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Investigating the characteristics of surface oscillations of flow through obstacles using Roshko and Ursell dimensionless numbers

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ABSTRACT: Vortex is shed by flow collision with obstacles in its path. If the frequency of vortex shedding equals the frequency of natural oscillations of flow, resonance will be created and transverse oscillation perpendicular to flow with greatest wave amplitude will occur. In this study, in order to investigate the characteristics of the transverse wave caused by the vortex shedding of the obstacles, 135 cylinder barriers with a diameter of 20 mm in 5 different configurations were arranged in the laboratory flume. In total, 900 tests were carried out which variables were flow discharge, average flow depth, channel slope, longitudinal and transverse distance between obstacles. In each test, after the formation of transverse oscillations, their characteristics including amplitude and frequency of wave were recorded. Then, the effective variables on transverse wave characteristics and their effects on the involved dimensionless numbers were investigated. The results indicated whatever the flow discharge is increased, the maximum wave amplitude due to resonance occurs in larger average flow depth, which has more amount. Also by changing the longitudinal distance of obstacles, Roshko's changes relative to increasing of Ursell were ascending at the beginning and they were reversed after reaching a certain range of Ursell number; moreover, by increasing the flow discharge, the rate of Ursell changes relative to Roshko decreased. Finally, by using dimensional analysis and statistical software, the equations between Roshko with Ursell and Froude numbers were proposed for each of the modes I and II and the validation of equations were approved (R2= 0.92).

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1. INTRODUCTION

When there is a set of obstacles in the direction of steady flow in downstream of obstacles, some microwave which called vortex will be shed. These microwaves cause the surface transverse wave, perpendicular to the direction of main flow. Whenever the frequency of vortex force shed from obstacles (f_s) is equal with the flow natural fluctuations of water (f), which is dependent on canal width and flow depth, resonance will happen and transverse wave with the largest amplitude will be created [1].

A lot of extensive researches with the similar subject with this research have been conducted. In most of them, the aim was examining drag and uplift forces on obstacles and these obstacles have been considered as a model of rigid vegetation in the flow [2-6]. A limited number of these researchers have been conducted to examine the features of wave and created frequency due to collision of flow with obstacles. Also in these researches, features for transverse wave were described by the relative amplitude of the wave or Strouhal number, but in the present study, features of wave have been described by two dimensionless numbers known as Roshko and Ursell [7-11].

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2. METHODOLOGY

Experiments related to this research were conducted in hydraulic laboratory flume in the technical faculty of Arak University. This flume had a rectangular section with 50 cm width, 60 cm height am 9 m useful length (without considering primary and terminal tanks). In order to vortex shed and create the transverse oscillation in the flow, 135 cylinders with the diameter of 20 and height of 250 millimeters were provided and used. These cylinders, which were made of Ertalon, were fixed and placed on the floor of flume by screws in parallel and zig-zag configuration. In Fig. 1 the vortex

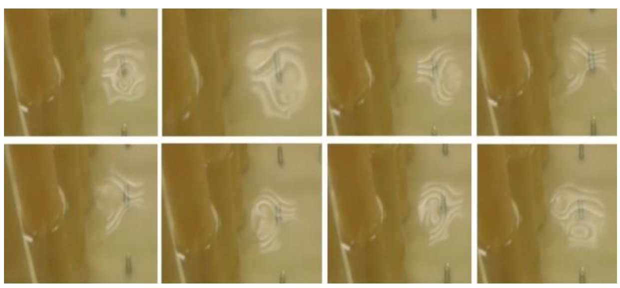

Fig. 1. A sample of vortex shedding from obstacles in the laboratory flume of present study

