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Investigation of Linear Dynamic Analysis and Ductile Design of High Rise Structure as per Revised Indian Code

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Abstract: This thesis gives a comparative seismic analysis of high rise structure in zone III and zone IV using the New IS 13920-2016 standards. The recent earthquakes in India revealed unequivocally that conventional structural design and construction techniques fail to meet fundamental seismic resistance standards. The use of ductile design and detailing methods in conventional construction is a critical topic that requires attention. The ductility of reinforced concrete structures as a whole is a difficult topic. However, specific design factors and reinforcing details may be used in particular critical spots of the building structure to reduce seismic damage and life-threatening collapse. The approaches are straightforward, affordable, and extensively detailed in the Indian Bureau of Standard Code of Practice's standard code of practise (IS13920). It is recommended to conduct a comparative analysis of the dynamic behaviour of high-rise structures using the response spectrum approach in accordance with IS 1893 Part1-2016 The investigation of characteristics including displacement, base shear, and tale drift. Examining factors including modal frequencies and acceleration in response spectrum load instances in both the X and Y directions. Ductile design of high rise structures in accordance with IS 13920-2016's new codal requirements. Additionally, it is recommended to analyse and design multi-story buildings using computational software such as ETABS and compare characteristics such as storey displacement, base shear and storey drift. The shear wall at the corner reduces storey X displacement by 46.245%. The intermediate shear wall reduces displacement by 54.617%. The central shear wall reduces displacement by 68.72%. Lower level shear wall displacement is central. Shear wall at corner reduces storey drift in X direction by 49.374%. Shear wall at centre reduces drift by 39.716%. Shear wall at centre reduces drift by 2.638%. Lower story drift in central shear wall. Shear wall at corner base shear drift is 63.646% greater than without shear wall. Base shear is 64.006% higher with a middle shear wall. Shear wall at the centre increases base shear by 65.765%. Center shear wall has stronger base reaction.
Keywords: Seismic analysis, Storey displacement, Response spectrum, Ductile design, High rise building.

I. INTRODUCTION

When earthquakes occur, a building undergoes dynamic motion. This is because the building is subjected to inertia forces that act in opposite direction to the acceleration of earthquake excitations. These inertia forces, called seismic loads, are usually dealt with by assuming forces external to the building. So, apart from gravity loads, the structure will experience dominant lateral forces of considerable magnitude during earthquake shaking. It is essential to estimate and specify these lateral forces on the structure in order to design the structure to resist an earthquake. The ductility of a structure is the most important factor affecting its seismic performance and it has been clearly observed that the well designed and detailed reinforced structures behave well during earthquakes and the gap between the actual and design lateral force is narrowed down by providing ductility in the structure.

The national building code of India (NBC) 2015 is likely to be released by bureau of Indian standards during December 2016/January 2017. Various sections of this NBC have undergone changes as per latest technologies and user requirements. The document CED 39 (and corresponding IS.1893) on “criteria for earthquake resistant design of structures” (part-1–general provisions for all structures and specific provisions for buildings) has undergone tremendous changes for structural design requirements.

The process of designing high-rise buildings have changed over the past years. In the most recent years it is not unusual to model full three-dimensional finite element models of the buildings.

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This due to the increased computational power and more advanced software. However, these models produce huge amount of data and results where possible errors are easily overlooked, especially if the model is big and complex. If the engineer is not careful and have a lack of knowledge of structural behaviour and finite element modelling, it is easy to just accept the results without critical thoughts. Furthermore, different ways of modelling have a big influence on the force and stress distribution. This can lead to time consuming discussion and disagreements between engineers as they often have different results from calculations on the same building. Instead of designing structures elastically to withstand lateral forces from severe and infrequent earthquakes, designing structures for lower force levels and higher ductility is a widely accepted practice in performance-based design.

A. *Study Objectives*

Based on the problem statements discussed earlier, the objectives of this study are:

1) Investigation of dynamic behavior of high rise structure by response spectrum method as per IS 1893 Part1-2016
2) Study of parameters such as diaphragm mass displacement, base shear and story drift.
3) Study of parameters such as modal frequencies and acceleration in response spectrum load cases in both X and Y direction.
4) Establish the impact of new revised codal provisions on the seismic behavior of high rise structures as compared to old code provisions
5) Ductile design of high rise structure as per new codal provisions given in IS 13920-2016

II. REVIEW OF LITERATURE

A. *Farinha, M. D. F., Bezelga, A. A., & Azevedo, A. V. (2006)*

This paper is intended to present a model that is being developed for use in the design of buildings with a reinforced concrete reticulate structure. First a brief reference is made to the applicability of the model, next the main requirements to be fulfilled by the system are mentioned, and lastly the main developments carried out are presented. The general use of integrated design systems is introducing several changes in the different phases of the design of building structures. Designers can free themselves of arduous and repetitive work and have more time available for conception and optimization of solutions. Then the necessary conditions are created for increasing design quality, which will certainly contribute to a better quality of the buildings.

B. *Rama Raju, K., Shereef, M. I., Iyer, N. R., & Gopalakrishnan, S. (2013)*

This paper states that, consideration of site specific lateral loading due to wind or earthquake loads along with vertical gravity loads is important for finding the behavior of the tall buildings. As the height of a building becomes taller, the amount of structural material required to resist lateral loads increases drastically. The design of tall buildings essentially involves a conceptual design, approximate analysis, preliminary design and optimization, to safely carry gravity and lateral loads. The design criteria are strength, serviceability and human comfort. The aim of the structural engineer is to arrive at suitable structural schemes, to satisfy these criteria. In the present study, the limit state method of analysis and design of a 3B+G+40-storey reinforced concrete high rise building under wind and seismic loads as per IS codes of practice is described. Safety of the structure is checked against allowable limits prescribed for base shear, roof displacements, inter-storey drifts, accelerations prescribed in codes of practice and other relevant references in literature on effects of earthquake and wind loads on buildings.

Svetlana Brzev IS:13920-2016. (2016) This paper states that , the Parliament of India has set out to provide a practical regime of right to information for citizens to secure access to information under the control of public authorities, in order to promote transparency and accountability in the working of every public authority, and whereas the attached publication of the Bureau of Indian Standards is of particular interest to the public, particularly disadvantaged communities and those engaged in the pursuit of education and knowledge, the attached public safety standard is made available to promote the timely dissemination of this information in an accurate manner to the public.

C. *Hosseini, M., & Rao, N. V. R. (2017)*

This paper states that, the shear walls are located on each level of the structure, to form an effective box structure, equal length shear walls are placed symmetrically on opposite sides of exterior walls of the building. Shear walls are added to the building interior to provide extra strength and stiffness to the building when the exterior walls cannot provide sufficient strength and stiffness or when the allowable span-width ratio for the floor or roof diaphragm is exceeded. Shear walls are analyzed to resist two types of forces: shear forces and uplift forces. Shear forces are created throughout the height of the wall between the top and bottom shear wall connections.

Uplift forces exist on shear walls because the horizontal forces are applied to the top of the wall. These uplift forces try to lift up one end of the wall and push the other end down. In some cases, the uplift force is large enough to tip the wall over. Shear walls are analyzed to the provide necessary lateral strength to resist horizontal forces. Shear walls are strong enough, to transfer these horizontal forces to the next element in the load path below them. The seismic motion that reaches a structure on the surface of the earth is influenced by local soil conditions.

D. Hosseini, M., & Rao, N. V. R. (2017)

This paper states that the, shear walls are located on each level of the structure, to form an effective box structure, equal length shear walls are placed symmetrically on opposite sides of exterior walls of the building. Shear walls are added to the building interior to provide extra strength and stiffness to the building when the exterior walls cannot provide sufficient strength and stiffness or when the allowable span-width ratio for the floor or roof diaphragm is exceeded. Shear walls are analyzed to resist two types of forces: shear forces and uplift forces. Shear forces are created throughout the height of the wall between the top and bottom shear wall connections. Uplift forces exist on shear walls because the horizontal forces are applied to the top of the wall. These uplift forces try to lift up one end of the wall and push the other end down. In some cases, the uplift force is large enough to tip the wall over. Shear walls are analyzed to the provide necessary lateral strength to resist horizontal forces. Shear walls are strong enough, to transfer these horizontal forces to the next element in the load path below them.

E. Gautam, K., & Gupta, M. (2020)

This study reviewed the recent developments in finding the response reduction factor for RC framed building and the influence of soil-structure interaction (SSI) effects in the various responses of the building. For Response Reduction Factor, the nonlinear analysis was done in order to capture all the hysteretic Energy beyond the elastic limit. Various approaches to pushover analysis and time history analysis have been mentioned in this review paper.

