

Critical Tornado Configurations For Guyed Transmission Towers Subjected to Tornado Loading

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SUMMARY

Global observations indicate an increasing trend in transmission line failures under High-Intensity Wind (HIW) events which can be attributed to the impacts of climate change. Tornadoes impose highly localized and multidirectional wind loads that can cause severe damage to transmission line systems. Guyed towers constitute one of the primary types of transmission line support systems and exhibit complex structural behavior when subjected to HIW events. The structural response of guyed towers is strongly influenced by the relative position of the tornado with respect to the tower and its supporting guys. Accordingly, extensive parametric studies are conducted on two distinct guyed tower systems, to determine the critical tornado configurations that lead to the peak internal forces causing the towers' failure. The resulting critical tornado positions are identified and discussed for both guyed tower systems.

Keywords: *High Intensity Wind, Tornadoes, Guyed Towers, Tower failure*

1. INTRODUCTION

Transmission lines play a significant role in delivering electricity from generation facilities to consumers. Thus, any disruption within Transmission Line systems (TLs) can result in substantial social and economic consequences especially under extreme winds such as tornadoes. In fact, there are limited studies in the literature examining the behaviour of transmission line systems under tornado wind loads. As a result, an extensive research program was developed under the supervision of Prof. El Damatty at The University of Western Ontario, Canada, over twenty years ago to investigate the behaviour of transmission line structures under HIW events. Hamada et al., (2010) and Hamada and El Damatty, (2011, 2015) carried out an in-depth study to evaluate the behaviour of transmission line structures under tornado-induced loads. Moreover, El Damatty and Hamada, (2016) proposed critical load cases for tangent towers subjected to F2 tornadoes by studying the critical tornado locations through an extensive parametric study which was then incorporated in the ASCE74-2020. The current study focuses on determining the critical tornado configuration for guyed transmission tower systems that lead to the peak internal forces in tower members causing their failure. This is highly significant for studying the failure mechanisms and post-failure behavior of guyed transmission tower systems.

2. METHODOLOGY

2.1. Tornado wind field

In the current study, the wind field adopted was developed and validated by Hangan H and Kim J, (2008) for F4 tornadoes. The Computational fluid dynamics (CFD) simulations for F4 tornadoes was scaled by Hamada et al., (2010) using the Fujita scale parameters to obtain the three-dimensional F2 tornado wind field which was then used in several studies. The CFD simulations were conducted in a steady state manner to control the complexity of the problem. The used F2 tornado model is scaled up to match the 3-sec gust velocity of F2 tornado. Figure 1, Figure 2 and Figure 3 illustrate the vertical profiles of the tangential, radial, and vertical velocity components within the near-ground region for different radial distances “r”.

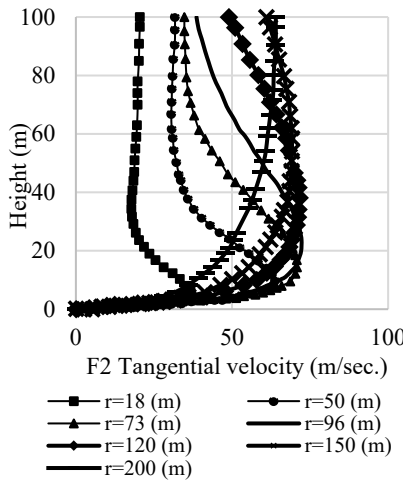


Figure 1: Tangential velocity profile (Hamada et al., 2010)

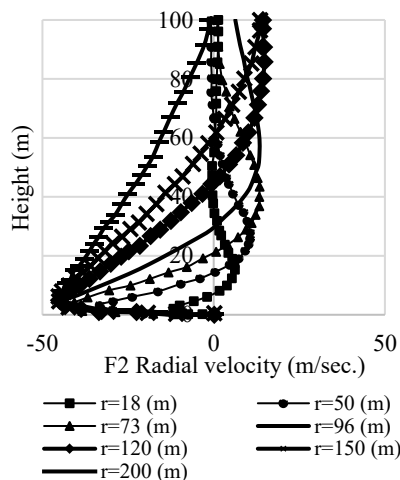


Figure 2: Radial velocity profile (Hamada et al., 2010)

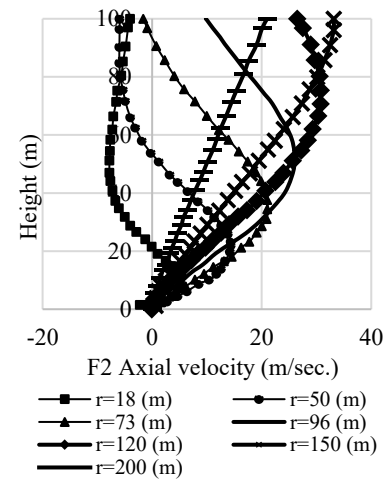


Figure 3: Vertical velocity profile (Hamada et al., 2010)

2.2. Numerical model

The studied guyed tower systems are analyzed using an in-house, nonlinear, three-dimensional FORTRAN code named “HIW” which is previously developed by Shehata AY et al., (2005) for the analysis of transmission lines under downbursts and then extended by Hamada et al., (2010) to be capable of investigating the behavior of such structures under tornadoes by incorporating the tornado wind field. In this numerical model, the tower is modelled using 3D frame elements. The cable reactions are calculated based on a semi-analytical approach developed by Aboshosha and El Damatty, (2014) to analyze the line conductors under HIW events incorporating the conductor’s geometric nonlinearity, the pretension force and sagging in addition to the flexibility of the insulators. After modeling the tower and the cables, the tower nodal forces are evaluated based on the tornado configuration. Further explanation of the evaluations of tornado forces on the lattice towers is described by Hamada et al., (2010). Furthermore, the numerical model was updated to include the simulation of supporting guy cables. The initial conditions of the supporting guys particularly its pretension force is represented by an equivalent straight bar element characterized by an equivalent modulus of elasticity to account for the guys’ geometric non-linearities in its axial stiffness in addition to incorporating the geometric stiffness matrix in the guy element stiffness matrix to account for geometric non-linearities in transverse directions. This approach was adopted by Hamada and El Damatty, (2015).

