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Comparison between ASCE-74 tornado load cases and synoptic wind loads for transmission lines

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SUMMARY:
Tornadoes are localized High Intensity Wind (HIW) events which can affect transmission line (TL) structures differently than the traditional synoptic wind included in various international codes and standards. The failure of many transmission lines during HIW events has initiated an extensive research program in the past two decades at the University of Western Ontario (UWO). New load cases simulating the most critical effect of tornadoes on TLs were recently incorporated in the ASCE-74 (2020) as an outcome of this research program. The objective of this study is to compare between the effect of the synoptic wind loads defined in the international codes with that of the new ASCE tornado load cases. Guyed and self-supported tower systems are considered as case studies. The critical tornado velocities that produce the same peak straining actions as the synoptic wind loads are determined. The results highlight the importance of including the tornado load cases in the design of transmission lines.

Keywords: High Intensity Wind, Transmission Line, ASCE-74 (2020)

1. INTRODUCTION

Tornadoes and downbursts are usually called High Intensity Wind (HIW) events. Tornado is a rotating wind vortex with high speed that moves upwards (Fujita, 1981). Tornadoes are classified into six groups from 0 to 5 in an ascending order in the Fujita F-scale according to the level of damage, the path width, and the wind speed (Fujita and Pearson, 1973). The wind fields associated with tornadoes have three velocity components in the tangential, the radial, and the vertical directions, which is different compared to synoptic winds such as hurricanes and typhoons. A large percentage of the weather-related failures of TL around the globe are shown to be caused by HIW events (Dempsey and White, 1996). Motivated by TL failures in Canada during HIW events, a research program was carried out during the past two decades. For tornadoes, the research covered various aspects such as characterizing the tornado wind field (Hangan and Kim, 2008; Ezami et al., 2022a), studying the behaviour and the failure of the towers (Hamada et al., 2010; Hamada and El Damatty, 2011; and Hamada and El Damatty, 2015), and validating the numerical results through experimental tests at the WindEEE facility (Ezami et al., 2022b).

The research program led to the development of load cases simulating the critical effect of tornadoes on a generic TL system (El Damatty and Hamada, 2016). The load cases focused on tornadoes having F2-scale since the majority of the observed tornadoes are F2 or less. The developed tornado load cases are divided into two groups. For each group, the towers are loaded by two different velocity profiles applied alternately in the longitudinal and the transverse directions. To consider the possible locations of the tornadoes, there are four different cases for each group denoted as Case 1 (A-D) and Case 2 (A-D). The conductors are loaded by a uniform velocity distribution that is applied along with a span reduction factor for each case. The tornado profiles provided in the ASCE-74 (2020) have a fixed peak tornado velocity of 70.2 m/s representing the maximum velocity of F2 tornadoes. The study aims to compare the effect of synoptic wind loads defined in the international codes and standard, such as ASCE-74 (2020), EN BS 50341 (2012), IEC 60826 (2017) and AS/NZS 1170.2 (2021), to the tornado load cases defined by ASCE-74 (2020). The critical tornado velocities that produce the same peak straining actions as the synoptic wind loads are determined.

2. CASE STUDY

Three real transmission line systems are considered, including two self-supported towers and a guyed tower as shown in Fig. 1. The self-supported towers (S1 and S2) support six conductors with three levels of cross arms. The guyed tower (G1) is supported by 4 guys with a diameter of 0.0165 m and carries two conductors with one cross arm level. The height of the towers is 44.39 m, 51.81 m, and 54.65 m for G1, S1 and S2, respectively. While the span of the line is 480 m, 450 m, and 213.36 m for G1, S1 and S2, respectively.

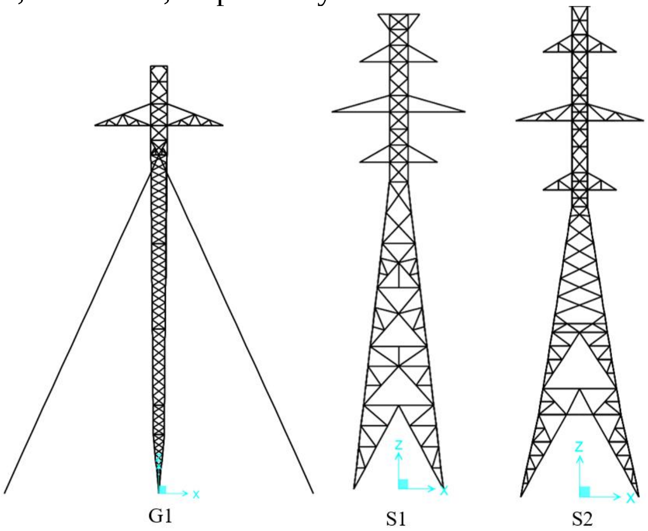

Figure 1. Considered transmission towers.