F. Cavdar, O. (2021)

In this paper, the seismic behavior of existing reinforced concrete tall building is investigated by the linear and nonlinear dynamic analysis. The selected reinforced concrete structure was designed according to “Turkey Seismic Code-2007” (TEC-2007). A typical 41 story reinforced concrete building is designed. Turkey Building Earthquake Code-2018 (TBEC-2018) is utilized for evaluating the seismic performance of the selected building. Natural earthquake acceleration record selected and adjusted for compatibility with the adopted design spectrum, is used.

G. Ferraioli, M. (2021)

This paper states that, the current generation of seismic design codes is based on a linear elastic force-based approach that includes the nonlinear response of the structure implicitly through a response modification factor (named reduction factor R in American codes or behaviour factor q in European codes). However, the use of a prescribed behaviour factor that is constant for a given structural system may fail in providing structures with the same risk level. In this paper, the behaviour factor of reinforced concrete frame structures is estimated by means of nonlinear static (pushover) and nonlinear incremental dynamic analyses. For this purpose, regular reinforced concrete frames of three, five, seven, and nine storeys designed for high ductility class according to the European and Italian seismic codes are investigated, and realistic input ground motions are selected based on the design spectra. Verified analysis tools and refined structural models are used for nonlinear analysis.

III. METHODOLOGY

The finite part analysis may be a numerical technique. during this technique all the complexities of the issues, like variable form, boundary conditions and masses are maintained as they are they’re however the solutions obtained are approximate. attributable to its diversity and adaptability as Associate in Nursing analysis tool, it's receiving abundant attention in engineering.

The quick enhancements in component technology and dynamic of price of computers have boosted this technique, since the pc is that the basic want for the applying of this technique. variety of in style whole of finite part analysis packages are currently accessible commercially. a number of the popular packages are STAAD-PRO, GT-STRUDEL, NASTRAN, NISA and ANSYS. victimization these packages one will analyze many complicated structures. The finite element analysis originated as a method of stress analysis in the design of aircrafts. It started as an extension of matrix method of structural analysis.

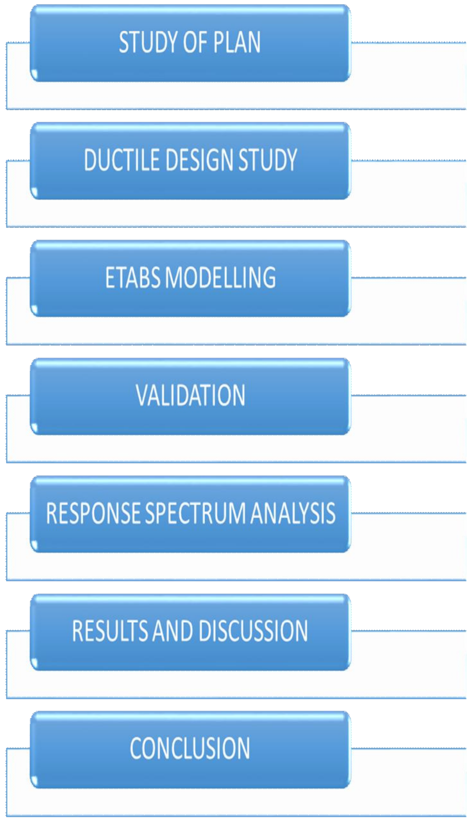

Figure 3.1 : Flowchart

A. General

Earthquakes are nature's greatest hazards to life on this planet. The hazards imposed by earthquakes are unique in many respects, and consequently planning to mitigate earthquake hazards requires a unique engineering approach. An important distinction of the earthquake problem is that the hazard to life is associated almost entirely with manmade structure expect for earthquake triggered landslides, the only earthquake effect that causes extensive loss of life are collapse of bridges, buildings, dams, and other works of man. This aspect of earthquake hazard can be countered only by designs and construction of earthquake resistant structure. The optimum engineering approach is to design the structure so as to avoid collapse in most possible earthquake, thus ensuring against loss of life but accepting the possibility of damage.

