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Numerical Analysis of Transmission Towers-lines Construction on Wind Forces

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Abstract: The numerical simulation of transmission tower-line under wind is important owing to the increasing number of wind-induced accidents recently. In this study, the wind loads, based on the harmonic superposition method and Kaimal wind spectrum, was constructed by MATLAB software according to Shinozuka theory. The three-dimensional (3D) finite element model for transmission tower-line was established. In the present study, the dynamic behavior and the mechanism of a typical transmission tower-line under wind is followed with great interest. The numerical simulation results showed that the displacement spectrum in the low frequency (0.1-0.5 Hz) was excited and the response of structure is remarkable, meanwhile the range of frequency is similar to that of wind spectrum. The displacement spectrum in 3Hz was excited, due to the main frequency of structure. The proposed method can be successfully performed and utilized on more structures.

Key words: Wind spectrum, transmission towers-lines, numerical analysis, finite element method, dynamic characteristics

INTRODUCTION

Transmission towers-lines construction is important in the daily life. It is not only that the investment is huge but the secondary disasters are significantly serious after the accident happens and we should pay more attention to this circumstance. The past failure was analyzed and found out that about 60% of the accidents are caused by the structures under wind overload. There are a lot of accidents under extreme wind effects in recent years around the world. In 2009, the storm in Brazil cause many transmission towers collapsed to make the traffic in serious paralysis. Torrential wind makes the region appear transmission towers collapse accident in Hangzhou, China, causing widespread blackouts in this region. The accident in Dongguan is due to the storm in 2010. Therefore, constructions play a crucial role in people's daily life.

At present, many scholars study dynamic characteristics of towers-lines under wind. The general pseudo-static method is used to establish the wind load in the traditional modeling theory (Loredo-Souza *et al*., 2003; Shu *et al*., 2012; Taillon *et al*., 2012). It has been a large number of studies along the traditional modeling method of power spectrum. However, it exist a series of limitations in the above method:

- The current majority model on wind load is established based on correlation function with the 2-dimension or 3-dimensions. However, the model will not reflect the actual detail characteristic and variation tendency of wind, because the dimensions of the actual wind may be higher than 3-dimension
- The ergodic principle is introduced to implement spectrum analysis method (Savory *et al*., 2001). However, it does not reflect the characteristics of real dynamic process. Wind condition is not single (such as downburst, storm)

Based on above analysis, we hold that it overcomes the above limitations through developing finite elements model with using commercial software ANSYS in this paper to implement wind spectrum loading the structure.

THEORY OF WIND SPECTRUM LOADING TRANSMISSION TOWERS-LINES

The structural dynamic equation subjected to the external load is usually expressed in matrix form as:

$$M\ddot{x} + C\dot{x} + kx = F(t) \quad (1)$$

Where:

$$x(t_0) = x_0, \dot{x}(t_0) = \dot{x}_0 \quad (2)$$

In this equation, the mass, damping and stiffness matrices are denoted by M, C and K respectively. Displacement, velocity, acceleration vector are denoted

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by $x, \dot{x}, \ddot{x}$, respectively. The external load F(t) is mainly wind load in this paper (Glanville *et al*., 1995; Yasui *et al*., 1999; Kaminski *et al*., 2013).

The energy characteristic of wind field is described by the power spectrum density function. Because the transmission towers are usually high and slender, Kaimal spectrum was adopted in this article:

$$\frac{nS(f)}{u_*^2} = \frac{200f}{(1+50f)^{5/3}} \tag{3}$$

where, S(f)-power spectrum density, f-similar coordinate and $f = nz/\bar{U}(z)$, z-the height above the ground, n-wind frequency (Hz), $\bar{U}(z)$-average wind velocity, u_*-related with ground roughness.

The harmony superposition method is adopted in this paper which can model random fluctuating wind loads time-histories of transmission towers-lines structure. Here is the simulation method fluctuating wind velocity. Suppose to simulate wind velocity time-histories on m point and get m variable on stationary Gaussian random process u^0_i = (i = 0, 1, 2..., m) on zero mean and the spectrum density matrix is:

$$S^0(\omega) = \begin{pmatrix} S^0_{11}(\omega) & S^0_{12}(\omega)\cdots & S^0_{1m}(\omega) \\ S^0_{21}(\omega) & S^0_{22}(\omega)\cdots & S^0_{2m}(\omega) \\ \cdots & \cdots & \cdots \\ S^0_{m1}(\omega) & S^0_{m2}(\omega)\cdots & S^0_{mm}(\omega) \end{pmatrix} \tag{4}$$

where, $S^0_{ii}(\omega)$ is the autocorrelation spectrum density function which is real form.$S^0_{ii}(\omega)$ ($i \neq j$) is the cross spectrum density function which can be expressed as:

$$S^0_{ij}(\omega) = \sqrt{S^0_{ii}(\omega) S^0_{jj}(\omega)} \mathrm{Coh}_{ij}(\omega) \tag{5}$$

