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Analysis of Twisted Tall Structure Considering Lateral Load using ETABS

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ABSTRACT

This research presents the structural behavior of RCC twisted building subjected to dynamic loads. The comparative study between RCC twisted building is made. In a twisted tall building various rate of twist for RCC twisted building was analyzed. The different rate of twist as 10, 12.5 & 15 degrees at the center of the RCC twisted building was considered. The modelling and analysis is done using ETABS. Dead loads, live load, seismic load and wind loads are assigned for modelled structures and results obtained are plotted for parameters such as displacement, storey drift, time period and base shear. The analysis for twisted building is done for gravity loads, lateral load using Response spectrum method. The models are considered for Zone V & the analysis is done as per the Indian standard codal provisions. From the comparative study of RCC building under Dynamic loads for various angle of twist for storey it is concluded that RCC twisted building is efficient under seismic and wind load. 10 degree angle of twist is efficient compared to 12.5 & 15 degree of angle of twist.

Keywords: RCC twisted building, Steel twisted building, base shear, time period, displacement & storey drift.

I. INTRODUCTION

Tall buildings emerged in the late 19th century in Chicago and New York. After decades of eclectic design in the early 20th century, the International Style prevailed during the mid-20th century and produced numerous prismatic Miesian style towers all over the world. Today's architecture, including tall buildings, can be understood only through recognition of the dominance of pluralism. This contemporary architectural design trend has produced various complex-shaped tall buildings, such as twisted, tilted, tapered and freeform towers, as are the cases with the twisted Cayan Tower in Dubai, tilted Gate of Europe Towers in Madrid and tapered freeform Phare Tower in Paris. This paper studies performance-based structural system design options for various complex-shaped tall buildings.

Tall buildings carry very large gravity and lateral loads. Therefore, structural impacts of twisting, tilting, tapering and free-forming tall buildings are significant, and more careful studies are required for the design and construction of complex-shaped tall buildings. Though not uncommon these days, complex-shaped tall buildings are a still very recent architectural phenomenon, and only a limited amount of related research has been conducted. This study presents comparative evaluation of multi storey high rise structure with twist at different angles and compares the results with the bare frame of conventional structure.

Method of Design and Analysis

Tall buildings of various complex forms and heights are designed with today's prevalent tall building structural systems, such as diagrids, braced tubes and outrigger systems, and their comparative structural performances are studied. Considering that the structural design of tall buildings is generally governed by lateral stiffness rather than strength, stiffness-based design methodologies are used to design the tall building structures of various complex forms.

Core structures are designed to carry only gravity loads for the tube type structures, such as diagrids and braced tubes. For outrigger structures, core structures are designed as braced frames to carry both gravity and lateral loads. The SEI/ASCE Minimum Design Loads for Buildings and Other Structures is used to establish the wind load.

Once the structural design and analyses of the rectangular box form tall buildings are completed, comparable complex-shaped tall buildings of each form category are designed with diagrids, braced tubes and outrigger structures. For twisted, tilted, tapered and freeform tall buildings, parametric structural models are generated using Rhino/Grasshopper to investigate each system's structural performance depending on the rate of twist, angle of tilt, angle of taper and degree of fluctuation of free form. The models are exported to structural engineering software, ETABS, for design, analyses and comparative studies. In order to comparatively estimate the structural performances of various structural systems employed for twisted, tilted, tapered and freeform structures, the preliminary structural member sizes determined for the conventional box form towers are also used for the complex-shaped tall buildings with some minor adjustments when necessary.

Types of Complex Structures

Twisted Tall Building

Employing twisted forms for tall buildings is a recent architectural phenomenon. Twisted forms employed for today's tall buildings can be understood as a reaction to rectangular box forms of modern architecture. In fact, this contemporary architectural phenomenon is not new in architecture. It is comparable to twisted forms of Mannerism architecture at the end of Renaissance architecture. For example, in Cortile della Cavallerizza at Palazzo Ducale in Mantua, Giulio Romano designed twisted columns. Twisted forms can be found again in today's tall buildings, such as the Shanghai Tower in Shanghai designed by Gensler.

