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Performance Based Approach for Seismic Design of Tall Building Diaphragms

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ABSTRACT: Construction industry is always trying to find out innovative and better technology in the field of design sector. Performance based design approach for seismic design has ability to signify higher levels of performance for a structure at various intensities of a seismic event.

In present work, the performance of the tall building has been checked against the Service Level Earthquake and the Maximum Considered Earthquake Level by performing the linear and nonlinear procedures with and without the assignment of Rigid and Semi – Rigid Diaphragms by using ETABS software. The performance of the tall building has been checked against the common P-delta effect using a formula based excel sheet.

Due to the incorporation of shear wall into the tall building, the value of Base Shear was found to be increased by 2.5 % with the help of Nonlinear Time History Analysis compared to Linear Response Spectrum Analysis. There was an increase in Time Period by 4 % with the help of Nonlinear Time History Analysis compared to Linear Response Spectrum Analysis. The Story Drift has been increased by 75 % with the help of Nonlinear Time History Analysis compared to the Linear Response Spectrum Analysis. There is a rise in Shear Force by 23 % using the Nonlinear Time History Analysis compared to the Linear Response Spectrum Analysis. The Bending Moment was found to be increased by 25 % using the Nonlinear Time History Analysis compared to the Linear Response Spectrum Analysis.

KEYWORDS: Performance based approach, Seismic design, Diaphragms, SLE Level, MCE Level.

I. INTRODUCTION

Performance based design is a state of the art design approach for the seismic-resistant design, which has been widely used for the seismic evaluation of existing buildings and the seismic design for a number of new tall buildings. To contemplate this effect, the structural over-strength factor, is multiplied by the seismic forces to forecast the maximum forces in members that are deemed to be elastic, especially in the design of diaphragms. The purpose of those factors is to make simple the process of structural design with the help of using elastic analysis procedures. These procedures do not consider the structural performance at component level, the ground motion characteristics and the redistribution of seismic demand in the various parts of building at the condition of inelastic behavior under strong seismic events.

The performance based seismic design adopts a procedure such that the structure would not be damaged beyond certain states at certain levels of ground motion and with specific levels of reliability. A performance level depicts a damage condition that is considered as satisfactory for a given building under certain ground motion. It has led to a new perception for the seismic design of tall buildings, pioneering to a smart take off in analysis and assessment methods from the prescriptive force based design methods which are based on linear elastic analysis under the action of reduced seismic loads and the principles of capacity design, to the non-prescriptive displacement-based design methods which are based on nonlinear analysis and performance evaluations with respect to the demand parameters which are expected. Buildings may be designed not only to protect life safety but also to enable continued post-earthquake occupancy and function is desired. This approach permits a building owner/ operator of the building to select an acceptable level of building damage for a given intensity of earthquake ground shaking which can then serve as a target or goal for the seismic design effort.

Seismic Performance Objectives:

The specific performance objectives for the design of building at two stages of earthquake hazards are represented in the Table 1.

Table 1 Seismic Performance Objectives

Level of Earthquake	Seismic Performance Objectives
Frequent/Service: 50 % probability of exceedance in 30 years (43-year return period), 2.5 % of structural damping.	Serviceability: Limited structural damage, should not affect the ability of the structure to survive future. Maximum Considered Earthquake shaking even if not repaired.
Maximum Considered Earthquake (MCE): 2 % probability of exceedance in 50 years (2475-year return period), 2 to 3 % of structural damping.	Collapse Prevention: Building may be on the verge of partial or total collapse, extensive structural damage; repairs are required and may not be economically feasible.

Acceptance Criteria:

At the SLE Level, various criteria's are considered such as the Story Drift should be less than 0.5 %. Members such as Core wall shear and Columns should remain essentially elastic.

For the MCE Level, the criterion considered is that the Story Drift should be less than 3 %.

1.1 Tall Building

Now day's tall buildings are becoming quite popular in most of the parts of the world. With the introduction of modern technology, the basic aim has been the same, to construct safer buildings keeping in mind the aspect of economy. Tall buildings have the potential to decongest the urban sprawl on the ground level, increases the density of urban regions, housing high number of families in lesser space. According to IS 16700: 2017, a building which is greater than 50 m but less than or equal to 250 m is considered as a tall building.

