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Analysis of Transmission Tower for Seismic Loading Considering Different Height and Bracing System

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Abstract--The four legged self-supporting tower is being used all over the world for transmitting electricity supply and for other purposes. Including the self-weight, transmission tower has to withstand against all forces like earthquake, wind and snow load etc. Therefore, transmission towers are generally designed for both structural and electrical requirements. In this study, four legged square type transmission tower has been analyzed for all four seismic zones (as per IS:1893(part-3)) considering three heights (40m, 50m and 60m) using STAAD.Pro software. Results are collected in terms of maximum deflection, maximum support reaction, maximum support moment, axial stress and bending stress criteria based on which salient conclusions are drawn.
Keywords: Transmission tower, Seismic analysis, Bracing system.

I. INTRODUCTION

A transmission tower is a tall structure also called as electricity pylon is usually a steel lattice tower used for supporting overhead cables. It is used in high AC and DC voltage and come in various shapes and sizes. They are the structures built to carry one or two circuits, although some transmission towers are also built to carry three or four circuits. Each circuit consists of three phases. Transmission towers support the phase conductors & earth wires of a transmission line. The necessity of electric power consumption has continued to enhance the rate of demand for developing countries. Transmission line tower is one of the important power supply structure. Transmission towers are necessary for the purpose of conveying electricity to various regions of the nation. This has led to increase in the structure of power stations and consequently increase in power transmission lines from the inducing stations to the various other corners where it's needed. Inter-connections between systems are increasing to enhance reliability and economy.
Some of the important literature on the topic are as follows:-
Alaa C. Galeb**,** Ahmed Mohammed Khayoon (2013), analyzed the transmission towers (1S2 and 2S2-132 kV types) that were subjected to multiple combinations of wind, seismic and dead loads, which were optimally designed for least weight. The fully stressed design and structural analysis were performed by using STAAD.Pro V.2006. The optimization problem was divided into two design spaces - Member area and Coordinate variable. It was found from the analysis that the 1S2 tower with angle section & X-bracing (under anti-cascade loading condition) has reduced the weight about 14% of the weight before optimization, It was observed that the reduction for 2S2 was 24% for the same conditions. Yash N. Patel, Jasmin A. Gadhiya, Hitesh K. Dhameliya, Kusha S. Pachchigar (2015), analysed transmission tower structure under seismic loading by STAAD Pro V8i. They designed the transmission line tower with economic consideration. Yusuf Mansur Hashim (2015), analysed transmission tower considering both static and dynamic analysis in three different models. The analysis performed by first order reliability analysis method for obtaining safest possible angle sections with their respective safety indices. They adopted response spectrum analysis method for dynamic analysis. They also obtained the frequencies and time period for different mode shapes as well as spectral accelerations and analysed tower using STAAD.Pro for obtaining the results. Siddu Karthik C S (2015), carried out earthquake analysis of transmission tower as per indian standard IS 1893:2002 (Part-1). They considered square type transmission tower and comparative analysis performed between wind zone I and seismic zone II. The tower has been analysed both statically and dynamically. The tower's seismic behaviour for zone II was tabulated and the deflections, axial forces, modal time period and base share were noted for both types of towers and compared for knowing which is safe in these. Jithesh Rajasekharan, S Vijaya (2014), analyzed telecommunication tower of varying heights with different bracing under wind and seismic effect. The wind effect on the tower was observed by applying the gust factor method and seismic effect on the structure was perceived by carrying out the modal analysis. The results obtained by this

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analysis were tabulated, compared and conclusions were drawn. Shivam Panwar, Yogesh Kaushik, Anubhav Singh, Nikhil Sharma (2016), analyzed and designed of a steel lattice transmission line towers using STAAD.ProV8i for wind and earthquake loading. They used two wind zones II and IV and compared to seismic zone IV for the same configuration of tower. In this study, the importance was given to the wind loading. The comparative study was done between wind and earthquake with respect to axial forces, deflections, maximum sectional properties and critical loading condition for both the zones. Sumit Pahwa,Vivek Tiwari, Harsha Jatwa (2014), analyzed 1S2 transmission tower under wind and earthquake loadingby taking into consideration of optimizing technique and comparative study is done between the wind and seismic loads. The optimization of wind and earthquake loading is conducted by plotting graph between wind forces with height, earthquake forces with height and tower with X and K bracing under wind and seismic load. All the analysis is performed using STAAD.Pro software and EXCEL spreadsheet. Srikanth, Neelima Satyam (2014), analysed transmission tower using Indian Standard IS: 1893:2002 (Earthquake) and dynamic analysis of tower performed considering ground motion of 2001 Bhuj Earthquake (India). They performed the analysis using numerical time stepping finite difference method. The tower was analysed using response spectrum analysis.

II. MODELLING AND LOADING DETAILS

This study includes comparative study of behavior of transmission tower with different geometrical configurations (12 cases) under seismic forces. A comparison of analysis results such as deflection, support reaction, support moment, axial stress and bending stresses have been carried out.

A. Problem Formulation

Selection of tower geometry

Selection of four seismic zones (Table 1)

Table 1: Seismic zone with zone factor

Seismic Zones as per IS 1893:2002(part-1)	Zone Factor
II	0.1
III	0.16
IV	0.24
V	0.36

Formation of load combination (13 load combinations) for seismic (Table 3)

Modeling of transmission tower

Analysis considering different height, seismic zones and each load combinations

Comparative study of results in terms of maximum deflection, maximum support reaction, maximum support moment, axial stress and bending stress for all different height tower.

