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Analysis & Upgrading Technique of Transmission Towers Due to Wind Zone Reclassification in India

Arnab Chakraborty[1], Ashok Kumar Sahoo[2], Hirdesh Kumar[3], Mr. Shivam Shekhar[4]

[1,2,3]UG Student, [4]Guide, Assistant Professor

Department of Civil Engineering, Lingaya's Vidyapeeth, Faridabad

Email : achakraborty866@gmail.com

ABSTRACT:

Enhancing existing transmission towers can often be a smarter, more economical choice compared to building new ones, especially given the hurdles that come with land acquisition. This process involves fortifying the towers to handle increased loads and endure environmental challenges, all while ensuring compliance with the latest building codes to prolong their operational lifespan. The National Building Code of 2016 introduced a revised wind map that has been integrated into the request for proposals (RFP) for transmission projects. To tackle the implications of shifting wind zones on current transmission line towers, it's crucial to strengthen both the towers and their foundations. This undertaking requires a comprehensive design review, careful material selection, and meticulous planning, not to mention scheduled shutdowns, which can significantly tug at the budget and availability. Our current work delves into the analysis and design of a strategy to bolster an existing tower set in wind zone 2, upgrading it to meet the standards of wind zone 4. We have done preemptive strengthening studies using international software (PLS TOWER) and suggested reinforcements of the existing towers in the line which shall support the requirement of higher wind zone. Through our analysis, we discovered that the wind load on the existing tower has surged considerably, resulting in multiple structural members failing under this new pressure. To address this, we've proposed utilizing multiple sub-bracing and a cruciform leg connection to accommodate these heightened loads. Moreover, we've explored the option of performing this work while the line is live, depending on the location of the strengthening efforts. This approach not only helps sidestep right-of-way complications but also ensures that the reliability of the transmission line remains intact.

KEY WORDS: Increased Loads, Wind Zones, Right-of-Way, Live Line Work, PLS TOWER

1. Introduction

Towers play a critical role in supporting essential infrastructure energy transmission. However, as these structures age and face increasing demands, their ability to maintain performance and safety can be compromised. Over time, factors such as environmental wear, extreme weather conditions, and evolving safety regulations can strain a tower's original design. Strengthening and retrofitting towers is therefore essential to ensure their continued reliability and safety.

The National Building Code of India (NBC), 2016 with updated wind speed maps, replaced the older IS 802: 2015 guidelines, significantly altering how wind loads are assessed for transmission lines. For projects built before 2016, the wind speed criteria may now be outdated in specific locations. These potentially underestimate the risks posed by stronger winds. To address this, it is crucial to reassess local wind conditions and calculate the increased wind loads based on updated wind zones. Reinforcements may need to provide for the existing towers to accommodate higher loads. Some of the upgrades can be possible during service conditions (live line), while others (e.g., cross arms, peak structures) may require shutdowns. This approach ensures the safety and reliability of transmission lines, particularly those built under older standards, in the face of evolving wind conditions.

Tower strengthening helps maintain the structural integrity of these vital assets, reducing the risk of failure and preventing costly replacements. The process of reinforcing towers to comply with updated codes, and extending their operational lifespan, is very challenging. As most of the lines are in operational condition, it is difficult to strengthen the towers without interrupting the service. In this context, understanding the key drivers for tower

reinforcement is crucial for maintaining the safety, functionality, and longevity of these critical structures.

Steel lattice towers are widely used in India and other developing countries for applications such as power transmission. These towers consist of key components like legs, which are vertical steel members that support the structure; bracings, which are diagonal elements that stabilize the tower by distributing loads; cross-arm members, which provide mounting points for equipment like power lines; and secondary members, which offer additional reinforcement. The lattice design is favored for its efficient use of materials, cost-effectiveness, and high load-bearing capacity, making it an ideal choice for such infrastructure. The ideal tower design is one that meets all electrical and structural requirements while using the minimum amount of steel. In this study, we analyzed the additional loading conditions and identified the most suitable strengthening scheme. However, it is important to note that while there is potential for tower strengthening, the scope for foundation strengthening is limited, and the towers cannot be reinforced beyond a certain threshold.

Figure 1: Tower failure incident near Bhopal (2019)

