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ILLUSTRATION OF TRANSMISSION LINE (TL) TOWER DESIGN WITH IS 802(PART 1/SEC1)-2015 AND IS 875 (PART 3):2015 CODE PROVISIONS IN WIND ZONE - 5 OF INDIA

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ABSTRACT

The revised version of IS 802(Part-1/Sec-1) code was released in 2015. In the code cycle between 1995&2015, the design wind load calculations on the Transmission Line (TL) Tower have been modified. Similarly changes for computation of wind loads with cyclonic load factor (k_4 factor) have been advised in the third revised (IS 875-2015) Wind loading code provisions in the wind Zone - 5(coastal area) of India. The number values 1.00, 1.15 and 1.30 of k_4 factor are attributed to the safety of the structures against the unprecedented higher gale speeds during the cyclones. This factor was not reflected in the IS 802 -2015 code provisions. Hence a comparative analysis with Gust factor method was utilized in STAAD Pro Connet V22 version Programme to illustrate the design specifications of 230 kV double Circuit 40 M high with 200 m span Transmission Line (TL) tower in Wind Zone 5 of India with IS 802-2015 version and IS 875-2015code provisions. The design specifications include top deflection, axial force in the bottom profile leg, Base Shear Force and Base Bending moments have obtained 37%, 33%, 35%and 46% more when k_4 factor is 1.00. Similarly, 56%, 56%, 58% and 78% higher when k_4 factor is 1.15. Finally, the above parameters have increased by 79%, 83%, 88%, and 115% when k_4 factor value 1.30 is applied with IS 875-2015 version. With the above inferences, the code provisions of IS 802 -2015 version cannot proportionate with mandatory recommendations of IS 875-2015 provisions in Wind zone -5 of India. Hence the provisions of k_4 factor may be admitted in IS 802 -2015 code for adequate safety of TL towers in (Coastal area) Wind zone-5 of India.

Keywords: IS 802(Part 1/Sec 1):2015, IS 875(Part 3):2015, k_4 Factor, Transmission line towers, Post cyclonic importance structures, Design wind speeds, Gust factor method.

INTRODUCTION

A transmission line (TL) consists of two separate structural systems, which includes the structural support system and the wiring system. The structural support system, comprising towers, poles, and foundations, has the primary task of supporting the load from the wire, insulators, hardware, and wire accessories, including accumulated ice. Tall lattice towers are widely used for power transmission lines. Design of electrical TL tower governs the proper application of industrial codes and standards for optimization of tower geometry in though transmission line design principles are more or less the same all over the world, but different countries/regions adopt the different regulations based on the safety and reliability conditions [1,2].

The design is primarily governed by the evaluation of wind loads and responses [3]. A small mistake in computations has resulted in a large variation in structural safety parameters because the wind loads are proportional to the square of the wind velocity. By structural property, the TL towers are designed as columns under gravity load and cantilever beams under lateral loads, hence heavy structural members are required even if they are subject to less wind pressure.

The available design standards for TL towers are based on Load Resistance Factor Design or Ultimate load theory, thus the margin available for reserve strength is quite low[4]. This necessitates the accurate calculations for both the loading as well as structural strengths. The TL industry has the repetitiveness of the tower geometry, it encourages the optimization to the maximum extent for commercially competitive. This necessitates the need to assess the proper wind load calculations. Normally the wind load on the towers are generated from the conductors and ground wires, but in the cyclonic region, major wind loads are generated on the tower body itself [5-7].

For the convenience of designers, the dynamic load for the wind sensitive structure is obtained by multiplying the mean wind loads with a factor called Gust Response factor [8]. The Gust Response factor, which was originally proposed by Alen Daven Port in 1961, is incorporated various international codes include the Indian standards (Bureau of Indian standards).

The Design of TL tower in India was made with the IS 802 code provisions (IS 802-2015(Part-1/sec-1, 2015). In the cycle of revision of the code recommendations from 1997 to 2015, the transverse wind load calculations have been modified in compliance with the international standards [9-10]. Similarly, the revised Wind loading code, in recent times, preferred the cyclonic importance factor (k_4 factor) with number value 1.0,1.15 and 1.30 to magnify the safety of lifeline structures in cyclonic regions of India (IS 875 (Part 3):2015, 2015) This factor is attributed to resisting the unprecedented wind speeds in this region.

