International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 08 | Aug 2018 www.irjet.net p-ISSN: 2395-0072

Comparative Study of Dynamic Analysis of Transmission Towers

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Abstract – *This paper describes the estimation of feasible solution to optimize transmission line tower for weight parameter. The cost of transmission line towers is about 35% to 40% of the total cost of the transmission tower. But lesser study is carried out in the field of minimizing weight of transmission line tower, also less literature is available on transmission line tower with cold form sections. Analysis of transmission line tower carried out as per standard codes, also comparative study is carried on the basis of different types of bracing systems (warren, horizontal, diagonal and diamond) and materials such as hot rolled and cold form sections. By designing transmission line tower with hot rolled sections using STAAD pro, hot rolled sections gives light weight design.*

***Key Words*: Optimization of tower, Hot rolled steel section, STAAD Pro.**

1. INTRODUCTION

Now a day's electricity is on high demand in the field of industries, commercial and residential use. The need of electricity increases due to rapid progress in industrial area and infrastructure. Requirement of electricity varying across the country and for far away locations of power plants, a network of electric transmission lines is required. The shape and size of the transmission line tower have received extensive attention. The tower is defined as tall structures with relatively small cross section and with a large ratio between the height and the maximum width. Tower structure acts as a single cantilever beam which is freely standing self-supporting and fixed at base. Guy tower is the structure which is pin- connected to its foundation and supported with guys or another element. Water towers, radio and television towers and the towers of power transmission lines are the examples of structures which belonging to the tower family. The transmission line tower is used to support conductors carrying electrical power and one or two ground wires at suitable distances above the GL and from each other the cost of transmission line towers is about 35% to 40% of the total cost of the transmission tower. The aim of every designer is to design the best (optimum) system, so that towers are constructed economical by developing different light weight configuration of transmission line tower. Following points are to be considered while designing the transmission line tower:

a) Selection of clearance

b) Tower configuration analysis

c) Tower weight estimation

d) Line cost analysis and span optimization

e) Economic evaluation of line

1.2 Types of tower

Tower structure is act as a single cantilever beam which is freely standing self-supporting and fixed at base. The structure which is pin- connected to its foundation and supported with guys or another element. Depending upon the size and type of loading, towers are grouped into two heads. a) Towers with large vertical loads (b) Towers with mainly horizontal wind loads. Towers with large vertical loads (such as those of overhead water tanks, oil tanks, meteorological instrumentation towers etc.) have their sides made up of vertical or inclined trusses. The towers, falling under the second category and subjected predominantly to wind loads, may be of two types:

i. Self-supporting tower

ii. Guyed Tower

I. Self-supporting tower

Free standing towers, known as lattice towers, are generally square in plan and are supported by four legs, fixed to the base. These towers act as vertical cantilever trusses, subjected to wind or seismic loads.

II. Guyed tower

In contrast to this, guyed towers are hinged to the base, and are supported by guy wires attached to it at various levels, to transmit the wind forces to the ground.

1.2.1 Tower configurations and bracings

The self-supporting towers, subjected predominantly to wind loads, are called lattice towers. Such towers are square or rectangular in plan. Following are the different types of bracings:-

a) Single web horizontal bracings: This is the simplest form of bracing. The wind shear at any level is shared by the single diagonal of the panel. Such bracings are used for towers up to 30 m height.

b) Warren type bracings: This is a double diagonal system without horizontal bracings and used for towers up to 50 m height.

c) Single web diagonal bracings: Struts are designed in compression and diagonals in tension.

d) Diamond type bracings: Similar to warren system. Horizontal member carries no primary loads designed as redundant supports.

1.3 METHODOLOGY

The four transmission line tower models using Hot Rolled section were developed. The analysis of transmission line towers was carried as per IS standards. The wind force was applied on the tower as per IS 875:2016. The total forces which will act on tower was calculated manually after that design of transmission line tower using STAAD Pro. Based on weight parameter the most economical and sustainable bracing system for tower was found out. Detailed analysis and design of tower using hot rolled sections was carried out.