Various methods for determining seismic forces in structures fall into two distinct categories:

(i) Equivalent static force analysis (ii) Dynamic Analysis

1) Equivalent Static Force Analysis

These are approximate methods which have been evolved because of the difficulties involved in carrying out realistic dynamic analysis. Codes of practice inevitable rely mainly on the simpler on the simpler static force approach, and incorporate varying degree of refinement in an attempt to simulate the real behaviour of structure. Basically they give total horizontal force (Base Shear) V, on a structure:

$$V = ma$$

Where,

m is mass of structure

V is applied to the structure by a simple rule describing its vertical distribution. In a building this generally consist of horizontal point loads at each concentration of mass, most typically at floor level. The seismic forces and moments in the structure are then determined by any suitable analysis and the results added to those for the normal gravity load cases. An important feature of equivalent static load requirement in most codes of practice is that calculated seismic forces are considerably less than those which would actually occur in the larger earthquakes likely in the area concerned.

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V=F1+F2+F3

2) Dynamic analysis

For large or complex structure static methods of seismic analysis are not accurate enough. Various methods of differing complexity have been developed for the dynamic seismic analysis of structures. They all have in common the solution of the equation of motion as well as the usual static relationship of equilibrium and stiffness. The three main techniques currently used for dynamics analysis are:

(i) Direct integration of the equation of motion by step by step procedure
(ii) Normal Mode Analysis
(iii) Response spectrum Technique

Direct integration provides the most powerful and informative analysis for any given earthquake motion. A time dependent forcing function (earthquake accelerogram) is applied and the corresponding response history of the structure during the earthquake force is computed. The moment and force diagram at each of series of prescribed interval throughout the applied motion can be found. Three dimensional nonlinear analysis have been devised which can take three orthogonal accelerogram components from a given earthquake, and apply them simultaneously to the structure. This is the most complete dynamic analysis technique and is unfortunately expensive to carry out.

Normal mode analysis depends on artificially separating the normal modes of vibration and combining the force and displacement associated with a chosen number of them by superposition. As with direct integration techniques, actual earthquake accelerograms can be applied to the structure and a stress-history determined, but because of the use of superposition the techniques is limited to linear material behaviour. Although modal analysis can provide any desired order of accuracy for linear behaviour by incorporation all the modal responses, some approximation is usually made by using only the few modes to save computation time. Problems are encountered in dealing with system where the mode coupling occurs.

Seismic Analysis using IS 1893 (Part1):2002

In this approach the earthquake force is applied on the structure using seismic coefficient method. In this method the design horizontal seismic coefficient Abfor the structure is given as

$$A_h = \frac{Z}{2} \cdot \frac{I_m}{R} \cdot \frac{S_a}{g}$$

Where,

Ah is seismic horizontal acceleration (Generally in the range of 0.05g to 0.2g) Z is zone factor as per different zones, IS 1893 (Part1):2002 has classified India in to four zones II to V. In zone II seismic intensity is low and very severe for zone v, I= importance factor, depending upon the functional use of the structures, R= Response reduction factor, depending on the perceived seismic damage performance of the structure, characterized by ductile or brittle deformations. However, the ratio I/R shall not be greater than 1.0 and Sa/g = Average response acceleration coefficient for rock or soil sites. This ratio depends upon the time period and site condition.

B. Ductile Design

Ductility refers to a material's (or structure's) ability to withstand substantial deformations without failing. The word is used in earthquake engineering to describe a structure's ability to withstand significant lateral displacements caused by ground shaking.

The stiffness of a structure indicates the amount of force necessary to move it by a certain quantity. If shifting Building A required greater force than shifting Building B, we would argue that Building A is stiffer. Stiffness may be favorable in terms of earthquake damage since it reduces the amount of deformation required of a structure.

However, there is such a thing as too much of a good thing. A structure that is excessively stiff (sometimes referred to as brittle) is prone to failure when subjected to relatively minor deformation demands. A brittle structure is an unreinforced masonry construction that will withstand only a small amount of movement before sustaining damage and collapse.

The capacity of a ductile structure to contort and release energy during an earthquake is also beneficial, since it will continue to distort without eventually failing or collapsing. A ductile structure is a correctly specified steel frame with sufficient elasticity to withstand substantial deformations before failing.

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IV. PROBLEM STATEMENT

In this project, a G+20-storey structure of a rectangular building with 3 m floor to floor heig ht has been analysed Non-Linear Dynamic Analysis of Multi-storey R.C.C Buildings using ETAB software in zones III and IV. The plan selected is Rectangular in shape. Medium soil condition has been selected for the structure. Proposed work design the high story building to find the location of maximum shear force in the beam to column joints. Complete analysis is carried out for dead load, live load and seismic load. Analysis Modeling of G+20 storey R.C.C frame structure using commercial software ETABS Connect for various seismic zones i.e. III, IV. Compare Shear Strength capacity of beam column joints for different zone. Beam column joints in a reinforced concrete moment resisting frame are crucial zones for transfer of load effectively between the connecting element (i.e, beam and columns) in structure and hence shear strength checked and Design by draft provision in IS 13920-2016.

