Design of Multistory Code Exceeding Building through performance-based seismic design

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ABSTRACT.
All the existing structures in India were initially designed in accordance with the Indian Standard codes to meet seismic demands. However, if structural requirements exceed code restrictions, traditional methods can be employed to assess structural behavior and meet seismic demands, especially for multi-storey buildings. This study focuses on performance-based seismic design using non-linear time history analysis to assess the core system of tall buildings, as per the revised IS 16700-2023 criteria and check the performance of the building at MCE level earthquake. The analysis will be performed in ETABS Non-linear software. The modelling approach used for the beam element will be a plastic hinge approach with M3 hinges and shear wall (area elements) by the fibre modelling approach with Fiber P-M3 hinges and gravity columns with P-M2-M3 hinges. Hinges definition and modelling parameters and performance levels is as per ASCE 41-17. In this paper,11 times histories have been taken from PEER ground motion database and this time history will be spectral matched at MCE level which serves as spectral matched time histories for ETABS analysis. By employing this approach, the building's behavior under Maximum Considered Earthquake (MCE) level ground motions can be realistically evaluated, allowing for optimization of structural members. Compliance with prescribed performance levels from ASCE 41-17 reduces the risk of unpredictable future earthquake causing major structural damage or loss.

Keywords: - Tall building, Reinforced concrete frames, Non-linear Dynamic analysis, performance based design, Time History Analysis.

1 Introduction

Performance-based seismic design (PBSD) is a concept that permits the design and construction of buildings with a realistic and reliable understanding of the risk to life, occupancy and economic loss that may occur because of future earthquakes. PBSD is based on assessing a building's design to determine the probability of experiencing different types of losses, considering the range of potential earthquakes that may affect the structure. This allows a building owner or regulator to select the desired performance goal for their building. It is an approach in which structural design criteria are expressed to achieve performance objectives. It ensures the structure reaches specified service and strength design demands. This research emphasizes enhancing the seismic resilience of structural and mitigating potential risks associated with seismic events [1]. Local level damage is prevented after optimization, and the impact is also seen in the inter-storey drifts and plastic rotation reduction, respectively [2]. PBSD also quantify the performance of the designed buildings. Performance-based seismic design (PBSD) approach is required for tall concrete buildings that do not fully satisfy the prescriptive requirements of IS 16700 [10]. The different levels of performance checks are Immediate occupancy (IO), Life Safety (LS) and Collapse prevention (CP). The analysis has been undertaken for 11 ground motions, and the PEER TBI guideline processed the results. In this research study lateral load-resisting system is core-only (Core + Gravity columns). The target performance objective is collapse prevention (CP) at the Maximum considered earthquake (MCE) level. The damage caused in the structure at the global level reduces the global level damage.

1.1 Lateral load resisting system

A system that resists lateral loads is necessary for a building to remain stable when subjected to horizontal forces like wind and seismic loads. It has structural components such as diaphragms, moment-resisting frames, bracing, and shear walls to transfer these forces to the foundation. These mechanisms safeguard the building's longevity and safety by preventing excessive lateral movement and structural damage. In areas where strong winds or seismic activity are common, it is imperative that a system that resists lateral loads be designed and installed correctly.

The below figure shows the force deformation relation and the modelling parameters to be used. ASCE 41 recommends 'modelling parameters', which essentially define the shape of the force deformation relationship, 'a' represents the usual plastic deformations representing the maximum load carrying capacity, after which 'c' represents the residual strength. It also allows the force-deformation relationship for a structural component to be obtained from experimental data; if the experimental data is not feasible, the relationship shown in Fig 1 can be used.

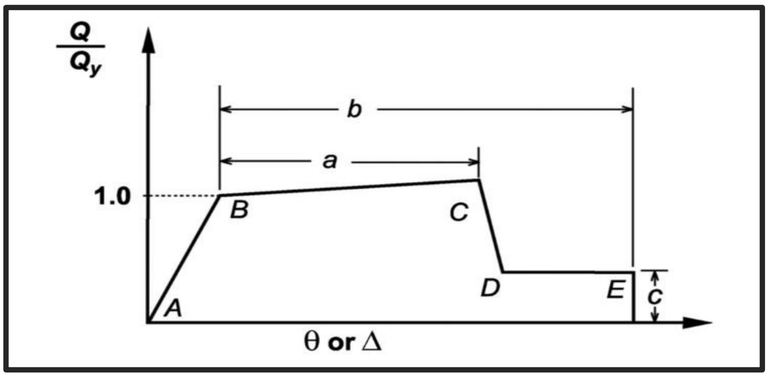


Fig. 1. FORCE DEFORMATION RELATION [11]

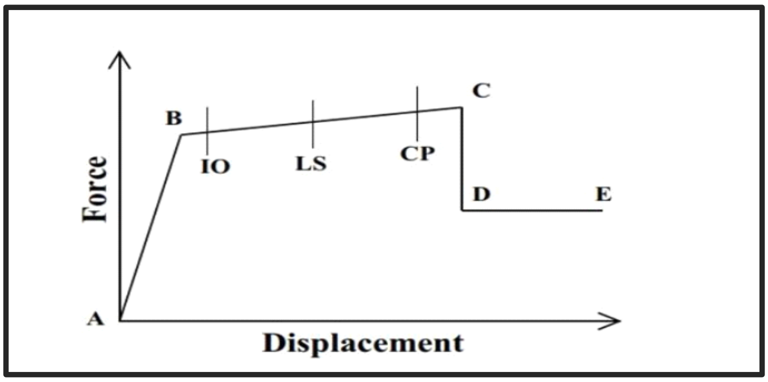


Fig. 2. ACCEPTANCE CRITERIA [11]

1.2 PROBLEM STATEMENT

To Justify the structural system used for the project per the revised codal provisions for its exceedance and for the challenges faced due to the damage caused by future uncertain earthquake ground motions in the structure causing unpredictable damage or loss of life and property.

