The Present Research Situation and Earthquake Damage Defensive Measures of the Transmission Lines

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SUMMARY:
Strong earthquake has serious impact on the safety and reliability of the operation to transmission tower-line system. This paper analyzed the main damage data of transmission lines at home and abroad in recent years, and discussed several methods and latest achievements of anti-seismic to the transmission lines. These investigations demonstrate the importance of considering the simultaneous multiple earthquake ground motion components and ground motion spatial variations on seismic responses of transmission tower-line system. The defensive measures of earthquake disaster to the transmission lines were proposed based on the existing experience of precautions against earthquake and disaster reduction.

Keywords: transmission lines; seismic hazard; seismic analysis; defensive measures of earthquake disaster

1. INTRODUCTION

In modern society, power system, as an important part of the lifeline project, which has the important status in the development of national economy and affects all aspects of people's life. Once happens the earthquake, the power system will be suffered serious damage, not only cause huge economic loss directly or indirectly, but also can cause secondary disasters, such as fire. It will cause the whole society paralyze, it also produces great difficulties to relief and emergency recovery. In this paper, the coupled model of transmission tower-line system which is set up by the finite element analysis software SAP2000 used to analyze seismic response affected by wave travel and the coherent effect. The defensive measures to the transmission lines were proposed based on the existing experience of precautions against earthquake and disaster.

2. EARTHQUAKE DISASTER OF THE TRANSMISSION TOWER -LINE SYSTEM

During the 1976 Tangshan earthquake (ML=7.8), a large proportion of the power system in Tangshan had paralyzed, which disrupted the power supply and seriously affected the relief work.

On October 17, 1989, Loma Prieta earthquake in the United States (ML = 7.2), the typical characteristic of which is the power system suffered significant damage. during the earthquake, HV power substation system of 230KV and 500KV had damaged seriously, many transmission towers collapsed, which made 1.4 million customers lost power.

On January 17, 1995, the Kobe earthquake in Japan (ML = 7.2), 38 high-voltage transmission lines, 446 distribution lines had damaged, many transmission towers collapsed.

On September 21, 1999, Chi-Chi earthquake in Taiwan (ML = 7.3), which cause large-scale damage to Super-High Voltage transmission towers of 345 kV. Electric power transmission systems generally cover extensive areas with some generating plants at considerable distances from the major demand sites, and a wide variety of local site conditions probably exist.

The 2008 magnitude 8 earthquake devastated the Sichuan province of China, according to incomplete statistics, many 110KV transmission towers collapsed due to the earthquake. The province power grid lost about 40% of its load following the earthquake, even through only a small portion of the service area lies within the region of severe shaking. Which delayed the response of emergency units and resulted in business interruptions.

3. THE MAIN FORMS OF EARTHQUAKE DAMAGE TO THE TRANSMISSION TOWER-LINE SYSTEM

The collapse of the transmission tower is the direct reason to cause the transmission lines devastate, transmission tower structure should be designed according to the corresponding rules in order to make it have the capacity to resist seismic, but there is no related code of aseismic design or literatures about the seismic design of transmission tower structures (Deng Hongzhou, Si Ruijuan, Deng Lingjun, 2001; The state economic and trade commission of the people's republic of china. DL/T 5154—2002, 2002; Liu Shutang. 2005).

The results of transmission tower-line system come from some scholars at home and abroad demonstrate that the main forms of seismic damage is shown as followings:

(1) Inhomogeneous settlement of ground and sand liquefaction are the main reason to lead the transmission towers tilt, topple, the damage of the component etc.

(2) The transmission tower happened to destabilization on the vulnerable points, sometimes may cause the whole structure instability.

(3) Seismic fault, surface rupture, ground deformation are one of the main reason to cause earthquake disaster of the transmission towers.

(4) Some parts (such as insulator, connection hardware, etc.) happened to fracture.

(5) The transmission lines happened short-circuited and wire breakage because of the earthquake response is too large.

(6) The tower structure is pulled down. The transmission towers are connected by conductors and some power engineering facilities. Because of dead weight and other external forces (wind load,

and the ice load), the unbalance tensile force are generated on the conductors, the towers collapsed when the unbalance tensile force is larger than the ultimate bearing capacity.

(7) The transmission lines collapsed continuously, because of the transmission towers were connected by conductors, when one tower collapsed, the others may be pulled down.

