Effects of regularly arrayed over square ribs roughness on resistance flow and momentum transport in an open channel

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1. Abstract

Flow resistance and momentum transport characteristic have been investigated in turbulent flow over regularly arrayed square ribs roughness elements in an open channel. Longitudinal and transverse spacing were λ/k=10mm and λ/k=8mm for mainstream direction, also at the δ/k=10mm and δ/k=5mm for transverse direction. Roughness high are k=10mm and k=5mm, respectively of each experiment. Detailed measurements of flow velocity in the vertical and horizontal cross section plane was used Particle Image Velocimetry (PIV). Results of the research shows that ratio of flow resistance between three and two-dimensional roughness was about 7% and momentum transport in the three-dimensional roughness cases is greater than two-dimensional roughness case was about 6%, because affected by barrier to flow in the pertaining the downflows of roughness elements for three-dimensional roughness cases is greater than two-dimensional roughness case.

Keywords: Square ribs; roughness spacing, flow resistance and momentum transport, PIV.

2. Introduction

A knowledge pertaining to resistance flow and turbulent flow structures is important in the solutions of several problems in hydraulics engineering. The Nikuradse's concept of an equivalent sand grain roughness size has been successfully used in a wide variety of problems involving hydraulic resistance to flow. Also effects of regularly arrayed over square strip roughness with varieties of spacing, size, shape and arrangement models have developed by Sayre and Albertson, (1961); Knight et al. (1979); Jean Piquet, (1999); Kameda et al. (2004); Valino et al. (2011). However, the maximum resistance flow particularly effects of transverse spacing between roughness elements still unknown.

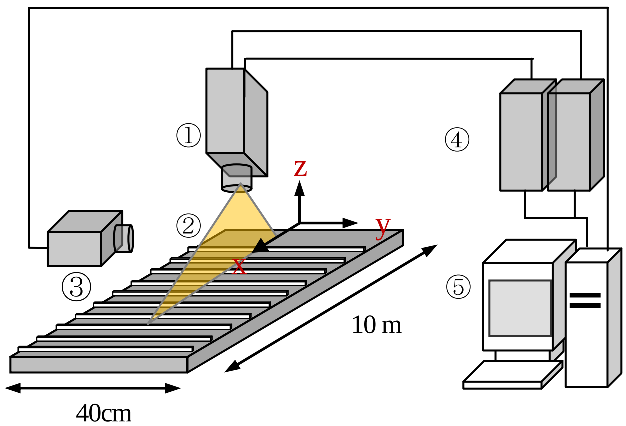
In this study, the magnitude of resistance flow and momentum transport have examined with varied longitudinal spacing of λ=(4;6;8;10;12;14;16)cm and varied transverse spacing of δ=(0.5;1.0;1.5;2.0;4.0)cm.

The results of the research for flow resistance and momentum transport have examined in detail.

3. Apparatus and method

Experiments test was used a circulation-type variable-slope straight, with dimensions are 10m length, 40cm width and 20cm height. The tracer of flow velocity measurements was used Nylon particle in 80um diameter and (1.02~ 1.05) kg/cm3 in specific gravity, flow velocity measurements was used PIV tools.

Square ribs roughness were arranged of 6meter length from the upstream end 2meter of the flume to the downstream, flow rate, Q= 4l/s, longitudinal and transverse spacing between roughness elements were λ=10cm and λ=8cm; at the δ=10mm and δ=5mm, roughness high are k=10mm and k=5mm, respectively. Uniform flow depth was measured of 6 points from upstream roughness to the end of roughness elements arrayed.



① Double- pulsed LASER Illumination System
② Laser sheet
③ CCD-Camera Kodak Mega plus ES1.0
④ YAG-Laser Main unit
⑤ P.C.with Visiflow-software (Timing control & Analyze)

Fig. 1 Flow measurements system

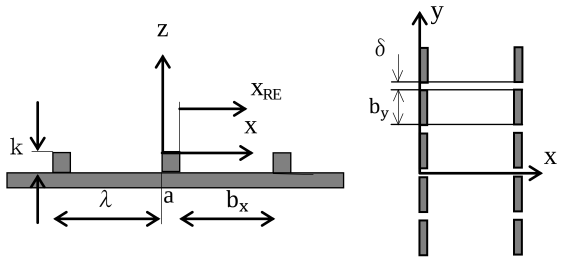


Fig. 2 Channel bed boundary conditions

Table 1 Flow measurement conditions

Parameters and variables		Case1	Case2
Mean flow velocity	U_m(cm/s)	12.56	11.81
Flow depth	h_0 (cm)	7.96	8.47
Channel slope	I_0	1/500	1/500
Aspect ratio	B/h_0	5.00	4.70
Froude number	$U_m/(gh_0)^{1/2}$	0.14	0.12
Reynolds number	$U_m h_0/\nu$	10000.00	10000.00
Relative roughness	k/H	0.126	0.118
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 arrangements		2 dim.	3 dim.

4. Results

Figure 3 shows the maximum values of resistance flow have occurred on the λ/k=10cm and λ/k=8mm for longitudinal spacing with the roughness high, k=10mm and k=5mm, respectively.