1.4 ANALYSIS OF TOWER

In tower design is based primarily on dead load, wind load, sag tension, broken wire condition, temperature effects, safety criteria, load acting on conductor, insulator, ground wire and in addition wind load acting on tower as per IS 875-2016.

A. Problem for Research:-

The following parameters for transmission line and its components are assumed from I.S. 802: Part 1: Sec: 1:1995, I.S. 5613: Part 2: Sec: 1:1989.

- Transmission Line Voltage : 220 kV (A/C)
- No. of Circuits : Double Circuit
- Right of Way (recommended): 35, 000 mm
- Tower Configuration : Vertical Conductor
- Angle of Line Deviation : 0 to 2 degrees
- Bracing Pattern : Four types
- Terrain Type : Plain
- Cross Arm : Pointed

B. Geometry of Tower

i. Height of Tower Structure

$H = h_1 + h_2 + h_3 + h_4$

$= 31.61$ m

ii. Base width of tower:

As per IS 802 (part 1 / section 1) 1995, base width of tower is to be taken as 1/5 th to 1/10th of total height.

Base width of tower = 1/6 X Total height of tower

= 5.3 m

C. Loads on Tower

a. Dead Load on Tower

1. Self-weight of tower taken by STAAD PRO itself.
2. Dead load on conductor = 8.579 kN
3. Dead load on ground wire =3.47 kN

b. Wind Load on Tower

Wind load is major load acting on tower. Wind loads on tower is calculated separately by following Indian Standards. For finding the drag coefficients for members of tower, the solidity ratio is taken from Table 30 in IS 875 (part 3) -2016 in the similar way prescribed in IS 826 (part 1/section 1).

$$\mathbf{F_{wc} = P_d \times C_{dc} \times L \times D \times G_C}$$

Where, F_{wc} = wind load on conductor

P_d = design wind pressure

C_{dc} = drag coefficient for ground wire

L = wind span

d = diameter of conductor/ground wire

G_c = gust response.

Following data is to be taken from IS: 802 (Part 1/section 1):1995

Wind zone	= 3
Basic wind speed(V_B)	=44 (m/s)
Design period	=150 years
Reliability level	= 2

Risk coefficient (k_1) =1.11

Terrain category = 2

Terrain coefficient = 1.00

Reference wind speed = $V_R = V_b/k_0$

= 32 m/s

Design wind speed (V_d) = V_R x k_1 x k_2

= 35.52 m/s

Design wind pressure (P_d) = 0.6 V_d^2

= 757 N/m^2

1. Wind load on conductor: -

$$F_{wc} = P_d \times C_{dc} \times L \times D \times G_C$$

= 9.3 kN

Where, F_{wc} = wind load on conductor

P_d = design wind pressure

C_{dc} = drag coefficient for ground wire=1.2

Drag coefficient for conductor = 1.0

L = wind span = 175 m

d = diameter of conductor/ground wire = 28.62mm

G_c = gust response. = 2.34

2. Wind load on ground wire:

$$F_{wg} = P_d \times C_{dc} \times L \times D \times G_C$$

= 3.52 kN

Where, F_{wg} = wind load on ground wire
P_d = design wind pressure
C_{dc} = drag coefficient for ground wire=1.2
Drag coefficient for conductor = 1.2
L = wind span = 175 m
d = diameter of ground wire = 9.45x10 $^{-3}$ m
G_c = gust response = 2.3

3. Wind load on insulator string:

$$F_{wi} = P_d \times C_{di} \times A_i \times G_i-$$

= 0.04 kN

Where, F_{wi} = wind load on insulator string

P_d = design wind pressure

C_{di} = drag coefficient for insulator string =1.2
A_i = 50 % of the area of insulator string projected on a plane which is parallel to longitudinal axis of the string.
Gi = gust response = 2.4

c. Calculation of Sag Tension

Indian standard codes of practice for use of structural steel in over-head transmission line towers have prescribed following conditions for the sag tension calculations for the conductor and the ground wire:

1. Maximum temperature (75°C for ASCR and 53°C for ground wire) with design wind pressure (0% and 36%).

2. Every day temperature (32°C) and design wind pressure (100%, 75% and 0%).

3. Minimum temperature (0°C) with design wind pressure (0% and 36%).

In this paper, the consideration of the sag of ground wire as 90% the sag of the conductor at 0°C and 100% wind condition.

Sagging = $wl^2 /8T_2 = 0.973 \ x \ 320 \ x 320/8 \ x \ 2282.5$

= 5.46 m

By increasing 4% of calculated sag we get

= 5.46 × 4%

= 5.70 m.

As per IS 5613 (part 2), section 1:1989

For both conductor and ground wire, all tension values are given FOS < 4 .So consider the minimum tension (tension for FOS = 4).To finding maximum sagging in all condition, parabolic equation used.

d. Broken Wire Condition

As per IS 802 (part 2/section 1) 1995 clause 12.3.3, for self-supporting transmission line tower, longitudinal load per sub conductor and ground wire shall be considered as 10 kN and 5 kN respectively.

e. emperature Effects

As per IS 802 (Part 1/section 1) 1995 clause 10.24, the tower may be designed to suit the conductor temperature of 750 C (max) for ACSR conductor.

f. Safety Criteria

As per CBIP manual for transmission line tower, safety criteria are to be considered for the calculation of safety criteria separate excel sheet is prepared to avoid repetitive calculations.

D. Finite Element Analysis of Tower:

Following models were analysed and designed using hot rolled and cold form sections

a. Diamond Shaped Bracing System

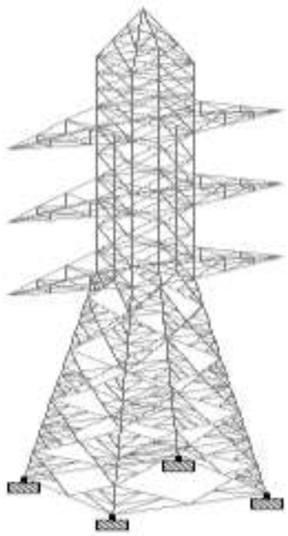

Fig 1 Diamond shaped bracing tower

b. Warren Type Bracing System

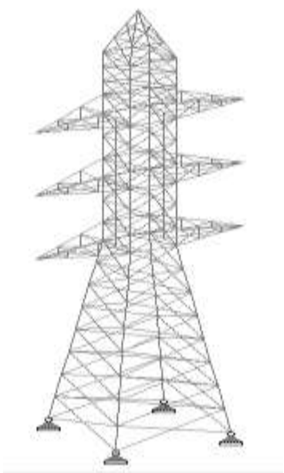

Fig 2 Warren type bracing tower

c. Single Web Horizontal System

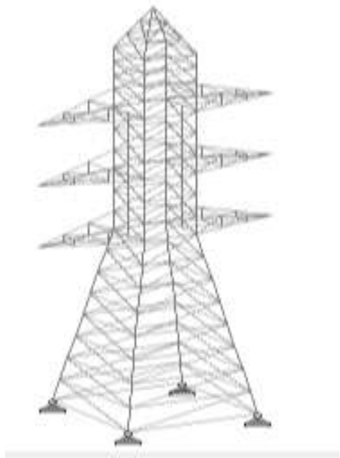

Fig 3 Single web horizontal tower

d. Single Web Diagonal System

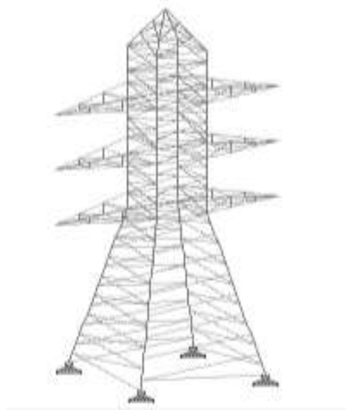

Fig 4 Single Web Diagonal Tower

2. DESIGN OF TOWER

Design of tower is carried out in STAAD Pro.V8i software. Loads on tower is calculated manually as per IS 802:1995 & CBIP manual.

