Development of Wind Resistant Reliability Design Methods for Overhead Transmission Towers considering Wind Direction Effects

Background

In the design of overhead transmission towers in Japan, the allowable stress design method is used. On the other hand, IEC60826 which provides International Standard in the electrical engineering field requests the reliability design based on the probability and statistical theory. Therefore, there is a possibility that correspondence to the reliability design is requested in our design practice in the future. In electric power companies in Japan, "Recommendations for Wind Loads on Transmission Towers (2005)", which introduced the latest study results such as directional design wind speed and equivalent static wind loads etc., was published in 2006. However, since this recommendation provides only estimation method for wind loads, it was necessary to develop practical design equations that were able to consider the wind direction effects to achieve the wind resistant reliability design.

Objectives

The purpose of this study is to develop design equations based on the reliability theory which enables a rational design considering wind direction effect at tower construction point.

Principal Results

1. Basic concept of wind resistant reliability design considering wind direction effects

The author showed two kinds of tower design procedures; the procedure based on a uniform designed wind speed that considered the influence of the wind direction on average (i.e. direction-independent design wind speed based design method), and the procedure based on the directional designed wind speed (i.e. direction-dependent design wind speed based design method). Moreover, the author also proposed the estimation method for a return period of design wind speed and a modeling uncertainty wind direction effect for the presented two design methods.

2. Wind resistant reliability analysis and estimation of return period of design wind speed

Non-exceedance probabilities of annual maximum load effect and reliability indices were calculated using the developed reliability analysis code for various kinds of overhead transmission lines in several areas (case number: 19712). Using the calculation results, equivalent return periods and modeling uncertainties were estimated for two design methods. As a result, the return period was estimated as 14.6 years for direction-independent design wind speed and as 88.3 years for direction-dependent design wind speed, respectively. The design response values evaluated using these wind speeds with the equivalent return periods indicate the values on average for the return period of 50 years. In addition, the distribution of modeling uncertainties was approximated by the Gumbel distribution (coefficient of variation 0.184) for direction-independent design wind speed and lognormal distribution (coefficient of variation 0.046) for direction-dependent design wind speed, respectively.

3. Development of design equations

The code calibration result based on a current allowable stress design method indicated reliability index 1.5. The author assumed 1.5, 2, and 3 as the target reliability indices, and proposed the load-resistant factor design equations to two kinds of design methods referring to the code calibration result.

4. Applications example of design equations

The design wind speeds and required strengths of members were provisionally calculated by presented two design methods for 275kV and tension type tower. Both required strengths of members by the two proposed methods became small compared with that of the allowable stress design method. As a result, the rationality of the consideration of the wind direction effects was confirmed. In conclusion, the author established a practicable and reasonable reliability design method for an overhead transmission tower.

Future Developments

The design equations considering the combination of wind and snow load will be further developed for the establishment of the overall reliability design method.

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Reference

T. Ishikawa, 2008, "Wind Resistant Reliability Design Method for Overhead Transmission Tower – Part 1 Development of Reliability Analysis Code and Estimation of Design Wind Speed considering Wind Direction Effect", CRIEPI Report N07032 (in Japanese)
T. Ishikawa, 2009, "Wind Resistant Reliability Design Method for Overhead Transmission Tower – Part 2 Development of Design Equations in LRFD Format considering Wind Direction Effect", CRIEPI Report N08060 (in Japanese)

