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Study on Dynamic Behavior of Towering Steel Structures with Supporting Frame under Wind Loads

Wei Tan[1,2a], Xiantao Fan[1b], Le Xu[1c], Zhanbin Jia[1d] and Yang Wang[*1,3]

[1]*School of Chemical Engineering and Technology, Tianjin University, Tianjin 300350, PR China*
[2]*State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, Tianjin 300072, PR China*
[3]*Tianjin Key Laboratory of Membrane Science and Desalination Technology, Tianjin 300072, PR China*

Abstract. Towering steel structures like chemical towers with supporting frame are typical structures in the engineering field. The main body of the structure is not in contact with the ground and fixed on the steel frame with a support, which is denoted as frame-supporting structure in this work. Displacement restrictors are set beneath and above the support to restrict the displacement of the towering and slender body causing the structure to be structural nonlinearity and statically indeterminate. This study investigated along-wind and cross-wind vibration of the structure experimentally and numerically. A field test is carried out to measure the natural frequency and damping ratio of the 42.5-meter-high structure vibrating in the wind, which is the prototype of the experimental model design. A non-contact excitation system including an electromagnetic exciter and a programmable signal generator is applied on the experimental model to simulate the wind loads and provide a vibration stimulation from initiation to stabilization. The displacement and strains of the structure are collected under different frame types by changing the heights of displacement restrictors. Concerning the numerical part, a 3D finite element model is established using ANSYS software. The numerical model is used to obtain data that is hard to attain through experiments as its results are corresponding to the experimental data showing that the height of displacement restrictors has a great influence on the vibration intensity of the structure. An optimum location, recommended as about 40% of the height, could decrease the vibration intensity and enhance the safety of the structure. Based on the results, a simplified formula in which the natural frequency and the damping ratio dominates the dynamic behavior of along-wind and cross-wind vibration, respectively, is derived from multi-degree-of-freedom. Some feasible optimization advices, like installing two layers of displacement restrictors, are given to reduce the vibration intensity of the

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[*]Corresponding author, Assistant Professor, Ph.D., E-mail: yangwang2017@tju.edu.cn
[a] Professor, E-mail: wtan@tju.edu.cn
[b] Ph.D. Student, E-mail: fanxiantao@tju.edu.cn
[c] Ph.D. Student, E-mail: xuleapple@126.com
[d] Engineer, E-mail: zhanbin.jia@tju.edu.cn

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structure. This work presents an important design guide to the frame-supporting towering steel structure and is of great significance to an economical and safety design.

Keywords: frame-supporting structure; wind loads; displacement restrictor; dynamic characteristics

1. Introduction

When a fluid flows around a circular body at a certain velocity, vortices form rhythmically from the leeward side and produce a periodic lift force on the body in a transversal direction. As the approaching flow velocity increases, the vortex shedding frequency is close enough to the body's natural frequency and that the circular body is induced to respond in the lift direction, which is named vortex induced vibration (VIV). If the particular fluid flow is wind, the vibration of a circular body subject to wind is often referred to as cross-wind vibration (CWV). In addition, due to the violent fluctuation of the along-wind loads, the along-wind vibration (AWV) is also significant especially when its velocity is high.

The self-supporting towering circular structure is one of the most common type in the chemical and civil engineering, such as the chemical tower, chimney, pier and the wind turbine. Towering self-supporting structures are usually set up outside and tend to suffer CWV and AWV during the whole period of lives. According to Robertson et al. (2001) and Peil et al. (2002), the CWV can cause deflection and fatigue problems of structures and even lead to collapses. Siringoringo et al. (2012) described AWV of a suspension bridge tower. Srinivas et al. (2007) studied the along-wind response of a tapered chimney. Ke, S.T et al. (2017) studied the average wind load on a super-large cooling tower, the results could provide references to the structure selection and wind resistance design of such type of steel cooling towers. In addition, the numerical study is becoming the main research method. Narendran, K. et al. (2018) studied the VIV in multi-column offshore platform by an explicit dynamic subgrid-scale model. Since the destructiveness of AWV and CWV, studies on the dynamic behavior of towering structures is remarkable to the economical and safe design.

Wind-tunnel is widely used to study the behavior of structures under wind loads. Carril et al. (2003) conducted an experimental investigation on lattice towers built in Brazil using a wind tunnel. Effects of wind forces and structure responses were analyzed. Ke, ST et al. (2017) studied the Multi-dimensional extreme aerodynamic load under typical four-tower arrangements by wind tunnel. Zhou et al. (2010) studied AWV and CVW of Guangzhou New TV Tower that wind force was measured and was used to compute wind induced responses by the experiment. In addition, field measurement is also applied to study the wind forces and responses of towering structures. Glanville et al. (1995) presented the results of a field measurement on a steel frame tower. Dynamic characteristics, including frequencies, mode shapes and damping values of the tower