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VIETNAM ACADEMY FOR WATER RESOURCES

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RESEARCH ON CERTAIN HYDRODYNAMIC FEATURES OF THE TRANSITION FLOW WITH THE INTEGRATION OF SURFACE-BOTTOM-SUBMERGED 3 WHIRLPOOLS BEHIND THE STEPPED SPILLWAYS

Specialization: Hydraulic constructions engineering

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SUMMARY OF THE TECHNICAL DOCTORAL THESIS

HA NOI - 2017

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INTRODUCTION

1. Urgency of the subject

Hydraulic jump, transitions and energy dissipation are complicated, diverse and heated issues. Research on different types of transitions have been nearly full work done, including surface, bottom mixed with flat-sloped stepped spillways and short stair risers; stepped spillways which angle is less than 15^0 and relatively high stair risers; stepped spillways which angle is more than 15^0 and significantly short stair risers.

A type of transition having less attention, with stepped spillways having curved stair noses, relatively high stair risers, and angle of more than 25^0, is transition flow with the integration of surface – bottom - submerged 3 whirlpools behind floodgate having stepped spillways.

The thesis topic "Research on certain hydrodynamic features of the transition flow with the integration of surface-bottom-submerged 3 whirlpools" is supposed to expand readers knowledge about surface hydraulic jump, including: forming requirements and basic hydrodynamic features of funnel-shaped flow; to enrich experimental researches' results; to gradually complete theories and calculations about hydraulic jump and energy dissipation in floodgate's downstream.

The transition flow with the integration of surface – bottom – submerged 3 whirlpools behind the stepped spillways forms funnel-shaped vortex with horizontal direction of flow (figure 1.2). Therefore, in this thesis, the transition flow with the integration of surface – bottom and submerged 3 whirlpools behind the stepped spillways is shortly called "funnel-shaped flow".

2. Purposes of the subject

Research on the forming requirements and basic hydrodynamic features of funnel-shaped flow (geometrical size of whirlpools, velocity distribution). Then, propose the way to construct stepped spillways to occur and stabilize funnel-shaped flow behind the floodgate.

3. Scope of the subject

Flat condition, gradually changing non-uniform flows; free streams not regulating through gate valves; Froude Fr number= 1,35÷4,5, stepped spillways having ratio a/P=0,14÷0,46; curved stair noses, continuity (non slotted), angle $\theta=25^0\div51^0$, the peak noses are lower than downstream water level.

4. Research methods

The research methods applied in this thesis includes investigation, status quo analysis, theoretical analysis to identify content and research orientation; experiments on physical models to identify geometrical parameters, basic hydrodynamic features of funnel-shaped flow, dimensional analysis, the π theorem to identify series of experiments; multivariate linear regression analysis to form experimental relationships.

5. Scientific and practical significance

Scientific significance: The thesis has clarified and expanded the knowledge about surface hydraulic jump, especially in funnel-shaped behind floodgate, and about its forming requirements and basic hydrodynamic features.

This thesis also enriches experimental researches' results; to gradually complete theories and calculations about hydraulic jump and energy dissipation in floodgate's downstream.

Practical significance: From the forming requirements and basic hydrodynamic features of funnel-shaped flow, the thesis has identified scientific basis to design stepped spillways having high stair rises, curved stair noses, and large angle in order to form energy dissipation in the downstream of the construction, create more economically and technically meaningful options when building, upgrading, maintaining, or operating the floodgate.

CHAPTER 1: OVERVIEW OF RESEARCHING ON TRANSITION AND ENERGY DISSIPATION

1.1. General concepts about hydraulic jump, transition and energy dissipation in the downstream of floodgate

Hydraulic jump is a common phenomenon in the downstream of floodgate, which is also a distinctive feature of the process of switching from swift flowing to smoothly flowing. Researching on hydraulic jump's features is a very meaningful task in designing energy dissipation.

Most of transition types of in the downstream relate to the formation of hydraulic jump, including: bottom transition relating to bottom hydraulic jump, surface transition relating to surface hydraulic jump; besides, there are other types of transition which do not relate to hydraulic jump, such as transition through free jet deflector.

Surface transition contains many different forwarding states, depending on the structure of stepped spillways and the downstream water level. When the stair rises are short and the angle is more than 16^0, multi vortex transitional flow behind the spillway are researches about dissipation tanks. When the stair rises are relatively high and the angle is more than 25^0, the downstream water level reaching the stair noses makes the flow velocity faster, forming vortexes in the surface and high waves behind the stepped spillways, supporting the forces of the surface whirlpool and bottom whirlpool, forming three whirlpools (Figure 1.2), which is called transitional funnel-shaped flow.

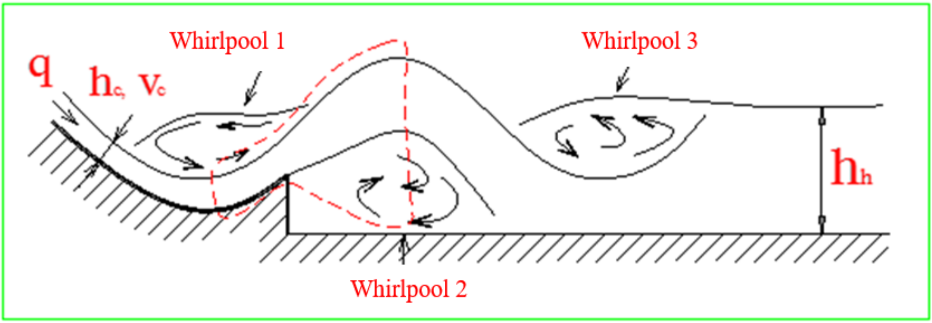


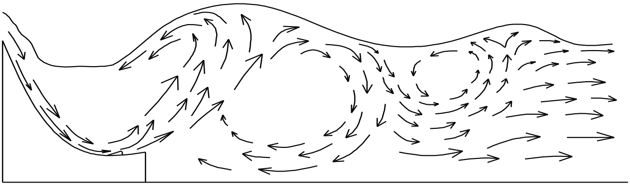
Figure 1.2. The shape of the funnel-shaped flow behind stepped spillway (Nanjing Hydraulic Research Institute, 1985)

1.2. Methods to research on hydraulics in the downstream of floodgate

The issue of hydraulics, especially the hydraulics in the downstream of floodgate, is very complicated yet not less exciting. It has been and will still be appealing to many scientists who pay interests in researching on the appearance, characteristics and states of the flow. Up until now, there are several methods of research to be used: Empirical research, Mathematical analysis and numerical analysis (or in other words, theoretical research), research by numerical and mathematical models, Semi-empirical research (integrating empirical and mathematical research).

1.3. Transition by multi-vortex in the downstream of small stepped spillways - Submerged buckets

Submerged buckets is a construction which noses having angle of more than 16^0, placed at the footage of the spillway's downstream. Its stair rises are very short, which functions to adjust the flow and form vertical vortexes in the downstream of the floodgate (Figure 1.3).



Hình 1.3. Multi-Whirlpool flow in submerged buckets (Peterka, 1958)

Submerged buckets are researched merely by western researchers base on empirical researching method. Among the researches, it is necessary to mention the work of Peterka through the dissipating construction called Basin VII, he experimented with many different types bucket: continuous and non-continuous (solid or slotted). From the practical experimental results, Peterka proposed certain principles to design dissipation tanks in order to ensure the efficiency and avoid erosion in downstream:

+ The minimum value of jet radius R_{min}/h_c only depends on Froude number at the front sliced surface (Fr_c) determined by formula (1-1), it is the quantity affecting the formation of this kind of dissipation.

$$\frac{R_{min}}{h_c} = 4(Fr_c)^{1,5}[1 + (0,5)Fr_c^2] \cong 2,2Fr_c^{0,5} \quad (1\text{-}1)$$

+ The minimum and maximum tail water depth limits (Tmin, Tmax) must be ensured: the value of the output flow must be in the range $T_{min}<T<T_{max}$.

1.4. Surface, surface – bottom mixed hydraulic jump and transition, dissipation behind the stepped spillways with the angle of less than 15^0

Surface hydraulic jump is hydraulic jump in the transitional surface flow, being formed behind a vertical stair of the end of spillway.

