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Experimental Investigation on Hydraulic Jump in Sudden Expansion Duct

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Abstract: *This paper presents an experimental investigation of the occurrence of hydraulic jumps due to two phase air-water flow in a rectangular duct in a horizontal position as well as inclined position .Hydraulic jump is a phenomenon frequently observed in an open channel flow. In this present experimental investigation, various parameters like strength of the hydraulic jump, location of hydraulic jump, length of hydraulic jump is found out and the effect of flow rate of water and the effect of air flow on Position of the Jump hydraulic jump is studied. Hydraulic jump results in the reduction of total energy of a moving fluid, which in turn prevents the fluid from scouring the channel banks. Also hydraulic jump enables a portion of the fluid's kinetic energy to reduce which stabilizes downstream flow conditions.*
Keywords: *hydraulic jump; open channel, location of jump, inclined position*

I. Introduction

A common phenomenon that occurs in hydraulic behavior is an abrupt rise in water surface elevation, caused by deeper, slower-moving water downstream. This is known as a hydraulic jump, and has been the focus of interest for hydraulics engineers for almost two centuries, mostly because of its potential for energy dissipation. Hydraulic jumps can also be highly erosive to the channels that contain them. In order to determine the required channel protection, practicing engineers must be able to predict the height, length, and location of a potential jump, which may be a difficult task depending on the channel shape.

The phenomenon is dependent upon the initial fluid speed. If the initial fluid speed is below the critical speed then no jump is possible. For relatively low initial flow speeds above the critical speed an undulating wave appears. As the flow speed increases further the transition grows more abrupt, and at high enough speeds the front will break and curl back upon itself. This rise can be accompanied by violent turbulence, eddying, air entrainment, and surface undulations.

II. Literature Review

Hydraulic jumps have been used as energy dissipation features for hydraulic structures for several hundred years (Peterka, 1983). It dissipates the excess energy of flowing water downstream of hydraulic structures, such as spillways and sluice gates. It also plays an important role in limiting supercritical flows, and potential erosion in mountain channels (Grant, 1997).

In order to study the complexity of flow transition .It is need to analysis the result on hydraulic jump which is useful for both analytical and laboratory result. Analysis has Height of the jump - the relationship between the depths before and after the jump as a function of flow rate, Energy loss in the jump, Location of the jump on a natural or an engineered structure

Experimental and theoretical studies of hydraulic jumps in one and two layer system has been presented in the literature (MCcorquodale,1986).The numbers of work for two layer case is considerably less than that of single layer. Benton (1954) first treated internal hydraulics jumps for two moving layers .He recognize that the principles of momentum conservation and decrease of energy are together insufficient to specify downstream condition, given a complete description of upstream flow. For jumps with negligible mixing of the layers, there are the three main approach which have been reported .The application of the momentum principle to individual layer was first suggested by Yih and Guha (1955) and used in the study of internal jumps in moving layers by Rajaratnam et al. (1991).They considered flows in horizontal rectangular channel with a free upper surface and assumed that no movementum was transferred between the layers, the shear at the boundaries and the interface were negligible and a hydrostatic distribution of pressure . To enable separate momentum equation to be written for each layer, they made the additional assumption that the mean pressure over the jumps section could be taken as the average of the upstream and the downstream pressure at the interface. The solution of the resulting momentum equation together with the continuity equation for each layer yielded at most four possible conjugate depths including the upstream state itself. The determination of unique conjugate state was investigated by Hayakawa (1970) on imposing the condition that energy loss is required at the hydraulic jumps. It was found that there always existed a solution of the momentum equation which was not a legitimate solution.

Chu and Baddaour (1977) and Wood and Simpson (1984) have queried the assumption of Yih and Guha (1955) since they imply that the contacting layer gains energy without associated work being done on it. These authors instead assumed that the energy loss in the contracting layers was negligible and that the combined momentum of the layer was conserved. Elimination of the unknown downstream pressure resulted in a particularly simple conservation relationship if prior knowledge of the contacting layer was available. The theories of Yih and Guha (1955) and Chu and Boudder (1977) have been evaluated experimentally for jumps in the lee of a towed obstacle and for a jump advancing into stationary layers of Wood and Simpson (1984). Even though experiments were carried out with saline and fresh water layers and so jump phenomenon would almost certainly involve an interfacial mixed layer ,both theories whilst neglecting the mixing of the fluids gave similar results differing only when the shear on the interface become large.

III. Experimental Details And Methodology

Experimental set-up was developed for characterization of flow pattern, with the main focus on hydraulic jumps, using a suddenly expanded rectangular section. A typical section consists of two ducts, one is a suddenly expanded rectangular section made up of transparent Perspex acrylic sheet having smaller section of dimensions 600 mm × 30 mm × 34 mm and larger section of dimensions 900 mm × 30 mm × 46 mm.

