EFFECTS OF REGULARLY SQUARE RIBS ROUGHNESS ON TURBULENT FLOW STRUCTURE IN CASES TWO AND THREE-DIMENSIONAL ROUGHNESS IN AN OPEN CHANNEL

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ABSTRACT

Effects of regularly arrayed of square roughness on turbulent characteristics in an open channel have been investigated with a completely rough bed surface with uniform stainless square ribs, where the roughness heights, k = 10mm, longitudinal spacing, λ = 4cm and transverse spacing, δ = 1cm. Detailed spatial measurements of streamwise and vertical velocity fluctuations were conducted using Particle Image Velocimetry (PIV) in a vertical plane along the completely rough bed surface.

Experimental results indicated that the maximum values of vertical and longitudinal distribution of main flow velocity showed that two-dimensional roughness is greater than three-dimensional roughness, also showed that the maximum values of Reynold shrear stress two-dimensional roughness have occurred at the front of the roughness elements, however the maximum values of Reynold shrear stress in case of three-dimensional roughness have occurred at the behind of the roughness elements, it was evident that two-dimensional roughness has two-directions of flow velocity i.e. on the x-axis and w-axis directions and three-dimensional roughness has three-direction of flow velocity on the x-axis, w-axis and v-axis directions, respectively.

It was described that three-dimensional roughness has barrier to flow bigger than two-dimensional roughness elements, although distribution of horizontal velocity, v-direction of this experiments yet explained.

KEYWORDS: open-channel, two and three-dimensional roughness, turbulence structures, PIV.

1. INTRODUCTION

The fundamental requirement for the evaluation of the flood safety at the rivers is to establish the law of turbulent structures. It is important to improve the accuracy of the estimation effects of the roughness elements to the flood in the river. Turbulent flow characteristics in the river flow are determined by a complex interaction system consisting of diverse sand waves, bed materials, channel form, in-channel vegetation and river structures. Current practice in the laboratory, to make judgments according scattered turbulence characteristics on the two and three directions flow caused by two and three-dimensional roughness elements which is arranged at the bed-flow in an open channel, and it is difficult to calculate the magnitude of flow velocity at the z point on the vertical direction of the bed-flow.

The law of turbulent flow over a completely rough bed in an open channel, which is part of basic knowledge, is dependent on the shape, distribution and size of bed roughness elements and on flow conditions. Important knowledge in this field has been accumulated through many studies.

It has been pointed out that in an area of turbulent flow over a completely rough bed in a wide straight channel with a rectangular cross section where the representative diameter of roughness elements is small relative to the water depth, the friction factor can be expressed in the form of a Prandtl–vonKarman logarithmic equation (Shohei Adachi, 1964,Sayre,W.W. et al.,1963). It has also been pointed out that in the region above the roughness sublayer defined by Raupach et al,1991., which is strongly affected by roughness, the logarithmic law and the universal distribution of turbulence characteristics hold true independent of the flow in the roughness sublayer (G.M.Smart,et al,2002). Others studies using direct numerical simulation (DNS) or particle image velocimetry (PIV), however, report that roughness affects not only the roughness sublayer but also the outer region and that mutual interference between the inner region and the outer region cannot be ignored. These reports indicate the necessity of a new approach.

(Leonardi S., et al,2003). As representative examples of laws of resistance derived by using artificial roughness elements, two dimensional roughness elements such as ribs and grooves and three-dimensional roughness elements such as warts and spheres have been studied (Nakayama,2006).

Ohmoto et al.,2005,2007, measured flow over a surface with high relative roughness formed by closest-packed spherical roughness elements by particle image velocimetry, which makes planar measurement possible, and found that there are stable, highly regular upward currents and downward currents in the vicinity of the roughness elements. As a result, the pointed out that in the flow in the roughness sublayer, uniformity of the mean flow and turbulence in the horizontal plane is disturbed considerably, and that the influence of roughness elements is strong. In particular, the pointed out that stable upward and downward currents are formed near the roughness elements and they are strongly correlated with main flow velocity, and that this correlation affects the law of resistance, mass transport and momentum transport of turbulent flow over a rough surface.

Ohmoto & Sukarno (2009) made measurements of flow over most closely filled spherical roughness elements with high relative roughness by using the PIV (Particle Image Velocimetry) method, a method that makes two-dimensional measurement possible. The measurements revealed that stable and highly regular upflows and downflows exist near the roughness elements. This has shown that in a flow within the roughness sublayer defined by Raupach et al., where the influence of roughness is strong, the homogeneity of the average flow and turbulence in the horizontal plane is disturbed considerably, indicating that the influence of roughness elements is very strong. It has been shown that if relative roughness is large, measured values of the resistance coefficient f derived from the Darcy–Weisbach equation tend to be slightly larger than the values of the friction coefficient derived from the logarithmic law for flow over a completely rough surface, and that the dimensionless Manning roughness coefficient is dependent on relative roughness.

