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"Comparing the Behavior of Transmission Line Towers with Different Bracing Configurations through Response Spectrum Analysis"

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Abstract— As the demand for electricity continues to rise, the cost-effective design of transmission line towers becomes increasingly important. These towers, which can account for a significant portion of the transmission line's cost, offer opportunities for optimization through exploring different lightweight configurations. This study aims to identify the most economical tower section and configuration adhering to Indian Standard IS-800. The analysis is conducted using SAP2000 software, comparing various bracing patterns and their impact on the tower's progressive collapse behaviour. A standard 220 kV double-circuit transmission line tower will serve as the case study, modelled and analysed within SAP2000. The tower will be having a height of 40 meters and a square base width of 11.5 meters. To facilitate fabrication, the members will be grouped. Steel optimization will be performed to determine the most suitable and cost-effective cross-sections. The Diamond bracing, Double bracing and Knee bracing Transmission tower will be subjected to various loads, including wind, earthquake, and its own dead weight. All analysed towers will be evaluated for both gravity and lateral loads (as per IS: 875(part-III)). The final report has presented a comparative analysis based on factors such as base shear, self-weight, modal time period, modal mass participation, and overall tower weight.

Keywords: Transmission Line Tower, Response Spectrum, time history Earthquake Loading, Loading, Wind Loading.

1. INTRODUCTION

1.1 General Introduction

The growing need for electricity can be met more efficiently by developing lighter designs for transmission line towers. Choosing the best configuration, along with the right bracing system, height, cross-arm type, and other parameters, plays a crucial role in creating a cost-effective transmission line tower design.

Transmission line towers are vital infrastructure, essential for delivering electricity to various regions. This has led to an increase in power station construction and the subsequent expansion of transmission lines from generating stations to areas where electricity is needed. Transmission lines must be stable and meticulously designed to withstand natural disasters. They must also adhere to national and international standards.

Planning and designing a transmission line involves meeting several structural and electrical requirements. From an electrical standpoint, the most important factor is insulation and maintaining safe clearances between power-carrying conductors and the ground. The conductor cross-section, spacing between conductors, and ground wire placement relative to conductors will determine the design of towers and foundations.

Transmission towers are modelled using various bracing patterns. Axial forces, deflections, and the tower's weight vary depending on the bracing pattern. Specific bracing patterns can help reduce the tower's weight. The main components of a transmission line include conductors, ground wires, insulation, towers, and foundations. Most of the time, transmission lines are designed to withstand wind and ice loads in the transverse direction.

Important aspects of constructing a transmission tower:

Table 1.1. Aspects of constructing a transmission tower

Sr. No.	Transmission Voltage	Basic Span	Width of Right of Way	Minimum Horizontal Clearance
1.	132 KV	335 m	27 m	2.9 m
2.	220 KV	350 m	35 m	3.8 m
3.	400 KV	400 m	52 m	5.6 m
4.	800 KV	Above 400 m	Above 52 m	9.2 m

1.2 Types of Transmission Towers

A. Type the type of transmission tower based on their Angel of deviation classified Are classified below

Table 1.2. Type transmission tower based on their Angel of deviation

Sr. No.	Type of Tower	Angle of Deviation
1.	Suspension Tower	Upto 2 Degrees
2.	Small angle Tower	Upto 15 Degrees
3.	Medium angle Tower	Upto 30 Degrees
4.	Large angle & dead-end Tower	Upto 60 Degrees & Dead End

1.3 Components of transmission tower:

Transmission tower consists of following parts

A. **Peak:** It Supports ground wire.

B. **Cage:** In between Peak and the Tower body.

C. **Cross arm:** It Supports the Conductors.

D. **Bracing:** To resist the lateral loads.

E. **Tower Body:** Main portion which connect Cage and Foundation.

F. **Body Extension:** For more clearance.

G. **Stub:** It projects tower body into the foundations.

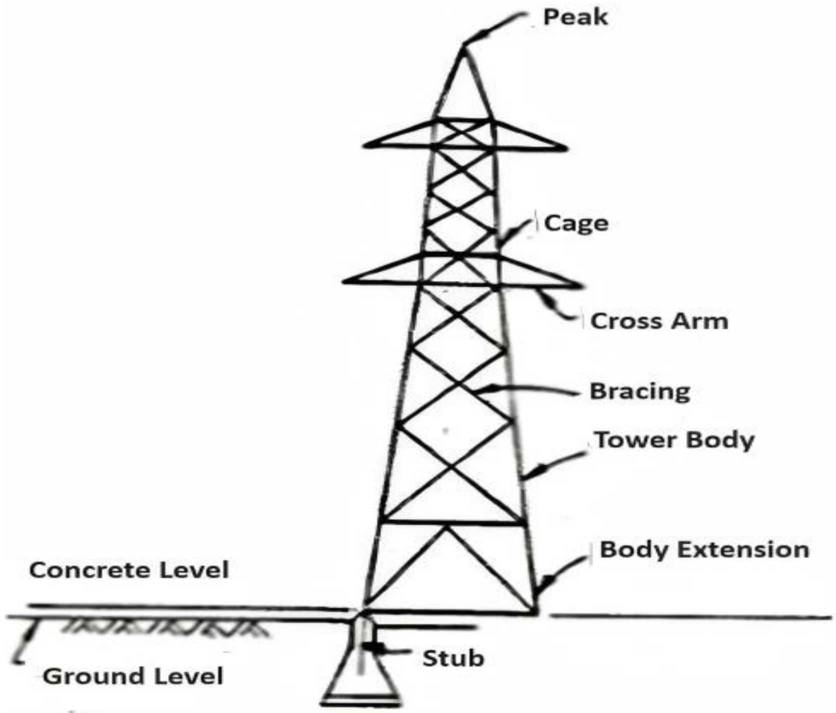


Fig.- 1 Transmission line Tower

2. LITERATURE REVIEW

2.1 Introduction

A significant body of research has investigated on Transmission Tower. This review synthesizes this scholarship, identifying central themes, methodologies, and debates.

2.2 literature review

Balaji Patil, K. S. Upase (2020) [5] – studied analysis and design of transmission tower by using different types of bracing. Author concluded that warren type bracings are not structurally stable as compare to two other types of bracing single web horizontal type bracing and single web diagonal bracing. Single web horizontal type bracings are structurally safe as compare to warren type and single web diagonal type bracings. Single web diagonal type bracing transmission tower is failed at bottom leg for wind speed 47m/s.

Tanvi G. Londhe (2018)[1] – studied the comparative study of different types of bracing of transmission tower by using SAP2000. Author concluded that the base reaction for single web horizontal type bracing is maximum while for single type bracing is minimum. The displacement value is higher for single web diagonal type bracing while, for warren type bracing has lower value. This implies that single web diagonal type tower behaves more rigidly than other types of towers. The weight of the single bracing tower is less as compared to other three type of bracing tower.

CH. Harshini, K. Sindhu Rani (2018)[6] – concluded that the displacement values are quite higher in the STAAD-Pro result than the ETAB result. The quantity of the steel required is higher in the STAAD result. Transmission tower with same bracing can be used at these two different wind zones with same seismic zone by using different steel members at different phases of the transmission tower according the effect of the load on the specific location members. In Staad pro self-weight of structure is considered as factor 1. Etab self-weight factor is 1.1 that means 10% of self-weight consideration is more in Etabs.

Heera Lal Bhardwaj, Ajit Ajit, Yogesh Kaushik (2015)[7] – studied that analysis and design of transmission tower by using STAAD-Pro and vertical configured self-supporting tower exhibits a saving of 2.65 % in the weight of structural steel. But it is to be noted that leg members of vertical configured tower HT steel sections are required to sustain the external loads. On the other hand, all leg members of the horizontal configured tower required only MS section to sustain the external loads by using STAAD-Pro.

2.3 Summary Of Literature Review

The researchers have been analyzing various structures using different bracing. Several investigators studied the influence flexibility of transmission line tower. They performed the studies by changing various type of bracing parameters of tower and structure.

3. RESEARCH OBJECTIVE

1. To find the most cost-effective and stable design for a transmission line tower. We'll achieve this by exploring different arrangements of bracing patterns.
2. To study the behavior of Knee, Dimond & Double bracing in Different Earthquake zone (III, IV & V).

4. Theoretical Formation

4.1 Seismic Base Shear

According to IS 1893 (Part-I): 2002, Clause 7.5.3 the total design lateral force or design seismic base shear (VB) along any principal direction is determined by,

$V_b = A_h * W$

Where,

A_h is the design horizontal acceleration spectrum

W is the seismic weight of building

4.2 Design Horizontal seismic coefficient

For the purpose of determining the design seismic forces, the country (India) is classified into four seismic zones (II, III, IV, and V). Previously, there were five zones, of which Zone I and II are merged into Zone II in fifth revision of code. According to IS 1893: 2016 (Part 1), Clause6.4.2 Design Horizontal Seismic Forces Coefficient Ah for a structure shall be determined by following expression.