The entire unit was supported on two leveling screws and a hinge at the extreme left of the smaller section. Hinge is provided so that entire unit can be inclined with horizontal. One centrifugal pump (specification: 0.5 HP, head 30/6 m, capacity 15/40 lpm , 2800 rpm, is used for circulation of filtered water. The water flow rate is measured by a rotameter .A rotameter bank containing two rotameter (calibrated in the range of, 1-30 CFM for air, and 1-20 LPM for water) is used for this purpose. A two stage reciprocating compressor is used for air supply at particular pressure. Volume flow rate of air was measured by using two rotameter calibrated in the range 0-10 CFM and 0-30 CFM. Flow rate of both air and water are controlled using control valves and the schematic test set-up is shown in figure 1.

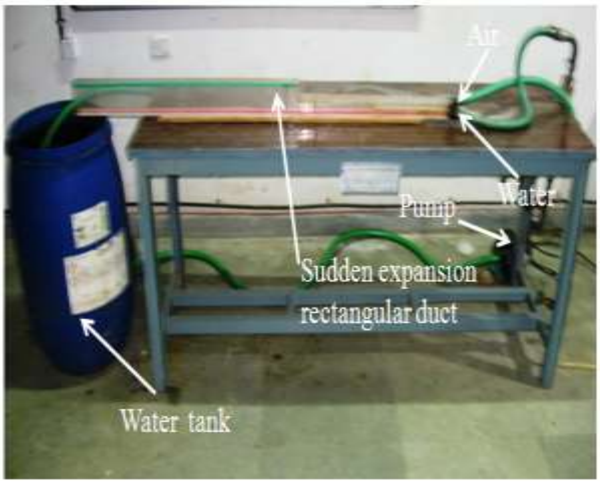

Fig.1. Schematic Test Set-Up

Flow patterns involving hydraulic jump were investigated corresponding to both horizontal and inclined (upward as well as downward) orientation of the duct, as well as for different volume flow rates of air and water.

The air and water was supplied at controlled flow rate to the inlet section by two different ducts. The air was supplied on the top of the water as shown in figure 3.3. The set up has a provision to change the test section from a constant one to a suddenly expanding one. The flow rates were controlled by control valve provided before the respective rotameter.

3.1 Accessories Details

1. Test Sections

A test section consists of two ducts one is a suddenly expanded rectangular section made up of transparent Perspex acrylic sheet having smaller section of dimensions 600 mm × 30 mm × 34 mm and larger section of dimensions 900 mm × 30 mm × 46 mm . Another rectangular duct section is without sudden expansion made up of transparent Perspex acrylic sheet having dimensions 1500 mm × 30 mm × 34 mm.

2. *Pump, Compressor, Flow Control Valves and Pipe Assembly*

A centrifugal pump of specifications 0.5 HP, head 30/6 m, capacity 15/40 LPM, 2800 rpm is used for delivering filtered water in the form of required flow rate. A gate valve of diameter 12.5 mm was connected in supply line to control the flow and the ball valve of the same connection is connected to the bypass pipe. The piping arrangement was made up of easy fit pipes with the connection 12.5 mm. A two stage reciprocating compressor was used for circulation of air. Flow rate of both air and water are controlled using control valve and bypass arrangement.

3. Water and Air Rotameters

A rotameter bank containing two rotameter (in the range of, 1-30 CFM for air, and 1-20 LPM for water) is used to measure and control the flow rate of the both water and air, with the thread connection of 12.5 mm (*i.e.* half inch) diameter, at NTP conditions. The resolution of the rotameter is 0.5 LPM, used for measuring the required flow rates during the experimentation**.**

Measurements

1. Discharge (*Q*)

Discharge (*Q*) in the flowing channel is measured with the help of water and air rotameters. The flow circulating duct is equipped with two rotameters that enable to measure the discharge through channel very precisely.

2. Water surface elevation

Water surface elevation is measured at the upstream and downstream of the jump with the help of scale marked on acrylic duct. The location of the jump and length of the jump through the entire section is measured with the help of measuring tape fixed on acrylic duct.

3. Slope of the duct

Experiments were carried out at different inclination of duct with different flow rate (upward and downward inclination) with the help of leveling screws by changing height at upstream and downstream.

4. **Visualization of flow pattern**

Various type of basic flow patterns are observed by mixing of Potassium permanganate ($KMnO_4$) with water which does not affect the any physical and chemical properties of water. Potassium permanganate has a tendency to give water a pink color.