Many transmission tower-line systems had been destructed in the earthquake, the researchers are lack of knowledge about the dynamic response of transmission tower-line system. Thus it can be seen, for high voltage grade, big capacity of the transmission lines, especially the long-span transmission tower line system, the analysis of earthquake dynamic response and dynamic stability are important to evaluate the security of the whole power system (The state bureau of technical supervision, ministry of construction of the people's republic of china. 50260—96. 1996).

The existing seismic calculation method of transmission tower-line system was mainly based on the simplified model that was not considered the coupling effect, which was too simple to make the result accurate enough. Therefore, it is necessary to establish a coupled transmission tower-line system in order to make the calculation method of earthquake-resistant more reasonable and practical.

4. THE PRESENT RESEARCH OF THE SEISMIC TO TRANSMISSION LINES

The seismic studies of high-voltage transmission tower-line systems are generally divided into two parts, one is the calculation of the natural vibration characteristics, another is the seismic response analysis. The calculation of natural vibration characteristics is the basis for the seismic response analysis and wind-resistant, which should be done before the seismic response analysis and wind-resistant.

4.1 Research to The Dynamic Characteristics of Transmission Tower-Line System

The transmission towers are often destructed, the main reason of the destruction is wind vibration and earthquakes, the dynamic characteristics of the transmission tower-line system play an important role to against the wind and earthquake, in which the natural vibration period is the key dynamic characteristics. According to the design experience of electric power department in China, the calculation formula of natural vibration period to transmission tower is gotten as following (Fu Pengcheng, Deng Hongzhou &Wu Jing, 2005):

$$T_1 = 0.034\frac{H}{\sqrt{B+\mathrm{b}}} \tag{4.1}$$

Where, *b*-the width of tower head; *B*- the width of the foundation ; *H*-the height of the tower; This formula can only apply to the towers which have regular shape.

The subspace iteration method is used to calculate the dynamic characteristics theory of the finite element model, the eigenvalue and eigenvector of the first n step can be obtained, the equation of the system without damping is as following:

$$\left[M\right]\left\{\ddot{u}\right\}+\left[K\right]\left\{u\right\}=0 \tag{4.2}$$

Where，$[M]$- the mass matrix of the system；$[K]$- the stiffness matrix of the system；$\{u\}$- the nodal displacement vector；$\{\ddot{u}\}$- the nodal acceleration vector；

The method used to solve the dynamic characteristics of the structure is applicable to single tower, when coupled transmission tower-line system is set up, the impact of the conductor cannot be neglected. Each order modes of transmission tower is difficult to distinguish. For transmission tower of small span, the quality of the conductors and towers have a little difference. So the effect of the conductors can be neglected. But for larger span, the quality of the wire is very considerable, Li Hongnan (Li Hongnan, Shi Wenlong & Jia Lianguang, 2003; Li Hongnan, 1997). put forward the reasonable earthquake-resistant calculation model of long-span transmission tower structure, and analyzed its seismic response, the results shows that the effects of the lines on the high voltage transmission tower increase with the span between two towers.

4.2 The Seismic Response Analysis of Transmission Tower-Line System

For the seismic response analysis of transmission tower-line system, the models of coupled transmission tower-line system were set up by the finite element software. According to different seismic design method, the input of the seismic waves is mainly based on the acceleration response spectrum and time history analysis method. The input of ground motion must consider spatial variation of seismic ground motions because of the distance of towers is very far. Seismic waves travel to different foundations of transmission tower will produce time delay, reflection and refraction, the filtering action of local site soil may lead to coherence loss, multi-support excitation method can be used to study the seismic response analysis.

With the help of finite element analysis software SAP2000, the transmission lines have been seen as an ideal flexible wire, the frame elements are chosen to simulate transmission line, A 500KV cat-head tower used in the practical engineering is selected, the total height of the transmission tower is 56.2m, the span of tower is 300m, the damping ratio of material to tower is 0.03, the members of tower are simulated by space beam elements, shown in figure 4.1. Steel-cored aluminium strand 4×LGJ-400/35 was chose, 4-bundle conductors were simplified as one transmission line, according to the GB/T 1179-2008《Overhead electrical conductors-Form wire, concentric lay, stranded conductors》(International Electrotechnical Commission GB/T 1179-2008,1997)，some technical parameters can be found, as is shown in table 4.1.