Table 2: Proposed dimensions of transmission tower

TOWER PARAMETERS	DIMENSIONS (in m.)
Base dimension	6
Height	60, 50 and 40
Number of bays along height	4
Top dimension	2

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Table 3: Table for load case details for seismic forces

Load case no.	Load case details
1.	E.Q. IN X DIRECTION
2.	E.Q. IN Z DIRECTION
3.	DEAD LOAD
4.	LIVE LOAD
5.	1.5(DL + LL)
6.	1.5(DL + EQX)
7.	1.5(DL - EQX)
8.	1.5(DL + EQZ)
9.	1.5(DL - EQZ)
10.	1.2(DL + LL + EQX)
11.	1.2(DL + LL - EQX)
12.	1.2(DL + LL + EQZ)
13.	1.2(DL + LL - EQZ)

B. Details Of Seismic Parameter

The following seismic parameters are used in evaluating the seismic loads on the structure:
Zone factor (Z) as per IS-1893:2002 Part -1 for different Zone as per clause 6.4.2.(See Table 1)
Importance factor (I) - depending upon the fundamental use. We have considered I as 1.5 in this study.
Average Response acceleration

Coefficient Sa/g - for medium soil site

$$Sa/g = \begin{cases} 1+15T & 0.00 \le T \le 0.1 \\ 2.5 & 0.1 \le T \le 0.55 \\ 1.36/T & 0.55 \le T \le 4.00 \end{cases}$$

Design horizontal seismic co-efficient

Ah for the structure: - Ah = Z.I.Sa /2.R g

C. Cases Of Analysis

Table 4 shows the cases which are used for analysis with respect of zone factors, height and seismic zones.

Table 4: Cases used for seismic analysis

Seismic Zone	Case Number	Height (m)	No. of bays	Top dimension	Bottom dimension
II	Case 1	40	4	2	6
	Case 2	50	4	2	6
	Case 3	60	4	2	6
III	Case 1	40	4	2	6
	Case 2	50	4	2	6
	Case 3	60	4	2	6
IV	Case 1	40	4	2	6
	Case 2	50	4	2	6
	Case 3	60	4	2	6
V	Case 1	40	4	2	6
	Case 2	50	4	2	6
	Case 3	60	4	2	6

Transmission tower was modelled in STAAD.Pro. A typical model is shown in Fig.1. There are 160 beams and 68 joints in the model. Following steps are adopted.

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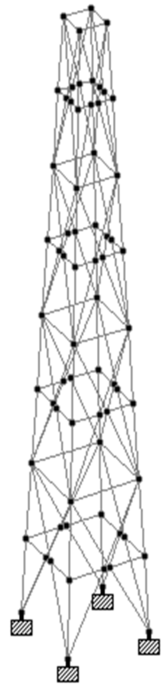

Fig. 1: Model of Transmission tower in STAAD.Pro

Application of Seismic Loads according to Zone II,III,IV & V on same sets of transmission line structures.

