Extended Abstract

Relationship between the Frequency of Transverse Waves and Characteristics of the Flow and Obstacles in Open Channels

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Introduction
Vortices resulted by fluids movement around cylinders were initially studied for gases. When a rigid cylinder is placed within a flow path (including gas or liquids), as the fluid particles reach the leading edge upstream of the cylinder, the velocity of fluid inclines to zero and the particle pressure decreases from the initial fluid pressure to a dynamic pressure at the stagnation point. Near the widest section of the cylinder, the boundary layers may detach from each side of the cylinder surface and form vortices and wake interfaces. Few research has been done on the formation of vortices in water environment and related phenomena. In a recent research, Ghomeshi et al. (2007) studied the transverse surface waves in a laboratory flume, 1.2 m in width and using cylinders with a diameter of 0.024 m.

Objectives
The present paper is focused on the transverse waves generated in a laboratory flume where the flow passes through a cluster of rigid vertical cylinders. The aim of the present research is to define the relation between the frequency of the transverse waves and the characteristics of the flow and obstructions in open channels.

Methodology
In the present study a laboratory flume, 6 m in length \((l)\), 0.72 m in width \((b)\), and with a height of 0.6 m was used. The bed slope was 0.005. The flow discharge \((Q)\) was adjusted to a constant value of 0.01 m\(^3\)/s using a magnetic flowmeter installed at the input system of the flume. The flow entered the laboratory flume passing a stilling tank. To control the depth \((h)\) and the velocity of water flow a weir gate was installed at the end of the flume. This weir was lowered in 5 mm intervals from a maximum value (proportional to the flow depth of the transverse wave of mode 1) to the height of zero during each experiment.

Plexiglas plates were used in the bed to stabilize the circular cylinders in the flow path. 250 wooden cylinders with the diameter of 0.025 m and the height of 0.35 m were used as rods. The rigid rods were screwed into the bed in desired distance and spacing for each arrangement (i.e. staggered or in-line).

Results and Discussion
Using the experimental data, the wave amplitude versus flow depth is drawn in graphs. In fig. 1 an example of such graphs is shown. In this graph the value of amplitude and flow depth are the average of measured values (laboratory data) read at three mentioned sections. In each experiment the hydraulic conditions of flow in the resonance state were determined for all types of transverse waves.
Proper formulations should be used in order to determine the proper values of Strouhal Number in open channels. Therefore at first, the frequencies of transverse waves \( f \) were calculated using the equation proposed by Dean and Dalrymple (1984), Eq. (1). Also the frequencies of transverse waves \( f_s \) are calculated by Eq. (2). The values of Strouhal Number are calculated from Fitz-Hugh’s graphs.

\[
f = \left( \frac{gn}{4\pi b} \tanh \frac{n\pi b}{h} \right)^{1/2}
\]  

where \( f \) = frequency of waves; \( g \) = acceleration of gravity; \( n \) = mode of the waves; \( h \) = depth of flow; and \( b \) is the width of the flume.

\[
f_s = \frac{SU}{D}
\]  

where \( f_s \) = frequency of vortex shedding; \( S \) = Strouhal Number; \( U \) = uniform flow velocity; and \( D \) is the diameter of vertical rods.

In fig. 2 the calculated and measured values of transverse wave frequencies are compared. According to fig. 2, Strouhal Number from Fitz-Hugh graphs is not a suitable approach to determine the frequency of transverse waves.

A special method should be employed to compute the frequencies of transverse wave. Dimensional analysis is used for this purpose. By statistical analyses, two distinct equations are proposed to calculate the Strouhal Number using SPSS software for two P/D ranges based on experimental data, Eqs. (3) and (4).

\[
S = \frac{K}{\left( \frac{T}{D} \right)^{1/2}} \left( \frac{P}{D} \right)^{1/2}, \quad \frac{P}{D} < 5
\]

where \( K \) is a constant coefficient equal to 1.21 and 1.48 for in-line and staggered arrangements, respectively.

\[
S = C \left( \frac{P / D}{(T / D)^{1/2} \cdot N} \right)^{1/3}, \quad \frac{P}{D} > 5
\]

where \( C \) is a constant coefficient equal to 0.43 and 0.52 for in-line and staggered arrangements, respectively.

**Conclusion**

1. By changing the hydraulic conditions of the flow, four types of surface waves were observed along the laboratory flume.
2. There is a direct relationship between the wavelength and the width of the laboratory flume in the resonance condition of the waves.
3. The maximum wave amplitude observed was 43 percent of the mean flow depth.
4. Taking into consideration that the majority of previous equations were intended for the calculation of Strouhal Number in gaseous fluids, the relationships between the Strouhal Number and each influencing parameter are calculated. Then, with the aid of dimensional analysis and SPSS software, two equations are suggested for calculating the Strouhal Number for a transverse wave in open channels.

**Keywords:** Vortex, Transverse wave, Wavelength, Frequency, Open Channels.
References