Surface hydraulic jump and surface dissipation are the field of interests of many scientist who conducted both theoretical and empirical researches. And the results of those researches are very much alike. Some examples to be listed are the ones of M.D. Chertousov, M.A. Mikhaliev, T.N. Astaficheva, A.A. Kaverin, B.M. Ivanov. In Vietnam, only Luu Nhu Phu having researches about hydraulic jump and waves behind the stepped spillways (1986). The researches mostly focused on identifying the height of the smallest stepped spillway forming surface hydraulic jump, the downstream limit depth forming surface hydraulic jump, the height of the tallest wave behind the stepped spillways, velocity distribution, and hydrostatic pressure on the bottom behind the stepped spillways. However, most of the researches are about the vertical stairs, with small angle of the noses ($\theta=0^0\div15^0$).

Generally, surface hydraulic jump is capable of causing large energy dissipation through the area of bottom vortex and surface vortex; flow velocity at the bottom is small so that it does not cause any serious erosion, taking part to reduce the downstream reinforcing requirement. As in big constructions, big water columns often manage to form surface transitional flow. However, states of hydraulic jumps react in a very complicated way when the downstream water level changes (sometimes changing from advantageous state to disadvantageous state). Therefore, it is less applicable than bottom hydraulic jump. In Vietnam, there are two constructions applying surface dissipation, named Thach Nham spillways in Quang Ngai province, and Thac Ba spillways in Yen Bai province.

1.5. Transition and dissipation in surface – bottom – submerged 3 whirlpools mixed flow with angle of more than 25^0 (funnel-shaped flow)

The formation of transitional funnel-shaped flows is based on the basis of using reverse curvature radius of the noses whose angle is more than 25^0 to form funnel-shaped water columns. Transitional funnel-shaped flows are different from transitional surface flows with the angle of 15^0 because of having big reverse curvature radius, thus, the funnel-shaped water columns are raised with big velocity, forming whirlpools on the surface in order to dissipate energy and avoid downstream erosion.

Funnel-shaped flow dissipators are effectively applied in some particular constructions in America, India, Japan, and China...

There are very few researches about funnel-shaped flow dissipators, only the one from Nanjing Hydraulics Research Institute, China provides different types of transitional funnel-shaped flows, and the equation to identify the depth limit of funnel-shaped flows (1-31), (1-32), (1-33), (1-34):

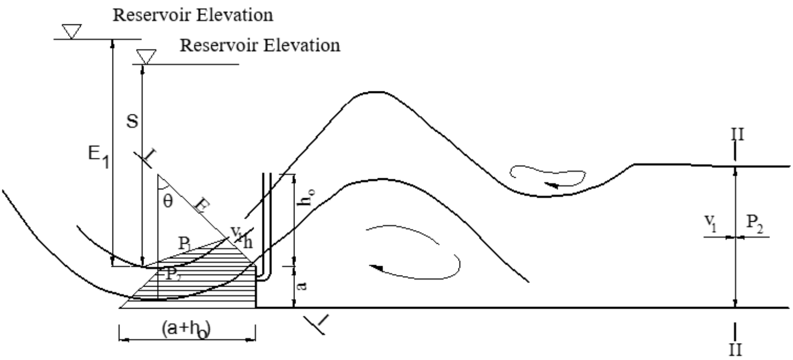


Figure 1.16. The graph the limited funnel-shaped flow (Nanjing Hydraulic Research Institute, 1985)

+ Standard funnel - curvature radius of single arc:

$$2Fr_1^2\cos\theta + \eta_a\cos\theta - \eta_a^2 = \frac{2Fr_1^2}{\eta} + \eta^2 - \eta_a\eta(\cos\theta + 2\eta_a) \quad (1\text{-}31)$$

+ Stretched funnel – stretched tangent of the funnel tip

$$2Fr_1^2\cos\theta + \cos^2\theta - \eta_a^2 = \frac{2Fr_1^2}{\eta} + \eta^2 - 2\eta_c\eta_a\eta \quad (1\text{-}32)$$

From the documents of 5 constructions model experiments, conclude and draw the experience on the ratio of pressure dissipation of the spillways surface: $\eta = \frac{0,76}{q\sqrt{g}S^{1,5}}$ (1-33). Besides, also from the documents of model experiments can be express: $\eta_c = \frac{h_1}{S}$ and $k_s = \frac{q}{\sqrt{g}S^{1,5}}$, for formula experience of the spillway having valve door: $\eta_s = 0,67k_s^{0,93}$ (1-34).

1.6. Conclusion of Chapter 1

1. Hydraulic jumps, transitions and dissipations are always complicated, diverse and heated issue. At the same time this researching was being taken, there were still basic researches about bottom hydraulic jumps, surface hydraulic jumps, and bottom – surface mixed hydraulic jumps of Russian scientists being published.

2. To form surface hydraulic jumps, the height of the stepped spillways must be bigger than a value a_{min} being identified by the experimental formula.

3. The researches about surface hydraulic jumps mostly relate to vertical stepped spillways having straight or curved to downstream edge of structure with angle of ($\theta=0^0\div15^0$).

4. Transitional surface flow relates to short stepped spillways, when the height of stepped spillways changes, the shape of downstream hydraulic changes as a consequence. If the relative height of stepped spillways is small, comparing to the depth of the downstream flow, the flow through that is still the bottom flow. If not, the flow is surface flow. If the position of the complete bottom flow changes, under the effect of stepped spillways' height, it will form the mainstream flow which creates waves and be disadvantageous to energy dissipation.

5. The multi-whirlpools transition type with very small stepped spillways and big angle of submerged buckets has been researched carefully by western scientists. However, those are just empirical researches taking placed in the labs, the height limit of stepped spillways is very small a = 0,05R.

6. The transition of surface flow with angle of more than 25^0 only witnesses the researches from Nanjing Hydraulics Research Institute, China basing on research data of some particular constructions. Therefore, when being applied to actual constructions, it is relatively subjective. There is no research result about the formation requirements and the criteria to transform between different flows modes.

7. The results about hydrodynamic features of hydraulic jumps are mostly about collected by empirical and semi-empirical methods, focusing on the limit forming different types of transitions. Theoretical researches accept the theory that velocity is distributed equally and pressure is distributed basing on hydrostatic rules, starting from the equation of momentum to identify the water surface line of jet deflectors behind the stairs. There are very few researches about the theories of hydrodynamic features of multi-whirlpool transition.

8. In Vietnam, only Associate. Professor. Dr. Luu Nhu Phu (1986) has researches about hydraulic jumps behind the stepped spillways. There are only two constructions applying surface dissipation, namely Thach Nham spillways,

Quang Ngai province, and Thac Ba spillways, Yen Bai province. In this stage, there are many irrigation and hydropower constructions are able to apply surface dissipation or funnel-shaped dissipation with the purpose to reduce the cost and boost up the construction time, namely Ban Mong spillways, Khe Bo spillways, Nghe An province…

9. In terms of structural works, funnel-shaped flow is the combination of submerged buckets type VII of Peterka (American scientists) with high stepped spillways to form surface hydraulic jumps, with many results of Russian and Chinese scientists. That perspective would orientate for the thesis in inheriting the research methods and scientific thinking of their pioneers.

10. Mathematical and physical models are two basic research methods which are widely applicable in downstream hydrodynamic researches. Regarding to the target of this thesis, physical models are more effective than mathematical models because of the complex features of the flow structure. Mathematical models can be used with physical ones but the time and expenses to calculate in 3D models are relatively the same with the case of physical models.

Therefore, funnel-shaped flow needs researching on formation requirements and basic hydrodynamic features to support the selection of dissipation and physical models.

CHAPTER 2: BASIS METHODOLOGY OF RESEACH ON HYDRODYNAMIC FEATURES OF TRANSITIONAL MIXED FLOW SURFACE – BOTTOM – SUBMERGED 3 WHIRLPOOLS BEHIND THE STEPPED SPILLWAYS

2.1. The basis of similarity theory and modeling

Dimension and similarity theories are basis theories of modeling hydrodynamic phenomena.

To ensure the transfer of results from models to reality, models must have similar conditions with the actual objects.