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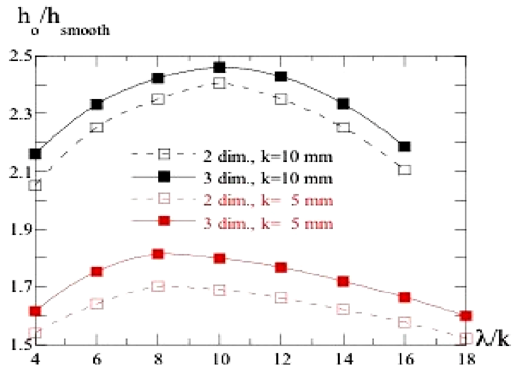

Fig. 3 Relation between uniform flow depth and longitudinal relative roughness spacing

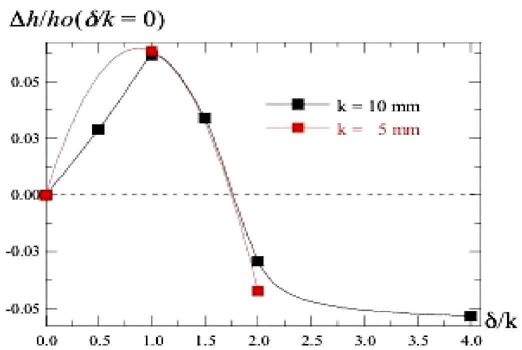

Fig. 4 Relation between flow depth and transverse relative roughness spacing

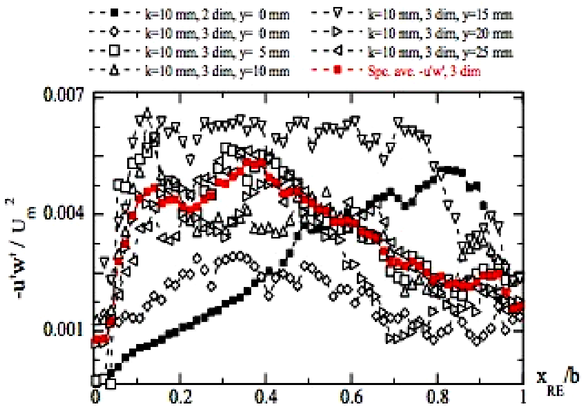

Fig. 5 Longitudinal distribution of Reynolds shear stress

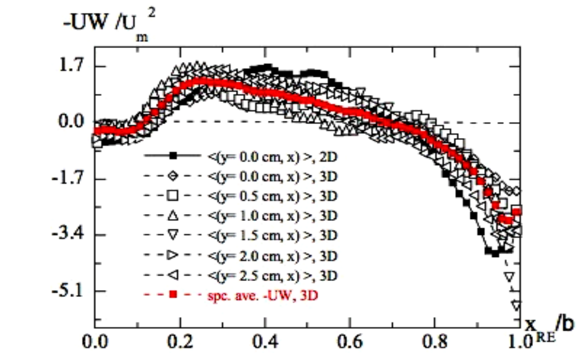

Fig. 6 Longitudinal distribution of convective momentum transport

Figure 4, shows the maximum values of resistance flow were occurred on the δ/k=10mm and δ/k=5mm for transverse spacing with roughness high are k=10mm and k=5mm, respectively. Figure 3 and Figure 4, also shows the values ratio of resistance flow between three-dimensional roughness cases and two-dimensional roughness case are about 7.3% for roughness high, k=10mm and about 7.2% for roughness high, k=5mm, respectively.

Figure 5, show the maximum value of Reynolds shear stress was located at the downflow of the roughness elements in the nondimensional values were about 0.985 in the x-axis direction about 0.5 from the upstream of the roughness element for three-dimensional roughness and 0.874 in the x-axis direction i.e. 0.8 to 0.9 for two-dimensional roughness case. Also shows the momentum transport became active in the groove region below 0.5 in the mainstream direction, indicated as affected of transverse roughness spacing, δ/k=10mm.

Figure 6, show the longitudinal distribution of convective momentum transport, and the maximum values of momentum were about 1.728 for three-dimensional roughness cases and 1.691 for two-dimensional roughness case and which were located by about 0.25 for three-dimensional roughness in the x-axis direction and about 0.4 for two-dimensional roughness case, in the x-axis direction The value of momentum transport have examined was about 6%, where is the cases of three-dimensional is greater than two-dimensional roughness case.

5. Conclusions

The knowledge was finding from this study are like on the bellow:

① The values ratio of resistance flow in the three-dimensional roughness cases is greater than two-dimensional roughness case were about 7.3 % and 7.2% for roughness high, k=10mm and, k=5mm, respectively, indicated, the resistance flow for three-dimensional roughness cases is greater than two-dimensional roughness case.

② The value of momentum transport in the three-dimensional roughness cases is greater than the two-dimensional roughness case was about 6% for roughness high, k=10mm.

③ The transverse spacing of δ/k = 10mm it is affected to the resistance flow velocity so that the causing of the uniform flow depth of three-dimensional roughness cases is greater than two-dimensional roughness case.

④Longitudinal and transverse spacing have influenced to the resistance flow and momentum transport characteristics.

6. References

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