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Analysis of load characteristics and responses of low-rise building under tornado

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Abstract

In this paper, the numerical model of the tornado generator is established by using the computational fluid dynamics (CFD) method. The radar observed wind profiles of Spencer tornado (1998) are used as inlet boundary condition to form tornado wind field, and the influence of surface roughness is taken into account. This method is used to generate the tornado wind field with the same intensity as recorded in our country, and the wind load characteristics of low-rise building located in different positions in the tornado wind field are analyzed. Then the finite element model of the building is established by ANSYS software, and the building is considered as steel frame-steel plate composite wall structure, which rationality of the finite element model is determined by the modal analysis. The one-way fluid structure interaction method is adopted to transfer the tornado load to the surface of the finite element model, and the displacement response, deformation and damage state of the wall surface and roof surface of the building in different locations of the tornado wind field are analyzed in detail.

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Keywords: Tornado; CFD; Low-rise building; Finite elemen model; Fluid structure interaction

1. Introduction

The tornado is a kind of violent rotating small-scale atmospheric vortex, although its region of influence is far less than the typhoon, but its rotating wind speed is much stronger than that of a strong typhoon, which leads to a very strong destructive force. In recent years, the number of tornadoes in the area of high population density has also increased, while the damage or collapse of the township low-rise houses due to the inability to resist the tornadoes is an important cause of casualty. Therefore, it is necessary to pay attention to the role of tornado in the design of civil

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engineering structures, which is of great significance to improve the capacity of disaster prevention and mitigation and to protect the safety of people's lives and property in the tornado-prone areas.

In order to reduce the huge losses caused by the tornado disaster, it is necessary to further study the failure mechanism of tornadoes to buildings. First of all, the formation method, the wind field structure and the evolution law of the tornadoes are to be studied. At present, the field observation, experimental simulation and numerical simulation are mainly used to study the tornado wind field in the world. The field observation is the most direct way to study the characteristics of tornadoes. Although the investment is large and many factors are difficult to control, it is paid more attention due to its authenticity [1,2]. Measuring tornadoes at the scene is a very difficult task, considering the establishing a tornado generator in the laboratory, which opens up new ways for researchers to explore tornadoes[3,4,5].

With the deepening of the experimental research methods, the corresponding numerical study is also carried out gradually. Lewellen et al. [6,7] studied the formation condition and mechanism of tornado vortex by the LES model. Kuai et al. [8] investigated the parameter sensitivity of the tornado field by changing the mesh size and model geometry. In order to study the effect of surface roughness on the tornadoes, Lewellen et al. [9] used the LES model to study the effect of surface roughness on the swirl ratio. Natarajan and Hangan [10] attempted to solve the effect of surface roughness on the tornado field with a wide range of swirl ratio (0.1~2.0), and found that the radial, axial and tangential velocities increased in the core area due to roughness. Liu and Ishihara [11] simulated the ground roughness by adding the momentum source in the Navier-Stokes equation. The research was pointed out that the ground roughness could increase the size of the tornado core region, but the size of core region would decrease when the swirl ratio was small. However, Diamond and Wilkins [12] simulated Ward tornado to observe the effects of movement and surface roughness on the wind field, and they found that the core radius is decreased with the increase of surface roughness.

The wind load and the internal and external pressure difference of the tornado will cause the shear, suction and torsion damage of the building structure. With the development of finite element analysis software, many researchers began to analyze the displacement and dynamic responses under external load by using the finite element analysis software. Dutta and Ghost [13] used the finite element method to analyze the response of the building frame under the action of the tornado, and compared the displacement response of the structure under the action of the transverse tornado and the displacement response under the action of the transverse tornado and the updraft. The study found that the response of the building was larger in the latter case and the displacement response of the frame was increased with the increase of the tornado translational speed. Thampi and Dayal [14] simulated the tornado-induced wind pressure distribution in the internal and external surface of the wooden frame house with the gable roof. Then, the deformation model of the wooden house was simulated by the finite element method, which was compared with the damage of the actual buildings by an EF5 tornado in Parkersburg, West Virginia, U.S., in 2008. Sabareesh and Matsui [15] simulated the destructive effect of the tornado with surface roughness to the buildings based on the experimental device.

In this paper, the numerical model of the tornado generator is first established based on the CFD numerical simulation method. Using the radar observation data of Spencer tornado as the inlet boundary condition, the tornado wind field of corresponding grade in our country is simulated, and the tornado load characteristics of the low-rise buildings in different locations in the tornado wind field are studied. Then, the finite element model of the low-rise building is established, and the structural response and stress state of the building under the action of the tornado are analyzed by the one-way fluid structure interaction method, and then the failure mode and failure mechanism of the low-rise building in the tornado wind field are analyzed.

2. Numerical model

2. 1. Numerical model of tornado generator

The present numerical model of the tornado simulator is shown in Fig. 1. The computational domain is a cylinder. The lower part of the cylindrical surface is the inlet of the computational domain with radius R_1 of 900 m and height H_1 of 320 m. The height of convection region H_2 is 800 m, and the radius of outflow region R_2 is 200 m. The radar observation data of the radial velocity and tangential velocity of the specified Spencer (1998) tornado within the inlet height range are fitted as follows: