JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

A Comparative study on response of RC Column with Different Slab System in Seismic Zones using Pushover Analysis

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Abstract : The research work is mainly aimed to study the behavior of columns when the structure is subjected to seismic loading conditions. Columns when loaded with seismic loads come under the category of columns with axial loading and biaxial bending. In this state, line of action of axial load will be eccentric to the longitudinal centroidal axis of the member.

A major part of previous researches done on the seismic analysis majorly covers the response of whole structure resisting lateral loads including wind and/or seismic loads. So, in this project the main focus is on the behavior of columns subjected to seismic effects. Pushover analysis method has been adopted for studying the response of the structure. The columns adopted for analysis are RCC columns. These have been analyzed under the variance of slab systems i.e., flat slab and conventional slab system with beams. These models have been analyzed under influence of earthquake loading conditions. Indian standard codes have been adopted for both static and dynamic analysis and design which has been carried out by using ETABS FEM software.

***Index Terms* – Compression members, Pushover Analysis, Flat Slabs.**

INTRODUCTION

Structural Engineers see design and analysis as fundamentally different but complementary tasks. Several conditions that must be made to model a structure using modern hand tools (softwares) almost ensure that the model will deviate from its actual geometry in some way. Hence, from a structural engineer's point of view, the purpose of design is to establish a structural system, which can be confidently implemented rather than just providing a precise characterization of what is to be expected while in service. The shift toward nonlinear analysis has removed much of the doubt that was present when only linear analysis was available; as the ability to model the structure continue, the results will become more accurate as uncertainties will reduce with non-linear analysis.

Columns come under the category of compression members. Columns are the vertically placed components in the frame which resist the axial or longitudinal load applied on them through slabs, beams etc. Unlike beams, the main reinforcement used in RC columns will be used to oppose compressive forces only. As per IS code, column is a compression member whose effective length is greater than three times the least lateral dimension otherwise the member is known to be a pedestal. Columns (having non-symmetric axial loading pattern) under the seismic loading conditions come under the category of columns with axial loading and biaxial bending. In this state, the line of action of axial load will be eccentric to the longitudinal centroidal axis of the member.

This eccentricity in loading is produced due to eccentricity in the action of earthquake which even displaces the loading on the column far away from its center. The higher the magnitude of earthquake, more will be the eccentricity and hence the column faces in-plane bending moments.

Indian Standard code suggests simplified procedure for the design of columns under bi-axial eccentric loads using Brewster's formula expressed as:

$$\left[\frac{M_{ux}}{M_{ux1}}\right]^{a_n} + \left[\frac{M_{uy}}{M_{uy1}}\right]^{a_n} \leq 1$$

Where M_{ux} and M_{uy} are the factored biaxial bending moments on the column and M_{ux1} and M_{uy1} are the uniaxial moments capacities of the column with respect to major and minor axes respectively. a_n is the constant which depends upon the factored load "P_u".

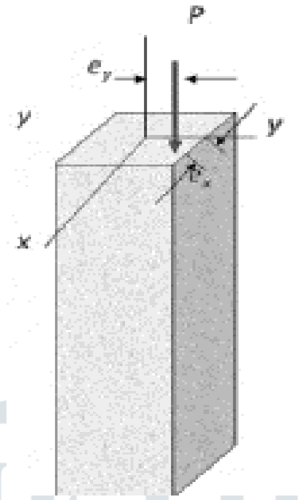

Figure 1: Column under axial loading and biaxial bending

The project involves the investigation of the response of the columns with respect to seismic loading conditions using pushover analysis method under the influence of number of storeys. Frame systems with flat slabs and conventional beam slabs have been analyzed.

LITERATURE SURVEY

In S. Mahesh and Dr. B. Panduranga Rao's research [1] a residential of G+11 multi story building is studied for earthquake and wind load using ETABS and STAAD PRO V8i. Assuming that material property is linear static dynamic analysis are performed. These analyses are carried out by considering different seismic zones and for each zone the behaviour is assessed by taking three different types of soils namely Hard, Medium and Soft. Different responses like story drift, displacements, and base shear have been plotted for different zones and different types of soils.

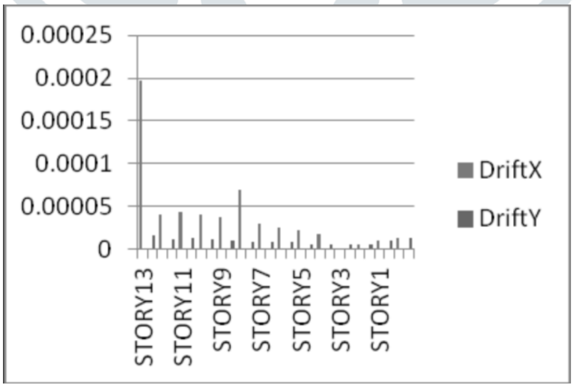

Figure 2: Typical Storey Drift Graph for the worst combination for all zones by Mahesh et. al.

Abhilash et. al. [2] discovered weak links and failure modes in structure with the increase in magnitude of loading. Here pushover analysis is done on a typical RCC structure by applying different lateral load patterns using ETABS and SAP2000. The lateral load patterns used here are uniform load distribution and equivalent lateral force distribution as per FEMA-257, lateral loads from response spectrum analysis as per IS-1893(2002) and the lateral load pattern as per Upper-Bound Pushover analysis method.

The Structure is first modelled in ETABS, and static and dynamic analysis is done. Then the dynamic behaviour of the structure such as modal participation factor, mass participation factors are obtained. From static analysis the member forces, center of mass of each floor are obtained which are required for modelling the structure for pushover analysis. Then the structure is modelled in SAP2000, and the material nonlinearities are assigned as hinges; M3 flexural hinges for beams and PMM flexural hinges for columns. Then each lateral load pattern is applied. The pushover curves, i.e., the load versus displacement curve is obtained.

The research done by Mrugesh D. Shah and Sumant B. Patel [3] is completely focused on analysis of structure using pushover analysis method where they stated the complete procedure for analysis using Etabs 9.7. Building as a symmetric structure with respect to both the horizontal directions. It was X-direction and Y-direction, each of 4m in length. All the slabs were considered as shell element of 150mm thickness. The model was the bare frame having beams, columns and slabs.

It has been observed that, on subsequent push to building, hinges started forming in beams first. Initially hinges were in B-IO stage and subsequently proceeding to IO-LS and LS-CP stage. At performance point, where the capacity and demand meet, out of 330 assigned hinges 261 were in A-B stage, 31, 38, and 0 hinges are in BIO, IO-LS and LS-CP stages respectively.

The seismic response of RC building frame in terms of performance point and the effect of earthquake forces on multi story building frame with the help of pushover analysis is carried out in the research conducted by G. S. Sai saran and V. Yogendra Durga Prasad [4]. In the study a building frame is designed as per Indian standard i.e., IS 456:2000 and IS 1893:2002. The main objective of this study is to check the kind of performance a building can give when designed as per Indian Standards.

After the study, the conclusion was made that, seismic performance of studied building is inadequate in zone 3 X-X direction, because there are some elements exceeding the limit level between life safety (LS)and collapse prevention (CP) , while that of zone 3 Y-Y direction is adequate, because some elements were not reached the Immediate Occupancy (IO) level and most of them had not reached the collapse point as well.

In the paper represented by Chung- Yue Wang and Shaing-Yung Ho [5], a method for the determination of the parameters of plastic hinge properties (PHP) for structure containing RC wall in the pushover analysis is proposed. The nonlinear relationship between the lateral shear force and lateral deformation of the RC wall is calculated first by the Response-2000 and Membrane-2000 code. The PHP (plastic hinge properties) value of each parameter for the pushover analysis function of SAP2000 or ETABS is defined as the product of two parameters α and β. Values ofα at states of cracking, ultimate strength and failure of the concrete wall under shear loading can be determined respectively from the calculations by Response-2000. While the corresponding β value of each PHP parameter is obtained from the regression equations calibrated from the experimental results of pushover tests of RC frame-wall specimens. The accuracy of this newly proposed method is verified by other experimental results. It shows that the presented method can effectively assist engineers to conduct the performance design of structure containing RC shear wall using the SAP2000 or ETABS codes.

Pushover analysis was performed on a nineteen story, slender concrete tower building located in San Francisco with a gross area of 430,000 square feet by Rahul Rana, Limin Jin and Atila Zekioglu. The lateral system of the building consists of concrete shear walls. The building is newly designed conforming to 1997 Uniform Building Code, and pushover analysis was performed to verify code's underlying intent of Life Safety performance under design earthquake.

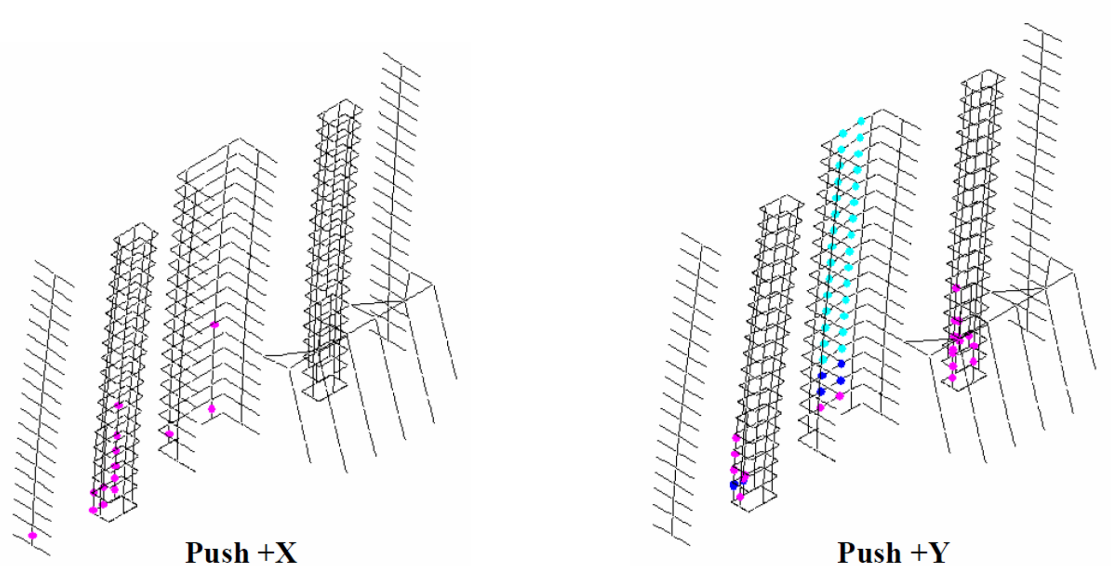

Figure 3: Building deformation and hinge development at performance point

Upon performing the various pushover runs shear hinges were found to develop at a few wall and spandrel locations which was considered undesirable for the performance objective. By performing trial runs with arbitrarily increased shear strength of the shear hinges at these locations, shear strengthening requirement was quantified as a factor of original shear strength.

