RESEARCH ON CABLES COUPLED EFFECT OF COMBO STEEL TUBE TOWER-LINE SYSTEM FOR LARGE CROSSING TRANSMISSION LINES

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ABSTRACT :

A tower-line system of large crossing transmission lines is a complicated special tower line coupled vibration system, suffering both from static and dynamic loads. Vibration is the main cause of its failure. Because of its high-weakness character, and lines and isolators rings having strong geometrical non-linearity, it is very difficult to calculate accurately. At present, in order to simplify the calculation, lines and tower are analyzed separately in present design code ignoring coupled effect of tower and lines, to result analyzing errors. In order to calculate dynamic response of tower-line system considering the coupled effects, with ANSYS program of the finite element method，it was established a new spatial analytical—numericalmodelof220kVcombo steel tube tower for large crossing transmission lines crossing Tiezhuang canal of Pearl River．Firstly，the exactitude of finite element modal and theoretic calculation was proved by environmental vibration testing and modal identification． In addition，some specialties were acquired by analyzing dynamic characteristics and seismic response of the tower considered transmission lines and none-considered transmission lines． The effects of transmission lines applied to tower were studied an d further disclosed coupled regularity of transmission lines applied to tower． It is shown that suspended cables have mass effects，which is not ignored． Simultaneously，suspended cables have coupled stiffness effects applied to tower on cross direction and longitudinal direction． Furthermore，it is found that suspended cables can depress seismic response of transmission towers． Finally，it is pointed out that suspended cable’s effect of depress seismic response whether or not have universality need to be further studied and cognized． The above research and analysis have some reference values for seismic and wind resistance design of similar transmission tower．

KEYWORDS: transmission lines tower, dynamic characteristics, seismic response, environmental vibration testing, coupled effect

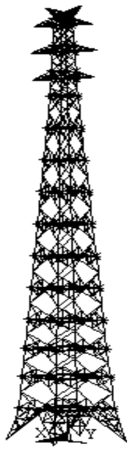
1. INTRODUCTION

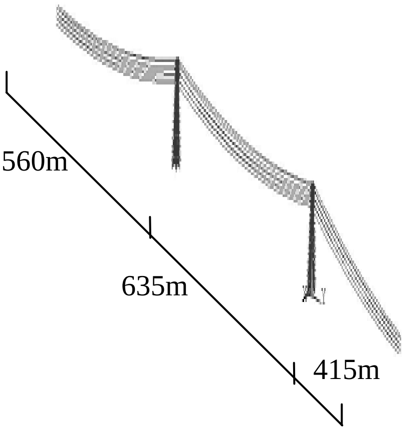
Long span transmission tower-line system is a complicated spatial tower-line coupled vibration system. Except for static loading, the transmission tower suffers dynamic loading also, and vibration is the main cause of its damage. Because the steel tower is high and soft, the transmission lines and the isolator strings behave greatly geometry non-linearity, so it is very difficult to calculate precisely. Currently, in order to calculate simply, according to relating regulation, the transmission system is separated into transmission lines and steel tower independently to analysis and to omit the coupling effect of transmission lines and the tower and so deviation is introduced.

In order to calculate precisely the dynamic response of transmission tower under dynamic loading coupled with the effect of transmission lines, it is necessary to analysis the coupling effect of transmission lines and isolator strings. A simple, precise and practical calculating model of transmission line and isolator strings system is needed, so as to greatly decrease the freedom of the system and its non-linearity effect. At home and aboard, there are some researches relating to the coupling effect of transmission line on the transmission tower line system (H.N. LI, etc.), which need to be improved. In this paper, after calculating of dynamic characters and seismic response of transmission tower with and without transmission lines, the coupling effect of transmission lines on transmission tower is analyzed.