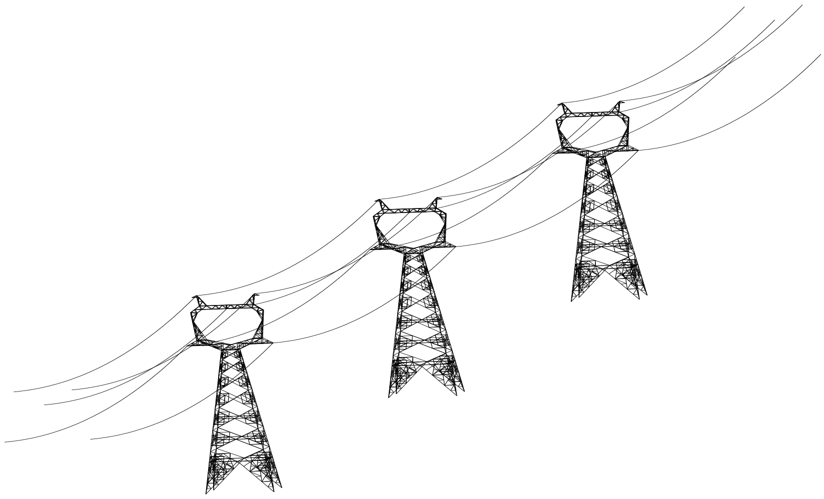

Figure 4.1. The coupled transmission tower-line system

Table 4.1. The technical parameters of conductor

Number of conductor	Cross-sectional area （mm^2）	Cross-sectional area of aluminium wire （mm^2）	Cross-sectional area of steel wire（mm^2）	Tensile force of calculation （N）	Mass per unit length （kg/km）	diameter （mm）
one	425.24	390.88	34.36	103900	1349	23.27
four	1700.96	1563.52	137.44	415600	5396	46.55

The spatial variation in the seismic response analysis must be considered due to the lager-span and high rise flexile characteristics of a transmission tower line system. In order to research traveling wave effect, coherence effect on the seismic response of transmission tower-line system, the following four cases can be chosen to research:

（1）the uniform excitation;（2）the non-uniform excitation only considered traveling wave effect;
（3）the non-uniform excitation only considered coherence effect;（4）the non-uniform excitation considered both traveling wave effect and coherence effect;

By analysis and comparison, under the four cases, the bending moment contrast curve of transmission tower is shown in figure 4.2, the shear force contrast curve of transmission tower is shown in figure 4.3, the axial force of transmission lines is shown in the figure 4.4.

