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Performance Based Approach for Seismic Design of Tall Building Diaphragms

[1]Shubham D. Khamkar , [2]Dr. Atul B. Pujari

[1]PG Student, Department of Civil Engineering,

K J College of Engineering and Management Research, Pune 411048, India

[2]Associate Professor, Department of Civil Engineering,

K J College of Engineering and Management Research, Pune 411048, India

Corresponding author E-mail : shubhamdkhamkar@gmail.com

Abstract

Construction industry is always trying to find new and better technology in the field of design sector. One such technology is the Performance Based Approach for Seismic Design which is a structural design methodology that brings flexibility in the process of design and offers design opportunities to enhance the performance of the building with encouraging innovation. The use of this performance based design approach for seismic design is its ability which it has to demonstrate higher levels of performance for a structure at various intensities of a seismic event. Due to these demands, the design of structures has not been limited to a certain extent but has led to a number of highly efficient tall building designs that would not be possible with a traditional code-based prescriptive approach.

Most of the studies showed that the need of tall buildings is increasing now days all over the world. Tall buildings are different than regular buildings due to their special architectural features and configurations. Generally, most of the tall buildings are located in the areas of high seismicity. Materials having high strength and innovative structural systems are needed to be developed to resist the challenges created by construction the tall buildings in regions of high seismicity.

In present work, a (G+26) storied building has been considered for the study. The work has been carried out with the help of ETABS software. The performance of the tall building has been checked against the Service Level Earthquake Level and the Maximum Considered Earthquake Level criteria by performing the linear and nonlinear procedures without the assignment of Diaphragms. After that, the performance of the tall building has been checked at the Maximum Considered Earthquake Level by assigning the Rigid and Semi-Rigid Diaphragms. The tall building has been checked against the common P-delta effect using a formula based excel sheet.

Keywords*: Performance based approach, tall building, Diaphragms, SLE Level, MCE Level, P-delta effect.*

1. Introduction

In the conventional method of designing a building structure for seismic forces (design based on forces), an equivalent seismic base shear is calculated based on the estimated fundamental period of the structure and an elastic response spectrum that represents the seismicity of the site. The value of the design base shear is dependent on height (period), type, location, and importance of the structure as well as on the nature of foundation soil. The value for shear is adjusted for taking into consideration the ductility capacity of the structure and its over-strength. After that it is distributed along its height with the help of an empirical relationship for determining its story level forces. It is now being recognized that the performance of a structure during the occurrence of an earthquake is a function of the ductility demand which is placed on it, or on the displacements. The method of design which is based on forces, which controls the strengths and indirectly the displacements, is not able to produce a uniform level of performance and so concerns have been expressed regarding the dependability and economy of this based method which is being used currently. In this study, a new method of design based on displacement will be put forth that could be used to design any structural system. The method can also be used for assessing the performance of any structure. By using a displacement-based method at various levels of hazard, the performance which is desired at each level of hazard can be achieved. From this point of view, displacement based design method could be considered as the main part of performance based design.

Performance based seismic design of tall buildings are generally based on the approach which consists of a preliminary design stage based on the capacity design principles under design earthquakes with a return period of 475 years (moderate years), followed by the two stages of performance evaluation, check of collapse prevention and service level, respectively. Service level evaluation stage checks the structure under the high probability of occurrence (frequent earthquakes) with return periods of 43-72 years (small to moderate earthquakes). Collapse prevention evaluation stage helps to check the structure hit by rare earthquakes with a return period of 2475 years (severe earthquakes). In the first stage of evaluation, it is generally preferable that the tall buildings remain essentially elastic. Linear response spectrum analysis is preferably utilized for this stage since the permanent damage is not appreciated; however it may be resorted to nonlinear response history analysis. In the second stage of evaluation the performance target is maintaining stability under expected strong earthquakes, namely these structures must be prevented against the action of collapse.

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 Objective**
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:

Detailed local acceptance criteria has been considered for the structural and non-structural elements in the performance based design which includes the process of checking element-by-element rather than the overall system R factor as used in the conventional design of new buildings.