igure 2: Tower failure due to heavy wind load

2. Literature Survey

F. Albermani, M. Mahendran, S. Kitipornchai (2003), found out tower strength improvement by adding a series of diaphragm bracing types at mid-height of the slender diagonal members. Qiang Xie, Li Sun (2012) proposed that sufficient diaphragms should be added in each panel of latticed transmission tower structures in order to enhance the load-carrying capacity and ductility of both the single and double-panel specimens. J.G. Teng a, T. Yu b, D. Fernando (2012) studied strengthening of steel structures with fiber-reinforced polymer composites. External bonding of FRP reinforcement has been clearly established as a promising alternative strengthening technique for steel structures. Chenghao Lu, Xing Ma, Julie E. Mills (2014) studied the structural effect of bolted splices on retrofitted transmission tower angle members. The Experimental tests and numerical results in their study showed that the bolt-splice joint and bolt connector played a critical role in the structural behavior of the bolt spliced reinforced member. Xuewu Liu, Kaiquan Xia, Yan Gao (2011), studied and experimented with the composite section strengthened by the angle-shaped member, such as cross-shaped section, Z-shaped section, T-shaped section, C-shaped section. Julie E. Mills, Xing Ma, Yan Zhuge (2012) showed experimental results verifying the effectiveness of the retrofitting method. Load sharing analysis showed that axial loads can be effectively transferred between original tower members and reinforcing members through the bolted-splice system. As reported by R. Balagopal N. Prasad Rao R. P. Rokade P. K. Umesha (2018), strengthening steel bolted connections in lattice towers with GFRP material is cost-effective, lightweight, and non-corrosive, offering enhanced tension capacity and the ability to operate under live-line conditions. It reduces capital costs by 72% compared to replacing steel structures. Also, it was seen that the cleat angle and double cross-plate connection show higher enhancement of compression strength compared to other types of connections. The cleat angle connection is cost-effective compared to other types of strengthening patterns.

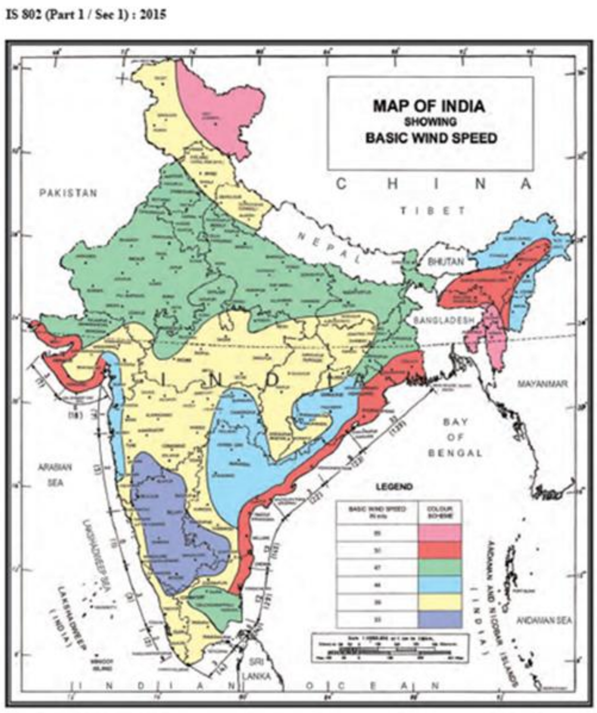
3. Scope of the Study

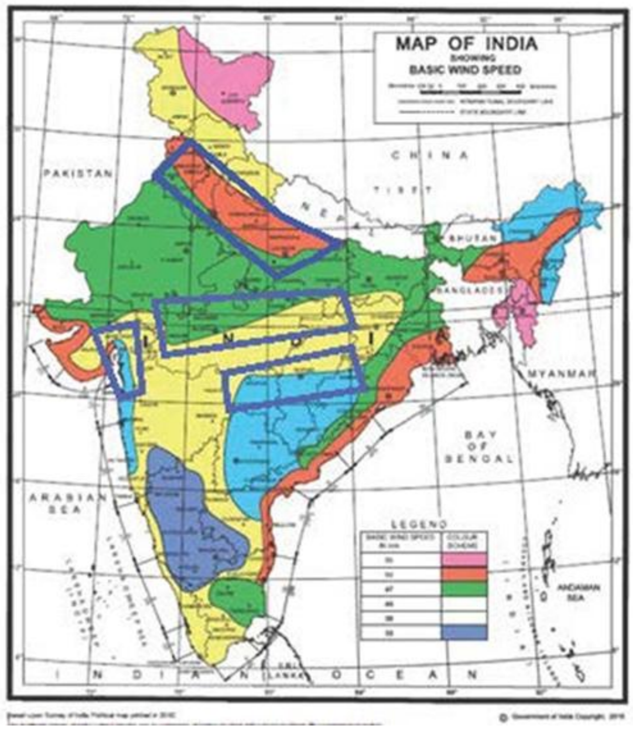
In the present scope of work, we have opted for the most economical way to strengthen the tower. A 3D analysis using PLS Tower has been developed. The 3D analysis using PLS Tower is purely a theoretical exercise, this exercise will provide additional safety for the performance of the towers in the higher wind zone areas. PLS-Models of the original designs (WZ-2) have been checked for analysis of towers using the higher loads (WZ-4). All the members which failed have been reinforced with proper reinforcements. Further, the reinforcement members are being connected by the proper methods by means of additional members and plates.

4. Methodology

- Identification of Wind Zone Changes: The revised wind map from the National Building Code 2016 was superimposed onto the old wind map to identify areas where wind zones have been modified. Boxes were used to highlight changes in wind zones, specifically areas shifting from WZ-2 to WZ-4 (Figures 3 & 4).

