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EXPERIMENTAL STUDY ON TURBULENCE FLOW CHARACTERISTICS OVER A STEP MODEL

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The present work investigates the turbulence characteristics of a boundary layer flow over a two-dimensional step model with a rough surface. A hot wire Constant Temperature Anemometer (CTA) system with a split fiber probe and an X-type probe is used to investigate the turbulence characteristics in a wind tunnel experiments under neutral conditions. Two different types of windbreak fence are set on the step model surface. Porosities (ϕ) of the fence are 0% and 50%. Measurements analysis includes mean velocity, turbulent velocity, Reynolds stress, turbulent energy and eddy viscosity profiles over the step model surface and in the wake region. The results obtained are as the following: a) Wind speed without fence is higher than that in the other cases adjacent to the solid surface, b) Flow separation is quite small at the windward corner of the step without fence and porous fence, and c) Distortion of flow at the windward corner of the step creates steep gradient of the velocity and large turbulent mixing.

KEY WORDS: *Air flow over mountain; step model, windbreak fence, wind tunnel*

1. INTRODUCTIONS

The flow separation and reattachment are of great importance in many engineering fields such as civil, mechanical, aerospace, chemical and environmental engineering, because they appear their inevitable occurrence seriously affects the flow characteristics as well as the performance of fluid machinery. Hence, any modern computational fluid dynamics code should be tested in some flow problem with separation and reattachment before its use; in particular, accuracy of numerical schemes and turbulence models should be thoroughly evaluated. Among a number of flow modes with separation and reattachment, the flow over a backward-facing step is of the simplest geometry, but when it is turbulent the flow structure is yet very much complex and much remains to be explored. Up to the present, many investigators have attempted turbulence measurement in the backward-facing step flow with sophisticated experimental techniques [1]. However, there are relatively few studies on airflow over step topography with turbulent boundary layer [2-8].

The purpose of the study is to obtain the database, which are useful for validating Computational Fluid Dynamics models (CFD) to predict airflow over local topography. Therefore, the present study is concerned with measuring and investigating the turbulence characteristics in a boundary layer over two-dimensional step with rough surface, which models a cliff under neutral condition.

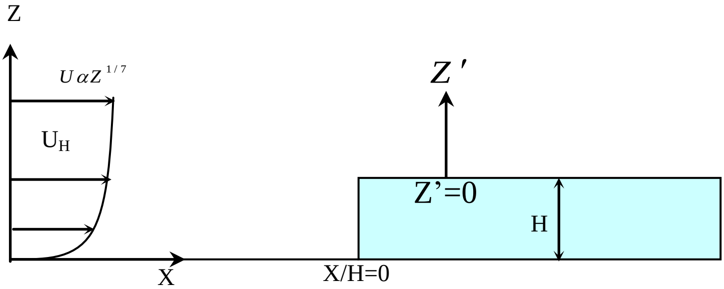


Fig. 1 Two-dimensional step model

2. EXPERIMENT APPARATUS AND PROCEDURE

Experiments were performed in a closed-circle boundary layer wind tunnel. The width and height of the test section were 2.2 and 1.5 m. The upwind fetch was 17m. The free stream velocity in the working section ranges from 1 to 33 m/s. A neutral stratified atmospheric boundary layer was simulated, using three spires, one 90 mm high cubic array placed just downstream of the contraction exit and followed by 60 and 30 mm cubic roughness element, covering 10.2 m of the test-section floor. This arrangement was employed to generate a thick turbulent boundary layer as the approaching flow. The mean velocity variation in the plane normal to the wind direction just after the contraction section is less than 1%. The turbulence intensity just after the contraction section is less than 0.5%.

Velocity was measured by. Three components of velocity vector (*U*, *V*, *W*) were measured using hot wire CTA system with a split fiber probe, which were 70 μm diameter and 1.25 mm long. An X-type probe was used to measure the Reynolds Stress.

3. TOPOGRAPHY MODEL

A two-dimensional step was used as a cliff model. The model is shown in Fig. 1. It is 75m high in the real scale. A 1/1000-scaled model (H=75 mm) was used in the wind tunnel experiment. Tripping wires (1mm rectangular column, 50 mm interval) are set at the surface of the floor of the wind tunnel and the upper surface of the step. The first tripping wire on the surface of the floor of wind tunnel is placed at *X/H*=-5.87. The first tripping wire on the upper surface of the step is set at *X/H*=0.13. Two types of windbreak fence are set at the same point of the tripping wire. One type is a solid fence and its porosity (ϕ) is 0%, the other type is porous fence (ϕ) is 50% while in case without fence, ϕ is 100%.