In terms of static response, twisted forms are not structurally beneficial. If solid towers are considered, the moment of inertia of a square plan does not change regardless of its twisted angle. However, if building type structures composed of many frame members are considered, the lateral stiffness of the twisted tower is smaller than that of the straight tower.

Fig 1 Twisted Structure

Tilted Tall Building

Buildings have traditionally been constructed vertically, orthogonal to the ground. When a building is found to be tilted, it is typically an indication of some serious problems occurred to the building. The leaning Tower of Pisa is a famous example of tilted buildings due to differential settlements. Today, however, tilted buildings are intentionally designed and built to produce more dramatic architecture, as are the cases with the Gate of Europe Towers of 1996 in Madrid designed by Philip Johnson/John Burgee, Veer Towers of 2010 in Las Vegas by Helmut Jahn, and the design of the Signature Towers in Dubai by Zaha Hadid. The structural performance of a tilted tall building is dependent upon its structural system and angle of tilt.

Compared to the perimeter tube type structures, such as braced tubes and diagrids, the outrigger system provides greater lateral stiffness for tilted towers because of the triangulation of the major structural components – the braced core, outrigger trusses and mega-columns – caused by tilting the tower.

Fig 2 Tilted Tall Structure

Tilted tall buildings are subjected to significant initial lateral deformations due to eccentric gravity loads. Gravity-induced lateral displacements increase as the angle of tilt increases in all the three structural systems. Among them, the outrigger structures produce relatively small gravity-induced lateral displacements again because of the triangulation of the major structural components. These gravity-induced deformations can be managed substantially through careful construction planning. As the angle of tilt increases, very large localized stresses are developed in tilted tall buildings. Though structural design of tall buildings is generally governed by lateral stiffness, careful studies on satisfying strength requirements are also essential for tilted tall buildings. Large tensile forces, not very often found in conventional vertical tall buildings, can be developed in tilted tall buildings. Careful design studies on the connections of the tensile members of tilted tall buildings are required.

II. LITERATURE REVIEW

Vikash Yadav and Anurag Bajpai (2020) research paper presented seismic behaviour of buildings for regular plan under seismic loads and combinations according to IS 1893: 2016 and assess the report of diagrid and braced frame lateral resisting force system structure. seismic parameters that are base shear, modes of vibration, time period, story deracination, story drop off and story constraint were evaluated. Structural analysis of G+44 story steel frame, diagrid structure with grid angle 67.32 was presented. In other two frame using x-bracing at all faces, at corner, at centre and damper at corner, at centre. The plan considered for all models was 30m X 30m and the method use for analysis was Response spectrum analysis method. All the members were designed as per IS456:2000, IS800:2007 and load combination for seismic force were considered as per IS1893(Part-

1):2016. The procedure of modelling analysis was done on ETABSv17.0.1 software.

Results stated that Drift was minimum in X-bracing in all faces after 27 story before 27 story Diagrid structure having minimum vale but overall comparisons shows with respect to diagrid structure, maximum value of drift is 5.16% less in Xbracing in all faces, 81.5% more in X-bracing at corner, 150.5% more in X-bracing in centre. Hence, results concluded that Diagrid structure was much better than other all considered models. In diagrid structure using 20-25% less building material by which the weight of building is reduced.

Javed Shaikh et al (2020) research paper investigated the behavior of a Twisted Skyscraper Building subjected to earth quake load and wind load by adopting Response spectrum analysis .The analysis is carried out with the help of FEM software's ETABS 2018. The building model in the study has G+50 (52) storeys with constant storey height of 3.5m.According to the Indian Standard Code Analysis and Design was carried in the research.

Results stated that the values of storey drifts decrease from top storey to bottom storey and the maximum value is obtained for storey 50 (i.e. 0.00065 and 0.000574 in X-Direction and Y-Direction resp) and according to IS 1893-2016 part 1 this values are within the limit(i.e. maximum drift allowed is 0.004 of storey height). Top storeys are more susceptible to the drifts, building torque, forces and moments and these values decrease as we move on to the bottom storeys. As the height of the building increases, lateral forces plays a dominant role. Therefore, certain provisions shall be made in order to resist these lateral forces so that building performance under the effect of lateral loads.

