Experimental Investigation on Wavelength and Frequency of Transverse Waves from Vortex Shedding in Open Channels

Abdolazim Ghomeshi[1], Mehdi Ghomeshi[2], Reza Azizi[3] and Abdolrahim Hooshmand[4]

Abstract

As a fluid flow is encountered with a cluster of obstacles, a boundary layer is formed upstream the obstacles while the flow separation occurs downstream of the boundary layer. Due to the vortex behind obstacles and the natural frequency of water in the channel, a wave is formed in a transversal direction which is technically referred to as transverse wave. The present study focused on the formation of transverse waves in the open channels.

In this study a laboratory flume is used. A cluster of wooden rods are used as obstructions in the flume set up in various arrangements (staggered and in-line arrangements) on the bed of the flume. After determining hydraulic conditions in maximum wave amplitude (resonance) stage, the frequency of transverse waves specified for wave modes 1 and 2 (i.e. n=1 and n=2). Results show that in each mode of waves, the amplitude of waves increases by decreasing the distances between the rods. Also the frequency of the wave mode 2 is approximately 1.5 times grater then of the frequency of the wave mode 1.

Keywords: Vortex, Transverse Wave, Frequency, Wavelength, Open Channels.

1- Introduction

Wave perpendicular with the current, is of phenomena that is created by passage of the fluid around the objects, and creation of vortex in special situations.

By creation of vortex caused by a barrier, an alternative movement is made behind that barrier, and if we increase the barriers, due to numerous alternative movements resulted from each barrier, and depending on the prevailing physical conditions; these movements might change into another regular movement, which is appeared in the form of a wave with measurable characteristics. This wave is perpendicular with the direction of fluid's movement. That's why it is called the wave perpendicular with the current.

The mentioned wave is a wave perpendicular with the current, so its cause also must create a frequency to make or resonate such a wave. The barriers on the way of the current are the causes of the frequency and each barrier acts as a source of producing frequency.

Considering the characteristics of forces caused by vortex and the fluid environment, in order to create visible waves, we need to make an arrangement of barriers, so that by accumulation of frequencies, each barrier is capable of creating a viable and visible wave. Therefore, some of the barriers must be put together so that by accumulation of frequencies caused by each barrier, and also by making specific physical conditions; these waves find the possibility to be formed. In simpler words, these barriers must be put next to each other and in the width of the canal (perpendicular with the direction of fluid's movement).

[1] Civil Engineer, Khuzestan Water and Power Authority.
[2] Professor, Faculty of Water Science Engineering, Shahid Chamran University.
[3] Ph. D. Candidate, Faculty of Water Science Engineering, Shahid Chamran University.
[4] Assistant Professor, Faculty of Water Science Engineering, Shahid Chamran University.

Arranging the barriers consecutively

The important issue that must be mentioned in this research is wave viability.

In fluid's environment, if turmoil is created, it might be removed due to the weight of fluid itself, and other factors like the momentum caused by the fluid's movement. In order to create conditions suitable in which a considerable amount of the fluid gets frequentative, it is necessary to put rows of barriers in many positions. In fact, the rows which are consecutively in-line or staggered cause the creation of wave in a remarkable length of the route, which largely contribute to the viability and visibility of the wave. It is vital to mention that besides the wave viability, due to the way fluid passes, and also because of the distances between these rows, the bases of each row can affect the previous and the next rows, proportional to the arrangement of the barriers (staggered or in-line). This issue can also affect the traverse wave which will be later described. Figures 1, 2.

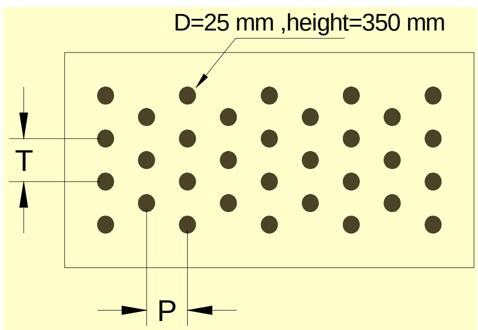


Fig. (2): staggered arrangement

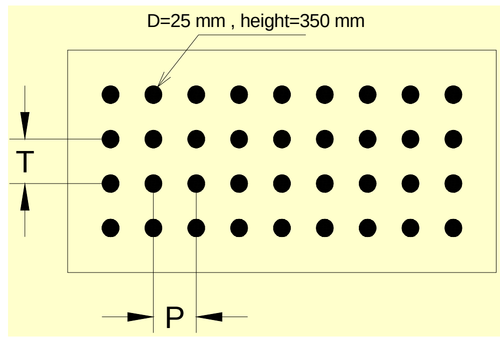


fig. (1): in-line arrangement

2- Study background

Most of the findings and researches on the vortexes caused by the passage of fluids around the barriers are related to the gases. Most of the research in this regard has been conducted by researches like Fitz-Hugh (1973), Belvins (1977), Zukauskas et al. (1988), etc. Oppositely, researches about the creation of vortex and related phenomena in the aqueous environment are quite scarce. The first findings are about the researches done by Crassse (1939) [2]. In another research, Zima and Ackermann (2002) suggested a formula for simulation of maximum values of the amplitudes of waves perpendicular with current, in dimensionless form (A / h) [4]. In a more recent research, Ghomeishi et al. (2007) have studied the formation of waves perpendicular with current, in open space passages; and suggested some relations to calculate the amplitude and the frequency of the waves [3].