Hence in this paper, a comparative analytical analysis for 40 m Lattice TL tower has been made between the IS 802-2015 code provisions and revised wind loading IS 875 2015Code recommendations duly considering k_4 factor in Wind zone-5 for understanding the needs and demands of design considerations.

LITERATURE REVIEW

From the history, it is enlightened that more than 80% of financial losses are from wind-related damages when compared to other natural disasters [11, 12]. The increased economic losses of telecommunication sectors due to wind-related damages are notified [13]. Similarly, many accidents including the damages and even collapse of electric TL towers due to strong winds/localised winds have been described all over the world[14-17]

International Electrotechnical committee recommendation of Probabilistic loading methods have been adopted for TL tower design in Indian codes(IS 802-1995(Part-1/sec-1, 1995& 2015). The reliability analysis is suggested since 79% of line failures are caused due to severe wind and ice loadings[18].

The wind load normal to the TL tower is determined with the drag coefficient which is the function of the solidity ratio of tower frame[19]. it is an acceptable criterion since much of the research is completed.

With the property of the tower geometry, free-standing lattice towers are sensitive to wind loads that produce both shear force, bending moments and torsional moments. Shear Forces and Torsions are resisted by web members/ bracings, whereas the bending moments give rise to axial member forces carried by leg members because steel structures are designed as pin joined structural system[19].

The need to study the critical performance of structural systems when subjected to natural intense loading conditions in the cyclonic area is affirmed. While numerous field experiments have been conducted to characterize wind in neutral conditions, the literature is scarce in addressing surface-level winds occurring over land in hurricanes.

Current design codes for lattice transmission towers contain only limited advice on the treatment of high-intensity wind effects (hurricanes) and structural design is carried out using wind load profiles and response factors derived for atmospheric boundary layer winds based on elastic response [20]. In this regard, some literature suggested more load cases to evaluate the response and to mitigate the damage of transmission towers under severe wind demands.

The east coast region of India has been reported the more number of Cyclones during the recent years [21]. The concept of development of Cyclonic importance factor was briefed and the necessity of adoption of gust loading factor for designing of TL tower was illustrated [22, 23].

The choice of the gust loading factor for the design of the telecommunication towers is illustrated and huge internal parameter variations with k_4 factor are obtained.

The case study of the gust factor of a strong typhoon contended the gust factors for the cyclones are same as normal winds [24]. Similarly, wind characteristic of a strong Typhoon Maemi 2003 is similar to non-typhoon normal winds [25]. But the cyclonic wind characteristics in Indian weather conditions are different with a large variation of turbulence intensity resulting in high damages have occurred [26-29].

The suitability of tubular monopole telecommunication towers in the coastal region is annexed by comparing the internal parameters associated with the importance factor[30,31].

The advantages of transmission monopole towers in urban areas with new generation conductors are tested with revised TL tower code provisions[32].

It is also suggested for the adoption of k_4 factor for the design of hoardings, a very low-cost structures in city limits, semi-urban areas with the anticipation of damages to property and life in the cyclonic region. These are high wind sensitive structural components that have characteristics of wind-borne debris.

A comparative analysis for 30 m height with square and triangle-shaped TL tower was analysed with STAAD pro software programme and found that triangular-shaped tower has lesser weight[33].

A large structural failure reports of TL towers during the recent decade for the coastal china has reported and the improved reliability levels of towers are asserted because the existing design with static loads are not sufficient to consider the accidental loads during the cyclones and more particularly the influence of dynamic load on response characteristics of the tower line system is suggested.

(Natarajan K, *et al*., 1995) described the failure reports in transmission line towers were quantified due to cyclonic storms and the specifications of IS: 802-1977, IS:802 (draft)-1989 codes didn't properly take into account the uncertainty factors in loading and material properties[34,]. Consequently, the reports for reliability-based design is highlighted.

The cyclonic factor (k_4) was recommended as 1.0, 1.15 and 1.30 based on the importance of the structures. However, it varies from 1.5 to 2.82 for the region of Bay of Bengal with the FT-I and Fréchet distributions [35].

