A Plan for Full-Scale Measurement of Transmission Line tower Under Wind Loads

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ABSTRACT

The purpose of this paper is to investigate and develop experimental methods for the full-scale field measurements of electricity transmission line structures. Several devices and instrumentation techniques have been developed for the proposed experimental methods. These designs are still in preliminary stages and are open for discussions.

INTRODUCTION

Electricity transmission line systems are engineered structures that traverse over all types of terrains. Wind loading is an important factor in the design of these transmission line systems, consisting of towers, conductors, and ground wires. A survey on transmission line systems revealed that over 50% of structure related failures have been caused by wind loads, especially by extreme wind loads such as thunderstorm downbursts and tornadic wind squall [1]. A typical example is the recent collapse of two transmission line towers in a northern Sydney suburb caused by a severe thunderstorm [2]. Economic considerations often govern the design of electricity transmission line towers resulting in efficiently designed structures in order to satisfy both serviceability and strength criteria. A good understanding of real-life fluctuating wind gusts, their loading on the electricity transmission line structures and the corresponding dynamic responses of the structures are required. Unfortunately, there is only limited guidance from Australian design standards. Hence, more research efforts in this area are required, especially full-scale measurement of existing structures under wind loadings, particularly under extreme wind loadings. Increasing our understanding of wind loadings and interactions between wind loading and structural response will be beneficial for both the modification of existing transmission line structures and future new design. This paper proposes a plan for full-scale field measurement of electricity transmission line structures.

METHODOLOGY -- A general consideration on the measurement methods

1. The complicated nature of winding loadings and response of transmission line tower under wind loadings

The loads on a transmission line tower are a combination of the wind loads acting directly on the tower itself and the loads transmitted from the conductors which make up to 60-80% of the total wind load effect on the support tower structures[1]. The complexity of the problem is due to complicated natures of wind loads, the response of conductor (which is long and very flexible) and the interaction between the supporting tower structures and conductors. Of particular interest is the response of the transmission lines and towers to more unusual wind loadings such as thunderstorm downbursts and tornadic wind squalls. Loading conditions associated with these extreme wind conditions and the response of the structures need to be examined closely for these are the circumstances causing most collapses of transmission line towers. Results from full scale measurements will enhance the understanding of these complex loading conditions and structural interactions and provide guidance for analytical/numerical analysis of transmission line tower under wind loadings.

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2. The methods developed by other researchers

A great deal of research in this area have been carried out in Japan and United States. These full-scale field measurements include measurements of dynamic/static structural properties of transmission line structures [3], response of transmission line conductors[1] and wind loads [1,3]. The results from these measurements have provided a better understanding of behaviours of the transmission line system peculiar to these nations/companies. Nevertheless, there are still some important problems left unsolved, for example, loadings and response of the structures under unusual wind conditions, the deflection/ displacement of the structures under wind load. These problems are essential to the design and reliability of the structures. In comparison, very little research on full-scale field measurements of electricity transmission line system have been conducted in Australia.

3. Objectives

The objectives of the proposed full-scale field measurements programme are: (1) Characterise the dynamic/static properties of transmission line structures under wind loadings, especially extreme wind conditions; (2) Provide data for improving/verifying dynamic finite element techniques used for transmission line structure modelling; (3) Devise a method to measure the displacement/deflection of the structure. Several measurement methods are considered for full-scale measurement of the response of tower structures under wind loadings. They will be discussed in the following section.

A PLAN FOR FULL-SCALE MEASUREMENT

The proposed full-scale field measurement programme consists of both intensive and extensive measurements schemes. The main advantage of an intensive measurement is that one can obtain a great deal of information with good accuracy. However, it tends to be expensive, time consuming and the data is "localised". An extensive measurement scheme, on the other hand, is a good complement of intensive measurement scheme. Although the extensive measurement scheme can not provide results as many and as accurate as those from the intensive measurements scheme, it can cover large areas which greatly increases the chance to capture some vital results such as those from thunderstorm downbursts or tornadic wind squalls. In order to cope with the two different proposed measurement scheme, special devices are to be developed for the measurement of accelerations and deflections of structures under wind loads.

1. Intensive measurement 1 -- dummy structures

The dummy structures (non-transmitting grid) are ideal for testing dynamic properties of the structures (including nature frequency of vibration, damping ratio and deflection mode shape etc), and measuring loads and structure response under ordinary wind condition and are particularly suitable for determining influence of conductors on the towers. Conventional instrumentations such as anemometers, accelerometers, load cells and swing angle indicators can be used in the measurements. References[1,3] provide detail of full-scale measurements of dummy structures of electricity transmission line tower. However, due to the difficulty of deflection measurement of the supporting tower structures, no results are available for deflection/displacement of tower structures under wind loadings. In this paper, two methods are proposed for the measurement of tower deflections .

Method 1 (Fig. 1) is based on principle of the Doppler effect. A device emitting signal is installed on the position to be measured on the tower. Three signal receivers are fitted on ground to form a triangle. The three receiver will receive the different signals when tower deflected by wind loading. By comparing with previous calibrations, the deflections of the tower structure can be determined. Method 2 is to use accelerometers to measure deflections which was developed by Glanville and Kwok [6] and was successfully used for the deflection measurement of a porous tower. Whether these two methods is suitable for the deflection measurement of transmission line tower will be determined through laboratory prototype tests and field tests.

