Loading Analysis of a Typical Electric Pylon

I. Jusoh, H. A. Ghulman, T. S. Mandourah, C. C. Tan

***Abstract*— Electric pylon is a structure made of steel having relatively high ratio for its length and width. The structure is strong enough to withstand gravity and several type of external forces. Electric pylon is one of the vital components of electric transmission line that make a transmission tower. The tower must be reliable and able to operate under several loading conditions. Environmental loading contributes the largest percentage of the total loads experienced by any typical tower structure. This paper investigates the loading condition usually experiences by typical pylon structure. The structure modeling is done using finite element software. The influence of various loading conditions on the structure is investigated and the critical elements of the tower structure are determined. From the result obtained, it shows that the most critical element is bracing member situated on the lowest level of the pylon structure. The result of this study also shows that the safety level in the entire structure is acceptable under all the most severe loading conditions.**

***Index Terms*—** *Electric Pylon, Structure modeling, External Loading, Structural response*

I. INTRODUCTION

Electric pylon is used to transmit and distribute electric energy from it source of production, the generating station, to the load centers for further transmission and distribution [1]. Transmission towers are constructed using angle section members which are eccentrically connected [2].

It is strong enough to withstand a number of forces namely; it own weight, the pull of conductors wires at the top of the tower, the effect of wind on the conductors and earth wires and the effect of wind on the tower itself. In practice, proper planning and preparation must be adhered to when working near to or on the structure [3]. The structure must also be adequately designed to not only support the weight of the wires and structure but also to safely transfers forces and moments from the structure to its foundation [4].

Before the construction of electric transmission lines, structural analysis should be done to ensure the safety of the structure. Structural analysis can be done by theoretical and verify by experimental methods. In theoretical and computer analysis, several assumptions and idealization as well as some basic calculations need to be considered. However, in experiment method, the physical model of the structure needs to be made available and data gathering set-up is the basic requirement for the anticipated good experimental results.

This paper focused on loading aspects on a typical electric overhead transmission structures. It mainly concern on loading behavior and its magnitude onto the structure as well as it basic response related to that particular loading. Under maximum loading conditions of the structure, related critical elements are also be highlighted.

Several case studies were considered in investigating the behavior of structure under certain loading conditions. Loading cases considered to acts on the structure are gravity load (dead load of transmission tower body, weight of conductors, insulator strings, earth wires and earth wire fittings), wind load, normal and broken wire loads, load due to angle of deviation of transmission line, members' buckling load and final case study is redundancy check when there is one or more members of the tower are broken. Some of these loading are illustrated in Figure 1.

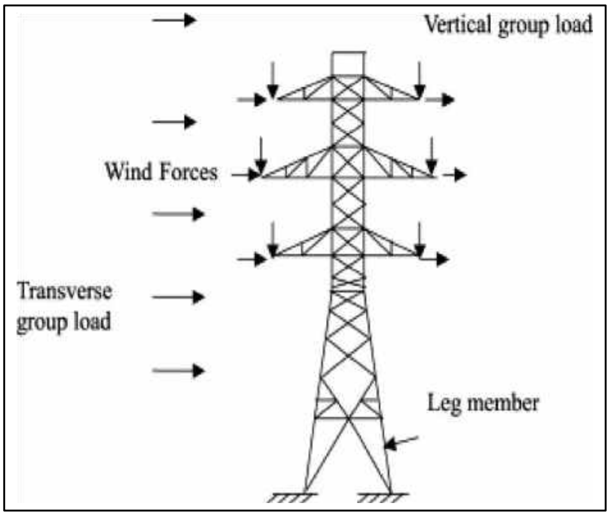

Figure 1: A suspension lattice steel tower resist combination loading from transverse and vertical directions [5].

II. METHODOLOGY

A. MODEL GEOMETRY & DESCRIPTION

The structural frame is assembled from an L-shaped cross-sectioned beam. The base of the structure is measured at 7.068 m by 7.086. The frame structure at levels 18.65 m 31.81 m is measured at 1.820 m x 1.820 m. There is an inclination of about 8 degree for the structural legs from ground to elevation of 18.65 m. There are four main horizontal bracing that supports the transmission lines at 18.65 m, 23.25 m, 27.85 m

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I. Jusoh, Mechanical Engineering Department, College of Engineering and Islamic Architecture, Umm Al-Qura University, Makkah. Kingdom of Saudi Arabia
H. A. Ghulman. Mechanical Engineering Department, College of Engineering and Islamic Architecture, Umm Al-Qura University, Makkah. Kingdom of Saudi Arabia
T. S. Mandourah. Mechanical Engineering Department, College of Engineering and Islamic Architecture, Umm Al-Qura University, Makkah. Kingdom of Saudi Arabia.
C. C. Tan. Acson Malaysia, Lot 4, Lorong 19/1a, Seksyen 19, 46300, Petaling Jaya. Malaysia

and 31.81 m with overhanging of 3.54 m from the vertical members.

