Collapsed performance otherness analysis for kinds transmission tower-line systems under wind-induced load

Zhang Zhuoqun\textsuperscript{1,2}, Li Hongnan\textsuperscript{1}, Shao kangjie\textsuperscript{3}

\textsuperscript{1}Faculty of Infrastructure Engineering, Dalian University of Technology, Dalian, 116024.

\textsuperscript{2}State Nuclear Electric Power Planning Design \& Research Institute CO., LTD, Beijing, 100095.

\textsuperscript{3}China Academy of Building Research, CABR Technology CO., LTD. Beijing, 100013.

Zhang Zhuoqun’s E-mail: zhangzhuoqun_2006@163.com.

Li Hongnan’s E-mail: hnli@dlut.edu.cn.

Shaokangjie’s E-mail: skj801@126.com.

Abstract. In this study, three-dimensional finite element models of transmission tower-line systems were established, analyzed and simulated wind-induced progressive collapse by birth-to-death element technique in ABAQUS/Explicit. This research provided clear step-by-step descriptions of various procedures for progressive collapse analysis of different transmission tower-line systems by wind load. The numerical simulation results demonstrated that wind-induced collapsed performance of transmission tower-line system could be simulated clearly. For the Claw-type and Stem-type double circuit transmission tower-line systems, the progressive collapse speed and path were different under the same wind loading and related to the structural topology form and material characteristics closely. Therefore, the numerical simulation of progressive collapse process was considered as a significant and necessary project.

1. Introduction

The power transmission tower-line system is considered as a kind of important power facility and plays a vital role in the operation of a reliable electrical power system\textsuperscript{1-2}. The interruption of electrical service due to the failure of transmission line structures can cause much devastating economical and social consequences. For example, the most severity accidents of transmission tower collapse were reported that there were seven towers fall down once by wind action in 1992 and 1993\textsuperscript{3}. The four transmission towers with 500kV were damaged in 1998. Six years later, the 3342km electrical transmission system was destroyed by severe typhoon called Yunna\textsuperscript{4}.

Following the interruption of electrical service events due to damage of transmission tower in recent years, there had been heightened interest among different types towers in evaluating the progressive collapse potential and in designing new buildings to resist collapse. Progressive collapse was also one of the most important issues in the field of structural engineering. During the past decade, the limitations of using linear models to simulate nonlinear dynamic response associated with
progressive collapse by Krauthammer\cite{5}. In China, simulation for the collapse of World Trade Center was processed with the finite element software of LS-DYNA, and the parameters were discussed with real conditions\cite{6}. The mason building and ferroconcrete structure were all developed to simulate collapse, and several papers discussed that the damage mechanism of a typical RC frame and high-rise buildings in earthquake \cite{7}. As the important life-line engineering project, the damage of transmission tower-line system could cause the power interruption and serious problem.

2. Numerical simulation method

2.1. Wind Load Model

The wind flow speed and direction change with time and space. As a changeable action, wind load is one of the important engineering structure design loads. Especially, for high-rise and super high-rise structures, it is also considered as a control load in transmission tower\cite{8}.

The total wind velocity in any point of a structure is the sum of the mean wind velocity and the turbulent wind velocity:

$$v(z,t) = \langle v(z) \rangle + v_f(z,t)$$  \hspace{1cm} (1)

Where, \(v(z,t)\) is the total wind velocity in structures, and \(\langle v(z) \rangle\) is the mean wind velocity, and \(v_f(z,t)\) is the turbulent wind velocity.

2.2. Birth-to-Death Element

In this work, the technique of element birth and death was used to simulate the progressive collapse process of transmission tower-line system in ABAQUS. When the overloaded structural elements were caused by wind, these elements would be defined as failure elements and subsequently led to the progressive collapse. The elements would be deleted or removed when the strain and stress increased over the critical value. Actually, the “killed” element was not removed from model. In fact, the element was fabricated or deposited in a particular process step, which was considered as inactive or “dead”. To achieve the element “death” effect, the selected “dead elements” were deactivated by multiplying their stiffness matrices with a reduction factor, which caused the element loads associated with the deactivated elements to be zeroed out in the load vector and the element strains were also set to be zero. Although the mass, specific heat and damping of deactivated elements were all set to zero likewise, it still appeared in element-load lists\cite{9,10}.