GEOMETRICAL PARAMETERS OF STRUCTURAL SYSTEMS

A typical commercial building (for office purpose) in Noida has been considered for the analysis and design. Total eight structural models have been considered for analysis. Four models having flat slabs and other four having conventional slabs supporting on the beams. These models are analysed under the influence of number of storeys (i.e., 30, 25, 20 and 15 Storied Structural Systems). The general specifications of the structures are as given below. The general specifications are same for all four types of structural systems only slab types and number of storeys vary.

General grid data for building structural systems

Table 1: Grid data in X-Direction

Name	Grid line direction	Label/ ID	Ordinate (in m)
COLUMNS	X (Cartesian)	A	0
COLUMNS	X (Cartesian)	B	7500
COLUMNS	X (Cartesian)	C	15000
COLUMNS	X (Cartesian)	D	25000
COLUMNS	X (Cartesian)	E	32500
COLUMNS	X (Cartesian)	F	40000

Table 2: Grid data in Y-direction

Name	Grid line direction	Label/ ID	Ordinate (in m)
COLUMNS	Y (Cartesian)	1	0
COLUMNS	Y (Cartesian)	2	7500
COLUMNS	Y (Cartesian)	3	15000
COLUMNS	Y (Cartesian)	4	25000
COLUMNS	Y (Cartesian)	5	32500
COLUMNS	Y (Cartesian)	6	40000