2 NEED FOR PERFORMANCE-BASED SEISMIC DESIGN

1. In this research study, the lateral load-resisting system is core-only (Core + Gravity columns).
2. The use of a core-only system is not allowed as per IS 16700:2023.
3. So, As per the guidelines provided by the National Disaster Management Authority (NDMA) of India and the Bureau of Indian Standards (BIS) for performance-based design of reinforced concrete buildings, all the ordinary buildings shall be assessed at least for the maximum considered earthquake (MCE).

4. The 'Non-Linear Time History Analysis' (NLTHA) is adopted to capture the actual behavior under MCE-level earthquake analysis.
5. NLTHA has been undertaken to independently verify the performance of the seismic force-resisting system under the MCE level.
6. The contribution of the gravity column and floor beams to the building's seismic resistance has been assumed to be negligible, so moment releases have been included to calculate conservative demands for the core elements and conservative drifts for assessing the gravity columns.
7. The analysis was undertaken for 11 ground motions, and the results were processed according to the PEER TBI guidelines.

The fig 2 & fig 3 shows the different performance levels which are Immediate occupancy (IO) which represents if the damage caused up to these levels, then the structure can be occupied immediately without any major damage, life safety (LS) represents if the damage caused upto these level then the structure may be subjected to minor structural damage, and Collapse prevention (CP) represents that if the structural damage caused upto these level then their can be major structural damage to the structure without having complete collapse.

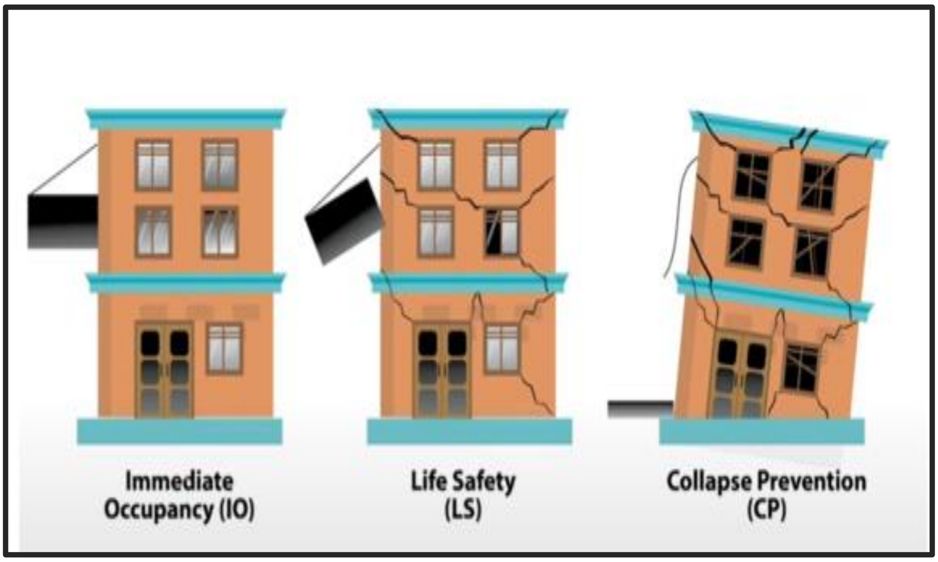


Fig. 3. PERFORMANCE LEVELS

3 CODE EXCEEDING ASPECTS

The structural system used for the project is a only system, which states that the lateral force resisting system is only the core, which will be designed to resist all the lateral force; hence stiffness of the floor outside of the core does not influence the lateral stability of the building. The Maximum height value for different structural systems is mentioned in Table 1 IS 16700-2017, but in the revised code IS 16700-2023, the value for only the core system is not mentioned, which exceeds the code for the structural system used for the project.