3. Wind-induced Collapsed Simulation

3.1. Transmission tower model

1. Claw-type Tower

As shown in Fig.1, the power transmission tower-line system included three towers (1\#, 2\#, and 3\#) and four span line\cite{12}. The tower was 60.5m high. The tower structural members were made of angle steel. The upper 8 cables were ground lines and lower 24 cables were single bundled conductor. The spans to adjacent towers were all 300m. The base points of the transmission tower were fixed on the ground, and the connections between transmission towers and lines were hinged, and the side spans of the lines were hinged at the same height of middle tower.

2. Stem-type Tower

Three-dimension finite element of transmission tower-line system was established according to practical project in China\cite{13}. 53.9m tower was constructed from steel angle sections with 206Gpa elastic modulus. The tower weigh is about 19.95 tons. The distance between adjacent towers was 400m. The upper 8 cables were ground lines and lower 24 cables were four-bundled conductor lines. The finite-element computer program ABAQUS was applied to analyze this model. The power transmission tower-line system included three towers (1\#, 2\#, and 3\#) and four span lines in Fig. 2.
3.2. Wind Simulation

In this article, the Kaimal fluctuating wind power spectrum and harmonic superposition method were applied to simulate strong wind load by MATLAB system. Mean wind speed at 10 m height was assumed to be 35 m/s. As shown in Fig.3, the two transmission towers were divided into 15 and 16 regions. The Fig.5 showed a simulated fluctuating wind speed at the point 8 of the Stem-type tower.

3.3. Numerical Analysis Results

For the transmission tower-line system with the realistic connections, three-tower and four-line finite element model was attacked by wind load and caused progressive collapses completely. Because the middle tower (2# tower) was usually considered as the most accurate to explain nonlinear dynamic response and progressive collapse behavior by several literatures, it was demonstrated in the Fig. 5-6. The Fig.5 showed the nonlinear dynamic response and the Claw-type of transmission tower-line system progressive collapse at the time 37.00 to 38.60s. The Stem-type of transmission tower-line system caused local region damage at the time 14.54 second and whole progressive collapse happened from the 14.65 to 15.30 second in the Fig.6.

1. Claw-type Tower

Three-tower and four-line finite element model was attacked by strong wind, which caused total progressive collapse. At the time 33.43 second, damage elements occurred on the main material of transmission tower, especially on the members close to the wind load point, and the damage went on from the middle to up and down, finally the 2# tower collapsed completely within several seconds. Fig5(c)–(f) revealed the whole progressive collapse process.

Before the 33.43 second, transmission tower-line system worked in elastic range and all of elements were worked well. As illustrated in Fig.5(b), at the time 33.44 second, the maximum stress of several transmission tower members reached or exceeded elastic deformation, and several elements entered into the plastic stage. Till 37.00 second, transmission tower-line system worked well and all of elements were not broken. Fig.5(d) shows, at the time 37.20 second, the maximum stress of several transmission tower members had reached or exceeded the material yield stress, especially on the members near the wind load point, and the structural collapsed. For some tower elements satisfied material death technique, these elements began to damage and were “deleted”, as shown in Fig.5(e), which lead to progressive collapse. This situation also demonstrated that progressive collapse of
structures was initiated by the loss of one or more load-carrying members. At the next instant, the dead elements lost load-carrying caused further redistribution of loads and the resulting elements damage might be disproportionate in the local region near the lost member, compared with the Fig.5(f), which also caused more and more elements failed and invalidated.

![Figures showing different stages of collapse](image)

2. Stem-type Tower

In order to compare and illustrate completely, the other type transmission tower (2# tower) was analyzed. In the same wind load case, collapses performance and anti-collapse capacity of Claw-type and Stem-type transmission tower-line systems were different. Before the 14.53 second, transmission tower-line system worked well and all elements were not failed. At the time 14.54, the maximum stress of several transmission tower members had been reach or exceeded the yield stress of material, especially for members near the wind load point, and then the structural would start to collapse. Then, more and more main material of tower members began to damage, and lost load-carrying. Ultimately, transmission tower-line systems collapsed completely, in few minutes.