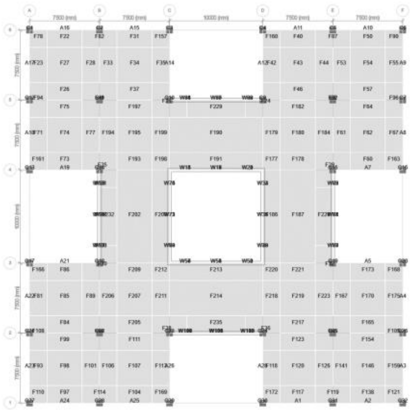

Figure 4: Typical structural Plan for flat slab structural system

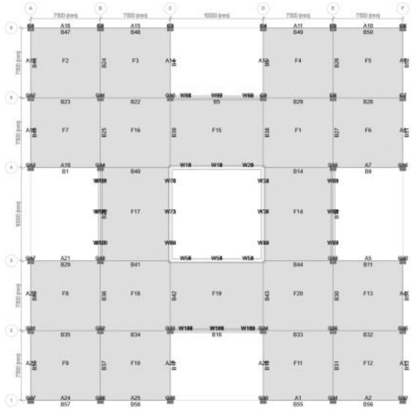

Figure 5: Typical structural Plan for Conventional beam slab structural system

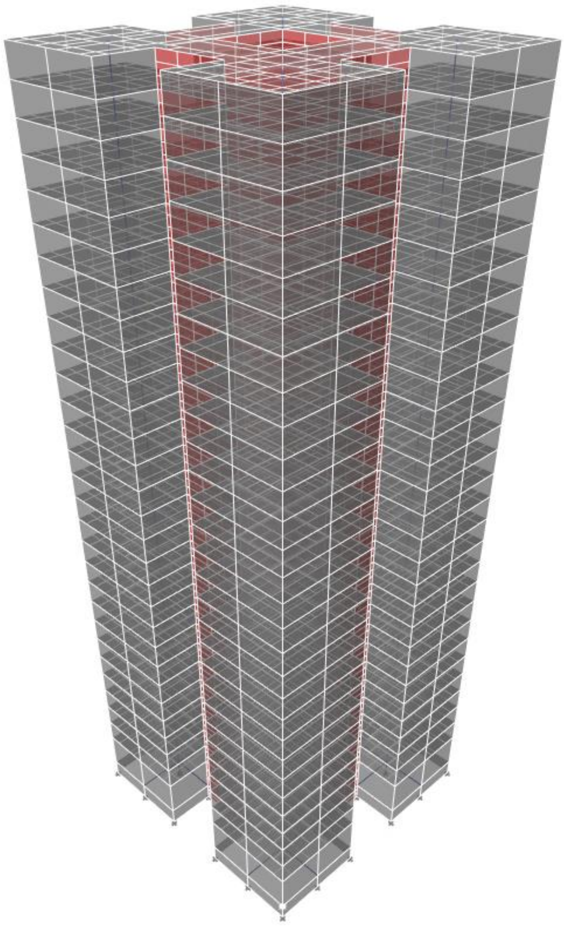

Figure 6: 30 Storied Flat Slab Structural Model

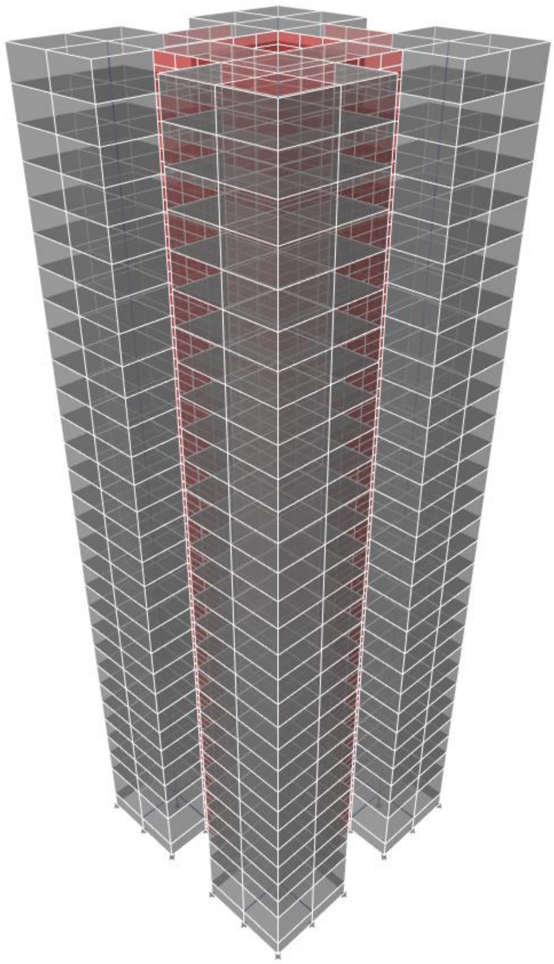

Figure 7: 3D Model of 30 storied conventional frame structural system

Material and section selection

The material properties include the type and characteristics of materials being used in the structural components in the system. Section properties consist of the geometry and dimensions of the member's cross-section. These properties are used for design and if the design checks do not pass, the section properties are modified. So, the final section design section sizes which passed the checks have been shown here.

Flat Slab Structural System

Slab Details

Thickness of slab	= 200 mm
Concrete grade used	= M30
Rebar Grade used	= HYSD 550

Drop Panel Details

Thickness of Drop Panel	= 400 mm
Concrete grade used	= M30
Rebar Grade used	= HYSD 550

Columns Details

Column Size	= 450×800 mm^2
Concrete grade used	= M30
Rebar Grade used	= HYSD 550

Shear Wall Details

Thickness of Shear wall	= 400 mm
Concrete grade used	= M40
Rebar Grade used	= HYSD 550

Conventional Slab Structural System

Slab Details

Thickness of slab	= 200 mm
Concrete grade used	= M30
Rebar Grade used	= HYSD 550

Beam Details

Beam Size	= 500×900 mm^2
Concrete grade used	= M30
Rebar Grade used	= HYSD 550

Columns Details

Column Size	= 550×900 mm^2
Concrete grade used	= M30
Rebar Grade used	= HYSD 550

Shear Wall Details

Thickness of Shear wall	= 400 mm
Concrete grade used	= M40
Rebar Grade used	= HYSD 550

RESULTS

Response From Columns

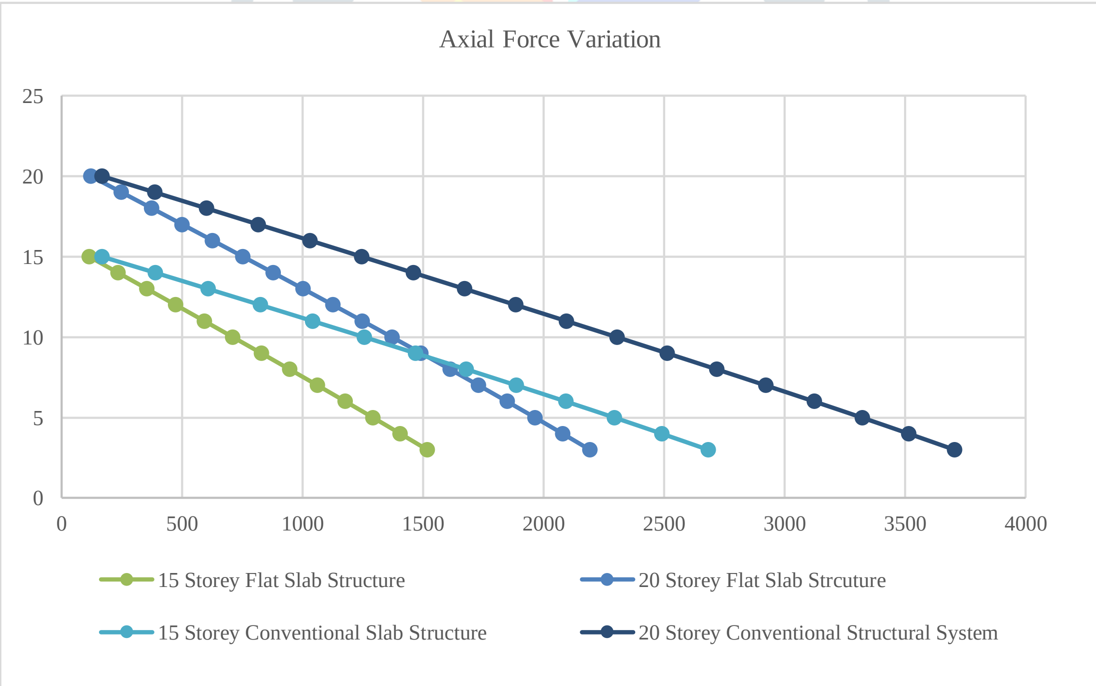

Figure 8: Comparison of Axial Forces in Columns- 15 & 20 Storey structures

Figures- 7 and 8 show the comparison of axial loads in the structures. Both represent axial forces for pushover load case systems. On both linear static and pushover loading conditions, 30 storied conventional structural system is subjected to maximum number of axial forces which travel along the line of axis of the columns.