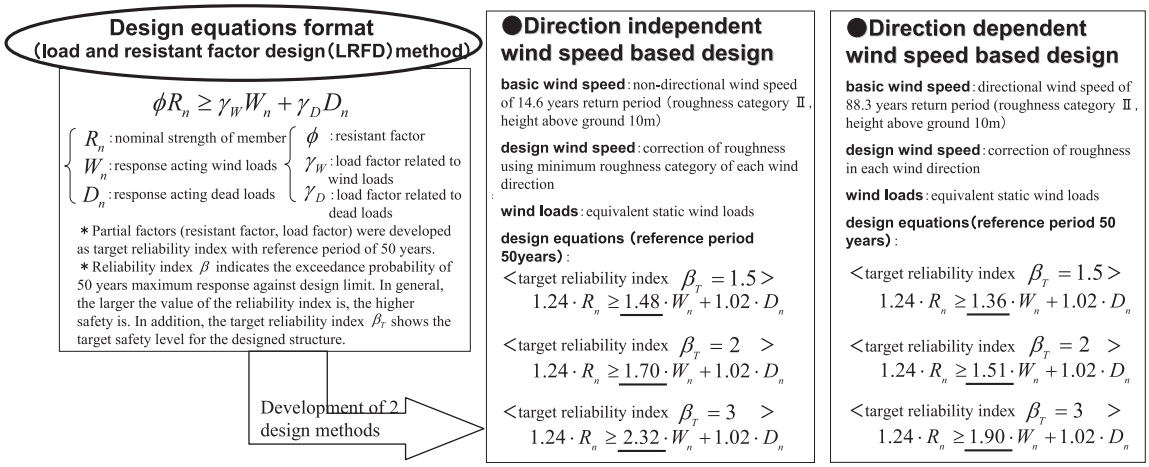


Fig.1 Development of reliability design method based on load and resistant factor design format

The author developed two kinds of design equations based on load and resistant factor design format, which is used as the reliability design method in general. Using direction-independent wind speed based design, it is possible to design with three time response calculations by same procedure as a current design. On the other hand, using direction-dependent design wind speed based design, we can estimate design values reflecting the actual condition of wind response at a construction point though the design work becomes complex because it is necessary to calculate the response value of each wind direction.

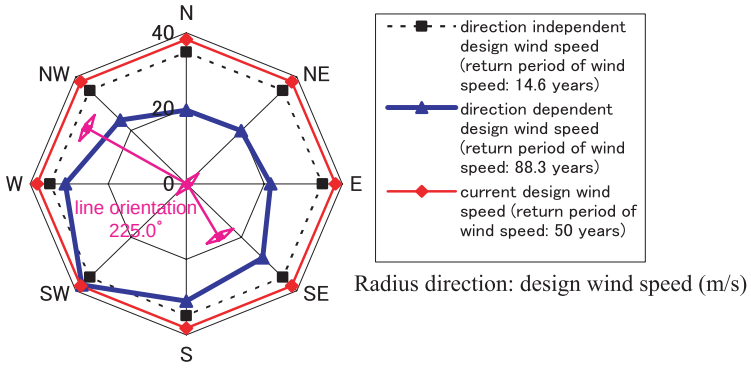
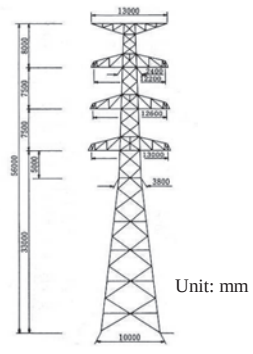
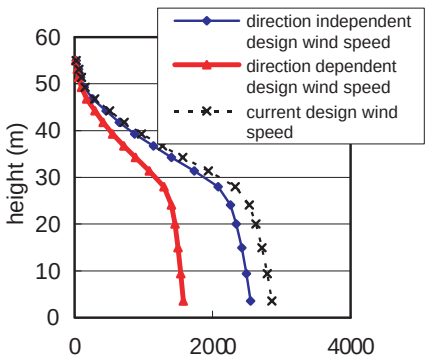


Fig.2 Estimation results of design wind speed by proposed methods

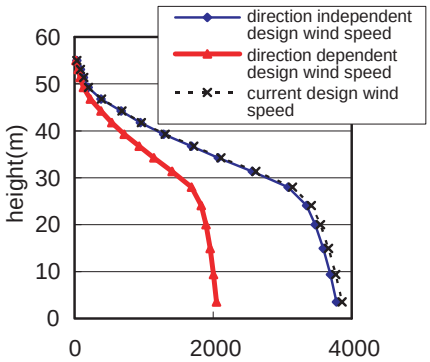
Fig.2 shows the design wind speeds at an imaginary construction point (Chiba meteorological observatory) using proposed methods and current method by which wind direction effects are not considered The response value (axis force of each member) estimated using the designed wind speed is indicated to be value corresponding to return period of 50 years concerning the load effect. The proposed methods can estimate the response value corresponding to return period concerning the load effect using the design wind speeds that are smaller than current designed wind speed.



Outline of example tower (275kV tension type tower, Height: 56m, load span: 400m, line orientation: see Fig.2)



required strength of menber(kN)
＜Target reliability index 1.5＞



required strength of member(kN)
＜Target reliability index 3＞

Fig.3 Application example of proposed methods

Both required element strengths by the two proposed methods became small compared with that of the current design method (allowable stress design method), and the rationality of the consideration of the wind direction effects was confirmed. In addition, the direction-independent wind speed based design can estimate the required member strengths according to line orientation. On the other hand, using the direction-dependent design wind speed based design which doesn't depend on line orientation, the required member strength becomes constant regardless of the line orientation.