![Figures showing different stages of collapse](image)

3.4. Contrastive Analysis

Compared with the Fig.5~6, the pictures showed that the Claw-type transmission tower-line system had much more anti-collapse capacity than Stem-type tower, and the initial time of progressive collapses was also late. It’s worth noting that the Claw-type duration time is as longer as 4 seconds and whole tower collapse did not happen at the beginning. The reason was that structural topology form, structural shape and material characteristics vary from the different type transmission towers. The initial failed region of the Claw-type tower was tower body, and Stem-type tower was the top of bottom cross arm. The initial damage location decided to progressive collapse process and velocity.
When the failed element was happened in the local region and was only the redundant member, the structure was not instantaneous collapse. If the surrounding elements of cross arm, tower leg element or tower head important region were damage, the collapse velocity would be larger. Therefore, to enhance the ability of resisting wind-induced collapse, main material choice was the most important issue. In the special type transmission tower, the surrounding elements of cross arm or topology form were also need to improve, such as Stem-type tower.

4. Conclusions
This study describes simulations and analyses of progressive collapses process for two classical transmission tower-line systems by ABAQUS/Explicit. The results support the following conclusions:
(1)The article describes a nonlinear response associated with progressive collapses process of transmission tower-line system induced wind load by the birth-to-death element technique in ABAQUS/Explicit. (2) Compared with the numerical simulation results between Claw-type and Stem-type of transmission tower-line system, it reveals that progressive collapse performance has much more divergence under same wind loading condition. In the same wind load, the Claw-type of transmission tower-line system has much stronger anti-collapse capacity than Stem-type tower. (3)The initial damage element region and last instantaneous deformation are all very important and directly decide to transmission tower-line system progressive collapse speed and path. Moreover, progressive collapse speed and path are also affected by conductor and ground lines. Therefore, the surrounding elements of cross arm, tower leg material and the special tower head material choice are the most important issues and need to be enhanced.

References
[1] Li H.N. and Bai H.F. High-voltage transmission tower-line system subjected to disaster loads[J].Progress in Natural Science, 2006, 16(9): 899-911.
[2] Zhang Z.Q., Li H.N., and Li S.F., et al. Disaster analysis and safety assessment on transmission tower-line system: an overview[J].China Civil Engineering Journal,2016,12(49): 75-88.
[3] Tang G.A. The analysis about the accident probability of 500kV transmission tower downburst in China[J]. Electric Power Construction, 1994, 15(11): 18-20.
[4] Li Y. and Bai H.F. Research on Overhead Transmission Line Environmental Load Response and Design Theory[J]. Electric Power Construction,2008, 29(9): 38-41.
[5] Krauthammer, T. AISC Research on structural steel to resist blast and progressive collapse [C].Proceedings of AISC Steel Building Symposium: Blast and Progressive Collapse Resistance, 2003, New York, 4-5 December.
[6] Lu X.Z. and Jiang J.J. Dynamic finite element simulation for the collapse of word trade center”, China Civil Engineering Journal,2001,34(6) : 9-10.
[7] Lu X.Z., and Lin X.C., et al. Numerical models for earthquake induced progressive collapse of high-rise buildings[J].Engineering Mechanics, 2010,27(11): 64-70.
[8] Simiu E. and Scanlan R.H. Wind effects on structures[D].Third edition, New York: John Wiley and Sons, 1996.
[9] Long R.S., and Liu W.J., et al. Numerical simulation of thermal behavior during laser metal deposition shaping[J]. Transaction of Nonferrous Metals,2008,18(3): 691-699.
[10] Nadimi S., Khousehmehr R.J., and Rohani B. et al. Investigation and Analysis of Weld Induced Residual Stresses in Two Dissimilar Pipes by Finite Element Modeling[J].Journal of Applied Sciences,2008,8(6): 1014-1020.
[11] Wang W.M. Study on the Seismic Analysis Method of Structure Considering Strain Rate Effect[D].Dalian University of Technology,2013.
[12] Li, Gang Li, Wenming Wang, and Li Tian. The Numerical Analysis of Transmission Tower-Line System Wind-induced Collapsed[J]. Mathematical Problems in Engineering, Volume 2013, Article ID 413275, 11 pages.