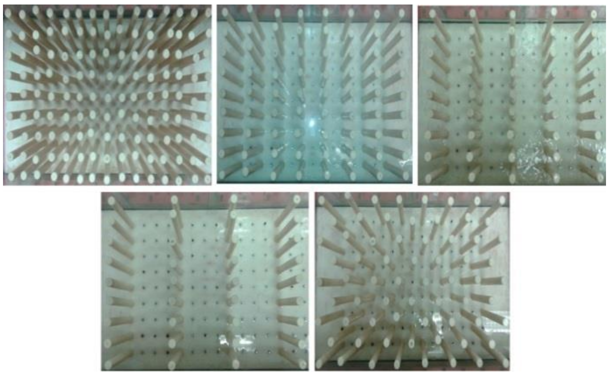

Fig. 2. The various obstacle configurations of present study

shedding phenomenon in one part of the experiment was shown. Canal slope was adjusted in two different statuses of 0.001 and 0.002 by using a hydraulic jack. The flow discharge in these experiments was 4.3, 8.6, 10.3 and 16 liters per second. Obstacles were arranged in the longitudinal and transverse distance of 5, 10, 15 and 20 millimeters in five different postures (Fig. 2). After creating the intended configurations of obstacles and adjusting flow rate and slope, by closing the terminal valve in the flume the, level of water increased sufficiently to create waves. In every stage of forming waves and having stability in amplitude and frequency of the wave, by using installedulers and chronometer, a measure will be done. This action was repeated until wave modes I and II were formed. Dimensionless numbers in this study were Froude (F_r), Reynolds (R_e), Strouhal (S_t.), Roshko (R_o) and Ursell (U_r) which were defined as follow:

$$F_r = \frac{V}{\sqrt{gH}} \quad (1)$$

$$R_e = \frac{VD}{\nu} \quad (2)$$

$$S_t = \frac{f_s D}{V} \quad (3)$$

$$U_r = \frac{A\lambda^{2}}{H^3} \quad (4)$$

$$R_o = \frac{f_s D^2}{\nu} \quad (5)$$

Where V is velocity of flow, g is gravitational acceleration of the earth, H is mean depth of flow, D is obstacle diameters, ν is kinematic viscosity, A is wave amplitude, f_s is the frequency of vortex shedding and λ is wavelength which is defined as Formula 6.

$$\lambda = \frac{2B}{n} \quad (6)$$

Where B is width of laboratory flume and n is wave mode.

3. RESULTS AND DISCUSSION

There are conditions, when an otherwise steady uniform flow in an open channel, containing obstructions formed by rigid cylinder vertical obstacles, can trigger resonance conditions which produce surface waves that propagate in a direction perpendicular to the longitudinal flow in the flume. These transverse surface waves are created by oscillating forces on the fluid that occur when vortices are shed periodically from the obstacles in the channel. When resonance conditions occur these periodic forces reinforce the wave generation. The waves then reflect back and forth between the channel walls increasing the wave amplitude to a limit governed by energy-dissipation effects. The resonance criteria required for the creation of the transverse waves is that the wave period, which is dictated by the channel's width and depth of flow, is equal to a multiple of the period of the vortex shedding from the obstacles.

An equation between Roshko and Ursell was proposed for modes I and II of transverse waves. The range of changes for Roshko was from 160 to 468 and for Ursell was from 0.02 to 36. Whatever the flow discharge to be lowered the gradient of Roshko variation will be higher than Ursell. According to laboratory observations, the reason of that was whatever the flow discharge decreases, Transverse oscillations are formed at lower depths than the flow that this result makes the progressive growth of Ursell versus Roshko number.

Also whatever the flow discharge to be lowered wave frequency variations in any modes are limited to a smaller interval and in the following, Roshko number changes will be slower than Ursell.

Changing the longitudinal slope of the flume has no significant effect on variation of two dimensionless numbers Roshko and Ursell relative to each other.

Finally, by using dimensional analysis to anticipate Roshko number with the help of Ursell, a dimensionless number, following equations are proposed.

$$R_o = 333.63 + 4.60\, U_r^{1.20} F_r^{0.03} \qquad n = I \quad (1)$$

$$R_o = 235.70 + 3.18\, U_r^{1.15} F_r^{0.32} \qquad n = II \quad (2)$$

In order to validate of these equations, the remaining 30%

of the laboratory data was used. The correlation coefficient squared for the first and second equation was 0.95 and 0.92 respectively, which confirms these equations.

4. CONCLUSIONS

Changes in Roshko and Ursell related to transverse waves were examined based on changes in flow features and some equations to predict wave feature were presented. Investigating the validation showed that the outputs of the proposed equations were corresponded to the laboratory results.

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