International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 05 | May 2022 www.irjet.net p-ISSN: 2395-0072

Performance Based Approach for Seismic Design of Tall Building Diaphragms

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Abstract - The construction industry is always trying to find out innovative and better technology in the field design sector. The performance-based design technique for seismic design has the ability to signify higher levels of performance for a structure at various intensities of a seismic event.

In the present work, the performance of the tall building has been checked against the Service Level Earthquake (SLE) and the Maximum Considered Earthquake (MCE) 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 the shear wall into the tall building, the value of Base Shear was found to be increased by 2.5 % with the help of Nonlinear THA (Time History Analysis) compared to Linear RSA (Response Spectrum Analysis). There was an increase in time by 4 % with the help of Nonlinear THA compared to Linear RSA. The Story Drift has been increased by 75 % with the help of Nonlinear THA contrasted to the Linear RSA. There is a rise in Shear Force by 23 % using the Nonlinear THA compared to the Linear RSA. The Bending Moment was found to be increased by 25 % using the Nonlinear THA compared to the Linear RSA.

Key Words: **Performance based approach, Seismic design, Diaphragms, SLE Level, MCE Level.**

1. INTRODUCTION

Performance-based design is an advanced technique for seismic-resistant structures that was widely employed in the assessment of existing buildings and the seismic design of several new tall buildings. The structural over-strength factor is increased by seismic forces to predict the greatest forces in elastic parts, such as diaphragms, in the design. The purpose of these elements is to make simple the process of structural design with the help of using elastic analysis methodologies. These approaches do not take into account structural performance at the ground motion characteristics, component level, and the seismic redistribution requirements in different parts of the building in the case of inelastic behavior during significant seismic occurrences.

An approach known as performance-based seismic design uses certain ground motion and reliability parameters to create a structural system that is not damaged beyond a predetermined point during an earthquake. Under the particular ground motion, a performance level depicts a damage situation that is regarded as suitable for a certain structure. It has led to a new perception of the tall building's seismic design, founding a smart take off in analysis & evaluation techniques from the prescriptive force-based design methods on the basis of linear elastic analysis under the action of decreased seismic loads and the principles of capacity design, to the non-prescriptive displacement-based design approaches on the basis of nonlinear analysis and performance assessments w.r.t. the demand parameters which are expected. Buildings may be constructed not just to protect people but also to allow for ongoing occupancy and operation after an earthquake. This method permits a building operator/owner of the building to choose an acceptable degree of building damage for certain earthquake ground shaking intensity which may then be used as a target or goal for the seismic design effort.

Seismic Performance Objectives:

Table 1 shows the precise performance criteria for the design of buildings at two stages of seismic risks.

Table 1 Objectives for Seismic Performance

Earthquake Level	Objectives for Seismic Performance
Frequent/Service: 50% likelihood of exceeding in 30years (43year return time), 2.5percent structural damping.	Serviceability: The structure's ability to endure future disasters must not be impacted by minor structural damage. Earthquake shaking is deemed to be the highest, even if it is not rectified.

MCE: 2% chance of exceeding 50 years (2475-year return duration) with structural damping between 2% and 3%.	Preventing Collapse: The building could be on the brink of entire or partial collapse, with substantial structural problems; repairs are necessary but might not be economically possible.

Acceptance Criteria:

At the SLE Level, various criteria 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 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 the economy. Tall buildings can reduce urban sprawl on the ground level, boost urban density, and house a high number of people in a small amount of area. According to IS 16700: 2017, a building that is greater than 50 m but less than or equal to 250 m is considered a tall building.

1.2 Diaphragms

Diaphragms in structural engineering transfer lateral loads to the structure's vertical resisting components, including shear frames or walls. In-plane shear stress is the primary mechanism by which diaphragm forces are transmitted to the vertical resisting parts. The most common lateral loads to be resisted are those caused by wind or earthquakes, although other lateral loads, including lateral hydrostatic or earth pressure, may also be resisted by the diaphragm's action. 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 enhance the structural performance along with cost-efficiency in the design of Tall Building Diaphragms under 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 SLE level (43year return period) using Nonlinear THA and Linear RSA.