3.1. Simulated Boundary Layer

A thick turbulent boundary layer was simulated by positioning spires and arranging roughness blocks for a distance of 10.2 m from just after the contraction section. The mean velocity profile is correctly expressed by the power law.

$$U \alpha (Z)^n \quad (1)$$

Where U is the mean velocity in the leeward direction; U_H is the velocity at a height Z_H; Z is the height above the ground, and n is the power exponent. In the present study, a turbulent boundary layer for neutral atmospheric conditions in a rural area was simulated on a scale of 1/1000. Reynolds number based on U_H and H is 3.5 x 104.

4. RESULTS AND DISCUSSIONS

Figure 2 shows the profiles of mean velocity in the vertical direction at six different lines A, B, C, D, E, and F of the three cases of fences (ϕ=0%, 50%, 100%). Here, Z' in Fig. 2 means the height from the upper surface of the step. The wind velocity adjacent to the solid surface without fence (ϕ=100%) is higher than that of the other cases. Flow separation at the windward corner of the step in case ϕ=100 and 50% is quite small even if it exists compared with that of the case ϕ=0. Relatively, large separation is caused by the solid fences in case ϕ=0%. The difference between case ϕ=0% and 50% is relatively small except for the area near the windward corner. A thick internal boundary layer is generated by roughness at lines A, D, E, and F in the cases ϕ=0% and 50%. Inversely, internal boundary layer in case ϕ=100% is very thin because there is no roughness and the surface is relatively smooth at the same lines. While, in the line C, a thick internal boundary layer is generated in case ϕ=100% compared with the other lines due to the turbulent mixing, which is created by the distortion of flow at the windward corner of the step. The profiles of turbulence velocity ($\sqrt{u^2} / U_H$) are shown in Fig. 3. The turbulence velocity shows higher value near the windward corner in case ϕ=100% due to the steep gradient of the velocity than that of the other cases. The value of turbulent velocity at lines E and F in case ϕ=0% is the largest of all cases. Fig. 4 shows the profiles of Reynolds stress ($\overline{-uw}/U_H^2$) at the same lines of Fig. 2 and 3. The absolute value in the case of ϕ=100% is larger than those of the other cases near the windward corner of the step. This large absolute value of ($\overline{-uw}/U_H^2$) in case ϕ=100% is considered to be produced by steep gradient of the velocity near the corner. It means the large effect of turbulence mixing. Therefore, this makes small separation at the windward corner of the step in case ϕ=100%. In the downward area on the step, the results of case ϕ=0% shows the largest absolute value of all three cases. This is considered due to the largest resistance on solid surface in this case. Fig. 5 illustrates the profiles of turbulent energy (k/U_H^2) at the same lines of Fig. 2 and 3. The peak value of turbulent energy appears near the windward corner in all cases. The value of case ϕ=100% at this point is larger than that of the other cases. This large value of turbulent energy in case ϕ=100% is considered to be closely related to small separation in this case as described above.

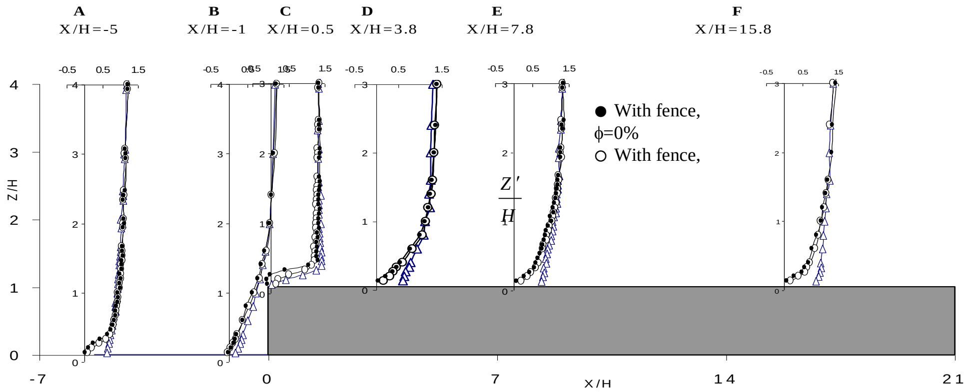


Fig. 2 Mean velocity component in longitudinal direction (U/U_H)

