey of both the structures.

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