1.2 Diaphragms

In structural engineering, a diaphragm is an element of structure which transmits lateral loads to the vertical resisting elements of a structure such as shear walls or frames. The diaphragm forces apt to be transferred to the vertical resisting elements primarily through in-plane shear stress. The most usual lateral loads to be resisted are those generated from the action of wind or earthquake, but other lateral loads such as lateral earth pressure or hydrostatic pressure can also be resisted by the action of diaphragm. There are three types of diaphragms namely Rigid Diaphragm, Semi-Rigid Diaphragm and Flexible Diaphragm.

1.3 Aim of Dissertation

The aim of the Dissertation is to study the Performance Based Approach to improve the structural performance and cost effectiveness in design of Tall Building Diaphragms under the seismic action.

1.4 Objectives of Dissertation

The Dissertation work is being carried out to achieve the following objectives:

1. To check the performance of the Tall Building at Service Level Earthquake level (43-year return period) using Linear Response Spectrum Analysis and Nonlinear Time History Analysis.
2. To check the performance of the Tall Building at Maximum Considered Earthquake level (2475-year return period) using Nonlinear Time History Analysis and Linear Response Spectrum Analysis.
3. To check the performance of the Diaphragms at Maximum Considered Earthquake Level.
4. To check the Tall Building against the P-delta effect.

II. LITERATURE SURVEY

^[1]Akshay Nagpure and S. S. Sanghai (2018) studied the effect of diaphragm flexibility on the seismic response of R.C.C. framed building by considering the diaphragm discontinuity. In this research, R.C.C. framed building structures were being analyzed with the help of ETABS software. By varying the flexibility of the floors and when plan irregularities were provided the linear time history analysis was performed. An attempt has been made to compare the responses of the structure when the flexibility of the floor diaphragm is changed and simultaneously when plan irregularities were provided.

^[2]Ankan Kumar Nandi and Jairaj C (2020) focused on the backstay effect i.e. podium structural interaction with the tower area and considered a retaining wall as increment of lateral stiffness as specified in latest tall building code IS 6700:2016 for low and high rise structures. They prepared the models with low to high rise stories by using flexible and rigid diaphragms considering the diaphragm at backstay placing the tower at center and at corner. They also studied the structural responses like natural periods, base shear, displacement and inter story drift.

^[3]Erhan Budak and Haluk Sucuoglu (2017) studied the performance based seismic design of reinforced concrete tall buildings. The behavior of tall buildings is crucial under seismic effects since the effect of seismic loading is one of the most enlightened problems in the field of earthquake engineering. A reinforced concrete unsymmetrical tall building with 34 stories was designed according to Turkish Seismic code. For both the levels i.e. service and maximum earthquake levels, Nonlinear Time History analysis was enlightened using a suite of ground motions for checking the results according to the determined target performance levels. The results showed that by using performance based approach satisfactory seismic performance can be obtained.

^[4]Kaushal Vijay Rathod and Sumit Gupta (2020) analyzed a ten storied building using the nonlinear time history analysis method. The main parameters which were considered were ductility, stiffness, damping and mass. The response parameters such as base shear, story drift, story displacement were taken into account. The work has been performed using the ETABS software.

^[5]Siddharth Y. Vekariya and Rajul K. Gajjar (2016) studied the performance based seismic design of multi - storied RCC buildings with diaphragm discontinuity with different shapes of opening diaphragm under the Design Basis Earthquake (DBE) and Maximum Considered Earthquake (MCE) by choosing the performance criteria in terms of Inter – Story Drift and Inelastic Displacement Demand Ratio. The openings in diaphragm reduced the capacity and produced higher drift at performance point.