In this study, in order to make a more exact turbulence structures characteristics of flow over two and three-dimensional roughness elements, square and rectangular cross-section ribs were chosen as roughness elements, and momentum transport were investigated by using PIV.

2. APPARATUS AND METHOD

The flume used in the experiment is a 10-m-long, 40-cm-wide, 20-cm-deep variable-slope re-circulating straight flume. A weir is installed at the downstream end so that water depth can be controlled. The flume bed and side walls are made of acrylic resin so that digital images can be taken through the side wall while laser light is illuminated from above.

In the right-hand coordinate system used, the x-axis is parallel to the direction of flow, the y-axis is parallel to the cross-channel (transverse) direction and the z-axis is the vertical direction (upward direction taken as positive). The mean flow velocity components and variable components corresponding to the respective axes are represented by U, V and W, and u', v', and w', respectively.

Figure 1 illustrates the coordinate system. Figure 2 shows the longitudinal and cross-sectional views of the roughness elements placed on the bed. Prismatic roughness elements made of stainless steel with a square cross section (k = a = 10mm) was used as roughness elements. The roughness elements were placed on the flume bed in a 6-m-long section whose upstream end was located at a distance of 2m from the upstream end of the flume. Three-dimensional roughness is expressed by longitudinal spacing, λ = 4cm and transverse variable spacing : (δ =0.5:1.0:1.5 and 2.0)cm.

The roughness element zone was 6 m long, and non-uniform flow occurred near the upstream and downstream ends of the roughness element zone. In the 3-to-4-meter long middle region, however, water depth was more or less uniform, and it was judged that flow was uniform.

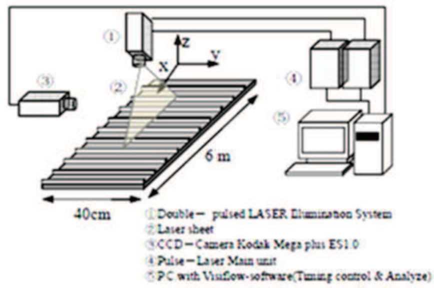
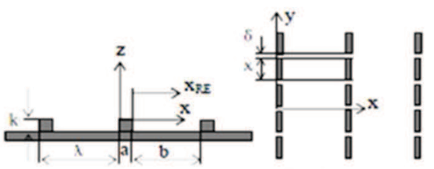


Figure 1 Experimental Apparatus



(a) side view (b) plan view

Figure 2 Boundary Conditions

Table 1 Experimental conditions for flow velocity

	Case 1	Case 2
Mean velocity, U_m(cm/s)	12.56	11.81
Flow depth H (cm)	7.96	8.47
Channel slope I_o	1/500	1/500
Aspect ratio B/H	5.00	4.70
Froude number $U_m/(gH)^{1/2}$	0.14	0.12
Reynolds number U_m H/v	10,000.00	10,000.00
Relative roughness k/H	0.13	0.12
Roughness height k(mm)	10.00	10.00
Friction velocity u_* (cm/s)	3.95	4.07
Discharge Q (l/s)	4.00	4.00
Roughness arrangement	2-D	3-D

Table 1 shows the experiment conditions under which flow over a rough surface was measured by using three-dimensional roughness elements. In all cases, the roughness Reynolds number exceeds 70, indicating that the surface is completely rough. For the purpose of flow measurement, particle image velocimetry (PIV), one of the widely used methods of non-contact measurement, was used.

3. RESULTS AND DISCUSSION

Mean Flow velocity

Experimental results of turbulent flow using square ribs roughness elements, the distribution of main flow velocity showed that two-dimensional roughness is greater than that three-dimensional roughness velocity was about 10.03%, and longitudinal distribution of main flow velocity showed that in the case of two-dimensional roughness is greater than three-dimensional roughness was about 7.59%, it was evident in both cases that three-dimensional roughness has barrier to flow is bigger than in the case of two-dimensional roughness, which was caused three-dimensional roughness elements having a relative roughness element spacing of $\delta/k = 1$ (i.e., the spacing between roughness elements in the transverse direction is about the same as the roughness element height, k). Base on evident above, it was enabling that in the case three-dimensional roughness has v-axis velocity direction, however need on next research.

