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Electricity Pylon with Broken Wires Condition

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***Abstract*— Transmission of electric power from a location to another usually done through conductor cables or wires where this wires are supported by structure known as an electricity pylon. The support structure assembled from L-section steel members that are strong enough to withstand external and gravity loads. The electricity pylon structure was design assembled strong enough to support external and internally transferred loads during its operation. During its service life there is a significant condition that put structure under extreme loading whereby the wires used in transmission of electric power are broken. This paper investigates the loading condition usually experiences by typical electricity pylon under this adverse conditions. Result shows that maximum load experienced by the structure during broken wires is 43.3 kN resulting the combined compressive stress of 211.49 MPa on element number 390.**

Keywords*— Applied Load; Broken Wires; Electricity Pylon; External Loading; Stress Response; Structural Modeling.

I. INTRODUCTION

The support structure employed for transmission of electricity is design to operate in extreme condition such as under high wind forces as well as during the occurrence of broken wires. Numerous loading combination usually experienced by the structure that includes external forces, dead load due to gravity force, transferred loads from adjacent elements as well as loading due to broken wires. Generally the structure 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]. In reference to safety during the service of the structure, adequate consideration must be given for transferring of forces and moments to its base [2]. Furthermore, during it service, there must be proper planning and preparation to adhere to when working in the vicinity or on the structure [3].

This paper focused on the effects of broken wires condition on loading and basic responses of a typical electricity pylon structures. At the end of the paper, loading magnitude onto the structure as well as it critical responses are highlighted.

Several loading cases known to acts on the structure can be from either longitudinal, transverse or vertical direction was illustrated in Fig.1. Generally there are gravity load, wind load, normal and broken wire loads, load due to angle of deviation of transmission line and members' buckling load. Several research works also considered seismic effects [4, 5] where the research focused on loading and seismic responses of straight line type and broken line type transmission tower-line systems subjected to non-uniform seismic excitations.

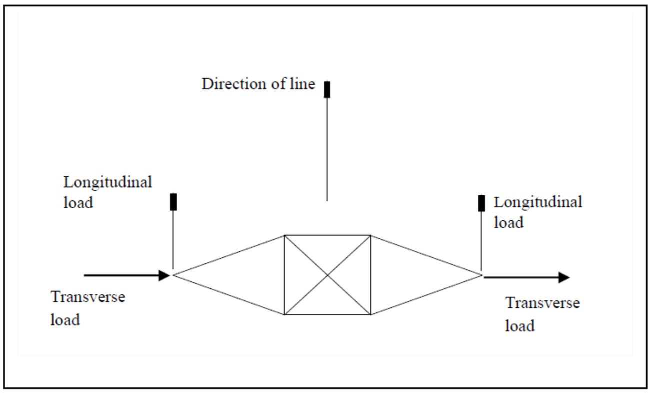

Fig. 1: Plan view of directional loads (Transverse and Longitudinal)

II. METHODOLOGY

A. Model Geometry and Description

Electricity pylon or transmission support structure is constructed using angle-section steel members which are eccentrically connected as shown in Fig. 2 [6]. The base dimension of the structure is measured at 7.068 m by 7.086 m. The frame structure dimensions at levels 18.65 m from the base and at 31.81 m from the base are 1.820 m x 1.820 m. There is an inclination of about 8 degree for the structural legs from ground level to an elevation of 18.65 m. There are four main horizontal bracing that supports the transmission lines at 18.65 m, 27.85 m and 31.81 m with overhanging member of 3.54 m from vertical members of the structure. Figure 3 shows the line elements model of the electricity pylon used in this study.

Some details of the structure are presented in form of elements arrangement as shown in Fig. 3. This sequence of element numbers is used in modeling of truss and frame for the structure. Details sizing of the element as well it nodes and related material were also considered as an input to the program. Fig. 2 shows a typical L-cross-section of the beam assembled to make a electricity pylon. Material used for the transmission tower structure in this study is mild steel BS4360 grade 43A and high tensile steel BS4360 grade 50C [7].

B. Methods of Pylon Analysis

The environmental loads considered in design can be assumed static or quasi-static (idealized steady wind). Static

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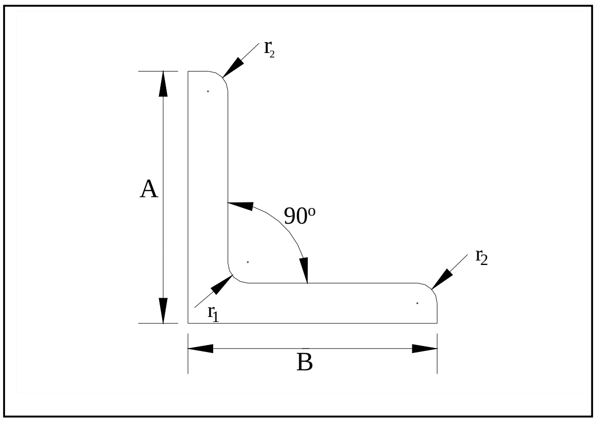

Fig. 2. L-section bar used to form a pylon structure.

analysis forms the basis of calculations in structural design of overhead power lines [8].