80% TL failures in America, Australia and South Africa are due to strong winds and these towers have similar and least capacity when the wind yaw angle is 30^o, 60^o and 90^o [36]. However, the wind yaw angle 0^o (wind along the conductor) shows the higher capacity of towers.

The need for the greater effect of fluctuating wind is appraised in the design of TL towers. The revised code recommended the lesser drag coefficients (IS 802-2015(Part-1/sec-1, 2015). These are neither complying the international codes like IEC, 2017nor at par with other Bureau of Indian standards code recommendations. Hence there are chances of the inadequacy of design wind forces compared to the previous versions and general wind code provisions.

Secondly, the revised code version of IS 802-2015 cannot advocate any additional wind speed multiplications factors for design requirements in cyclonic region/Wind speed zone 5. However, the revised Wind loading code adopted the cyclonic load factors for the preferred safety of structures in cyclonic regions of India (IS 875 (Part 3):2015, 2015).

Hence, at first targeted analytical studies assessing the design parameters in the cyclonic area is made between the IS 802-2015 and IS 875-2015 code recommendations (IS 875 (Part 3):2015, 2015) (IS 802-1995(Part-1/sec-1, 1995). Secondly, the correlation assessment between the IS 802-2015 revised code and 1997 version was made.

METHODOLOGY

The existing 220 kV double circuit tower for 200 m span was studied. A 40 m height tower profile is structured with equal steel angles. It supports an overhead power line on three cross arms carrying a three-phase electric circuit each. It is a square base of 5.95 m. The conductors are ACSR conductors with 30 mm diameter. Wind load acting on the tower body and conductors in the transverse direction is determined with appropriate recommendations of the codes (IS 802-1995(Part-1/sec-1, 1995) (IS 802-2015(Part-1/sec-1, 2015). It is otherwise known as the wind direction is perpendicular to the conductor span, which is the weakest link path for assessing tower capacity.

To determine the wind load on the tower, the tower is divided into panels. These panels are normally be taken between the connection points of profile legs and bracings. The solidity ratio is computed form the property of each panel openness. Then the drag coefficients were computed from these solidity ratios from the respective codes (IS 875 (Part 3): 2015, 2015) (IS 802-2015(Part-1/sec-1, 2015).

The final panel wind load calculations have been computed vide Equation 1 with IS 802 code & Equation 2 for 875 code (IS 875 (Part 3):2015, 2015) (IS 802-2015(Part-1/sec-1, 2015). In the former code, the reference wind velocity is considered as 10-minute reference meteorological wind velocity (V_R=V_b/1.375), while in the latter equation the hourly wind velocity is recommended based on the turbulence Intensity. Both are related to mean wind speeds lasting for a greater number of days in a year [37].

The Gust Response factor(G) in the former equation is a function to the height of the structure (IS 802-2015 (Part-1/sec-1, 2015), whereas, in the latter equation, a closed-form solution with background factor of wind loading contribution and structure resonance factors are assigned (IS 875 (Part 3):2015, 2015). The model of TL tower was analyzed using STAAD Pro commercial software programme[38].

The geometric properties of 40 m high transmission towers are shown from Tables 1 and 2. The tower has been modelled as a 3D space frame using the STAAD. Pro (CONNET v22) software application programme. Figure-1 shows the assigned wind loads of the tower in STAAD application.

Table-1. Panel Heights of the tower.

Panels	No’s
5m	2
4m	2
3.5m	5
2m	6
1.5m	8

Table-2. Sectional properties of 40 m tower.