Table 4.1 Seismic Zones of India

Seismic Intensity	Low	Moderate	Severe	Very Severe
Zone	II	III	IV	V
Z	0.10	0.16	0.24	0.36

India has been divided into four seismic zones. Zone II and Zone III are major zones covering more percentage of land area in India. Eastern India has higher seismic intensity. It fails under zone V. North-East India falls under zone IV. Geographical statistics of India show that almost 54 % of the land is vulnerable to earthquakes. Table 3.1 & Fig.3.2 shows various seismic zones of India with tentative percentage of land area.

I = Importance factor is used to obtain the design seismic force depending on the functional use of the structure, characterized by hazardous consequences of its failure, it's post-

Earthquake functional need, historic value, or economic importance (IS 1893-2016 cl.no.6.4.2/table6/pg.no.18)

R = Response reduction factor depending on the perceived seismic damage performance of the structure characterized by ductile or brittle deformations which is shown in Table 3.2 ((IS 1893-2016 cl.no.6.4.2/Table7/pg.no.23).

Sa/g = Average response acceleration coefficient (dimensionless value). The value of Sa/g is obtained from fig.3.3 from IS: 1893 (Part 1): 2016.

Table No 4.2: Detail Features of Tower Structure

Sr. No	Parameters	Values
1	Material Used	Steel Grade Fe-250
2	Total height of tower	40m
3	Unit weight of steel	78.50 KN/m3
4	Poisson Ratio	0.2-Concrete And 0.15-Steel
5	Code Of Practice Adopted	IS800:2007, IS1893:2016 IS875-part -III
6	Seismic Zone for IS1893:2016	II, III, & IV.
7	Importance Factor	1
8	Response Reduction Factor	5
9	Foundation Soil	Medium
10	Live Load	$7KN/M^2$
11	Earthquake Load	As Per IS 1893-2016

4.3 Different bracing pattern

A. Double Bracing Tower Structure

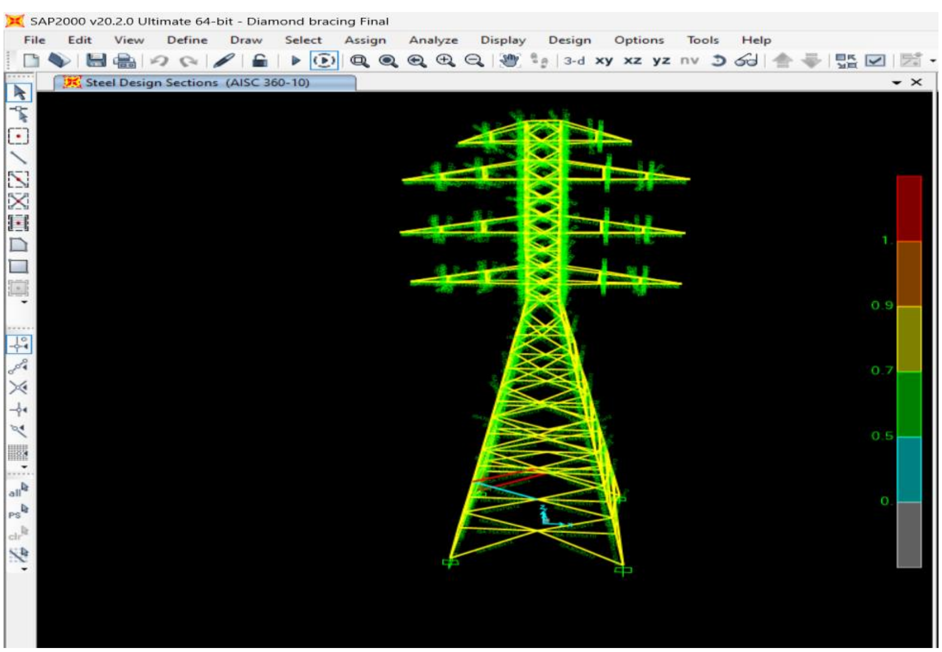
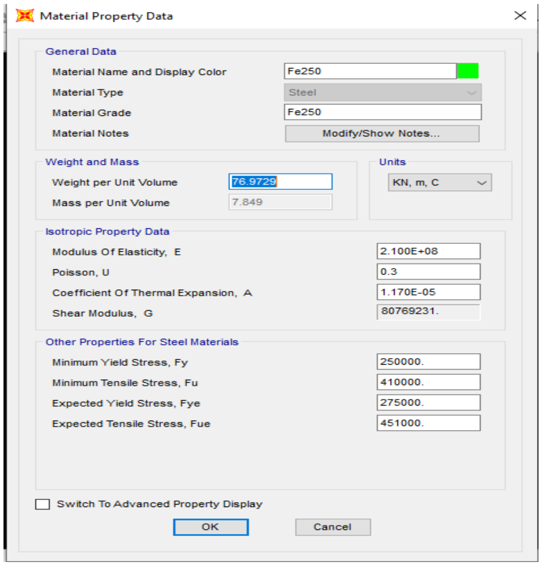
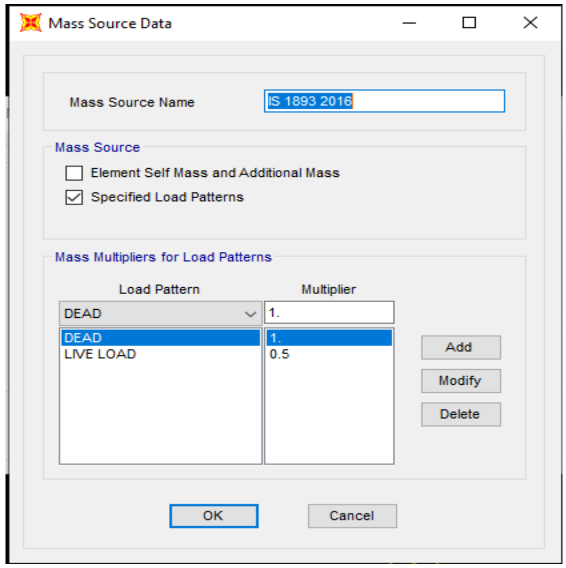


