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Experimental Investigation of the Characteristics of Surface Oscillations due to Passing flow Through Rigid Vegetation

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ABSTRACT: By passing and strike flow with vegetation, pressure area in upstream of plant and low pressure area in its downstream is formed. The pressure difference created in this way triggers separation of the boundary layer and consequently formation of vortices downstream of vegetation. When the frequency of vortex rooted from vegetation becomes equal to the natural frequency of the channel, transverse stationary surface waves are generated. In natural channels in areas where the flow rate is on the wane, the probability of growing plants is on the rise, incontrovertibly there is a free flow beside a flow passing through the plants.

In this study, the characteristics of the surface transverse oscillations caused by vegetation, introduced as rigid barriers, were investigated under different configurations of barriers and over a range of width percentage covered by obstacles (WPO). Totally, 378 experimental tests were conducted in a rectangular channel of 9 m length and 50 cm width. The variables studied included flow discharge, flow velocity and WPO. Moreover, flow discharges were ranged from 5 to 15 liters per second. It is shown that, as long as WPO increases, transverse oscillation are formed at larger depths, which also have a larger oscillation amplitude. For a certain flow depth, increasing WPO results in growth of oscillation amplitudes. Based on dimensional analysis, regression relationships were extracted to predict the relative amplitude of transverse oscillations as a function of WPO, among other affecting parameters. Overall, the empirical equations proposed in this study were found to reproduce experimental results with acceptable accuracy.

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1- Introduction

The fluid-structure interaction has major practical significance in various fields of engineering and science such as designing heat exchangers, groups of bridge piers, electricity generation, and other similar engineering structures. Extensive research has been devoted to study this phenomenon that arise in designing various engineering structures.

When the steady flow of water in a rectangular channel passes around an array of rigid vertical cylinders, the vortex shedding can trigger large fluid oscillations or surface waves. Transverse surface waves are created in a channel if the frequency of vortex shedding is in phase with the natural frequency of the transverse oscillation of the water wave for the channel's width and depth [1]. The vertical cylinders can represent bridge piers, a group of piles driven in a stream bed, or the rigid stems of plants in a wetland [2].

When the amplitude of the wave is large and its frequency is small, the power of the wave and its effect on the structures become more significant; therefore, among the wave-dependent variables, more attention should be paid to its relative amplitude [1-7]. So far, a variety of relationships have been proposed to predict the relative amplitude of transverse oscillations based on wave characteristics, barrier characteristics, and dimensionless numbers of Strouhal or Froude [1-7]. Almost all of these studies [1-7] have dealt with cases in which the width of the channel along the specified reach is entirely covered by barriers. In the present study, it is tried to investigate the influence of width percentage covered by obstacles on the relative amplitude of the transverse oscillation. This is motivated by the fact that in natural channels such as rivers, because of the lower flow velocity along the sides than the middle part, the plants are more likely to grow in shallower parts. Therefore, there is always a free flow in the vicinity of a flow that passes through the vegetation.

2- Methodology

The experiments were conducted in a rectangular flume of 9 m long, 50 cm wide and 60 cm deep with a constant longitudinal slope of 0.001. During the experiments, the flow rate, which varied from 5 to 15 liters per second, was recorded by an ultrasonic flow meter. In order to simulate vegetation, 135 cylinders of 2 cm diameters (D) and a height of 25 cm

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were installed on the flume bed. Longitudinal distance (P) and transverse distance (T) between barriers at all stages of the experiments was considered constant and equal to 5 cm. Totally, 378 experimental tests were conducted with seven ratios of channel width has been covered by barriers (N_p) as shown in Figure 1. For every arrays of barriers, increasing the flow velocity continued until wave mode I changed to the wave in mode II. In each test, the values of amplitude (A), flow depth (H), frequency (f_s) of transverse wave and flow velocity (V) were recorded. The Froude (Fr), Reynolds (Re), Strouhal and Ursell (Ur) numbers are, respectively, defined as follows:

$$Fr=V/\sqrt{gH} \quad (1)$$

$$Re=VD/\nu \quad (2)$$

$$St=(f_s D)/V \quad (3)$$

$$Ur=(A\lambda^2)/H^3 \quad (4)$$

Where ν is the kinematic viscosity and λ is wavelength.