S.no	Angular section sizes
1	150x150x16
2	150x150x12
3	90x90x6
4	80x80x6
5	75x75x6
6	70x70x5
7	65x65x6
8	60x60x5
9	50x50x4
10	45x45x4

The wind load on towers is determined for transverse direction with equations 1 & 2

$$F_{wt\ TRANS} = P_d \text{ x } (A_{eT} \text{ x } C_{dT} \text{ x } G_T \quad (1)$$

$$Fz = C_{i,z} x A_{ex} P_d x G \quad (2)$$

Where, $F_{wt\ TRANS}$ = wind load in the transverse direction, in newton. C_{dT} is Drag Coefficient transverse face for the panel under consideration, these are the functional coefficients of Solidity ratio. G_T = gust response factor of the tower. P_d is Design wind pressure in N/mm^2. This is determined with equations 3.

$$Pd = 0.6 \text{ x } V_d^2 \quad (3)$$

Where V_d is design wind speed. This factor is determined with equation 4 for 802 -2015 code and equation 5 for IS 875 code recommendations.

$$V_d = (V_B/1.375) \text{ x } K1 \text{ x } K_2 \quad (4)$$

$$V_d = (V_B) \text{ x } k_1 \text{ x } k_{2i} \text{ x } k_3 \text{ x } k_4 \quad (5)$$

In the IS 875 part 3 2015 version code recommended the Cyclonic impact factor- k_4 factor- in cyclonic regions (Wind zone 5), is a function for the importance of lifeline structures (IS 875 (Part 3):2015, 2015). But it was not reflected in Equation 4 related to IS 802-2015code requirement (IS 802-2015(Part-1/sec-1,

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2015). With the above load data, the panel loads are converted into nodal loads. While modelling, the geometrical properties of Tables 1 and 2 are applied. The TL towers are modelled as three-dimensional truss elements hence the tower elements are assumed to take only axial forces.

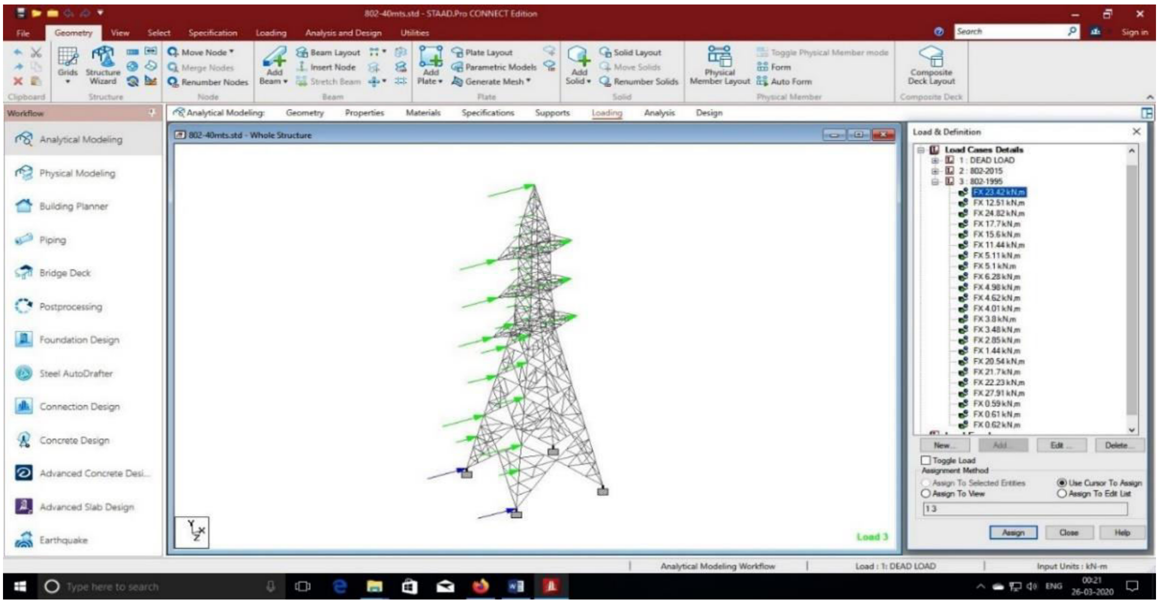

Figure-1. Forty metre transmission tower line modelling in STAAD pro application.

RESULTS AND DISCUSSIONS

A comparison of variation of lateral displacements at the top of the tower, shear forces at the base, axial forces at the first-panel profile legs and Base bending moments between IS 802 (Part1/Sec1) 2015& IS 875 (Part 3) 2015 and between IS 802 (Part1/Sec1) 2015 and IS 802 (Part1/Sec1) 1995, for a 40-meter height four legged transmission tower are performed with steel angular members as profile legs and bracings with Gust factor loading method provisions. The results are shown in figures through 2 to 8.