Fig. 1.2 Transmissions Line Tower X-Bracing Modes

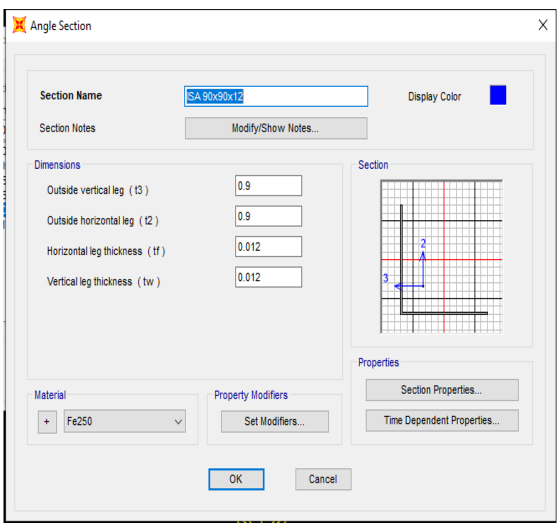
A. Material Defines



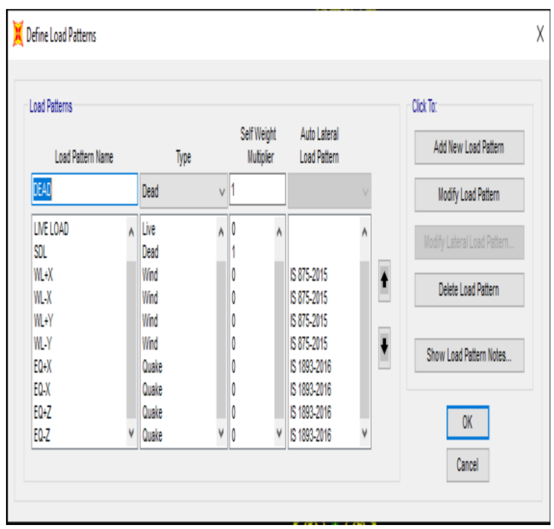
B. Mass Source



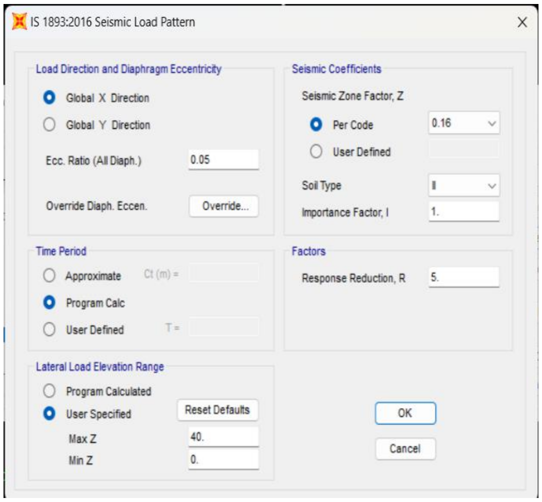
C. Frame Section Define



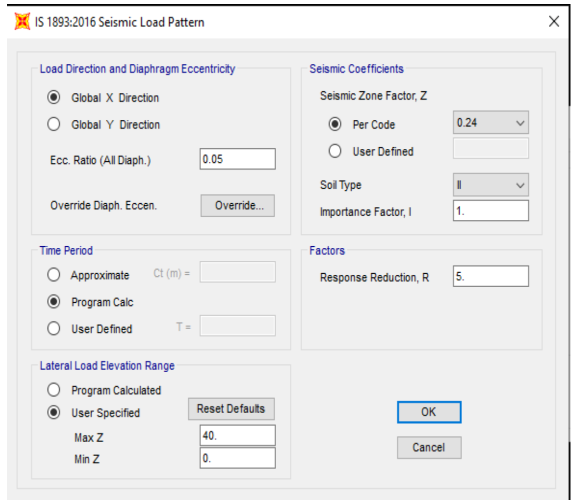
D. Load Pattern Define



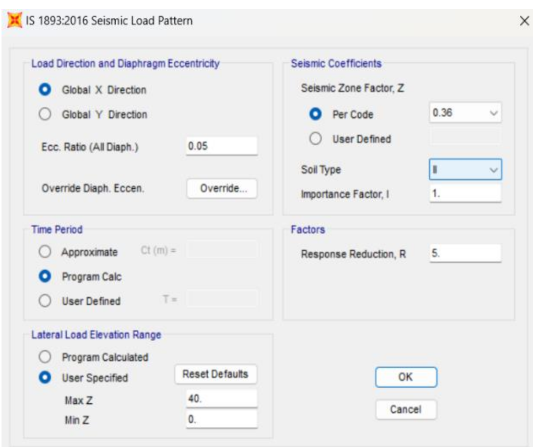