IV. Results and Discussion

4.1. Hydraulic jumps formed in a duct in horizontal position

Experiments were conducted for the hydraulic jumps in the ducts without any inclination to horizontal. Under these conditions experiments were conducted both for hydraulic jumps due to single phase and two-phase air-water flow, and are described as follows:

The hydraulic jump observed during laboratory experiment in unexpanded horizontal test-section without air flow is depicted in figure 2.

Fig.2. Hydraulic jump in a horizontal test-section without air flow (Q_w =2.0 × 10^{-4} m^3/s, Q_a=0.0), (h_1=10 mm, h_2=30 mm)

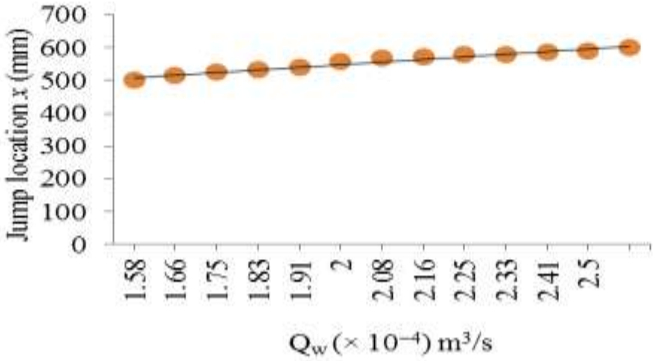

Fig.3. The location of the jump formed in unexpanded horizontal section with no induction of air

As already mentioned, hydraulic jumps are also formed in a single phase flow of water through the test-section (i.e. when there is no flow of air). Under these conditions when the volume flow rate of water (Q_W) is relatively high, hydraulic jump is not observed throughout the test-section. When (Q_W) is gradually reduced, at a particular volume flow rate hydraulic jump is formed near the extreme left (or near the exit plane) of the test-section .This jump is relatively weak and more or less steady. The strength of the jump is defined as the ratio of the height of the water layer after the jump (h_2) to that of height of the water layer before the jump (h_1).The unexpanded section gets flooded with water, while flow in the remaining section remains as partially filled flow and no hydraulic jump is observed throughout the test-section.

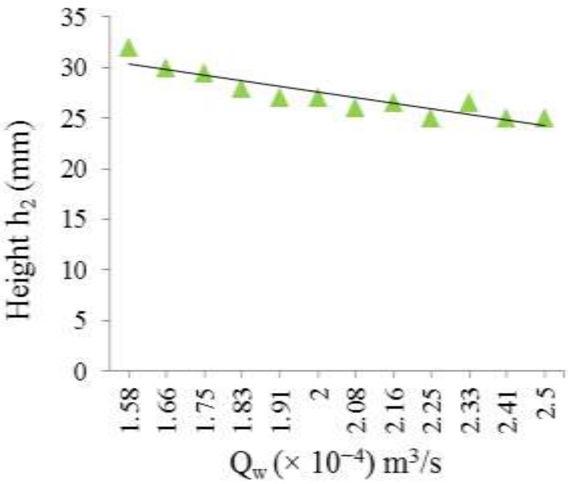

Fig.4. Downstream height of the jump (h_2) formed in unexpanded horizontal section with no induction of air

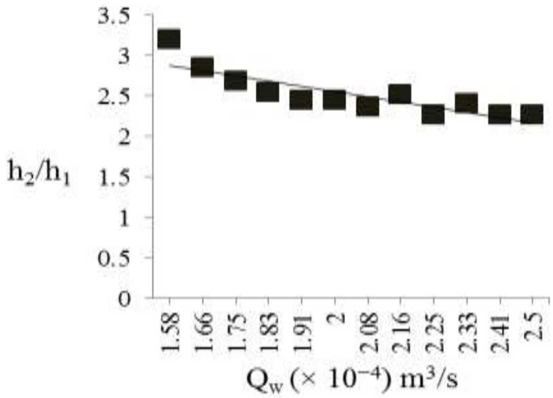

Fig.5. Strength of the jump formed in unexpanded horizontal section with no induction of air

For checking the effect of water flow rate on the downstream height of the jump same experimentation procedure has been carried out as that of previous one .The multiple readings were taken at different water flow rates. The graph of the reading was plotted for downstream height of jump (h_2) in mm against the water flow rate in m^3/s as shown in figure 4. As the volume flow rate of water increases the height of jump initially increases and it decreases to the exit of the test-section due to volume flow rate of water.

For checking the effect of volume flow rate of water on the strength of the jump experimentation have been carried out by changing the volume flow rate of water. The readings were taken for each volume flow rate throughout the test-section. The graph of strength of the jump is plotted against the water flow rate as depicted in figure 5.