Figure 3: Old WZ map of India as per IS 802 (Part 1 / Sec 1): 2015 Figure 4: New WZ map of India as per National Building Code (NBC), 2016





- Wind zones 2 to 4 have been selected for analysis based on the updated map.
- Loading Calculations for WZ-4: Using the IS 802 (Part 1 / Sec 1): 2015 (reaffirmed 2020) standard, wind pressures for WZ-4, other wire load calculations have been done based on the same design spans / weight spans originally used for WZ-2. Loading trees for WZ-4 have been created to be used for running the PLS-models.
- We have worked with D-type tower which have been checked for WZ-4, and the reinforcements have been worked out.
- Development of PLS-Models: The original designs for WZ-2 were analyzed by running PLS-models with the newly calculated higher loads for WZ-4. All structural members that failed under the increased loading conditions were identified and highlighted in RED for reinforcement.
- Reinforcement Design: Structural drawings were referenced to determine the most practical approach for implementing reinforcements. Key reinforcements included:
  - Star leg connections to reinforce failing corner legs with suitable joints and stitch plates.
  - Additional redundant members (such as lattices, cross arm members, belt members, and peak members) were added to improve the overall load-carrying capacity of the tower components.

5. General Considerations:

Modeling Approach: For the present study, 765 kV single circuit tension transmission line tower has been considered. PLS Tower software is used for the analysis and design of steel latticed towers. The program performs design checks of structures under user specified loads. For electric power structures it can also calculate maximum allowable wind and weight spans and interaction diagrams between different ratios of allowable wind and weight spans.

- All dimensions are in mm and loads are in Kg
- Load and Loading combinations criteria on the ground wire, conductor and all the towers are found using IS: 802 (Part-1/Sec-1): 2015.
- The designs conform to the relevant requirements of Technical Specification and IS: 802 (Part-1/Sec-1): 2015. For design of compression
- members, the strut formulae given in IS-802(Part-1) 2015 are adopted.
- Mild Steel conforming to IS-2062, 2006 or equivalent (Fy = 250 N/mm^2 = 2549 kg/cm^2)
- High Tensile Steel conforming to IS-2062, 2006 or equivalent (Fy = 350 N/mm^2 = 3569 kg/cm^2)
- Bolts & Nuts as per IS: 12427-2001 Grade 5.6/5.0 or equivalent are considered and 16mm Dia Bolts are considered in tower design.

Table 1: Configuration of Tower

Description	Square Tower
Base Width at +0m BE	17706 mm
Hamper (Cage) Width	4800 mm
Topmost Hamper (Peak) Width	3200 mm
Height of Tower	47375 mm

Table 2: Line Characteristics

Phase Configuration	Vertical
Ground Clearance	18 m
Sag Error	150 mm
C.L. to G.L.	225 mm
Mid Span Clearance	9 m
Angle of Shield	10 Deg.
Final Unloaded Tension for conductor at Everyday Temperature	Not to exceed 22% of UTS
Final unloaded Tension for Earth-wire/OPGW at Everyday Temp.	Not to exceed 20% of UTS
Earth wire Sag	90% of conductor sag
Wind Zone	4
Reliability Level	2
Terrain Category	2

Table 3: Electrical Characteristics

Nominal Voltage	765 kV
Maximum System Voltage	800kV
Rated Frequency	50 Hz
System Neutral Earthing	Effectively earthed
BIL (Impulse)	2400 kV (Peak)
Switching Surge Withstand Voltage	1550kV (rms)
Power Frequency Withstand Voltage	830kV (rms)

Corona Extinction Voltage At 50 Hz, Under Dry Condition	510kV (rms) min
RIV Voltage at One MHz for Phase to Earth Voltage Of 305 kV Under Dry Condition	1000 Micro volts (max)
Short Circuit Current and Duration	50 kA for one second

Table 4: Climatic Condition

Temperature For Creep Calculation	32 Deg
Maximum Ambient Temperature	50 Deg
Everyday Temperature	32 Deg
Minimum Temperature	0 Deg
Maximum Temperature Conductor	85 Deg
Maximum Temperature Shield Wire	53 Deg

Table 5: Conductor Properties

Size/Code	ACSR Bersimis
Number Of Conductors Per Phase	4
Conductor Spacing	457 mm
Approximately Diameter	35.05 mm
UTS	154 KN
inear mass of the Conductor	2181 Kg/Km
Cross Sectional Area	725 mm2
Modulus of Elasticity	6322 Kg/mm^2
Coefficient of Linear Expansion	0.000012 Deg C

Table 6: Earth wire Properties

Number Of Earth Wire/OPGW	One GSS wire & one OPGW
Earth Wire Size	7/3.66mm
Approximate Diameter GSS	10.98mm
Approximate Mass GSS	583 Kg/Km
UTS	68.4KN
Coefficient of Linear Expansion	11.5 X e-06
Cross sectional Area	73.65 mm2
Modulus of Elasticity	19361 Kg/mm^2

Table 7: OPGW properties

Overall Diameter	12.00mm
UTS	92.9 KN
Approximate Mass	455 ± 10%kg/km
Cross sectional Area	73.5 mm^2
Modulus of elasticity	140KN/mm^2