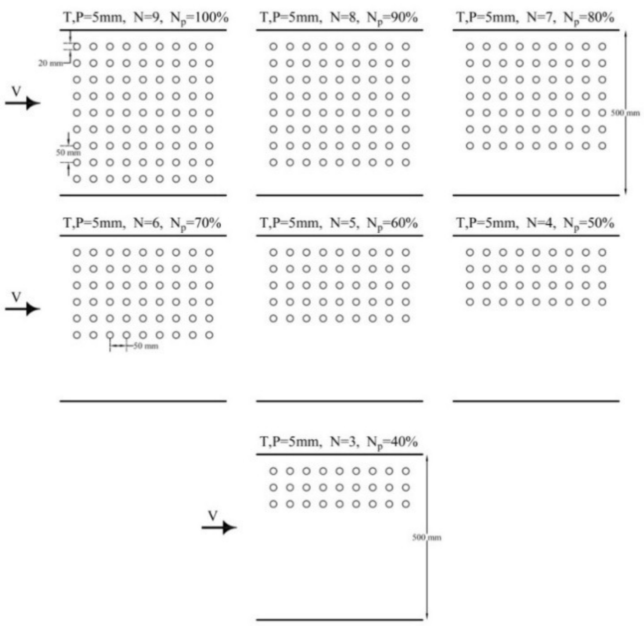

Figure 1. Obstacles arrangements considered in the experiments (T and P denote, respectively, the transverse and the longitudinal distances between barriers, N is the number of obstacle rows in the transverse direction, N_p is width percentage covered by obstacles)

3- Results and Discussion

The relationship between Reynolds and Strouhal numbers in modes I and II of transverse waves was evaluated.The Reynolds obstacle number ranged from 1051 to 6154 and the Strouhl number ranged from 0.05 to 0.36. Investigations showed that by increasing Reynolds number, Strouhal number was decreased in both wave modes. As well, by decreasing WPO, Strouhal number was decreased. Reducing the number of Strouhal number by increasing the Reynolds number can be attributed to the fact that with increasing the average flow rate and the turbulence of the vortex, the frequency of the wave decreases and therefore the number of strouhal decreases.

In these experiments it was found that by increasing the WPO, transverse oscillations occur in greater depth and with greater range of amplitude. In addition, it was found that at a constant flow depth, by increasing WPO, the oscillation amplitude also increases which its ascending trends are constant in each of the modes I and II for various discharge. Finally, based on dimensional analysis, the empirical expressions were derived to predict the relative oscillation transverse amplitude. In addition to Reynolds, Strouhal and Ursell numbers, the effect of WPO were also incorporated here. The resulting formulas for wave mode I and II are respectively given by:

$$A/H=0.215N_p^{1.25}\, Re^{(-0.34)}\, St^{(-1)}\, Ur^{0.42} \quad (5)$$

$$A/H=30N_p^{0.67}\, Re^{(-1)}\, St^{(-1)}\, Ur^{0.50} \quad (6)$$

In order to validate the formulas, the remaining 10% of the laboratory data was used. Accordingly, the correlation coefficient squared equaled 0.91 and 0.99 for Equations 5 and 6 respectively, which confirms the validity of the obtained relationships.

4- Conclusions

The characteristics of the surface transverse oscillations caused by vegetation, introduced as rigid barriers, were investigated under different configurations of barriers and over a range of width percentage covered by obstacles (WPO). Also regression relationships were extracted to predict the relative amplitude of transverse oscillations as a function of WPO, among other affecting parameters. Overall, the empirical equations proposed in this study were found to reproduce experimental results with acceptable accuracy.

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