A. *Preliminary Data Required for Analysis*

Table 1. Parameters to Be Consider for Rectangular Geometry Analysis

Sr. No.	Parameter	Values
1.	Number of stories	G+20
2.	Base to plinth	3m
3.	Grade of concrete	M30
4.	Grade of steel	Fe 500
5.	Floor to Floor height	3 m
6.	Total height of Building	66m
7.	Soil Type	Medium
8.	Dead Load	Calculated By Software
9.	Live load on roof	2 kN/m2
10.	Live load on floors	3 kN/m2
11.	Frame size	32m X 40m building size
12.	Grid spacing	8 m grids in X-direction and Y-direction.
13.	Size of column	300mm x 750 mm
14.	Size of column	350mm x 750 mm
15.	Size of beam	230mm x 600 mm
16.	Depth of slab	200 mm
17.	Importance factor for office building	1
18.	Damping percent	5 %

A. IS Code use:

1) IS Code for Dead Load: - IS 875 Part 1
2) IS Code for Dead Load: - IS 875 Part 2
3) IS Code for Seismic Load: - IS 1893-2016 Part 1
4) IS Code for Ductile Detailing: IS 13920:2016

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V. MODELING

A. Prepare Model in ETABS

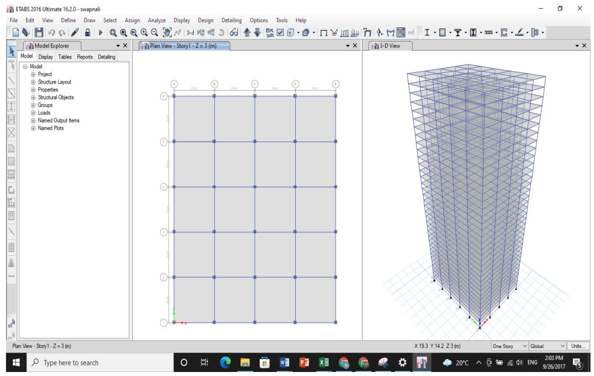

Fig 1: Prepare modeling in ETABS.

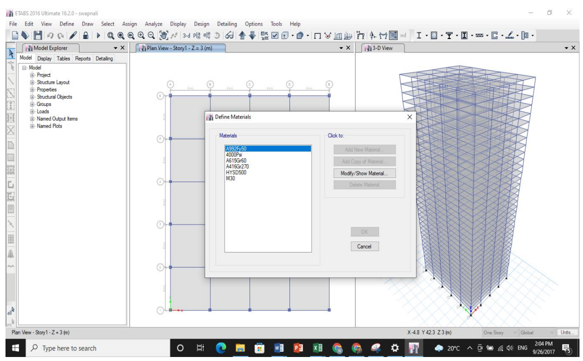

Fig 2: Define material property.

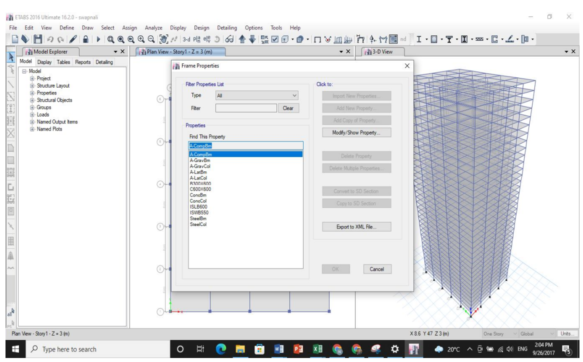

Fig 3: Define Member properties.

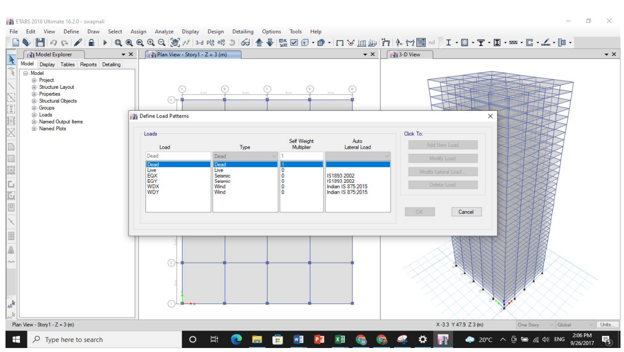

Fig 4: Assign loads.

