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# Wind-induced response analysis of transmission tower-line system considering joint effect

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## ABSTRACT

Wind load is one of the main control loads of transmission tower-line system. To accurately analyze the wind-induced response of transmission tower-line system, the hysteretic curves of the typical joints of the transmission tower are obtained by numerical simulation. On this basis, the finite element model of the transmission tower-line system considering the bolt slip of joints is established by ANSYS software. The wind load is generated by harmonic wave superimposing method, and the dynamic response of tower-line system with ideal frame model and model considering joint effect under wind load is studied, and the effect of wind speed on the wind-induced response of the tower-line system is discussed. The results show that the ideal frame model significantly underestimates the wind-induced response of transmission towers, and the greater the wind speed is, the more serious the underestimation is. Compared with ideal frame model, the displacement at the top of the tower considering joint effect increases. Therefore, the joint effect cannot be ignored in wind-induced analysis.

**Keywords**: transmission tower-line system; wind load; joint effect; wind-induced response

## 1. INTRODUCTION

Wind load is the main control load of transmission tower-line system (Zhu et al. 2019). Therefore, in order to minimize the influence of wind load, many scholars have conducted in-depth studies on wind load and wind-induced response of tower-line system. With the development of computer technology, numerical simulation has gradually become the main means to study the dynamic response of structures under wind load (Liu et al. 2019). Zhang et al. (2013) simulated wind-induced progressive collapse of transmission tower-line system using ABAQUS/Explicit. Fu et al. (2019, 2020) studied the vulnerability of transmission tower-line system under wind and rain loads by establishing a numerical model of uncertainty, and proposed the concept of critical collapse surface.

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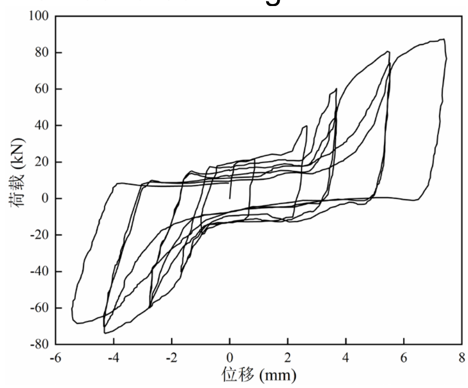
In fact, strong winds can cause the vibration of transmission tower, the joint will be subjected to cyclic loading, the stress state (size and direction) will change, in a semi-rigid connection state (Li et al. 2021). However, the commonly used numerical models ignore the influence of joints and simplify the joints to hinge or rigid connection, which leads to a certain difference between the calculation results and the experimental results (Wang et al. 2018).

A review of the abovementioned papers indicates that the influence of joint behavior on the wind-induced response of transmission tower-line system is still not considered. In this paper, the model of transmission tower-line system considering joint effect is established, and the influence of joint effect on dynamic response of transmission tower-line system under wind load is studied. In Sec. 2, the establishment of transmission tower-line system considering joint effect is introduced. In Sec. 3, wind load simulation is performed. Then, the influence of joint effect on the structure is studied, and the influence of wind speed is discussed in Sec. 4. Finally, Sec. 5 concludes the study.

## 2. TRANSMISSION TOWER-LINE SYSTEM

A 500 kV transmission line with 1 tower and 2 span lines is selected as the research object. The total height of the transmission tower is 99.9 m, and the base size is 18 × 18 m. The span of transmission line is 300m. LGJ630/45 4-bundled conductors and JLB20A-150 ground wire are adopted. The ideal frame model of transmission tower is established by ANSYS, and all members are simulated by BEAM189 element. Based on the ideal frame model of transmission tower, the joint effect is introduced by adding zero-length nonlinear spring element COMBIN39 to the member connection part. Firstly, the low cyclic loading tests and numerical simulation of the bolted joint are carried out to obtain the hysteresis curve of the bolted joint. Then the skeleton curve of the joint is extracted and the axial stiffness of the spring element is set by the real constant. The test device and the hysteresis curve are shown in Fig. 1. The conductor is simulated by LINK10 element, and LINK8 element is used to simulate the ground wire. The finite element model of transmission tower-line system is illustrated in Fig. 2.

(a) test device




(b) hysteresis curve

Fig. 1 Low cyclic loading tests

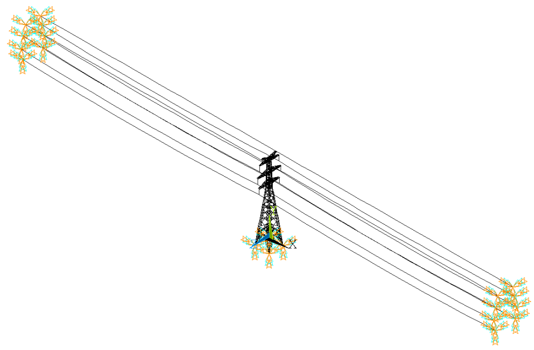


Fig. 2 Transmission tower-line system model

### 3. SIMULATION OF WIND LOAD

According to Chinese code (National Energy Administration 2012), the harmonic superimposing method is used to simulate the time history curve of fluctuating wind speed. Fluctuating wind speeds are generated using the following parameters: (1) the basic wind speed is 20 m/s; (2) terrain roughness coefficient α is 0.16 (CECS 2012); (3) the Davenport spectrum is adopted for wind speed power spectrum; (4) the total time is 100 s, with a time interval of 0.1 s; (5) the cutoff frequency is 5 Hz. In this paper, the transmission tower is divided into 14 parts from bottom to top, as shown in Fig. 3.