2. ANALYZING MODEL OF TRANSMISSION TOWER LINE SYSTEM

Reference to M.G. Cao, etc.(2005), the system is a double circuit on the same tower. Transmission lines on the top of the tower is vertically ranged into 4 layers, in which the highest layer is ground lines, and the others are all 2 sets of double divisions lines. Each set of double division line and each ground line are modeled with single lines. According to shape seeking theory of the transmission line, pure tension linear bar is used for transmission line with initial strain. Its basic length is 20m. APDL language of ANSYS is used to create joints and elements. The finite-element model of the system is shown in Fig.1.





a Single tower (122*m*) *b system*

Figure 1 The finite element model of 220 SZK combo steel tube transmission lines towers

3. ANALYSIS OF DYNAMIC CHARACTERISTICS COUPLED WITH TRANSMISSION LINES

3.1. Dynamic Characteristics of Single Tower

With the finite-element model of the above combo steel tube transmission lines towers, static analysis is carried out under its self-weight, take the shape and stress of the final static loading as initial state to analysis its model. By sub-space alternating method, the initial 18 periods and relating modes are solved, as shown in Table 3.1.

Table 3.1 The frequencies and periods of SZK122

No.	X-direction		Y-direction	
	Frequencies/Hz	Periods/s	Frequencies/Hz	Periods/s
1	0.973	1.028	0.973	1.027
2	2.936	0.341	2.959	0.338
3	5.252	0.190	5.334	0.188
4	7.937	0.126	8.073	0.124
5	10.719	0.093	10.871	0.092

The first 5 periods and relating modes along x-direction and y-direction are shown in Figure 2. The vibration of transmission tower in x-direction (lateral to the line direction, that is side direction) or in y-direction (along the line direction, that is longitudinal direction) is generally symmetry with little effect of line arms and ground line arms. Each period of single tower scatters apart. There are 5 modes in x-direction and 5 modes in y-direction among the initial 18 modes.

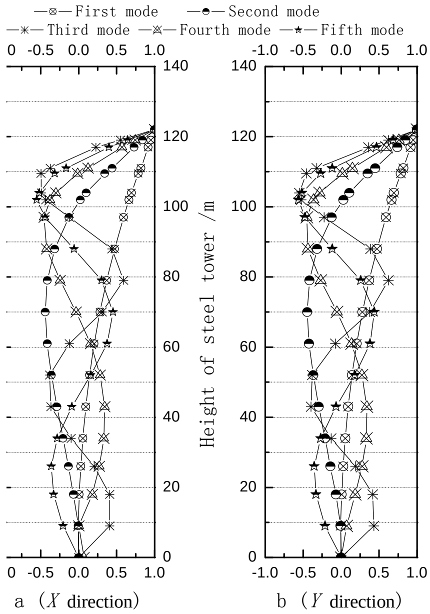
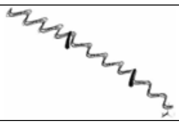
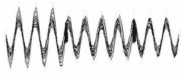
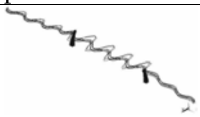
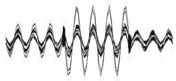
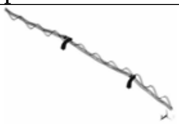
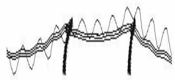
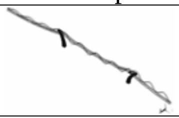


Figure 2 The initial 5 vibration modes of SZK122

3.2. Dynamic Characteristics of Tower Line System

With the above ANSYS finite-element model of the system, by non-linear static analysis, the final static balanced position, elastic stiffness matrix and initial stiffness matrix are found. Then by sub-space alternating method, the frequencies and modes of the tower line system are solved. Because the modes of tower line system are mainly those of transmission lines and they distribute closely so steel tower modes coupled with transmission lines are difficult to separate strictly. The initial 600 modes of the system are got, and after comparing some conclusions are drown. The typical modes mainly of lateral and longitudinal vibration of the steel tower coupled with transmission lines. The first mode along x-direction and y-direction of the transmission tower are shown in Table 3.2.

Table 3.2 Some typical vibration modes of SZK122 transmission tower-lines systems

No.	frequency (Hz) / period (s)	vibration (3-dimension)	vibration (in horizontal plan or vertical plan)
321	0.955		
	1.047	The line vibrates laterally and the tower vibrates laterally with the same phase.	
322	0.970		
	1.031	The line vibrates laterally and the tower vibrates laterally with the opposite phase.	
323	1.001		
	0.999	The line vibrates longitudinally and the tower vibrates longitudinally with the same phase.	
329	1.019		
	0.981	The line vibrates longitudinally and the tower vibrates longitudinally with the opposite phase.	