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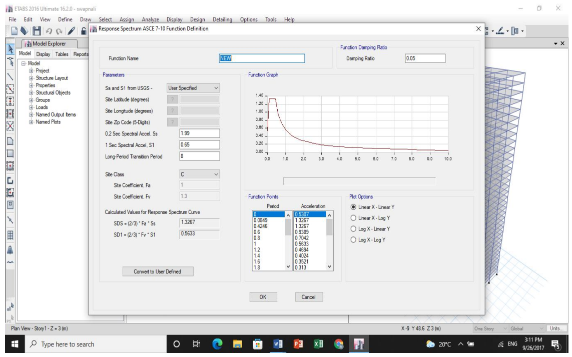


Fig 5: Define soil property and zone factors.

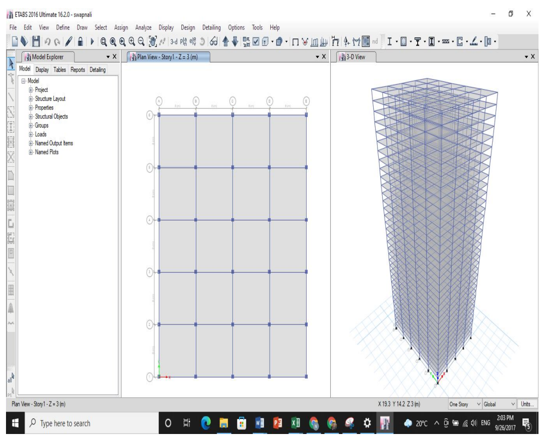
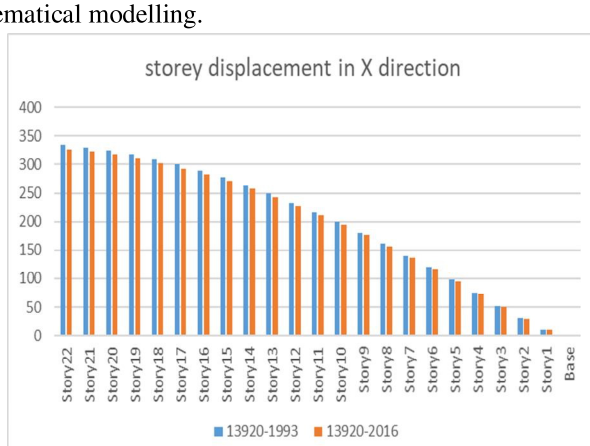


Fig 6. 2D and 3D View Model.

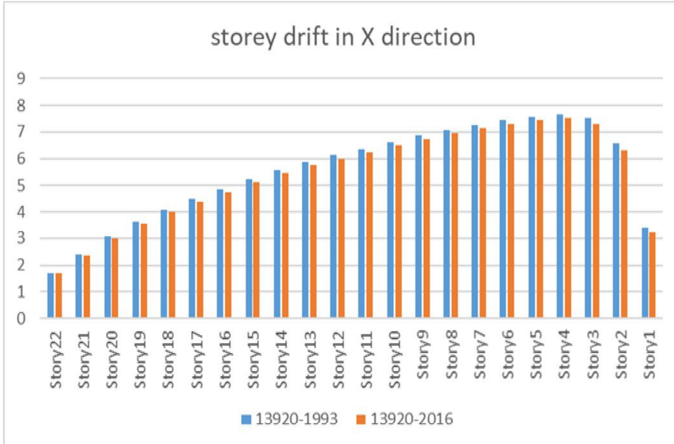
VI. RESULTS AND DISCUSSION

In this project, a G+20-storey structure of a rectangular building with 3 m floor to floor height has been analysed Non-Linear Dynamic Analysis of Multi-storey R.C.C Buildings using ETABS software in zones III, IV. The plan selected is Rectangular in shape. The structure has been analysed for both static and dynamic wind and earthquake forces. Hard, Medium and soft soil condition has been selected for the structure. The finite element method (FEM) is a widely used method for numerically solving differential equations arising in engineering and mathematical modelling.