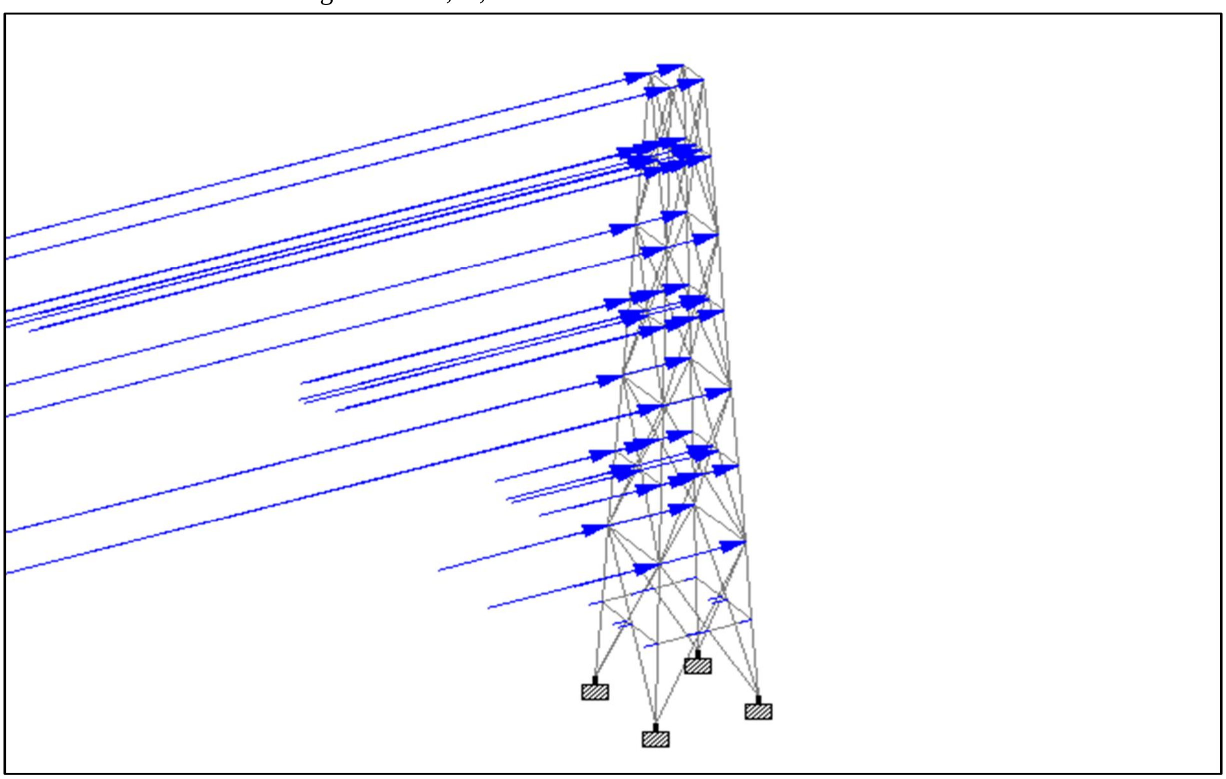

Fig. 2: Seismic Loads in X Direction acting on the structure in STAAD.Pro

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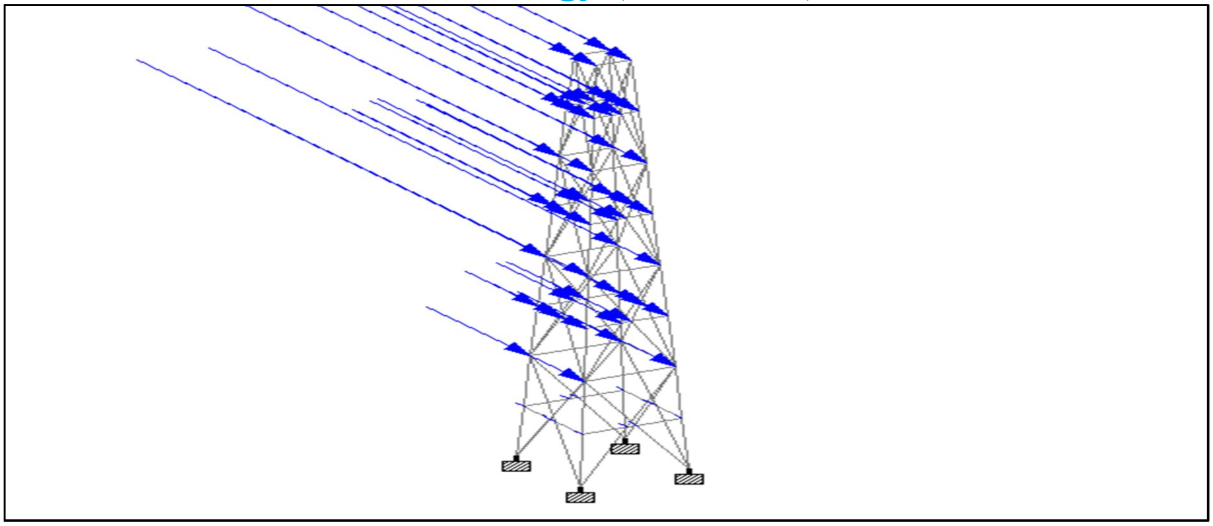

