論 文 の 内 容 の 要 旨

論文題目

Numerical study of tornado induced flow fields and aerodynamic force by using LES model
(LESモデルを用いた数値流体解析による竜巻状渦に伴う流れ場と空気力に関する研究)

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Tornado is considered as the most destructive among the atmospheric phenomena. In order to reduce the damage caused by tornado, people need to know the following three points: 1. three dimensional flow fields in tornado; 2. effects from ground roughness and tornado translation; and 3. tornado induced aerodynamic forces on building. For the first point, even though some experimental and numerical researches have been done, the systematical research about the evolution of the flow fields as a function of swirling strength has not been carried out so far. And the link between the tornado in observation and that in the lab is not built. With respect to the second point, the roughness and translation effects to the flow fields in tornado, the researches are very limited. For the ground roughness effects, the conclusions from previous researchers are not consistent and people still don't know the reason why tornado can still bring very large damage in urban area. For the tornado translation effects, previous researchers have found some differences between the stationary tornado with the translating tornado. However, people still don't understand if it is necessary to take the tornado translating effects into consideration to reproduce the tornado flow fields in observation exactly. As for the third point, tornado induced aerodynamic forces on building, there is no fully three dimensional numerical research so far. And for civil engineers, they want to know if it is possible to estimate the tornado induced forces by using conventional methods, such as existed code or wind tunnel.

In this study the systematic research about the evolution of flow fields as a function of swirling strength is carried out firstly and the link between the tornado in the simulation with that in observation is built. The effects from ground roughness is examined in detail and the question why tornado can still bring very large damage in urban area is answered. Tornado translation effects are clarified numerically. Three dimensional numerical simulation is carried out to compute the tornado induced aerodynamic forces and a method estimating the tornado induced forces by using conventional wind tunnel is proposed.

In Chapter 1, the general background of this study, review of previous researches, objectives and outline of this thesis are presented.

In Chapter 2, the fundamental concepts and formulation of the FVM method and the LES

turbulent model are firstly briefly outlined, followed by the introduction of the method simulating the ground roughness and tornado translation. The sliding grid method used to simulate the tornado induced aerodynamic forces on building is also presented. Then the convergence criteria is introduced and at last the method modeling the particles which are applied to visualize the flow fields is introduced.

In Chapter 3, tornado-like vortices are investigated by using LES turbulence model. Four typical tornado configurations, weak vortex, vortex breakdown, vortex touch-down and multi-vortex are examined to provide the detailed information of the turbulent flow fields. It shows very good comparison between simulated tornado with the experiment. The force balances in radial and vertical direction are also evaluated by adopting the time-averaged axisymetrical Navier-Stokes equation. The local swirl ratio is used as an index to describe the surface intensification and the geometry of tornado vortices. The similarity between the simulated tornadoes and the full scale tornado is investigated. At last, the relationship between the local swirl ratio and the Fujita scale is derived to transfer the simulated tornado-like vortices to the full scale tornadoes. The transferred tornados in the numerical simulations show good agreement with the observed tornados in the Fujita scale.

In Chapter 4, the effects of ground roughness and the translation of tornado on the flow fields of two typical tornado-like vortices, vortex breakdown and multi-vortex, are investigated. It is found that at the multi-vortex status the maximum wind speed does not decrease when ground is rough and the height of maximum wind speed is still very low. The introduction of the tornado translation makes the simulated flow fields much closer to the tornado in real situation. The similarity of the flow fields after the introduction of the ground roughness and the translation of tornado is also studied. On one hand the local swirl ratio is still found to be the determinant of the flow fields very close to the ground. On the other hand, the relationship between the local swirl ratio and the Fujita Scale still holds.

In Chapter 5, the forces acting on a gable-roof building induced by a tornado are numerically calculated and the effects of building size as well as translation of tornado are examined. The numerical results show good agreement with experiment and the effects of building size as well as translation of tornado are not important. Volume averaged velocity is found to be the link between the tornado and straight-line wind situations. Removing the tornado induced atmospheric pressure drop, the building in tornado experiences similar responses with those in wind tunnel if the directions of volume velocity are same. Based on this finding, a method estimating the tornado-induced aerodynamic forces on the building model by using the conventional wind tunnel is proposed and good agreement is found in the outer region of tornado.

Chapter 6 summarizes the conclusions of this study. Tornados induced flow fields are

successfully reproduced and the link between simulated tornadoes with observation is built. Maximum wind speed does not decrease when ground is rough and the height of maximum wind speed is still very low. Translation effects have to be considered to reproduce exactly the observed tornadoes. Tornado induced aerodynamic forces are successfully reproduced. Volume averaged wind velocity is proposed to estimate tornado induced forces by wind tunnel and good agreement is found in the outer region.