6. Design Analysis:

Wind Pressure Calculation as per WZ-4

FOR TOWER TYPE-SD

WIND PRESSURE CALCULATIONS

(Clause 8.3, IS 802 (Part 1 / Sec 1): 2015)

Wind Zone to be considered for design	=	4	47.00	M/sec
Design wind speed (Vr)	=	47/1.375		
	=	34.182	M/sec	
Basic span	=	400	M	
Reliability Level	=	2		
Terrain Category	=	2		
Factor K1	=	1.12		
Factor K2	=	1		
Design wind speed (Vd)	=	Vr x K1 x K2		
	=	34.182 x 1.12 x 1		
	=	38.284	M/sec	
Design wind pressure (Pd)	=	0.6 x $(Vd)^2$		
Design Wind Pressure (Pd)	=	(0.6 x 38.284^2)		
	=	879.399	N/m^2	
	=	**89.643**	**Kg / m^2**	

(I) Wind Pressure on Conductor (Pc) = Pd x Cd x Gc

Average Height of conductor considered for wind pressure calculation (h)	**44.315**	M

Sag at Min temp and nil wind (m) =	11.141
Minimum ground clearance	14.500
Spacing between conductor	0.229
Maximum Sag of conductor	14.864
Allowance for sag error or creep	0.150
B.C.A to T.C.A.	13.000
Body extension	9.000

Less2/3rd Sag at Min temp.	2/3 X 11.141	7.427		
Avg. height of Conductor in M		**44.315**		

Where Pd = Design Wind Pressure

Cd = Drag Coefficient 1

Gc = Gust Response Factor = 2.237

(Refer Table -7 of IS 802–1995/Sec-1)

= 89.643 x 1 x 2.237

Wind Pr. on Conductor (Pc) = 200.53 Kg/m^2 Say 201 Kg/sqm

<u>FOR TOWER TYPE-SD</u>

<u>(II) Wind Pressure on Earthwire (Pe) = Pd x Cd x Gc</u>

Average Height of earthwire considered for wind pressure calculation (h) **51.292** M

Sag at Min temp and nil wind (m) =		7.426
Minimum ground clearance		14.500
Spacing between conductor		0.229
Maximum Sag of conductor		14.864
Allowance for sag error or creep		0.150
B.C.A to T.C.A cross arm		13.000
Height of G.W peak		4.500
Maximum body extension		9.000
Less2/3rd Sag at Min temp.	2/3x7.426	-4.951
Average height of Ground wire in M		**51.292**

Where Pd = Design Wind Pressure

Cd = Drag Coefficient 1.2 for earth wire

Gc = Gust Response Factor = 2.296

(Refer Table -7 of IS 802–1995/Sec-1)

Wind Pressure on Earth wire (Pe) = 89.643 x 1.2 x 2.296

Wind Pressure on Earth wire (Pe) =	**246.98**	**Kg/m²**	**Say 247 Kg/sqm**

(III) Wind Pressure on Insulator (Pi) = Pd x Cd x Gc

Height of insulator attachment point considered for wind pressure (h)	**51.742**	M

Minimum ground clearance	14.500
Spacing between conductor	0.229
Maximum Sag of conductor	14.864
Allowance for sag error or creep	0.150
B.C.A to T.C.A cross arm	13.000
Maximum length of insulator	0.000
Maximum body extension	9.000
Maximum leg extension	0
Height of Insulator attachment point in M	**51.742**

Where	Pd = Design Wind Pressure		
	Cd = Drag Coefficient	1.2	for Insulator
	Gc = Gust Response Factor =	2.492	

(Refer Table - 6 of IS 802–1995/Sec-1)

Wind Pressure on Insulator (PI)	=	89.643 x 1.2 x 2.492		
Wind Pressure on Insulator (PI)	**=**	**268.07**	**Kg/m²**	**Say 269 Kg/sqm**