2. To check the Tall Building performance at the MCE level (2475year return period) by Linear RSA and Nonlinear THA

3. To check the performance of the Diaphragms at Maximum Considered Earthquake Level.

4. To check the Tall Building against the P-delta effect.

2. LITERATURE SURVEY

[1] S. S. Sanghai and Akshay Nagpure (2018) studied the influence of diaphragm adaptability on the seismic response of R.C.C. framed buildings by taking the diaphragm discontinuity. In this research, R.C.C. framed building structures were being analyzed with the help of ETABS software. By varying the floor's flexibility and when plan abnormalities were given the linear THA was performed. The structure's reactions were compared when the floor diaphragm's flexibility was modified and plan imperfections were added at the same time.

[2] Ankan Kumar Nandi and Jairaj C (2020) focused on the “backstay effect”, i.e., the podium structural contact with the tower region, and regarded a retaining wall as a “lateral stiffness” increase as required in the newest tall building code IS 6700:2016 for high as well as low rise buildings. They prepared the models with low to high rise stories by using flexible and rigid diaphragms considering the diaphragm at the backstay placing the tower at the center and the corner. They also studied the structural responses such as inter-story drift, displacement, base shear, and natural periods.

[3] Erhan Budak and Haluk Sucuoglu (2017) studied the performance-based seismic design of reinforced concrete tall buildings. The tall structure’s behaviour under seismic influences is significant since the impact of seismic loading is among the most well-understood issues in earthquake engineering. The Turkish Seismic Code was used to create a 34-story reinforced concrete unsymmetrical tall structure. Applying a ground set of movements to verify the findings in accordance with the established goal performance levels, a Nonlinear THA was performed for both the levels of service and maximum earthquake. The findings showed that by using a performance-based approach satisfactory seismic performance can be obtained.

[4] Sumit Gupta and Kaushal Vijay Rathod (2020) analyzed a ten-storied building using the Nonlinear THA method. The main parameters which were considered were mass, damping, stiffness, and ductility. The response variables like story drift, story displacement, as well as base shear 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 R.C.C. buildings with diaphragm discontinuity with numerous

shapes of the opening diaphragm under the DBE ("Design Basis Earthquake") and MCE by selecting the performance standards in terms of Inter–Story Drift as well as "Inelastic Displacement Demand Ratio". The openings in the diaphragm reduced the capacity and produced higher drift at the performance point.

3. PROBLEM STATEMENT

The current IS codes do not properly address the issue of the seismic performance of tall buildings. These codes primarily assess life safety and are intended to control damage under the occurrence of small & moderate earthquakes, as well as avoid collapse in case of earthquake occurs. But the definite reliability of these codes is not known. So, we need improved design procedures that result in better performance. The performance-based approach to seismic design can help us to achieve these goals. The performance-based approach has the ability to design buildings of any complexity from single-detached houses to high-rise buildings and offices. Such an approach allows for the development of tools and methodologies to assess the full life cycle of building processes, from commercial transactions through procurement, construction, and assessment of outcomes. However, not much previous research was conducted on the performance-based method of seismic design on tall buildings associated with diaphragms. Hence, this study was developed to study the performance-based method of seismic design on tall building diaphragms by checking the performance of the tall building at Service Level Earthquake and Maximum Considered Earthquake level using Nonlinear THA, Response Spectrum Analysis, and the effect of P-delta on Tall Building Diaphragms.

4. THEORETICAL CONTENTS

4.1 Seismic Hazard

It is a possibility that an earthquake will take place in a certain geographical region, within a specified period, and with ground motion intensity greater than a specified value of the threshold.

4.2 Seismic Zone Factor

Zone factors are based on the estimated magnitude of occurring earthquakes in various regions. The MCE level and the service life of the building in a zone are used in IS Code. The IS Code analyses four seismic intensity zones ranging from low to extremely severe, with factors ranging from 0.10 to 0.36.

Table 2 Seismic Zone Factor (Z)

Seismic Zone	2^{nd}	3^{rd}	4^{th}	5^{th}
Factor (Z)	0.10	0.16	0.24	0.36

4.3 Importance Factor

It is employed to differentiate the degrees of importance for different sorts of structures. It is a factor that is applied to calculate design seismic force on the basis of functional usage of the structure, which is described by the precarious ramification of its failure, the requirement for the building after the earthquake, economic importance, or historic value.