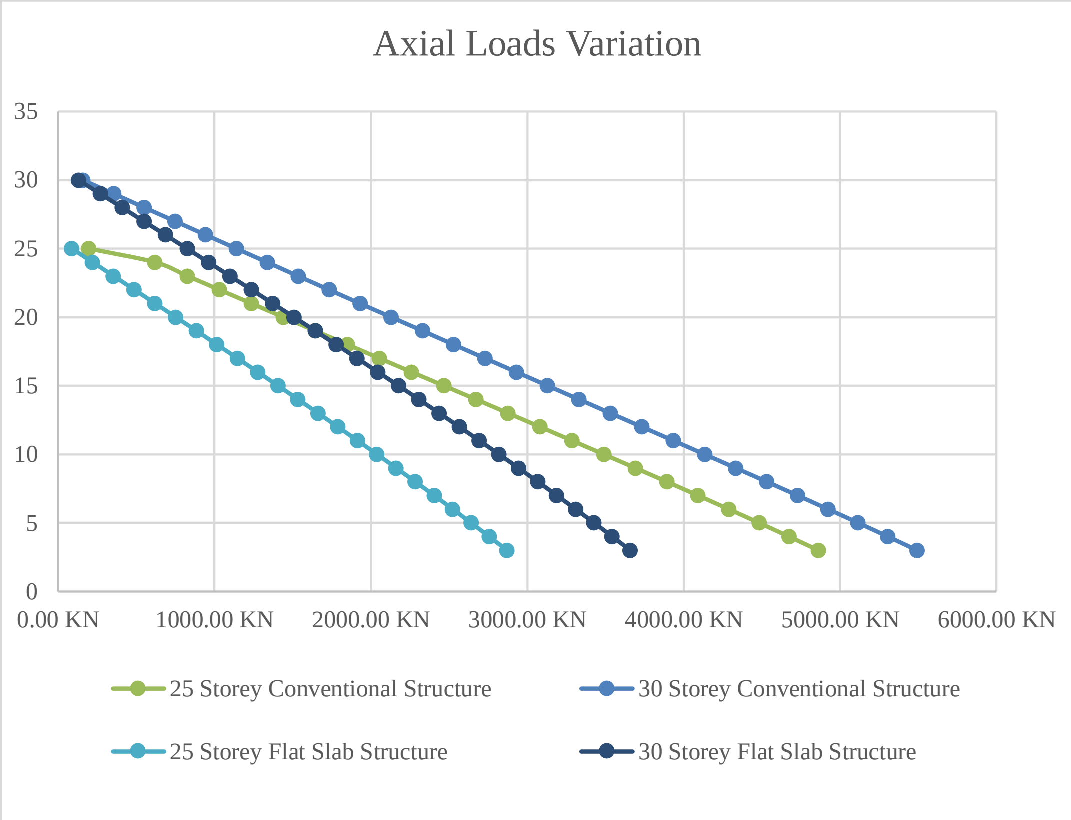

Figure 9: Comparison of Axial Forces in Columns- 25 & 30 Storey structures

It is to be noted that the columns do not undergo direct axial deformation when loaded in case of pushover function as it serves the lateral loading conditions and hence the compression members of the structure undergo biaxial deformations when loaded. The safest structure which undergoes minimal axial deformations is the flat slab structural system with 15 storeys. These forces are more in conventional slab systems because of beams provided to restrain slabs increasing the dead weight of the system. Hence more the structural elements, more will be the load on columns and vice-versa.

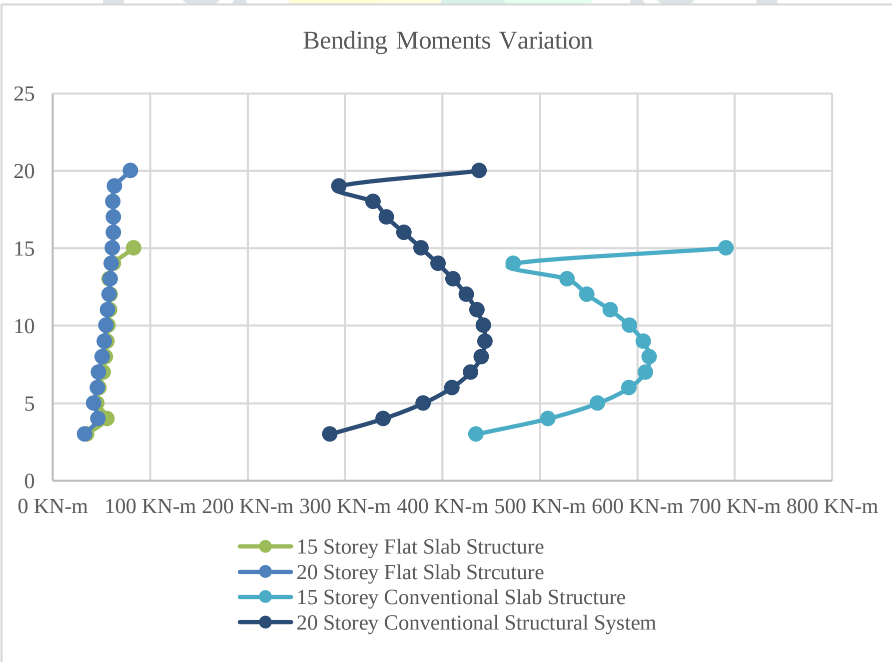

Figure 10: Comparison of max. Bending Moments in Columns- 15 & 20 Storey structures