Fig. 3: Seismic Loads in Z Direction acting on the structure in STAAD.Pro

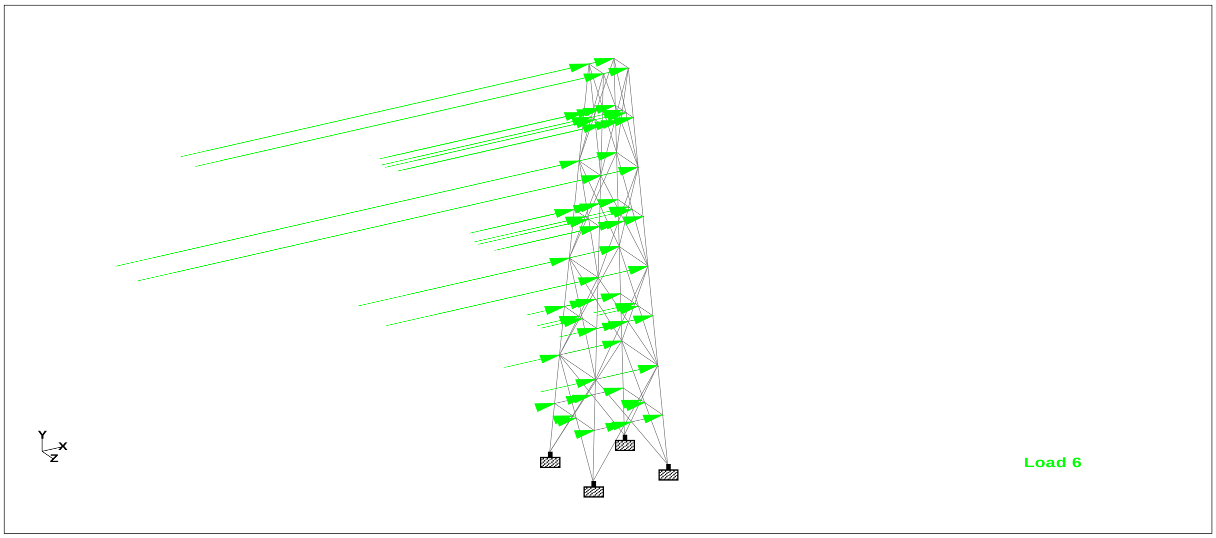

Fig. 4: Seismic Loads DL + EQX acting on the structure in STAAD.Pro

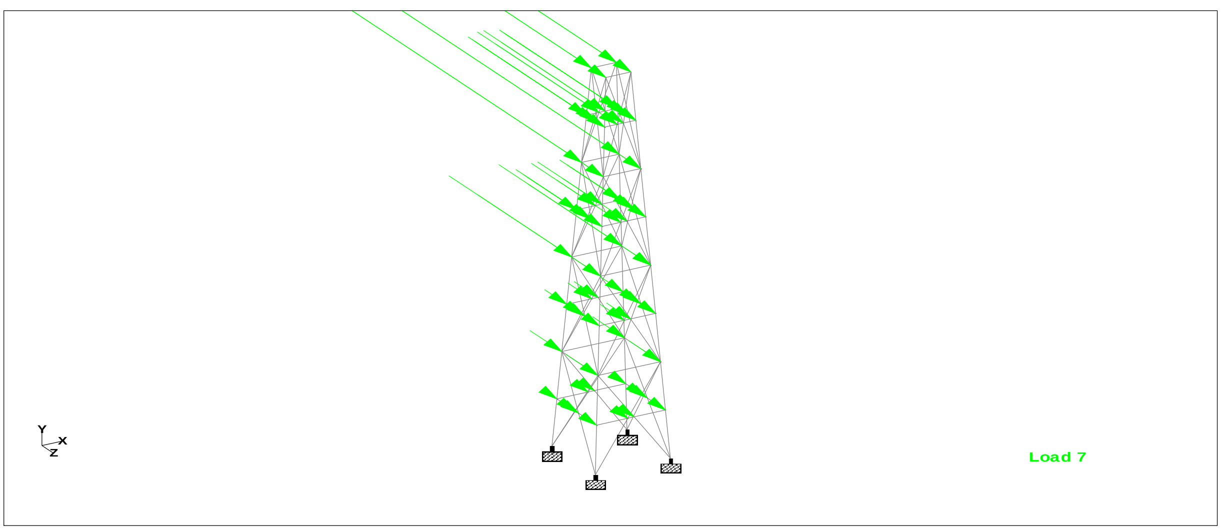

Fig. 5: Seismic Loads DL + EQZ acting on the structure in STAAD.Pro

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Analysis considering different diaphragm models (12 cases mentioned above) used STAAD.Pro software.

Results presented in the form of graphs and tables.

Parametric and comparative study of all cases in terms of maximum deflection, maximum support reaction, maximum support moment, axial stress and bending stress.

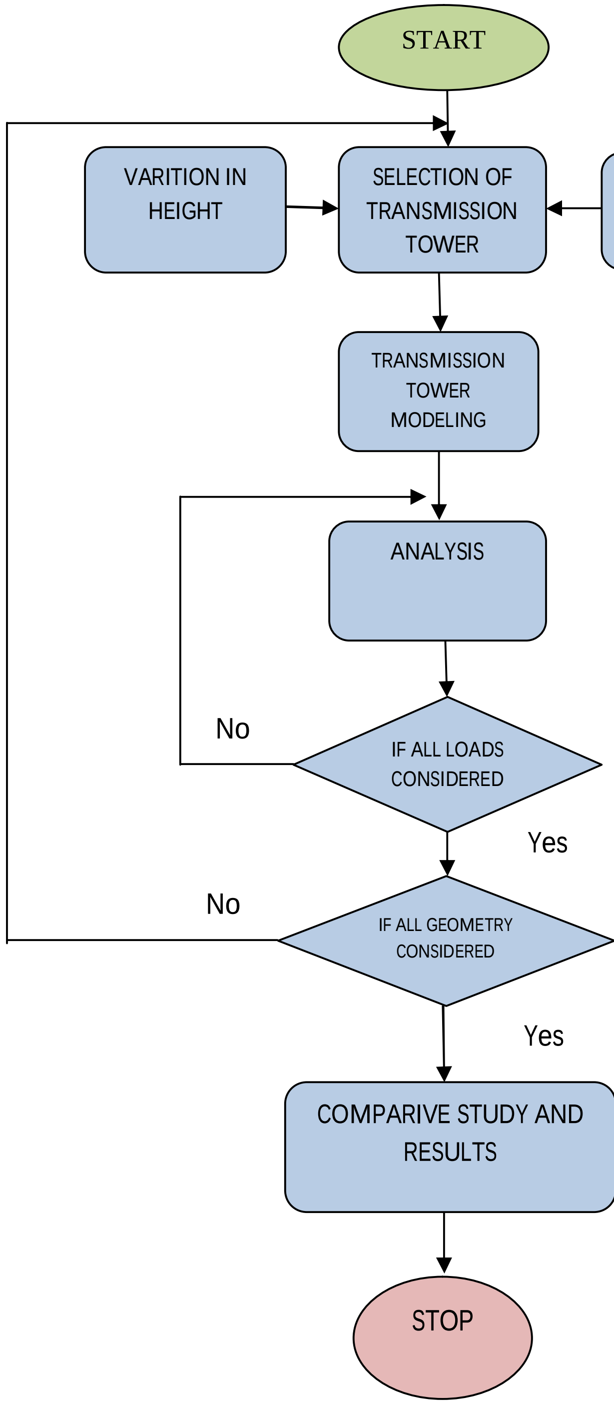

Fig.6: Flow chart of adopted methodology

III. RESULT AND DISCUSSION

The behavior of towers under different loading conditions has been analyzed for four seismic zones with different parameters. The tables, graphs and the discussions with respect to variations of the particular zones are given as follows:

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Maximum deflection for different zones and cases are given in Table 5 and shown in Fig.7.