Table 3 Importance Factor (I)

Sr. No.	**Structure**	**I**
i)	Community buildings and essential services like monumental structures, schools, hospitals emergency buildings such as fire station buildings, railway stations, radio stations, television stations, a telephone exchange, big community halls such as assembly halls, cinemas, power stations, & subway stations	1.5
ii)	All other buildings	1.0

4.4 Response Reduction Factor

It is a factor that reduces the real base shear force in order to attain design lateral force during DBE shaking.

Table 4 Response Reduction Factor for the Building System (R)

Sr. No.	**Lateral Load Resisting Systems**	**R**
	Frame Systems for Buildings	
i)	OMRF ("Ordinary RC Moment-Resisting Frame")	3.0
ii)	SMRF ("Special RC Moment-Resisting Frame")	5.0

Sr. No.	Lateral Load Resisting Systems	R
iii)	Steel frame with a) Eccentric braces b) Concentric braces	 5.0 4.0
iv)	SP 6 specifies the design of a steel moment-resisting frame.	5.0
	Building using Shear Walls	
v)	Load-bearing masonry wall buildings a) Reinforced with vertical bars and horizontal bands at jambs of openings and corners of rooms b) Reinforced with horizontal RC bands c) Unreinforced	 3.0 2.5 1.5
vi)	Ordinary reinforced concrete shear walls	3.0
vii)	Ductile shear walls	4.0
viii)	Buildings with Dual Systems	
ix)	Ordinary shear wall using OMRF	3.0
x)	Ordinary shear wall using SMRF	4.0
xi)	Ductile shear wall using OMRF	4.5
xii)	Ductile shear wall using SMRF	5.0

4.5 Soil Type

The categorization provided below will identify the kind of soil on which the structure is placed.

a) Type 1 soil - hard or rock soils.

b) Type 2 soil - Medium stiff soils, and

c) Type 3 soil - soft soils

4.6 Seismic Zonation Map of India

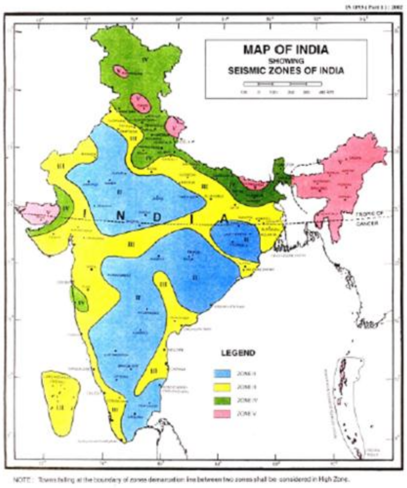

Figure 1 India's Seismic Zonation Map

The 1st India seismic zonation map was produced in 1935 with G.S.I. ("Geological Survey of India"). With numerous adjustments made afterward, this map was initially dependent on the amount of damage experienced by various areas of India owing to the occurrence of earthquakes. The above map indicates the 4 different seismic areas of India. Following are the various seismic areas of the nation, which are noteworthily revealed on the map:

Zone 2nd: Least active seismic zone

Zone 3rd: Moderate seismic zone

Zone 4th: High seismic zone

Zone 5th: Highest seismic zone

5. METHODOLOGY

The overall methodology includes performing seismic design of tall buildings with the assignment of diaphragms using the novel approach i.e. 'The Performance-Based Approach'. The building performance was explicitly verified at the SLE (43-year return period) using the Linear RSA method and the Nonlinear THA method. After that, the performance of the tall building was verified at the MCE level (2475year return period) using the Nonlinear Response History method and Linear Response Spectrum method. After that, the performance of the diaphragms was verified at the 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 were done using the ETABS software.

6. ANALYSIS WORK

The analysis work has been carried out in ETABS Software to verify the tall building's performance at the SLE and 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, and core shear walls for checking the performance against the acceptance criteria.

Table 5 Seismic, Sectional and Material Properties of Structure

Seismic Zone	IV
Soil Form	2
"Response Reduction Factor"	5
Importance Factor	1
Wall	300mm Thick
Slab	150mm Thick
Column Size	500x 500mm
Beam Size	300x 500 mm
Concrete	M40
Rebar	Fe500

The typical plan and three-dimensional view of the tall building are demonstrated in the figure below.