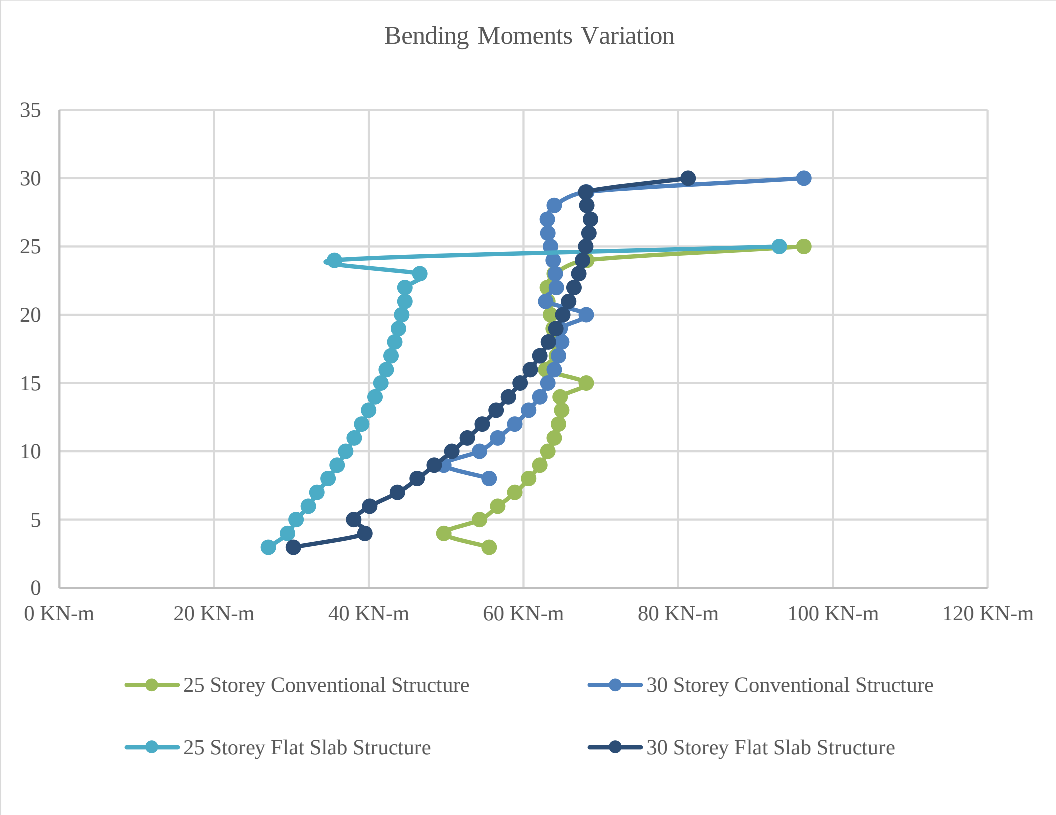

Figure 11: Comparison of max. Bending Moments in Columns- 25 & 30 Storey structures

The comparison of bending moments developed in the columns have been shown in figures- 9 and 10 for pushover load cases. A combination of Four models is represented in one figure for single load case. When only wind and gravity loads are considered, the conventional slab structure bears least magnitude between starting to 19th story which abruptly jump to 2nd highest magnitude at 20th storey. It may be considered as the safest one as magnitude of bending moments in least till 19th storey. 20 storied flat slab structural system has to bear major number of bending moments because there are no lateral restraints to the columns in form of beams for the structure. When pushover load case is considered, the bending moment is peak in case of conventional structural system with 15 stories and in each structure, highest magnitude is in the topmost story.