4. 2 Hydraulic jumps due to two-phase air-water flow

Another kind of experimentation had carried out for visualisation of hydraulic jump due to two-phase air-water flow in unexpanded as well as expanded horizontal duct. The water flow rate during the experimentation was kept constant while the air flow rate increases small increment. The images are showing the experimentation and the effect of air flow rate on the hydraulic jump at different flow rate of air. In single phase flow as water flow rate increases downstream height decreases but in case of two phases due to introduction of air at same flow rate of water initially jump height is increased. If we increase the air flow rates then the top surface get disturbed as shown in figure 6.

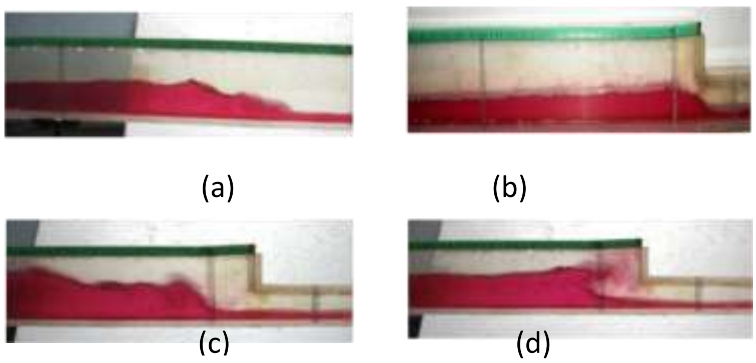

Fig.6. Hydraulic jump in horizontal test-section with induction of air (a), (b), (c), (d) top surface of jump get disturbed due to air., ($Q_w = 1.91 \times 10^{-4}$ m^3/s, $Q_a=3.19 \times 10^{-3}$ m^3/s)

Hydraulic jumps formed with relatively less volume flow rate of air (jumps located near to the exit plane of the test-section) are relatively weak jumps and more or less steady .With further increase in the volume flow rate of air the location of the jump moves upstream , i.e. towards the expansion point (x reduces).

4.3 Effect of Obstruction on Hydraulic Jump in Sudden Expanded Duct

Another kind of experimentation had been carried out for checking the effect of obstruction on the hydraulic jump. The different sizes of obstacle heights were fixed at exit plane of test section. It is observed that the hydraulic jump which were formed in horizontal test section without obstacle, the location of jump shifts towards the downstream. After placing the obstacle at exit plane of test section the location of hydraulic jump shifted to upstream and after certain condition whole test section get flooded even at high flow rate of water as shown in figure 7.

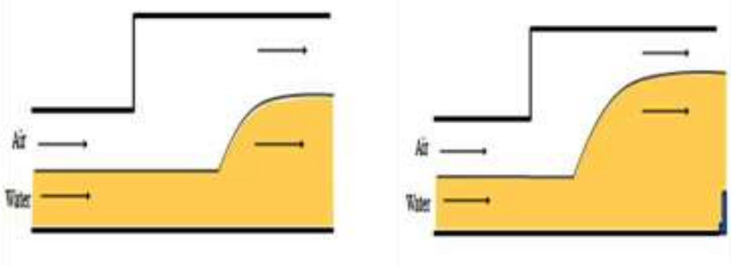

Fig.7. (a), (b) Effect of obstruction at the downstream of duct

4.4 Position of the Jump

The position of hydraulic jump in rectangular and expanded section are shown in figure 8 (a) and figure 9 (b) .As the air flow rate increases the position of jump shifts towards downstream where the cross section is constant, while in case of sudden expansion duct position of jump shifts towards upstream.

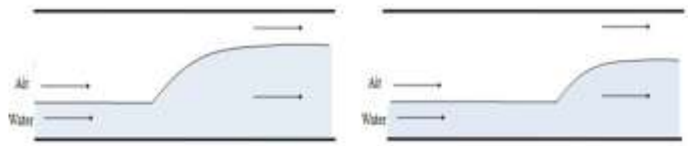

Fig.8. (a) Position of jump in rectangular channel without sudden expansion

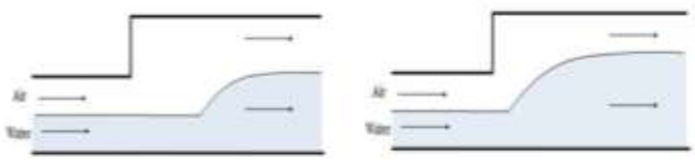

Fig.9. (b) Position of jump in rectangular channel with sudden expansion

V. Conclusion

It is observed that, as volume flow rate of water is in between 1.58×10^{-4} m^3/s and 2.5×10^{-4} m^3/s; jump is observed within the test section. As volume flow rate of water increases no jump is formed. Since, on introduction of an air at lower flow rate the jump location get shifted towards upstream part of the test section, the hydraulic jump is observed even for higher flow rate of the water

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