III. PROBLEM STATEMENT

The current IS codes do not properly address the issue of seismic performance of tall buildings. These codes primarily assess life safety and are intended to control damage under the occurrence of minor and moderate earthquakes, prevent the collapse in case of major earthquake occurs. But the actual reliability of these codes is not known. So we need improved design procedures that result in better performance. Performance based approach for seismic design can help us to achieve these goals. Performance based approach has the ability to design building of any complexity from single-detached homes to high rise buildings and offices. Such an approach provides the freedom to develop tools and methods to evaluate the entire life cycle of the building processes, from the business dealings, to procurement, through construction and the evaluation of results. However, not much previous research was conducted on performance based approach of seismic design on tall building associated with diaphragms. Hence, this study was developed to study the performance based approach for seismic design of tall building diaphragms by checking the performance of the tall building at Service Level Earthquake and Maximum Considered Earthquake level using Response Spectrum Analysis, Nonlinear Time History Analysis and the effect of P-delta on Tall Building Diaphragms.

IV. THEORETICAL CONTENTS

4.1 Seismic Hazard

A seismic hazard is the probability that an earthquake will take place in a certain geographical area, within a given period of time and with a ground motion intensity exceeding a given value of threshold.

4.2 Seismic Zone Factor

Zone factors are based on the expected intensity of occurring earthquake in different zones. In IS Code, it is based on the Maximum Considered Earthquake (MCE) level and the service life of the structure in a zone. The IS Code considers 4 zones ranging from low to very severe seismic intensity, where the factor varies from 0.10 to 0.36.

Table 2 Seismic Zone Factor (Z)

Seismic Zone	II	III	IV	V
Factor (Z)	0.10	0.16	0.24	0.36

4.3 Importance Factor

Importance factor is introduced for the purpose of varying the degrees of importance for various types of structures. It is a factor that is used to obtain design seismic force depending on the functional use of the structure which is characterized by the precarious ramification of its failure, its need after post-earthquake, historic value or importance of economy.

Table 3 Importance Factor (I)

Sr. No.	Structure	I
i)	Important service and community buildings, such as hospitals; schools; monumental structures; emergency buildings like telephone exchange, television stations, radio stations, railway stations, fire station buildings; large community halls like cinemas, assembly halls and subway stations, power stations	1.5
ii)	All other buildings	1.0

4.4 Response Reduction Factor

Response Reduction Factor is the factor by which the actual base shear force should be reduced for the purpose of obtaining design lateral force during the design basis earthquake (DBE) shaking.

Table 4 Response Reduction Factor for Building System (R)

Sr. No.	Lateral Load Resisting Systems	R
	Building Frame Systems	
i)	Ordinary RC moment-resisting frame (OMRF)	3.0
ii)	Special RC moment-resisting frame (SMRF)	5.0

iii)	Steel frame with	
	a) Concentric braces	4.0
	b) Eccentric braces	5.0
iv)	Steel moment resisting frame designed as per SP 6	5.0
	Building with Shear Walls	
v)	Load bearing masonry wall buildings	
	a) Unreinforced	1.5
	b) Reinforced with horizontal RC bands	2.5
	c) Reinforced with horizontal bands and vertical bars at corners of rooms and jambs of openings	3.0
vi)	Ordinary reinforced concrete shear walls	3.0
vii)	Ductile shear walls	4.0
	Buildings with Dual Systems	
viii)	Ordinary shear wall with OMRF	3.0
ix)	Ordinary shear wall with SMRF	4.0
x)	Ductile shear wall with OMRF	4.5
xi)	Ductile shear wall with SMRF	5.0

4.5 Soil Type

The type of soil on which the structure is placed shall be identified by the classification given below:

- Soil Type I - Rock or hard soils
- Soil type II - Medium of stiff soils, and
- Soil Type III - Soft soils

4.6 Seismic Zonation Map of India

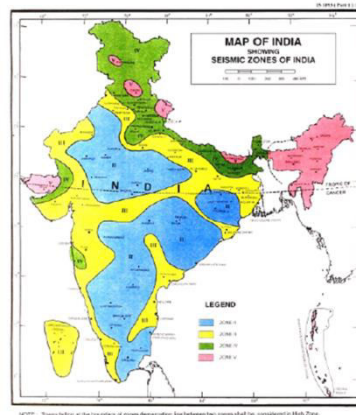


Figure 1 Seismic Zonation Map of India

The Geological Survey of India (G.S.I.) first published the seismic zonation map of India in the year 1935. With numerous modifications made afterwards, this map was initially based on the amount of damage suffered by the different regions of India due to the occurrence of earthquakes. The above map shows the four distinct seismic zones of India. Following are the various seismic zones of the nation, which are noteworthy shown in the map:

Zone II: Least active seismic zone

Zone III: Moderate seismic zone

Zone IV: High seismic zone

Zone V: Highest seismic zone

V. METHODOLOGY

The overall methodology includes performing seismic design of tall building with assignment of diaphragms using the new approach i.e. 'Performance Based Approach'. The performance of the building was explicitly checked at the Service Level Earthquake level (SLE) (43-year return period) using the Linear Response Spectrum analysis method and Nonlinear Time History analysis method. After that the performance of the tall building was checked at the Maximum Considered Earthquake (MCE) level (2475-year return period) using the Nonlinear Response History method and Linear Response Spectrum method. After that the performance of the diaphragms was checked at the Maximum Considered Earthquake (MCE) Level using this performance based design approach. Then the P-delta effect check of the tall building was carried out using a formula based excel sheet. The complete analysis and design of the tall building with diaphragms was done using the ETABS software.

VI. ANALYSIS WORK

The analysis work has been carried out in ETABS Software to check the performance of the tall building at Service Level Earthquake (SLE) level and at Maximum Considered Earthquake (MCE) level according to the Acceptance Criteria suggested by the Tall Buildings Initiative Pacific Earthquake Engineering Research Center.

In this present study, (G+26) story R.C.C Tall Building is considered with a panel of 68m X 18m. The building is situated in Seismic Zone IV with the following seismic, sectional and material properties. The model consists of various elements such as beams, columns, core shear wall for checking the performance against the acceptance criteria.

Table 5 Seismic, Sectional and Material Properties of Structure

Seismic Zone	IV
Soil Type	II
Importance Factor	1
Response Reduction Factor	5
Beam Size	300 mm x 500 mm
Column Size	500 mm x 500 mm
Slab	150 mm Thick
Wall	300 mm Thick
Concrete	M40
Rebar	Fe500

The typical plan and 3D view of the tall building are shown in figure below.