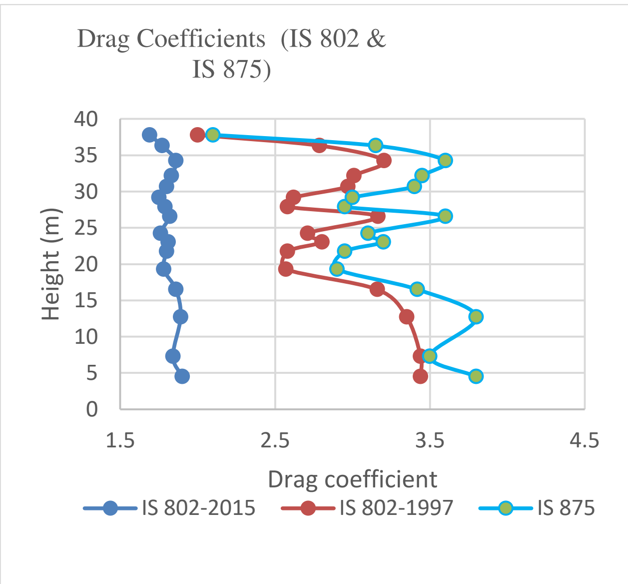

Figure-2. Variation of drag coefficient.

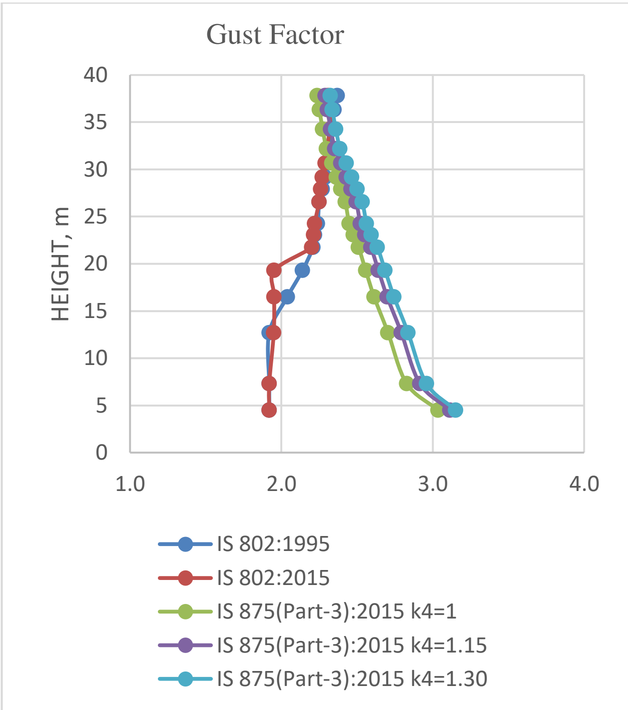

Figure-3. Variation of GUST factor.

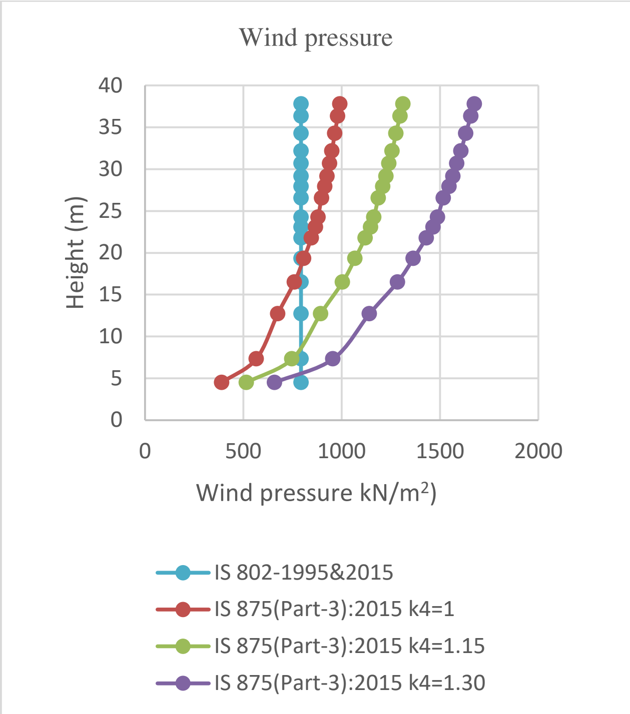

Figure-4. Variation of wind pressure.