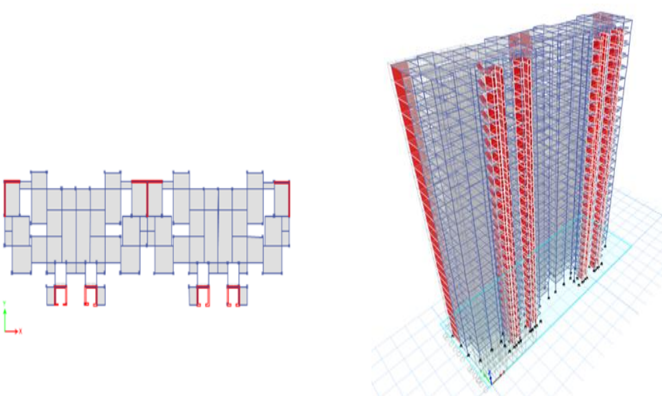

Figure 2 Plan and 3D View of Tall Building

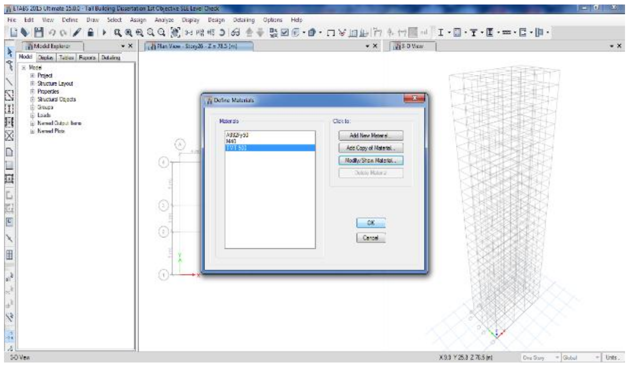

Figure 3 Defining the Materials

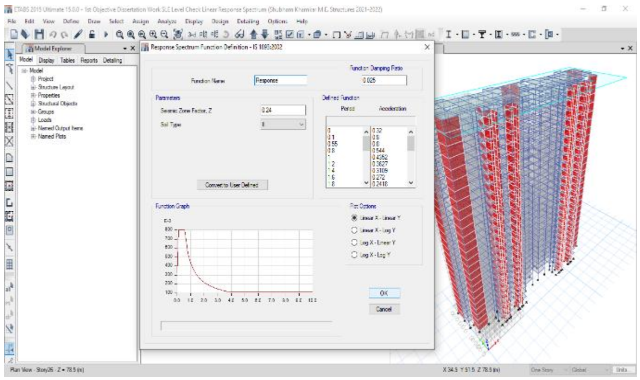

Figure 4 Defining the Response Spectrum Function

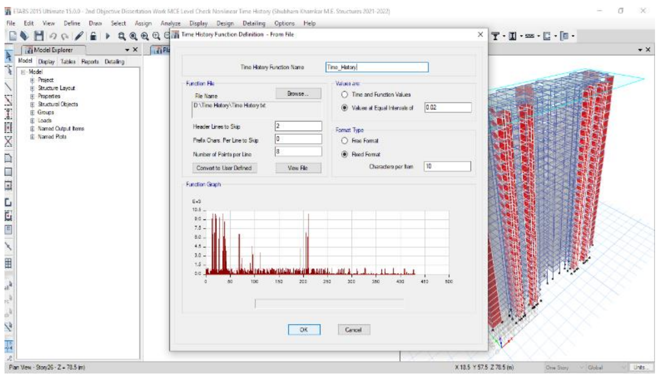

Figure 5 Defining the Time History Function

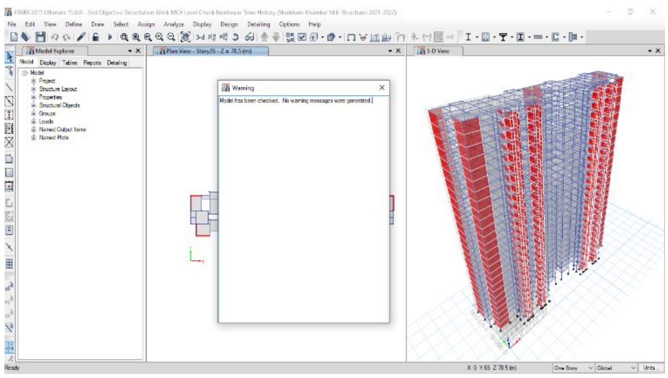

Figure 6 Model Checked. No errors or messages detected

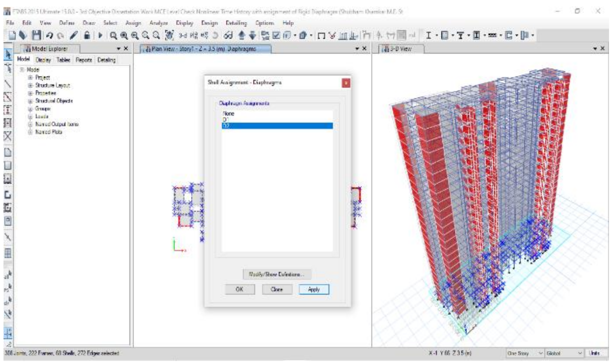

Figure 7 Assigning the Diaphragm to Tall Building

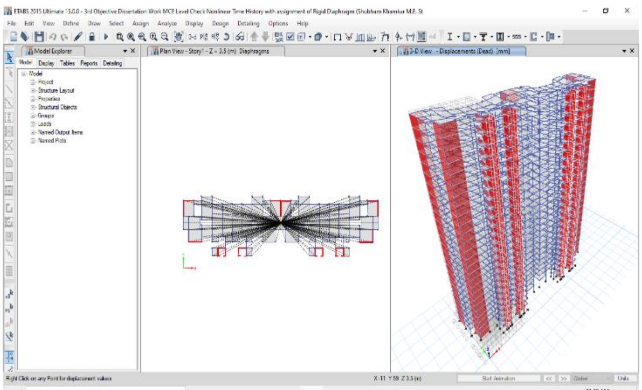

Figure 8 Analysis Competed.