3- Materials and methods

In this research, a laboratory flume was used with a rectangular section with a length of 6 meters, width of 72 cm, height of 60 cm, and constant slope of 0.005. The current's Debby was constant through the test as 10 lit/sec. Depth (and speed) control was done by a sliding valve, attached at the end of the flume. In this research, in every test averagely 250 wooden cylinders were used as the barriers of the route, with 25 mm of diameter and height of 35 cm. The whole surface of the flume was covered by grid Plexiglas plates in two longitudinal and transverse directions with the distances of 3 cm; in a way that we could install cylinder barriers with different distances of T and P (T is the distance between consecutive barriers in each row, and P is the distance of rows from each other) in two arrangements of in-line and staggered. (Figure 3)

Fig. (3): Installation of cylindrical obstacles on experimental flume

In this research, 3 tests were conducted with different densities of cylinder barriers (general characteristics of the tests have been presented in the table number 1). In these tests, after the current was run, the height of sliding valve differed from a certain maximum value (proportional with the depth of current that waves form perpendicular with the current) to the zero height, with five-millimeter paces. With gradual decrease of current depth, different synchronous wave currents (n=1, 2, 3, 4) were formed alongside the width of the laboratory flume. In order to have better visibility of the first and second synchronous n=1, 2; characteristics (frequency, wavelength, etc.) were recorded for these two situations.

Table (1): Summery of data measurements configurations for experimental studies

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
number of experiment	**T** **(mm)**	**P** **(mm)**	obstacles arrangements	**B** **(mm)**	**Q** **(lit/s)**	N …	**T/D** …	**P/D** …
1	**90**	**90**	staggered	**720**	**10**	**7.5**	**3.6**	**3.6**
2	**60**	**60**	in-line	**720**	**10**	**11**	**2.4**	**2.4**
3	**60**	**60**	staggered	**720**	**10**	**11**	**2.4**	**2.4**

Tests' numbers have come in the first column of table 1, and in columns 2, and 3; transverse (T) and longitude (P) distances have been defined. In column 4 we have barriers' arrangement, column 5 the width of laboratory flume, column 6 current Debby, column 7 barriers density (the average of barriers in two consecutive rows), column 8 dimensionless proportion of transverse distance to the barriers' diameter (D), and finally in column 9 we see the dimensionless proportion of longitude distance to the barriers' diameter.

Parameters like current depth in laboratory flume and also the wave amplitude (in the form of maximum movement of current surface on the flume's wall) were measured in three sections with barriers. Also, in this stage, the type of wave (n=1, 2, etc.) as registered and documented.

4- Laboratory observations

With gradual decrease of current depth (with decrease of height of lower valve with paces of 5 mm in each stage) the wave n=1 starts to oscillate with limited amplitude. When the current depth decreases more, the wave n=1 amplitude increases, until it gets to the maximum amplitude in the Resonance condition (Figure 4). When current depth decreases again, the amplitude also gradually comes down until the wave n=1 completely disappears and the oscillation in the water surface gets zero, or it enters the second type wave n=2, in a transitional stage, and without being zero. By more decrease of current depth, the wave amplitude in n=2 gradually increases and after reaching to a maximum, it decreases by lowering of current depth, and eventually enters the third type of wave n=3.

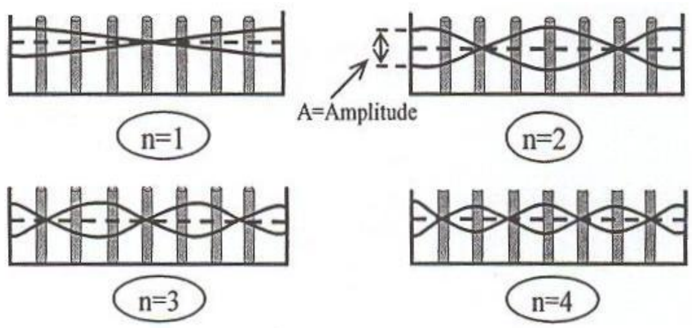


Fig. (4): Modes of oscillation occurring across the laboratory flume.

5- Registering the frequency

Each complete movement of rising and lowering of water surface is considered as an oscillation, and the numbers of these oscillations are written down in one minute intervals in every stage. All the readings were registered in all the stages.