After get the spectrum density matrix $S^0_{ii}(\omega)$, random wind velocity time-histories are generated on the harmony superposition method through the following steps:

Cholesky decomposition of $S^0_{ii}(\omega)$, we can obtain:

$$S^0(\omega) = H(\omega)H^{*T} \tag{6}$$

where, $H(\omega)$ is lower triangular matrix, $H^T(\omega)$ is $H(\omega)$ transposed matrix of complex conjugate.

To solve the random phase on related characteristics, according to character of the autocorrelation function on the diagonal elements, $H_{ii}(\omega) = H_{ii}(-\omega)$ for non-diagonal elements.

Different points between the related characteristics of random phase can be expressed as:

$$\theta_{ij}(\omega) = \tan^{-1}\left\{\frac{\mathrm{Im}[H_{il}(\omega)]}{\mathrm{Re}[H_{il}(\omega)]}\right\} \tag{7}$$

where, $\mathrm{Im}[H_{il}(\omega)]$ and $\mathrm{Re}[H_{il}(\omega)]$ are imaginary part and real part of $H_{ij}(\omega)$.

According to Shinozuka theory, wind velocity time-histories of the simulation points can be simulated through the following equation:

$$u_i(t) = \sum_{j=1}^{i}\sum_{k=1}^{N} \left|H_{ij}(\omega_k)\right| \sqrt{2\Delta\omega} \times \cos\left[\omega_k t - \theta_{ij}(\omega_k) + \varphi_{jk}\right] \tag{8}$$

where, N-frequency sampling points, $\Delta\omega$-Frequency sampling interval, φ_{jk}-independent phase angle of uniform distribution with the range of 0~2π.

The wind velocity time-histories data is obtained by above methods and need to obtain the wind loads through relevant analysis of wind velocity and loads. Wind loads contain two parts loading in the transmission towers-lines, one act on the towers and other act on the wires (Albermani *et al*., 1993; Hu *et al*., 2001; Napolitano *et al*., 2013).

Wind loads which impose on the towers are expressed as:

$$F_1(t) = \mu_S A U(t)^2/1.6 \tag{9}$$

where, μ_S-structure shape coefficient, A-The simulation area for transmission towers, U(t)-wind velocity.

Wind loads which impose on the wires are expressed as the following equation:

$$F_2(t) = \mu_S d l U(t)^2 \sin^2\theta/1.6 \tag{10}$$

where, μ_S-line shape coefficient, d-diameter of lines, θ-line length, U(t)-wind velocity, θ-the angle between wind and line.

SIMULATION PROCEDURE

Pre-process: Finite element numerical model is established through defining element types, material properties, boundary conditions, geometric model based on the structural dynamic model and meshing of the entire model.

Post process:

- Modal analysis-Finite element numerical model is solved through selecting method of mode and read modal results

- Time-history analysis-Wind loads time-history is simulated by using the harmony superposition method and the wind spectrum parameter including average wind velocity, ground roughness, height above the ground and Kaman constant. It establishes a reasonable wind loads library through simulated wind loads to assist load input of numerical model. Finally, output time history results under wind loads
- Spectrum analysis-Above time-history results import MATLAB and PWELCH method is utilized to obtain spectrum analysis results with window function library. Window function library is established through several window functions built up by the spectrum analysis order of MATLAB

NUMERICAL EXAMPLE

Analysis model of transmission towers-lines structure are built up in this study. In the model, there are 22560 BEAM188 elements, 6400 LINK10 elements and 24 MPC184 elements.

BEAM188 element is adopted to simulate the bar which can accurately simulate the stress and strain status of bar. BEAM188 can customize the interface shape with 6 degrees of freedom, including three translational freedom degrees UX, UY, UZ and three rotational freedom degrees ROTX, ROTY, ROTZ.