+ The feature of nonstop movement having Strukhan standard: $S_h = \frac{b}{vt}$

+ The feature of block force having Froude standard: $Fr = \frac{V}{\sqrt{gb}}$

+ The feature of viscous force having Reynolds standard: $Re = \frac{vb\rho}{\mu}$

+ The feature of pressure having Euler standard: $Eu = \frac{p}{\rho v^2}$

In the case of this thesis, the flow through the spillways is the flow without pressure, and the main block force is gravity. Therefore, Froude standard is used to setup research model. Other standards are satisfactory conditions.

2.2. Form the equations for experimental study

Using dimensional analysis method and Theorem π was build the equation (2-12) to identify the series of experiments and factors affecting research general experiment elements of the thesis.

$$F\left[\frac{h_h}{a},\frac{R}{a},\frac{\mathrm{P}}{\mathrm{a}},\theta,\frac{\mathrm{D}}{\mathrm{a}},\frac{\mathrm{a}}{\mathrm{h_k}},\frac{1}{\mathrm{Re}},\frac{\mathrm{L}}{\mathrm{a}},\frac{\mathrm{aV}}{\mathrm{q}}\right]=0 \qquad (2\text{-}12)$$

+ Identify the depth limit of downstream to form funnel-shaped flow, (2-12) will become:

$$\frac{\mathrm{h_{gh}}}{\mathrm{a}}=\mathrm{F_1}\left[\frac{\mathrm{P}}{\mathrm{a}},\frac{\mathrm{a}}{\mathrm{h_k}},\frac{\mathrm{D}}{\mathrm{a}},\theta\right] \qquad (2\text{-}13)$$

+ Consider the length of the vortexes in the funnel-shaped flow, (2-12) will become:

$$\frac{\mathrm{L}}{\mathrm{a}}=\mathrm{F_2}\left[\frac{\mathrm{h_h}}{\mathrm{a}},\frac{\mathrm{P}}{\mathrm{a}},\frac{\mathrm{a}}{\mathrm{h_k}},\frac{\mathrm{D}}{\mathrm{a}},\theta\right] \qquad (2\text{-}14)$$

+ Consider the flow speed in the funnel-shaped flow, (2-12) will become:

$$\frac{\mathrm{aV}}{\mathrm{q}}=\mathrm{F_3}\left[\frac{\mathrm{h_h}}{\mathrm{a}},\frac{\mathrm{P}}{\mathrm{a}},\frac{\mathrm{a}}{\mathrm{h_k}},\frac{\mathrm{D}}{\mathrm{a}},\theta\right] \qquad (2\text{-}15)$$

2.3. Experimental planning application in researching basic hydrodynamic features of funnel-shaped flows

If the complete factors experimental have 2 levels with m of affecting factors, the minimum number of experiments to conduct is 2^m. In the case of this thesis, the series of experiments conducted are the combination of parameters: angle 0, the radius of the noses R, the height of the stairs a, the height of the construction P, flow rate q (Figure 2.2). Therefore, the number of experiments to conduct is N = 2^5 = 32 experiments.

Making 9 plans with the input parameters from table 2.3, each plan with 4 levels of flow traffic, respectively 0,09 m^3/s/m, 0,18 m^3/s/m, 0,265 m^3/s/m and 0,325 m^3/s/m. Overall, there were 33 cases of experiments, when combining to the downstream water levels, there were more than 150 experiments to be conducted.

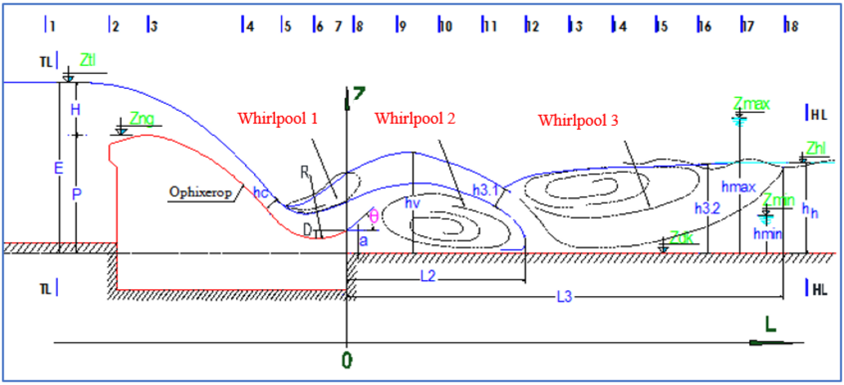


Figure 2.2. Structure, Hydraulic parameters of funnel-shaped flow and the cross section position

Table 2.3 The planned parameters of experiments

Plan	**Plan signals**	**θ (độ)**	**R (cm)**	**P (cm)**	**a (cm)**	**D (cm)**	**a/P**	**D/a**
1	$\theta = 51^0$, R=17,8, a/P=0,32	51	17,8	62,2	20,0	6,60	0,32	0,33
2	$\theta = 51^0$, R=17,8, a/P=0,24	51	17,8	55,6	13,3	6,60	0,24	0,50
3	$\theta = 51^0$, R=17,8, a/P=0,14	51	17,8	48,9	6,7	6,60	0,14	0,99
4	$\theta = 44^0$, R=18,6, a/P=0,46	44	18,6	62,2	28,9	5,22	0,46	0,18
5	$\theta = 40^0$, R=21,7, a/P=0,39	40	21,7	68,9	26,7	5,08	0,39	0,19
6	$\theta = 40^0$, R=21,7, a/P=0,32	40	21,7	62,2	20,0	5,08	0,32	0,25
7	$\theta = 40^0$, R=21,7, a/P=0,24	40	21,7	55,6	13,3	5,08	0,24	0,38
8	$\theta = 32^0$, R=25,5, a/P=0,28	32	25,5	62,2	17,6	3,87	0,28	0,22
9	$\theta = 25^0$, R=29,6, a/P=0,32	25	29,6	62,2	20,0	2,77	0,32	0,14
	Max	***51***	***29,6***	***68,9***	***28,9***	***6,60***	***0,46***	***0,23***
	Min	***25***	***17,8***	***48,9***	***6,7***	***2,77***	***0,14***	***0,41***

When researching on the relationship among different parameters, multi-linear regression model is often used, the mathematical function describing the equation is the experimental regression function (2-17):

$$Y = b_0 + b_1X_1 + b_2X_2 + \cdots + b_mX_m \qquad (2\text{-}17)$$

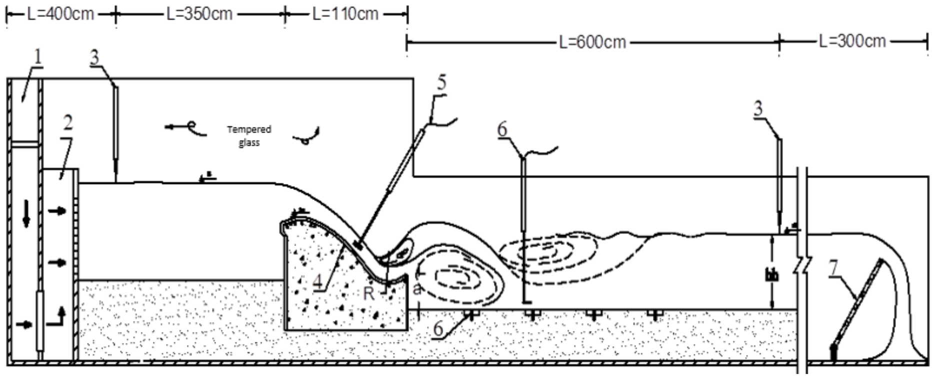
From the data of experiments $b_0, b_1, \ldots, b_m$ were estimated from software like Microsoft Excel, SPSS, R.

To validate the suitability of the overall regression model, we used Sig.F to be the basis for approving or denying the theory: Sig.F < α: the model is meaningful. Sig.F > α: the model is not meaningful. Normally, $\alpha = 0.05$

To validate the formula which was constructed from the regression model, applying Holdout method. In this method, the data of experiments is divided into two categories: setting the formula, and checking the formula.

Correlation coefficient (r) is one parameter to evaluate the relationship between x and y. $-1 \le r \le +1$, r=0 means x and y do not correlate. x and y slightly correlate when $|r|<0,3$. Correlate when $|r| = 0,3 \div 0,75$. And closely correlate when $|r| = 0,3 \div 0,75$. Covariate when r>0 and invert when r<0. r can be calculated easily by using data analyzing software.

