

Introduction

1. The rationale of the thesis

Weirs play an important role in irrigation and hydropower headworks, and have been researched and developed along with the development of science and technology to meet practical requirements. The curved Weirs are most commonly used in large and medium irrigation and hydropower projects with two common types of cross-sections: Creager-Ophixerop [2], [12] and WES [12], [25], [31],[45], [48].

The weirs with breast wall have been used in the world [29], [30], [34], [35] [37], [45], and in Vietnam [8], [14]. This weir type has the advantages such as increasing water levels and flood prevention storage, flood discharging when low water level, optimizing the size of valve gate and mechanical equipment, and reduction in construction costs. They have a wide application range in all types of weirs either newly constructed or repaired for safety enhancement and flood prevention.

Weirs with breast wall have advantages and are widely applicable, but related research results are limited, if any, only referring to geometry dimensions, discharge calculation or an introduction of a specific work. In Vietnam, there are over 7,000 reservoirs with a capacity of over 37 billion m³ (in which 675 large dams)¹ many of which need to be repaired and upgraded. There is a need of application of weirs with breast wall in flood prevention works; however there is no scientific research on the hydraulic regime for this weirs type.

Therefore, studying the hydraulic regime of weirs with breast wall to determine its hydraulic characteristics for practical application is necessary, with scientific and practical meaning, contributing to a comprehensive view on hydraulic characteristics of flood discharge works.

2. Objectives of the study

To clarify the hydraulic characteristics of weirs with breast wall;

To propose methods, formulas, and graphs to determine discharge, velocity and pressure for weirs with breast wall.

3. Objects and scope of study

Study objects are some hydraulic characteristics including flow regime, discharge, velocity, pressure for weirs with breast wall in pressured flow case.

¹National environmental report 2012

The scope of the study focus on WES and Ophixerop weirs with breast wall at their working condition with $H/H_d \leq 1.5$ or $H/D \leq 3$ and free flow after the breast walls or fully opened valve gate.

4. Research Methodology

Inheritance Historical method: Researching and collecting the research results from inside and outside the country;

Data collection method to gather experimental results of actual works;

Experimental model of physical model: Construction, experimenting and collecting hydraulic model data;

Statistical method: Analyzing, evaluating, verificating and comparing the outcomes with other research results from inside and outside the country. Developing formulas, tables, graphs for calculation in actual application.

5. Scientific and practical significance

Scientific significance: The thesis will contribute to the clarification of the hydraulic regime, the flow regime of weirs with breast wall and provide additional scientific basis for calculating hydraulic characteristics of weirs with breast wall.

Practical significance: Contributing to address the optimization problem in operating reservoirs, improving the performance of irrigation and hydropower works for increase in flood prevention storage to ensure the safety of the downstream population.

6. New contributions of the thesis

The thesis has 3 new contributions as follows:

1. Developing and proposing new formulas and graphs to calculate flow coefficient μ for weirs with breast wall when $H/D = 1.6 \div 3.0$.

2. Determining flow velocity coefficient ϕ to calculate the water depth in case of pressured flow. Developing and recommending the application of a dimensionless coordinate table to calculate water surface profile and velocity on the weirs surface.

3. Proposing the method to determine the pressure reduction coefficient C_{pmax} to determine the minimum value of the pressured flow section on weirs with breast wall. Developing dimensionless graphs to calculate the weirs surface pressure at the free flow section.

CHAPTER 1 OVERVIEW OF WEIRS WITH BREAST WALLS

1.1 General overview of weirs with breast walls

1.1.1 The structure of weirs with breast walls

Weirs with breast wall are the spillway type which are arranged not only with the weirs crest but also have breast walls section on the top. The breast wall is a shield above the threshold aims to limit the possibility of rapid increase in discharge due to high upstream water level to control the discharge. The breast walls may be straight or curved shape, or movable form. This type of weir in actual operation experiences free flow or pressured flow. In this thesis, 2 types of weirs with breast walls are selected for study: Creager-Ophixerop and WES in pressured flow condition.

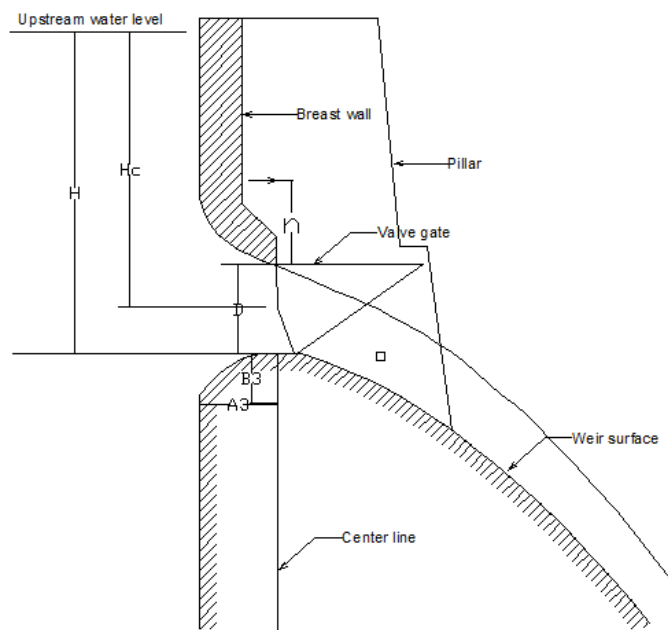


Fig 1.1 Diagram of weirs with breast walls

Weirs with breast walls consist of a curved weir surface at the bottom, exposed to the lower part of the water nappe. At the upper boundary, the bottom of the breast wall is similar to a tunnel entrance or sluice (Figure 1.1 ÷ 1.3), exposed to the upper part of the water nappe.

Therefore, the difference in the structure of this type of weir is the curve shape of both the breast walls and the weirs' surface.

1.1.2 Some practical applications of weirs with breast walls

Reservoirs often have multi-purpose roles. In addition to providing water for irrigation or power generation, large reservoirs often have the task of flood prevention for downstream areas. Even flood prevention is the main task of some reservoirs such

as Hoa Binh, Son La ... Then the weirs have to regulate a large flood in the reservoir. The water column at the weir crest can be up to several tens of meters, so that if using a normal weir with a sluice gate, the height of the valve gate is very high and it is difficult to operate. For example, in Son La hydropower project (Figure 1.4), due to water storing and PMF flood prevention tasks, the difference between the normal water level of 197,80 m and the PMF level of 228.10 m is $H_{\max} = 30.3$ m. Arrangement of a weir with breast walls can optimize the valve gate size to 12m and increase the capacity for flood prevention up to 3 billion m^3 , contributing to flood reduction, and cut the flood for the downstream areas.

1.1.3 Flow characteristics through weirs with breast wall

Flow through a weir with breast wall when the upstream water level changes from low to high experiences two flow modes is free pressured (exposed flow as normal weirs) and pressured flow.

Pressured flow occurs when the upstream water level is higher than the lower boundary of the breast walls. The flow at the entrance of the breast walls is pressured flow, and after the walls is free flow. But due to the impacts of the pressure flow under the breast walls, the hydraulic characteristics of the opening flow are different from full free flow regime. Studies on this regime are very limited. In Vietnam there is no code or guideline for calculation.

1.2 Studies on weirs with breast wall

Studies on weirs with breast wall are mainly from India and China, they cover: downstream weirs curve, upstream weirs curve, curve of the lower boundary of the breast walls, calculation of flow and discharge coefficient [30], [45].

The equation for calculating weirs curve developed by India [30] (1.2):

$$X^2 = kH_d Y \quad (1.2)$$

The equation for calculating weirs curve developed by China [18] [45] (1.3):

$$X^2 = 4\varphi^2 H_d Y \quad (1.3)$$

The elliptical curve of the lower boundary of the breast walls is represented by equation (1.7)[30].

$$\frac{X^2}{A_2^2} + \frac{Y^2}{B_2^2} = 1 \quad (1.7)$$

According to [45], the curve of the lower boundary of the breast walls may be rounded; or elliptical and be connected to the straight section under the breast walls with a slope of 1:4 ÷ 1:6.

The pressured discharge under the breast walls is given by (1.10) [29], [45].

$$Q = \mu\omega\sqrt{2gH_e} \quad (1.10)$$

In which the flow coefficient is determined as follows:

- In preliminary design, we can take $\mu=0.74\div0.82$ when $H/D=2.0\div2.4$; $\mu=0.83\div0.93$ when $H/D=2.4$. The coefficient μ can be calculated through the loss of water surface[45].

- According to [29], [30] flow coefficient is calculated by formula (1.11).

$$\mu = 0,148631 + 0,945305 \frac{H}{H_d} - 0,326238 \left(\frac{H}{H_d}\right)^2 \quad (1.11)$$

These results are incomplete, and the formula for calculating the discharge coefficient μ is inadequate because it only gives a range of value without determining the dependencies. The flow coefficient is calculated only based on H/H_d ratio, but does not take into account the flow regime and the characteristic of the orifice such as the height D . There is no study on the limit of pressured flow regime, velocity, and pressure. These are the limitations that existing studies have not been addressed.

1.3 Research results on curved weirs

The research results on curved weirs have resulted to formulas, graphs, tables for selection of geometric shapes, discharge capacity, water surface profile, velocity and pressure [12], [17], [29], [30], [31], [35], [45], [48], [50], [51]. These documents can basically be used for designing, but for specific structures, it is still important to conduct experimental research for verification and optimization.

1.4 Research results on deep discharging, and shallow-deep discharging structures

The deep discharging structures have similar characteristics to weirs with breast wall but can deal with a higherwater head, this feature has been studied by many scientists. The research direction focuses on flow regime, flow rate and pressure distribution on the ceiling of the entrance. These results have been successfully applied to many strucures in the world as well as in Viet Nam.

Studies on the hydronamic pressure at the ceiling of the entrance of the tunnel by G.A. Vorobiov, N.P. Rozanop, E.I. Dubintric, S.M. Sliski [51], [52] introduced the

pressure reduction coefficient C_p . C_p coefficient is determined based on experiment. The coefficient C_p depends on the size and shape of the entrance, its actual application is very large and the decisive factor for selecting entrance shape. The coefficient C_p at point (i) at the ceiling of the tunnel entrance is calculated by formula (1.25).

$$C_{pi} = \frac{2g(H_i - p_i / \gamma)}{v_k^2} \quad (1.25)$$

When the boundary profile and the coefficient C_p at point (i) are known, it is possible to calculate the excessive pressure therein according to formula (1.7):

$$\frac{p_i}{\gamma} = H_i - C_p \frac{v_k^2}{2g} \quad (1.26)$$

The minimum pressure at the boundary of the inlet is determined by the formula (1.27):

$$\frac{p_{i \min}}{\gamma} = H_i - C_{p \max} \frac{V_k^2}{2g} \quad (1.27)$$

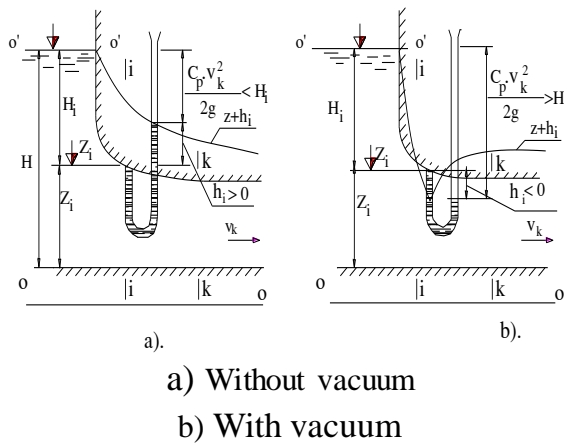


Fig 1.28 Diagram for determining pressure and pressure reduction coefficient C_p at the entrance [51], [52]

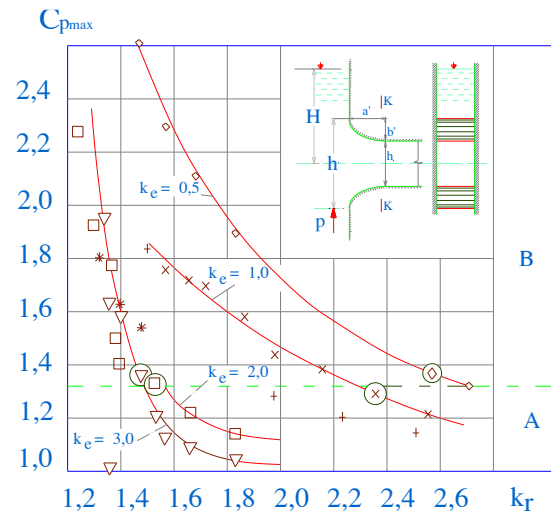


Fig 1.30 $C_{p \max}$ coefficient at the flat entrance [50], [51]
A. Nonseparated flow zone
B. Separated flow zone

The entrance structure of weirs is similar to the entrance of a deep discharging structure, the difference comes from that both the upper and lower boundary of weirs are curved.

1.5 Existing issues

So far, there are research results on weir with breast walls including shape, dimensions, and flow calculation... ; But it still does not reflect the scope of work, hydraulic characteristics, not quantify the factors affecting the shape, ability to discharge and pressure in this over flow weirs. The problem exists mainly:

1/ Undistributed the regime flows through weirs;

2/ Determining the flow factor μ is difficult because it is only for a range without specifying the dependent factor. The formula for calculating the flow factor in terms of the H/H_d ratio does not reflect the flow regime and the characteristic of the hole is height D ;

3/ There are no guidelines on how to determine hydraulic elements such as surface water, velocity, pressure on the spillway;

4/ It has not been shown how to determine the minimum pressure on the spillway, breast walls.

The determination of the existence of this contributes to the nature of the flow in weirs with breast wall, reducing the experimental mass.

1.6 Conclusion of Chapter 1

The weirs which has medium and high head can choose shallow, deep or shallow-deep discharge. Each form has a range of applications and certain advantages and disadvantages. The two curved weirs with two types of cross section as Creager - Ophixerop and WES are most widely applied.

With the open flow through the spillway or current flowing through the sewers, tunnels, the results of the research are relatively sufficient to meet basic research requirements, practical design.

The weirs with breast walls are the intermediate form between shallow and deep discharge, which has the advantage of being able to increase flood prevention volume, optimize valve gate, and discharge the flow of water at low levels. It promoted the advantages of both the shallow and bottom discharge so it used for medium and high weirs. The research results on this form of discharge are available, but inadequate, some studies are specific to specific works.

The following part of the thesis will study some hydraulic features such as determination of flow regime, determination of flow, velocity, pressure and construction of experimental functions applied in calculations.

CHAPTER 2 RESEARCH METHODOLOGY ON HYDRAULIC CHARACTERISTICS OF WEIRS WITH BREAST WALLS

2.1 Method of determining the flow regime

The general method for determining surface water flow is to compute and draw water lines in the Creager-Ophixerop overflow, WES on the same surface, in proportion to the breast walls and breast walls curve. The weirs have a free-flowing breast walls when the water surface flow has not touched the breast walls, demarcation flow when the water begins to touch the lower edge of the breast walls and pressured flow when water surface profile completely floods the lower boundary of the breast walls.

2.2 Hydraulic modeling research methods

2.2.1 *The same standard with hydrodynamics*

The thesis uses the hydraulic modeling method with the following equation:

$$\varphi(\text{Fr}, \text{Eu}, \text{Re}, \text{Sh}) = 0 \quad (2.1)$$

Flow through in weirs with breast wall is modeled, the flow is influenced mostly by gravity. Therefore, studying the hydraulic model needs to satisfy the Euler and Froude standards, these are identical as calculating pressure respect to actual water heads, the unit of measurement is meter (m H₂O).

The standard formula following Froude standard below:

$$\text{Fr} = \frac{v^2}{gl} = \text{idem or } \frac{\lambda_v^2}{\lambda_g \lambda_1} = 1 \quad (2.3)$$

Then other criteria are considered satisfactory conditions.

2.2.2 *The method of experimental planning and developing regression*

The thesis develops empirical regression equations by modeling based on the arrangement of experiments to measure the output respect to inputs. This can help to find the optimal working domain of the system. Inputs are testable and controllable variables so that the researcher can adjust. Therefore, this is an important method commonly used in research to develop black-box models to demonstrate complex structural systems.

2.3 Developing experimental equations

The thesis studies some hydraulic characteristics of flowing through weirs with breast wall. When considering pressured flow regime through the breast walls, the variables that may change during the study are the characteristics of liquid including: specific gravity ρ , dynamic viscosity η , accelerated gravity g ; and geometric parameters including length L , water head H , height of the orifice of the breast walls D , height of the entrance of the breast walls D_1 , length of the breast walls along the flow direction D_2 , height of weirs crest P , width of the weirs bay B , the water head of the weirs H_d ; discharge Q . The measured parameters in model include velocity v , the flow depth h_i . The pressure is measured as water head in m so it is also demonstrated as the flow depth. From this we have an equation:

$$f(Q, H, D, D_1, D_2, P, b, H_d, g, \rho, \eta, h_i, v_i) = 0 \quad (2.10)$$

In the equation above the number of independent variables $n = 13$. Using the Buckingham method (Pi theorem) with the selection of three basic quantities Q, D, ρ we have a new function with $n - 3 = 10$ dimensionless variables (2.4).

$$F(\pi_1, \pi_2, \pi_3, \dots, \pi_{n-3}) = 0 \text{ or } \pi_1 = G(\pi_2, \pi_3, \dots, \pi_{n-3}) \quad (2.11)$$

Determining dimensionless combinations by the Buckinghamian method results in the equation for dimensional quantities and the general experimental equation (2.5).

$$F\left[\frac{H}{D}, \frac{D_1}{D}, \frac{D_2}{D}, \frac{P}{D}, \frac{b}{D}, \frac{H_d}{D}, \frac{D^5 \cdot g}{Q^2}, \frac{1}{R_e}, \frac{h_i}{D}, \frac{D \cdot v_i}{q}\right] = 0 \quad (2.12)$$

Equation (2.12) is used to determine series of experiments and is used for general and empirical research of the thesis.

$$\text{When studying the discharge capacity: } \mu = F_1 \left[\frac{H}{D}, \frac{H_d}{D}, \frac{D_1}{D}, \frac{b}{D} \right] \quad (2.13)$$

When studying pressure or water head: $\frac{H_i}{H_d} = F_2 \left[\frac{H}{D}, \frac{H_d}{D}, \frac{D_1}{D}, \frac{b}{D} \right]$	(2.14)
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When studying the water velocity on the surface of the structure for accelerated flow:

$$\frac{v_i}{v_r} = F_3 \left[\frac{H}{D}, \frac{H_d}{D}, \frac{D_1}{D}, \frac{b}{D} \right] \quad (2.15), \text{ with } v_r \text{ being the flow velocity at the last cross section}$$

of the breast walls at downstream.

2.4 Experimental model

The thesis studied 04 experimental models (Table 2.1). In which:

- Developing and experimenting 01 model for Creager-Ophixerop weirs with 4 different orifice heights.

- Exploiting and using data of 03 experimental models with WES cross-section type of overflow.

Table 2.1 Experimental models

No	Parameter	Unit	Model 1	Model 2	Model 3	Model 4
1	Spillway surface curve		Creager-Ophixerop	WES	WES	WES
2	Water head of spillway shape H_d	m	12	20.03	17.2	20.03
3	Orifice height (exit)D	m	5; 6; 7; 8	11.4	13.0	11.4
4	Entrance height D_1	m	9.5÷12.5	17.6	17.6	17.6
5	Weir height (P)	m	62	138	138	138
6	Width of one weir bay b	m	11	15	15	15
7	Model ratio		1/64	1/48	1/48	1/100

Table 2.3 Case studies in model 1

No	Water head $H = Z_{\text{upstream}} - Z_{\text{crest}}$ (m)	H/H_d	H/D	Q Model (l/s)
A	D=5 m			
1	7.82	0.65	1.56	14.8
2	8.42	0.70	1.68	17.4
3	9.32	0.78	1.86	19.5
4	11.34	0.94	2.27	23.2
5	14.45	1.20	2.89	27.8
6	15.85	1.32	3.17	29.7
7	18.68	1.56	3.74	33.1
8	21.99	1.83	4.40	36.5
B	D=6 m			
1	10.39	0.87	1.73	20.75
2	1.93	0.99	1.99	24.01
3	14.47	1.21	2.41	28.49
4	17.26	1.44	2.88	32.73
5	20.47	1.71	3.41	36.84

No	Water head $H = Z_{\text{upstream}} - Z_{\text{crest}}$ (m)	H/H_d	H/D	Q Model (l/s)
C	D=7 m			
1	9.63	0.80	1.38	19.39
2	11.75	0.98	1.68	25.76
3	13.59	1.13	1.94	29.80
4	15.87	1.32	2.27	34.92
5	19.20	1.60	2.74	40.58
6	22.39	1.87	3.20	45.33
D	D=8 m			
1	10.80	0.90	1.35	23.18
2	11.30	0.94	1.41	25.08
3	13.75	1.15	1.72	31.93
4	16.42	1.37	2.05	37.94
5	19.67	1.64	2.46	43.61
6	22.66	1.89	2.83	48.42
E	Use the result of free surface in the model 1			
1	9.75	0.81		19.66
2	12.00	1.00		27.41
3	12.95	1.08		31.09
4	14.15	1.18		35.61
5	15.30	1.28		40.13

2.5 Conclusion of chapter 2

The selection of curves, spillway sizes, breast walls and upstream transition sections should meet the conditions ensuring unloading flow, meeting flood level requirements, simple structure, stream flow, small loss, non-cavitation, easy to work, saving material weight and easy to arrange the structure such as valve slot, and valve gates.

Thesis selected using research methods hydraulic model with Froude standard and experiment planning theory to determine the hydraulic characteristic with laboratory quantities is big enough to comply with the same conditions on hydraulic to ensure the accuracy and reliability of the results. This is a highly reliable traditional research methodology and has been used for most construction hydraulic studies up to now.

The data processing method follows experimental planning method with empirical regression function (2.20). In terms of shape, the thesis selected two spillway types WES and Creager-Ofixerop with H/H_d ratios = $0.5 \div 2.60$, $H_d / D = 0.92 \div 4.40$; The breast walls shape is ellipsed and the circle lines combined the straight lines for study.

The thesis used six scenarios with 60 experimental cases, of which 30 were for WES form and 30 for Creager-Ofixerop form.

Experimental model of the thesis has been tested by experiments models determine the hydraulic characteristics of opened flow cases and compared with declared documents. Results of error of water surface line $<\pm 5\%$, flow error in the range of $2 \div 5\%$, pressure error $<\pm 0.5\text{m}$. Most comparative results give the error value $<5\%$, which indicates the reliability of the experimental model.

Such methods of hydraulic model testing is reliable enough to research the thesis characteristics under pressed flow regime below the breast walls (or flowing full breast walls).

Research results from this method will be presented and discussed in Chapter 3.

CHAPTER 3

RESULTS AND EVALUATION ON SOME HYDRAULIC CHARACTERISTICS TESTING OF WEIRS WITH BREAST WALL

3.1 The experimental and evaluation results

3.1.1 Determination of flow regime limit

Experiments are undertaken from low water level to high water level to gradually observe and measure water level at free-flow, separated flow, and then pressured flow. In the table 3.1 are 19 experiment cases. Results for cases of $H/D \geq 1.6$ together with figures are used to draw water surface profile in pressured flow regime.

Table 3.1 Experiment results table for flow regime determination

Sequence of experiments	D (m)	h_v (m)	H (m)	H/D	Depth of entrance h_1 (m)	h_1/h_v	Depth of exit h_z (m)	h_z/D	Flow regime
	Model 1								
1	5	9,5	7,82	1,56	7,71	0,81	5,00	1,00	$h_1/h_v < 1$, $h_2/D = 1$, separated flow
2	5	9,5	8,42	1,68	8,35	0,88	5,03	1,01	$h_1/h_v < 1$, $h_2/D > 1$, pressured flow
3	5	9,5	9,34	1,87	9,15	0,96	5,09	1,02	$h_1/h_v < 1$, $h_2/D > 1$, pressured flow
4	6	10,5	8,33	1,39	8,10	0,77	4,74	0,79	$h_1/h_v < 1$, $h_2/D < 1$, non-pressured flow
5	6	10,5	8,87	1,48	8,51	0,81	5,76	0,96	$h_1/h_v < 1$, $h_2/D < 1$, separated flow
6	6	10,5	9,92	1,65	9,79	0,93	6,06	1,01	$h_1/h_v < 1$, $h_2/D > 1$, pressured flow
7	6	10,5	10,95	1,83	10,62	1,01	6,10	1,02	$h_1/h_v > 1$, $h_2/D > 1$, pressured flow

Sequence of experiments	D (m)	h_v (m)	H (m)	H/D	Depth of entrance h_1 (m)	h_1/h_v	Depth of exit h_z (m)	h_2/D	Flow regime
8	7	11,5	9,62	1,37	9,38	0,82	6,86	0,98	$h_1/h_v < 1$, $h_2/D < 1$, non-pressured flow
9	7	11,5	11,81	1,69	11,71	1,02	7,02	1,00	$h_1/h_v > 1$, $h_2/D = 1$, pressured flow
10	8	12,5	13,75	1,72	13,63	1,09	8,01	1,00	$h_1/h_v > 1$, $h_2/D = 1$, pressured flow
11	8	12,5	16,42	2,05	16,40	1,31	8,02	1,00	$h_1/h_v > 1$, $h_2/D = 1$, pressured flow
Model 2, 3									
10	11	17,16	17,04	1,49	14,61	0,85	10,89	0,96	$h_1/h_v < 1$, $h_2/D < 1$, separated flow
11	11	17,16	17,20	1,51	15,22	0,89	10,91	0,96	$h_1/h_v < 1$, $h_2/D < 1$, separated flow
12	11	17,16	19,05	1,67	17,00	0,99	11,40	1,00	$h_1/h_v = 1$, $h_2/D < 1$, pressured flow
13	11	17,16	20,03	1,76	20,03	1,17	11,40	1,00	$h_1/h_v > 1$, $h_2/D < 1$, pressured flow
14	13	17,16	17,20	1,32	15,03	0,88	11,51	0,89	$h_1/h_v < 1$, $h_2/D < 1$, free flow
15	13	17,16	18,20	1,40	15,20	0,89	11,61	0,89	$h_1/h_v < 1$, $h_2/D < 1$, free flow
16	13	17,16	19,72	1,52	17,15	1,00	11,85	0,91	$h_1/h_v = 1$, $h_2/D < 1$, separated flow
17	13	17,16	20,40	1,57	17,44	1,02	13,48	1,04	$h_1/h_v > 1$, $h_2/D > 1$, pressured flow

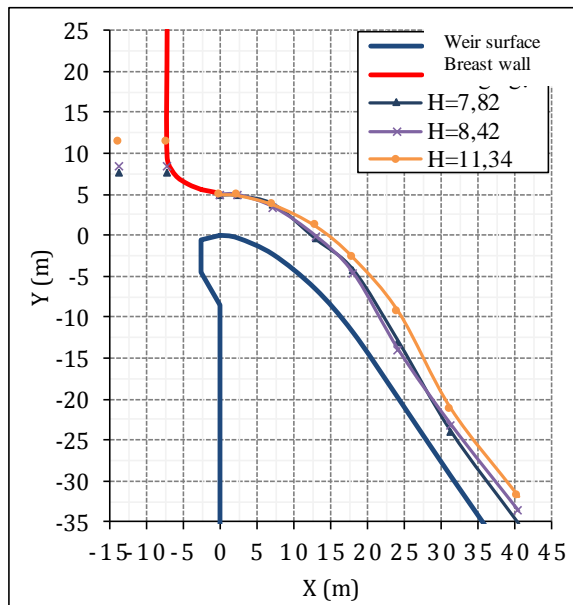


Figure 3.1 Experiment result for flow regime in model 1, $D=5m$

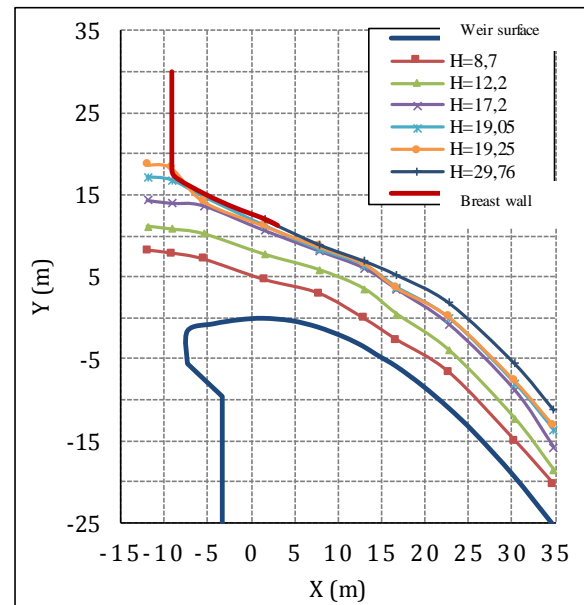


Figure 3.2 Experiment result for flow regime in model 2

3.1.2 Discharge capacity and flow coefficient

The experiment statistics of 12 cases for Creager-Ofixerop weirs and 15 cases for WES weirs within $0.8 < H/H_d < 1.89$ or $1.6 < H/D < 2.83$ are shown in table 3.2 and displayed in Figure 3.5 ÷ Figure 3.6

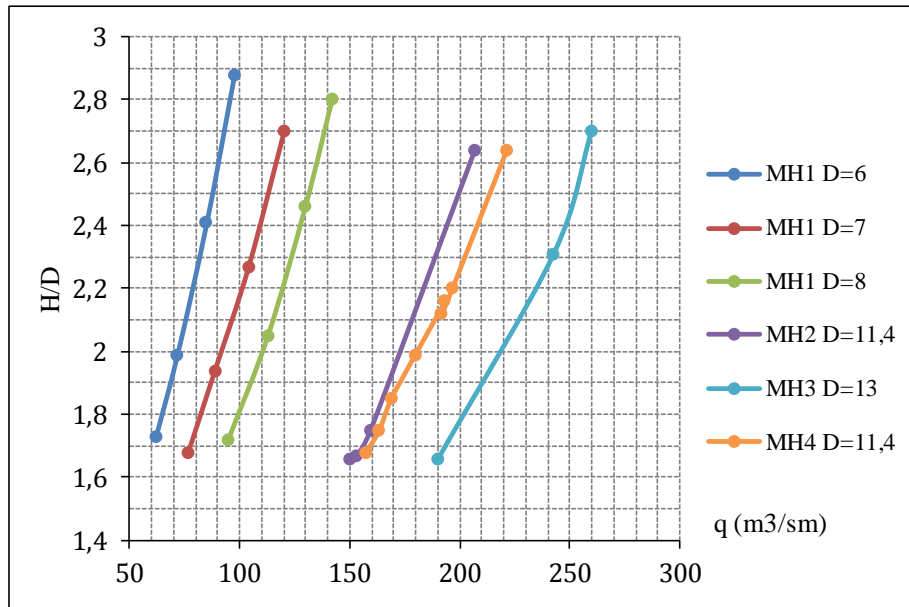


Figure 3.5 Discharge capacity determination

The figure 3.5 indicates that the discharge capacity is proportional to orifice height, the lines showing discharge capacities respect to orifice heights tend to be parallel. Altogether, they exhibit a linear relationship between discharge capacity and orifice height.

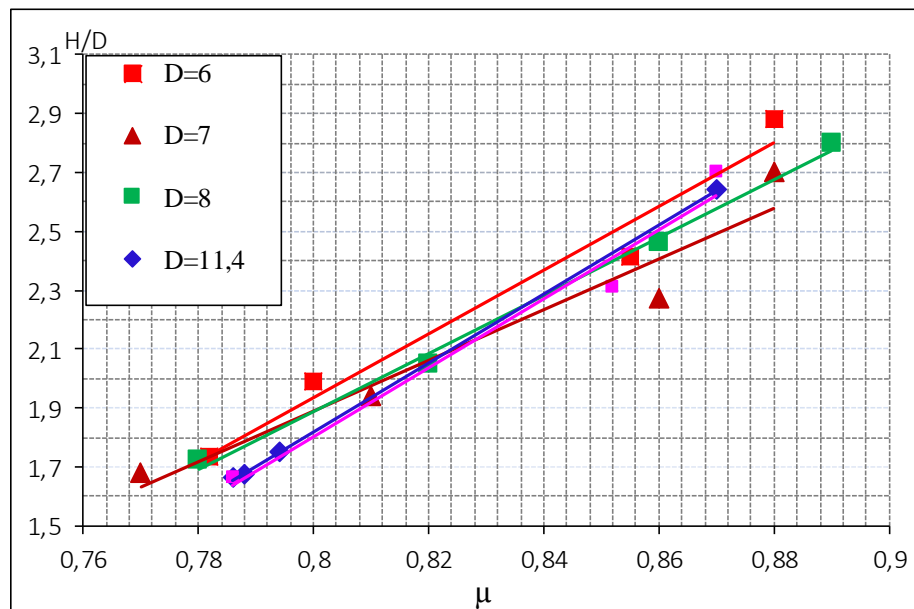


Figure 3.6 Flow coefficient μ determination

Figure 3.6 shows that, in experimental models, the distribution of flow coefficient is relatively concentrated, with a value of $\mu = 0.76 \div 0.888$. The coefficient μ is proportional to the ratio of H/D .

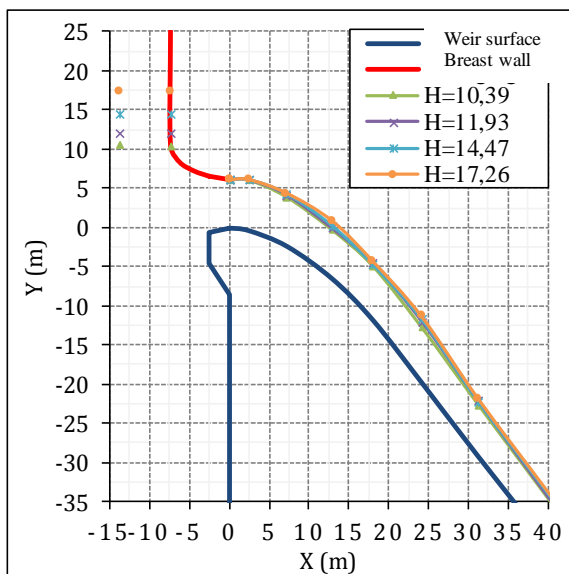
3.1.3 Water surface profile

Experiments have been conducted for cases where water surface profile is at the ratio of $H/D=1.68\div 3.2$ for two types of weir cross sections: WES and Creager-Ophixerop.

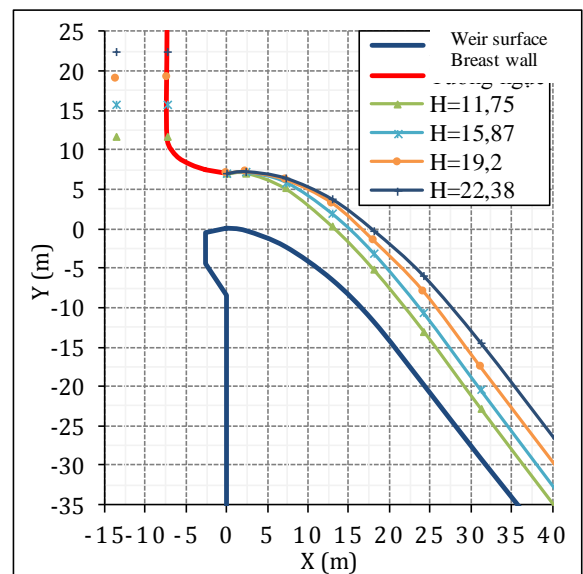
The experiment and graphs show that when $H/D=1.6\div 2.8$ the water flow nappe after the breast walls is closely to the weir surface and its depth is equal to the height of the orifice. The depth of the flow decreases gradually as it moves towards the downstream, this expresses typical characteristics of accelerated flow.

In cases of $H/D>3$, the depth of the flowing out of the orifice tends to surpass the orifice height. This is a sign of a separated flow, causing high vacuum. It is completely in line with recommendations when selecting $H/H_d<1.33$.

For the two studied weirs, when $H/D > 1.6$, the flow going through the breast walls is pressured flow. The flow depth at the section right after the breast walls varies insignificantly and is approximately as high as the orifice height of the breast walls. This results from that the weirs' top is flat, with minor horizontal slope (roughly $\theta < 7\div 8^\circ$, $\cos(\theta) > 0.99$). The accelerated flow ($Fr > 1$) moving out from the orifice maintains its depth to the section with a greater slope. In cases where $H/H_d > 3$, the separated flow tends to occur.



b) $D=6m$



c) $D=7m$

Figure 3.7 Water surface profile of pressured flow - model

3.1.4 Experimental and evaluation results of flow velocity

The results of flow velocity measurement as well as water surface profile on weirs surface are as below.

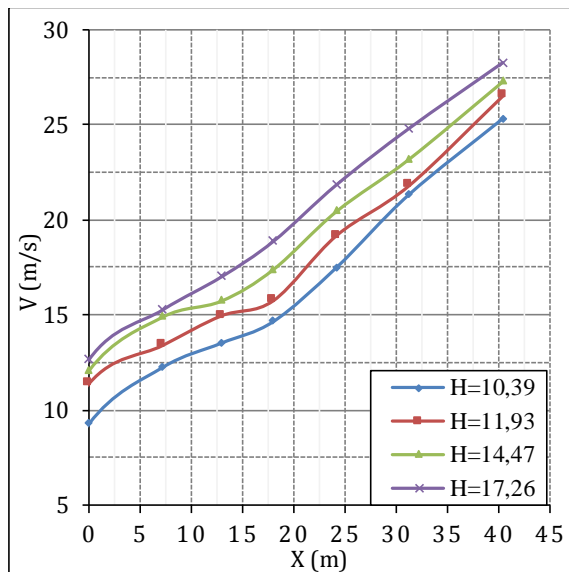
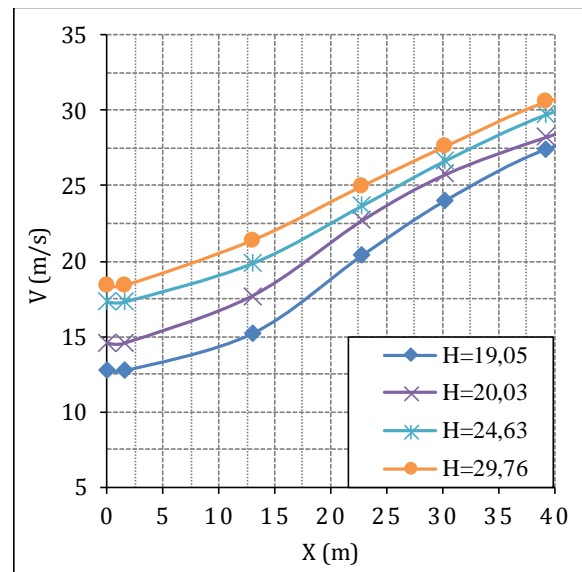


Figure 3.12 Velocity distribution for model 1, $D=6m$



Hình 3.15 Velocity distribution for model 2

The measurement results indicate that flow velocity distribution is in line with the rule, the flow velocity increases gradually from the weirs crest to the straight transition section on the weirs surface. The velocity will increase if the upstream water level rises and there is no difference in rules among studied cases.

3.1.5 Pressure distribution on weirs surface with breast walls

3.5.1.1 Results and evaluation of pressure Experiment on weirs surface

1/ Results and evaluation of pressure experiment on weirs surface in model 1

The results of pressure measurement at center line of the bay for model 1 with $D=5\div 8m$ are displayed on figure 3.18÷figure 3.21.

Studies are undertaken with a range of $H/D=1.35\div 3.4$ or $H/H_d=0.80$ to 1.89, results and graphs analysis show that

- When $H/H_d \leq 1$, vacuum pressure does not occur on the upper surface and vice versa. Vacuum pressure increases when $H/H_d > 1$.
- The vacuum pressure is highest near the weirs crest, the vacuum zone stretches from the weirs crest to downstream in the interval of $X/H_d = (0\div 1.2)$.
- The vacuum value can exceed the allowed value for cavitation prevention on surface ($h_{ck}=5\div 6m$) when $H/H_d > 1,6$.

These above comments demonstrate that the results are in accordance with the rules of pressure distribution on the weirs surface for free flow but value may differ and they are also consistent with recommendations for open flow, $H/H_d < 1.33$.

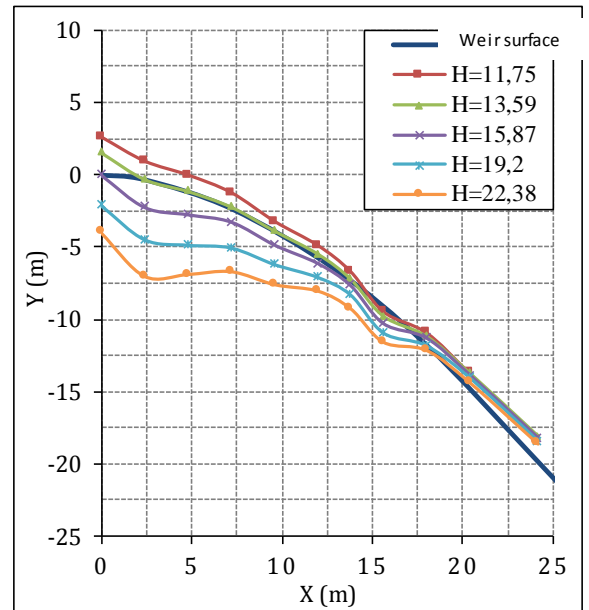
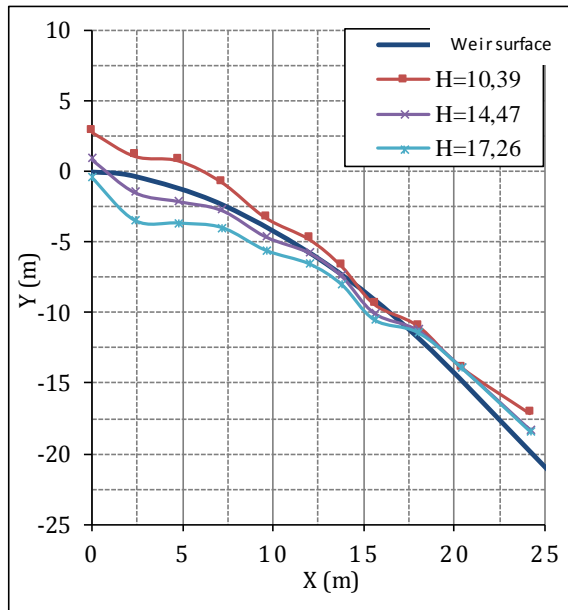


Figure 3.19 Pressure line at center line for pressured flow in model 1, $D=6m$

Figure 3.20 Pressure line at center line for pressured flow in model 1, $D=7m$

2/ Results and evaluation of pressure Experiment on weirs surface in model 2

Results of experiments on pressure at center line of the bay and at pin pillar in model 2 are exhibited on Figure 3.22÷ Figure3.23.

According to the law of pressure distribution on weirs surface, because of the impacts caused by the curve section, the flow pressure tends to gradually decreases from upstream to downstream. Additionally, the pressure reduces rapidly and vacuum can possibly exist as in the interval $X = (-0,2 \div 1,4)H_d$ depending on the ratio of H/H_d . The more H/H_d ratio rises, the larger the pressure reduction and vacuum zones.

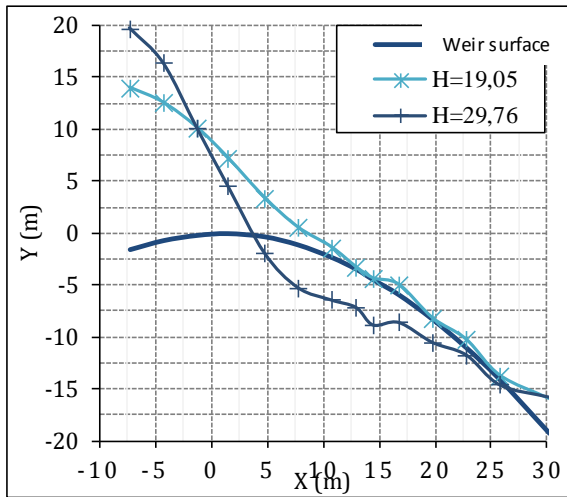


Figure 3.22 Pressure line at center line for pressured flow in model 2

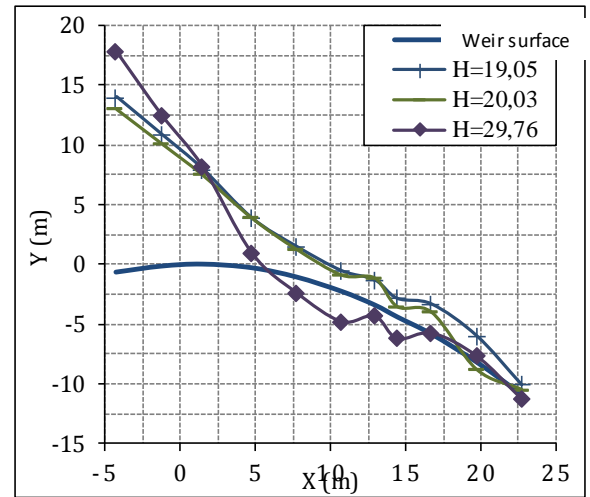


Figure 3.23 Pressure line at pillar for pressured flow in model 2

3.1.5.2 Results and evaluation of pressure experiment on breast walls

- Positive pressure zone $h_p > 0$ located at about 2/3 of the length of beginning section of the breast walls..
- Dropping pressure zone, $h_p < 0$, located at 1/3 of the end section of the breast walls, the higher the water level, the greater the vacuum pressure.
- The vacuum pressure value can exceed the allowed value when $H/D > 3$.
- The pressure distribution rules on the breast walls among various experimental cases are not different.

The distribution forms on breast walls for the two forms of weirs in experimental models are similar.

3.2 Determine some of the hydraulic characteristics of a weirs with breast walls

3.2.1 Formular for calculation of flow coefficient

From the results of the empirical formula analysis and correlation analysis, the variables of the non-dimensional function of flow coefficient μ have been identified as Equation (2.13). Since this formula, combined with linear polynomial function, nonlinear or exponential function, uses linear regression analysis to find the relationship between empirical variables and μ . Many types of functions integrated by the non-dimensional variables and function forms of μ -formulas have been investigated and tested, but the linear function form used for the f_1 function get the best result as form (3.1)

$$\mu = b_0 + b_1 \frac{H}{D} + b_2 \frac{H_d}{D} + b_3 \frac{D_1}{D} + b_4 \frac{b}{D} \quad (3.1)$$

In addition to inherit the existing research results, especially in Indian studies, combined with the correlation analysis, the flow coefficient μ correlates very well with the H/D the correlation coefficient is 0.92), while the H/H_d coefficient correlated to the lower μ only 0.83. So, this study uses functional form of Equation (1:11), instead of H/H_d by H/D obtained the formula (3.2)

$$\mu = M \left(\frac{H}{D} \right)^2 + N \left(\frac{H}{D} \right) + P \quad (3.2)$$

Set of developing functions from experimental data includes cases: 5 orifice heights D , 3 entrance heights, 3 H_d , and 17 H/D values. Set of verifying functions includes 2 cases: orifice height D with $H_d/D = 1.71$ and 1.78 with $D_1/D = 1.77$ and 1.83 . The discrepancy is calculated as a relative error $(\mu_{tn} - \mu_{tt}) / \mu_{tn}$.

Regression tool of the Microsoft Excel Software is used to determine the regression coefficients of the equations for the regression coefficients of the experimental function (Table 3.5), The formulas from (3.3) to (3.6) are in the linear form (3.1) and formula (3.7) is in the polynomial form of degree 2 in the form (3.2).

Table 3.5 Correlation parameter and experimental function coefficient for flow coefficient

<i>Formula</i>	Coefficient of experimental function					Correlation parameter		Error (%)	
	<i>b₀</i>	<i>b₁</i>	<i>b₂</i>	<i>b₃</i>	<i>b₄</i>	<i>S</i>	<i>Sig.F</i>	<i>Min</i>	<i>Max</i>
Formula(3.3)	1,8700	0,0638	0,5797	-1,0967	-0,1507	0,797	0,0073	-3,85	3,58
Formula (3.4)	0,7410	0,0660	- 0,0481	0,0136		0,784	0,0033	-3,53	3,22
Formula (3.5)	0,7150	0,0727	- 0,0246			0,929	3E-07	-2,22	2,96
Formula (3.6)	0,6741	0,0721				0,915	1E-07	-2,82	2,33
Formula(3.7)	M	N	P						
	-0,0432	0,2640	0,4695			0,932	2,37E-07	-2,93	2,89

Table 3.5 Used the regression equations to calculate the flow coefficient as follows:

$$\mu = 1,8700 + 0,0638 \frac{H}{D} + 0,5797 \frac{H_d}{D} - 1,0967 \frac{D_1}{D} - 0,1507 \frac{b}{D} \quad (3.3)$$

$$\mu = 0,7410 + 0,066 \frac{H}{D} - 0,0481 \frac{H_d}{D} + 0,0136 \frac{D_1}{D} \quad (3.4)$$

$$\mu = 0,7150 + 0,0727 \frac{H}{D} - 0,0246 \frac{H_d}{D} \quad (3.5)$$

$$\mu = 0,6741 + 0,0721 \frac{H}{D} \quad (3.6)$$

$$\mu = 0,4695 + 0,2637 \left(\frac{H}{D}\right) - 0,0432 \left(\frac{H}{D}\right)^2 \quad (3.7)$$

Comparison on error and correlation degree shows that the formula (3.7) is most suitable to define the flow coefficient of the weirs with breast wall for the pressured flow. This relationship is shown in Figure 3.32.

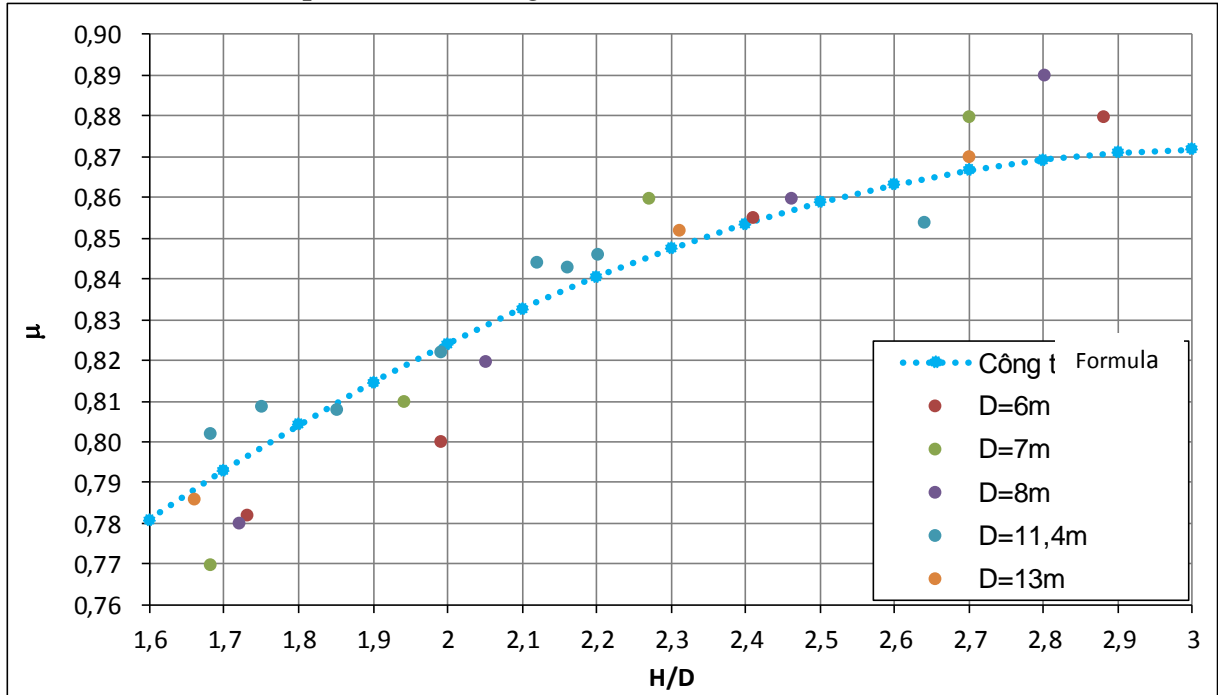


Fig 3.32 Relationship between flow coefficient μ and ratio H/D

Equation 3.7 is also compared with existing works and the results show that most deviations are less than 5% and the maximum deviation $<8\%$.

3.2.2 Determining surface water profile and flow velocity

3.2.2.1 Determining water surface profile

The equation for determining water surface profile is equation (1.16). However, the difficulty in applying this equation is to determine the velocity coefficient φ in the case of pressured flow. The thesis suggests the value $\varphi = 0.94 \div 0.98$ for the case of pressured flow, as shown in Figure 3.33 with $\varphi = -0.001X + 0.99$ and develop water surface profile $Y/D = f(X/D, H/D)$ for water levels $H/D = 1.6; 1.8; 2.0; 2.2$ and 2.6 which are the actual water columns for the mentioned weirs. The results are shown in Table 3.6, Figure 3.34 for WES and in Table 3.7, Figure 3.35 for Creager-Ophixerop weirs.

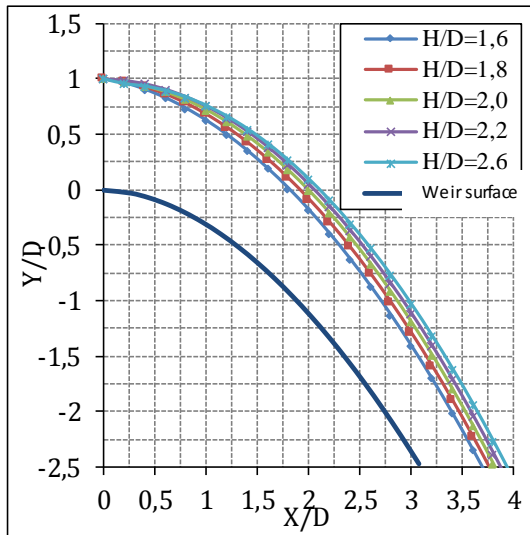


Fig3.34. Coordinates of water surface profile expressed as function $Y/D = f(X/D, H/D)$ for WES weirs

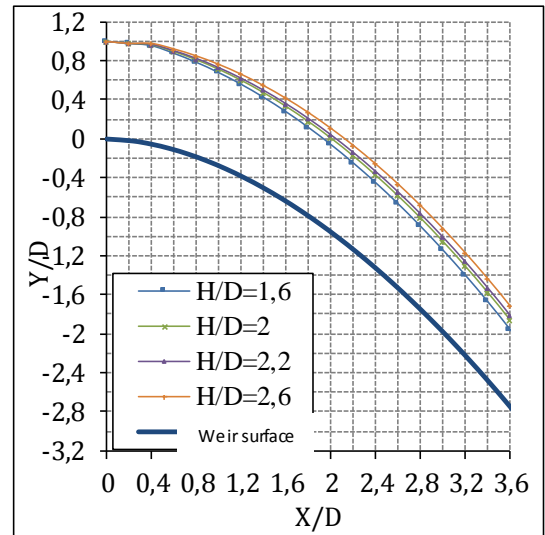


Fig3.35. Coordinates of water surface profile expressed as function $Y/D = f(X/D, H/D)$ for Creager-Ophixerop weirs

3.2.2.3 Velocity calculation

Flow velocity is calculated according to formula $V_i = q/h_i$

In which: h_i - flow depth at cross section i that is calculated using table or nondimension graph (Table 3.6, Figure 3.34 for WES weirs; Table 3.7, Figure 3.35 for Creager-Ophixerop weirs).

3.2.3 Pressure Distribution

3.2.3.1 Creager-Ophixerop pressure distribution

For convenience in reference, calculate the results of the pressure test performed in terms of the dimensionless form by function of h_p/H_d by dividing the result by H_d . From the pressure results for empirical cases, using empirical statistical methods with designed H_d water column values, experimental cases with H/H_d ratios, the averaging of these values with $H/H_d = 0.9$ to 1.5 and $H/D = 1.6$ to 2.6 and then converted to $h_p/H_d = f(H/H_d, X/H_d)$ or $h_p/D = f(H/D, X/D)$ between the Creager-Ophixerop surface weirs when flowing with H/H_d or H/D cases is encountered in practice to facilitate the effective use. Figure 3.36, Figure 3.37.

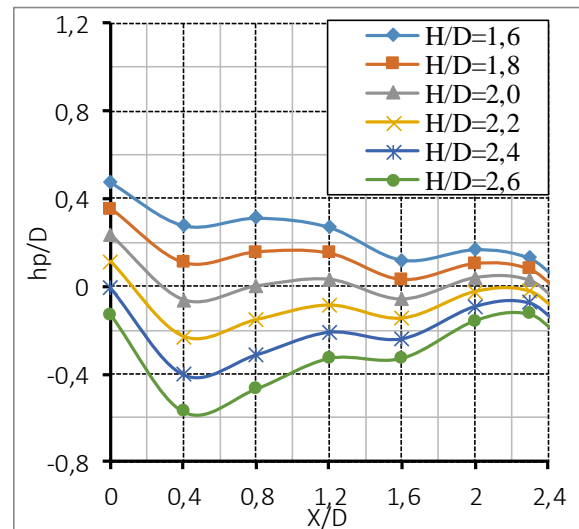
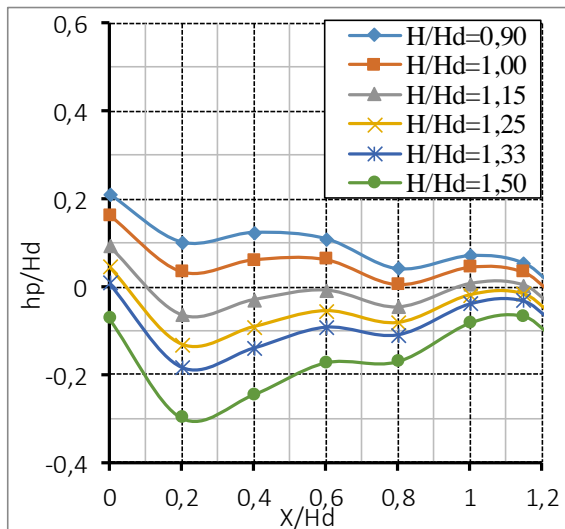


Fig 3.36 Pressure $h_p/H_d = f(X/H_d, H/H_d)$ for Creager-Ophixerop weirs

Fig 3.37 Pressure $h_p/D = f(X/D, H/D)$ for Creager-Ophixerop weirs

3.2.3.2 Pressure Distribution Rule on WES surface weirs

To do the same with Creager-Ophixerop weirs to obtain the pressure distribution graph for WES surface weirs as shown in Figures from 3.38 to 3.40;

Fig 3.38. Pressure $h_p/H_d = f(H/H_d, X/H_d)$ at center line of WES surface weirs

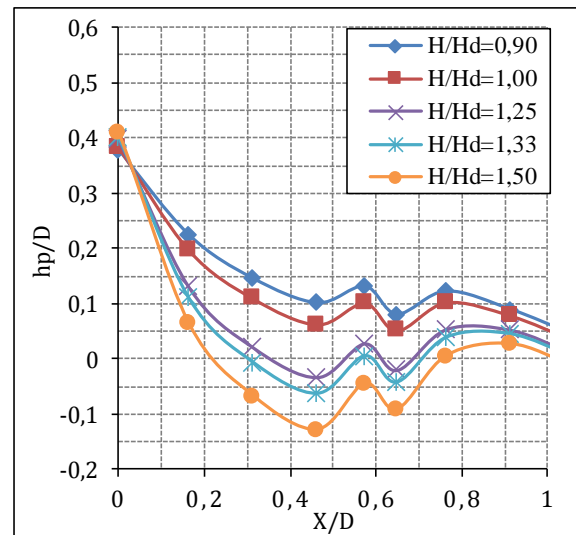
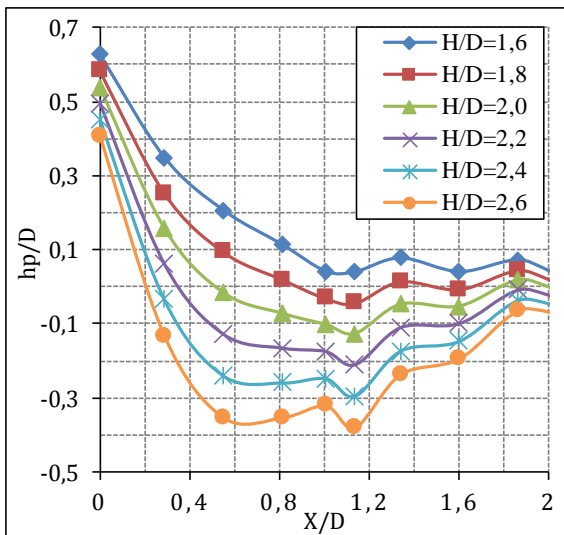
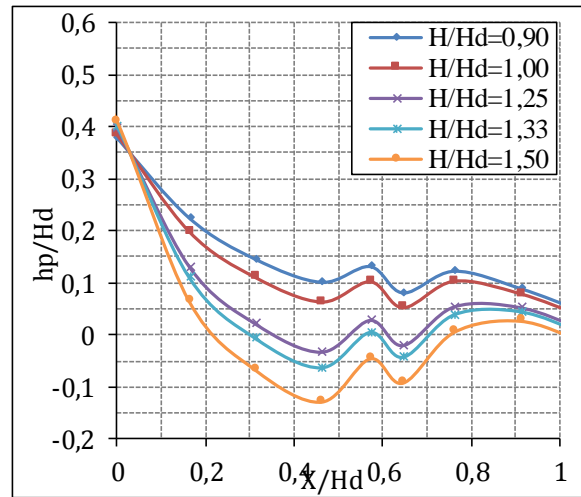


Fig3.39. Pressure $h_p/D = f(H/D, X/D)$ at center line of WES weirs

Fig3.40. Pressure $h_p/D = f(H/D, X/D)$ at pillar of WES weirs

3.2.4 Calculating pressure on breast walls

Diagram of pressure calculation on the surface of the breast walls is similar to the tunnel and sluice entrance. In order to calculate the pressure distribution under the breast walls and the surface weirs in the pressured flow, possible to use the method of calculation at the entrance to the tunnel, the sluices are shown in [2], [7], [51], [52]. The breast walls pressure is calculated by the formula (1.26). From the results of test in the experimental models shown in table PL3.23 and figures 3.30 ÷ figure 3.31 calculate the pressure drop coefficient C_p , the results are shown in table 3.9, table 3.10.

For weirs with the WES cross-section form: From the results shown in the table above, each location on the breast walls and surface weirs of pressured flow has a C_p value, the C_p value increases with the flow direction and the C_{pmax} value at the cross-sectional end of the pressured flow part.

In the models, the C_{pmax} value from the experiments is consistent with the theoretical calculation. Thus, it is possible to use the formula (1.25) to determine the pressure in the weirs with breast wall in the pressured flow region with the C_p coefficient referred to [51], [52].

3.3 Conclusion of Chapter 3

Through the results of the 19 experimental cases as well as observation, it is noticed that pressured flow of weirs with breast wall exists when $H/D > 1.6$;

The results of the hydraulic models such as flow regime, surface water profile, discharge capacity, flow velocity and pressure distribution rule are in accordance with the published documents.

The results and evaluations on the models are reliable enough to provide a basis for developing a method that can determine some hydraulic characteristics of weirs with breast walls.

The relative hydraulic characteristics that are considered are the water column, discharge, flow regime through weirs, flow velocity and pressure on breast walls and weirs surface.

The thesis uses the linear regression method to find the relationship between the experimental variables and flow coefficient and determined that the Equation (3.7) is the most appropriate equation to calculate flow coefficient for pressured flow of weirs with breast walls. This formula represents the relationship between $\mu = f(H/D)$.

Using equation (1.16) combined with the flow factor graph ϕ in figure 3.33 to define the water surface profile or It can also be determined according to table 3.6, figure 3.34 for WES surface weirs; table 3.7, figure 3.35 for Creager-Ophixerop weirs.

The thesis proposes applying formulas (1.25) and (1.26) that are used to calculate pressure of sluice and tunnel to determine pressure on breast walls and weirs surface at pressured flow section. The smallest pressure on breast walls at pressured flow section is calculated by formula (1.27).

The thesis uses the empirical statistical method to propose a mean for determining the pressure distribution pattern on weirs surface at free flow section after breast walls

(Figure 3.36, 3.37 for Creager-Ophixerop and Figure 3.38 ÷ Figure 3.40 for WES surface weirs).

CHAPTER 4 CALCULATION PROCEDURE FOR HYDRAULIC CHARACTERISTICS OF WEIRS WITH BREAST WALLS

In order to facilitate the application of the above mentioned research results, Chapter 4 presents the procedure for calculating hydraulic characteristics such as surface water profile, discharge, velocity and flow pressure for weirs with breast wall and an example for application in a specific work.

4.1 Hydraulic calculation procedure

4.1.1 Determining size of works

Based on the tasks of the work, the design water levels of reservoir are determined as the same as those of conventional spillway reservoirs. Main parameters of weirs with breast wall that have to be defined are weirs crest profile, at both upstream and downstream side, lower face profile of breast walls and orifice height D . Regulatory calculations to determine the upstream water level (Z_{up}) corresponding to design frequencies have to be conducted.

These results are used as inputs for calculating hydraulic characteristics.

4.1.2 Discharge capacity calculation

Calculating discharge capacity if open flow as with a normal weirs calculation. Flow is determined by formula (1.14) for Creager-Ophixerop cross section or (1.15) for WES cross section.

Flow of weirs has pressured flow is defined by formula (1.10), with μ determined by formula (3.7).

4.1.3 Calculation for water surface profile and velocity

Interpolating from the table (3.7) or figure (3.35) for the Creager-Ophixerop cross-section, and table 3.6 or Figure 3.34 for the WES cross section, the surface water profiles (in relationships $Y/D = f(X/D, H/D)$) respect to upstream water levels are obtained. Converting the water surface profiles to the real coordinates of the work $Y = f(X, H/D)$ by multiplying both sides by D , then representing them on the same weir's coordinates. Hence, water depths h_i on weirs surface at computed cross-sections are determined. The average velocity in each section is calculated by formula $V = q/h_i$.

4.1.4 Pressure distribution

4.1.4.1 On weir surface

Interpolating from Figure (3.36÷3.37) for Creager-Ophixerop cross section, Figure (3.38÷3.40.) for WES cross section, pressure on weirs' surface is determined respect to upstream water levels (in relationship $h_p/D = f(X/D, H/D)$).

Converting pressure to the actual value of the work with $h_p = f(X, H/D)$ and then displaying it on the same weirs surface coordinates to determine pressure on the weirs surface at calculated points.

4.1.4.2. On breast walls

Based on the flexure of breast walls to gain k_e ;

The flare degree k_r is determined as the flare factor of the entrance following ratio h_v/D ;

Using k_e , k_r and figure (1.30) to gain C_{pmax} ;

Replacing C_{pmax} into formula (1.27) to calculate the maximum residual pressure on the breast walls.

4.1.5 Calculation procedure

Hydraulic calculation procedure to determine hydraulic characteristics for weirs with breast walluch as discharge capacity, surface water profile, velocity, and pressure. The calculation procedure is shown in Figure 4.1

4.2 Application

The thesis uses data on water level, discharge of Ban Lai spillway to propose and calculate the application plan of weirs with breast walls. The thesis conducts steps in the process to design and calculate weirs with breast wall for Ban Lai reservoir. Calculation results meet the requirements of flood prevention for the reservoir. Flood cut volume in the design case is 870 m³ to meet the discharge requirement of 845 m³.

Table 4.7. Comparison Table on thesis calculation results and expected regulating plan

No.	Parameter	Unit	Calculation result of alternatives		
			Investment projects	Expected regulating	Thesis
1	Works level		1	2	2
2	Weir and spillway route		Two routes	Same route	Same route
3	Elevation of Dry weir crest	m	319,00	316,50	316,50
4	Water level	m	314,50	302,45	302,45
5	Dead water level	m	294,50	294,50	294,50
6	Designed flood level	m	315,63	312,48	312,48
7	Test flood level	m	317,16	315,53	315,53
8	B surface	m	215,00	50	50
8	Deep discharge dimension	B x H	D=8 m	(4 x 3,2) m	(4,2 x 7,0)m
9	Number gate of deep discharge	Cửa	1	5	2
10	Threshole elevation of Deep discharg	m	296,50	294,00	294,00
11	Q discharge 1%	m ³ /s	918,00	873,00	870,00
12	Q discharge 0,2%	m ³ /s		949,00	1494,00

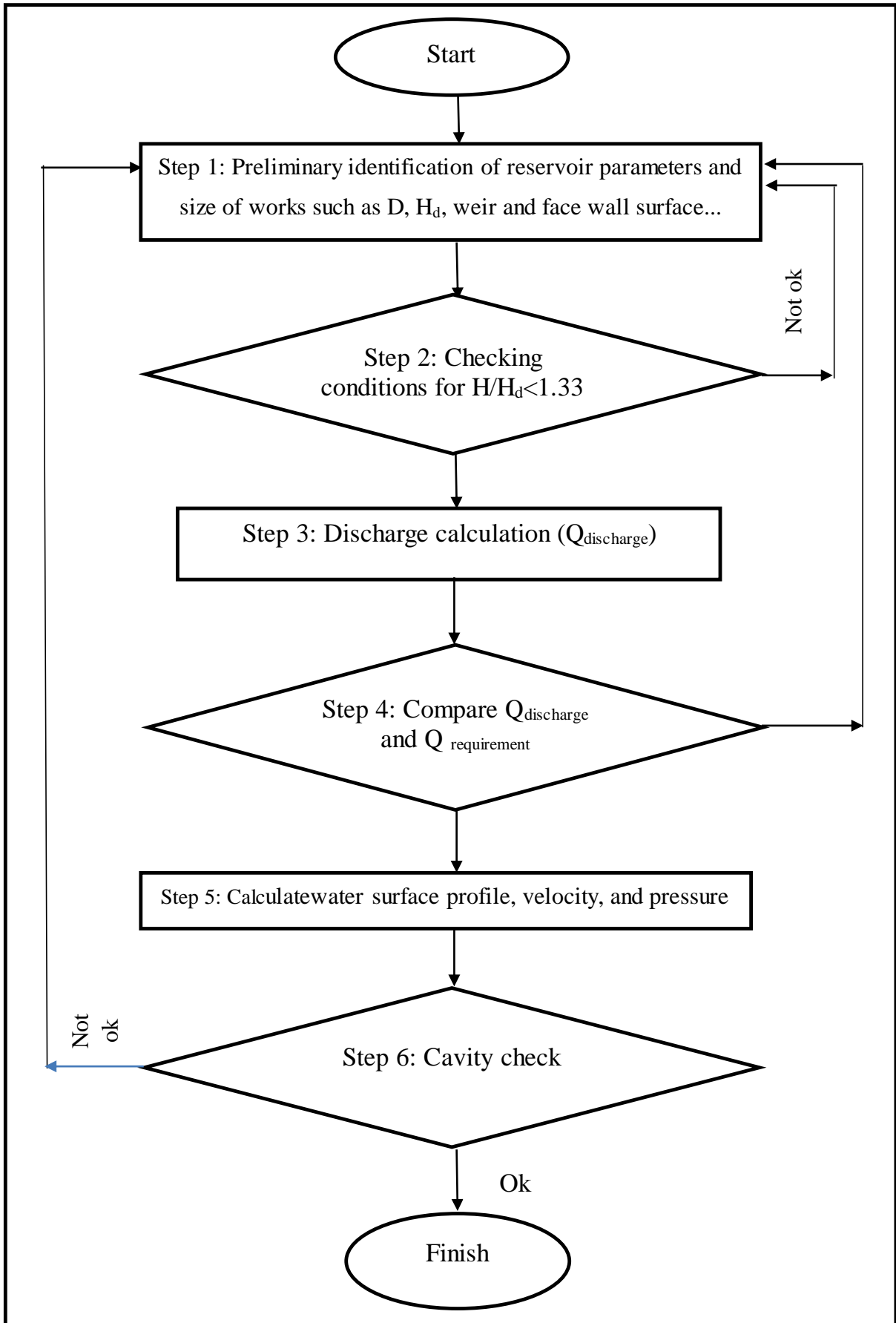


Figure 4.1 Hydraulic calculation diagram of weirs with breast wall

4.3 Conclusion of Chapter 4

The calculation procedure is designed to give designers a visually intuitive and prediction on hydraulic characteristic of flow through weirs with breast walls. This will shorten the calculation time, reduce the volume of physical model experiments and contribute to improve the efficiency of design work.

Ban Lai Reservoir can be applied an weirs with breast wall structure to reduce the weirs height while still ensuring the task of flood prevention.

CONCLUSIONS AND RECOMMENDATIONS

1. General conclusion of the thesis

Creager-Ophixerop and WES are two of the most common cross-section types of the weirs. Their hydraulic characteristic calculations are adequately guided through existing references.

Creager-Ophixerop and WES weirs with breast wall have practical applications. However, the studies on hydraulic characteristics of these spillway are very limited. It is difficult to find reference materials for calculation.

The thesis uses physical modeling, processes data by experimental planning methods with linear regression functions to determine the hydraulic characteristics of weirs with breast wall.

Creager-Ophixerop weirs is experimentally studied on a 1/64 scale model with 4 cases of orifice height $D = 5 \div 8\text{m}$ at the National Key Laboratory for Marine Dynamics. Experimental results of WES weirs modelling (in model 2, 3 with scale of 1/48; model 4 with scale of 1/100) are gathered, analyzed and evaluated.

Through computation and theoretical and experimental analysis on flow regime, the quantitative limit of flow regime from non-pressure to pressured flow when $H/D \geq 1.6$ is defined.

The experimental results on the dimensionless transformations and data processing following the least squares method lead to a new formula (3.7) to calculate flow coefficient following ratio H/D that can directly present pressured flow regime. The thesis also provides graphs for determining the water surface profile, velocity, and pressure on the weir surface.

The thesis provides a procedure of hydraulic calculation for weirs with breast wall and it is successfully applied to a construction work.

2. New contributions of the thesis

The thesis has achieved the following major scientific findings and contributions as following:

1. Developing and proposing formula (3.7): $\mu = 0,4695 + 0,2637 \left(\frac{H}{D}\right) - 0,0432 \left(\frac{H}{D}\right)^2$ and graph 3.32 to calculate flow coefficient for weirs with breast wall; the range of working water column $H/D = 1.6 \div 3.0$.

2. Determining flow rate coefficient $\varphi \approx 0,94 \div 0,99$ following figure 3.33 to calculate the water depth based on formula (1.16) for pressured flow case. Developing

and suggesting the application of nondimension coordinates table 3.6, figure 3.34 for WES weirs; table 3.7, figure 3.35 for Creager-Ophixcerop weirs to calculate water surface profile and velocity.

3. Proposing method to determine pressure reduction coefficient C_{pmax} to calculate minimum pressure following formula (1.25): $C_{pi} = \frac{2g(H_i - p_i / \gamma)}{v_k^2}$, (1.27):

$\frac{p_{i\min}}{\gamma} = H_i - C_{p\max} \frac{V_k^2}{2g}$ for pressured flow section of weirs. Developing dimensionless graphs in figure 3.36÷3.37 for Creager-Ophixcerop weirs and figure 3.38÷ 3.40 for WES weirs to calculate pressure on weirs surface at free flow section.

3. Recommendations

1. Applying weirs with breast wall in designing the discharging works of reservoirs having the task of flood prevention, to improve discharge capacity and to optimize valve gates and mechanical equipment in new designs and repair for safety enhancements;

2. Applying the data, formulas and graphs set up by the thesis into calculation of WES and Creager-Ophixcerop weirs with breast walls due to lack of guiding references.

4. Further research

1. Continuing research to complete the calculation of some hydraulic characteristics with greater working water column, as well as issues related to velocity, pressure, vortex and cavitation, and other weirs curves;

2. Research and reviewing the working conditions in spatial problem in which shapes and sizes are taken into account;

3. Research mathematical models in order to optimize design options; reducing the volume and cost for studying experimental models.