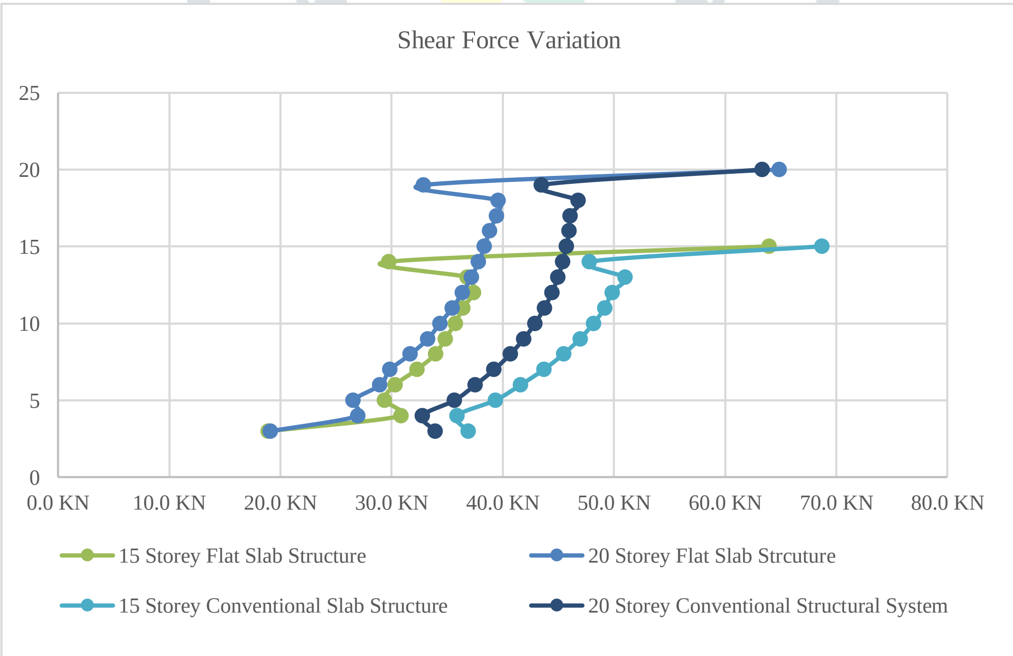

Figure 12: Comparison of max. Shear Forces in Columns- 15 & 20 Storey structures

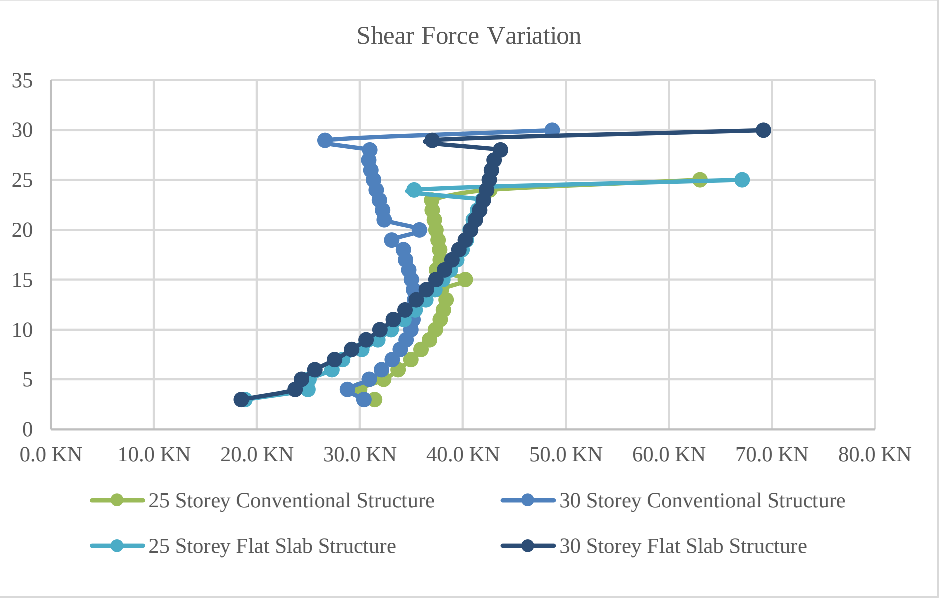

Figure 13: Comparison of max. Shear Forces in Columns- 25 & 30 Storey structures

Figures- 11 and 12 show the maximum shear forces due to pushover load case. In case of gravity loads combined with wind loads, the maximum magnitude of the shear force is produced in the columns present in conventional structural system having 30 stories. This shear force peaks in the column present in highest story. Flat slab structural system with 15 stories shows safest response with respect to LS load case. On other hand, when pushover load case is chosen for the behaviour of column, 30 storied conventional structural system shows maximum magnitude of shear force and 20 storied flat slab structure is in the safest zone.

Response from whole structural system

The below curves are according to NTC 2008 in which graph is plotted keeping spectral acceleration on Y-axis which is usually measured in multiples of gravitational constant or acceleration due to gravity and spectral displacement on X- axis. As shown in legend, the green coloured line with intermediate crosses is the capacity curve of the structure. The global response of the structure is governed by this curve which is, in other words, base shear vs displacement curve. Red coloured curve represents EPP (elastic perfectly plastic) representation of the pushover curve (Bilinear Force-Displacement Curve). Yellow coloured line represents demand cure of the structure. T^* represents the time period of the equivalent reduced SDOF system and T_c represents the corner period between short and medium period range represented in seconds.