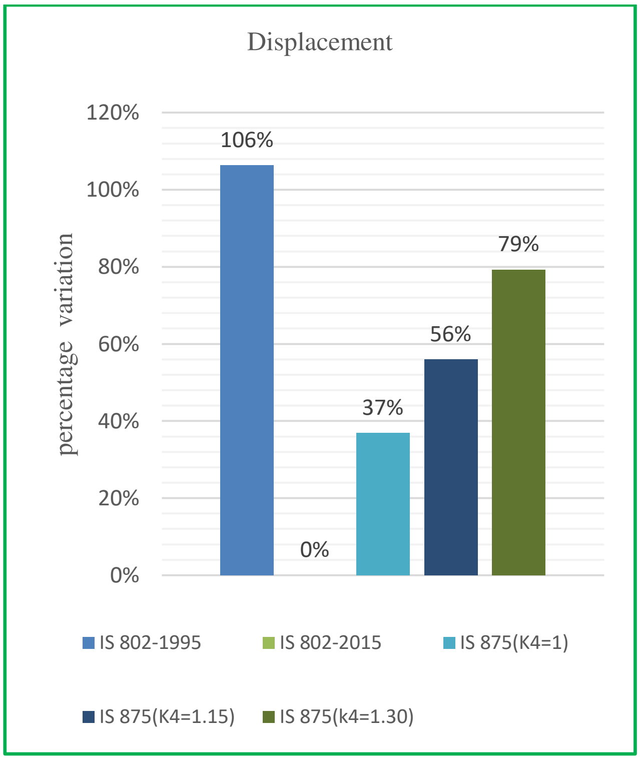

Figure-5. Variation of top displacements.

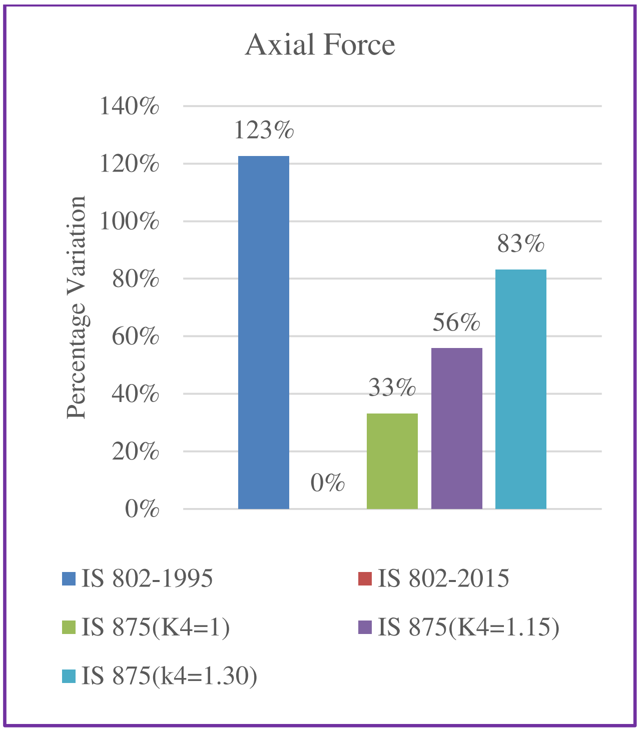

Figure-6. Variation of axial force.