Asra Fathima and Shashi Kumar N V (2020) objective of the research paper was to investigate the behaviour of a multi-storey vertical irregular residential building under lateral loads. The project is carried out by FEM software E-Tabs. The building model used in this work has 15 stories each storey has a height of 3m. Seismic analysis was conducted on a RCC Residential building by using two types of analysis namely Linear Analysis and Non-Linear Analysis.

Results stated that the displacement obtained from linear analysis is 70% higher when compared to the displacement obtained from the Non-Linear analysis. Hence we can conclude that for tall buildings Nonlinear methods of analysis holds good this gives lower value of all the parameters hence the percentage of steel used in construction can be reduced. Base Shear of a building increases as the zone factor increases. For the same building base shear in Zone-2 is 3966.36 KN and in Zone-5 are 14278.9 which show that base shear increases by 30%.

Hanna Golasz-Szolomicka and Jerzy Szolomicki (2019) research paper presented the construction and architectural characteristics of the most spectacular twisted forms of high-rise buildings that have hotel, office, residential and public functions. Buildings are characterized by different bodies and plans that are not related to the function of the object. They were designed on a convex plane (ellipse, circle, convex triangle), quadrilateral and on complex system. The central core plays a major structural role in all presented buildings.

Mix of complex computing power, new architectural trends and sustainability were the main factors which have been driving this new design. The development of computer technologies and the BIM system had a positive effect on designing of the twisted building. Designers are currently supported by innovative computer software when designing extra-ordinary shapes. In order to simplify the design process, this software must allow rapid shape generations and enable the huge amount of digital data of the components to be handled. In addition, designing the façade system of a twisted tall building, due to its variety, is also a significant issue. However, this complicated form of a high-rise building is not only aesthetic but also plays an important role in the carrying of dynamic loads. The use of aerodynamic twisted forms is an effective method of reducing wind loads on buildings. The effect of the wind on a building is neatly blocked by breaking up the wind flow. Although the cost of erecting such a building is much larger than an orthogonal building, its construction offers the opportunity to test new materials and construction technologies.

Youyi Xiong and Chonghou Zhang (2018) author created a series of finite element models of twisted diagrid tube structure to explore the influence of general components arrangement on the properties of the entire structure. Using finite element software SAP2000 V14, research explored the internal forces of the major components in the twisted frame structure. The establishment of the model is to highlight the role of the parameters.

Results stated that the maximum axial force of the side columns is larger than the maximum axial force of the corner columns at the corresponding position. And with the increase of twist angle, the gap between the two increased. The reason for this phenomenon is the tilt level of side columns is less than corner columns. Therefore, the side column has a better transmission of force. The influence of rotation angle on the components shows that the internal force of the side columns and diagonal bracing tend to increase as the rotation angle of the floor increases. However, the changing tendency of corner column shows decline after a short increase, the maximum value of internal forces, or the most unfavorable situation occurs when ω = 1 o . Then the internal force shows a decreasing trend with the increase of ω, and when ω=3 o the internal force is less than the traditional situation.

Prashanth Kumar N and Dr. Y.M.Manjunath (2018) research paper presented investigated the vertical geometric irregular RC buildings of 15 storey for seismic performance. Five buildings, one regular and four irregular buildings were considered with geometric irregularity by considering the IS 1893 codal provisions and analysis is done by ETBAS 2016 version using three different seismic analysis methods (linear static, response spectrum and time history method) The analysis is done. Bhuj time history was used for time history method. The analysis is done according IS 1893-2016(part 1).

Results stated that linear static method gives higher results in terms of storey displacement, base shear, story drift compared to response spectrum. The stiffness is an important parameter in seismic analysis in response spectrum and time history method. It was concluded that geometric irregular buildings are more vulnerable to earthquakes and proper care should be taken in the design of these buildings. Compared to regular structures, Irregular structures are subjected to twisting force i.e. torsion.