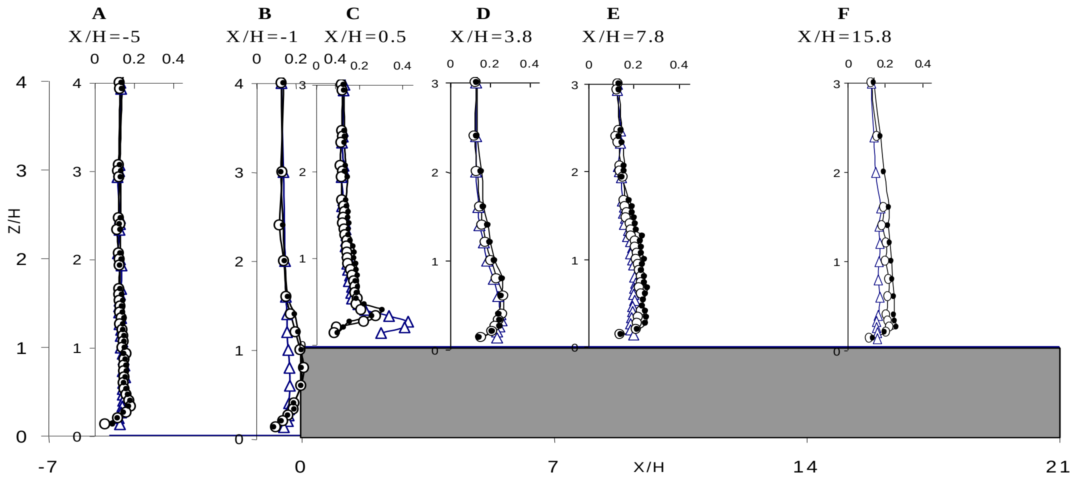
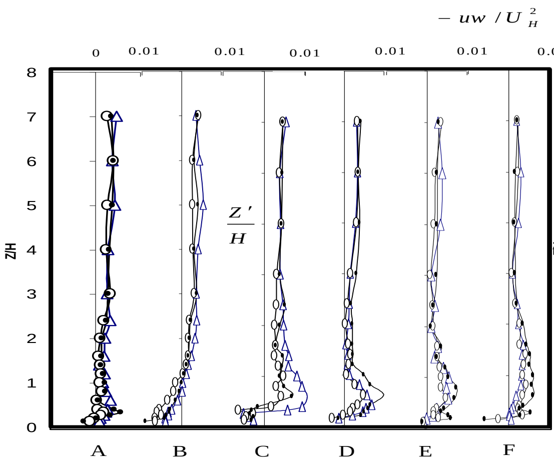


Fig. 3 Turbulence velocity component in longitudinal direction, $\sqrt{u^2}/U_H$



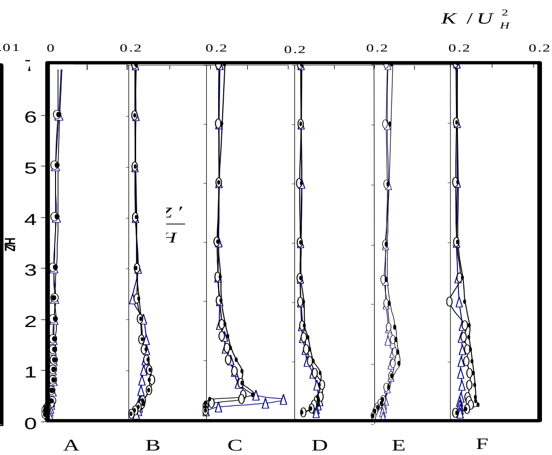


Fig. 4 Reynolds stress ($\overline{-uw}/U_H^2$)

Fig. 5 Turbulent energy

k/U_H^2

5. CONCLUSIONS

Study on the turbulence characteristics of flow over two- dimensional step with rough surface was conducted in the neutral stratified boundary layer in the wind tunnel experiments. The following conclusions were obtained. a) Wind speed without fence is higher than the other cases at adjacent to the solid surface, b) Flow separation is quite small flow at the windward corner of the step without fence and porous fence, c) Distortion of gradient of the velocity and large turbulent mixing generates a thick internal boundary layer, and d) Without fence, the gradient of mean velocity is steepest, turbulent energy and the absolute value of Reynolds stress is largest near the windward corner of the step.

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دراسة معملية لخصائص سريان الهواء المضطرب فوق نموذج خطوة

أجريت هذه الدراسة بغرض توصيف خصائص الهواء المضطربه في نفق هوائي أعد لذلك. ولذا فإنه تم محاكاة بنموذج ثنائي الأبعاد خطوة واحدة مع السطح الخشن في الظروف المعتدلة مع قياس سرعة الهواء باستخدام نظام الأنيوموميتر تابت الحرارة. وقد تم محاكاة السطح الخشن بوضع نوعين من حواجز الرياح مساميتها صفر و50% وقد تم قياس السرعة المتوسطة والاضطرابية وإجهاد رينولدز والطاقة الاضطرابية وشكل دوامة اللزوجة. وقد تبين من الدراسة أن:

1. سرعة الريحِ بدون حواجز أعلى مِنْ الحالاتِ الأخرى المجاورة للسطحِ الصلبِ
2. إفتراق صغيرُ جداً في ناحية الريحِ للخطوةِ بدون حواجز أو وجود حواجز مثقّبةِ المسامية
3. تشويهَ التدفقِ في ناحية الريحِ للخطوةِ تحدث الميلَ الحادَّ للسرعةِ و العاصفةِ المختلطة تكون هي الكبيرةِ.