In this results of the research also shown that the vertical distribution of main flow velocity is bigger than longitudinal distribution of main flow velocity was about 2.44%, it was evident according logarithmic law for turbulent flow in an open channel, the convective momentum transport have given effect on main flow velocity.

The magnitude of vertical and longitudinal distribution of main flow velocity can be described using Figures 1 and Figure 2.

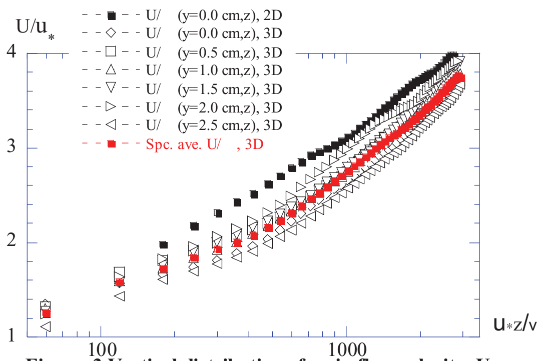


Figure 3 Vertical distribution of main flow velocity, U comparing 2-D and 3-D at $\lambda = 10$ cm

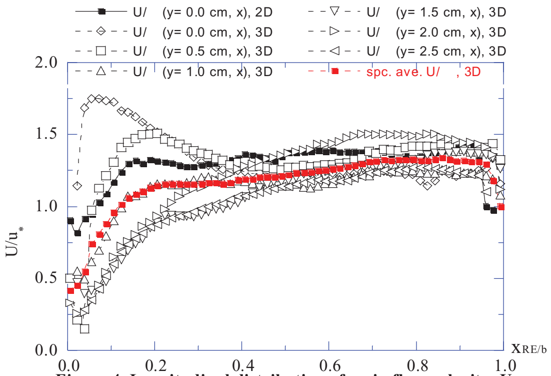


Figure 4. Longitudinal distribution of main flow velocity, U comparing 2D and 3D, at the z=0 cm and λ =10 cm

Turbulence Characteristics

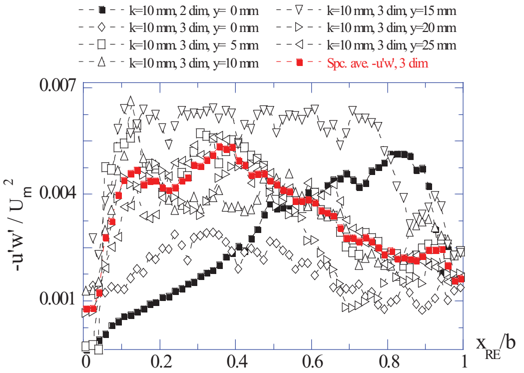


Figure 5 Longitudinal distribution of Reynolds shear stress, comparing 2D and 3D, z=0cm and λ=10cm

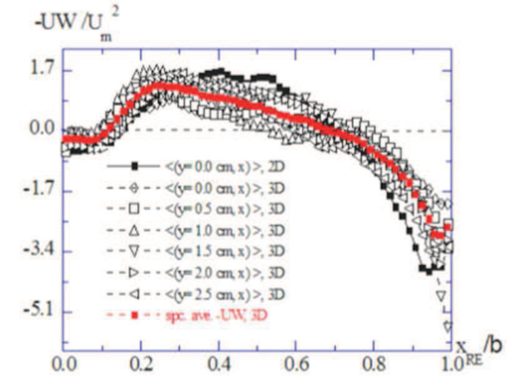


Figure 6 Longitudinal distribution of convective momentum Transport, comparing 2D and 3D, z=0 cm and λ=10cm

Figure 5 Longitudinal distribution of Reynolds shear stress, $(\overline{u'w'})$, showed that in the case of two-dimensional roughness the maximum value of shear stress was located at the front of the roughness elements around (0.8-0.9) x-axis from x = 0, it was describe that barrier of flow two-dimensional roughness was concentrated at the front of the roughness elements, it was also enabling that in the case of two-dimensional roughness has two-direction of flow velocity, i.e. on x-axis and y-axis direction, respectively.

Figure 6 Longitudinal distribution of convective momentum transport, UW, showed that in the case of two-dimensional roughness, the maximum of convective momentum transport was located at the (0-1.5) x-axis from x=0, in this conditions three-dimensional roughness is bigger than two-dimensional roughness, it was evident that three-dimensional roughness according at vertical and longitudinal distribution of main velocity has barrier of flow is bigger than in the case two-dimensional roughness. Also from figure 6 shown that the momentum transport of two-dimensional roughness is smaller around at (7-10) x-axis, from x=0.