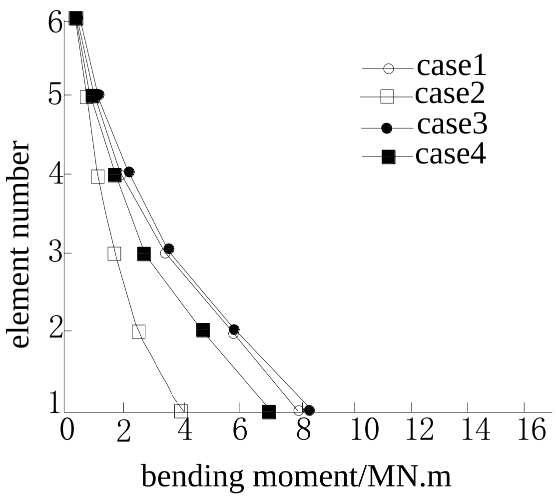

Figure 4.2. The bending moment of tower

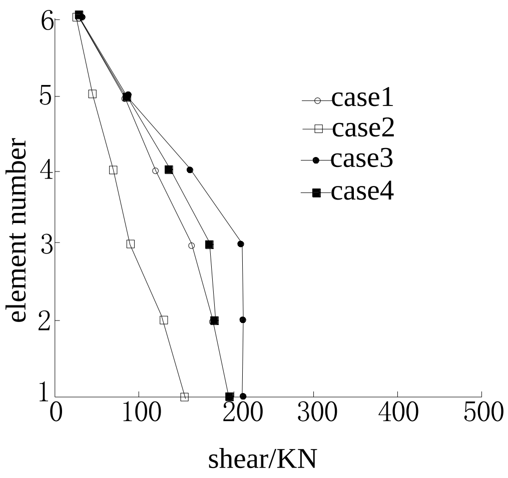

Figure 4.3. The shear force of tower

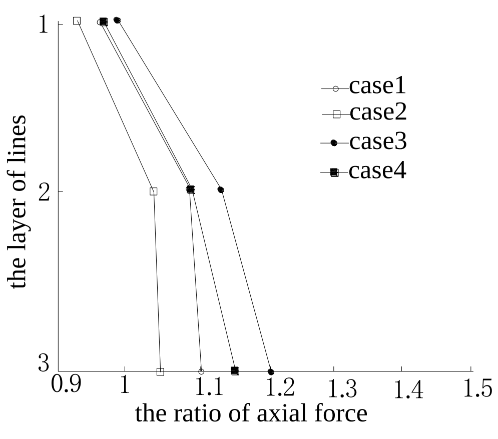

Figure 4.4. The ratio of axial force to the lines

It can be seen that whether the bending moment or the shear force of transmission towers which is only considered the traveling wave effect is much less than the uniform excitation, both the bending moment and the shear force increased substantially when only considered coherence effect, thus it can be seen that the influence of the coherence effect to the seismic response of transmission towers cannot be ignored. Considering the traveling wave effect and coherence effect at the same time, the results of the fourth case is close to the uniform excitation because the traveling wave effect is favorable to the structure, but the coherence effect has the adverse effect to the transmission towers. The traveling wave effect and the coherence effect are both have great effect on the seismic response, which should be considered at the same time. It can be seen from figure4-4 that the axial force from the top of tower which is affected by non-uniform seismic excitation is much less than other layer of tower. the maximum growth rate of axial force on the transmission lines is 11% under the second case, when only consider coherence effect, the maximum growth rate is 6%, it can be reach to 16% considered the traveling wave effect and coherence effect, it can be concluded that coherence effect has less influence to the axial force of transmission lines than the traveling wave effect.

The seismic response of tower-line system was researched used multi-support excitation method, the earthquake input was considered traveling wave effect and coherence effect. The study shows that the effect of non-uniform seismic excitation is larger than the uniform excitation.

5. THE DISASTER DEFENSE MEASURES OF EARTHQUAKE TO TRANSMISSION LINES

The earthquake engineering and social organization took the defense measures in order to prevent or mitigate the loss of power grid caused by strong earthquake. The earthquake engineering is an organization to ensure the safety of the power grid through seismic design, seismic strengthening and damping control. Social organizations improve the seismic resistance of power grid through enhancing the ideology of seismic, mechanism of disaster relief and seismic fortification criterion.

5.1 Raise The Consciousness of Social Earthquake Preparedness and Endeavour to Develop The Seismic Risk Analysis of Power Grid.

The safe operation of the transmission lines has important economic and social meaning, the design and research departments should strengthen earthquake disaster consciousness of transmission lines. The major engineering must carry out seismic safety evaluation according to the related national policy (Cao Meigen, Zhu Quanjin & Mo Zenglu, 2007). The design unit should know seismic activity and seismotectonic of the earthquake in order to evaluate earthquake geological hazard and analyzed the probability of earthquake risk.

5.2 Strengthen The Key Technologies of Transmission Lines and Carry Out The Research About Health Monitoring, Seismic Identification and Reinforcement of Lines in Service.

The transmission lines must be strengthened in order to ensure that the power grid can be operated securely. The statics problem of transmission lines has got very good settlement, but to all kinds of dynamic loads, there are a lot of work to do, such as vibration of coupled transmission tower-line system, the dynamic stability of transmission tower, earthquake resistance and disaster mitigation, all of which should be researched in the future.

5.3 Strengthen The Analysis of Disaster Data, Improve The Standard Aseismatic Design of The Existing Transmission Lines.

In order to reduce the earthquake disaster and extract experience, the data collected from the earthquake should be well analysed and researched, the experiences and lessons can be transformed into relevant standard principles. In addition, the corresponding technical measures to the earthquake-resistant should be made more reasonable.

6. CONCLUSION

The seismic response of tower-line system was researched used multi-support excitation method, the earthquake input was considered traveling wave effect and coherence effect. Most of the electrical transmission tower-line systems are large-span structures, the local site on structure response is also an important factor, the effects of the multi-component ground motions and the different local site conditions on responses of the transmission tower-line system on uneven site with multiple soil layers should be made in the future.

China is one of the countries in the world with a frequent occurrence of earthquake, many transmission lines were built on the meizoseismal area, so ensure the safety of the transmission lines in the seismic is particularly important.

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