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PERFORMANCE BASED SEISMIC DESIGN OF TALL BUILDINGS

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Abstract* – With the increase in the height of a structure, the performance and conceptual design is governed by lateral loads. Traditionally, linear elastic methods have been found satisfactory in analysis and design of the structure assuming its elastic behaviour but its limitations have been recognized in predicting the ductile behaviour of the structure, as during an earthquake. Further development led to the importance of dynamic over static design concepts to understand non-linear behaviour of the structures emerged. Even though the dynamic methods were more efficient, they were more exhaustive and cumbersome to apply, discouraging many from using them. In lieu of the limitation stated above, the many jurisdictions allow designs using alternative procedures (based on the established principles of engineering mechanics and based on the current prescriptive provisions). One such alternative approach is opting for "Performance Based Design" which uses rational analysis to demonstrate serviceability and safety objectives of Tall Buildings intended by the prescriptive codes. In this work, two structural systems namely, gravity frame with core (system 1) and moment frame with core (system 2) have been analyzed, designed and compared based on the various seismic parameters.

***Keywords*—Performance based seismic design (PBSD), shear core wall, moment frame, gravity frame, storey displacement, storey drift, storey shear, base shear, hinge results**

I. INTRODUCTION

Traditionally, linear elastic methods have been used to analyze and design the structures. In lieu of their limitations, one emerging alternative approach is "Performance Based Design" which uses rational analysis to demonstrate serviceability and safety objectives of Tall Buildings (which as per IS 16700-2017, is a building of height greater than 50m but less than or equal to 250m). The purpose of Performance Based Seismic Design (PBSD) is to eliminate the height restrictions for specific structural systems imposed by the prescriptive codes and to allow the design team to demonstrate high performance levels for the structure during a seismic event. The guidelines laid down by Pacific Earthquake Engineering Research Centre (PEER) can be used as a basis for seismic design of tall buildings and for development of procedures that can be incorporated into the future building codes to make them a standard practice. The investigation was conducted in an attempt to compare two structural systems namely, *gravity frame with core (system 1)* - the core resists gravity loads and seismic loads while the columns resist only gravity loads & *moment frame with core (system 2)*- the core & the columns both resist gravity loads and seismic loads, with respect to seismic parameters such as maximum storey displacement, maximum storey drift, storey shear, base shear & hinge results in tall buildings using PBSD. Each model so chosen is a G+25 storey building having a plan area of 30m x 30m with a shear wall core of 15m x 15m. The perimeter is connected to the core by rigid slabs. The core is connected by means of spandrel beam.

II. LITERATURE REVIEW

Tall Building Initiative (TBI) by Pacific Earthquake Engineering Research Centre (PEER) (2017)
Provides performance-based procedure for seismic design of tall buildings.
The following are the steps for seismic design-

1. Confirming design process with all stakeholders in regards of all aspects of Performance Based Design followed by establishing Risk Category and performance objectives of the structure.
2. Determining response spectra for seismic input for service level shaking and maximum considered earthquake level.
3. Conceptual Design along with approval from authority and PEER reviewers.
4. Preliminary design as per codes followed by final design for two levels considered earlier.
5. PEER review to check final design.

MJN Priestley (2000) advocates the use of displacement-based design rather than force-based design coupled with displacement check. Comparison of 3 methods. In conclusion, design based on strain or drift performance i.e. performance-based seismic design is simple, rational and economical as compared to traditional methods.

MK Gupta et.al (2015) investigated the performance of structure subjected to seismic loads for different configurations which are ordinary moment resisting frame, special moment resisting frame and braced steel frame. A detailed comparison regarding the 3 systems is done pertaining to the following factors – materials, maximum base shear, moments, storey drifts, average story displacements based on analysis done in STAAD Pro for a G+4 structure.

Z.Tuna (et.al 2012) compares the performance of two 42 storey buildings in California, USA. Building 1 consists of coupled core wall while Building 2 consists of coupled core wall with perimeter moment resisting frame thus acting as dual system. Modelling and analysis was performed using PERFORM 3D for enhanced performance-based design as per TBI – PEER.

III. DESCRIPTION

A. Objective

The objective is to use PBSD for analysis & comparison of two structural systems namely system 1 and system 2, and design them to achieve desired level of performance. It is expected that the building designed meets the performance requirements of the maximum storey displacement, base shear, storey shear, storey drifts and hinge results

B. Section Properties

The following dimensions were obtained using approximate analysis & subsequent iterations of the G+25 frame.

1) Beam Section:

Reinforced Concrete Rectangular
300mm wide & 400mm deep
Longitudinal bars and Ties: HYSD 500
4 null beams of negligible dimensions have been modelled to apply area loads to the slab sections and to ensure that the loading transfers without the object contributing to structural stiffness.

2) Column Section:

Reinforced Concrete Rectangular
400mm wide & 700mm deep (up to storey 14)
350mm wide & 600mm deep (from storey 15 to storey 25)
Longitudinal Bars: HYSD 500 (8 nos. 20mm diameter)
All the columns are oriented in such a way that the columns placed along the global X direction of the building have their longer side parallel to the global X direction while the columns placed along the global Y direction of the building have their longer side parallel to the global Y direction.

3) Slab Section:

150mm deep using M40 grade concrete

4) Core:

Shear wall of thickness 300mm up to storey 14 and 200mm from storey 15 to storey 25

C. Loads

The following four basic loads are considered.