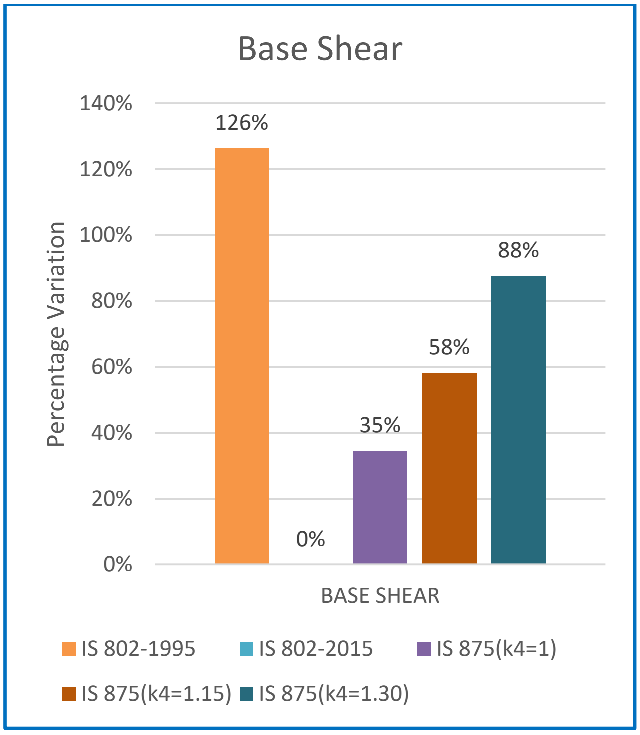

Figure-7. Variation of base shear.

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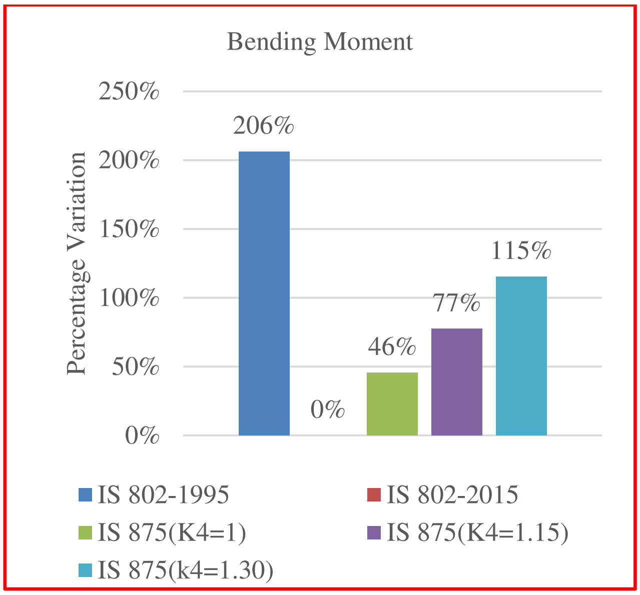

Figure-8. Variation of base bending moment.

DISCUSSIONS

With the above methodology, the 40m height TL tower was simulated with the IS 802- 2015 code recommendations (IS 802-2015(Part-1/sec-1, 2015). And the same model was simulated for IS 875 Part3-2015 code procedure for coastal areas with cyclonic importance factor (k_4 factor) (IS 875 (Part 3):2015, 2015).

The drag coefficient is one of the primary shape factors of the structure to find the wind force. Figure-2 shows the variation of the drag coefficient, it is varied from 1.60 to 1.9 for IS 802- 2015 version (IS 802-2015(Part-1/sec-1, 2015). But it is varied from 2.10 to 3.8 for IS 875 2015 code (IS 875 (Part 3):2015, 2015). Moreover, it varies from 2.0 to 3.8 for IS 802- 1995 version. Here a huge difference of drag coefficients was observed for the same solidity ratios in IS 802- 2015 revised versions IS 875-2015 code provisions (IS 802-2015(Part-1/sec-1, 2015) (IS 875 (Part 3):2015, 2015). However, a slight difference is observed for IS 802-1995 and IS 875-2015 code provisions (IS 875 (Part 3):2015, 2015) (IS 802-1995(Part-1/sec-1, 1995).

Similarly, the wind pressure variation along the height of the tower is depicted in the Figure-3. It is almost vertical and approximately constant over the height of the tower for IS 802 code provisions (IS 802-2015(Part-1/sec-1, 2015)[6], but it follows the velocity profile in the IS 875 -2015 code provisions (IS 875 (Part 3):2015, 2015).