III. OBJECTIVES

The main aim is to present comparative study on structural behavior of RCC twisted buildings against bare frame under dynamic loads.

- To study seismic parameters (base shear, storey displacement, storey drift, time period) of the RC structures by linear static method, response spectrum method.
- To study the behavior of the RCC twisted building for 10, 12.5 and 15 degree in middle floor angle of twist.
- To study the behavior of the RCC twisted building under seismic load

IV. METHODOLOGY

Steps followed for Analysis

Step 1: Numerous research paper were analyzed from different authors all around the globe in order to identify the research done till date and understand their limitation which provide a base and scope for further research.

Step 2: This step presents the selection of matrix for the measurement and define the guidelines for selection of materials as ETABs being an international software for designing, it supports american, australian, Chinese and Indian codes for the analysis.the display units is selected for metric SI where the steel design code is selected as IS 800:2007 and concrete design code as IS 456:2000.

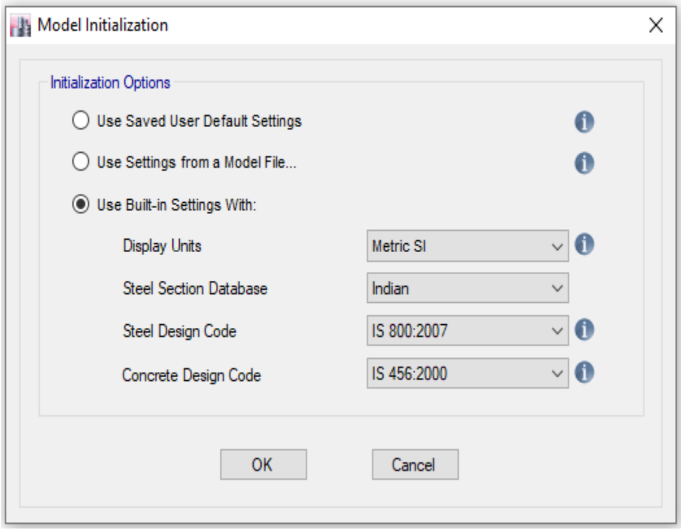


Fig 3 Model Initialization.

Step 3: Designing the frame of the twisted structure

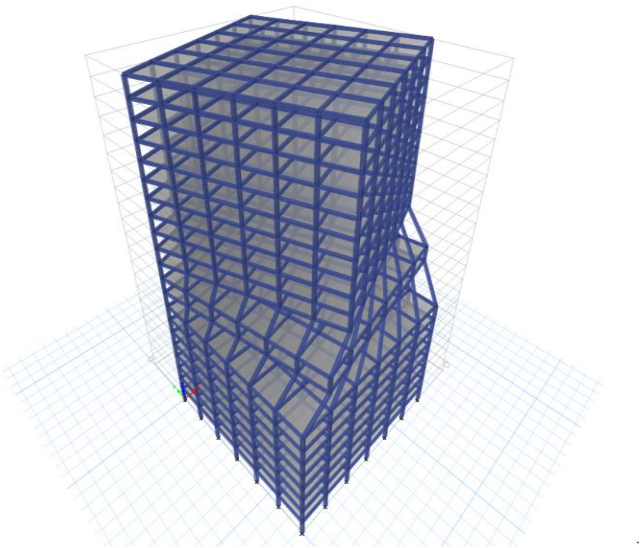


Fig 4 Designing the frame.

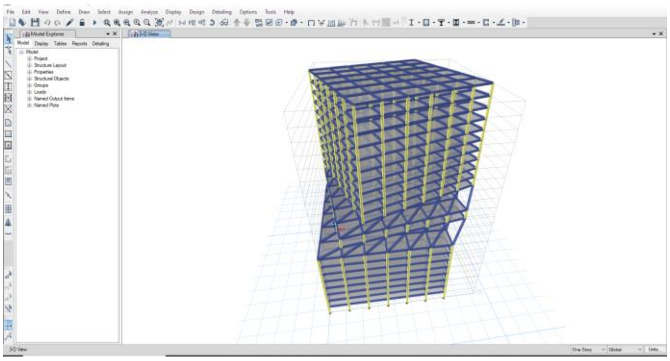


Fig 4 : 3D view of structure

Step 4 Defining material properties for the beam and column for concrete and steel where the material properties and mass is predefined as per selection of grade of concrete