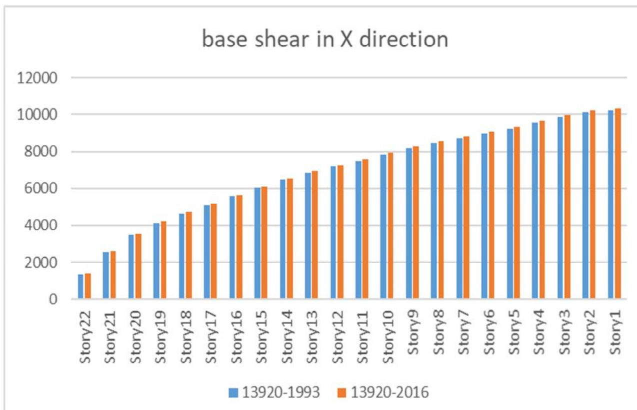
Graph 1: storey displacement in mm in X direction

The graph shows storey displacement in x direction in mm for zone III. IS-13920-1993 has the higher displacement which IS 333.637 mm and IS 13920-2016 has the lower displacement which is IS 325.844mm.



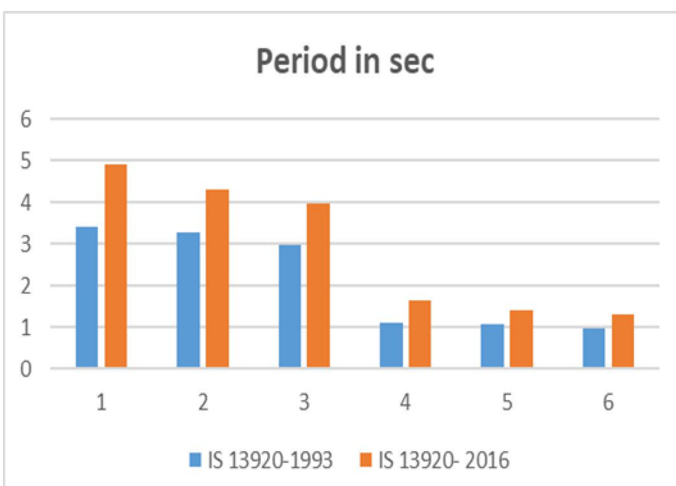
Graph 2: storey drift in mm in X direction

The graph shows storey drift in X direction in mm for zone III. IS-13920-1993 has the higher drift which is 1.697mm and IS 13920-1993 has the lower drift which is 1.674 mm.

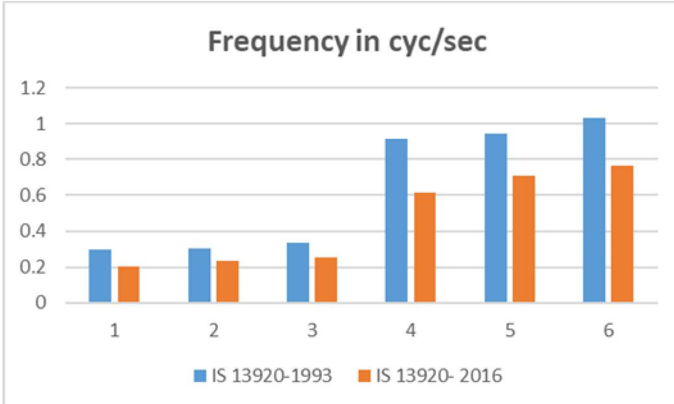


Graph 3: base shear in X direction

The graph shows base shear in X direction in KN for zone III. IS-13920-2016 has the higher shear which is 1387.1415 KN and IS 13920-1993 has the lower shear which is 1357.018 KN.



Graph 4: Time period



Graph 5: frequency

The graph shows time period and frequency in seconds and cycle/seconds respectively. IS 13920-1993 has lower time period and higher frequency than the IS 13920-2016.

VII. CONCLUSIONS

The 1993 version of IS 13920-1993 incorporated some provisions on the design beam column joints.

1) The storey displacement in X and Y direction for zone III structure with IS-13920-1993 has the higher displacement and IS 13920-2016 has the lower displacement
2) The base shear is X and Y direction for zone III structure with old IS code has the lower base shear than new IS code.
3) Old code has the higher storey drift than the old code for the structure.
4) Base shear is increase with using new IS 13920-2016 code column C/S aspect ratio & minimum dimension of column & shear design of beam Column joint.
5) Time period & story Drift is decrease with using new code requirements compare to old code data.
6) The displacement is also decrease with new IS requirements.
7) Using the new code requirements of shear design of beam column joint, they are effective for high rise building.
8) The revision of codes is a periodic process which results from continuous and systemic research in the related field. IS: 13920-2016 is the first revision of the code on ductile detailing of RC structures subject to seismic forces. The first revision has added some design aspects also along with detailing. The provisions of earlier code have been suitably modified keeping in view more strength and stiffness and enhanced energy dissipation in the event of an earthquake along with ductility for seismic resistance of structures. The revised code will lead to major modifications in beam-column design owing to the inclusion of strong column-weak beam theory. Hence it can be concluding that IS 13920:1993 should be restricted for Practitioner.