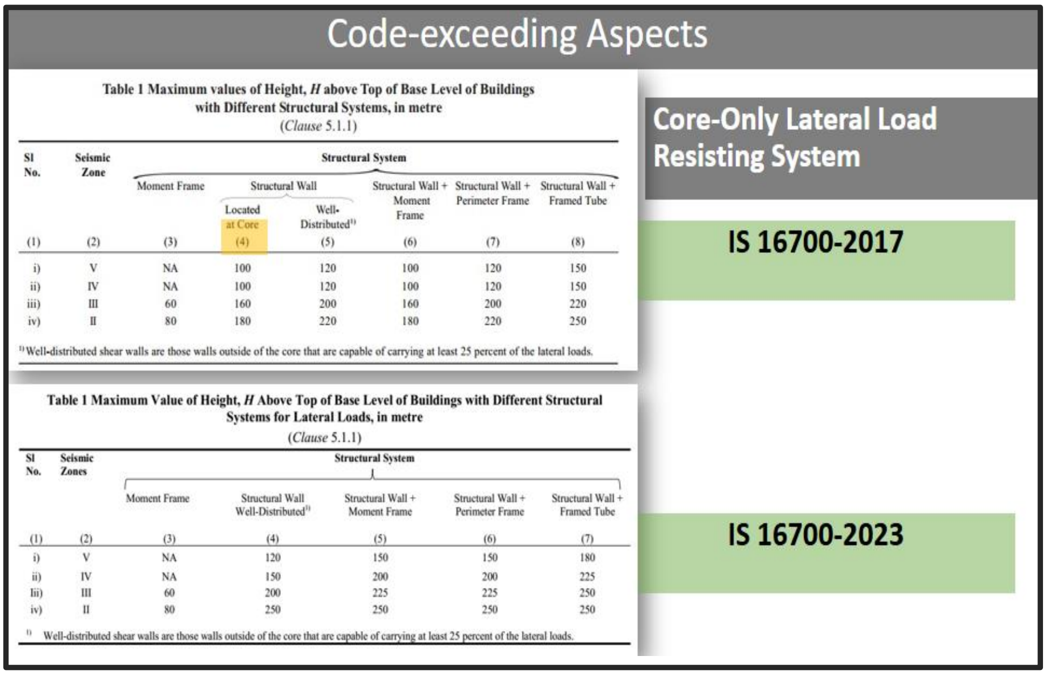


Table 1 Maximum values of Height, *H* above Top of Base Level of Buildings with Different Structural Systems, in metre
(*Clause* 5.1.1)

Sl No.	Seismic Zone	Structural System: Moment Frame	Structural Wall: Located at Core	Structural Wall: Well-Distributed[1]	Structural Wall + Moment Frame	Structural Wall + Perimeter Frame	Structural Wall + Framed Tube
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	V	NA	100	120	100	120	150
ii)	IV	NA	100	120	100	120	150
iii)	III	60	160	200	160	200	220
iv)	II	80	180	220	180	220	250

[1] Well-distributed shear walls are those walls outside of the core that are capable of carrying at least 25 percent of the lateral loads.

Table 1 Maximum Value of Height, *H* Above Top of Base Level of Buildings with Different Structural Systems for Lateral Loads, in metre
(*Clause* 5.1.1)

Sl No.	Seismic Zones	Structural System: Moment Frame	Structural Wall Well-Distributed[1]	Structural Wall + Moment Frame	Structural Wall + Perimeter Frame	Structural Wall + Framed Tube
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	V	NA	120	150	150	180
ii)	IV	NA	150	200	200	225
Iii)	III	60	200	225	225	250
iv)	II	80	250	250	250	250

[1] Well-distributed shear walls are those walls outside of the core that are capable of carrying at least 25 percent of the lateral loads.

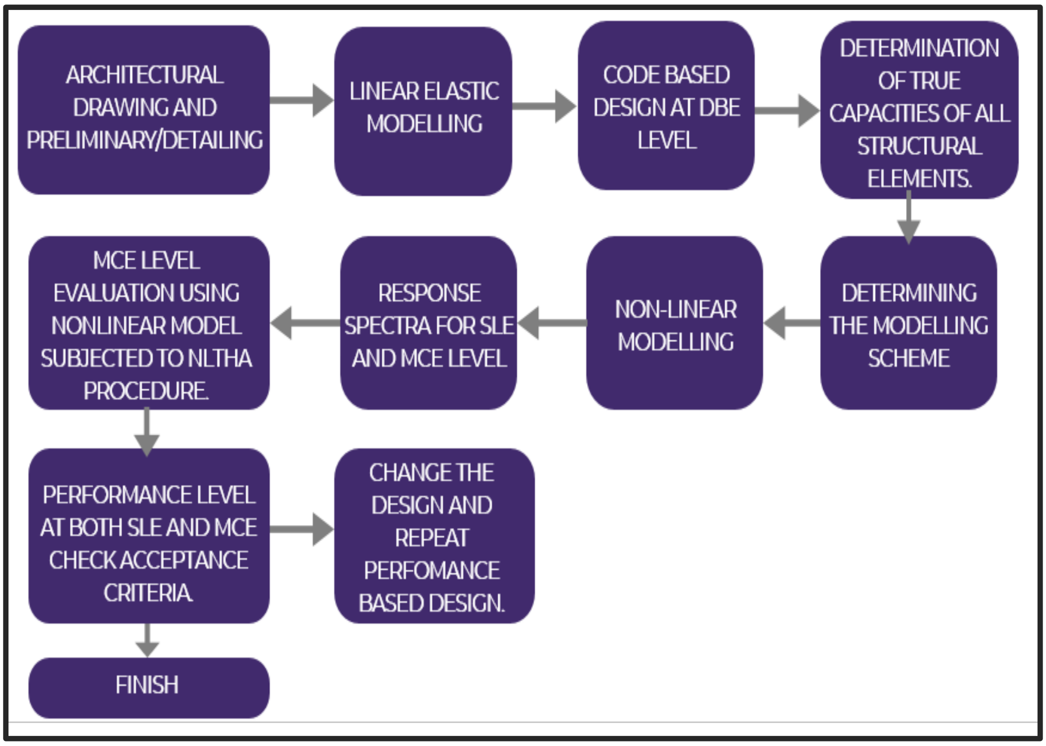
Fig. 4. COMPARISON OF IS 16700 CODAL ASPECTS