7. 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 structure base. The base shear avoids 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 THA compared to Linear RSA.

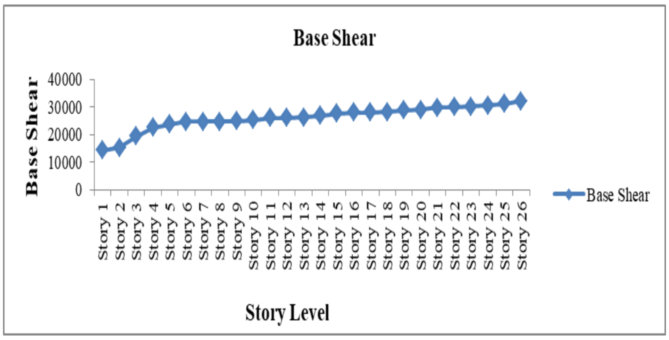

Figure 9 Graphical illustration of Base Shear for Linear RSA.

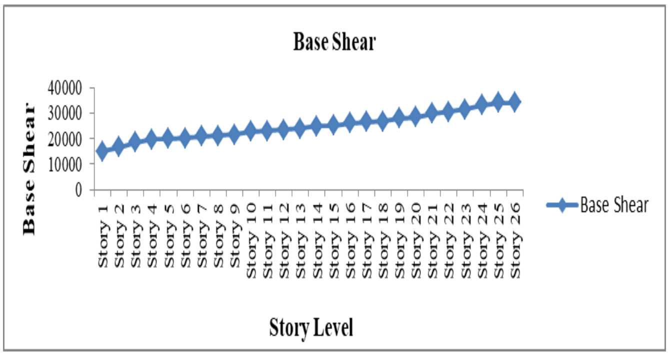

Figure 10 Graphical representation of Base Shear for Nonlinear THA

2. Time Period:

The free vibration of the structure is undammed. 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 THA compared to Linear RSA.

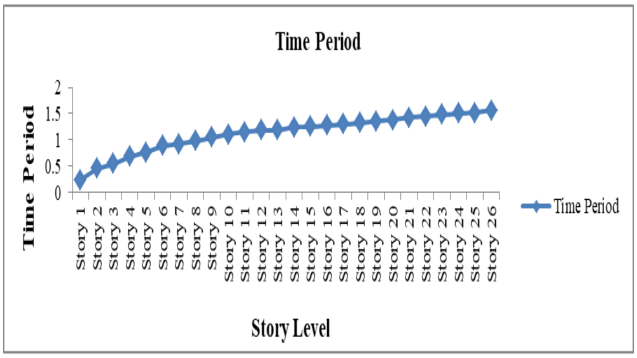

Figure 11 Graphical representation of Time Period for Linear RSA.