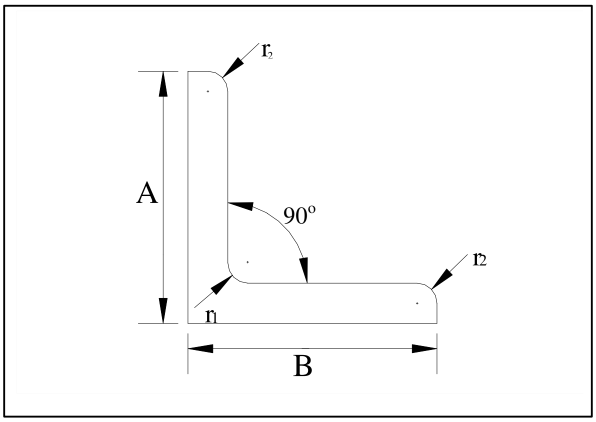

Figure 2: L-section bar used to form a tower structure.

Element used to construct the model for tower structure is the L-sectional steel bar element as shown in Figure 2. It is usually used to model truss and frame structures. Details of structure are presented in form of nodes and elements as shown in Figure 3. Details sizing of the element as well it related material must also be considered as an input to the program.

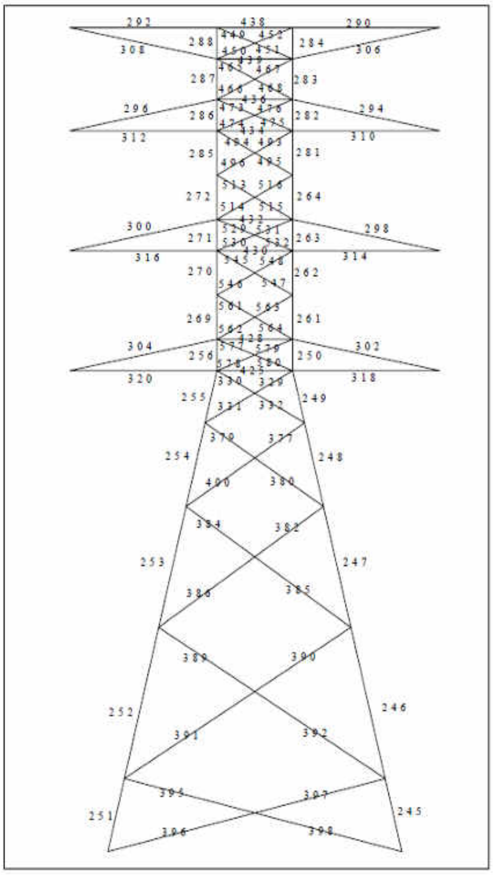

Figure 3: Element Numbers (Front row)

Right selection of material for tower structure is important to ensure its strength and reliability. It should conform to a standard specification and to have a required minimum strength level. It is important that the structure to have a good mechanical property due to high external loading. For example, the 132 kV electric transmissions line, mild steel BS 4360 grade 43A and high tensile steel BS 4360 grade 50C have been chosen as the material for tower body [6].

B. METHODS OF ANALYSIS

Static analysis forms the basis of calculations in structural design of overhead power lines. The environmental loads considered in design can be assumed static or quasi-static (idealized steady wind). The environmental load cases are based on statistical data of wind and ice accretion. They provide a good estimate of the extreme forces that a transmission line is subjected to during its service life [7]. For the majority of towers, simple static analysis of the structure under the factored loads is sufficient to determine the loading effects [8].

In certain circumstances, the dynamics effects also need to be examined. A good example of this would be when a transmission line is subjected to accidental loads such as shock loads induced by conductor ruptures. The occurrence of this type of loading event is rare but unpredictable, and the amplitude of the forces generated is significant [7]. Wind loading is by its nature a dynamic force, which effect on a structure as a whole is to start it vibrating at its natural frequency and so inducing dynamic bending. This causes shear and bending stresses at all points, depending on the mass and acceleration of that point [9].

III. LOADING AND RESPONSE

Several types of load are acting on transmission tower namely; a) Wind load, b) Dead load which include weight of tower structure, conductor and insulator, earth wires and earth wire fittings, c) Tension in conductors and earth wires and d) Upward vertical load.