7. Results

Table 8: Wind Load Comparission WZ-2 Vs WZ-4

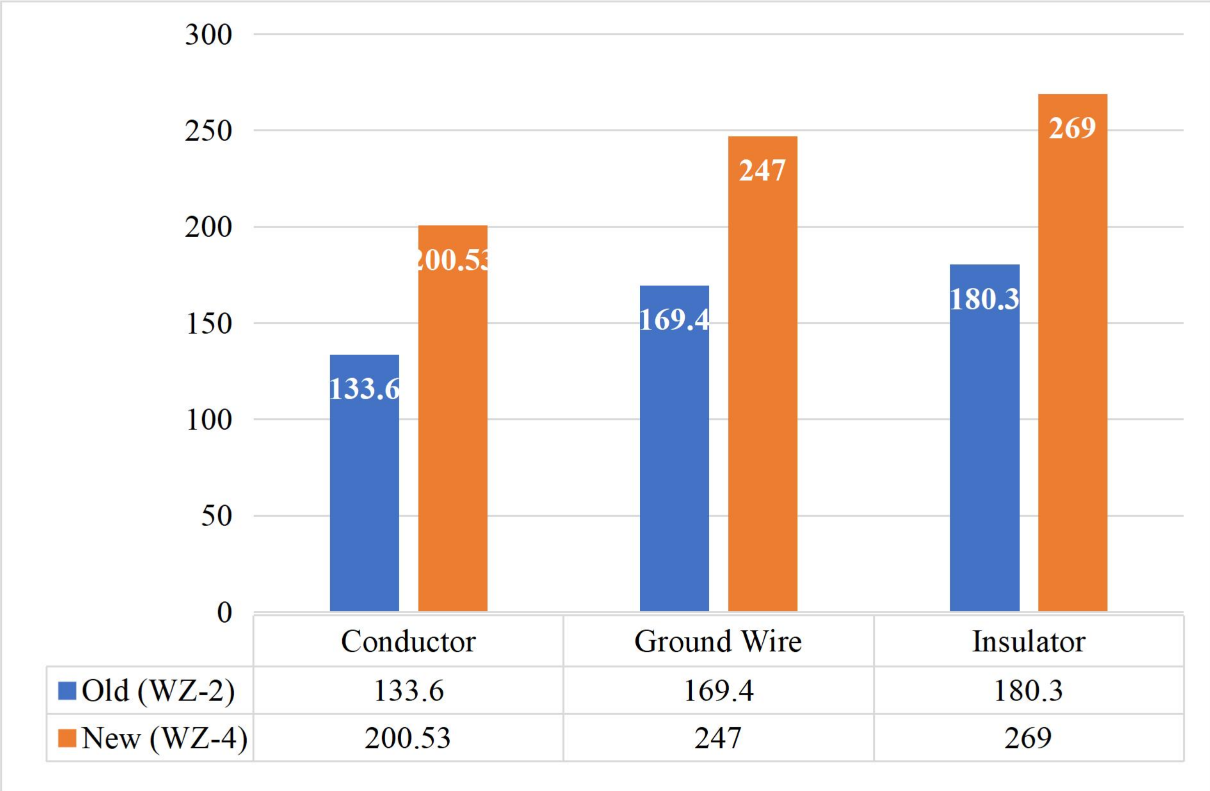


Table 9: Comparission b/w WZ-2 Vs 4 Load Case

C-1 Reliability Condition (32 Deg & Full Wind)

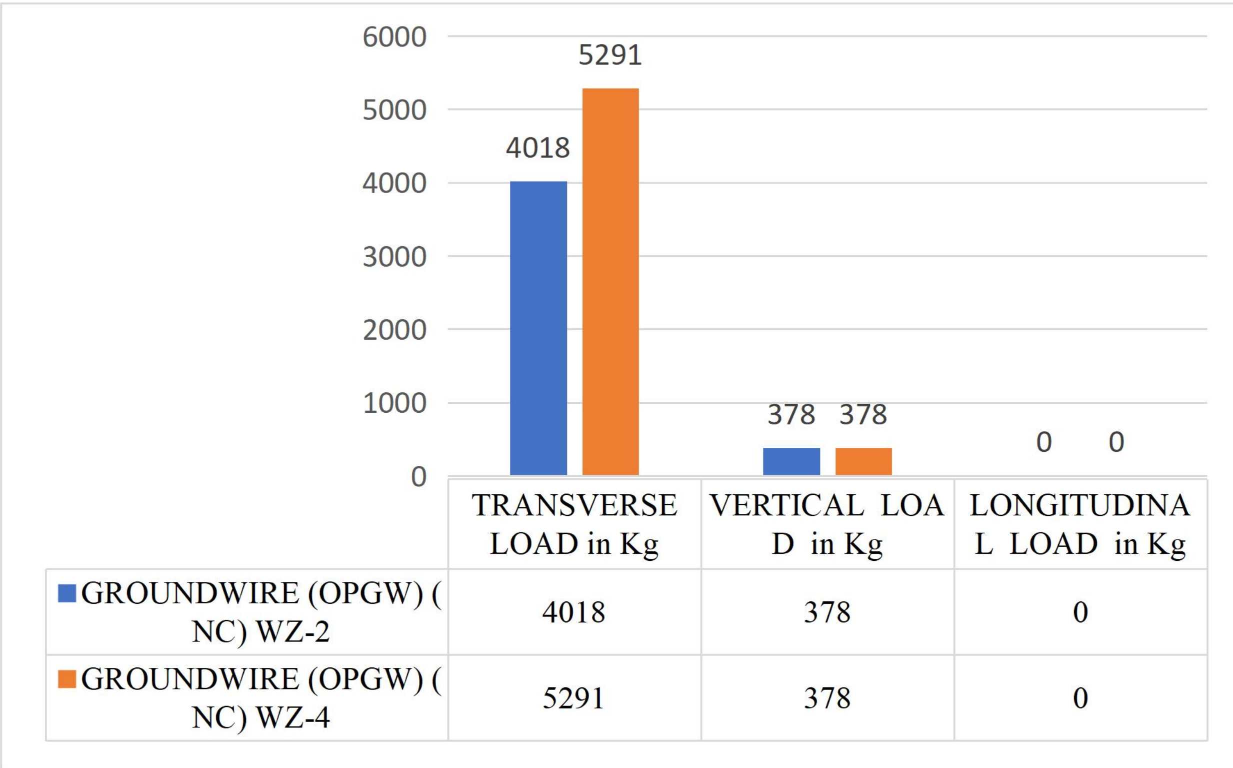
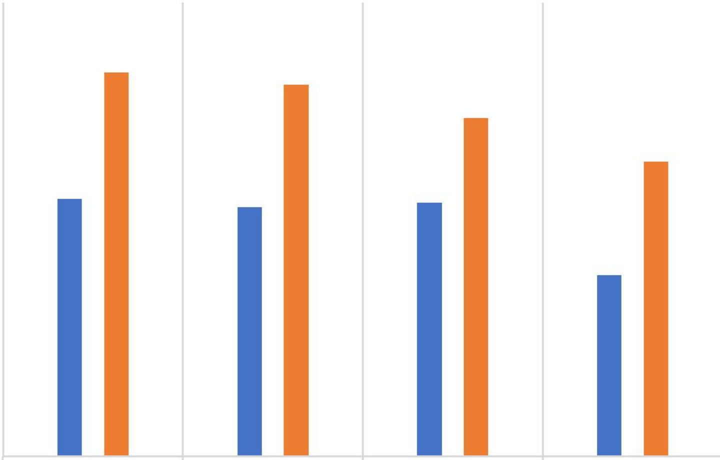