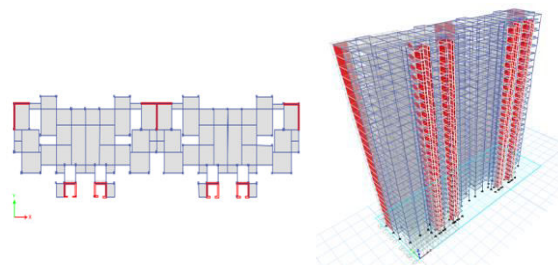


Figure 2 Plan and 3D View of Tall Building

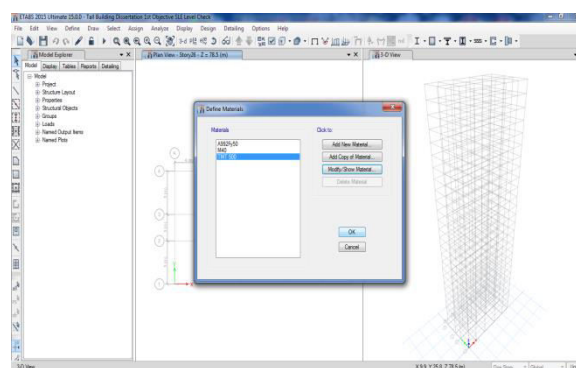


Figure 3 Defining the Materials

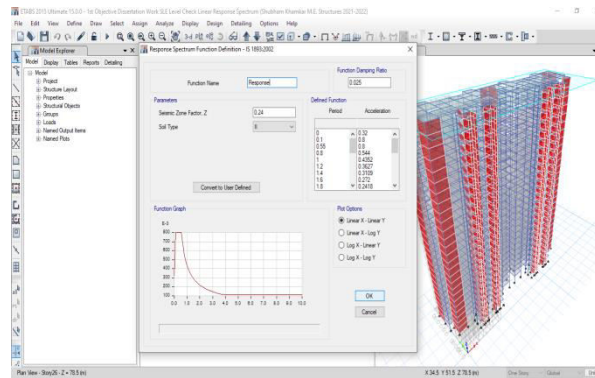


Figure 4 Defining the Response Spectrum Function

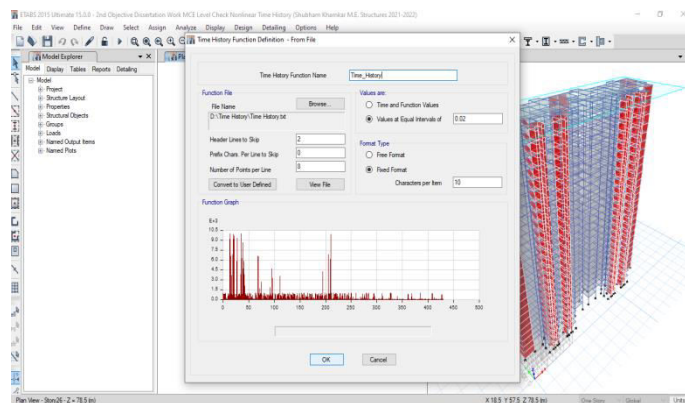


Figure 5 Defining the Time History Function

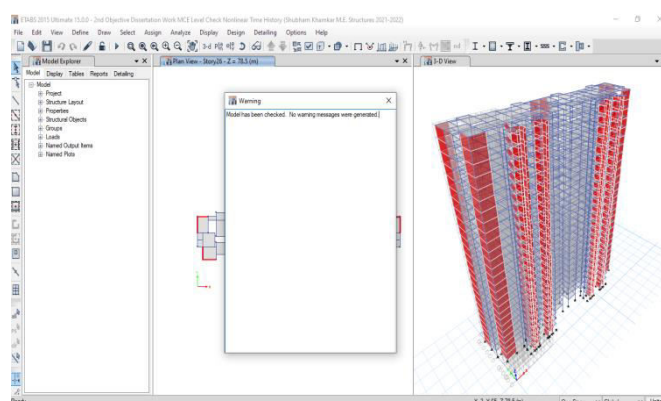


Figure 6 Model Checked. No errors or messages detected

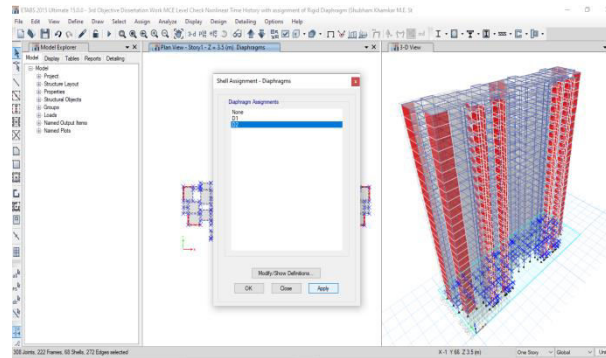


Figure 7 Assigning the Diaphragm to Tall Building

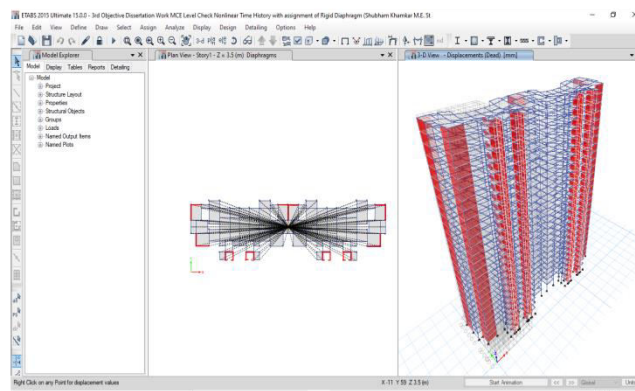


Figure 8 Analysis Completed.