3. METHOD OF THE ANALYSIS

3.1. Analysis under Synoptic Wind Load

Finite Element analysis is conducted for the TL systems under the synoptic wind loads defined in the four aforementioned standards. Two load cases are included; the first one considers synoptic wind load only, while the second one considers combination of synoptic wind load and ice loads. In order to compare the results between different design standards, a reference 3-sec gust wind speed at 10 m height of 40 m/s is assumed for the first case. For the second case, the reference wind speed is assumed to be 17.88 m/s with 25.4 mm ice accretion on the conductors. Open terrain exposure is assumed for both cases. Two wind directions are considered, the transverse and the longitudinal directions. Consequently, four different synoptic load cases are included, denoted as C1 (Trans.), C1 (Long.), C2 (Trans.) and C2 (Long.). The systems are analyzed under the four load cases along with the gravity loads. The peak axial forces, F_{NG}, due to the combination of the gravity load and the synoptic wind load cases are determined.

3.2. Analysis under Tornado Load Cases

The tornado loads are calculated according to ASCE-74 (2020) using an assumed tornado velocity (V_t). The systems are then analyzed using finite element modelling to determine the peak axial forces in each member, F_{TG}, due to the peak effect of all tornado load cases together with the effect of gravity loads. The peak axial forces due to tornado and synoptic wind are compared by calculating the factor $\lambda_{T/N}$ as expressed in Eq. 1. The analysis is repeated by increasing the tornado velocity by an increment of 5 m/s till the factor $\lambda_{T/N}$ becomes equal to one. At this point, the tornado velocity is identified as the critical tornado velocity (V_{tcr}) at which the tornado loads have the same effect on the tower as the synoptic wind loads.

$$\lambda_{T/N} = \frac{F_{TG}}{F_{NG}} \tag{1}$$

4. RESULTS

The critical tornado velocity and the critical load cases for the three systems are presented in Table 1. For the guyed tower, the critical synoptic wind case is the longitudinal load case where most of the critical members are located between the guy arm and the base. The reason for this is that the guyed tower behaves as a beam with an overhanging cantilever. Decreasing the conductor forces increases the bending moment on the main body of the tower between the guys and the base, making the members below the guys more critical. Tornado loads generate conductor forces less than the synoptic wind loads as the conductor gust response factor for the tornado is less than that for the synoptic wind. As such, the critical load case is associated with the longitudinal synoptic wind load case, where no loads are applied to the conductors. For the self-supported towers, the critical tornado is associated with the transverse load case of the synoptic wind. This is because the self-supported tower behaves as a cantilever, where the critical load case occurs when the conductors are loaded. The difference between the self-supported towers S1 and S2 is that the span of S1 is larger than the span of S2. Accordingly, the span reduction factor (SRF) of S2 is larger than the SRF of S1, causing larger conductors load on S2. The system S2 is therefore more vulnerable to tornadoes with lower critical tornado velocity as shown in Table 1.

The results indicate a variation in the critical tornado velocities for the different standards. This is due to the differences between the standards in defining the wind pressure and the gust response factors for the towers and the conductors. As a comparison between the four standards, BS (2012) and IEC (2017) produce the highest forces on both the towers and the conductors. Meanwhile, the forces on the towers and on the conductors defined by ASCE-74 (2020) and AS/NZS (2021) are comparable. Accordingly, the critical tornado velocity is following a trend where the highest critical velocity corresponds to the BS (2012) code followed by IEC (2017), while the critical velocity for ASCE-74 (2020) and AS/NZS (2021) are similar. The maximum critical velocity is 44, 49, and 42 m/s for system G1, S1, and S2, respectively. Since the maximum velocity F2-tornado is 70.2 m/s, the studied systems are considered to be vulnerable to tornado events.

Table 1. Critical tornado velocity for different design standards.

Design Standard	ASCE_2020 Tornado Critical Case			Synoptic Wind Critical Case			V_{tcr}		
	G1	S1	S2	G1	S1	S2	G1	S1	S2
ASCE (2020)	2A	2A	2A	C1 (Long)	C1 (Trans)	C1 (Trans)	38	43	37
BS (2012)	2A	2A	2A	C1 (Long)	C1 (Trans)	C1 (Trans)	44	49	42
IEC (2017)	2A	2A	2A	C1 (Long)	C1 (Trans)	C1 (Trans)	42	48	41
AS/NZS (2021)	2A	2A	2A	C1 (Long)	C1 (Trans)	C1 (Trans)	40	44	38

5. CONCLUSIONS

Three transmission line systems are analyzed under the new tornado load cases defined in the ASCE-74 (2020) and the synoptic wind loads defined by four international standards, ASCE-74 (2020), BS (2012), IEC (2017) and AS/NZS (2021). The critical tornado velocities that generate the same straining actions on the tower members as the synoptic wind loads are reported. The critical tornado velocities range between 37 to 49 for the considered systems. The studied systems are vulnerable to tornadoes with reference velocities greater than the reported values if they are designed to synoptic wind only without a significant safety margin. It is recommended that tornado load cases to be included in the design to reduce the risk of the transmission line failures during such HIW events.

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