Table 2 Acceptance Criteria (Service Level)

Item	**Limit**
Story Drift	0.5 percent
Core Wall Shear	Remain essentially elastic
Columns	Remain essentially elastic

The essentially elastic behavior is defined as not more than 20 % of the elements are ductile actions having a D/C ratio between 0 and 1.5. No elements are allowed to have a D/C ratio > 1.5.

Table 3 Acceptance Criteria (MCE Level)

Item	**Limit**
Story Drift	3 percent

According to IS 16700: 2017, a building greater than 50 m but less than or equal to 250 m is considered as a tall building. Also a building is considered as a tall one when it extends higher than the maximum reach which is available to fire fighters.

In structural engineering, a diaphragm is an element of structure that transmits lateral loads to the vertical resisting elements of a structure such as shear walls or frames. Diaphragms are typically horizontal but they can be varied at an angle such as in a gable roof on a wood structure or concrete ramp in parking garage. The diaphragm forces tend to be transferred to the vertical resisting elements primarily through in-plane shear stress. The most common lateral loads to be resisted are those which are resulted 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. The three types of diaphragms are namely Rigid Diaphragm, Semi-Rigid Diaphragm and Flexible Diaphragm.

2. Literature Review

[1]Dalal Sejal P, Vasanwala S A et.al evaluated the performance based seismic design on structure. They stated that Performance Based Seismic Design is an elastic design methodology which is done on the basis of potential performance of the building under different ground motions. The derivative of the PBSD method, which is known as the Performance Based Plastic Design (PBPD) method which has been widely recognized as an ideal method for use in the future practice of seismic design was also reviewed and discussed.

[2]J. P. Moehle studied the performance based approach for tall buildings in the US. He stated that for the application of performance based procedures understanding the relation between the performance and nonlinear response, selection and manipulation of ground motions which are suitable for the seismic hazard, interpretation of results to determine design quantities based on nonlinear dynamic analysis procedures is necessary.

[3]M. Firoj and S. K. Singh studied the Response Spectrum analysis for Irregular Multi – Storied structure in Seismic Zone V. In this study, a (G+10) storied building was analyzed with the help of Response Spectrum by using three different computer software's i.e. ETABS, STAAD Pro and SAP 2000. They studied the displacements of joints, time period, axial forces and the mass participating factors. The design response spectrum curve suggested by the IS: 1893 Part – I for seismic design was utilized for the purpose of performing the dynamic analysis.

[4]Sardasht Sardar and Ako Hama investigated the effect of P-delta in seismic response of structures with different heights. For indicating the effect of P-delta, the nonlinear static analysis i.e. the Pushover analysis and nonlinear dynamic analysis i.e. the Time History analysis were performed. The result showed that the P-delta has a significant impact on the behavior of structure mainly on the amplitude of peak of the building when the height of the structure is increased.

3. Overall Methodology

The overall methodology consisted of performing seismic design of tall building diaphragms using the new approach i.e. 'Performance Based Approach'. For the first stage of evaluation, 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. In the second stage of evaluation the performance of the building was checked at the Maximum Considered Earthquake (MCE) level (2475-year return period) using the Nonlinear Response History 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. The complete analysis and design of the tall building with diaphragms was done using the ETABS software.

4. Analysis Work

In this present study, (G+26) story R.C.C Tall Building is considered with a panel of 24m X 13m. The modeling work is done in ETABS. 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

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Table 4 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