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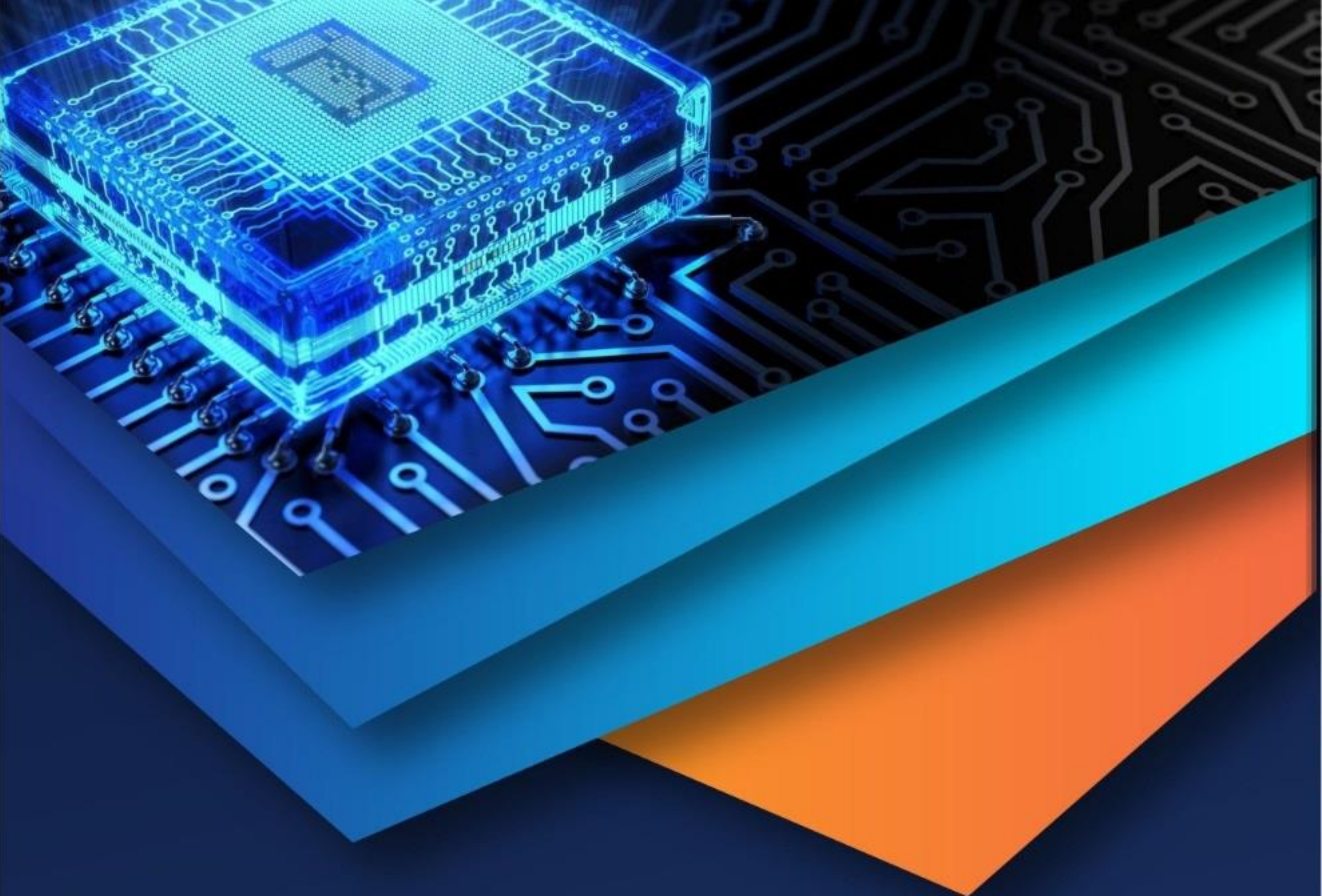

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