3.1 Geometric Aspects

Table 1. Geometric Aspects

Sr No.	Parameters	Dimension/Types
01	Plan Shape	Rectangular
02	Ht. of each story	3.2 m
03	Concrete unit weight	25 KN/m3
04	Slab thickness	200 mm
05	Wall thickness	1000/800/600 mm
06	Concrete grade	M80
07	Steel grade	Grade 550 D
08	Floors	6 Basement + G + 30 storey

4 METHODLOGY FOR PERFORMANCE BASED SEISMIC DESIGN



5 DETERMINATION OF MODELLING SCHEME FOR NON-LINEAR ANALYSIS

- **The effects of nonlinearity can be introduced either right at the material level, cross-section level or mem
ber level.**

5.1 Plastic Hinge approach

The plastic hinge modelling approach assumes that all inelastic deformation is concentrated at certain points or locations defined by the zero-length hypothetical elements known as “plastic hinges”. The inelastic relationship is directly defined at the cross-section or member level to include the effects of nonlinearity in the overall structural stiffness (instead of specifying the inelastic material properties). For all the coupling beams, the plastic hinge approach is adopted and modelled as a line element with M3 degree of freedom hinges in ETABS. As shown in fig 5 & fig 7.

5.2 Fiber hinge approach:

The cross-section of a structural member is divided into a number of uniaxial “fibres” running along the larger dimension (length) of the member. Each particular fiber is assigned a uniaxial stress-strain relationship, capturing various aspects of material nonlinearity in that uniaxial fiber. For Core/Shear walls, the fibre modelling approach is adopted and modelled as a Shell/Area element with Fibre P-M2-M3 degree of freedom hinges in ETABS. As shown in fig 6.