2.4. Mô hình thí nghiệm



1-Thin spillway, 2-Calm zone, 3-Water level sensor, 4-Medium pressure sensor, 5-Velocity sensor, 6-Pulsation pressure sensor at the bottom, 7-Control gate.

Figure 2.4. Layout of experiments

The experiments were conducts on cross section models in glass trough width B=0.4m in Hydraulic Research Center, National Laboratory of river and coastal enginering, Vietnam academy for Water Resources. (Figure 2.4, Image 2.1). The experiments ensures the national standards (TCVN: 8214 – 2009).

The cross section models in the experiments are placed specifically to describe in details the hydrodynamic features of flows. (Figure 2.2).

a. The model of spillways *b. The model after being installed*

Ảnh 2.1. Experimental models

Measuring devices: + Discharge: Measuring by Rectangular trough with Sharp-creted weir. The discharge is identified by using the formula Redhbock; + the height of water surface: using permanent water measuring needle, using water standardized; machine Ni04 and mire to measure the height of the flow surface, integrating with manually check by steel ruler. + The length of hydraulic jumps: measuring by rulers. + Velocity: measuring by velocity sensors E30, E40 and PEMS; + Dissipation efficiency: identified by calculating the energy upstream and downstream.

With each level of discharge (Q), by adjusting the downstream valve gate, it is possible to change the open degree with very small steps. Corresponding to each state of the transitional flow, stabilize downstream water level and conduct measuring parameters.

Error of discharge is 2%, error of flow velocity 3%, error of water level 2,5%, error of length of vortex 2,5%.

In the conditions of the thesis experiments: Re_m=(9.000.000÷325.000.000)> Re_{gh}= (5.000÷10.000). Therefore, the flow in the model will function the same way as in the auto model zone. The results in these experiments are totally applicable in reality when using the original object transformations with the ratio $\lambda \leq 100$. With constructions of larger scales, the results can still be referred effectively.

2.5. Conclusion of Chapter 2

1. On the basis of similarity and modeling theories, experiment planning has built up the Methodological basis to identify hydrodynamic features of funnel-shaped flows.

2. With research subjects and in the provided conditions, constructed models ensures that the experiments conducted in the auto model zone can be applicable in reality.

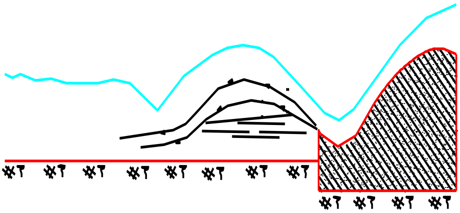
3. After evaluating the error of measurements on models, it can be seen that the error is less than 3%.

CHAPTER 3: **HYDRODYNAMIC CHARACTERISTICS OF TRANSITIONAL FLOW WITH INTEGRATION OF SURFACE – BOTTOM - SUBMERGED 3 WHIRLPOOLS BEHIND THE STEPPED SPILLWAYS**

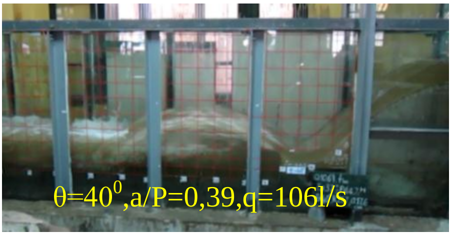
3.1. Upper and lower limit of forming transitional flow with integration of surface - bottom - submerged behind the stepped spillways (funnel-shaped flow)

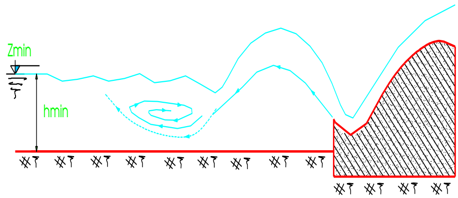
3.1.1. The transitional mode shift in the downstream of the stepped spillways with proportion a/P=0,14÷0,46 and the angle of θ=25^0÷51^0

From upstream to downstream, the whirlpools are numbered 1, 2, and 3. The whirlpool 1 is counterclockwise that appear just above the launcher nose. The whirlpool 2 is the backward swirl, clockwise, appearing behind the stepped spillway. The whirlpool 3 is a swirling swirl, counterclockwise, that appears behind the jet deflector, after the whirlpool 2. There are seven basic forms of transitions are respectively from low to high water levels (Figure 3.1)

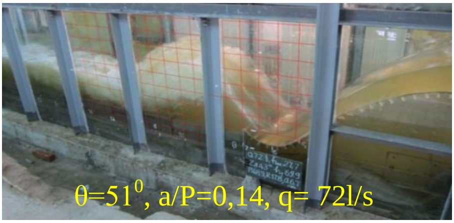


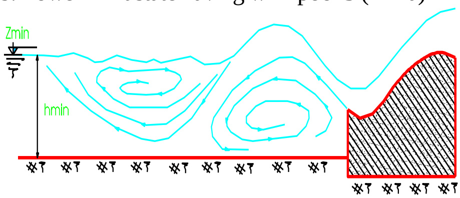
a. free radioactive flow



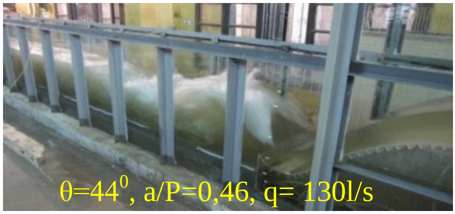


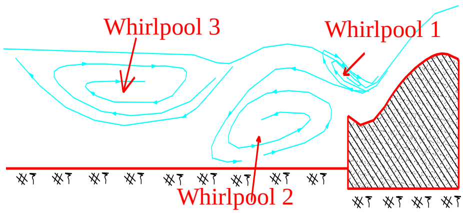
b. Lower limit state having whirlpool 3 (TT2a)



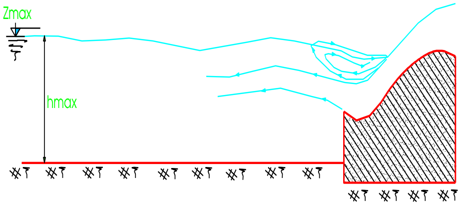


c. Lower limit state having whirlpool 2, 3 (TT2b)

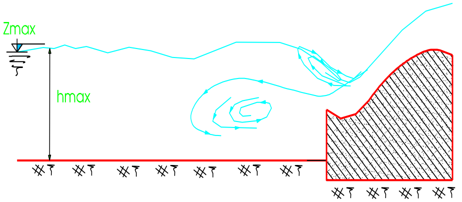




d. The funnel-shaped flow (HT3)



e. Upper limit state having whirlpool 1 (TT4a)



g. Upper limit state having whirlpool 1 và 2 (TT4b)

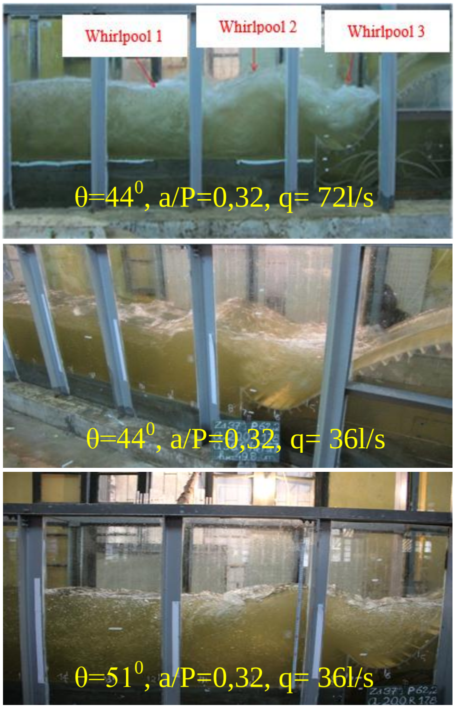


Figure 3.1. The types of transition in the downstream of the stepped spillways with proportion a/P=0,14÷0,46 and the angel $\theta=25^0\div51^0$

3.1.2. The funnel-shaped flow and the status of limitation

The funnel-shaped flow is a transitional flow of surface-bottom-submerged, which simultaneously appears in three whirlpools vertically in the downstream of the stepped spillways (Figure 3.1d).