From the initial 600 modes, by comparing their periods, frequencies and modes, following conclusions can be drawn.

(1) Lateral vibration modes of the steel tower basically coupled with lateral vibration of transmission lines are commonly appeared and which approximate to the first vibration modes in x-direction of free vibration of single tower and the periods are longer than the first period of the single tower (1.028s). Mainly because the effects of the adding lateral stiffness of the transmission lines and suspending rods system are relatively small compare to the adding mass effects that is the adding lateral stiffness of the transmission lines are very small.

(2) Among the initial 600 vibration modes, only the 323rd mode of the system is a longitudinal mode of the steel tower coupled with transmission lines in the same phase and only the 329th modes of the system is a longitudinal mode of the steel tower coupled with transmission lines in the opposite phase. These two modes are closed to the first vibration mode in y-direction of single tower, with periods to 0.999s and 0.981s respectively, which are shorter than the first period in y-direction of single tower. We could find that by considering the mass of transmission lines and their longitudinal stiffness, the first longitudinal period of the steel tower shall be shorter mainly because the effects of the transmission lines and suspended rods system on the longitudinal stiffness of the steel tower are much greater than mass effects, that is the adding longitudinal stiffness of the transmission lines is much greater.

3.3. Environment Vibration Test and Mode Identification of the System

In order to verify the first mode of the tower model in lateral and longitudinal directions, site environment vibration test of a steel tower suspended with transmission lines under ground pulsing is carried out. We did three tests, one in x-direction, one in y-direction and one for torsion, each with two samples and the sample time is set to 600s with the sample frequency as 256Hz. So there are 6 data samples altogether. By using Pulse Analyzers signal collecting and analyzing system to suitable FFT transformation, several frequencies of the transmission tower coupled with transmission lines could be identified. By comparing the vibration parameters of tests to those of theory analyzing, it shows that the model of the finite-element-method has good accuracy.

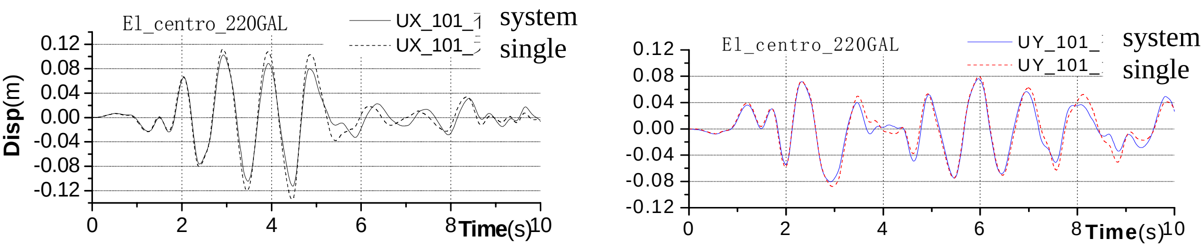
The first lateral vibration frequency of transmission tower coupled with transmission lines by test is 0.938Hz, which is lower than the first lateral frequency of the single tower, and is closed to the 322nd mode. There are many modes of lateral vibration of the transmission lines. After coupled with the transmission lines, the first lateral frequency of the transmission tower is lower than that of single tower and its period is prolonged.

The first longitudinal vibration frequency of transmission tower coupled with transmission lines by test is 1.000Hz, which is higher than the first longitudinal frequency of the single tower, and is closed to 323rd and 329th modes, which are the only two longitudinal vibration modes among the initial 600 modes. After coupled with the transmission lines, the first longitudinal frequency of the transmission tower is higher than that of single tower and its period is shortened.

4. SEISMIC RESPONSE ANALYSIS COUPLED WITH TRANSMISSION LINES

The Chinese current code for design of seismic of electrical installations regulates that when calculating dynamic characteristics of transmission tower, the weight of transmission lines and lightning lines can be omitted. But some researches indicate that, for far apart transmission tower, the mass of the transmission lines are very great comparing to the mass of steel tower, the seismic response of the steel tower shall be increased because of the transmission lines and so this effect can not be omitted.