2.3. Description of the studied guyed towers

In the current study, two guyed transmission line systems used by Hydro-one company are investigated to determine the critical tornado configurations. The first guyed transmission line named G1 as shown in Figure 4 **Error! Reference source not found.** G1 has a height of 44.39 m and the cables' span is 480 m. The conductors and ground-wire initial sags are 20 m and 13 m, respectively. G1 tower is supported by four guys, each having a pretension force of 35 kN. The second guyed tower is a V-shaped guyed tower labeled as G2 as presented in Figure 5. The towers' height is 46.57 m and the cables have a span of 460 m. G2 is supported by four guys, each having a pretension force of 22 kN. The conductors and ground-wire initial sags are 13.5 m and 16 m, respectively.

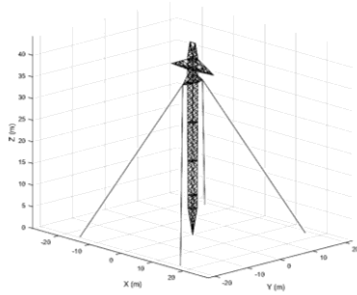


Figure 4: G1-Tower

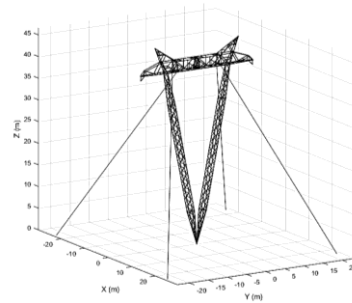


Figure 5: G2-Tower

2.4. Parametric study

Extensive parametric studies are conducted on two guyed transmission line systems which involve many quasi-static analyses by considering different tornado locations. The tornado locations are identified by (R and θ) with respect to the tower of interest as shown in Figure 6. More than 400 analyses are conducted for each guyed system involving various combinations of R and θ .

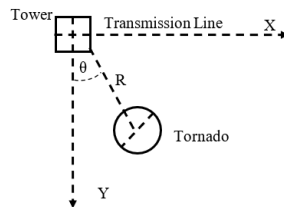


Figure 6: Geometric Parameters of tornado relative to a transmission line system.

3. RESULTS AND DISCUSSION

After conducting numerous parametric studies, the ratio of each member's peak axial force to its capacity is calculated and defined as the strength factor " λ ". The tornado configuration producing high λ values for chord members is evaluated for each guyed tower system. Both systems lead to the same tornado configuration which is at $R = 125$ m and $\theta = 165^\circ$. This critical tornado configuration causes the failure of approximately 35% - 40% of the total failed chord members for both systems as shown in Figure 7 and Figure 8 for G1 and G2, respectively.

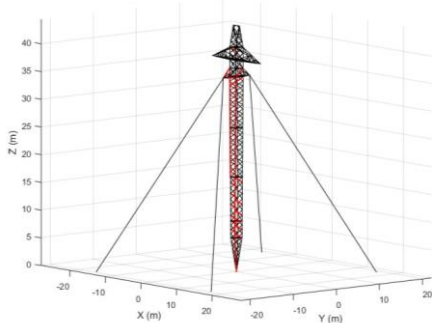


Figure 7: G1-Failed chord members

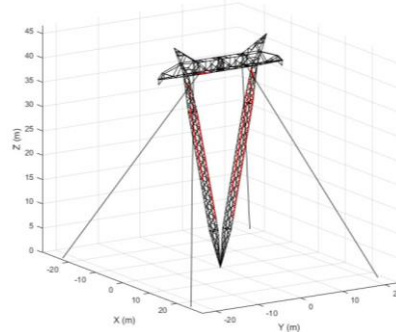


Figure 8: G2-Failed chord members

A guyed tower may be idealized as an overhanging beam. The deduced critical tornado configuration leads to limited transverse velocity profile acting on the cables. As a result, the cables' reactions are relatively small. For G1, the conductor level is higher than the guy level, therefore, when minimum load acts on the cantilever portion, the tower members below the guy level exhibit higher internal forces. For G2, a single cross arm supports both the conductors and the guy cables, therefore, large portion of the conductor loads is transferred to the ground through the guys. However, for this tower type, the aerodynamic loading of the tower face is higher than the transverse direction. As such, the deduced tornado configuration is governing for both towers.

4. CONCLUSIONS

This study identified the critical tornado configurations governing the failure of two distinct guyed transmission tower systems through an extensive parametric. For both systems, a consistent critical tornado position is obtained, producing peak axial demands in various chord members. These findings provide insight into the critical tornado location for guyed towers which is highly significant for identifying the failure mechanisms and post-failure behavior of guyed tower systems.

ACKNOWLEDGEMENTS

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