VORTEXING

Lab5

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Fluid Machinery

Lab reports

Name	ID	Grp/sec
Ahmed Ihab Elmessery	5035	
Ibrahim mostafa Elshenhapy	4715	2/2
Mohannad Mahmoud	5123	2/2
Omar Ashraf El-Maleh	4552	2/2
Seif eldin tarek	5251	

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Introduction

A vortex is defined as a region of flow that is rotating around an axis that can either be straight or curved. Vortex formation occurs when the transition from open channel (free surface) flow to pressure flow is not smooth and uniform. When flow does not maintain gradual transitions that attempt to keep a uniform velocity distribution and acceleration, then vortices can occur, a vortex with an air core then forms when the liquid level reaches a critical height. The formation of the dip and the onset of the vortex occur almost simultaneously. [1]

Many of the problems which can occur at closed conduit intakes are a consequence of a free surface vortex. Free surface vortices are a very highly organized turbulent free-surface flow phenomena which occurs due to the residual angular momentum in the flow at a closed conduit intake. They occur commonly at free-surface flows into a closed conduit, such as a sink or bathtub drain. Vortices can be classified into:

1- Free Surface Vortices (fig. 1)

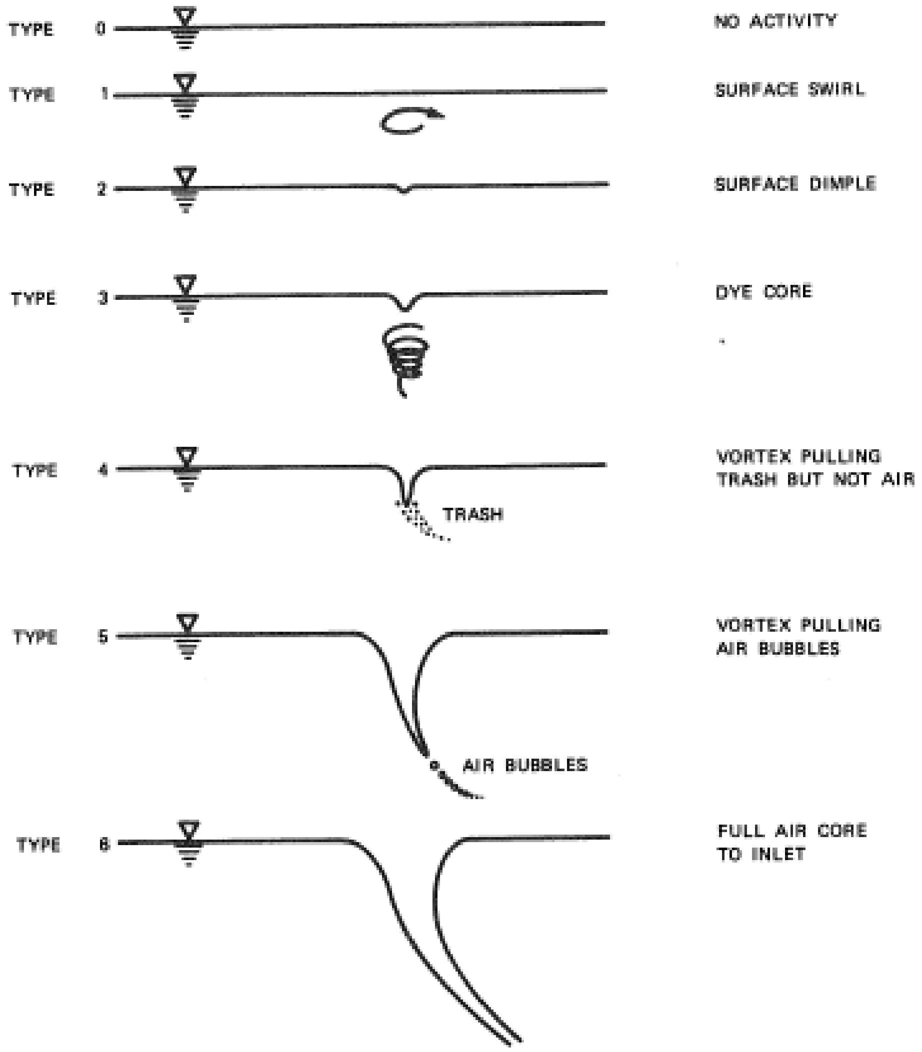


Figure 1 free surface vortices

2- Sub-Surface Vortices

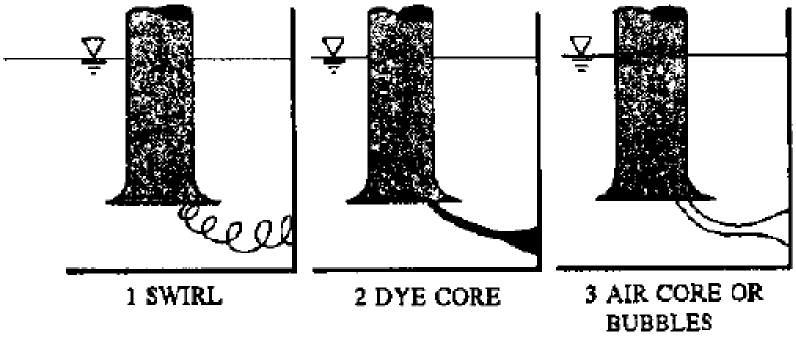


Figure 2 Sub-Surface Vortices

Reasons of vortex formation

Although the basic principles of vortex formation are well established it is still difficult to understand how vortices are generated at intakes and why they vary in strength and position in an unpredictable way.