By the above spatial finite-element model of transmission tower line system, static analysis under its self-weight is carried out at first, and take the final state of shape, position and its stress as the initial state of instantaneous analysis, then analysis under three kinds of ground motion (El-Centro wave, Taft wave and field artificial wave) at 7 degrees of seismic intensity to get its non-linear seismic responses. By comparing the seismic responses of the points at the top of the tower with and without transmission lines, we can get its differences affecting the transmission lines. Figure 3 shows x and y-directional displacement ratio of A4 tower at node 101 between single tower and systems. Table 4.1 shows the maximum displacement ratio of A4 tower at dominated node between single tower and systems.



a) X-direction b)Y-direction

Figure 3 X, Y-directional displacement ratio of A4 tower head's 101node between single tower and systems

From the analysis of combo steel tube tower with and without transmission lines under seismic excitation, we can get following conclusions.

Table 4.1 Maximum displacement ratio of A4 tower head's dominated node between single tower and systems

Node number	Ux			Uy			U		
	El	Taft	Field	El	Taft	Field	El	Taft	Field
101	0.84	0.94	0.94	0.92	0.92	0.84	0.92	0.94	0.91
501	0.83	0.95	0.94	0.92	0.93	0.88	0.92	0.94	0.91
505	0.84	0.95	0.94	0.93	0.93	0.88	0.92	0.93	0.92
601	0.84	0.94	0.95	0.92	0.93	0.86	0.92	0.93	0.93
605	0.84	0.95	0.93	0.92	0.94	0.86	0.92	0.94	0.91
701	0.84	0.94	0.94	0.92	0.94	0.87	0.93	0.94	0.92
705	0.83	0.95	0.91	0.92	0.94	0.87	0.92	0.95	0.91
Note: El refers to El-Centro wave, Taft refers to Taft wave and Field refers to field artificial wave.									

(1) The transmission lines have seismic reduction effect on the displacement response of head nodes of the transmission towers laterally and longitudinally. Displacement response of the system is decreases at 10% generally, and seldom to about 15% from that of single tower.

(2) Because of the transmission lines, supporting forces of the transmission tower are much greater than those of single tower with the increase of about 10%. Though the transmission lines can decrease the displacement response of the steel tower, because of the mass of the transmission lines could not be omitted, supporting forces and bar internal forces shall not be decreased, this should be noted in design.

(3) The transmission lines have some seismic reduction effect on the displacement response of transmission tower, but this effect is not very great. And this is fitting for the effect of transmission lines on the dynamic characteristics of transmission lines. The transmission lines have both mass effect and stiffness effect on the lateral and longitudinal vibration of the system. Its mass prolongs the periods of the steel tower but its adding stiffness decreases the periods of the steel tower, as a result, dynamic characteristics of the tower have not much changes, so the seismic responses change only a little.

5. CONCLUSIONS

From the above analysis we can get some regular effects of transmission lines on the transmission tower, which can give conference to seismic design and wind design of similar transmission tower.

(1) By comparing the dynamic parameters of transmission tower of system, single tower and by site test, we know that with the increasing of cross section of transmission lines, their mass can not be omitted, but the suspended transmission lines shall add to some stiffness effect both on longitudinal and lateral direction of the steel tower, and so their mass effect shall balance to their stiffness effect on both directions, that is why the transmission lines have only little effect on the dynamic characteristics of compo steel tube tower, but for more softer angle tower, its mass effect and stiffness effect can not be omitted or one of them can not be omitted. The adding stiffness of the suspended transmission lines in longitudinal direction is much greater than in lateral direction, by omitting nonsymmetrical effect on the head of tower, the first frequency of the transmission tower shows the longitudinal stiffness effects of the suspending transmission lines is 6.6% higher than relating lateral stiffness.

(2) By comparing seismic responses of transmission tower with and without transmission lines, we know that the transmission lines have some seismic reduction effect on the displacement of transmission tower but this effect is not very great. Weather the seismic reduction effect of the transmission lines has universality is uncertain, and needs more researches forward to consider both mass effect and stiffness effect.

ACKNOWLEDGMENT

This research is a part of special project of great basic former research of Chinese science ministry with number 2004CCA03300 and great key science project of Guangzhou with number 2004Z1-E0051.

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