Fig. 4 shows the simulated fluctuating wind speed at two simplified points of transmission tower. As shown in Fig. 5, the overall trend of wind speed power spectrum at the simulation point is consistent with that of the target spectrum, indicating that the simulation method and the parameters are reasonable and effective.

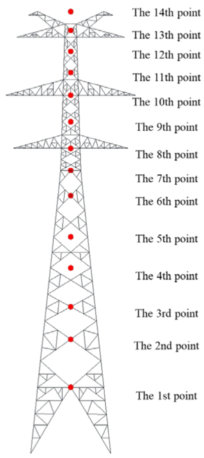



Fig. 3 Simulation point for simulated wind speeds

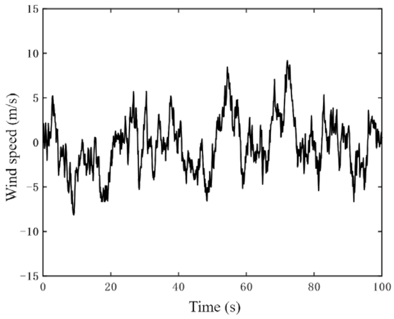



Fig. 4 Wind speed curve of point 6

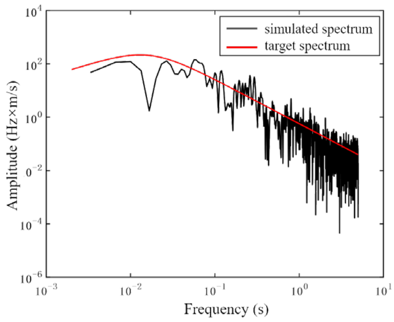



Fig. 5 Point 6 power spectrum comparison

The variation of mean wind speed along height can be described by the following power-law wind speed profile:

$$v_z = v_{10}(\frac{z}{10})^{\alpha} \quad (1)$$

where $v_z$ = mean wind speed at an altitude of $z$ m; $v_{10}$ = basic wind speed representing mean wind speed over a period of 10 min at an altitude of 10 m; $z$ = altitude; and $\alpha$ = terrain roughness coefficient.

The total wind speed of each simulation point can be obtained by superposition of fluctuating wind speed and mean wind speed, and then the total wind speed is converted to the wind load of transmission tower-line system by Eq. (2).

$$F_i(t) = \mu_s A_i V_i(t) / 1.63 \quad (2)$$

where $F_i$(t) = wind load; $\mu_s$ = shape coefficient of structure, according to the Chinese code (CECS 2012); $A_i$ = windward area; and $V_i$(t) = total wind speed.

## 4. WIND-INDUCED RESPONSE ANALYSIS

Since the most unfavorable wind attack angle of the transmission line is 90°, the working condition of the wind direction perpendicular to the transmission line is considered. Simulations of four wind load scenarios are carried out, as listed in Table 1.

Applying the calculated wind load time-history curve to the transmission tower-line system for time-history analysis, the wind-induced response of the structure can be obtained, in which the tower top displacement and acceleration observation points is shown in Fig. 6.

Table 1 Scenarios of wind vibration analysis

| Case No. | Joint effect | Wind speed (m/s) | turbulence intensity (%) |
|---|---|---|---|
| Case 1 | without | 15 | 10 |
| Case 2 | without | 20 | 10 |
| Case 3 | with | 15 | 10 |
| Case 4 | with | 20 | 10 |

### 4.1 *Analysis of Joint Effect*

Fig. 7 illustrates the displacement time-history curve of the tower top observation point under wind load of ideal frame model and model considering joint effect. For ideal frame model, the peak displacement of tower top is 0.179 m, and the root mean square(RMS) $u_{RMS}$ is 0.106 m; and the peak displacement of tower top in model considering joint effect is 0.530 m, and the RMS $u_{RMS}$ is 0.431 m. Compared with ideal frame model, the top displacement of the tower considering joint effect is greatly increased, and the displacement is about three times that of ideal frame model. Therefore, it is necessary to consider joint slip when analyzing the dynamic response of tower-line system.