The lower limit status is initiating status of all three whirlpools 1, 2 and 3. When the depth of the downstream is less than h_{min}; there are two occurrences: both whirlpools 2 and 3 (Figure 3.1c) occurs 25/32 times and only whirlpool 3 (Figure 3.1b) is shown 7/32 times before all three whirlpools appear.

The upper limit status is the exit status of all three whirlpools 1, 2 and 3. The flow depth is greater than h_{max}, two cases are occured: the whirlpools 1 and 2 simultaneously appear (Figure. 3.1g) with 5/32 times and the whirlpool 1 only appears (Figure 3.1e) with 28/32 times after all three whirlpools appear.

3.1.3. Correlation between limited depth and empirical variables

By correlated analysis, using the experienental data processing software to achiev the monochromatic correlation of the quantities to be investigated with empirical variables and non-dimensional variables. Then, the empirical equation is chosen to determine the limited depth from non-dimensional variables to select one best empirical equation:

$$\frac{h_{gh}}{h_k} = f_1\left[\frac{a}{P}, \frac{a}{h_k}, \frac{D}{a}\right] \text{ and } \frac{h_{gh}}{h_k} = f_{11}\left[\frac{a}{P}, \frac{a}{h_k}\right]$$

3.1.4. The minimum and maximum flow depth forming the funnel-shaped flow

In order to form the equation for the calculation of the minimum flow depth (h_{min}) and the maximum one (h_{max}) is the limited depths for the appearance of the funnel-shaped flow. Using the multivariate linear regression analysis, experimenting with different types of functions, the appropriate function to form the solution equation is the linear function and the exponential function.

The data set of the experiment is divided into 2 sets: 25 experimental data of 7 scenarios, 5 angles (25^0, 32^0, 40^0, 44^0, 51^0), 5 values of a/P (0,24; 0,28; 0,32; 0,39; 0,46); The set of formula tests is used to evaluate the error of the formula consisting of 7 experimental data in two cases with a 51^0 angle and a/P=0,14 and an angle of 40^0 with a/P=0,32. The error in this thesis is considered as the relative error $(h_{tn}-h_{tt})/h_{tn}$.

From the experimental data, use regression analysis tools to determine the coefficients of the experimental equation. The results show that Sig.F <0,05, so the hypothesis functions are consistent with empirical parameters. Comparison of error and correlation, the selection was determined by the formula: the lowest depth of downstream h_{min} (standard error 0,03, correlation coefficient 0,97, maximum error with set of formula is 6,3% and the set of formula test is 9,4%); The maximum depth of the downstream h_{max} (standard error 0,02, correlation coefficient 0,99, maximum error with set of formula is 5,5% and the set of test formula is 9,3%).

$$\frac{h_{min}}{h_k} = 1{,}906\left(\frac{a}{P}\right)^{-0{,}117}\left(\frac{a}{h_k}\right)^{0{,}355}\left(\frac{a}{D}\right)^{0{,}122} \quad (3\text{-}11)$$

$$\frac{h_{max}}{h_k} = 1{,}584\left(\frac{a}{P}\right)^{-0{,}601}\left(\frac{a}{h_k}\right)^{0{,}695}\left(\frac{a}{D}\right)^{0{,}02} \quad (3\text{-}12)$$

Figure 3.2, Figure 3.3 shows that the results of the formulas (3-11) and (3-12) are very concentrated and are within the range of less than 10%; For the results calculated according to formulas (1-14), (1-15) of T. Astaficheva; Formula (1-17), (1-18) of the Nanjing Hydraulic Research Institute, China has a margin of error greater than 10%.

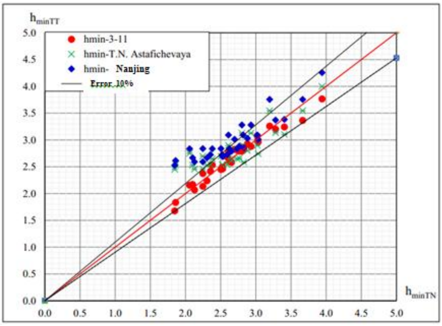


Figure 3.2. Relationship between experimental data and calculated data h_{min}

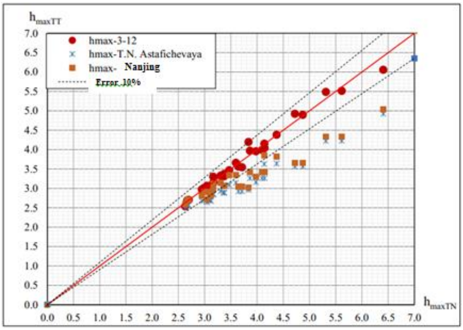


Figure 3.3. Relationship between experimental data and calculated data h_{max}

Based on the experimental data and the results of the relational calculation (Figure 3.6), this relationship shows that: + At the low head of the horizontal axis, when a/H=0,25 with the narrow angle, the two upper and lower limit lines overlap, and the larger angle of Δh_{gh}=0,56h_k; + When the a/H≈2,0 the scope of the steady-state flow between the two status of the limitation of the narrow angle is Δh_{gh}=0,92h_k and the larger angle Δh_{gh}=2,5h_k. It is significant to apply this into the energy dissipation of the funnel-shaped flow in the downstream of floodgate.

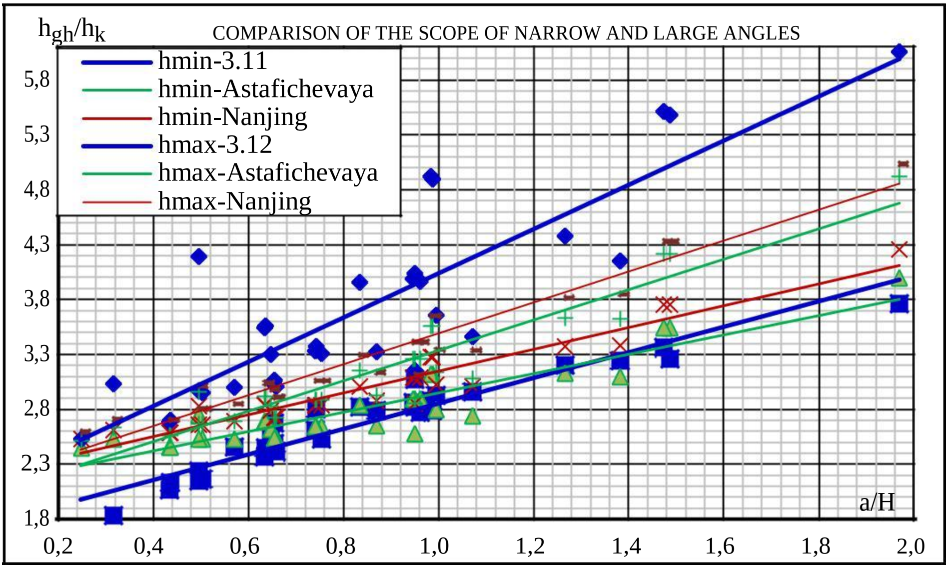


Figure 3.6 The relation between h_{gh} /h_k and a /H of angles less than 15^0 and angles greater than 25^0

3.2. Characteristics of the shape of the funnel-shaped flow

By the construction of the empirical formula in Section 3.1, comparison of error and correlated level, selected formula (3-15) to determine the maximum height of curvature up flow (h_v) with standard error of 0,04, correlation coefficient is 0,98; the maximum error of the formula set is 7,9% and the set of formula test is 4,3%.

$$\frac{h_v}{a} = 1{,}342\left(\frac{h_k}{a}\right)^{0{,}138}\left(\frac{D}{a}\right)^{0{,}016}\left(\frac{E}{a}\right)^{0{,}648} \quad (3\text{-}15)$$

The experimental results show that: $1{,}2 \le L_2/h_v \le 2{,}0$; $2{,}4 \le L_3/h_v \le 4{,}4$. The empirical formulas are created to calculate the confines of the whirlpools in the downstream of the stepped spillway when the funnel-shaped flow corresponds to the most frequent occurrences:

$$\frac{L_2}{h_v} = (1{,}4 \div 1{,}8) \quad (3\text{-}16); \qquad \frac{L_3}{h_v} = (3{,}0 \div 3{,}7) \quad (3\text{-}17)$$