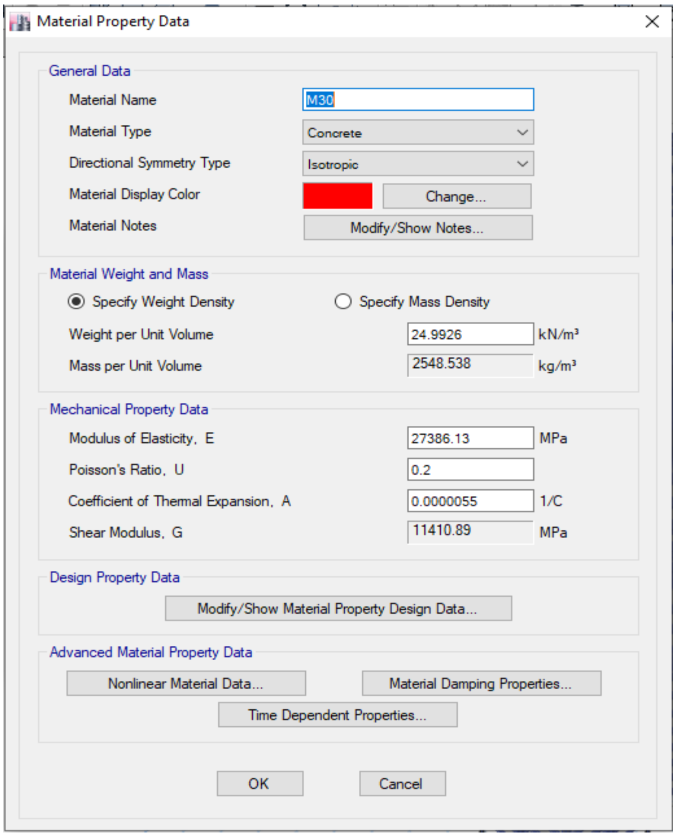


Fig 5 Defining Material Properties

Step 5 Defining section properties for beam and column

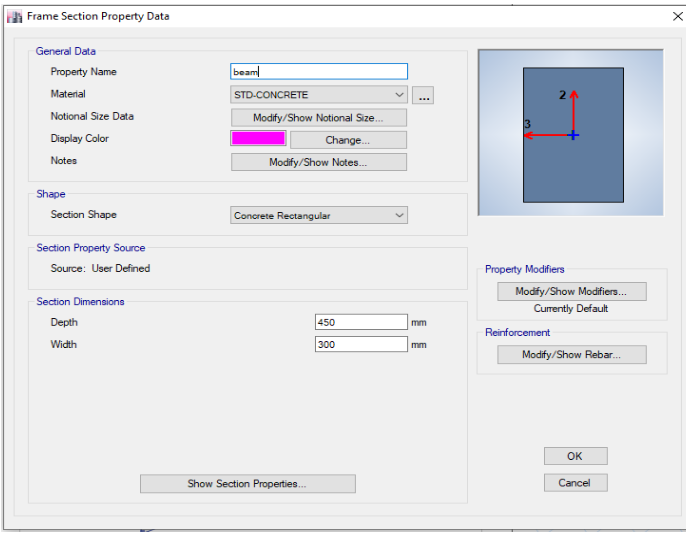


Fig 6 Defining section properties for beam

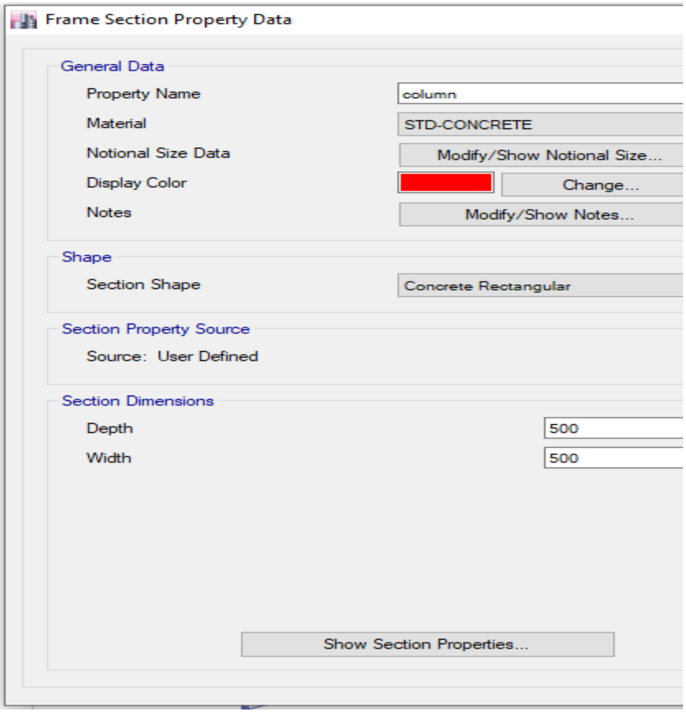


Fig 7 Defining section properties for column