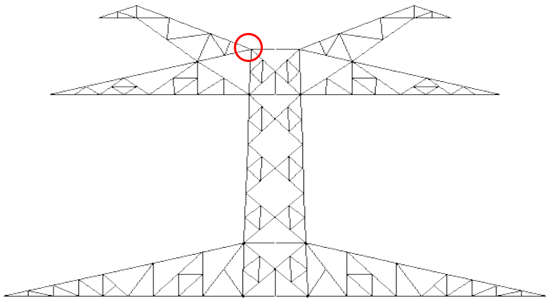


Fig. 6 Observation point diagram

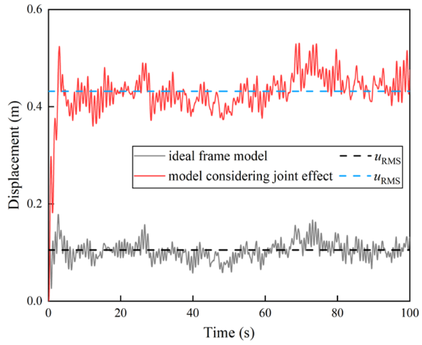
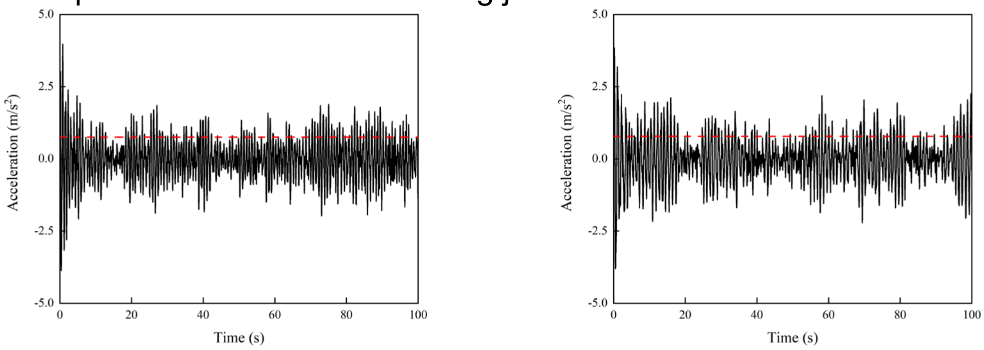



Fig. 7 Tower top displacement

Fig. 8 shows the acceleration time-history curves of the tower top observation point under wind load of ideal frame model and model considering joint effect. The peak acceleration of ideal frame model is 3.974 m/s$^2$. The peak acceleration of model considering joint effect is 3.841 m/s$^2$. Compared with ideal frame model, the acceleration of the tower top is reduced after considering joint effect.

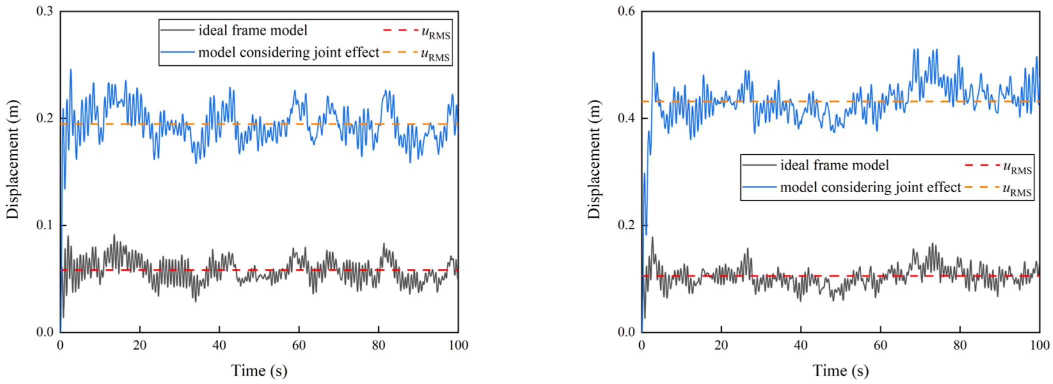



(a) ideal frame model (b) model considering joint effect

Fig. 8 Comparison of tower top acceleration

4.2 *Analysis of Wind Speed*

Fig. 9 shows the time-history curves of tower top displacement under different wind speeds. When the wind speed is 15 m/s, the peak displacement of the tower top of ideal frame model is 0.092 m, and the peak displacement of the tower top of model considering joint effect is 0.246 m. When the wind speed is 20 m/s, the peak displacement of the tower top of ideal frame model is 0.179 m, and the peak displacement of the tower top of model considering joint effect is 0.530 m. When the wind speed increases from 15 m/s to 20 m/s, the tower top displacement of model considering joint effect is 2.6 times and 2.9 times that of ideal frame model, respectively. This shows that the influence of joint effect on wind-induced response of tower-line system increases with the increase of wind speed.




(a) wind speed 15 m/s (b) wind speed 20 m/s

Fig. 9 Tower top displacement under different wind speeds

## 5. CONCLUSIONS

In this paper, the dynamic response of transmission tower-line system under wind load is studied by establishing a transmission tower-line system model considering joint slip. The effect of wind speed on the wind-induced response of tower-line system is discussed. The conclusions are summarized as follows:

(1) Ignoring joint slip effect will significantly underestimate the displacement response of transmission tower under wind load, and with the increase of wind speed, underestimation will become more serious.

(2) Compared with ideal frame model, the displacement response of model considering joint effect increases, but the acceleration at the tower top decreases.

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