3.3. The distribution of flow velocity, and the structure of the funnel-shaped flow

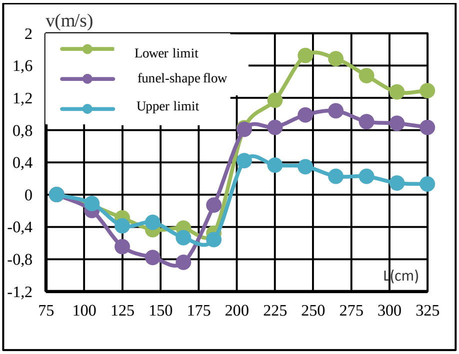


Figure 3.21 The distribution of bottom velocity in the downstream with the transitional status

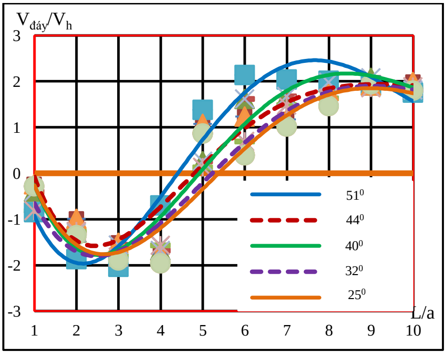


Figure 3.24 The distribution of bottom velocity in the downstream of the stepped spillway of the funnel-shaped flow

From the results of experiments, the relations have shown that: +The maximum of mean velocity occurs at the narrowing position (position at the end of the threshold, the start of the funnel-shaped structure) and nose position; +On the downstream channel, the maximum mean flow velocity appears in the form of free-flowing current, at positions immediately preceding and following the point of discharge; +The area immediately after the nose, the flow pours down to the downstream, the flow velocity decreases; +The largest bottom velocity occurs in the case of the flow of the lower limit, is as twice as the bottom velocity in the case of funnel-shaped flow. (Figure 3.21); +Deceleration of the bottom flow velocity along the downstream channel when h_h/h_k in the status of free flow ($h_h<h_{min}$) is faster than the bottom submerged and the funnel-shaped flow ($h_h> h_{min}$); +The vortex bottom flow velocity (the bottom of the whirlpool 2) and the bottom flow velocity in the downstream channel (the bottom of the whirlpool 3) are nearly symmetric, the maximum velocity value is about 2 times the flow velocity value after the hydraulic jump. $V_{thebottomHLmax}=2V_h$ ($V_h = q/h_h$) (Figure 3.24).

3.4. The energy dissipation of the funnel-shaped flow

Based on the results of the experiment, establish the relation between ΔE and Froude numbers (Figure 3.26). This relationship shows that the case of the funnel-shaped flow ($h_{min}<h_h<h_{max}$) is drained by the turbulence of the three whirlpools, the energy dissipation reaches over 30% to over 60% and depends on the value a/h_h treatment. This is the best steady status in the spuential status of the downstream with bottom velocities and waves on the surface of the downstream being minimal.

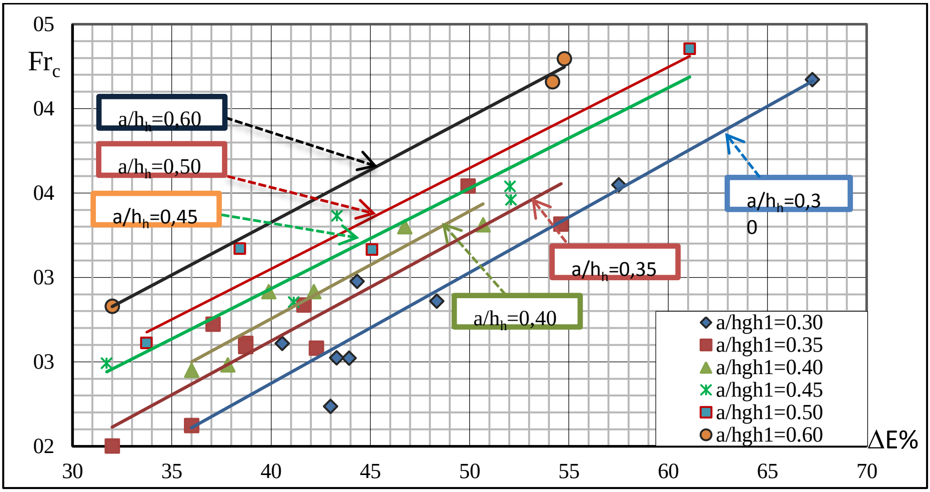


Figure 3.26 The relation of effective energy dissipation ΔE% ~ Fr_c with a/h_h

3.5. Conclusion of Chapter 3

1. The funnel-shaped flow is a kind of water jump with the integration of surface-bottom-submerged. It was created on the structure of a curved nose, an angle $\theta=25^0\div51^0$, the height of the stepped spillway a/P=0,14÷0,46 with many outstanding features compared to the surface-bottom hydraulic jump behind stepped spillway with an angle $<15^0$. When the funnel-shaped flow appear, there is no long wave in the downstream and big energy dissipation from 30% to 60%, small bottom bed velocity.

2. The transition in the downstream of the stepped spillway with curved nose angle, an angle $\theta=25^0 \div 51^0$, the height of the stepped spillway a/P=0,14÷0,46 converted into 7 basic forms (1) the radioactive transition by accelerated flow (2) the status of lower limit - TT2 (TT2a and TT2b), (3) the funnel-shaped flow - HT3, (4) upper limit state - TT4 (TT4a and TT4b) and (5) the transition flow of bottom-submerged - HT5. In these seven forms, there are three known forms of the transition, four of which are called status, which is the limitation to convert the transitions. The transition forms obtained are consistent with the previous research results of D.I. Cumin, Nanjing Institute of Hydraulic Research, China.

3. By empirical formula (3-11), (3-12) to determine the minimum flow depth (h_{min}) and the maximum flow depth (h_{max}) is the appearance of the funnel-shaped flow. With the structure of angle $\theta= 25^0 \div 51^0$ for the appearance of the funnel-shaped flow is 2,5 times larger than the angle of the stepped spillway with an angle $\theta<15^0$. It is significant when applying the energy dissipation of funnel-shaped flow in the downstream of the floodgate.

4. The height of curvature up flow (h_v) in the case of the funnel-shaped flow is minimum, reaching the maximum value with the status of the upper limit and can be determined by the experimental formula (3- 15).

5. The proportion of length of the whirlpool 2 to the maximum height of h_v varies between (1,2÷2,0) times; the proportion of length of whirlpool 3 with the maximum height of h_v varies between (2,4÷4,4) times.

6. The funnel-shaped flow has the largest bottom flow velocity in the downstream channel with approximately 2 times as the flow velocity in the downstream channel, the location where the maximum flow velocity of the bottom is at a distance equal to (2÷5) the height of the stepped spillway a.

CHAPTER 4: THE PROCESS OF CALCULATION FOR CHOOSING THE STRUCTURE TO FORM TRANSITION FLOW WITH INTEGRATION OF SURFACE – BOTTOM – SUBMERGED 3 WHIRLPOOLS

4.1. The choice for the structure of energy dissipation of funnel-shaped flow

The structure of energy dissipation of the funnel-shaped flow is the one that creates the flow of surface-bottom-submerged of the 3 whirlpools behind the stepped spillway in an interval that is large enough of the downstream water level change; there is a small flow velocity at the bottom of the downstream, far away from the construction, and a large amount of energy dissipation.

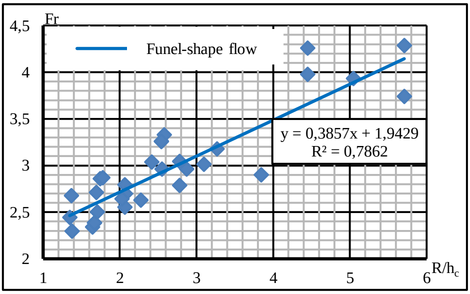


Figure 4.3. The relation between Froud number and R/h_c of funnel-shape flow

Correlation analysis shows that it is correlated tightly between Froude number and R/h_c (r=0,89), while for other non-dimensional variables, correlation was low or not correlated.