VII. RESULTS AND DISCUSSION

1. Base Shear:

Base shear is the only distinguishing parameter of the normal biggest sidelong powers which can substitute place as an effect of the ground shaking at the base of the structure. The base shear avoid on the state of the site on which the structure needs to stand and furthermore the dirt strata which is in charge of moving burden and bearing the heaps. Here the value of base shear has been increased by 2.5 % with the help of Nonlinear Time History Analysis compared to Linear Response Spectrum Analysis.

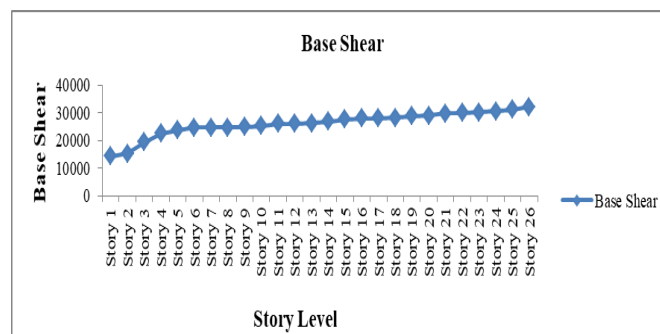


Figure 9 Graphical representation of Base Shear for Linear Response Spectrum Analysis

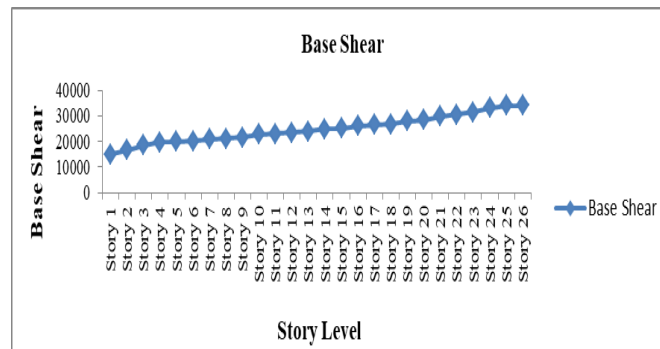


Figure 10 Graphical representation of Base Shear for Nonlinear Time History Analysis

2. Time Period:

The free vibration of the structure is undamped. The estimations of the time period are acquired by the investigation utilizing the Etabs software. As the structure is not comparative hence the nature of the time period is fluctuating. The time period has been increased by 4 % with the help of Nonlinear Time History Analysis compared to Linear Response Spectrum Analysis.

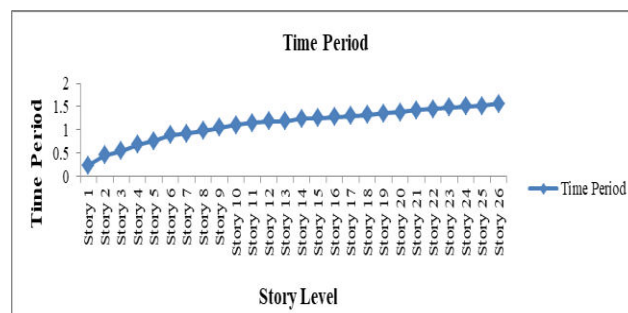


Figure 11 Graphical representation of Time Period for Linear Response Spectrum Analysis

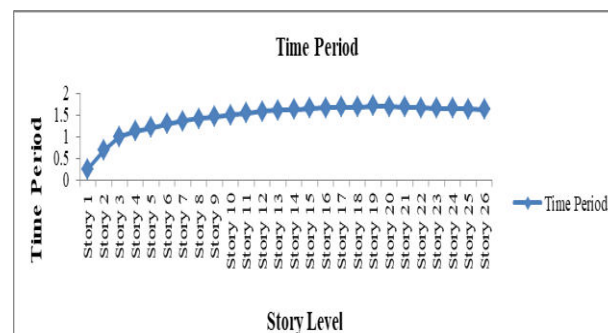


Figure 12 Graphical representation of Time Period for Nonlinear Time History Analysis

3. Story Drift:

The story drift is the lateral movement of the story with respect to its floor. The story drift value is obtained by performing analysis using ETABS with the help of using different analysis procedures. Here the story drift has been increased by 75 % with the help of Nonlinear Time History Analysis compared to Linear Response Spectrum Analysis. The story drift at both the levels (SLE and MCE Levels) is within the acceptable limits.