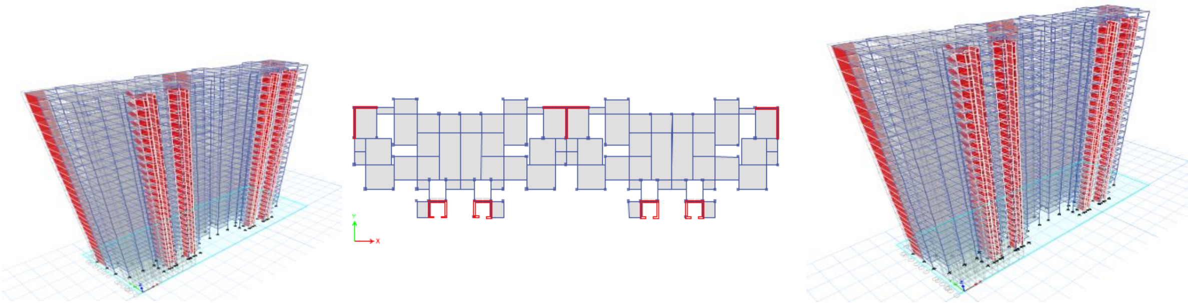

Figure 1 Plan and 3D view of Tall Building

5. Results

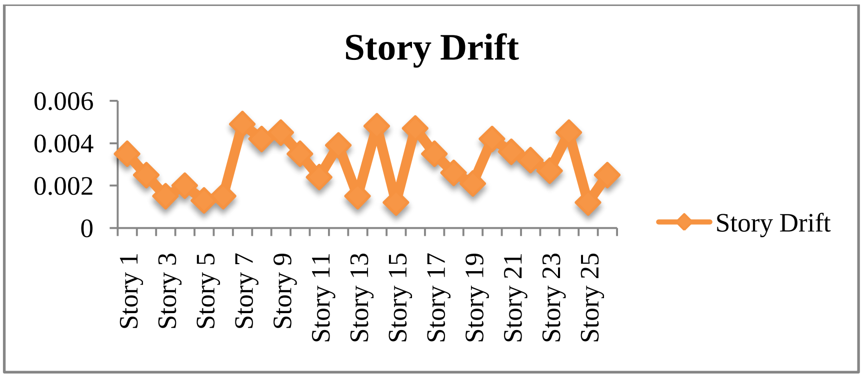

Figure 2 Maximum Story Drift for SLE Level < 0.5 %

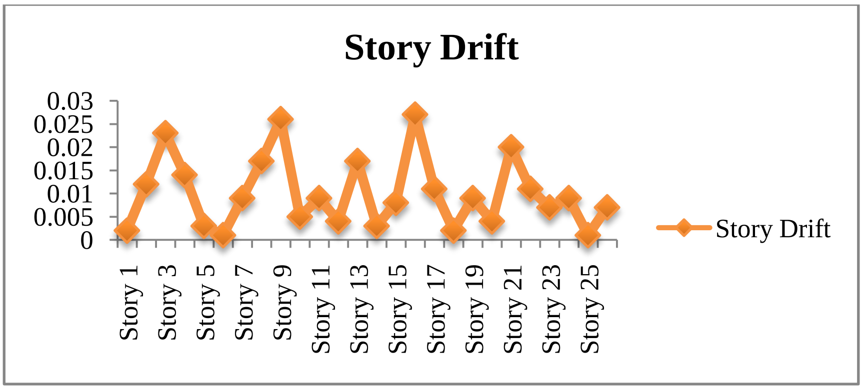

Figure 3 Maximum Story Drift for MCE Level < 3 %

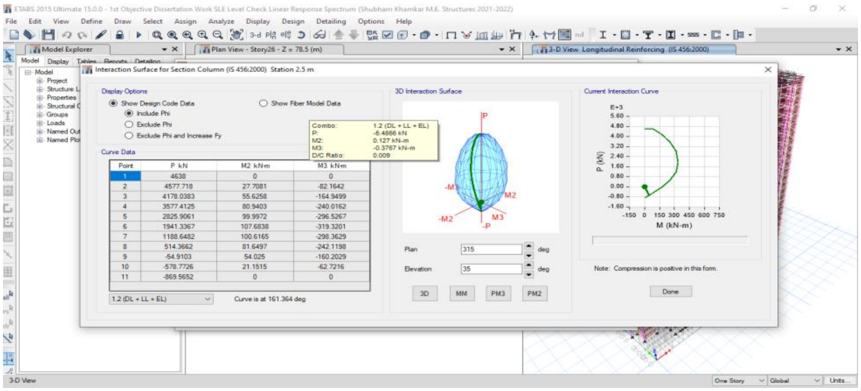

Figure 4 D/C < 1.5. Members remain essentially elastic

6. Conclusion

The performance based design approach captures the most reliable behavior of diaphragms under the action of seismic design which can lead to better structural performance and cost effective design. The proposed design method can be used for achieving multiple performance objectives satisfying both Life Safety and Collapse Prevention performance objectives. By using the performance based approach for seismic design of tall building, the acceptable criteria's for Story Drift and DCR Ratios were satisfied.

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