Create the chart to show the relationship between Froude number and the proportion R/hc for funnel-shaped flow (Figure 4.3). On the basis of this chart you can choose the radius for the structure or can calculate the radius (R_{tt}) by formula (4-3):

$$R_{tt} = 2,59(Fr_c - 1,9429)h_c \quad (4\text{-}3)$$

In order to have a reasonable structure of stepped spillway, it is possible to create funnel-shaped flow and the small bottom bed velocity need to meet the following requirements (4-4):

$$\theta = 30^0 \div 45^0;\ \frac{a}{h_k} \geq \frac{1}{3};\ 0,14 \leq \frac{a}{P} \leq 0,46;\ \frac{a}{E} \geq 0,6737\frac{a}{P} - 0,0233 \quad (4\text{-}4)$$

4.2. The process of calculation for choosing the structure of energy dissipation of the funnel-shaped flow

The structural dimensions of the stepped spillway are: height (a), radius (R) and angle (θ).The process of calculation is shown in the diagram (Figure 4.5).

4.3. Tính toán ứng dụng đối với tràn xả lũ Bản Mồng

With the structure of energy dissipation of funnel-shaped flow has: the height of the stepped spillway a=4,99m, the angle of $\theta=40^0$, the radius R = 13,0m with all of discharges levels and the large changes of downstream water level (from 7,09m to 8,36m) (Table 4.3, Figure 4.8)

Table 4.3. Results of calculating, checking and comparing for Ban Mong spillway

Parameter	Unit	P_{KT}	P_{TK}	P_{TX1}	P_{TX2}	P_{TX3}	P_{TX4}
Angle 40^0							
Q	m^3/s	6215,47	4915,47	4036,56	2580,60	1460,91	221,91
h_{min}	m	17,68	15,98	14,68	12,11	9,48	4,22
h_h	m	20,24	18,64	17,46	15,30	13,18	10,21
h_{max}	m	24,76	23,61	22,68	20,71	18,45	12,58
h_v	m	26,05	24,71	23,71	21,73	19,72	15,35
L_2	m	46,88	44,48	42,67	39,12	35,50	27,64
L_3	m	96,37	91,43	87,71	80,41	72,98	56,81
$V_{đáymax}$	m/s	8,19	7,03	6,17	4,50	2,96	0,58

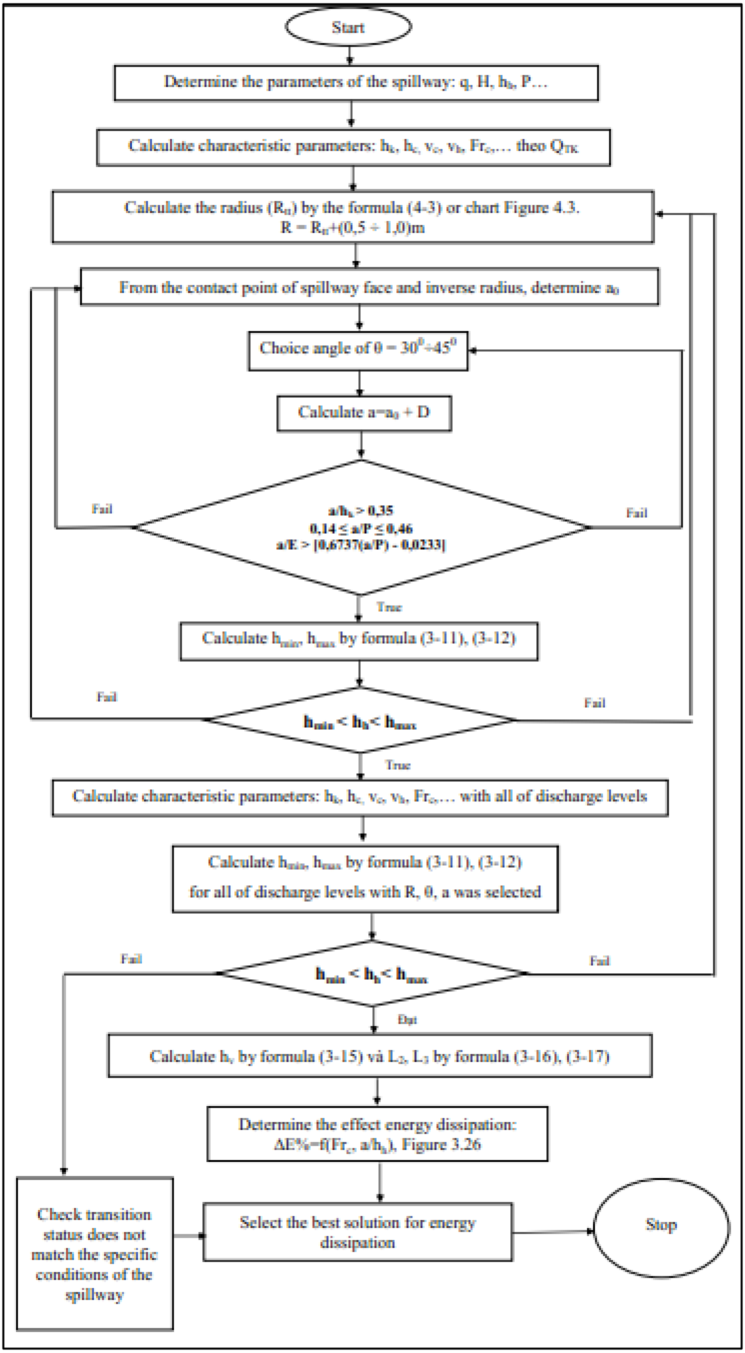


Figure 4.5 the graph presents the choice for the structure of energy dissipation of the funnel-shaped flow

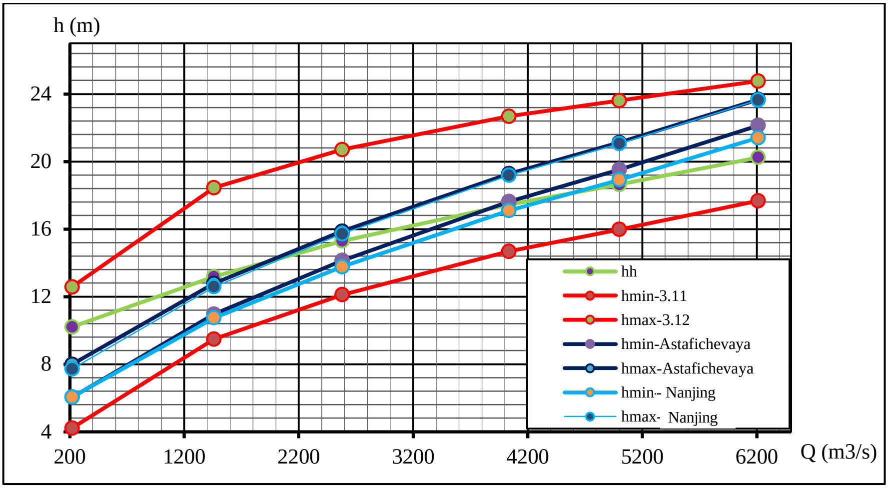


Figure 4.8 The relation between Q-h with angle 40^0

Figure 4.8 shows that the case of small angle ($\theta=0^0\div15^0$) does not form a surface flow if discharge is small or large, the surface flow only is formed when the discharge is in the range of (2.000 $m^3/s\div4.000m^3/s$) with small range of downstream water (about 2,0m).

Figure 4.9 shows that with angle of 45^0 for the maximum range to form funnel-shape flow , however, variation between the angles is not much.