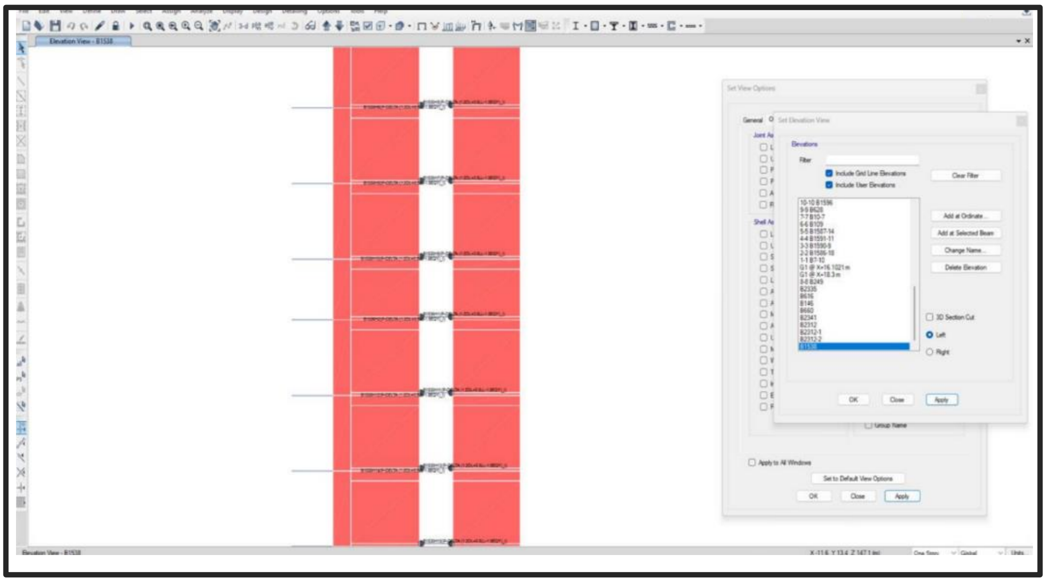


Fig. 5. ELEVATION OF COUPLING BEAMS PLASTIC HINGE MODELLED IN ETABS

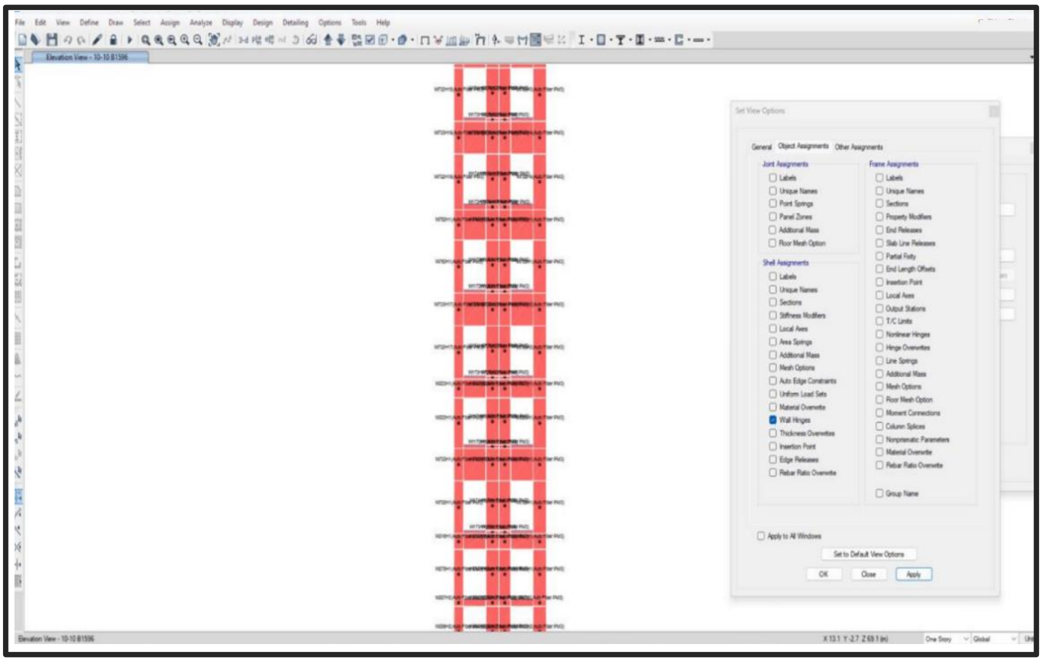


Fig. 6. ELEVATION OF CORE WALL SHOWING FIBRE HINGE MODELLED IN ETABS

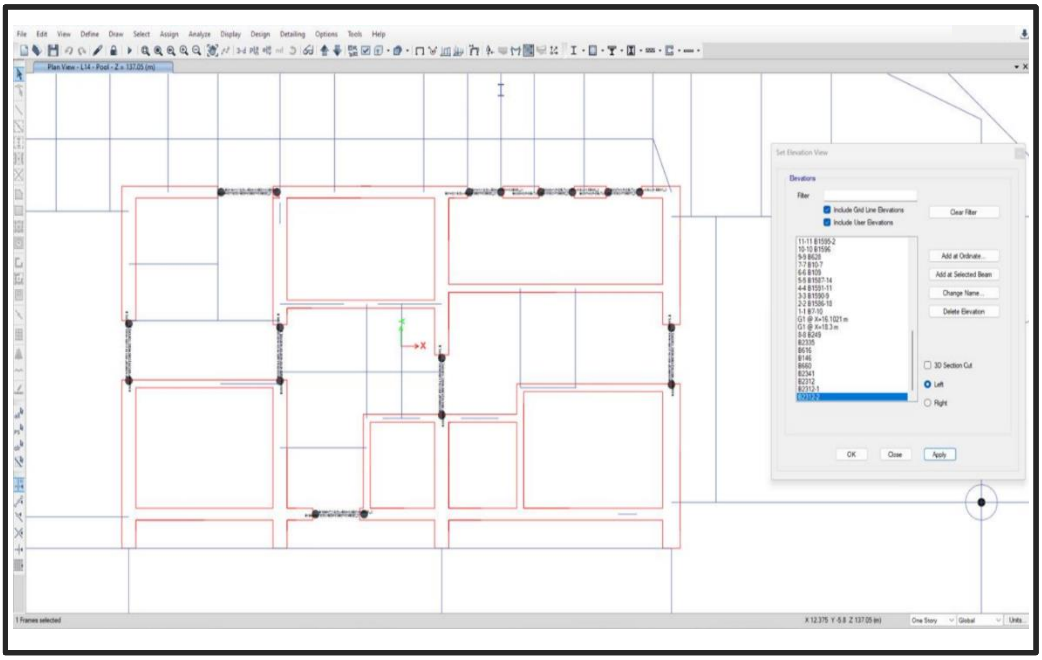


Fig. 7. PLAN OF CORE WALL SHOWING PLASTIC HINGE MODELLED IN ETABS

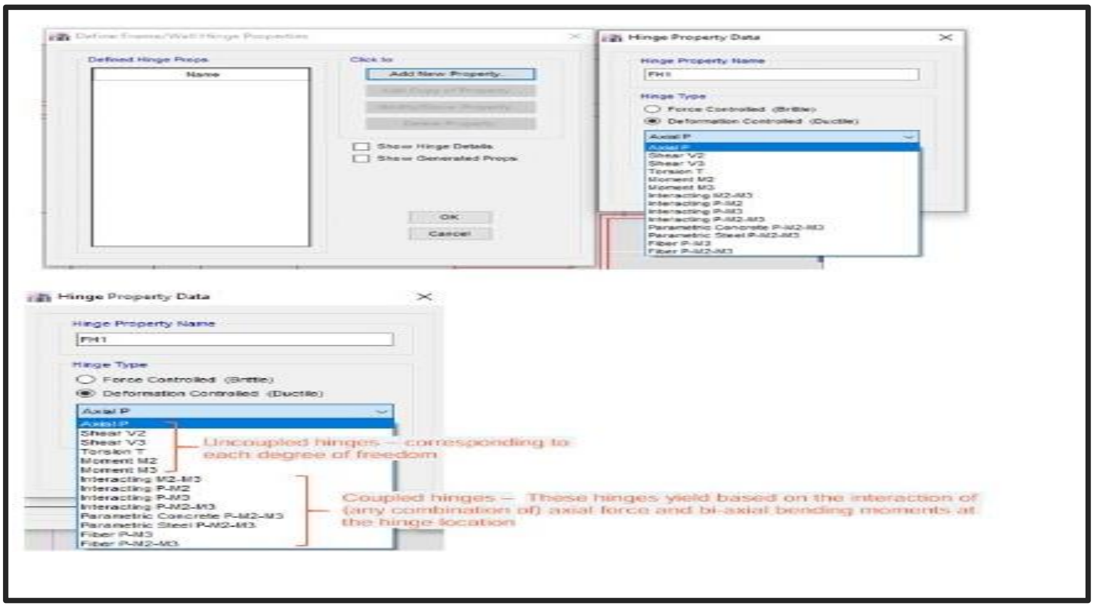


Fig. 8. DEFINING HINGE PROPERTY IN ETABS

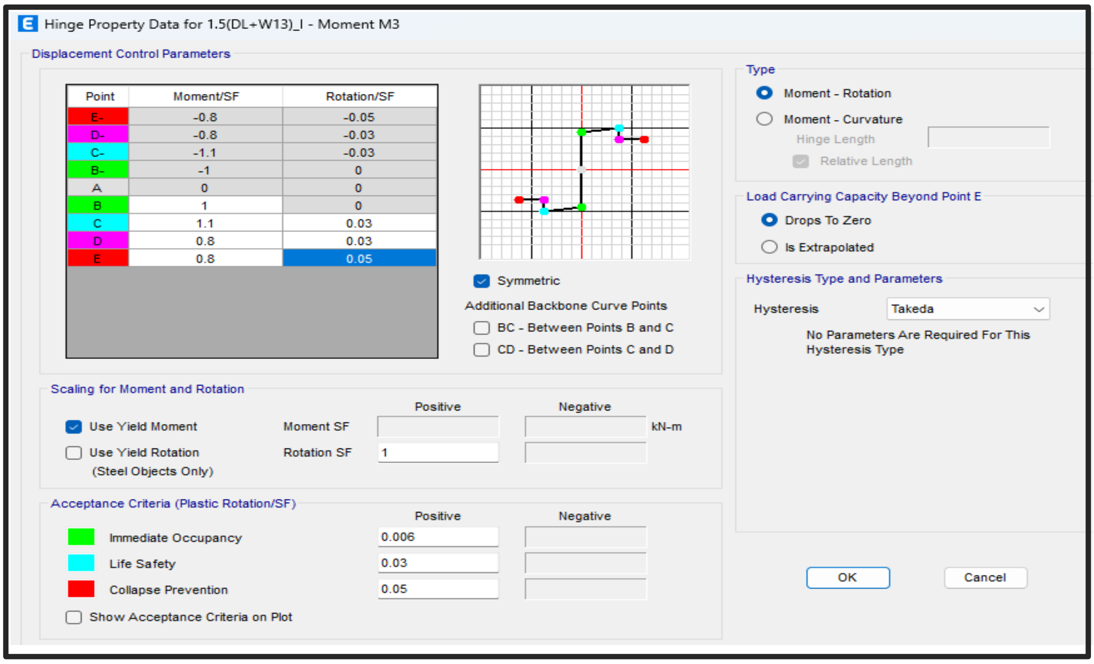


Fig. 9. Inputs of Modelling Parameters and Acceptance Criteria for diagonally reinforced coupling beams in ETABS

6 Fibre Modelling Parameters Considered:

(Values for concrete and steel parameters are as per ASCE 41, NDMA DRAFT and Mander's Curve and IO,LS, and CP Levels are as per ASCE 41).

Table 2. Parameter for concrete

Strain at Unconfined Compressive Strength	0.002
Ultimate Strain Capacity	0.05
Final Slope	-0.1

Table 3. Parameters for reinforcement

Strain at onset of Strain Hardening	0.05
Ultimate Strain Capacity	0.145
Final Slope	-0.1

Table 4. Acceptance Criteria in concrete (For Compression)

IO Level (0.67*LS Level)	0.00134
LS Level (0.75*CP Level)	0.002
CP Level (1*Ultimate Strain)	0.005

Table 5. Acceptance criteria in reinforcement

IO Level (0.67*LS Level)	0.025
LS Level (0.75*CP Level)	0.0375
CP Level (1*Ultimate Strain)	0.05

7 RESULTS

- For Non-linear time history analysis Component modelling and acceptance criteria is considered as per PEER Tall Buildings Initiative (TBI) and ASCE 41. Results of analysis is compared with TBI guidelines and IS 16700:2023. Performance of building has been assessed by comparing following results with acceptance criteria.