The wind load constitutes an important and major component of the total loading on towers and so a basic understanding of the computation of wind pressure is useful [5]. Wind load in several directions were considered in order to determine its related maximum magnitudes. This is done in determining the critical wind direction experienced by the structure during operation. Basic wind directions as refer to one structure are transverse and longitudinal directions as illustrated in Figure 4.

In service, the structure experiences wire tensional forces in several directions due connection between towers as shown in Figure 5. These directional tensile forces were considered as a line deviation in loading model on the structure. Behavior of structure under normal loading conditions was compared to the one under specific operational loading conditions such as under broken wire conditions which usually caused significant increases in external loading onto certain part of the structure.
From the investigation, it was found that wind acts in 45º direction gives maximum loading and response onto the structure, thus this angle is considered as a critical loading angle for the structure.

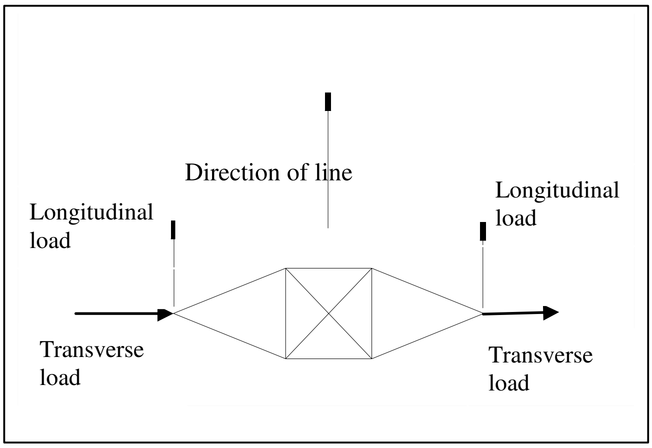

Figure 4: Directional Loads (Transverse and Longitudinal)

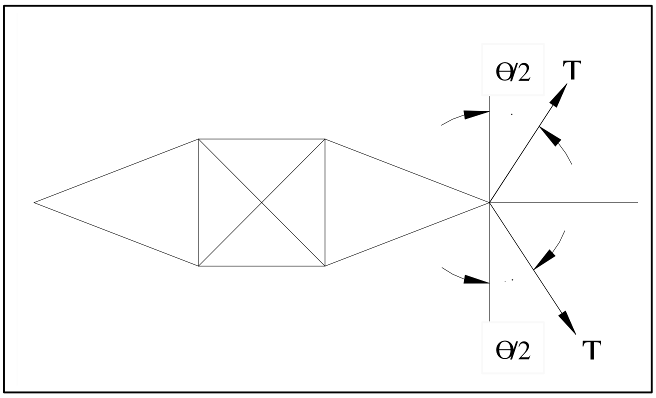

Figure 5: Conductor tension due to line deviation

IV. RESULTS AND DISCUSSION

The first step in analysis in this study is to estimate the dead load (gravity load) on the structure. It does not change position or magnitude with time. The effect of gravity forces acting on each element of the structure is determined using finite element analysis. Since gravity loads are acting vertically and the applied force in X and Z directions are comparatively small. Therefore, total applied load in Y direction is chosen to illustrate the magnitude of forces supported by the structure. The maximum applied force in Y direction is shown in Table 1. The distribution of these forces is illustrated in Figure 6.

It was found that the vertical downward force has a maximum value of 22.4 kN and exerted on node 594, 628, 601, 604, 609, and 646 which is on joining part between insulator strings and tower cross arms of the structure. The vertical force is contributed by the summation of the entire gravity load includes weight of the tower structure, conductors, earth wires, insulators and earth wire fittings. The maximum downward displacement in the vertical direction is 7.78mm and exerted on node 594 and 628. The highest maximum combination stress for this case study is 71.34 MPa and exerted on element no. 298.

Table 1: Result for effects of gravity load on the electric transmission tower structure.