3. MODELLING APPROACH

Transmission tower is modelled using STAAD Pro.V8i. Tower with different type of bracing system are modelled. Tower configuration for each viz. base width, height length etc. is same.

4. RESULTS AND DISCUSSION

The loading on transmission line tower was calculated manually, then that values of loading are applied on FE model and analyze that model. But for achieving perfect result hot rolled sections are analyzed in STAAD Pro.V8i software.

A. Weight of Hot Rolled Section Tower for Four Types of Bracing System:-

Following results are given idea about the weight of transmission line tower for different bracing system which is made with hot rolled sections.

Table 1:- Weight of tower with hot rolled sections

Sr. No.	Types of tower bracing system	Weight of tower
1	Diamond shaped bracing system	311.215 kN
2	Warren type bracing system	626.123 kN
3	Single web horizontal bracing system	375.829 kN
4	Single web diagonal bracing system	454.818 kN

Discussion:

As per above results seen that, the transmission line tower with diamond shaped bracing system using hot rolled section is optimum as compared to other three types of bracing system. The diamond shaped bracing system tower has 40-50% weight less than the other type of bracing system. Also the stability against the wind, broken wire condition and such other sudden loading, the other structures are not feasible.

B. Base reaction of Hot Rolled Section Tower for Four Types of Bracing System:-

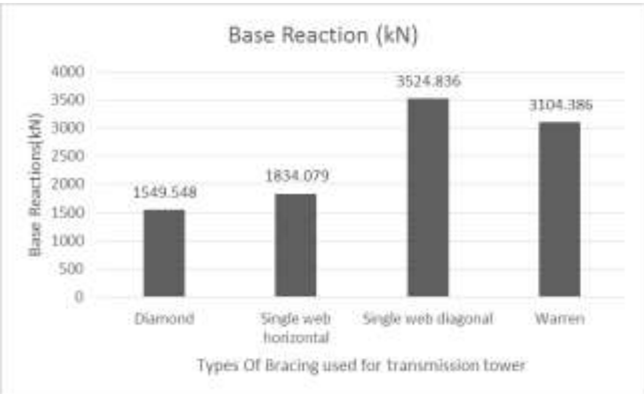

Fig 5 Base reaction vs types of bracing system for transmission tower

Discussion:

The above graph represents the value of base shear of transmission tower for different types of bracing system. The maximum value of base reaction is for single web diagonal type bracing system having value as 3524.836 kN. The minimum value of base reaction is for diamond type bracing system having value as 1549.548 kN.

C. Displacement of Hot Rolled Section Tower for Four Types of Bracing System:-

The displacement values are extracted as results by selecting top point and intermediate point of the transmission tower models.

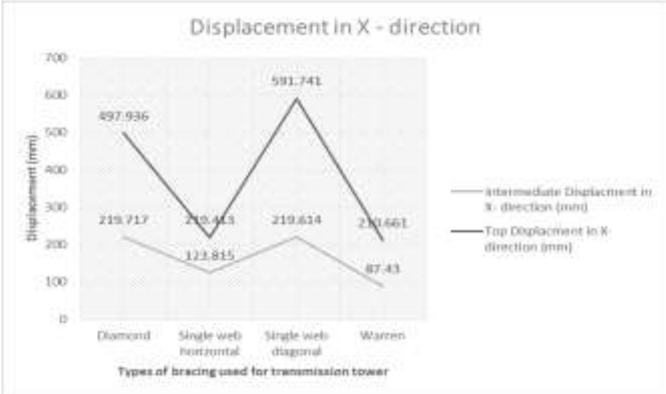

Fig 6 Displacement in X direction vs types of bracing system for transmission tower