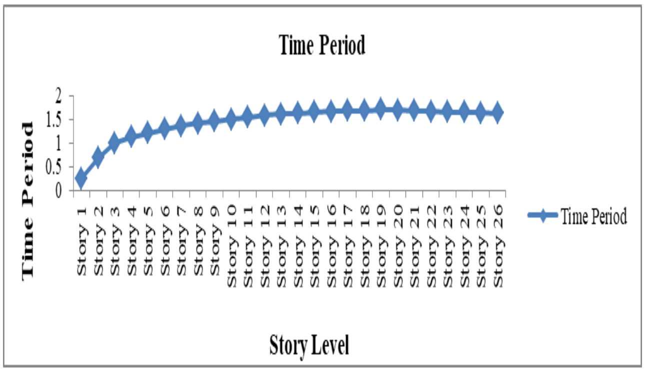

Figure 12 Graphical representation of Time Period for Nonlinear THA

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 THA compared to Linear RSA. The story drift at both the levels (SLE and MCE Levels) is within the acceptable limits.

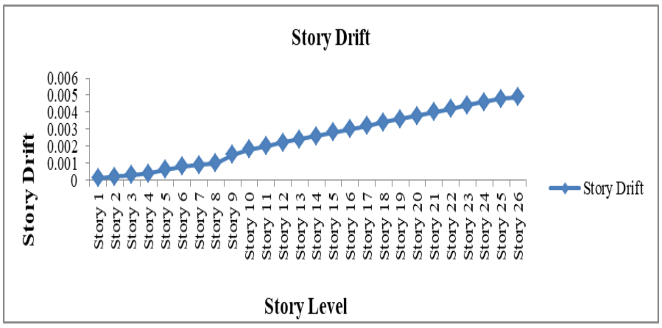

Figure 13 Graphical representation of Story Drift for Linear RSA

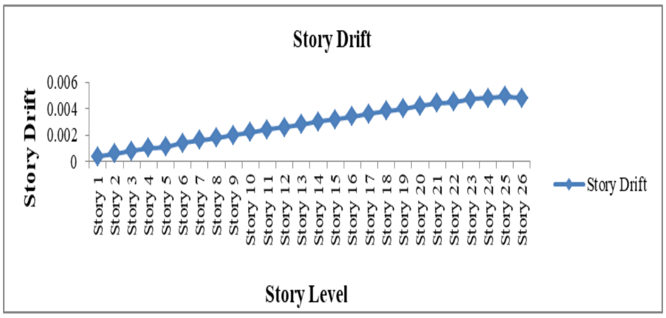

Figure 14 Graphical representation of Story Drift for Nonlinear THA

4. Shear Force:

It is the force applied to a material in a direction perpendicular to its extension and parallel to its cross-section. There is a rise in shear force by 23 % using the Nonlinear THA compared to Linear RSA.

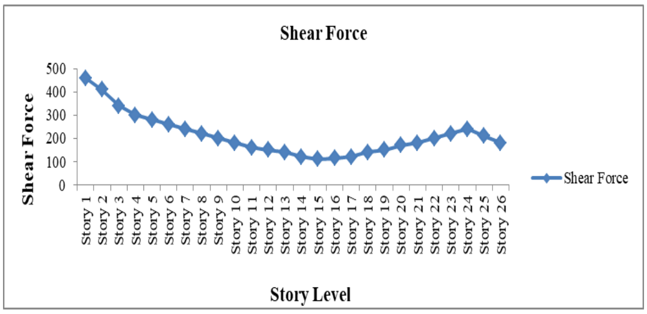

Figure 15 Graphical representation of Shear Force for Linear RSA

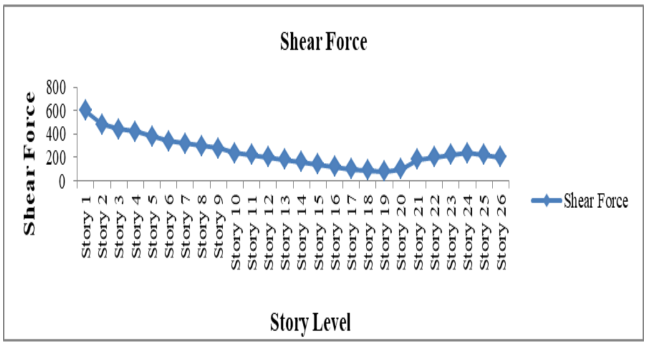

Figure 16 Graphical representation of Shear Force for Nonlinear THA

5. Bending Moment:

It is a response caused in a structural element by the application of an external moment or force that causes the element to bend. There is a rise in bending moment by 25% using the Nonlinear THA compared to Linear RSA.