1. Dead Load
2. Live Load (2 kN/m² on all floors)
3. Pushover load in X direction (PushX)
4. Pushover load in Y direction (PushY)

These (3 & 4) are non-linear static loads in X & Y direction respectively. The structure is subjected to gravity loading and a monotonic displacement controlled lateral load which continuously increases through elastic & inelastic behaviour until an ultimate condition is reached. In this case, the acceleration is provided along both the directions until the displacement value (Ux& Uy) of H/250 is reached.
Here H= 3.5*26= 91 m
Thus, Ux= Uy = H/250= 0.364 m= 364 mm (due to symmetry of the plan)
For carrying out design based on these above basic four cases, IS 1893 2016 is used.

D. Load Combinations

The load combinations that are used for the analysis and design of two systems is shown in Table I

TABLE I
LOAD CASES

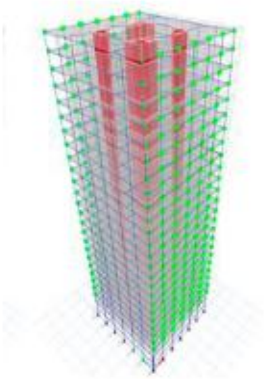
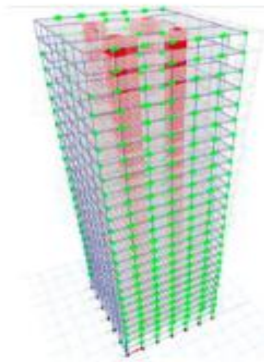
Load Combination	Loads	Scale Factor
DCon1	Dead Load	1.5
DCon2	Dead Load Live Load	1.5 1.5
DCon3	Dead Load Live Load PushX PushY	1.5 1.5 1 1

IV. RESULTS & DISCUSSIONS

The results have been obtained for both the structural systems with respect to the following five seismic parameters and have been compared as shown in Table II

Table II

Seismic Parameter	System 1	System 2	Discussion
4.1 Storey displacements It is total displacement of any particular storey with respect to ground and there is maximum permissible limit prescribed in IS16700 - 2017. It is the absolute value of displacement of the storey under action of the lateral forces. Maximum possible storey displacement should not be more than *H*/250 where H is the total height of the building. Thus, in our case, its value is equal to 0.364m as mentioned before.	The maximum storey displacement in Global X and Global Y direction for Push X and Push Y case is 0.3639m which is within the specified limits as per IS 16700-2017. Accordingly, the maximum displacement is at the top floor.	The maximum storey displacement in Global X and Global Y direction for Push X and Push Y case is 0.3639m which is within the specified limits as per IS 16700-2017. Accordingly, the maximum displacement is at the top floor.	The maximum displacement for both the structures is the same for all iterations because the procedure of pushover analysis requires the designer to input the value of target displacements. These target displacements serve as a criterion for calculating member forces and thus, designing the frame for these forces developed corresponding to the target displacement. The results of storey displacement are consistent with the target displacement, indicating that the model is correct and can be used for further design.
4.2 Storey drifts Generally, drift is defined as the relative lateral displacement of the two stories or the displacement of a particular story with respect to other. Storey drift is expressed asthe ratio of the relative displacement to the height of the building.	The maximum storey drift for Iteration 2 in Global X direction for Push X case, as shown in Figure 4.8 is 0.00494 which occurs at storey 11 and it decreases above and below that particular storey.	The maximum storey drift for Iteration 2 in Global X direction for Push X case, is 0.00505 which occurs at storey 11 and it decreases above and below that particular storey.	The value of storey drift for the final Iteration is same in both the structural systems in both the directions, this is because storey drift is a related parameter to storey displacements.
4.3 Storey Shear The design seismic force to be applied at each floor level is called storey shear. It is a fraction of the total dead load and a part of the live load acting at each floor level. This force increases as we go lower.	The maximum storey shear is at the base. Its value is 8034.6 kN.	The maximum storey shear is at the base. Its value is 15243.9 kN.	The maximum storey shear in case of the system 1 is significantly lesser than that of the system 2. In general, because a flexible building is hard to excite, it will have a lower base shear as compared to a stiff building with other conditions intact. Thus, stiffer the building will be, more will be the storey shear.

4.4 Base Shear Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. It is equal to the sum of all the story shear forces at different floors.	The maximum base shear is 8096.8 kN	The maximum base shear is 15362.0 kN	The maximum base shear in case of the system 1 is significantly lesser than that of the system 2. In general, because a flexible building is hard to excite, it will have a lower base shear as compared to a stiff building with other conditions intact. Thus, stiffer the building, more is the base shear
4.5 Hinge Results Hinge results are based on the backbone (capacity) curve for every frame element. Plastic hinges were assigned at 0.01 relative distance for every frame element indicative of the different performance levels (IO, LS, CP). Hinge results for the same frame element in both cases were compared stepwise for pushover analysis.			For both systems, Hinges formed are in elastic range corresponding to IO level without plastic rotation on faces parallel to lateral force application. More number of hinges are formed in system 1 with a slightly higher magnitude of moment as compared to system 2. A lesser stiff system indicates higher magnitude of moment along with more number of hinges

V. CONCLUSION

After comparing the results with respect to the five parameters specified above, the following can be concluded.

1. Evidently supported by the hinge results, Moment Frame with Core is a stiffer system as compared to Gravity Frame with Core Evidently supported by the hinge results.
2. Moment Frame with Core being a stiffer system attracts higher values of Base Shear and has higher Storey Shear which will need to be provided for while designing the structure.

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