E. Earthquake Load Define Zone III



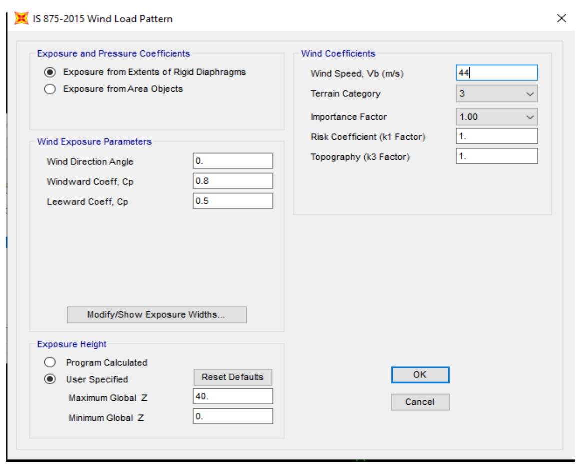
F. Earthquake Load Define Zone IV



G.Earthquake Load Define Zone V



H. Wind Load Define



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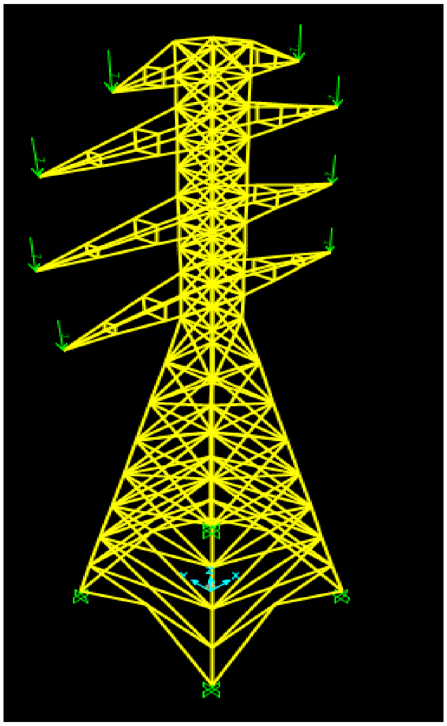
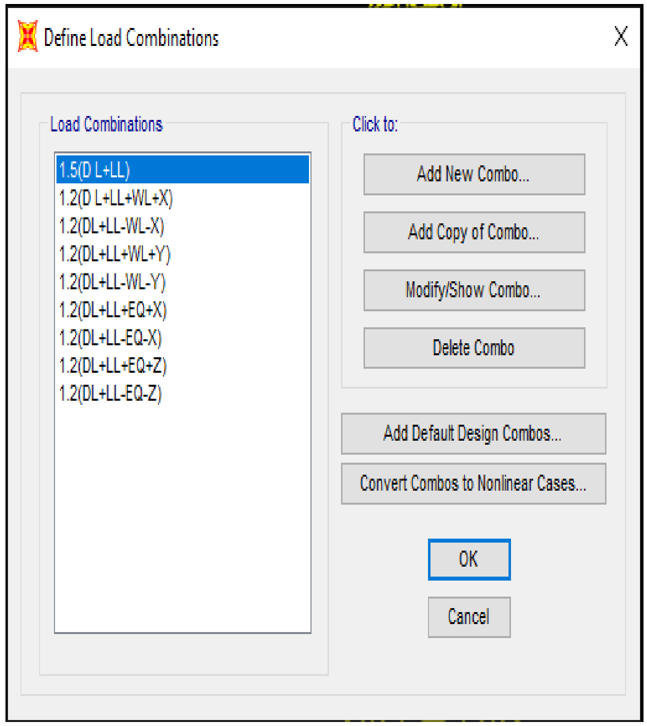
I. Load Apply in Tower