In this paper loading and analysis are conducted using a finite element software. Structures are modeled and its related details input of loading parameters, element sizes and material properties, wire loads, wind loads as well directional of wire pull and prevalence wind were selected. 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 [9].

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 or broken wires. The occurrence of this type of loading event is rare but unpredictable, and the amplitude of the forces generated is significant [9]. 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 [10].

III. LOADING AND RESPONSE

Several types of load are acting on transmission tower namely wind load, dead load, tension in wires and 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 [11]. Basic wind directions as refer to one structure are transverse and longitudinal directions as illustrated in Fig. 3.

In this study, analysis is conducted to investigate how the structural respond to three different types of broken wire conditions and also comparing it to normal loading condition. The three different combination of broken wire conditions are earth wire broken, top conductor and middle conductor broken and finally middle and bottom conductor broken. The summary of result for broken wire conditions is illustrated in Table 1.

Appropriately, combination of the various loads under the two conditions (broken and normal conditions) should be considered in design stage. In addition, appropriate factors of safety must also be considered.

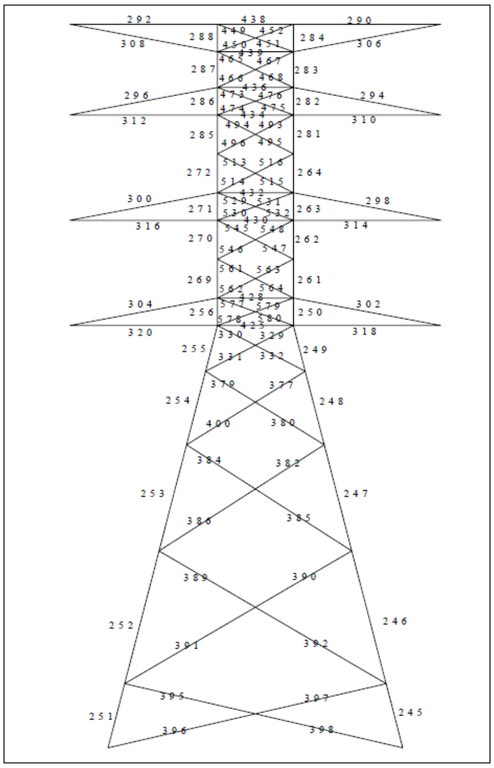

Fig.3. Element numbers on electricity pylon model

It is obvious that the greater the number of broken wires considered during design stages the more robust and heavier the tower structure is going to be. On the other hand, the tower designed for less stringent broken conditions will be lighter and consequently more economical. It is clear that a judicious choice of the broken-wire conditions should be made so that to achieve economy consistent with reliability of the structural member [11].

Loadings on tower structure are different for normal and broken wire conditions. In broken wire conditions, one additional longitudinal loading due to simultaneous breakage of any two phases or one phase conductor and one earth wire, on the same side of the tower. Since the force acting on the tower structure in broken wire condition are combination of force from different direction, total applied load is chosen because it gives the best representation for combination loading on different direction. The total applied loads for three different broken wire conditions are shown in Figs. 4 - 6. The value of maximum applied load for wind load on three different directions is shown in Table 1.

It is desired that structure to design for reduced vertical and transverse loadings plus the unbalanced longitudinal force at maximum working tension due to the breakage of one sub-conductor or one earth wire. In situation where a conductor breaks, the pull on a suspension tower may be assumed to reduce the specified maximum working tension by 70%.

This reduction does not apply to an earth wire breakage Tension tower shall be designed for vertical and transverse loadings plus the full unbalanced longitudinal forces at maximum working tension due to the simultaneous breakage of two adjacent conductors (or four sub-conductors) on the same side of the tower or one earth wire. Calculation of

