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Experimental Study on Aerodynamic Features of Boundary Layer Developed past Spires over Wall Surfaces

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論 文 名　：Experimental Study on Aerodynamic Features of Boundary Layer Developed past Spires over Wall Surfaces

Title　（スパイヤー風下に発達する壁面境界層の流体力学的特性に関する実験的研究）

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論 文 内 容 の 要 旨

Thesis Summary

Rapid urbanization has become a global trend. According to the United Nations' 2014 report, 54% of the world population is currently residing in cities and is expected to reach 66% by 2050. In particular, megacities are continuously expanding due to the remarkable economic development especially in Asian regions. Under these circumstances, the pollutant emissions from industrial factories and automobiles have increased in cities, hence, air pollution and urban heat island phenomena have been widely observed.

Meanwhile, characteristics of the atmospheric boundary layer over urban surfaces dominate the transport processes of heat, moisture and pollutants, and has significant impact on the damage of strong gust, , the thermal environment of street canyons, and the diffusion process of toxic gases by terrorist attacks. Therefore, various researchers of urban climatology and wind engineering have continuously investigated the features of the urban boundary layer.

The flow state of urban atmosphere is mostly turbulent owing to both the mechanical shear due to the urban roughness and buoyancy production from heated surface. Therefore, the prognostic equations of velocity, temperature, and scalar concentrations cannot be directly solved, and the assumptions and modelling are essential to describe the phenomena. Thus, scaled model wind tunnel experiment remains as an important tool for the phenomenological grasp. In fact, wind tunnel experiments have significantly contributed to deepen the understanding of the urban airflow and transport processes. This thesis focus on a method by using spires to reproduce quasi-urban atmospheric boundary layer in a wind tunnel through the comprehensive review and the experiment.

In chapter 1, the author explained the significance of studies on the atmospheric boundary layer of urban areas and the issues of relevant wind tunnel studies, and described the purpose of this doctoral thesis with the composition of each chapter.

In Chapter 2, the author reviewed the past studies on the adjustment methods of inflow condition for scaled model wind tunnel experiment in wind engineering and urban climate fields. On a sufficiently wide smooth surface, the power law of the turbulent boundary layer is 1/7, whereas in the atmospheric urban area the power index takes a value range between 1/4 to 1/6. When a scaled down urban area model is installed in the wind tunnel and the wind flow around the model is observed, it is necessary to create a profile of the incoming wind flow that matches the power law with an appropriate index corresponding to the target area. In addition, it is impossible to reproduce the turbulent flow boundary layer over rough surface that sufficiently developed in the limited fetch length wind tunnel. Hence, these so-called passive methods have been adopted where various obstacles to produce the velocity reductions near the ground surface are installed in the windward position of the wind tunnel to generate a boundary layer similar to the urban atmospheric boundary layer.

Among these passive methods, the author focused on a slender vortex generator of a quarter elliptic-wedge or triangular shape, i.e. spire, and measured the downwind flow behind row of spires. This chapter provides the comprehensive review on past studies on the flow features behind spires. As a result, 1) spire was generally used in the wind tunnel experiments in the wind engineering field and experimental data on the influence of the shape and spacing between spires on the flow field was studied. Despite the popularity of spires, a comprehensive knowledge of the flow features past multiple spires has not been well compiled, and knowledge of the arrangement of spires has been shared only inside each laboratory, 2) The experimental data of the flow behind spires developing over smooth surface are limited, 3) The turbulence generated by the individual wake of each spire is not uniform in the spanwise direction.

In the third chapter, following to the comprehensive review of Chapter 2, multipoint measurement on the mean velocity and the turbulence statistic in the streamwise direction leeward row of spires was carried out, and the boundary layer thickness as well as the spanwise uniformity of the mean flow was studied.

The experiment was conducted in an open-circuit suck-through wind tunnel with a working section of 0.3m high x 0.3m wide and a total of 2.5m streamwise length. In order to obtain longer distance between the upwind row of spires and the measurement point i.e. fetch length, a smaller dimension of spire (0.05m) compared to the spire dimension that is generally used in wind engineering experiment was adopted. Subsequently, the author successfully acquired the experimental data of smooth surface for fetch length up to 26 times of the spire height. Based on this experimental result, the author clarifies that a fetch length of 13 times of the spires height is the least streamwise distance required for the wake of elliptic-wedge spires developing over smooth surface to generate a naturally developed wall boundary layer with less than 1% lateral heterogeneity.

In chapter 4, the author reports the results of wind tunnel experiments on the development process of the wake flow behind spire under a condition where only one spire was installed normal to the wall at the center of the wind tunnel. In this experiment, since in Chapter 3 discussed the recovery process of the wake flow behind row of spires for longer fetch distance, this chapter focus on the interaction between the individual wake of the spire with the development of wall shear boundary layer over the tunnel floor. The question of whether the wall shear boundary layer is delaying the recovery process of the wake flow generated behind single spire is considered. In this experiment, in order to reproduce the contrasting boundary layer depth, two types of walls i.e. a smooth wall and a regular cube array were adopted; for each wall, the spanwise distribution of the streamwise velocity was measured at two downwind positions and seven heights within and above the wall boundary layer with and without a spire. The experimental results demonstrate that the spanwise variations of the velocity behind a spire above the wall boundary layer show good agreement with the 2D self-similar profile for a 2D wake flow in a free shear flow. In contrast, the spanwise profiles of the velocity within the wall boundary layer show clear discrepancies from the 2D wake flow, the expansion of the wake width in the lateral direction is compressed, and the velocity deficit within the wake region is more significant compared with the data above the wall boundary layer. From these results, it suggests some mechanism occur between the wake flow generated behind spire with the wall shear boundary layer.

Chapter 5 elaborate the results of each chapter in this paper and describes future research subjects.