J. Load Combinations



4.4 Types of Loads

Unless otherwise specified, all loads listed, shall be considered in design for the Indian Code following load combinations shall be considered.

Load case

1) DL: Dead load

2) LL: Live load

3) EQ: Earthquake load

4) WL: Wind Load

4.5 Load combination

1. 1.5DL+1.5LL
2. 1.2DL+1.2LL + 1.2EX
3. 1.2DL+1.2LL- 1.2EX
4. 1.2DL+1.2LL+ 1.2EY
5. 1.2DL+1.2LL - 1.2EY
6. 1.2DL+1.2LL+1.2WLX
7. 1.2DL+1.2LL-1.2WLX

8. 1.2DL+1.2LL+1.2WLY

9. 1.2DL+1.2LL-1.2WLY

10. (0.9DL±1.5EQ)

5. RESULTS AND DISCUSSIONS

Based on the work as mentioned in earlier chapters the results are presented below:

5.1 Base Shear Results of Diamond Bracing

Table 5.1.1 Base Shear Transmission Line Tower Diamond Bracing response spectrum method of Earthquake Zone III.

TABLE: Auto Seismic - IS 1893:2016							
Load Pat	Z Code	Soil Type	R	T Used	Coeff Used	Weight Used	Base Shear
Text	Text	Text	Unitless	Sec	Unitless	KN	KN
EQ+X	0.16	II	5	0.0624	0.04	1649.213	65.969
EQ-X	0.16	II	5	0.0624	0.04	1649.213	65.969
EQ+Z	0.16	II	5	0.0629	0.04	1649.213	65.969
EQ-Z	0.16	II	5	0.0629	0.04	1649.213	65.969

Table 5.1.2 Base Shear Transmission Line Tower Diamond Bracing response spectrum method of Earthquake Zone IV.

TABLE: Auto Seismic - IS 1893:2016							
Load Pat	Z Code	Soil Type	R	T Used	Coeff Used	Weight Used	Base Shear
Text	Text	Text	Unitless	Sec	Unitless	KN	KN
EQ+X	0.24	II	5	0.0624	0.06	1649.213	98.953
EQ-X	0.24	II	5	0.0624	0.06	1649.213	98.953
EQ+Z	0.24	II	5	0.0629	0.06	1649.213	98.953
EQ-Z	0.24	II	5	0.0629	0.06	1649.213	98.953

Table 5.1.3 Base Shear Transmission Line Tower Diamond Bracing response spectrum method of Earthquake Zone V.

TABLE: Auto Seismic - IS 1893:2016							
Load Pat	Z Code	Soil Type	R	T Used	Coeff Used	Weight Used	Base Shear
Text	Text	Text	Unitless	Sec	Unitless	KN	KN
EQ+X	0.36	II	5	0.0624	0.09	1649.213	148.429
EQ-X	0.36	II	5	0.0624	0.09	1649.213	148.429
EQ+Z	0.36	II	5	0.0629	0.09	1649.213	148.429
EQ-Z	0.36	II	5	0.0629	0.09	1649.213	148.429

5.2 Base Shear Results of Double Bracing

Table 5.2.1 Base Shear Transmission Line Tower double Bracing response spectrum method of Earthquake Zone III.