In pumping stations, it is clear that vortices can result from:

1- Flow separation at obstructions and discontinuities

2- From flow along vertical side walls.

3- When the liquid level reaches a critical height. The formation of the dip and the onset of the vortex occur almost simultaneously.

4- Initial disturbances such as rotational motion and vibration due to environmental disturbances can augment the vortex formation

5- The velocity is too high when the fluids enter the pump at the suction line entrance

Harms of Vortexing

In large closed conduit intakes, however, free surface vortices are a severe problem which should be avoided. Free surface vortices have been found to cause:

1- flow reductions due to decrease in the effective Diameter of flow

2- Additional head losses in intake

3- Increased risk of cavitation

4- vibrations

5- structural damage

6- surging due to formation and dissipation of vortices

7- Loss of efficiency in turbines and pumps.

8- Slug flows in downstream due to entrained air

9- They have also been found to be a safety hazard at lock intakes

Figure 3 Vortex which formed at Horspranget, Sweden, hydropower intake

Governing parameters:

Geometric parameters

1- Dimensions of the intake tank

2- Position of the intake pipe

3- Size of the suction pipe

4- The depth of water or submergence of intake pipe

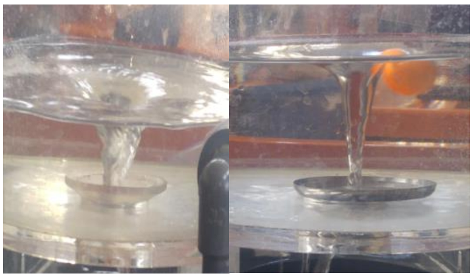


Figure 4 effect of changing intake diameter on vortex strength

Flow parameters:

1- Reynolds number (Ratio of inertial to viscous forces)

2- Coefficient of discharge (can be termed as Froude number(inertial/gravitational))

3- Weber number (Ration of inertial to surface tension forces)

4- Kolf number (centrifugal to inertial forces)

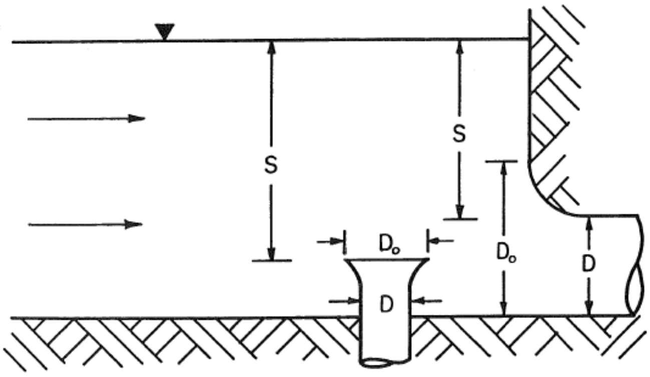
Dimensional analysis:

A dimensional analysis can be performed to determine the important parameters influencing vortex formation at horizontal as well as vertical intakes. Most investigators have focused upon a critical submergence, S_c, also known as the minimum submergence defined critical submergence as the smallest depth at which strong and objectionable vortices will not form. If the intake is set such that S < S_c, a 'vortex will form, whereas if a S>S_c, a vortex will not form. This definition implies that air entraining vortices are the only types of vortices detrimental to pumps or turbines

The functional relationship can be written for S_c as:

$$\boxed{S_c = f\,(D', D_o, Q, \Gamma, \rho, \mu, \sigma, g, \delta_i)}$$

Where:
d = diameter of the pipe intake,
Do = diameter of the bellmouth intake,
Q = discharge,
Γ = Circulation,
p = density of the fluid,
μ = dynamic viscosity,
σ = surface tension of the fluid,
g = acceleration due to gravity,
δi = length parameter, distance from side walls, length of approach side walls, height of the bellmouth, etc.



With P , Q, and D as the repeating variables this can be simplified using Buckingham's pi theorem to:

$$\frac{S_c}{d} = f\left[\frac{D_o}{d}, \frac{Q}{\nu D}, \frac{\Gamma D}{Q}, \frac{Q}{d^2\sqrt{gD}}, \frac{\rho Q^2}{\sigma D^3}, \frac{\delta_i}{D}\right] \quad i = 1,\dots n$$

- Many experimental studies have indicated that surface tension effects are negligible
- Many investigators have concluded that viscous forces in and around the intake can be ignored if the Reynolds number is large.

If Webber number and Reynolds number are dropped from consideration, the dimensional analysis reduces to

$$\frac{S_c}{D} = f_4\left[\frac{\Gamma D}{Q}, \frac{V}{\sqrt{gD}}, \frac{\delta_i}{D} \quad i=1 \dots n\right]$$

Therefore, the factors most affecting free surface votexing are:

1- Depth of intake pipe from surface
2- Diameter of pipe (increasing diameter leads to decreasing the flow speed)
3- Circulation of flow
4- Flow speed

Precautions to prevent Vortexing:

Design precautions:

The intake design guidelines which are available usually require near perfect flow conditions just upstream of the outlet. The requirements are that:

- The upstream flow should be uniform across the channel width

- Supporting pillars should be streamlined to eliminate the possibility of flow separation reaching the intake,
- Stagnant flow areas should be filled; for a horizontal intake a vertical face is better than a sloping face,
- Average approach channel velocities should be kept below .6 m/s.
- Trash racks should be designed to act as flow straightening vanes.

A poor channel design can be due to These factors:

- Abrupt changes in flow directions (e.g. sharp corners or any design which leads to an asymmetric distribution of flow,
- Rapidly diverging channels,
- a steep slope, and
- Blunt support pillars.

These recommendations indicate that there should not be any flow separation upstream of the intake if vortex-free operation is desired.

With this type of approach channel, an intake submergence of 1.5 D for the horizontal intake is recommended

Remedial actions:

The remedial actions taken once a vortex is discovered at an intake are usually limited to very minor modifications. It may be economically unfeasible or physically impossible to alter the size or depth of the intake, and/or the upstream flow conditions by improving the upstream boundaries. With these limitations, remedies are usually limited to three types of solutions

1- Those which disrupt the angular momentum of the flow such that the formation of a vortex is inhibited e.g. (baffles , floats or fins)
2- Those which force the vortex to try to form in a zone where it is difficult to form
3- Those which increase the area of the outlet such that the intake velocities are decreased. e.g. (conical shaped inlet)

None of these solutions destroys the angular momentum upstream of the intake, and thus there still may remain a large amount of swirl entering the intake that is hazardous to the turbines or pumps.