Figures 5 and 6 shown that effects of square ribs roughness with roughness arrangements on longitudinal spacing, λ=4cm, and transverse spacing δ=1cm have made distribution of Reynolds shear stress, $\overline{u'w'}$, and convective momentum transport, UW, three-dimensional roughness has barrier to flow is bigger than two-dimensional roughness.

The equation of momentum transport, $\overline{u'w'}$, could be defined using by Ohmoto's equation (2010) like on the bellow:

$$\text{Momentum transport} = \left(-\overline{u'w'}\right) + (-UW) + \nu\frac{du}{dz}\bigg|_{\substack{2-D\\ Max.}} \tag{1}$$

$$\text{Momentum transport} = \left(-\overline{u'w'}\right) + (-UW) + \nu\frac{du}{dz}\bigg|_{\substack{3-D\\ Max.}} \tag{2}$$

Ratio of Momentum transport could be calculate as follow,

$$\text{Momentum transpot} = \frac{\left(-\overline{u'w'}\right)+(-UW)+\nu\frac{du}{dz}\Big|_{\substack{3-D\\ Max.}}}{\left(-\overline{u'w'}\right)+(-UW)+\nu\frac{du}{dz}\Big|_{\substack{2-D\\ Max.}}} \tag{3}$$

The results analysis of ratio momentum transport could be shown like on the Table 3

Table 3: Momentum transport

Variables	3D	2D	3D/2D
$-\overline{u'w'}$, maximum	0.98491	0.8746	1.05757
-UW, maximum	1.7285	1.6911	%
Total	2.7 1341	2 .5657	6%

Momentum transport in the cavity between roughness elements by advection, in currents by downflow, then to be the upward flow, it's strong in the narrow areas either in the case of two-dimensional roughness also three-dimensional roughness, weak inflow occurs in a wide area, shows a similar distribution trend. In the case of three-dimensional roughness compared to the two-dimensional roughness, the maximum value of the flow of the momentum was generated on the upstream side, for its size is about the same tend to be slightly smaller the maximum value of the outflow.

In addition, In the case of three-dimensional roughness the total of momentum transport into the cavity roughness showed a large value with 6.0% compared two-dimensional roughness. However, the average value of momentum transport of three-dimensional roughness is obtained 7% from the longitudinal side surface. Spatial variation in the transverse direction is not caught off enough. In this regard I want to do further study for the next work.

4. CONCLUSIONS

In this study, for the purpose of investigating the structures of flow over two and three-dimensional roughness elements with a higher level of exactness than in the past, turbulent flow was investigated by using prismatic roughness elements, and momentum transport was investigated by using particle image velocimetry. The findings of this study are as follows:

1. Mean flow velocity of vertical and longitudinal distribution of main flow velocity showed that two-dimensional is greater than three-dimensional was about 10.13 % and 7.59%, it was evident that in the case of three dimensional roughness has barrier of flow is bigger than two-dimensional roughness. It was also evident that in the case of three-dimensional roughness has x-axis, w-axis and v axis velocity directions, whereas in the case of two dimensional has two direction velocity on the x-axis and w-axis, respectively.
2. Turbulent characteristics of two-dimensional roughness showed that the maximum value of Reynolds shear stress was located at the front of roughness elements around (0.8-0.9) from xRB=0, it was enabling that two-dimensional roughness has two direction of velocity, i.e. x-axis and w-axis direction, respectively. Also in the case of three-dimensional roughness showed that the maximum value of Reynolds shear stress have occurred at the behind of roughness elements around (0.1-0.4) from x=0, it was enabling

that in the case of three-dimensional roughness has three velocity direction, i.e. on the x-axis, w-axis and on the v-axis, however in this experimental concentration research to horizontal velocity direction not yet defined. Both of cases of turbulence characteristics in the case of two and three-dimensional roughness enabling create momentum transport which was caused velocity resistance.

3. Turbulence characteristics of convective momentum transport have occurred near at the roughness elements, such as shown on the Figure 6. The convective momentum transport on the case of two-dimensional roughness is smaller than three-dimensional roughness have occurred at the (0.1-0.3), x-axis, from x=0, also on the three-dimensional roughness is bigger around (0.7-1.0) at the front of roughness element, x-axis, from x=0. Both of the area which was made momentum transport were located near of the roughness elements, it was evident that square ribs roughness with height, k=1 cm, longitudinal spacing, λ=4cm, and transverse spacing, δ=1cm) have made velocity resistance.
4. The values of momentum transport of this experimental results, showed that in the case of three-dimensional roughness is bigger than two-dimensional roughness was about 6%. Where the maximum values of three-dimensional roughness equal to 1.785 and two-dimensional roughness equal to 1.6911, respectively.

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