TABLE: Auto Seismic - IS 1893:2016						
Load Pat	Z Code	Soil Type	R	Coeff Used	Weight Used	Base Shear
Text	Text	Text	Unit less	Unit less	KN	KN
EQ+X	0.16	II	5	0.04	1406.226	56.249
EQ-X	0.16	II	5	0.04	1406.226	56.249
EQ+Z	0.16	II	5	0.04	1406.226	56.249
EQ-Z	0.16	II	5	0.04	1406.226	56.249

Table 5.2.2 Base Shear Transmission Line Tower double Bracing response spectrum method of Earthquake Zone IV.

TABLE: Auto Seismic - IS 1893:2016						
Load Pat	Z Code	Soil Type	R	Coeff Used	Weight Used	Base Shear
Text	Text	Text	Unit less	Unit less	KN	KN
EQ+X	0.24	II	5	0.06	1406.226	84.374
EQ-X	0.24	II	5	0.06	1406.226	84.374
EQ+Z	0.24	II	5	0.06	1406.226	84.374
EQ-Z	0.24	II	5	0.06	1406.226	84.374

Table 5.2.3 Base Shear Transmission Line Tower double Bracing response spectrum method of Earthquake Zone V.

TABLE: Auto Seismic - IS 1893:2016						
Load Pat	Z Code	Soil Type	R	Coeff Used	Weight Used	Base Shear
Text	Text	Text	Unit less	Unit less	KN	KN
EQ+X	0.36	II	5	0.09	1406.226	126.56
EQ-X	0.36	II	5	0.09	1406.226	126.56
EQ+Z	0.36	II	5	0.09	1406.226	126.56
EQ-Z	0.36	II	5	0.09	1406.226	126.56

5.3 Base Shear Results of Knee Bracing

Table 5.3.1 Base Shear Transmission Line Tower knee Bracing response spectrum method Earthquake Zone III.

TABLE: Auto Seismic - IS 1893:2016						
Load Pat	Z Code	Soil Type	R	Co effs Used	Weight Used	Base Shear
Text	Text	Text	Unit less	Unit less	KN	KN
EQ+X	0.16	II	5	0.017576	858.801	15.094
EQ-X	0.16	II	5	0.017576	858.801	15.094
EQ+Z	0.16	II	5	0.017576	858.801	15.094
EQ-Z	0.16	II	5	0.017576	858.801	15.094

Table 5.3.2 Base Shear Transmission Line Tower knee Bracing response spectrum method Earthquake Zone IV.

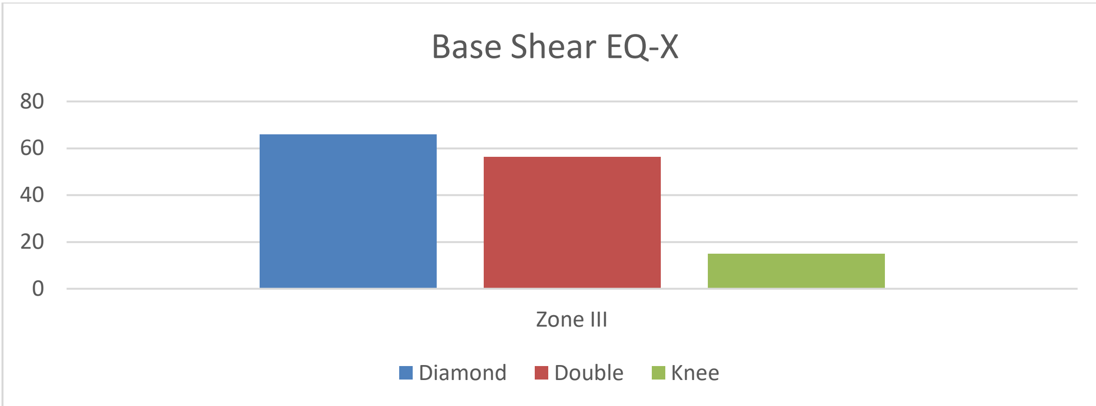
TABLE: Auto Seismic - IS 1893:2016						
Load Pat	Z Code	Soil Type	R	Co effs Used	Weight Used	Base Shear
Text	Text	Text	Unit less	Unit less	KN	KN
EQ+X	0.24	II	5	0.026364	858.801	22.641
EQ-X	0.24	II	5	0.026364	858.801	22.641
EQ+Z	0.24	II	5	0.026868	858.801	23.074
EQ-Z	0.24	II	5	0.026868	858.801	23.074

Table 5.3.3 Base Shear Transmission Line Tower knee Bracing response spectrum method Earth. Zone V.

