Pressure Fluctuations On Semi-Circular Inflatable Dam Model

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ABSTRACT Inflatable dam is a closed tube made of flexible material and usually filled with air or water or any other suitable fluid. It anchored along its base across the river or the stream. The major problems encountered in the use of the inflatable dams are the vibrations which are resulted from the hydrodynamic forces. Vibration problems reduce the expected life of the inflatable dam and sometimes lead to dam failure. It was believed that the vibration was strongly correlated to the pressure fluctuation on the surface of the dam due to the instability of the falling nape. This causes negative pressure zones on the downstream face of the dam. Thus it was planned to investigate experimentally the distribution of the mean pressure on the outer surface of a model dam fabricated to simulate an inflatable dam. The experiments were conducted in a horizontal rectangular channel of 15 m long, 1.37 m wide and 0.67 m deep. The flow conditions upstream the dam model were subcritical with free flow at the downstream face of the dam model. The analysis of the measured pressure on the surface of the dam model indicated that the negative pressure zone is located on the downstream side of the dam. The effect of the flow rate on the movement of this negative pressure zone is traced and located. Fair agreement was obtained with other authors results on relatively similar inflatable dam model.

INTRODUCTION

In recent years, inflatable dams have gained considerable importance for its diversified uses, light weight, ease in transportation and installation and availability of flexible and tough material. When inflatable dam inflated it forms a barrier. This barrier can close off the flow of water partly or entirely. But when deflated the tube will be empty and will not cause an obstacle to the flood flow of water. One of the earliest definitions of an inflatable dam can found in a U.S.A. Patent taken out by Mesnager in 1948 [1,2]. The inflatable dams are anchored to a concrete base along their lengths across the water way to form a barrier. The term "Fabriadam", which has become synonymous with the structure, was patented by Imberston [3] as the Imberston-Fabriadam in 1956. It was originally developed and used as an adjustable gate to control water level in rivers or reservoirs, but has since proved its worth in other applications. Due to the increasing demand of water use and control, there is a need for simple and economic structures both in design and construction. The ability to adjust the height of the dam and hence regulate and control the water level of a river or canal can make it a cheaper alternative to other conventional forms of control. Inflatable dams have already exhibited their potential in different water control applications where they can be used to back upstream water with no overflow or to operate under overflow conditions. Many engineering applications for the inflatable dams were reported in the literature, see e.g. [4,5,6,7,8]. As any structure, the inflatable dams has their own advantages and disadvantages. They are cheaper than other conventional alternatives as lighter material are used. Also, they can be constructed within shorter periods without specialized labor force. Moreover, little maintenance is required compared with the conventional structures. Added to the above, they are tough and flexible. On the other hand, their disadvantages may include the less expected life than other conventional hydraulic structures and their limited ability to resist the abrasion caused by debris [9]. Also, The uncertainty of fabric behavior with age is a major disadvantage of the inflatable dams.

Hitch [10] and Hitch and Narayanan [11] have measured pressure distribution over a model inflatable dam similar to the theoretical shape of such dam when inflated by air and retains water from its upstream side. The model was a rigid and fabricated from sheet metal bronze to form an elliptic shape (assumed by a flexible dam when the upstream water level is coincident with the crest of the dam). They claimed that although the shape was strictly for hydrostatic conditions, it was approximately the same for overflowing conditions for small rates of flow. Their rigid model was placed in a flume 0.365 m wide and 0.560 m deep. Seven pressure taps were distributed over the perimeter of the model dam. They expressed the results in non-dimensional form as the variation of non-dimensional pressure head (h/E) with the non-dimensional specific head (E/H), where h is the mean pressure head, H is the crest height of the model and E is the specific energy of the upstream flow. The values of h/E were -0.2 to 0. and values of E/H were 1 to 1.7. The present results were compared to those of Hitch [10].

The critical problem for the flexible hydraulic structures such as inflatable dams is the occurrence of vibrations. It is believed that these vibrations are due to the hydrodynamic forces resulting from overflow. Vibration problems reduce the expected life of the inflatable dams and sometime lead to failure. The Vibrations of inflatable dam may be attributed to the pressure fluctuations on the outer surface of the dam. Hitch [10] claimed that the vibration is believed to be due to the separation of nape causing fluctuating negative pressure. Hence, it is important to investigate the distribution of pressure on such dams of different shapes to locate the zones of negative pressure. These zones are usually unstable where the pressure are strongly fluctuates. Therefore, this study comes on the line to add more information on the distribution of the mean pressure on the circumference of dam model semi-circular shape in order to locate the zones of negative pressures where the pressure is expected to fluctuate and causes damage or failure to the structure.

EXPERIMENTAL SET-UP

The experiments were conducted in a horizontal rectangular channel of 15 m long, 1.37 m wide and 0.67 m deep. The channel is constructed on a steel frame with a glass side walls and was supplied with water by a vertical pump which pumps the water from a sump to the entrance tank through a 250 mm pipe. The discharge passing through the channel is measured by means of a volumetric tank located below the flume outlet. A sight glass tube is installed vertically along the wall of the volumetric tank with graduated scale calibrated in liters. Figure (1) represents the basic details of layout of test model. The test model was built using a 1 mm thick copper sheet formed in a semi-circular shape 25-cm in diameter and the crest height was 127 mm from the bed of the flume. The selection of the size of the diameter of the model was based on real length to height ratio. The model dam was fixed on a steel plate 1 mm thick, 137 cm long and 45 cm wide. The model was fixed by means of silicon rubber from all sides to ensure no leakage. The model dam was fixed in the middle of the flume 7.25 m away from the flume's inlet. Ten pressure taps, each of 1 mm diameter were drilled with flushed surface along the perimeter of the model dam The locations of the tapes from the beginning of the semi-circle in the upstream side are 20, 45, 82, 119, 156, 193, 230, 267, 304 and 341 mm. The center line of the ten holes in the direction of the flow were 68.5-cm away from the side walls of the flume to minimize the side effect. A reference manometer was set at 120 cm upstream of the model to measure the reference pressure head upstream the dam model. The test section, the test model, the connection of the holes and pressure taps to the manaometers are presented in Figure 1.

Flexible tubes were used to connect the pressure taps (from the inside of the model through 6 mm diameter brass tubes) to a manifold then to a manometers board through a 5-cm hole drilled in the bed. The manifold was provided with 10 valves to control the release of air from the tubing system. The pressure was measured using the multiple manometer for all taps at the same time. Also, the pressure was measured at a reference point 1.2 m upstream of the model. The advantage of this point was to make a double check on the manometer reading since the depth of water at that point can easily be measured using the point gauge. This reference point provides information on the water depth upstream of the model.

The multiple manometer was calibrated before use to ensure accurate measurement of the pressure on the body of the dam model. Experiments have been carried out under subcritical flow conditions upstream the model. The discharges ranged from 59 to 173 lit/sec, the upstream Froude number ranged from 0.146 to 0.288 and the upstream water depths ranged from 208 to 270 mm. A total of 11 runs were conducted with upstream depth, discharge and upstream Froude number as indicated in Table (1).

Table 1. Range of discharge upstream Froude number and upstream water

Run	Q (l/s)	Fr	H (mm)
1	59.03	0.146	208.0
2	70.23	0.164	216.0
3	75.25	0.171	220.0
4	95.88	0.213	233.0
5	107.99	0.214	240.0
6	119.76	0.230	246.0
7	131.23	0.245	251.0
8	138.50	0.251	256.0
9	147.30	0.256	262.0
10	163.90	0.277	267.o
11	173.00	0.288	270.0

ANALYSIS AND DISCUSSIONS

The relationship between the non-dimensional parameters h/E and E/H is presented in Fig. (2) for the ten pressure taps. It could be noted that the upstream zone of the model (locations from 1 to 5) demonstrates similar pattern of variation of h/E with increasing E/H; a slight increase followed by a steady level. At the crest (location 6) where the energy is expected to be minimum and critical flow condition may occur, h/E dropped about 40% from its level on location (5). The non-dimensional mean pressure head h/E was found to decrease with increasing the upstream energy head. Locations (7) and (8) were at negative pressure zone. Negative pressure at that area may be attributed to the separation of nape from the downstream face of the model dam. Negative pressure moves to higher negative values when energy is increased. Reattachment of nape is believed to occur at location 9 as h/E is approximately zero. However, for E/H greater than 1.9, the pressure at tap (9) begins to increase revealing that reattachment of nape is no longer at this location. The nape at this stage is back in contact with the dam body of the model at a location between (8) and (9). After the reattachment occurred, the dam is subject to positive pressure as can be seen at location (10) where the pressure is higher than that at crest at lower E/H values and higher than location (5) at higher E/H. At this location (10), the increase in pressure level is sharp. At maximum flow rate, h/E is almost 1.5 times the value at the minimum E/H of the present study.

Similar relationships have been prepared between the mean pressure head (h), and the upstream energy (E) as presented in Fig.(3) to analyze the mean pressure distribution. From Fig. 3, the upstream part of the model, locations (1 to 5), similar patterns are observed. The mean pressure head (h) increases with the increase of the energy head. The sensitivity of the location to the increase in upstream energy becomes less pronounced when approaching the crest. The mean pressure head (h) increased about 30% over the whole range at location (1) while it increased 25% at location (5). At the downstream face of the model, the pressure variation with (E) follows different behavior at each location. At the crest, location (6), the pressure head (h) decreases when energy increases (flow rate increases). The nape is separated from the body of the model at a point between (6) and (7) resulting in negative pressure measured at (7) and (8) and a reattachment at (9) giving positive pressure head at (9) and (10). However, when the energy head was low the negative pressure zone commences after location (7) giving negative pressure at locations (8) and (9). The pressure head at (10) increased almost 2.5 times its value at the minimum upstream energy head. The computations of the specific energy (E) show that E is minimum at the crest indicating critical flow conditions at this location which could explain why the pressure on the crest was varying in a manner different from other locations.

Figure (4) shows the results of studying the distribution of mean pressure around the circumference of the model, Fig.(4) is prepared. It is observed that pressure head is reduced towards the crest of the model dam to reach its lower value at locations (7) and (8) and then begins to increase at locations (9) and (10). The pressure at each location increases with the flow rate except at locations (5) and (6). Same behavior can be noticed for different values of Q except at the crest, location (6), where the pressure is reduced with the increase in flow. At location (9) there was in-consistence in the relation of pressure with the flow rate.

Figure (5) presents the relationship between h and the upstream Froude number F_r. This relationship exhibits similar pattern to that with the energy head. The mean pressure increases when Fr increases for pressure taps located in the upstream face of the model. For locations on the crest and the downstream face of the model (6 to 10), the variation was similar to that for (h) vs. (E) as Froude number is dependent on energy head.

COMPARISON

Comparisons between present results and those of Hitch [10] are presented in Fig. (6). Measurements of pressure in Hitch's study and the present study were not at the same relative locations. The comparison was made between the seven pressure taps of Hitch's model and 7 taps out of 10 of the present study. The seven taps from the present study was selected such that the relative perimeter up to the point under consideration is mostly the same in both studies. The relative perimeter, (P_r=a/L), is defined as the ratio between the perimeter up to the point measured from the upstream side (a) to the total perimeter of the model (L=392 mm). The relative locations of the taps in Hitch's study [10] were 0.054, 0.207, 0.387, 0.549, 0.721, 0.810 and 0.95. The relative perimeter of the taps in the present study are <u>0.051</u>, 0.115, <u>0.209</u>, 0.304, <u>0.398</u>, 0.492, <u>0.587</u>, <u>0.681</u>, <u>0.776</u>, and <u>0.870</u>. Comparing the relative perimeter of Hitch's study with those of the present study, the corresponding pressure taps of the present study are (1), (3), (5), (7), (8), (9) and (10) which approximately has the nearer relative perimeter (P_r). These taps were denoted as 1, 2, 3, 4, 5, 6, and 7 in Figure (6).

The range that can be compared between Hitch's study and the present investigation is from E/H = 1.5 to 2.1. It is found that the values of h/E are approximately the same. At locations 2 and 3 lower values of h/E were obtained. The behavior of them becomes totally different downstream the crest as the shapes of Hitch's model and the present model were different. This can be seen when comparing locations 4 where negative pressure occurs in the present model while it did not for Hitch's model due to their different configurations. The zone behind location (4) towards the downstream end of the model was generally under negative pressure as can be seen on the figure from location (5) for both models. Locations (6 and 6) demonstrate a similar behavior for both models. The pressure of these locations was negative at lower values of E/H and increased with increasing E/H. The significant difference between h/E values at location (6 and 6) for both models may be attributed to the fact that the selected locations has a relative perimeter value (P_r=0.776) which was far from the corresponding (P_r) value in Hitch's model (P_r=0.81). At the last location (7 and 7) the pressure was always positive and the difference between present results and those of Hitch may be also attributed as above.

CONCLUSIONS

An experimental study was conducted on an inflatable dam model of semi-circular shape to investigate the pressure distribution on the surface of the dam model. The analysis and discussion of results revealed the following main conclusions:

1- The mean pressure increases with the increase of the flow rate at the majority of the pressure taps except at and near to the crest. Different behavior is observed on the downstream face of the dam.

2- Negative pressure occurs at downstream side of the dam where separation of the nape is expected and pressure fluctuations are maximum.

3- The mean pressure becomes low as the crest is approached and when the negative pressure zone is passed, the pressure begins to rise again.

4- The present study is highly recommended that different shapes should be tested under different flow conditions to specify a practical and hydraulically safe inflatable dam to avoid problems resulting from negative pressure zones.

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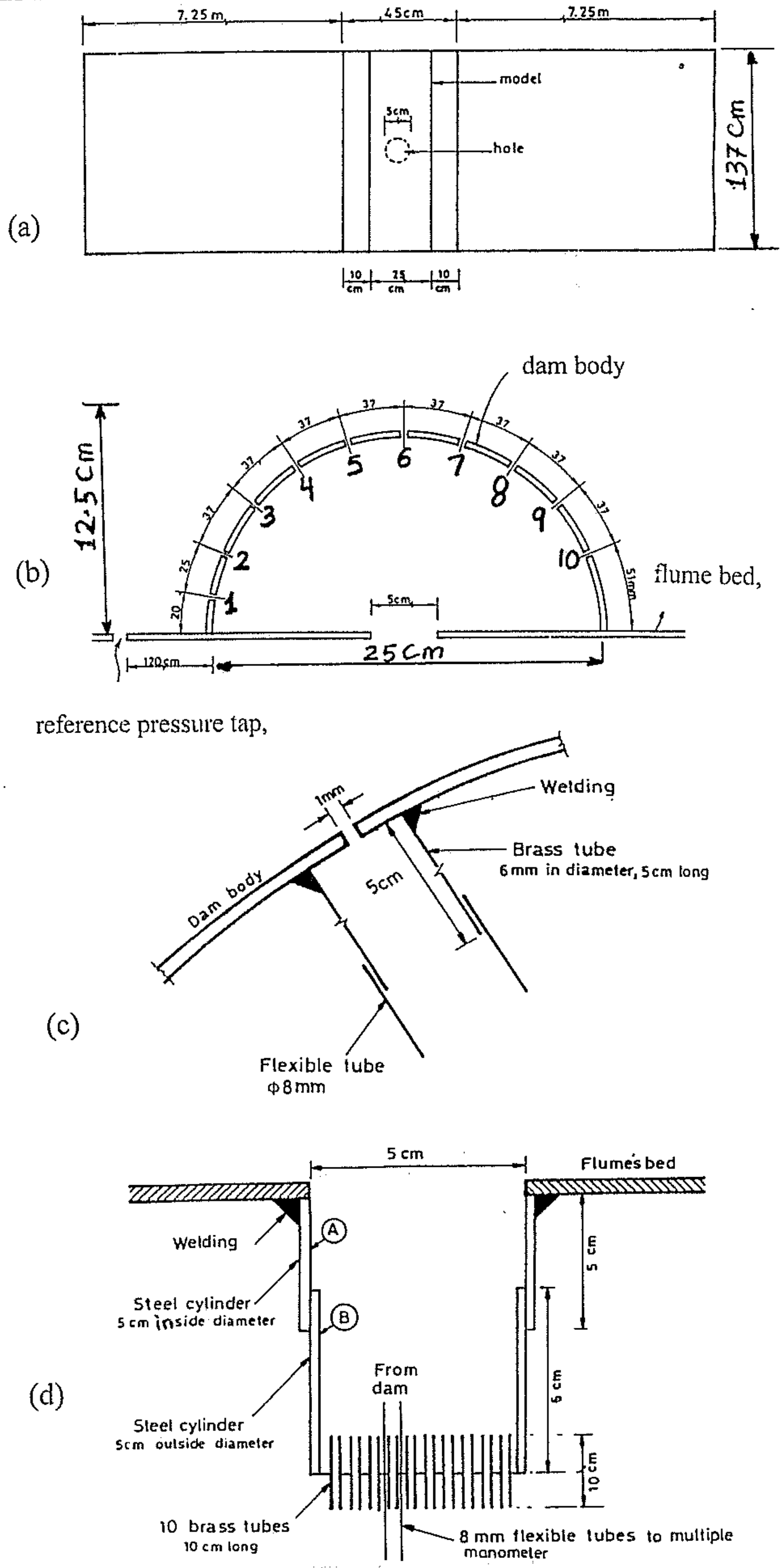
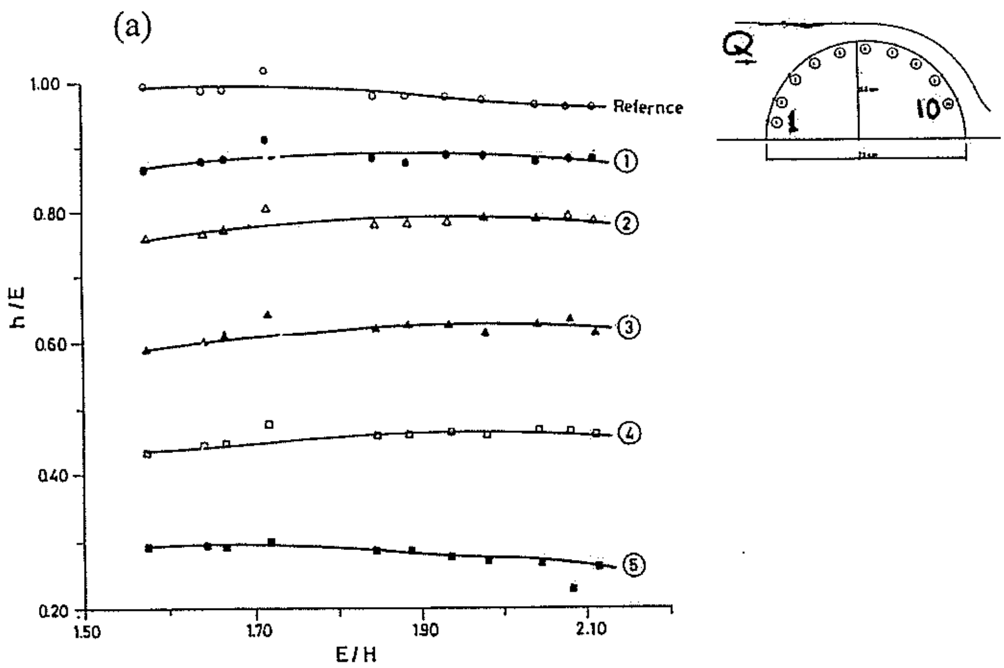


Figure 1. Experimental arrangement, (a) test section, (b) test model, (c) details of a pressure tap and (d) bottom hole to connect pressure taps to multiple manometers board.



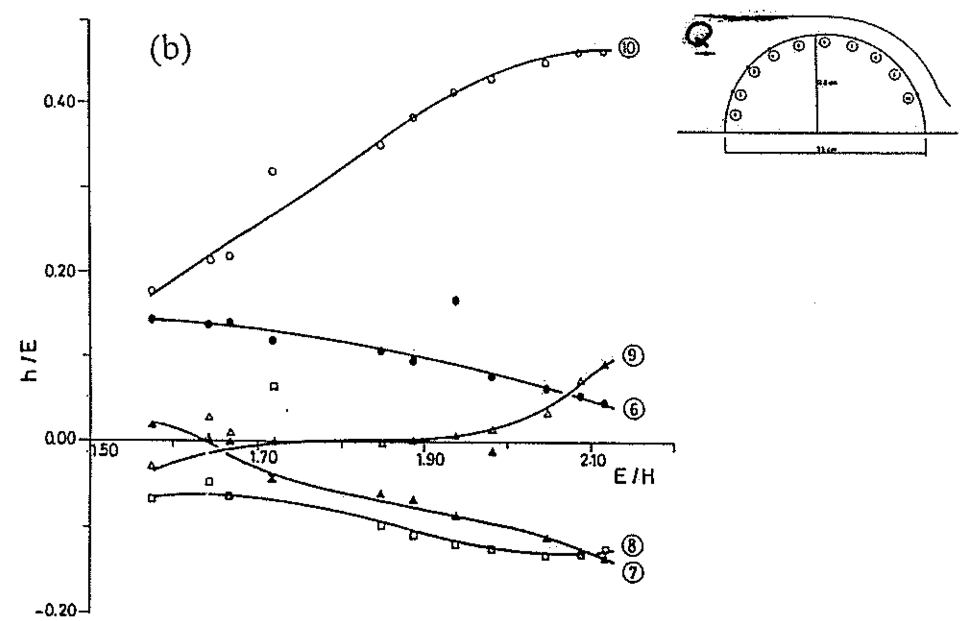


Figure 2. Variation of mean pressure head ratio h/E, with the energy head ratio E/H for (a) the upstream pressure taps from 1 to 5 (b) downstream pressure taps from 6 to 10.

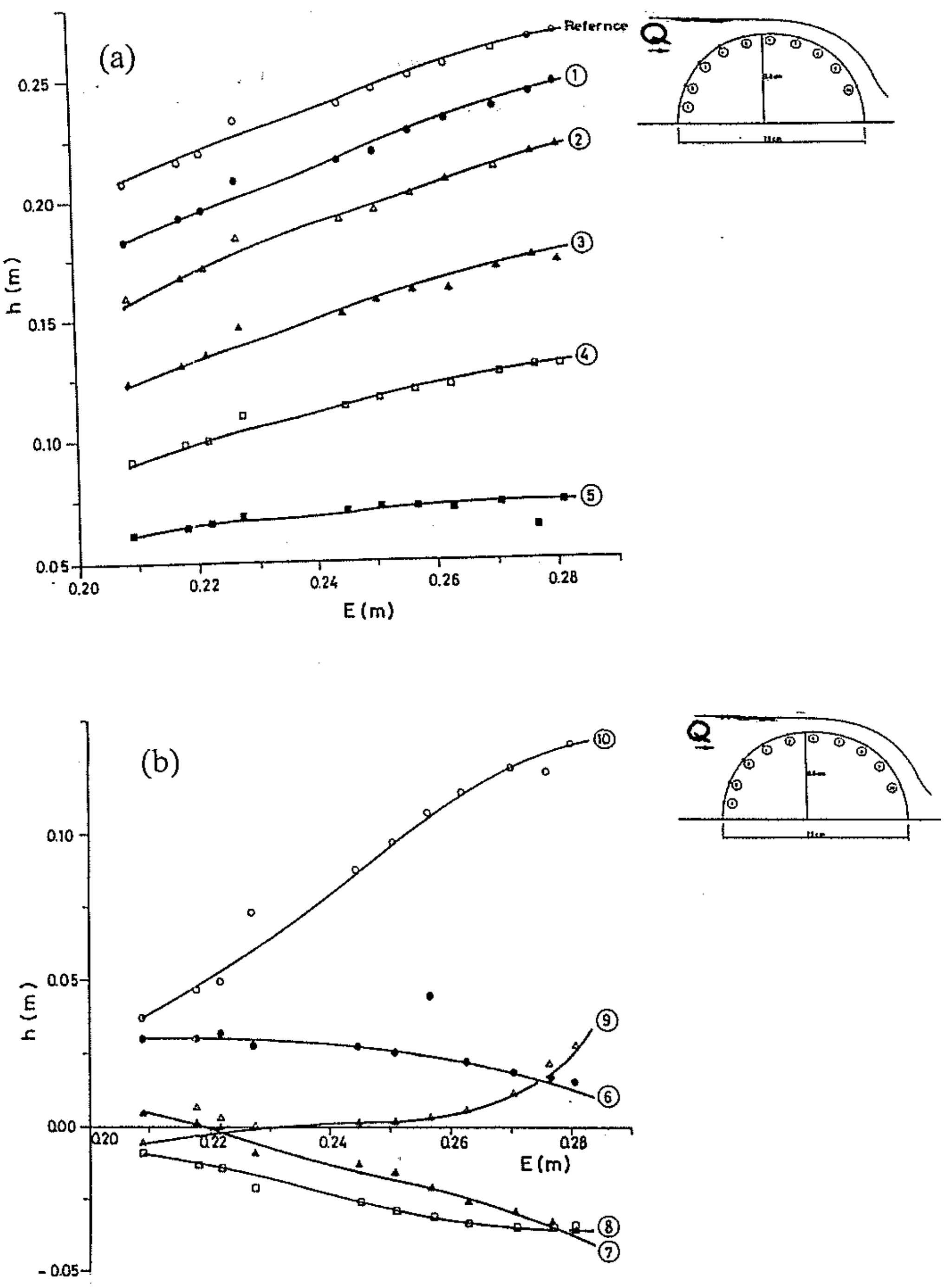
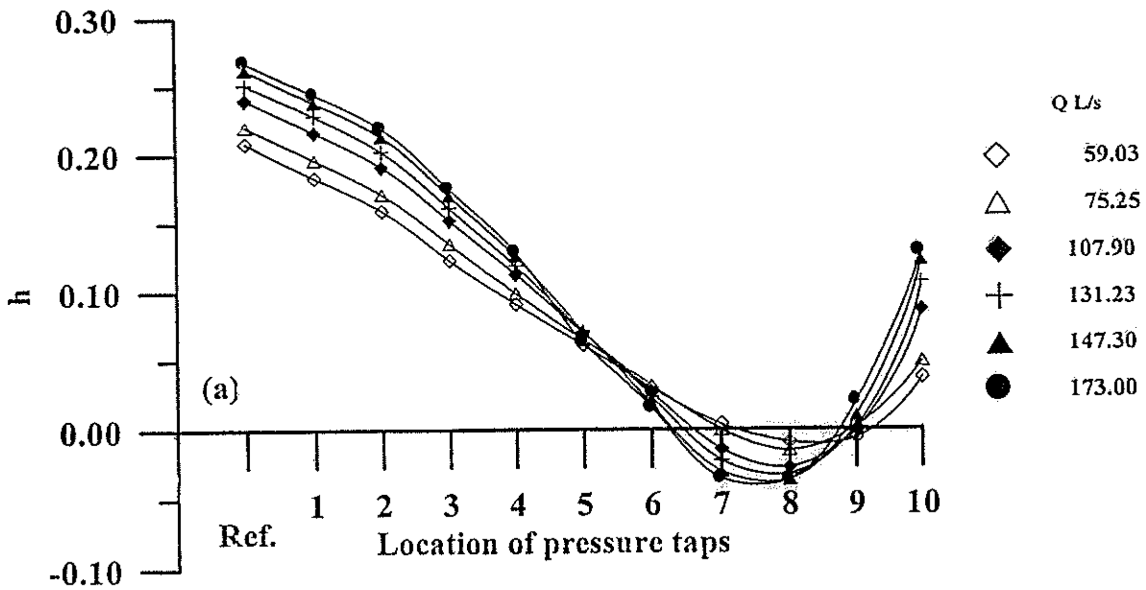


Figure 3. Variation of mean pressure head h, with the energy head E for
(a) the upstream pressure taps from 1 to 5 (b) downstream pressure taps from 6 to 10.



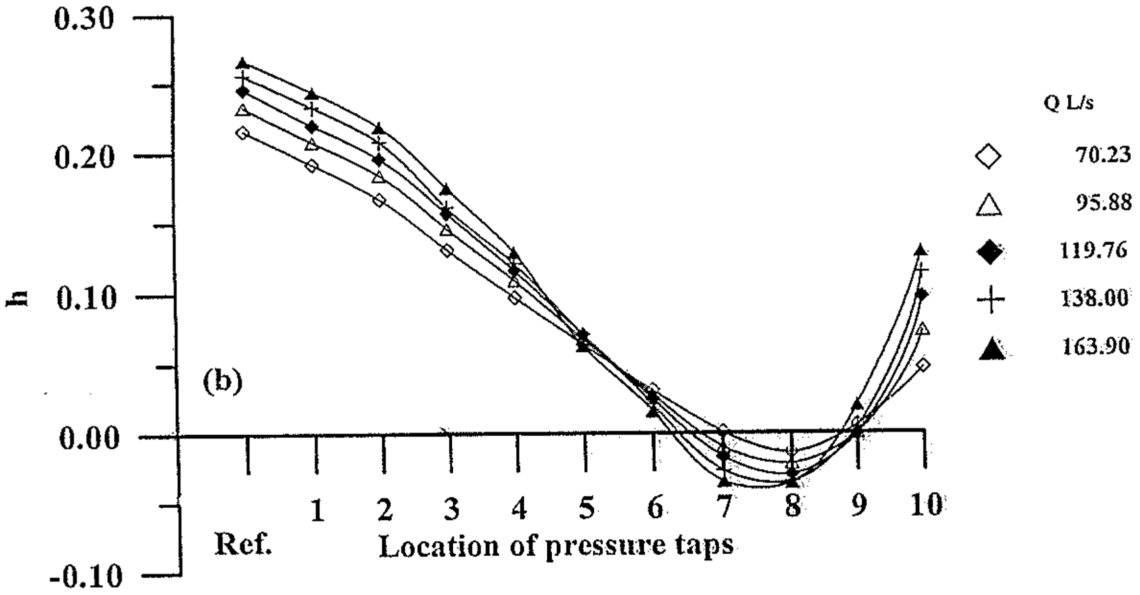
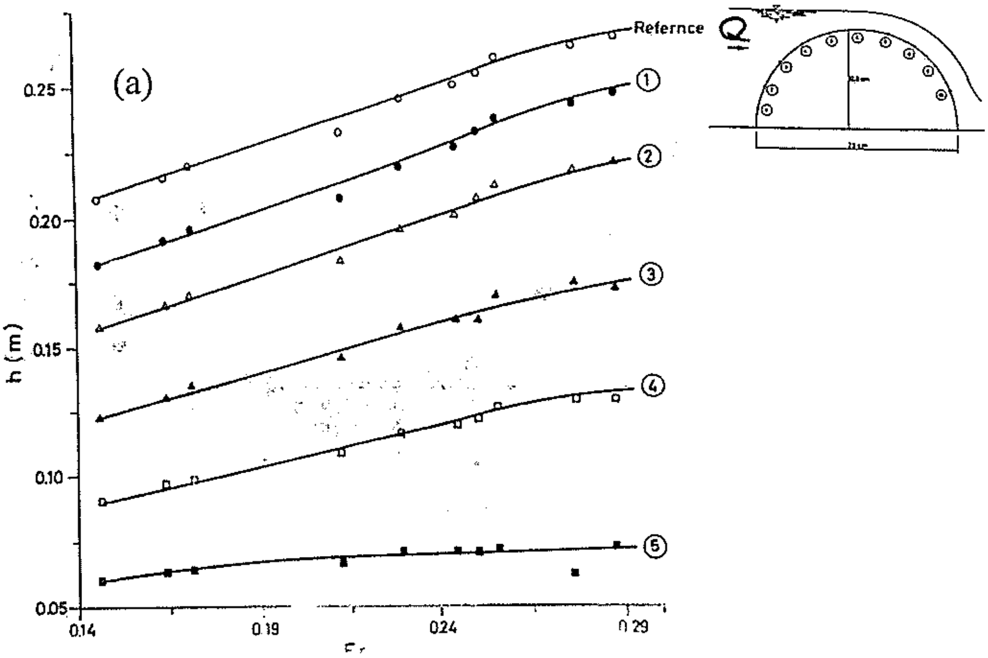


Figure 4. Fluctuation of mean pressure head over the model surface with tap number for runs (a) 1,3,5,7,9,11 (b) 2,4,6,8,10.



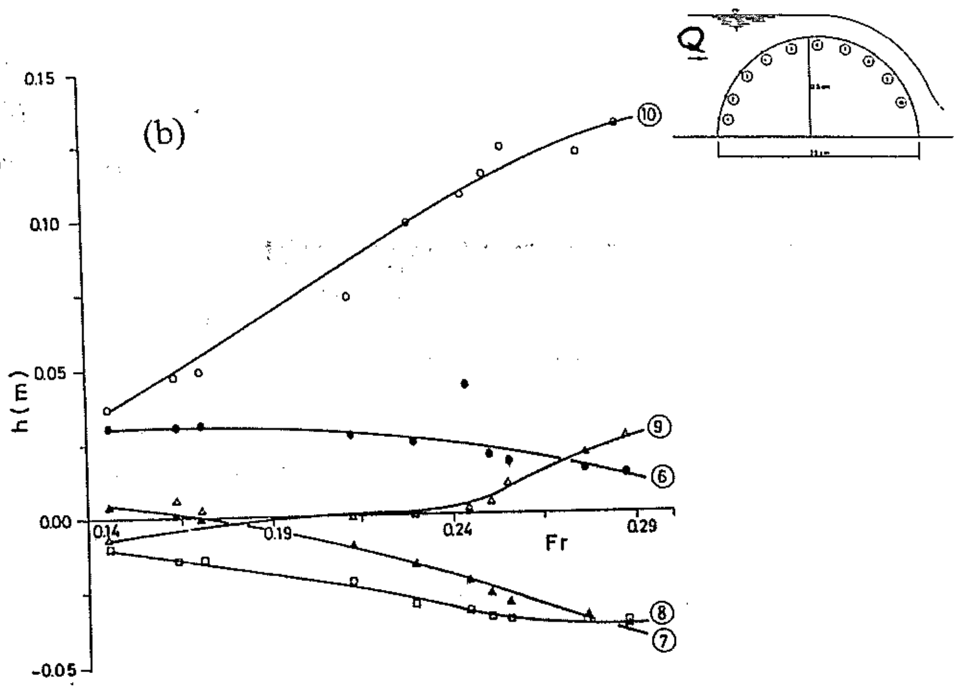


Figure 5. Variation of mean pressure head h, with the upstream Froude number Fr, for (a) the upstream pressure taps from 1 to 5 (b) downstream pressure taps from 6 to 10.

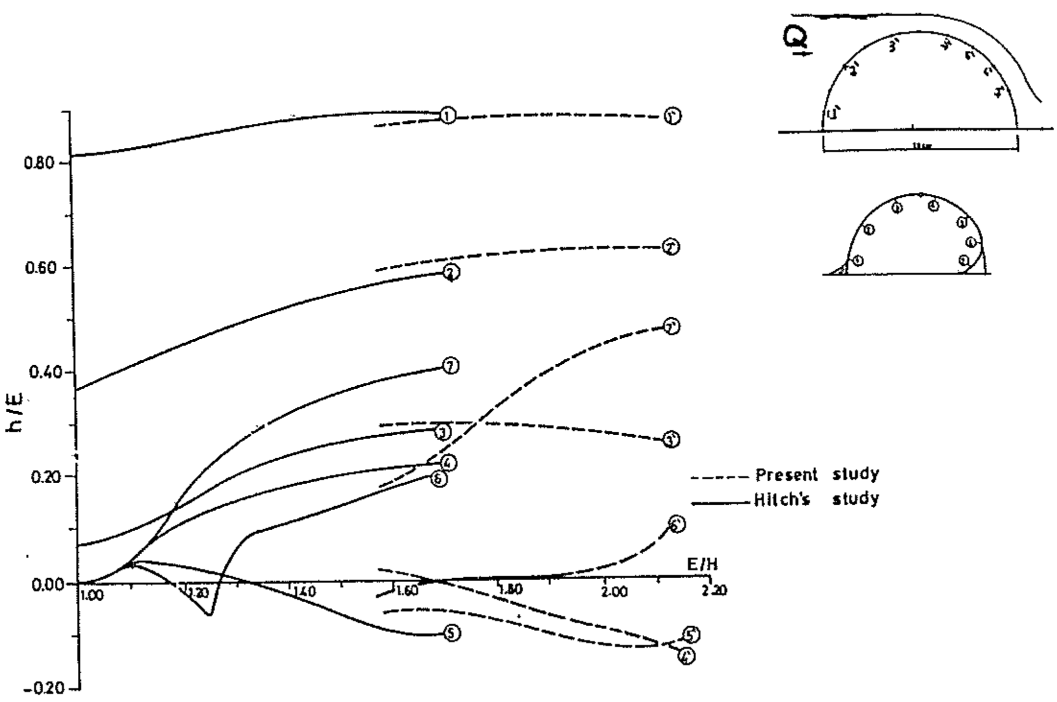


Figure 6. Comparison of present results with those of Hitch [10].