The variation of gust factor values is depicted in Figure-4. It is varied from 1.90 to 2.2 for IS 802 code (it increases along with the height) and for IS 875 code it varied from 2.20 to 3.2 (in this case it decreases along with the height) (IS 802-2015(Part-1/sec-1, 2015) (IS 875 (Part 3):2015, 2015).

However, the comparison was made between IS 802-2015 revised version and IS 875-2015 code recommendations and also between IS 802-2015 revised code and 1997 version. The respective variation of internal parameters is depicted in Figure-4 through 8. The comparisons were made in terms of the percentage of variations with reference to IS 802-2015 code recommendations. Finally, the following observations were found.

Figure-5 depicts the variation of top displacement. It increases to 37%, 56% and 79% for k_4 = 1.0, k_4 = 1.15 and k_4 = 1.30 of IS 875(part3) 2015 provisions respectively. It also shows the 107% more variation for IS 802-1997 Provisions.

The resulted axial forces variations are presented in the Figure-6. It increases to 33%, 56% and 83% for k_4 = 1.0, k_4 = 1.15 and k_4 = 1.30 of IS 875(part3) 2015 provisions respectively. It also shows the 123 % more variation for IS 802-1997 Provisions.

The accomplished variation of Base shear is demonstrated in the Figure-7. It increases to 35%, 58% and 88% for k_4 =1.0, k_4 = 1.15 and k_4 = 1.30 of IS 875(part3) 2015 provisions respectively. It also shows the 128% more variation for IS 802-1997 Provisions.

The achieved variation of Base Bending moment is shown in Figure-8. It increases to 46%, 77% and 115% for k_4 = 1.0, k_4 = 1.15 and k_4 = 1.30 of IS 875(part3) 2015 provisions respectively. It also shows the 206 % more variation for IS 802-1997 Provisions.

CONCLUSIONS

The 230-kV transmission lattice tower of 40 m height and 200 m design span was analyzed under the action of load patterns from wind design regulations IS 802-2015 and wind loading code IS 875-2015 version for terrain category 2 in (cyclonic region) wind zone -5 of India. Particularly, IS 875(part3)-2015 revised code version incorporated the k_4 factor in the cyclonic region for adequate safety of lifeline structures against the unprecedented high cyclonic gale speeds. This factor was not reproduced in IS 802-2015 version. Secondly, the variation of drag coefficients for the same solidity ratios was observed between the codes. Hence an illustration was made for the TL tower with this k_4 factor in cyclonic region/wind zone -5 of India. According to the results obtained, the main conclusions can be drawn as follows:

The TL tower has been designed with 50 m/s wind speed with IS 802-2015 recommendations. However, recognizing the fact that the higher gale wind speeds more than 50m/s have been experienced in wind zone -5 of Indian cyclone region, the IS 875-2015 incorporated the k_4 factor (1.30) for the safety of lifeline structures includes TL Towers.

With the incorporation of k_4 factor number value 1.30 in IS 875-2015 version, the design specifications include top deflection, Axial force in the bottom profile leg, Base Shear Force and Base Bending moment parameters have increased by 79%,83%, 88%, and 115% in comparison with IS 802-2015 Provisions.

Similarly, the general structure design with k_4 factor = 1.00 in IS 875-2015 version, the design specifications include top deflection, Axial force in the bottom profile leg, Base Shear Force and Base Bending moment parameters have increased by 37%, 33%,35%and 46% higher in comparison with IS 802-2015 Provisions.

This phenomenon was inferred since the lesser drag coefficients were established in IS 802-2015 recommendations.

With the perception of the above two conclusions, the higher variation in the Base bending moment is identified among all the design parameters

The highest number value 1.30 of k_4 factor is detailed for the safety of lifeline structures including TL towers, Telecommunication Towers and other buildings/structures to impart the services during and after the cyclone occurrences.

Finally, it is concluded that code provisions of IS 802 -2015 version cannot associate with mandatory recommendations of IS 875-2015 provisions in Wind zone -5 of India. Hence the highest number value 1.30 of k_4 factor may be admitted in IS 802 -2015 version code for adequate safety of TL towers to impart the services during and after the high unprecedented wind speeds occurrences in cyclonic region/ Wind zone-5 of India.

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