LINK10 element is used to simulate the ground wire and wire which bear the axial tensile stress. LINK10 has three translational freedom degrees UX, UY, UZ and can simulate geometry nonlinear large deformation, such as simulating loose chain or cable structure. So the properties of LINK10 can accurately reflect the actual status of the transmission ground wire and wire.

MPC184 element is utilized for simulation of insulator. MPC184 element has the function of the rigid connecting rod and ensures its rigidity is much larger than the wire element, so MPC184 can well reflect the insulator's actual condition.

It all constrains the translational and rotational freedom degrees of the junction with transmission towers bottom legs and basic and translational freedom degrees of (ground) wire initial and terminal points. The finite element model is shown in Fig. 1. The coordinate direction as shown in Fig. 1, the vertical wire is X direction, along wire direction is Z direction and height direction of the transmission tower is Y direction.

The simulation method in this paper does not require large sum of data concerning wind velocity time history. Rather, it employs only calculating parameters of transmission towers-lines and wind load in Table 1.

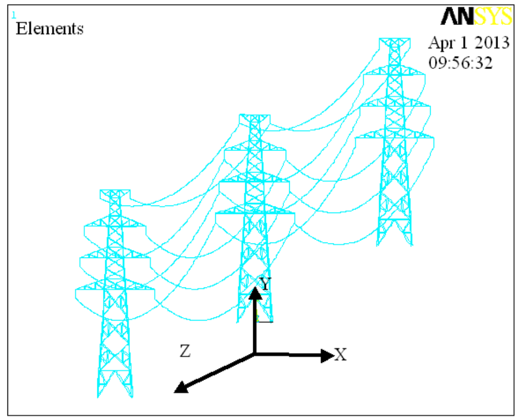

Fig. 1: Finite element model of transmission towers-lines

Table 1: Calculating arameters

	Parameters	Parameters values
Towers	Height (m)	H = 24
	Span (m)	L = 400
Wire	Type	LGJ-240/40
	Diameter (mm)	0.08778
	Weight (N/m)	3.988
	Elasticity modulus (N/mm^2)	76000
Ground wire	Type	JL/LB1A-95/55
	Diameter (m)	0.016
	Weight (N/m)	3.300
	Elasticity modulus (N/mm^2)	91100
Simulation of Wind load	Kaman constant	0.4
	Ground roughness	0.03
	Height above the ground (m)	40
	Average wind velocity of 10 m (m sec^{-1})	30

RESULTS AND DISCUSSIONS

The vibration modes of towers-lines are illustrated in Fig. 2 and it can be observed that the vibration amplitude of towers-lines structure are increasing large and the vibration direction of the structure are different with the increase of structural modes.

The displacement time-history of the transmission tower under the wind loads along the wind direction is shown in Fig. 3 which varies with time. It can be observed that the displacement maximum of the tower is 23 mm which meets requirement of technical regulations DL/T5154-2002 in China.

The wind-velocity spectrum and the displacement response spectrum are illustrated in Fig. 4. It can be observed that wind velocity spectrum and response spectrum are consistent and the difference of them is that frequency with peak value of spectrum is 0.3 and 3Hz, respectively. Because after wind spectrum