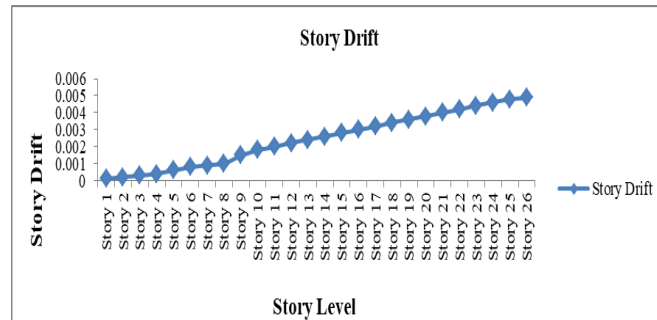


Figure 13 Graphical representation of Story Drift for Linear Response Spectrum Analysis

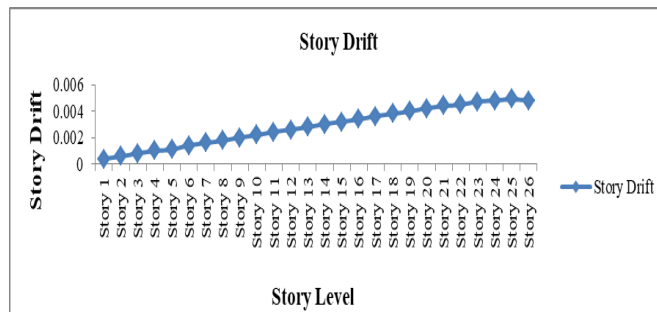


Figure 14 Graphical representation of Story Drift for Nonlinear Time History Analysis

4. Shear Force:

Shear force is the force acting on a substance in a direction perpendicular to the extension of the substance, acting in a direction to a planar cross section of the body. There is a rise in shear force by 23 % using the Nonlinear Time History Analysis compared to Linear Response Spectrum Analysis.

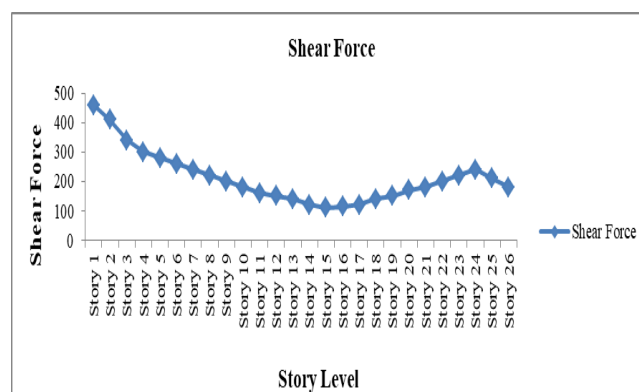


Figure 15 Graphical representation of Shear Force for Linear Response Spectrum Analysis

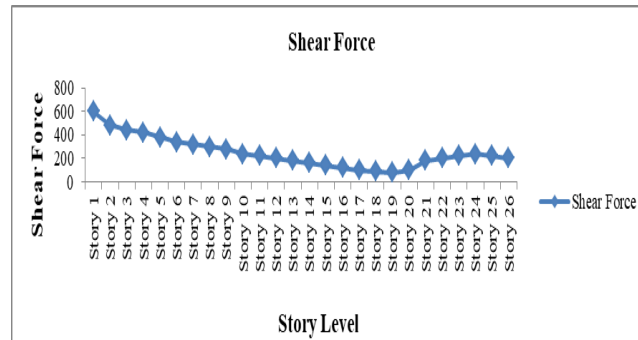


Figure 16 Graphical representation of Shear Force for Nonlinear Time History Analysis

5. Bending Moment:

Bending moment is the reaction induced in a structural element when an external force or moment is applied to the element, causing the element to bend. There is a rise in bending moment by 25 % using the Nonlinear Time History Analysis compared to Linear Response Spectrum Analysis.