Step 6 Defining Loading Condition for general load combinations and seismic load as per IS 1893 Part I 2016.

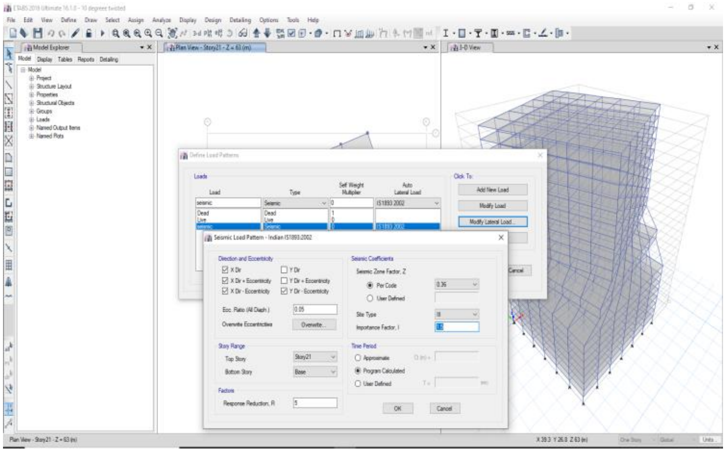


Fig 8 Defining Load Pattern and Combination

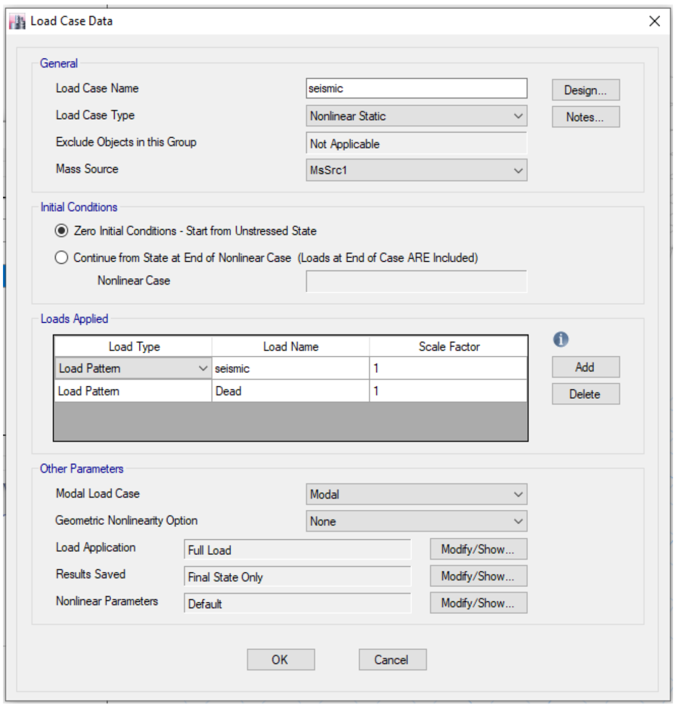


Fig 9 Defining Seismic load data as per IS 1893 part I 2016.