1. Inter storey drifts and global shear forces.
2. Diagonal reinforced coupling beam plastic hinge rotation.

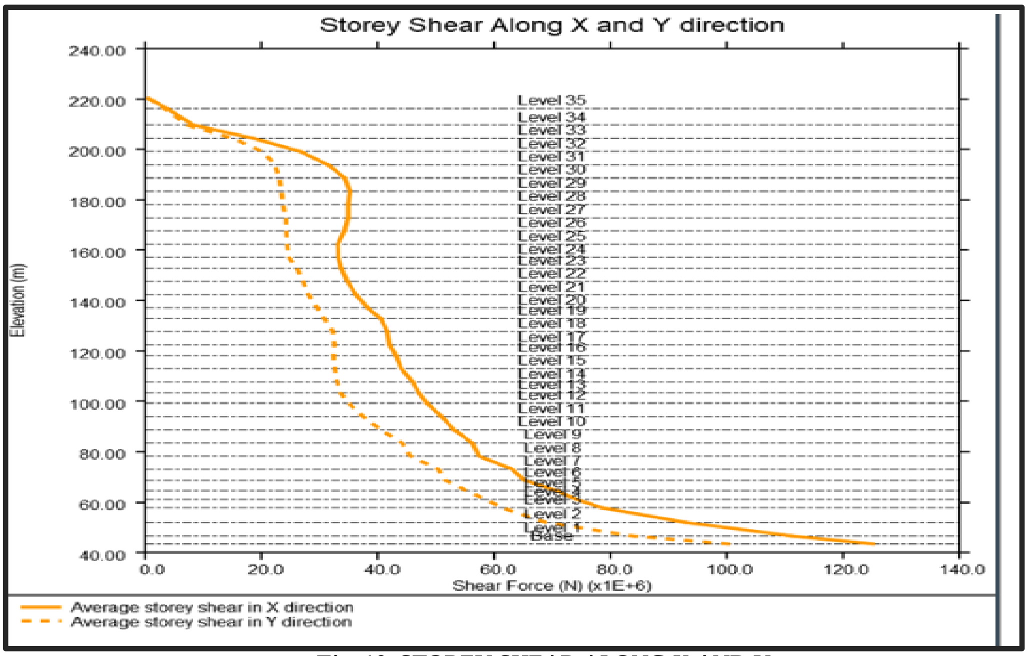


Fig. 10. STOREY SHEAR ALONG X AND Y

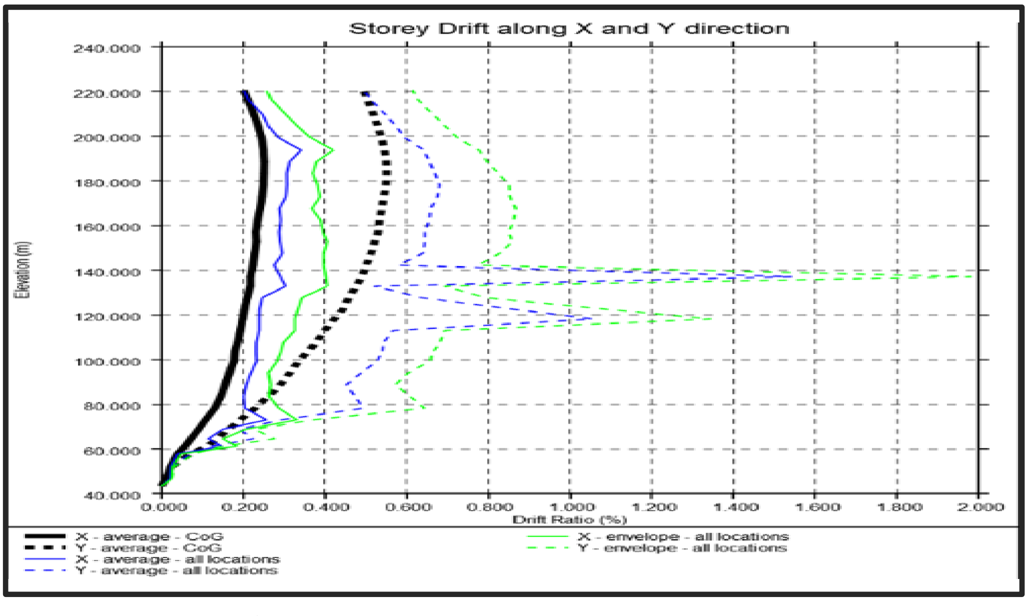


Fig. 11. STOREY DRIFT ALONG X AND Y

7.1 Storey Drift ratio:

- Global behavior has been assessed by reviewing the storey shear forces and storey drift ratios up to the building's height. Fig 10 shows the peak storey force across 11 ground motions in both the X direction (solid line) and the Y direction (dashed line). This shows the higher forces in the X direction.
- As per IS: 16700:2023 inter-storey drift ratio at any storey shall not exceed 3% in the MCE event. Inter-storey drift calculation based on individual ground motion or averaged across ground motions is unclear as per IS: 16700:2023. As per PEER TBI guidelines, the peak drift ratio averaged across the ground motions shall not exceed 3%, and the maximum drift ratio from any ground motion shall not exceed 4.5%. For the current study, both criteria are checked.

7.2 Diagonally reinforced coupling beams:

- The performance of the diagonally reinforced coupling beams has been assessed by comparing the peak plastic rotation averaged over the 11 ground motions against the acceptance criteria for each performance level. It shows how the peak plastic rotation relates to each performance level, and the below figure shows the performance level achieved. This shows that all coupling beams achieve the Immediate Occupancy performance better than the acceptance criteria of Collapse Prevention at MCE.

