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博士論文（要約）

Numerical study of turbulent flow fields in urban area and complex terrain using canopy models

（キャノピーモデルを用いた都市域内および複雑地形上の乱流場の数値予測）

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Most human activities are happened within the bottom of atmospheric boundary layer. In order to reduce the wind damage and make full use of wind energy, accurate prediction of both mean wind speed and turbulence is necessary, which requires accurate modelling of the effect of both surface roughness, such as buildings and trees, and topography. Canopy model, which is considered as alternative option of the rigid wall approach to allow prediction in large area, has been applied by some researchers with $k-\varepsilon$ model on modelling both buildings and trees. It is found that the mean wind speed can be well predicted, but predicted turbulence show discrepancy with measurements. The LES model has not been applied with canopy model to predict such flow fields. In addition, many efforts have been made on prediction of turbulent flow over terrain, and the steep terrain with smooth surface is found to be the most difficult one. $k-\varepsilon$ model shows poor prediction of both mean wind speed and turbulence, while LES model is found to be able to predict mean wind speed well but overestimate turbulence to some extent. What's more, the fact that application of numerical prediction in the real situation involves many issues and the current situation of absence of general guideline motivates present research to provide recommendations.

This study challenges two most complex conditions, the urban area with most complex surface roughness distribution and the mountainous area with most complex terrain. The LES model will be applied at first with canopy model to predict turbulent flow fields over three classical urban elements, staggered urban-type cube array, a row of trees and the isolated high-rise building. Then LES results will be used to clarify the applicability and limitation of modified $k-\varepsilon$/Canopy model. For prediction of turbulent flow over steep terrain, the hybrid RANS/LES model, which is expected to provide reasonable boundary condition for LES calculation and therefore show improvement, will be investigated and improved. The mechanism of turbulence motion over steep terrain with different surface roughness will be clarified. Finally, recommendations on application of numerical simulation in real situation will be provided on inflow generation, grid system determination and effects of database.

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 governing equations are given at first. The introduction of three RANS models, LES model as well as the hybrid RANS/LES model is then described. Two approaches of modelling surface roughness, the wall function and the canopy model, are also presented.

In Chapter 3, the LES model is applied at first with canopy model on prediction of turbulent flow fields over three classical urban elements, staggered urban-type cube array, a row of trees and the isolated high-rise building. Both mean wind speed and turbulence results simulated by modified $k-\varepsilon$/Canopy model and LES/Canopy model are compared to show the applicability and limitation of modified $k-\varepsilon$/Canopy model. Quadrant analysis is used to identify the organized motion in the wake region of tree, which can also explain the slow recovery of turbulent kinetic energy in the wake region of tree by modified $k-\varepsilon$/Canopy model.

In Chapter 4, the performance of two hybrid RANS/LES models will be investigated at first on prediction of turbulent flow over steep 2D ridge and 3D hill with smooth surface. Then the modified DDES model will be proposed. In order to clarify the mechanism of turbulence motion over steep terrain with smooth and rough surface, the probability density function (PDF) analysis and the quadrant analysis are carried out for steep 2D ridge by using the results from simulations with modified DDES model. Strong skewed organized motion is identified in the wake of steep terrain with smooth surface, which accounts for the deficiency of RANS model.

In Chapter 5, the performance of a synthetic method will be compared with precursor simulation method on turbulent inflow generation at first. Then procedure of inflow generation based on wind tunnel database for precursor simulation is proposed and validated. Hybrid grid system and iteration procedures are proposed to determine grid resolution and domain size, and applied in a real mountainous area with complex terrain. Database effects in complex terrain and urban area have been investigated and a procedure of combination of databases on roughness is developed.

Chapter 6 summarizes the conclusions of this study.

The content of Chapter 3, 4, 5 and 6 is scheduled to be published within 5 years.