Table 5: Deflection for all zones of seismic

Maximum deflection(mm) in all seismic zone			
Zones	Cases		
	case-1	case-2	case-3
II	3.364	6.201	10.368
III	5.381	9.981	16.582
IV	8.07	14.876	24.867
V	12.104	22.286	37.54

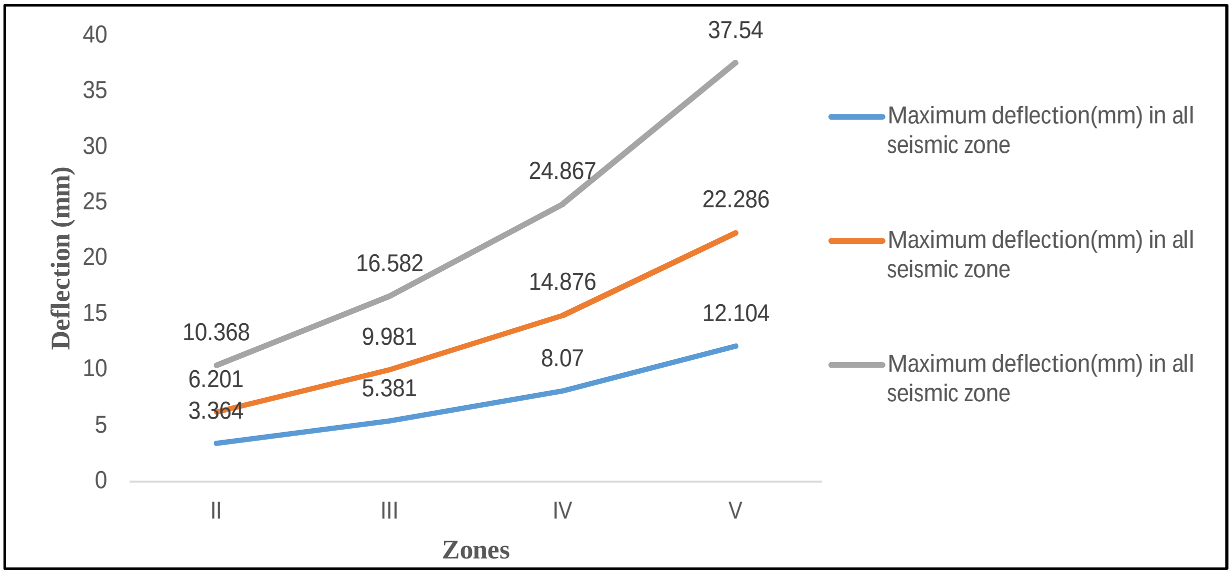

Fig. 7: Deflection (mm) for all earthquake zones.

From Fig. 7, it is observed that deflection for 60m high transmission tower in seismic zone V is maximum than all seismic zones of 40m and 50m high transmission tower. Deflection increases linearly with respect to seismic zone for all the cases.

Support reaction for all zones are given in Table 6 and shown in Fig. 8.

Table 6: Support reaction for all zones of seismic

Maximum support reaction(kN) in all seismic zone			
Zones	Cases		
	case-1	case-2	case-3
II	783.936	971.861	1167.365
III	883.68	1101.061	1327.662
IV	1016.673	1273.361	1541.391
V	1216.161	1533.468	1861.525

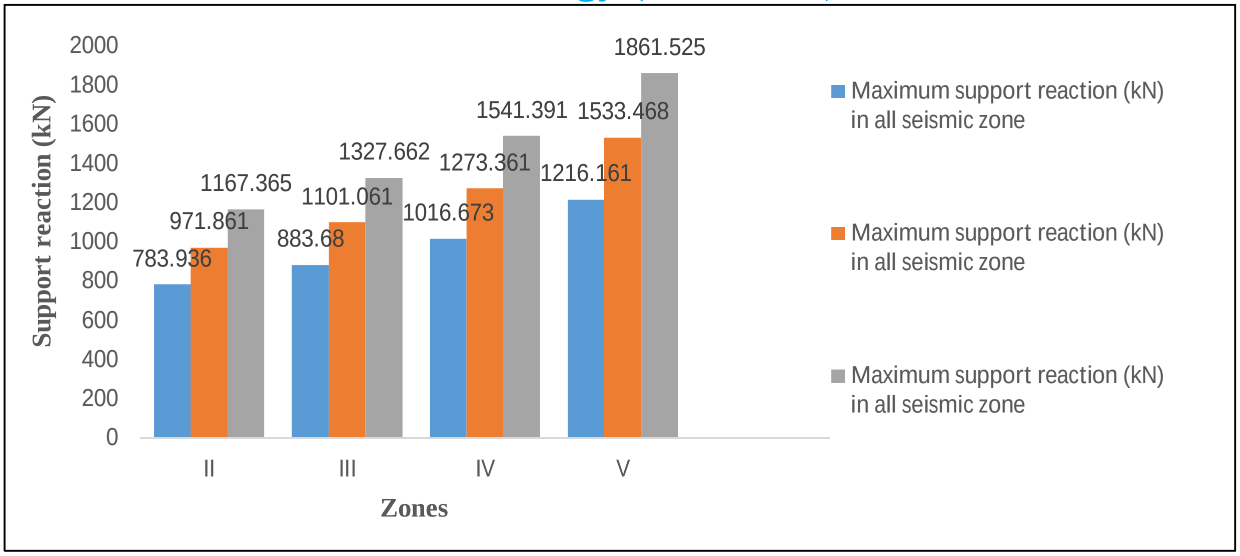

Fig. 8: Support reaction (kN) for all seismic zones.

From Fig. 8, it is observed that support reaction for 60m high transmission tower in seismic zone V is maximum than all seismic zones of 40m and 50m high transmission tower. It can be observed that zone II for case 3 is equivalent to zone III for case 2.

Support moment for all the seismic zones for all cases are given in Table 7 and shown in Fig. 9.

Table 7: Support moment for all zones of seismic

Maximum support moment (kN-m) in all seismic zone			
	Cases		
Zones	case-1	case-2	case-3
II	22.231	26.764	76.293
III	27.587	33.075	84.098
IV	34.728	41.493	94.503
V	45.439	48.694	110.339

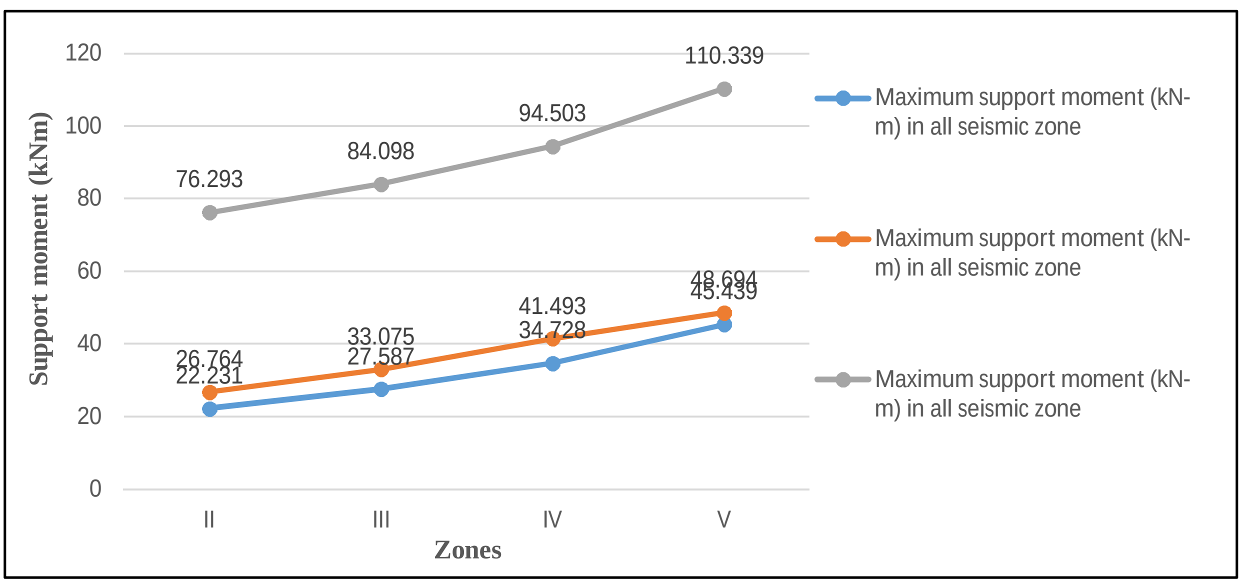

Fig. 9: Support moment (kN-m) for all seismic zones.

From Fig. 9, it is observed that support moment for 60m high transmission tower inseismic zone V is maximum than all wind zones of 40m and 50m high transmission tower. Support moment increases linearly with increase in tower height.

Axial stress for all the zones and cases are given in Table 8 and shown in Fig. 10.

Table 8: Axial stress for all zones of seismic

Maximum Axial stress(N/mm^2) in all seismic zone			
	Cases		
Zones	case-1	case-2	case-3
II	23.928	21.7	9.662
III	25.961	23.428	15.46
IV	28.672	25.731	23.189
V	32.738	26.152	34.345