2. Intensive measurement 2 -- energised line structures

In the situation where there is no non-transmitting grid available, the measurements may have to be conducted on existing energised line structures which have been proven to be extremely difficult. Not only is it difficult to access a dangerous environment for the installation of instruments (especially delicate instruments), but also many electronic instruments malfunction and analog/digital data become corrupted in strong electromagnetic field. In this case, a design to shield electronic instrument and data from such an electromagnetic field, such as the system designed by Bank [7], is required. However, the high cost and the safety aspect of such an experimental approach is a major obstacle for any this type of project.

3. Extensive measurements

For the extensive measurement scheme, since only extreme events are of interest, all the measurements are for the maximum value only. The devices to be developed for the measurements are purely mechanical devices which are unaffected by the interference from the strong electromagnetic field of energised electrical lines. The cost of these devices are expected to be low so that it may be possible to install a large numbers of devices to a large part of an electricity transmission network. In order to obtain more completed information, it is desirable to include at least measurements of maximum wind speed, maximum acceleration and maximum deflection.

The measurement of the maximum wind speed is to be based on a wind speed and direction recording device which has been successfully used in a wind climate study by Walker and Marshall[4] and Holmes et al [5]. Modifications are to be made for environmental protection and possibly for recording wind duration.

The device to be developed for recording maximum acceleration is based on a pendulum with a scratch tip and a scratch plate. In order to eliminate angular rotations of the structures from the results, a gyroscopic type device is used to home the acceleration device (Fig.2b). From the records on the scratch plate, the maximum horizontal accelerations can be determined.

A strip-shape device is to be developed for the measurement of the maximum deflections of the structures. (see Fig. 3) With two high stiffness base plates fixed on a position/member to be measured, a high stiffness bar/strip is secured by a calibrated pin. When the deformation of the member fitted with such a device exceeds the calibrated breaking strength of the securing pin, the pin will break and the strip falls down. By using a set of colour coated strips (for example three strips) secured by pins of different calibrated breaking strength, dislogement of different colour strips indicates the different exceedance of different displacements. Displacement/deflection of the tower structure can be easily surveyed with a binocular. This method is particularly valuable when one considers the difficulties of access to the structures and the safety aspect of close inspections.

For three proposed methods, the devices are active as soon as they are installed. Replacement and results collections are only needed when an area has encountered extreme winds. It only requires minimum manpower for maintenance and observation. Since the paths of thunderstorm downbursts and tornadic wind squalls are unpredictable and the swathe paths can be no more than 500m in width, using these types of simple and low cost devices may be the only possible means to capture the unusual wind load events. The disadvantage of this type of methods is inferior accuracy and its lack of time information. All the proposed devices are in the early design stage and prototypes are to be tested in the next stage.

CONCLUSIONS

1. Accurate, expensive and sophisticated methods are required for full-scale field measurement of electricity transmission line structures in order to provide detailed time history of wind loads and the response of the structures.
2. Measurement on the energised transmission line structures are extremely difficult and costly.
3. Development of a simple device for the measurement of displacement/deflection of the tower structures is possible but the design requires refinement and testing.

4. Development of purely mechanical devices creates an opportunity to measure the tower structure response under extreme wind loads.

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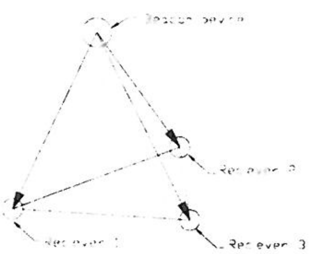


Fig 1. A illustration of deflection/displacement measurement of a supporting tower structure using idea of beacon device

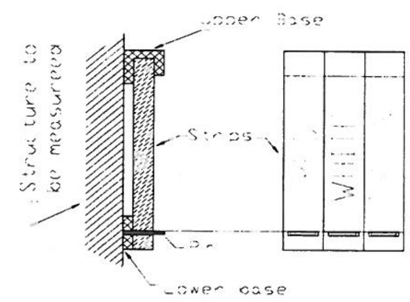
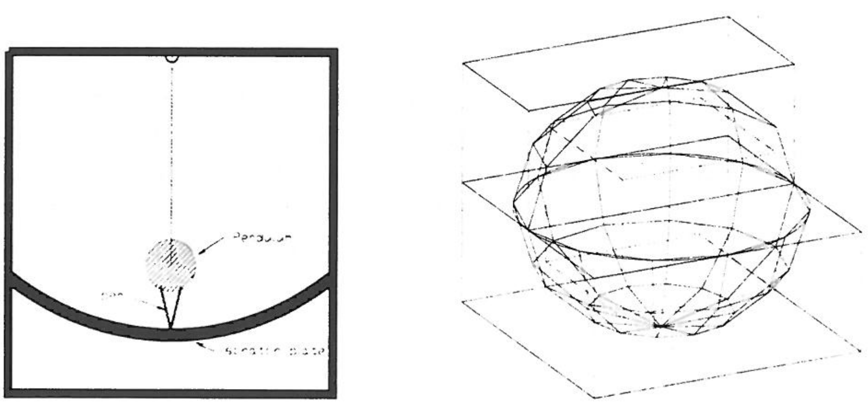


Fig 3. A schematic diagram showing a device developed for measurement of maximum deflection



(a) (b)

Fig 2. A schematic diagram showing a device developed for measurement of maximum acceleration