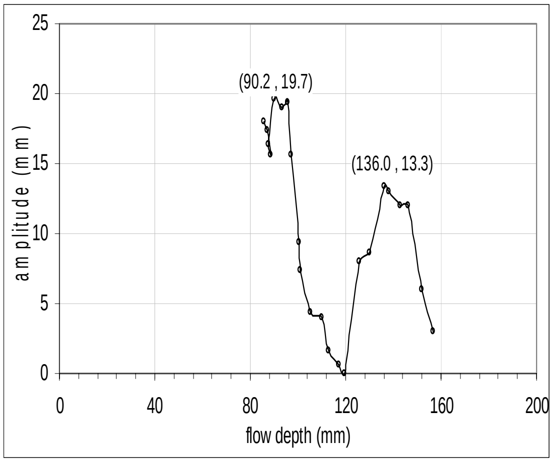
6- Data analysis

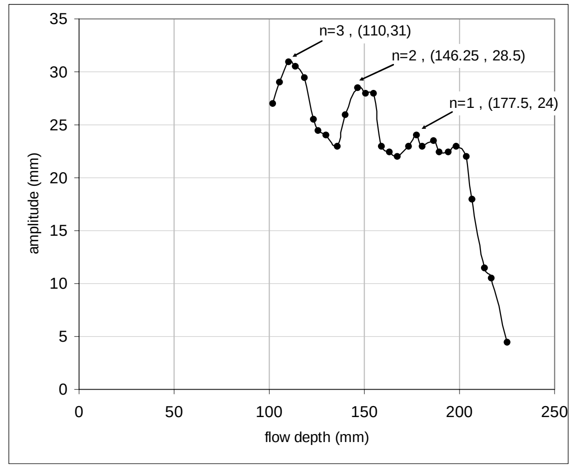
In order to show the conditions of hydraulic current at maximum amplitude of the waves, the wave amplitude diagram is drawn opposite the current wave (A-h) in each type of the wave (figure 5).

According to studies by Linhard, 1996, vortex at the bottom of barriers is formed when the Reynolds number for barriers (UD/ν) is located in one of the two following areas. *U* is current speed, *D* the diameter for cylinder barriers, and *v* is the cinematic viscosity of the fluid [2].

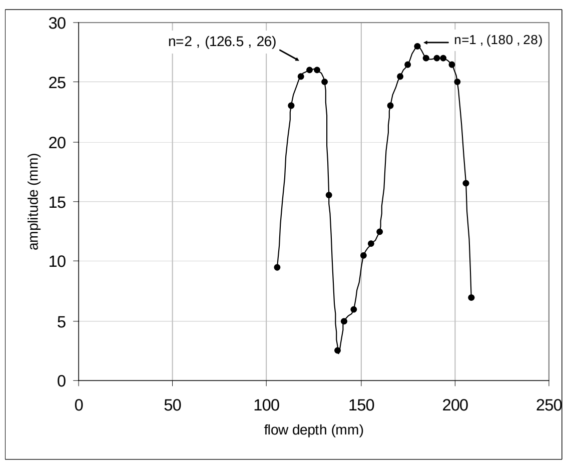
$$40 < Re < 3\times10^{5} \quad , \quad Re > 3.5\times10^{6} \quad (١)$$

In the conducted tests in this research, Reynolds number for barriers was in the first interval (40 to 300,000). The current regime (according to declination number) was also under critical throughout the tests





(a) Experiment No. 1: P=90, T=90, Stagger (b) Experiment No. 2: P=60, T=60, Inline



(c) Experiment No. 3: P=60, T=60, Stagger

Fig. (5): A-h variation in three experiments

7- Results

Due to the passage of water around the installed barriers in the canal, and due to the vortex of the barriers, an oscillation is formed behind each barrier. A wave perpendicular with the fluid is formed due to lapping of these oscillations and adaptation to the physical conditions of the canal; which is called the wave perpendicular with current caused by vortex.

Wave's shape

The shape of formed wave is a stable wave, which is formed by interference of two reciprocate waves and the clash with the canal's body

Wave frequency

Wave frequency or the number of oscillations in every second has a special number through each test, and for each wave shape (synchronous). In other words, wave frequency remains constant by formation of a wave shape.

Also the wave frequency in the second synchronous n=2, is almost 1.5 times bigger than the first synchronous n=1, according to the numbers.

In each arrangement of the barriers, the frequency of each wave shape will be different from the same wave frequency in the other tests. Therefore, we can conclude that the frequency also depends on the number of barriers in each transverse row.

The magnitude of amplitude

The percentage of wave amplitude to the water depth in the maximum amplitude value is seen in the table 2. Also, the magnitude of the amplitude in the maximum value is seen in the table 3. According to these tables, we conclude that by decreasing the distance between the barriers in each wave condition, we will have an increase in the amplitude; but the proportion of amplitude increase to depth (proportional increase) does not follow the above-mentioned condition.

Table (2):Percent amplitude to depth

Modes of oscillation			Arrangement of obstacles
n=3	n=2	n=1	
-	22%	10%	Stagger P=90,T=90 ; The first experiment
28%	17%	14%	In-line P=60, T=60 ; Second experiment
-	20%	16%	Stagger P=60,T=60 ; Third experiment

Table (3):Maximum amplitude in each experiment (mm)

Modes of oscillation		Arrangement of obstacles
(mm) n=2	(mm) n=1	
19.7	13.3	Stagger P=90,T=90 ; The first experiment
25	24	In-line P=60, T=60 ; Second experiment
26	28	Stagger P=60,T=60 ; Third experiment

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