	Peak plastic hinge rotation	Performance
0→1	< 0 rad	Lintel remains elastic
1→2	0–0.006 rad	Below limit for IO (Immediate Occupancy)
2→3	0.006–0.03 rad	Below limit for LS (Life Safety)
3→4	0.03–0.05 rad	Below limit for CP (Collapse Prevention)
4+	>0.05 rad	Lintel collapse

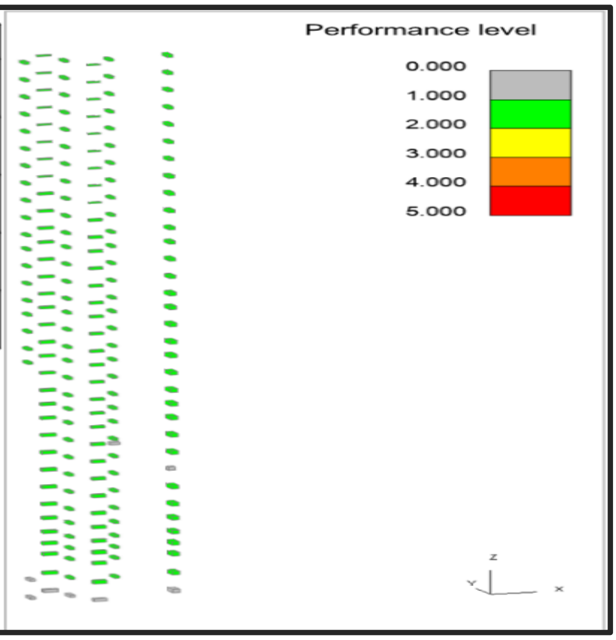


Fig. 12. PERFORMANCE LEVELS COUPLING BEAMS

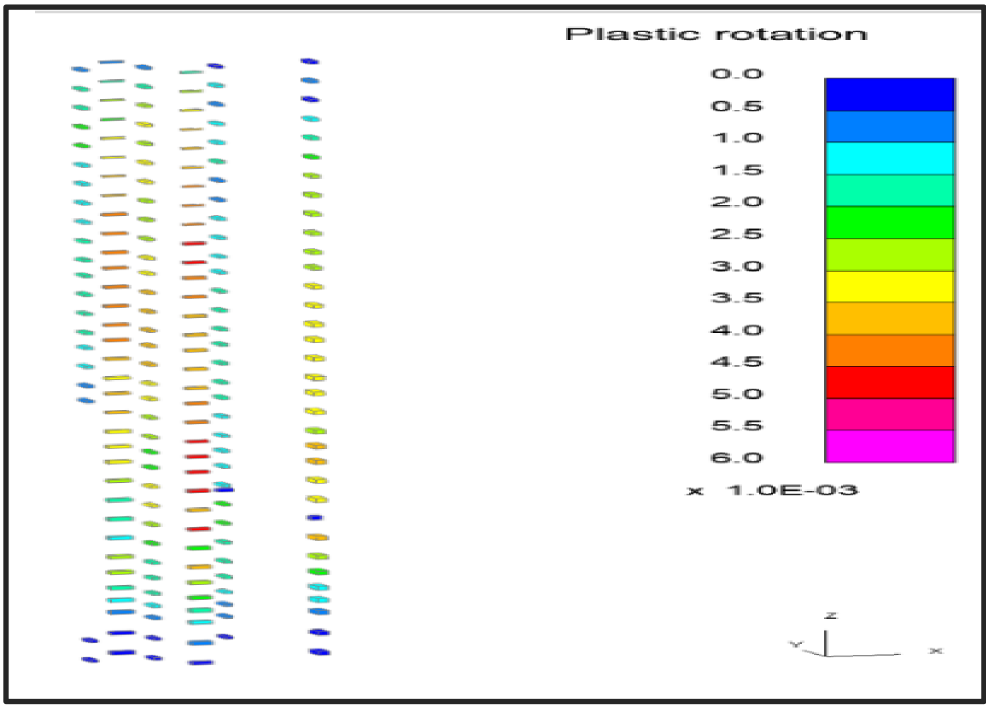


Fig. 13. PLASTIC ROTATION OF COUPLING BEAM

8 CONCLUSION

1. The structure has been analysed using ETABS NON-LINEAR to assess the performance under the MCE level seismic loading. The approach for the NLTH analysis followed the PEER TBI guidelines which refer to ASCE 41 for component modelling and acceptance criteria. Collapse prevention is a critical performance target as it aims to avoid total collapse despite significant damage, thus providing a high level of safety during extreme seismic events. The results have been calculated from 11 bi directional ground motion that were applied to the model.

2. The target performance objective was Collapse Prevention (CP) at the MCE level. The results presented demonstrate that the building achieves the Life Safety (LS) performance objective which is a better performance than Collapse Prevention. The plasticity developed in the diagonally reinforced coupling beam elements is well distributed over the structure and within the allowable rotations for Life Safety performance. Storey drift ratios remain within target levels and column rotations are within target levels for gravity columns. High shear stresses have been identified within some of the core walls but these are within acceptable limits.

3. The inter storey drift ratios, as per PEER TBI guidelines, the peak drift ratio averaged across the ground motions shall not exceed 3%, and the maximum drift ratio

from any ground motion shall not exceed 4.5%. These ratios are well within the limits, hence satisfying the global structural behaviour likely to achieve the target performance and satisfying the structural members for the nonlinear time history analysis.

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