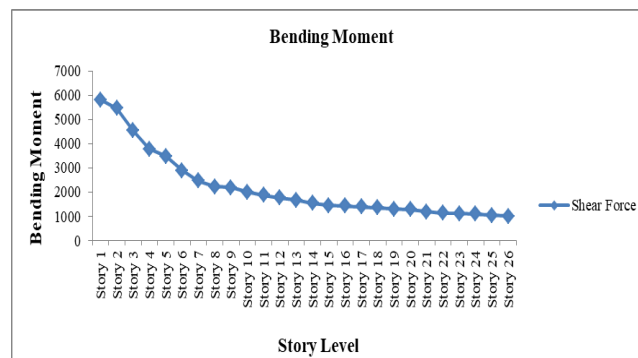


Figure 17 Graphical representation of Bending Moment for Linear Response Spectrum Analysis

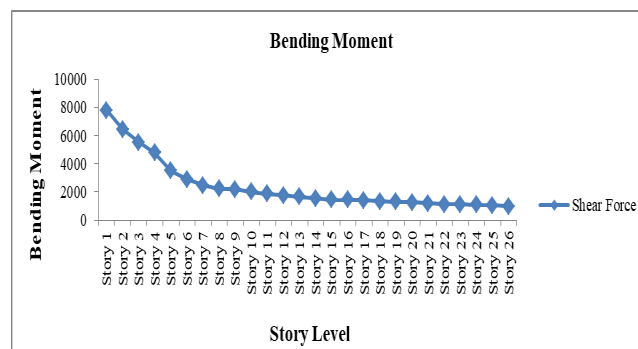


Figure 18 Graphical representation of Bending Moment for Nonlinear Time History Analysis

P-Delta effect:

The tall building was checked against the common P-delta effect using a formula based excel sheet. The tall building was safe against the P-delta effect. So it is not taken into account while the analysis and design of the building.

VIII. CONCLUSION

- [1] Performance based approach for seismic design explicitly checks the global and component responses of the tall building against the detailed acceptance criteria for multiple seismic events rather than applying the modification factors for estimating the deformation and forces under single code specified seismic demand level.
- [2] The performance based design approach apprehends the most authentic behavior of diaphragms under the influence of seismic design which can lead to better structural performance and cost effective design.
- [3] The proposed design method can also be used for achieving multiple performance objectives which satisfies the aspects such as Life Safety and Collapse Prevention performance objectives.
- [4] The increase of the diaphragm rigidity increases the total base shear of the tall building. As the height of building increases, base shear decreases. Due to the incorporation of shear wall into the tall building, the value of base shear was found to be increased by 2.5 % with the help of Nonlinear Time History Analysis compared to Linear Response Spectrum Analysis.
- [5] For a given height of building, if the numbers of storeys are increased then it gives high stiffness and hence less time period. The variation in the time period results shows that other factors also affect the time period of the tall building along with overall height and the base dimension of the tall building. There was an increase in time period by 4 % with the help of Nonlinear Time History Analysis compared to Linear Response Spectrum Analysis.
- [6] The story drift has been increased by 75 % with the help of Nonlinear Time History Analysis compared to Linear Response Spectrum Analysis.
- [7] There is a rise in shear force by 23 % using the Nonlinear Time History Analysis compared to Linear Response Spectrum Analysis.
- [8] There is a rise in bending moment by 25 % using the Nonlinear Time History Analysis compared to Linear Response Spectrum Analysis.
- [9] By using the performance based design approach, criteria's such as Story Drift and DCR Ratios were satisfied for both the SLE and MCE Levels..

IX. FUTURE SCOPE OF WORK

Within the limited scope of the present work, the broad conclusions drawn from this work have been reported. Further study can be undertaken in the following areas:

- [1] In the present study, the acceptance criterion for Story Drift and DCR has been considered. Further the study can be enhanced by extending the parameters such as bracings, diagrid systems.
- [2] Further the study can be carried out by considering the comparison of other parameters such as joint displacements, natural frequency, etc. with and without the action of diaphragms.

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