Parameter	**Magnitude**	**Occurred at Node/Element**
Maximum vertical force	-22.4 kN	Nodes 594, 628, 601, 604, 609 and 646
Maximum vertical displacement	-7.78 mm	Nodes 594 and 628
Maximum combination stress	71.34 MPa	Element 298

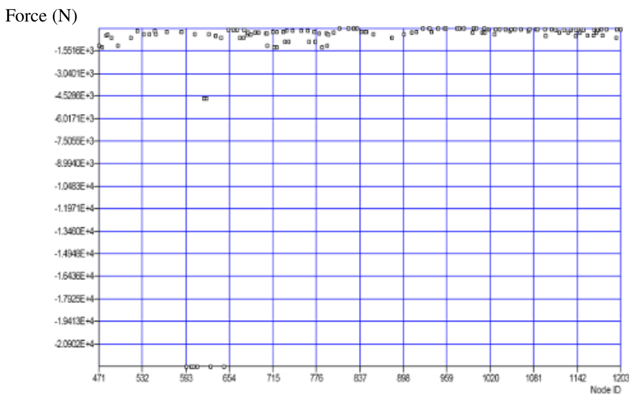

Figure 6: Vertical downward force due to effects of gravity load.

The magnitude of maximum applied load for wind load on three different directions is shown in Table 2. The total applied load for wind in transverse, longitudinal and 45º is shown in Figure 7.
In this case, structure's loading and responses due to wind load on three different directions were investigated followed with estimating maximum wind load and its related direction. The three different directions are transverse, longitudinal and 45º. It was found out that, wind in transverse direction gives the maximum value of the total applied force which is 24.5kN and exerted on node 594, 601 and 609 as illustrated in Table 2.

Table 2: Result for comparison of wind load in three different directions

Parameter	Transverse wind	Longitudinal wind	45º wind
Maximum total applied force and location	24.5 kN (at nodes 594, 601, and 609)	19 kN (at nodes 594, 628, 601, 604, 609 and 646)	21.9 kN (at nodes 594 , 628, 601, 604, 609 and 646
Maximum displacement and location	107.72 mm (at node 622)	45.81 mm (at node 622)	92.92 mm (at node 622)
Maximum combination stress and location	124.19 MPa Element 245	106.56 MPa Element 390	167.95 MPa Element 245

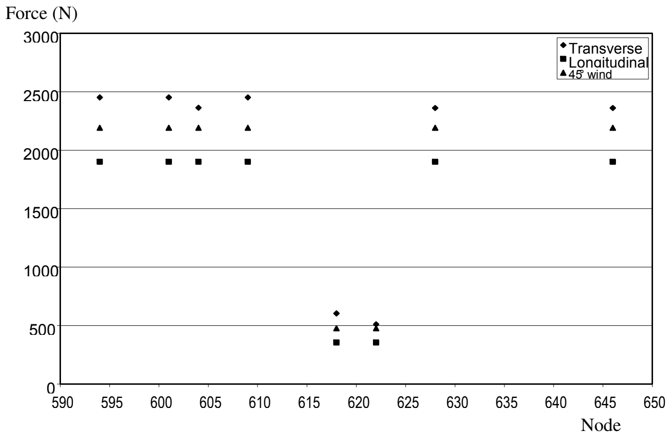

Figure 7: Total applied force for wind in three different directions

The total applied force as indicated in Figure 7 acting on the structure gave a physical response in the form of structure displacement. This is shown in Figure 8 as related to three wind loading directions namely transverse, longitudinal and angled at 45^{o}.

Total translational displacement for wind load in three different directions is given in Table 2 and plotted in Figure 8. The maximum displacement is wind on transverse direction which is 107.72mm and exerted on node 622.

Figure 8 shows that wind load in transverse direction gives maximum displacement at the topmost of the structure as compare wind on 45° and longitudinal directions. Maximum total translation for wind load on three directions is within the safety limit of permissible deflection according to practice which stated that for small angle and straight line tower, displacement should not exceed 1/100 of structure's height.

From the result, it shows that wind load on 45° incident angle is the most critical and given the largest value of maximum combination stress which is 167.95 MPa. Table 2 shows the maximum combination stress was acting on element 245.

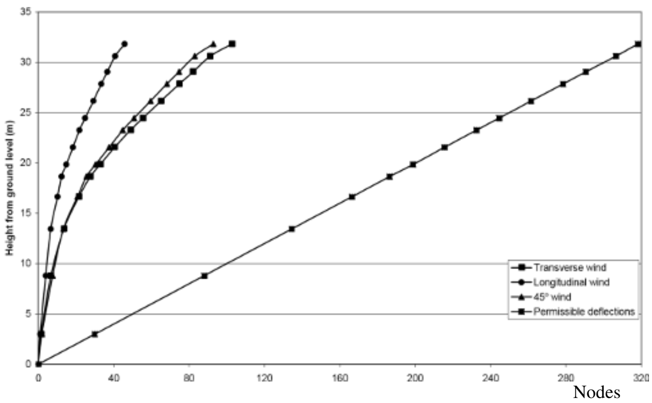

Figure 8: Displacement for wind in three different directions

The summary of result for normal loading condition (base case) is illustrated in Table 3. These magnitudes are used as a reference in comparing other results generated from the study.