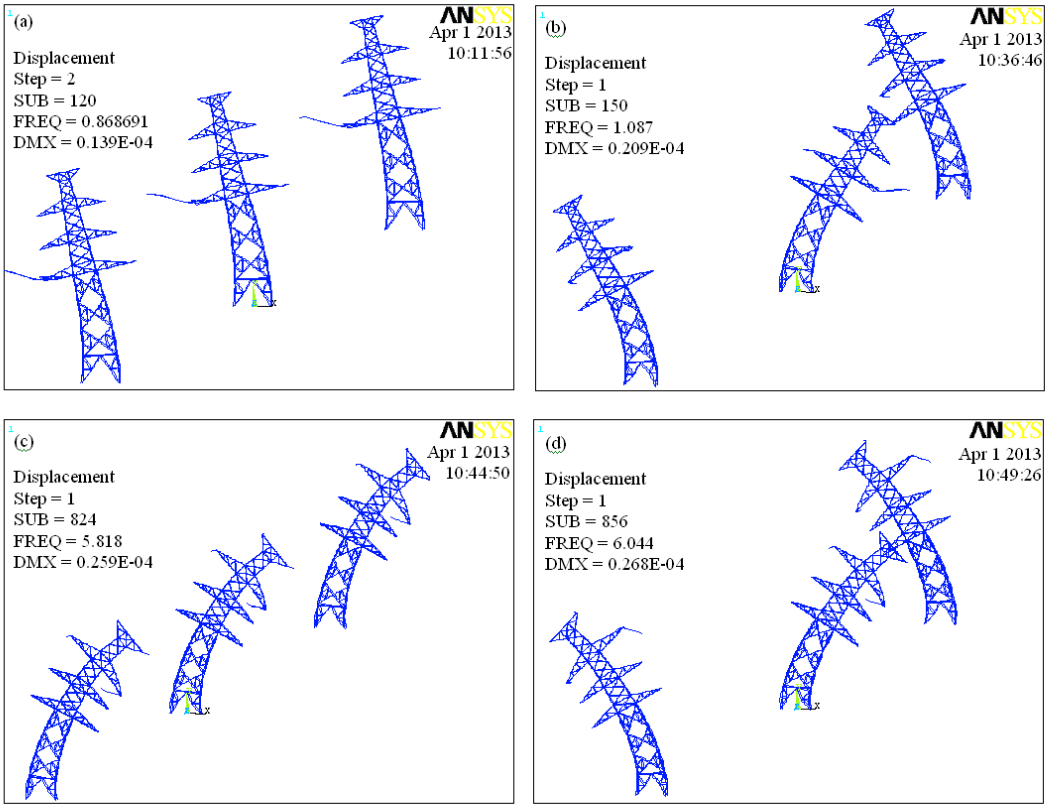

Fig. 2(a-c): Modes of transmission tower-lines, (a) Mode 1, (b) Mode 2, (c) Mode 3 and (d) Mode 4

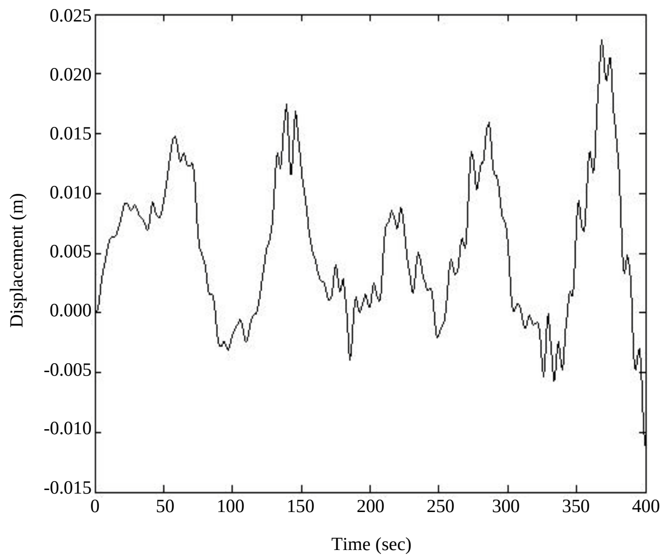

Fig. 3: Displacement time-history of the transmission tower under the wind loads along the wind direction

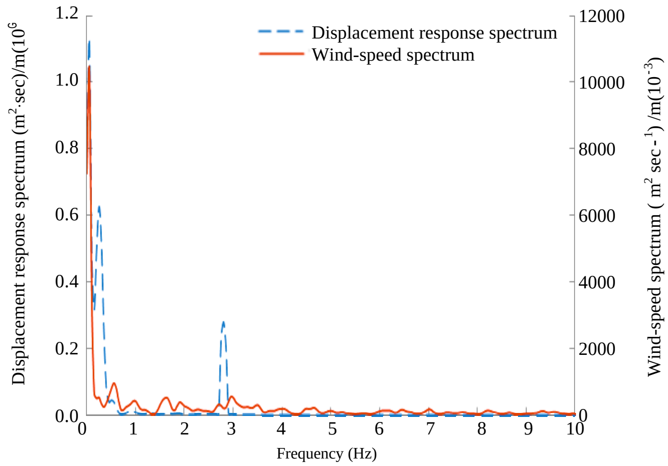

Fig. 4: Wind-velocity spectrum and the displacement response spectrum

load the structure, response spectrum obtained exist wind velocity spectrum and energy distribution of the structure.

CONCLUSION

Wind velocity is mainly utilized in the traditional FE method imposing on the structure to obtain the result of modal analysis, time-history analysis. A framework of finite element-based computational mechanisms is developed in this study for successfully implementing wind spectrum load the transmission towers-lines structure and on the basis of original modal analysis and time-history analysis, spectrum analysis framework is established to obtain structural response spectrum.

It is worth for us extending this method to study wind spectrum imposing on more structures in the future.

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