Examples of vertix inhibitors

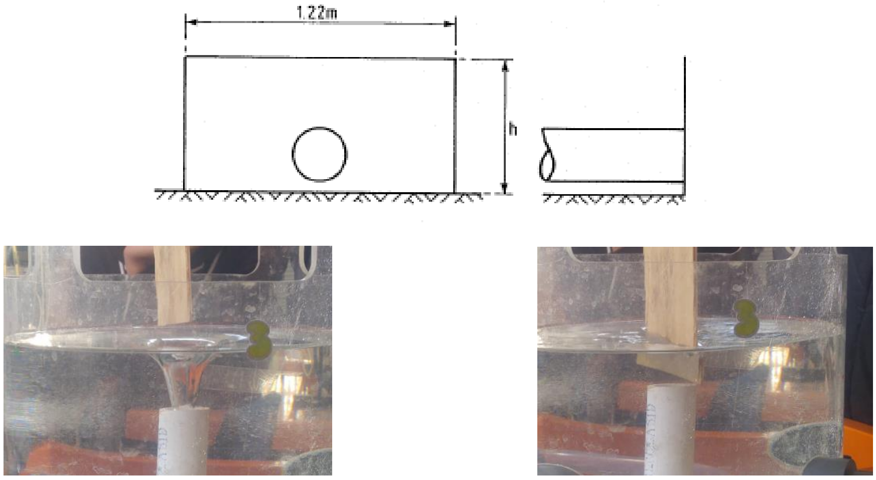


Figure 5 Headwall

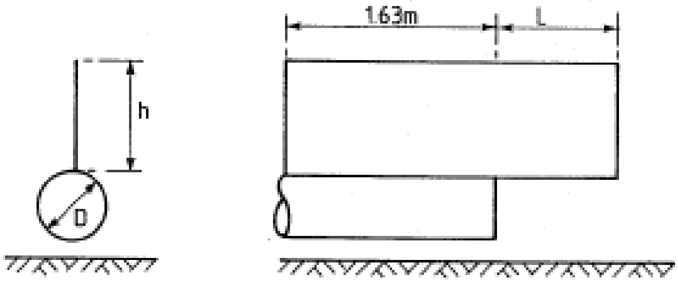
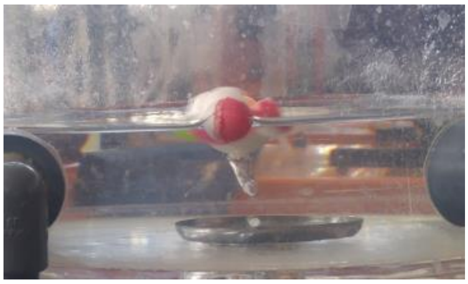


Figure 6 Fin



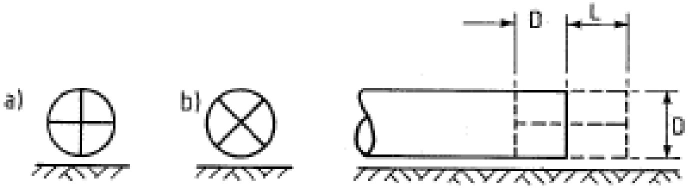


Figure 7 Cruciform

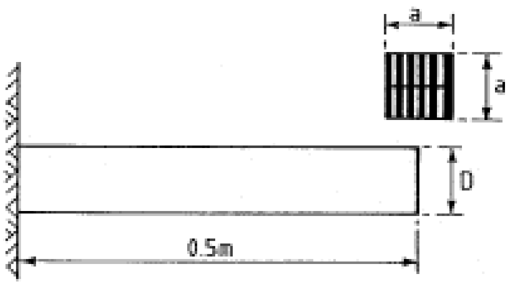


Figure 8 Raft floating on Surface

References

[1] Bottazzi, Floreale, & Molina. (2007).

[2] Gulliver, A. J. (1983). AN EXPERIMENTAL STUDY OF CRITICAL SUBMERGENCE. *ST. ANTHONY FALLS HYDRAULIC LABORATORY*.

[3] Karassik, I. J., Messina, J. P., & Heald, P. C. (2001). *PUMP HANDBOOK.* New York: McGRAW-HILL.

[4] Walker, K. (2016). Intake Vortex Formation and Suppression at Hydropower Facilities. *Science and Technology Program*.