Table 3: Result for normal condition (base case).

Parameter	Magnitude	Node/Element
Max. applied force (kN)	21.9 kN	Nodes 594 , 628, 601, 604 & 646
Max. displacement (mm)	92.92 mm	Node 622
Max. stress (MPa)	167.95 MPa	El 245

The loading of structure under broken wire condition were also studied. This is considered as the worst loading condition under minimum temperature and maximum wind. From Table 4 and Figure 9, the maximum applied loads on the structure occur when middle and bottom conductor broken and also top and middle conductor broken which is 43.3kN. Maximum applied load exerted on nodes 601 and 609 when middle and bottom conductor broken and exerted on nodes 594 and 601 when top and middle conductor broken. In term of displacement, the maximum displacement on the structure occurs when top conductor and middle conductor broken as shown in Table 4. The maximum value of displacement is 124.27 mm and exerted on node 618.

Table 4: Result for broken wire conditions

Parameter	Earth wire broken	Top and middle conductors broken	Middle and bottom conductors broken
Total applied force	21.9 kN (at nodes: 594, 628, 601, 604, 609, 646)	43.3 kN (at nodes: 594, 601)	43.3 kN (at nodes: 601, 609)
Displacement	88.13 mm (node 622)	124.27 mm (node 618)	90.78 mm (node 622)
Combined stress	-173.12 MPa (El 390)	-211.49 MPa (El 390)	-209.61 MPa (El 390)

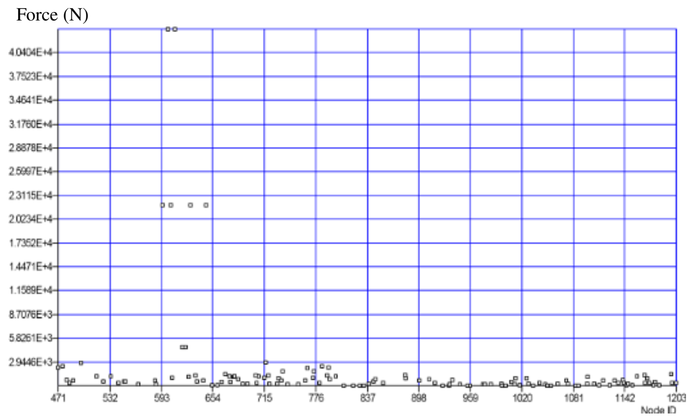

Figure 9: Total applied loads for middle conductor and bottom conductor broken conditions

From the Table 4 and Figure 10, top and middle conductor broken condition is most critical and given the highest value of maximum combination stress which is 211.49 MPa and exerted on element 390. Element 390 is bracing member situated at the bottom side of tower for connecting the main legs of the tower structure. The value for highest maximum combination stress for middle and bottom conductor broken condition is -209.61 MPa.

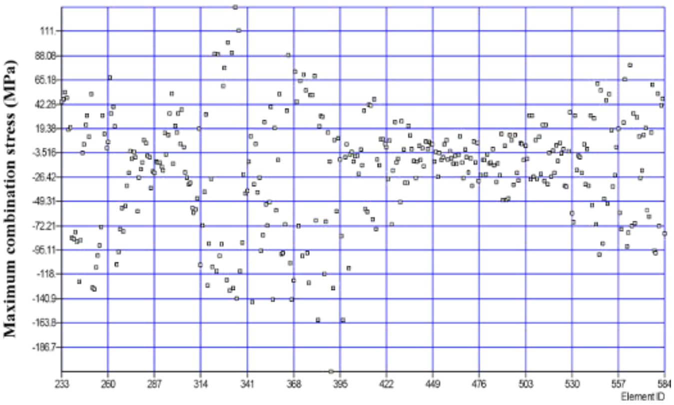

Figure 10: Maximum combination stress for middle conductor and bottom conductor broken.

V. CONCLUSION

From this study the following conclusions may be drawn;

1. Results presented are outcomes of investigation on transmission structure under several loading conditions.
2. Several type of loads acting on the structure namely wind load, dead load, tensional load and upward vertical load.
3. Maximum wind load experienced by the structure is 24.5 kN resulting with a stress of 124.19 MPa in the structure. This condition gives rise to a maximum translational displacement of 107.72 mm.
4. The highest loading magnitude occurred during broken wire condition resulting maximum combined stress of -211.49 MPa on element 390 located at the lowest level of structure.

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