TABLE: Auto Seismic - IS 1893:2016						
Load Pat	Z Code	Soil Type	R	Co effs Used	Weight Used	Base Shear
Text	Text	Text	Unit less	Unit less	KN	KN
EQ+X	0.36	II	5	0.039545	858.801	33.962
EQ-X	0.36	II	5	0.039545	858.801	33.962
EQ+Z	0.36	II	5	0.039545	858.801	33.962
EQ-Z	0.36	II	5	0.039545	858.801	33.962

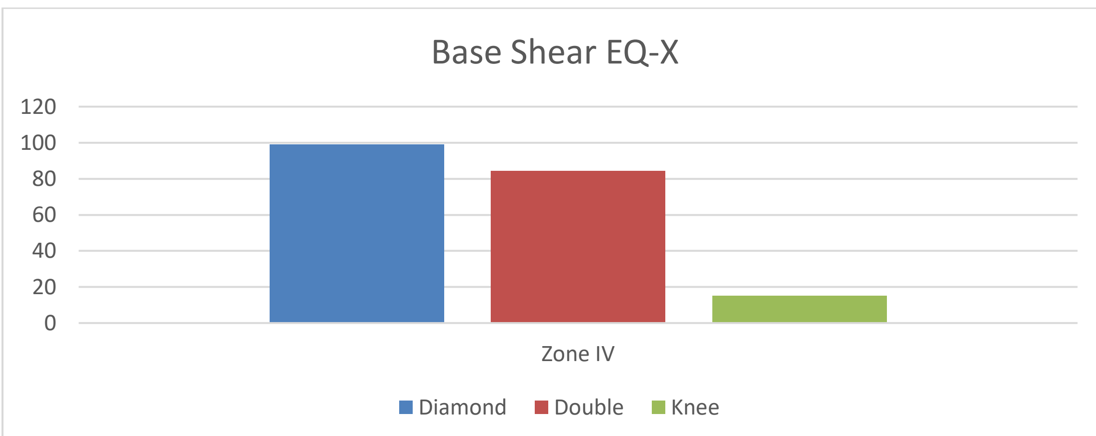
Graph 5.1 base shear vs. bracing (diamond, double and knee) of earthquake

Zone III.



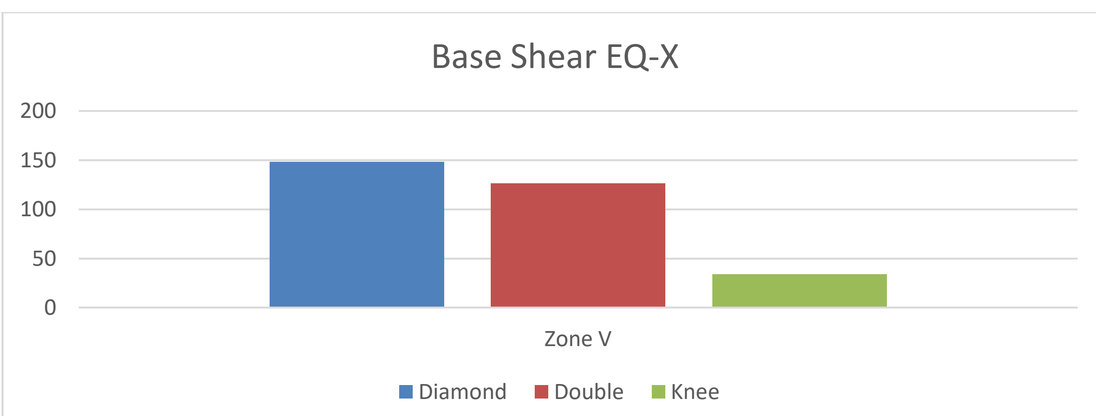
Graph 5.2 base shear vs. bracing (diamond, double and knee) of earthquake

Zone IV.



Graph 5.3 base shear vs. bracing (diamond, double and knee) of earthquake

Zone



6. Conclusion

In the present study, Relative Analysis of transmissions line tower using different bracing pattern in structure with different seismic zone III , Zone IV & Zone V.

The structures are analyses for earthquake zone III , Zone IV & V with medium soil and Results Compare. It has been made on base shear, the analysis results following conclusions are drawn.

1. The Base Shear of Diamond Bracing & Double Diagonal Bracing in Zone III is closely spaced, While Base shear of Diamond Bracing is increased 4.37 times as compare to knee bracing system.
2. The Base Shear of all three bracing in Zone III, IV, & V is increased in the same ratio 1:1.17:3.72.

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Code Used

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