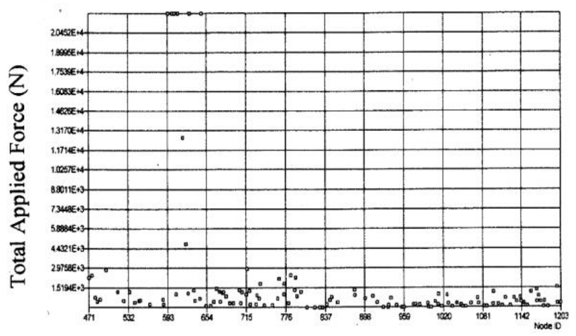

Fig. 4. Total applied loads for earth wire broken conditions

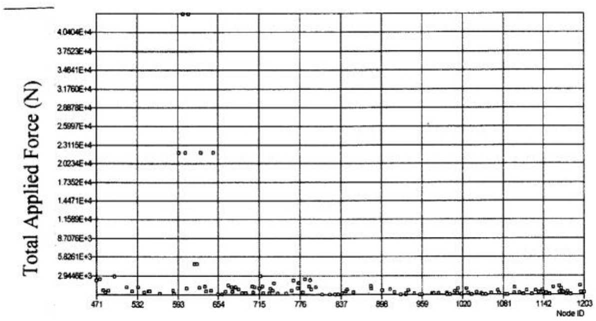

Fig. 5. Total applied loads for middle conductor and bottom conductor broken conditions.

stresses in tension tower members under broken wire loadings shall be made for the worst conditions of loading of that particular member for the range of loadings for which the tower may be employed [7].

From this 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.

IV. RESULTS AND DISCUSSION

The loading of structure under broken wire condition is considered as the worst loading condition under minimum temperature and maximum wind. Three load-cases were studied for broken wires conditions as tabulated in Table 1.

One case in Table 1 and Fig. 4 shows that the condition where earth wire is broken. Total applied load onto the structure is 21.9 kN which induced combined compressive stresses or 173 MPa at node 390. In that moment the maximum displacement is 88.13 mm occurs at node 622. Note that element 390 is bracing member situated at the bottom side of tower for connecting the main legs of the tower structure.

Second worse response under broken wires conditions occurs when the middle and bottom conductor broken. This instant produced applied load of 43.3 kN at nodes 601 and 609 correspond to compressive stress of 209.61 MPa at node 390. Maximum displacement in this case is 90.78 mm at node 622. These are shown in Table 1 and Fig. 5.

The worse-case response under broken wires condition experienced by the structures is happening during top and middle conductors broken. The total applied load acts on the structure is 43.3 kN (as refer to Fig. 6) resulting maximum magnitude of combination stress of 211.49 MPa exerted on element 390. Maximum displacement is 124.27 mm occurs at node 618.

Total translation displacement for wind load in three different broken wire conditions are illustrated in Fig. 7. The magnitude of displacement is also geometrically depends on the location of nodes with reference to the base of the pylon, i.e. the further up the nodes, the higher value of its displacement. The values of maximum displacement for three different broken wire conditions are shown in Table 1.

The magnitude of applied forces acting on the structural nodes and elements are very much affected by the direction of external loading as well as the direction tension within the wires that attached between adjacent electricity pylon. In addition, the translational displacement also affected by the orientation of the structure built on its base with respect to the direction of wire pulls and direction of external loading interact with the structure.

Figs. 8 – 10 shows that magnitude and distribution of combination stresses experienced by each element on the structures under three broken wires conditions. As previously highlighted, the maximum stress occurs when the top and middle conductors are broken.

Stresses within the structural elements are results from external loads acting onto the structure, location of the element within the structure, the parameters of elements itself such as the size, the material, global and local orientations as well as transferred loads from adjacent element. Selected boundary conditions also influenced the final outcome of individual elements' stress. Therefore proper consideration and arrangement as well as selected configuration of elements

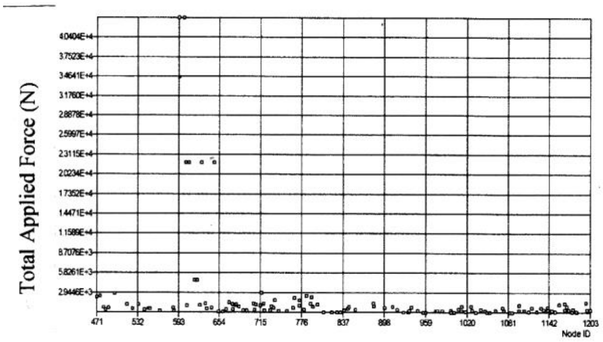

Fig. 6. Total applied loads for top conductor and middle conductor broken conditions.

TABLE 1. 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)

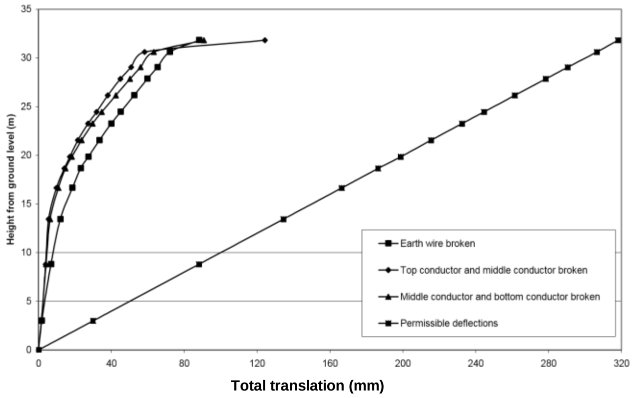

Fig. 7. Elemental translational displacement (for three different broken wire conditions) as refer to the height from the base of the pylon.