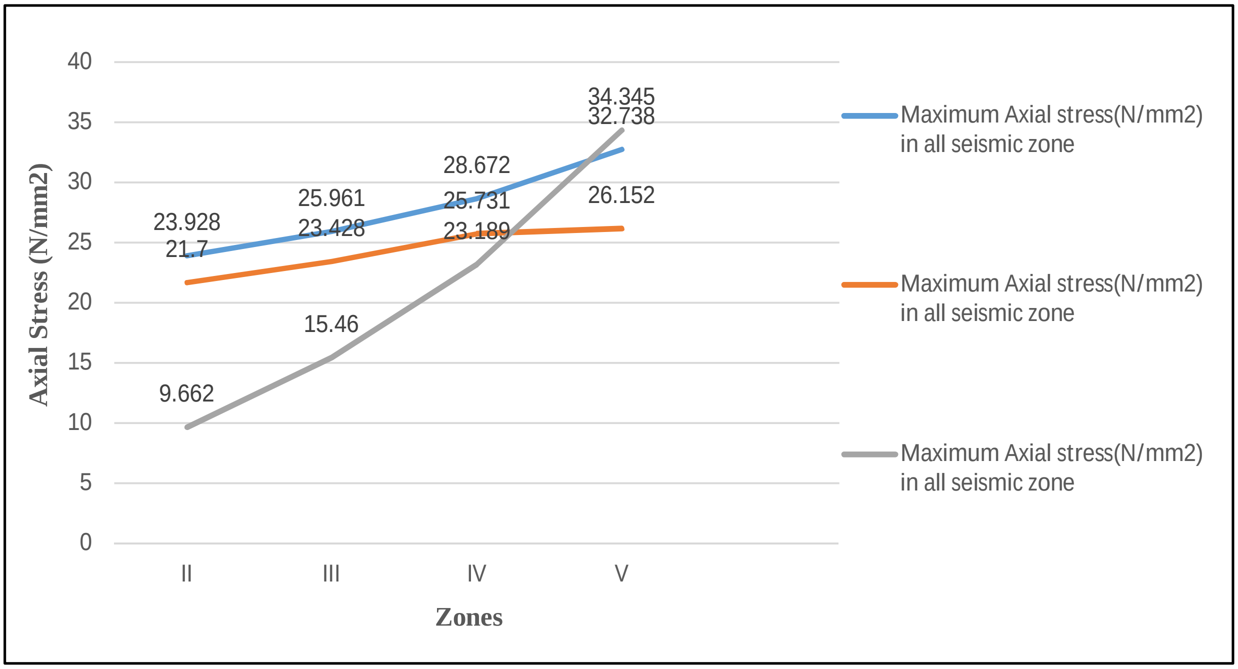

Fig. 10: Graphs of Axial stress for all zones of seismic.

From Fig. 10, it is observed that axial stresses for 60m high transmission tower in seismic zone V is maximum than all zones of 40m and 50m high transmission tower. Rate of increase of axial stress increases with increase in height.

Bending stress for all the zones are given in Table 9 and shown in Fig. 11**.**

Table 9: Bending stress for all zones of seismic.

Maximum Bending stress(N/mm^2) in all seismic zone			
	Cases		
Zones	case-1	case-2	case-3
II	13.061	20.349	23.088
III	20.323	21.444	23.147
IV	21.827	31.384	23.226
V	31.969	57.792	22.55

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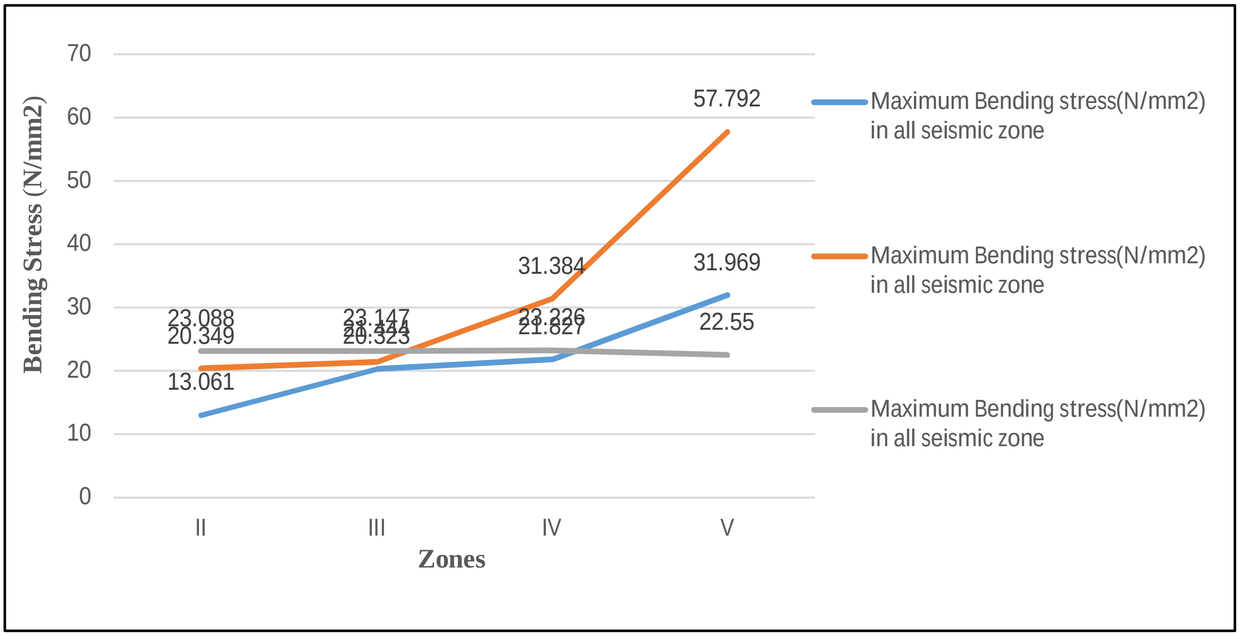

Fig. 11: Bending stress (N/mm^2) for all seismic zones.

From Fig. 11, it is observed that bending stresses for 50m high transmission tower in seismic zone V is maximum than all zones of 40m and 60m height. Bending stress is minimum and constant for 60m height.

IV. CONCLUSIONS

The following are the salient conclusions of this study:

A. Deflection

Maximum deflection of tower which has 40m of height deviates between 3.3 to 12.2 mm, the tower which has 50m of height deviates between 6.2 to 22.3 mm and the tower which has 60m of height deviates between 10.3 to 37.6 mm, So it is clear that the deflection is critical for 60m high tower in all zones of seismic.

B. Support Reaction

Support reaction of tower which has 40m of height deviates between 783 to 1217 kN, the tower which has 50m of height deviates 971 to 1534 kN and the tower which has 60m of height deviates between 1167 to 1862 kN. It is clear that the support reaction for 60m high transmission tower in seismic zone V has larger value than 40 and 50m high transmission tower in all zones of seismic.