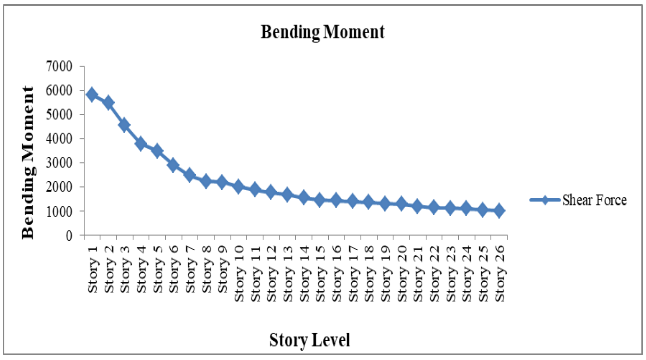

Figure 17 Graphical representation of Bending Moment for Linear RSA

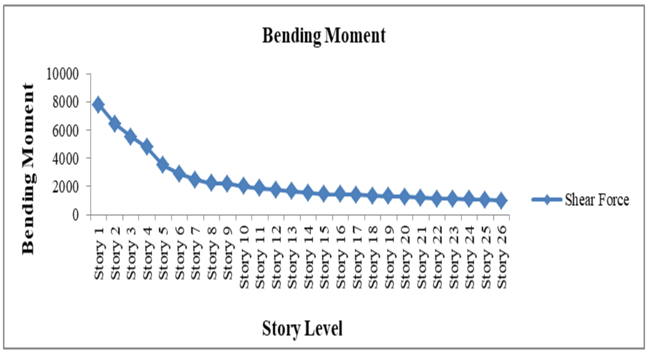

Figure 18 Graphical representation of Bending Moment for Nonlinear THA

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 considered while the analysis and design of the building.

8. CONCLUSION

[1] Performance-based approach for seismic design explicitly checks the global & component responses of the tall building against the comprehensive acceptance standards for numerous seismic events instead of applying the "modification factors" for estimating the deformation and forces under a single code identified seismic requirement level.

[2] The performance-based design approach apprehends the most authentic behavior of diaphragms under the influence of seismic design which may lead to better "structural performance" as well as cost-effective design.

[3] The proposed design method can also be used for achieving multiple performance objectives which satisfy the aspects like Life Safety & Collapse Prevention performance objectives.

[4] The increase of the diaphragm rigidity increases the total base shear of the tall building. As the building's height rises, base shear decreases. Due to the incorporation of the shear wall into the tall building, the value of base shear was found to be increased by 2.5 % with the help of Nonlinear THA compared to Linear RSA.

[5] For a given building's height, if the number of stories is 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 the time period by 4 % with the help of Nonlinear THA compared to Linear RSA.

[6] The story drift has been increased by 75 % with the help of Nonlinear THA compared to Linear RSA.

[7] There is a rise in shear force by 23 % using the Nonlinear THA compared to Linear RSA.

[8] There is a rise in bending moment by 25 % using the Nonlinear THA compared to Linear RSA.

[9] By using the performance-based design approach, criteria such as Story Drift and DCR Ratios were satisfied for both the SLE and MCE Levels.

8.1. FUTURE SCOPE OF WORK

The main results gained from this study have been given within the confines of the current work. The following areas may be studied further:

[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, and 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.

ACKNOWLEDGEMENT

A special thanks to my Guide Dr. Atul Bhimrao Pujari for introducing the present topic and for guiding me morally to work on it conveniently. His dedicated participation, regular guidance and support provided me to maintain my progress in track and made me liable to achieve my objectives.

I would also like to thank K J College of Engineering and Management Research, Pune for providing me all the facilities and support for doing this research work.

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