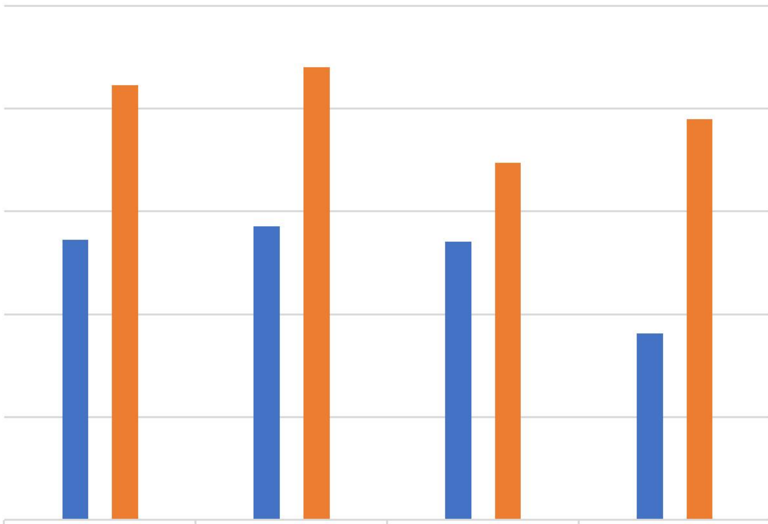
Table 10: Foundation Loads Comparission b/w WZ-2 Vs 4

Compression Force WZ-2 Vs WZ-4,



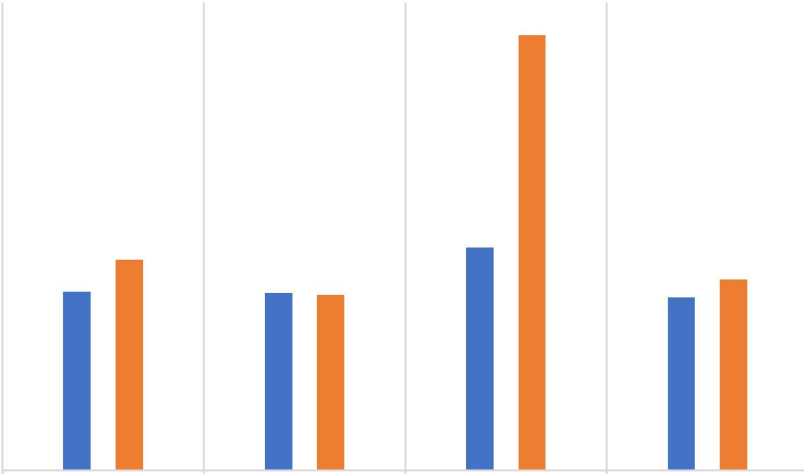
	CASE-1	CASE-2	CASE-3	CASE-4
Compression Force In Leg Dir. (kg) WZ-2	170188	164803	167671	120007
Compression Force In Leg Dir. (kg) WZ-4	254002	245689	223875	194791