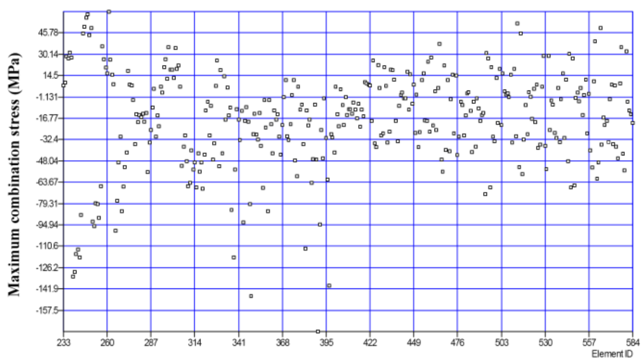

Fig. 8. Maximum combination stress for earth wire broken.

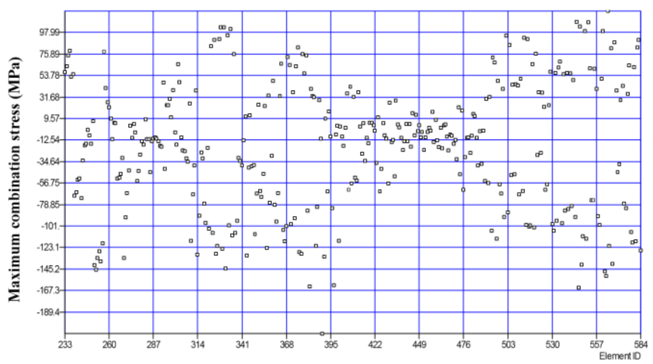

Fig. 9. Maximum combination stress for top conductor and middle conductor broken.

are very significant in the resulting structural responses to all related loads.

There are two parts of the structures are focused in this study namely legs and bracings. The idea is to simulate the integrity of the structure when one or more of its member fail or broken.

Simple redundancy aspects were also investigated. From this study the effect of failure in one or more than one members on the integrity of the structure can be observed. Selection of structure members for this study is based on the high stress experienced under prescribed loading conditions. Detail outcome of redundancy study is presented in Table 2.

TABLE 2. Result for redundant test in broken wire condition

Tower member	Condition	Element removed	Maximum combination stress (MPa)	Effect to the tower structure
Main leg member	One elements removed	233	261.3MPa exerted on element 239	Not fail
	Two elements removed	233 & 234 (on the same leg)	605.1MPa exerted on element 239	Fail
		233 & 245 (on different leg)	-25477.7MPa exerted on element 251	Fail
Bracing member	One elements removed	342	265.7MPa exerted on element 233	Not fail
	Two elements removed	342 & 347 (on the same side)	586.8MPa exerted on element 233	Fail
		342 & 346 (on different side)	-362.7MPa on element 239	Not fail

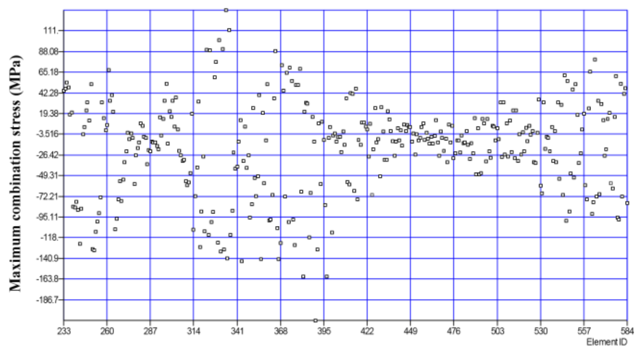

Fig. 10. Maximum combination stress for middle conductor and bottom conductor broken.

V. CONCLUSION

The following conclusions may be drawn from the study on the electricity pylon under broken wire conditions;

1. Results presented in this paper are outcomes of study on electricity pylon under broken wires conditions.
2. Several conditions considered experienced by the structure for the analysis namely earth wire broken, top and middle conductors are broken as well as middle and bottom conductors broken.
3. The maximum magnitude of applied loads, translational displacement occurs when the top and middle wires are broken.
4. The structural response in this condition indicates the maximum combined compressive stress of 211.49 MPa occurs on element number 390. MPa.
5. Total applied load experienced by the structure is 43.4 kN resulting with ranslational displacement is 124.27 at node number 618.

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