Step 7 Analyzing the structure on parameters of storey displacement, shear force, axial force and bending moment.

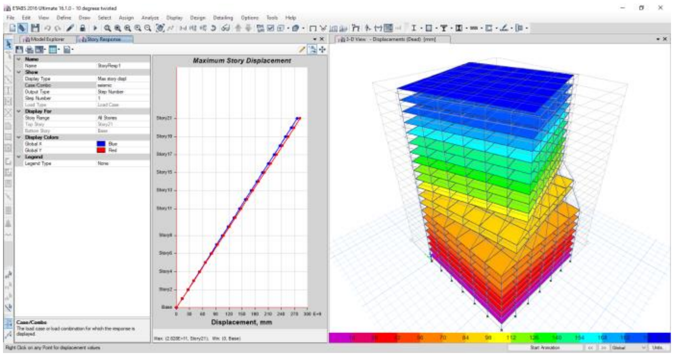


Fig 10 Storey Displacement

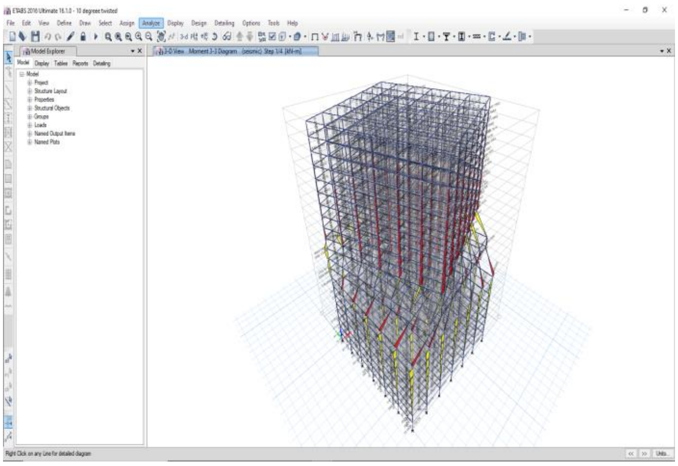


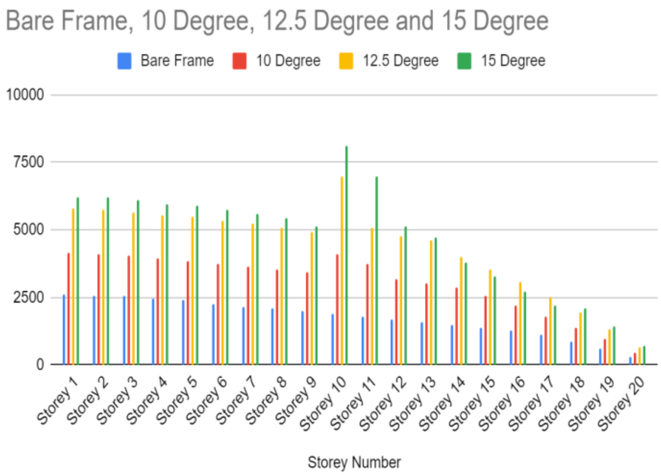
Fig 11 Moment

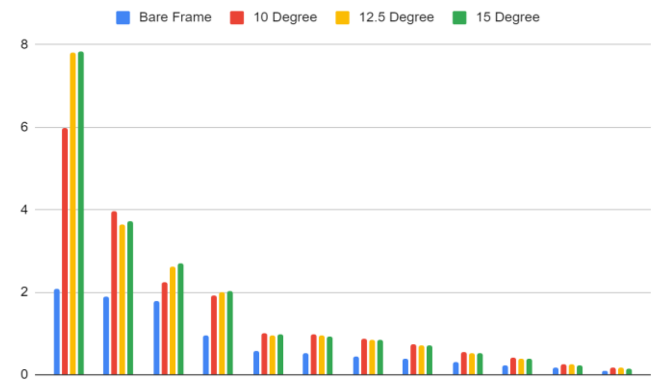
Step 8 Compiling the results and tabulating the data for the preparation of comparative graphs for chapter 5.