Uplift Force WZ-2 Vs WZ-4,



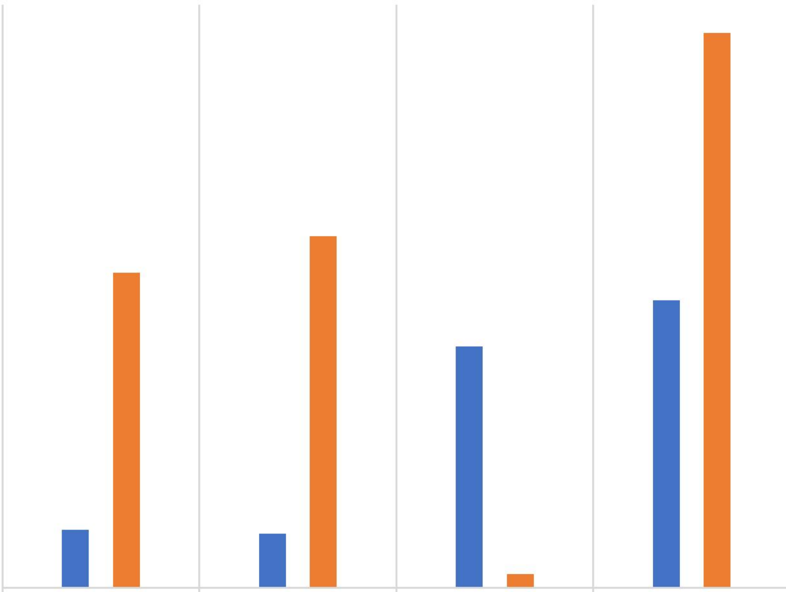
	CASE-1	CASE-2	CASE-3	CASE-4
Uplift Force In Leg Dir. (kg) WZ-2	136399	142828	135266	90702
Uplift Force In Leg Dir. (kg) WZ-4	211450	220107	173776	194792

Transverse Shear WZ-2 Vs WZ-4,



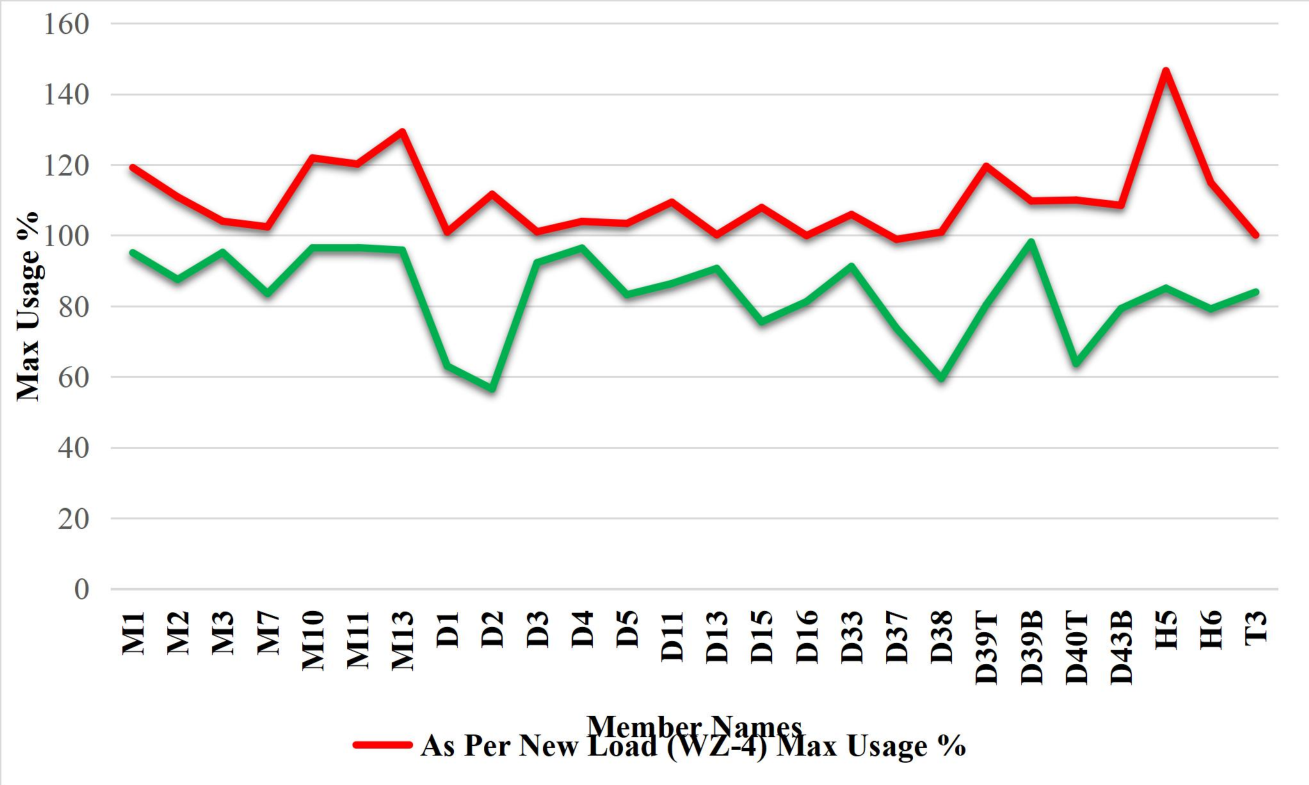
	CASE-1	CASE-2	CASE-3	CASE-4
Residual Shear Horizontal To Leg - Tran. (kg) WZ-2	7643	7601	9527	7411
Residual Shear Horizontal To Leg - Tran. (kg) WZ-4	9020	7503	18627	8184

Longitudinal Shear WZ-2 Vs WZ-4,



	CASE-1	CASE-2	CASE-3	CASE-4
Residual Shear Horizontal To Leg - Long. (kg) WZ-2	1187	1109	4967	5910
Residual Shear Horizontal To Leg - Long. (kg) WZ-4	6476	7227	280	11415

Table 11: Design Summary Comparission



8. Strengthening Scheme

- Additional redundant members to be provided to improve the overall load-carrying capacity of the tower components.