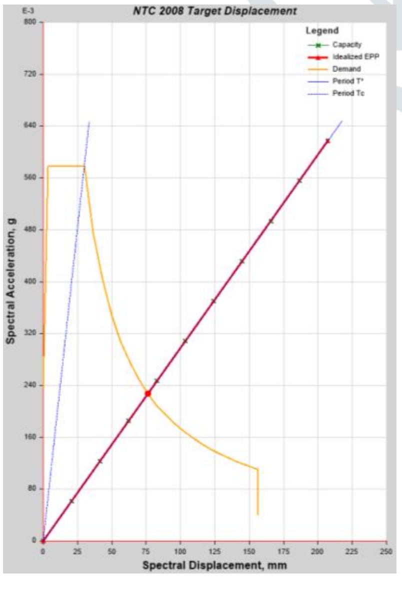

Figure 14: Target Displacement curve for 20 Storied Conventional Structural System

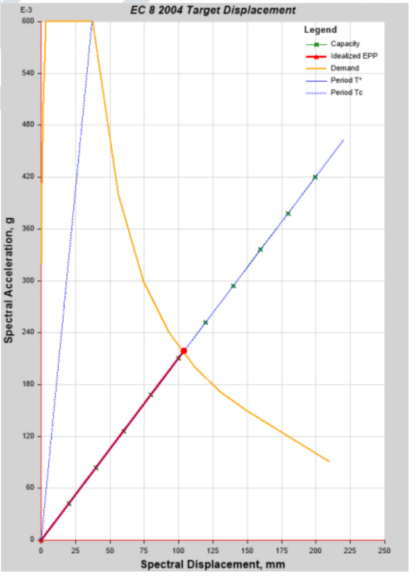

Figure 15: Target Displacement curve for 20 Storied Flat Slab Structural system

Table 3: 20 Storied Conventional Slab Structural System- NTC Target Displacement Table

Spectral Displacement	Spectral Acceleration	Period (Sec)
0.00 mm	0.00 g	0.00 Sec
20.70 mm	0.06 g	1.16 Sec
41.40 mm	0.12 g	1.16 Sec
62.10 mm	0.19 g	1.16 Sec
82.80 mm	0.25 g	1.16 Sec
103.50 mm	0.31 g	1.16 Sec
124.20 mm	0.37 g	1.16 Sec
144.91 mm	0.43 g	1.16 Sec
165.61 mm	0.49 g	1.16 Sec
186.31 mm	0.56 g	1.16 Sec
207.01 mm	0.62 g	1.16 Sec

Table 4: 20 Storied Flat Slab Structural System- NTC Target Displacement Table

Spectral Displacement	Spectral Acceleration	Period (Sec)
0.00 mm	0.00 g	0.00 Sec
19.96 mm	0.04 g	1.38 Sec
39.91 mm	0.08 g	1.38 Sec
59.87 mm	0.13 g	1.38 Sec
79.82 mm	0.17 g	1.38 Sec
99.78 mm	0.21 g	1.38 Sec
119.73 mm	0.25 g	1.38 Sec
139.69 mm	0.29 g	1.38 Sec
159.64 mm	0.34 g	1.38 Sec
179.60 mm	0.38 g	1.38 Sec
199.56 mm	0.42 g	1.38 Sec

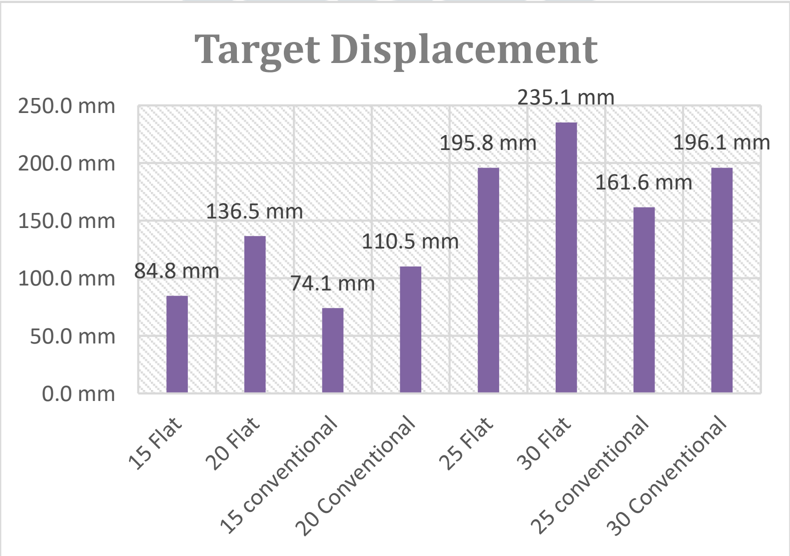

Figure 16: Comparison of Target Displacement from Pushover Curves

The flat slab structural system with 20 stories gets earliest and maximum target displacement at a spectral acceleration of about 0.191g whose displacement stretches to 136.5mm. 15 storied conventional structural system shows minimum target displacement of about 74.1 mm which is attainable when spectral acceleration is 0.341 g which is in fact highest acceleration value among all the structural systems.

15 storied flat slab structural system and 20 storied conventional beam slab system show not-so-high and not-so-low displacements (i.e., 84.8mm for flat slab structural system and 110.5mm for conventional slab structural system) and spectral accelerations (i.e., 0.306g for flat slab structural system and 0.227 for conventional slab structural system) and hence lie in adequate conditions.

CONCLUSION

The axial load data for columns suggest that 15 storey flat slab structural system is in safest condition as it has least number of structural components and hence least dead load on the structure and 30 storied conventional structure has most vulnerability due to heavy structural components.

Bending moments due to Non-Linear Static (pushover) load case are in high intensity in 15 storied conventional structural system. Similar to bending moments, Shear forces in columns are also high in 15 storey conventional slab structure.

Pushover curves conclude that flat slab structural system having 30 storeys has achieved maximum target displacement within minimum spectral acceleration. 15 Storey conventional structural system shows safest response with respect to pushover analysis curves.

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