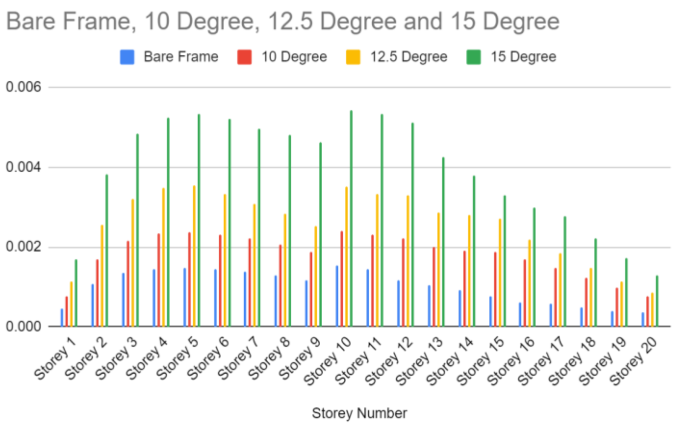
Table 1: Geometrical details

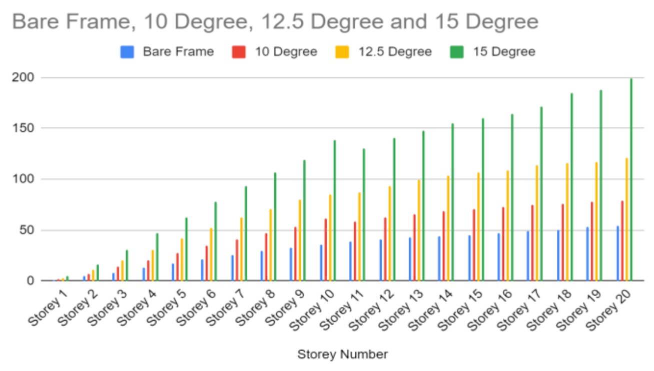
Structure Type	RCC Frame structure
Number of stories	G+20
Storey height	3m
Bay width in both direction	5m
Beam size	450x300mm
Column Size	500x500mm
Slab	175mm
Grade of Concrete(fck)	M30
Grade of steel (fFy)	Fe415
Live Load (LL)	3 kN/m2
SIDL (230mm wall)	12kN/m
Floor finish load (FF)	1kN/m2
Seismic Zone (Z)	V
Important Factor (I)	1.5
Response Reduction Factor (R)	5
Soil Type	III
Type of structure	Special moment resisting frame

V. RESULTS & DISCUSSION









VI. CONCLUSION

Shear Force

Shear force was maximum at storey 10th in case of structure with twist of 15 degree at the center in comparison to other cases. The same rise in shear force was seen in all the cases except the bare frame. Shear force was 61% more in the case of structure with 15 degree twist and variation of 8% was seen with structure with 10 degree twist in comparison to bare frame.

Time Period

Mode difference was seen in the first phase where the bare frame was most stable in comparison to other cases. Besides the structure with twist of 10 degree resisted the vibrations in time history analysis when compared to other modes.

Base Shear

Base shear was maximum in case of bare frame whereas the structure with twist of 10 degree at center well contained the base shear in comparison to other considered cases.Base shear was 50% higher when compared to other cases of structure with twist.

Storey Drift

Storey drift is higher in structure with a twist of 15 degree when compared to other cases. Storey drift is greatly influenced by the presence of irregularity. It was found that a structure with a twist of 15 degree at center showed maximum storey drift, whereas bare frame showed least storey drift. The results are within the permissible limit as per the Indian Standard code IS 1893:2016 (clause 7.11.1).

Displacement

Displacement linearly increases in case of bare frame structure but variation in displacement was seen in the twist on the structure with 10 degree, 12.5 degree and 15 degree.

Axial Force

Variation of 12% was seen in case of 10 degree, 16% in 12.5 degree and 18% in 15 degree structures when compared to bare frame. Still the structure was found stable in all the four cases considered to be safe.

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