Discussion:

The above graph shows the displacement in X direction for transmission tower having four different types of bracing system. The maximum top displacement of 591.714 mm is for single web diagonal type of bracing system and maximum intermediate displacement of 219.717 mm is for diamond type of bracing system. The minimum top displacement of 210.661 mm is for warren type bracing system and minimum intermediate displacement of 87.430 mm is for warren type of bracing system.

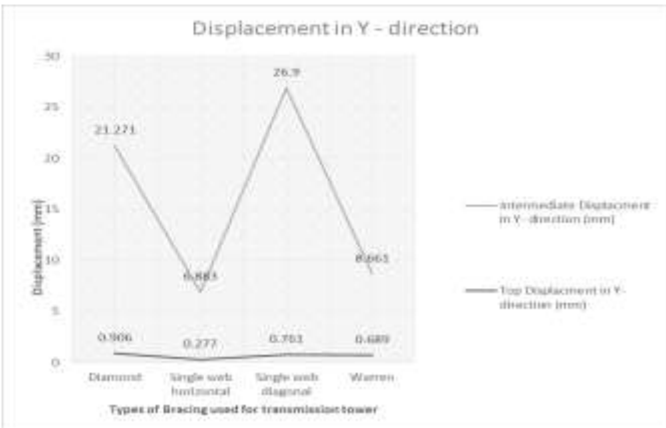

Fig 7 Displacement in Y direction vs types of bracing system for transmission tower

Discussion:

The above graph shows the displacement in Y direction for transmission tower having four different types of bracing system. The maximum top displacement of 0.906 mm is for diamond type of bracing system and maximum intermediate displacement of 26.900 mm is for single web diagonal type of bracing system. The minimum top displacement of 0.277 mm is for single web horizontal type bracing system and minimum intermediate displacement of 6.883 mm is for single web horizontal type of bracing system.

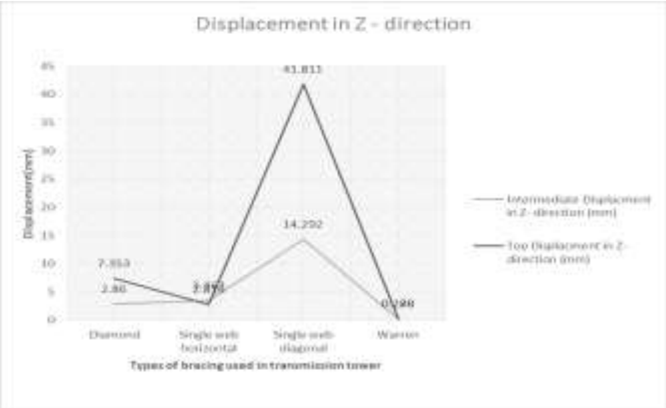

Fig 8 Displacement in Z direction vs types of bracing system for transmission tower

Discussion:

The above graph shows the displacement in Z direction for transmission tower having four different types of bracing system. The maximum top displacement of 41.811 mm is for single web diagonal type of bracing system and maximum intermediate displacement of 14.292 mm is for single web diagonal type of bracing system. The minimum top displacement of 0.288 mm is for warren type bracing system and minimum intermediate displacement of 0.278 mm is for warren type of bracing system.

5. CONCLUSIONS

The following conclusions are drawn for transmission tower by using four different types of bracing viz. diamond bracing, single web horizontal bracing, single web diagonal bracing and warren bracing on the basis of the researches and analysis done through the STAAD Pro V8i.

1) The base reaction for single web horizontal type bracing is maximum while for diamond type bracing is minimum.

2) 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 tower.

3) The weight of the diamond bracing tower is less as compared to other three type of bracing tower.

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