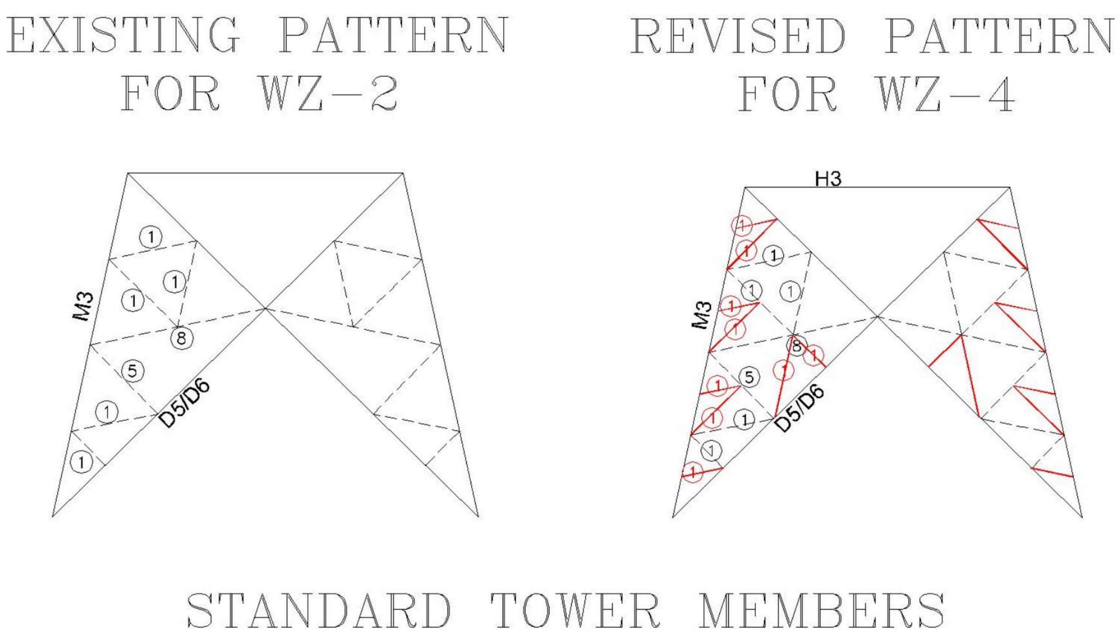


Figure 5: Revised Structural Drawings

- Star leg connections to reinforce failing legs

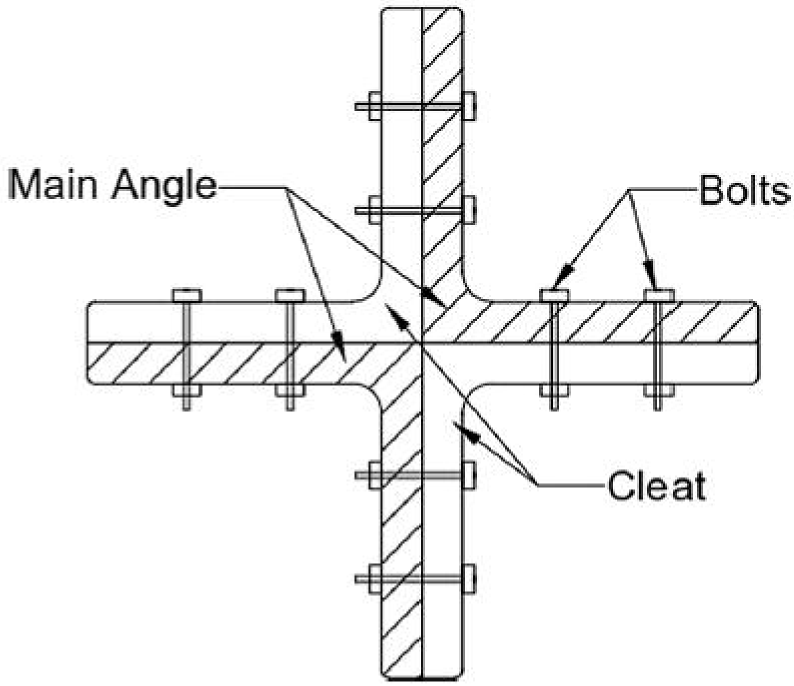


Figure 6: Leg Connection Details

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