C. Support Moment

Support moment for the tower of 40m height deviates between 22 to 46 kN-m in all zones of seismic, the tower which has 50m of height deviates between 26 to 49 kN-m and the tower which has 60m of height, it’s support moment values deviate between 76 to 111 kN-m for all zones of seismic, So it is observed that the support moment values are critical for 60m high tower in seismic zone V.

D. Axial Stress

Axial stress for towers for 40m of height deviates between 23 to 33 N/mm^2, for all zones of seismic, the tower which has 50m of height deviates between 21 to 27 N/mm^2 and the tower which has 60m of height deviates between 9 to 35 N/mm^2 for all zones of seismic. It is found that the axial stress for 40m high tower is more than the 50m high tower in all seismic zones and 60m high tower for seismic zones of II, III and IV, but axial stresses for 60m high tower in seismic zone V is larger than all seismic zones of 40 and 50m high tower.

E. Bending Stress

Bending stress for tower which has 40m of height deviates between 13 to 32 N/mm^2, the tower which has 50m of height deviates between 20 to 58 N/mm^2 in all zones of seismic and the tower which has 60m of height deviates between 22 to 24 N/mm^2. It is observed that the bending stress value for 50m high tower in seismic zone V is critical than all the seismic zones of 40 or 60m high tower.

So, from the above results, it is clear that the 60m high tower is critical than 40m and 50m high tower in case of deflection, support reaction, support moment and also in the case of axial stress in seismic zone V, but for bending stress, 50m high tower is critical than 40m and 60m high tower in all seismic zones. This paper will help in understanding the effect of seismic load on tower structure by considering different seismic zones.

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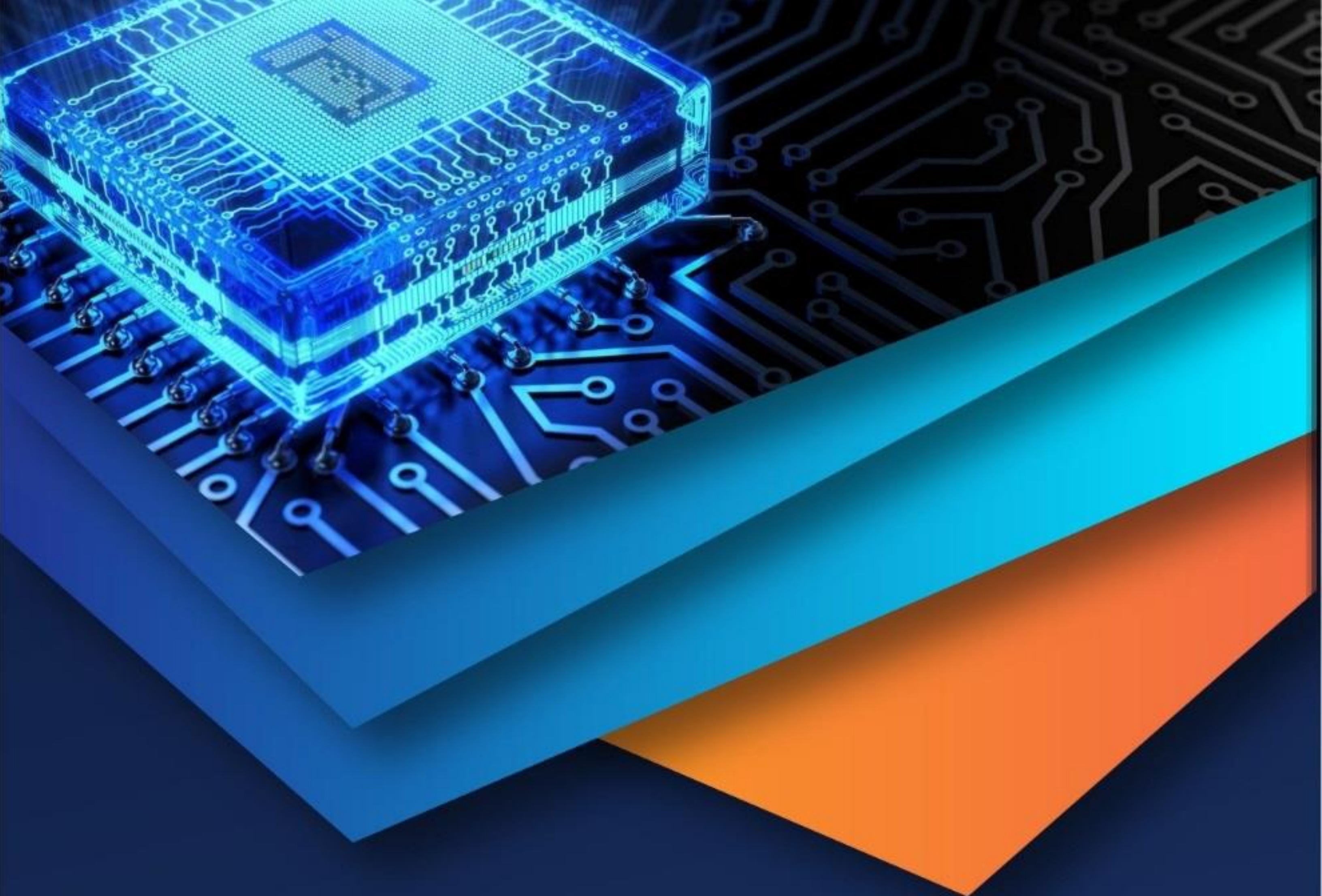

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