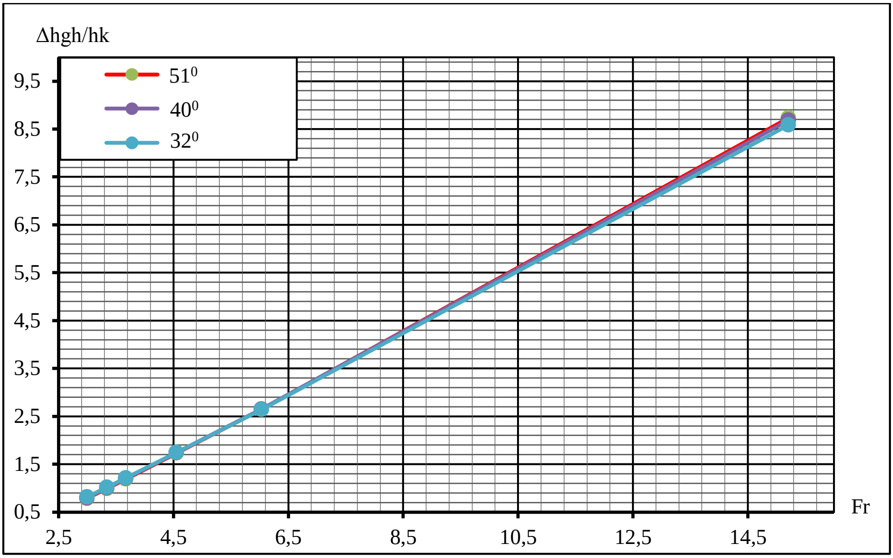


Figure 4.9. The limit to form the funnel-shape flow follow Froude number

Results of experiments on physical models of Ban Mong spillway according to the design of alternatives of energy dissipation show that: + The efficiency of energy dissipation is about 44% to 55%; + Total length of energy dissipation basin and the reinforcement section behind the basin (section 1) is 72,0m, the maximum flow velocity in the basin is 25,4m/s, the maximum flow velocity behind the basin is (section 1) is 6,12 m /s.

The results of calculation for energy dissipation of Ban Mong funnel-shaped flow show that the maximum flow velocity is about 8,19 m/s in the scope of the whirlpool 2 (about 47,0 m).

Thus, when using the energy dissipation of the funnel-shaped flow will reduce the length, as well as thickness of reinforced bottom, which is more economically beneficial.

4.4. Conclusion of Chapter 4

1. Through the investigation of the relationship between the elements of the stepped spillway, the parameters was proposed for the structure of the stepped spillway to satisfy the condition (4-4) to form the funnel-shaped flow in the downstream of the floodgate.
2. The calculation process is designed to shorten time, reduce calculation effort, reduce some of the volume of experiment, help the designer to have a closer look at the ability to work as well as predict hydraulic flow through the construction from specific conditions when calculating, which contributes to the design, management and operation of the construction to achieve high efficiency.
3. With Ban Mong spillway, it is possible to apply the structure of energy dissipation of the funnel-shaped flow, which will reduce the consolidation in the downstream but still ensure safe.

CONCLUSION AND RECOMMENDATION

I. CONCLUSION

1. General conclusion of the thesis

(1) Hydraulic jump, transition and energy dissipation are are always complicated, diverse and heated issues. Forms of the bottom transition, the transition with integration of the bottom with the flat stepped spillways or the nose with a small angle ($\theta=0^0\div15^0$) has been studied relatively well, but due to the instability and long-wave in the downstream so, it has been applied rarely in Vietnam. Forms of the transition with very small stepped spillways and large angles of the structure of energy consumption are elaborately studied by Western scientists; however, there are empirical studies in the lab, the very limited stepped spillway with a = 0.05R.

(2) The results of hydrodynamic characteristics of the multi-whirlpool flow are mainly obtained from empirical and semi-empirical research methods, focusing on the limitation of the formation of transition. The theory assumes that the velocity is evenly distributed, and the pressure is distributed according to the hydrostatic law. Under research conditions of the thesis, the experimental method on the physics model gives the best results.

(3) The transition with integration of surface-bottom-submerged 3 whirlpools is an extension of surface hydraulic jumping, which is a multi-swirl transition, with a power consumption of up to 60%. "Cut" wave propagation in the downstream by the formation of "3 whirlpools" behind the stepped spillways with the inverse radius, large angle ($\theta = 25^0 \div 51^0$). The funnel-shaped flow has the bottom bed velocity is much lower than the energy dissipation of the bottom and long-range energy dissipation of the same conditions.

(4) The hydraulic funnel-shaped flow model has been built in the glass flume, to ensure similar standards to the current empirical standards and transfer into the actual model scale $\lambda_L \leq 100$, the measurement error on the model is less than 3%.

(5) The transitional mode in the downstream of the stepped spillways with inverse radius, angle of $\theta = 25^0 \div 51^0$, the height of the stepped spillways $a/P = 0.14 \div 0.46$, which was converted into 7 basic forms in accordance with the results of the previous studies of surface flow.

(6) The funnel-shaped flow appears in the wide range of changes in water level downstream from the lower limit - the minimum flow depth (h_{min}) to the upper limit - maximum flow depth (h_{max}).

(7) The maximum height ratio of curvature up flow (h_v) for the smallest depth in the downstream formed the funnel-shaped flow varied between (1,2÷1,92) times and with the largest downstream depth forming the funnel-shaped flow varied between (1,02 ÷ 1,14) times. The minimum height of h_v in case of the funnel-shaped flow and achieved the maximum value when it is in the status of the upper limit.

(8) The limit of rolling whirlpools in the downstream of the stepped spillways of the funnel-shaped flow is in proportion to the maximum height of water column (h_v), the limit of the whirlpool 2 is $L2 = (1,2 \div 2,0)h_v$ and the limit of the whirlpool 3 is $L3 = (2,4 \div 4,4)h_v$.

(9) The funnel-shaped flow has the largest backflow velocity that is equal to about 2 times as the flow velocity in the downstream channel. The location of the largest bottom flow velocity is equal to (2÷5) the height of the stepped spillway a.

(10) The structure of stepped spillway for forming the funnel-shaped flow needs to be selected to satisfy the conditions (4-4). This is also the limit of the empirical formulas constructed from this thesis.

(11) The process of calculating, selecting the structure of nose to form the funnel-shaped flow is constructed and applied for the successful calculation for a real construction.

2. New contributions of the thesis

(1) Build experimental formulas to determine the upper limit of h_{max}, the lower limit h_{min} of the water column in the downstream to create the transition with integration of surface-bottom-submerged three whirlpools and the height of curvature up flow h_v of the integrated transition behind the stepped spillways with inverse radius and angles of 25^0 to 51^0.

(2) Propose the shape and size of the stepped spillways, the nose to ensure the transitional mode of surface-bottom-submerged three whirlpools behind the stepped spillway.

(3) Set up the calculation process to select the nose size to create the transition flow with integration of surface-bottom-submerged three whirlpools and determine the hydrodynamic characteristics of the integrated transition behind the stepped spillway.

II. PROPOSAL

+ Apply the transitional form, the energy consumption of funnel-shaped flow into the design of the energy consumption to the optimum economic and technical options;

+ Apply the data, formulas and relations established by the thesis into the calculation for the design of funnel-shaped constructions with energy dissipation which was previously not enough scientific argument to design the form of transitional flow with economic efficiency.

III. FURTHER RESEARCH

+ Continue to study the improvement of hydrodynamic characteristics in the more detailed direction of the thesis results such as the size of the rolling whirlpools, characteristics of the surface water in the funnel-shaped flow; detailed distribution of the flow velocity, pressure, flow velocity, pressure fluctuations;

+ Expand the scope of research in spatial problem, the flow through gate valve, the conditions of the bottom boundary to obtain better results of this thesis;

+ Develop a hydraulic calculation program to select the appropriate structure of the funnel from the research results of the thesis;

+ Research on the application of discontinuous nose type, to improve the capacity of diffuse flow to enhance the energy dissipation in the downstream of the stepped spillway;

+ Apply of a three-dimensional or two-dimensional mathematical model for analyzing the structure of the funnel-shaped flow is also a way to enrich understanding of hydrodynamic characteristics of the funnel-shaped flow.

LIST OF PUBLISHED WORKS

1. Nguyen Quoc Huy, Defining the limits to form funnel-shape flow in stepped spillway with inverse radius, large angle, Journal of Agriculture and Rural Development, Vol. 20, No. 2, pp. 76-84, October 2016.

2. Nguyen Quoc Huy, Le Van Nghi, Characteristics of the shape of the funnel-shape flow behind the stepped spillway with large angles, Journal of Water Resources science and Technology, No. 34, pp. 55-64, August 2016.

3. Nguyen Quoc Huy, Le Van Nghi, Calculation of energy dissipation of surface flow behind stepped spillway with inverse radius and large angles, Journal of Water Resources Science and Technology, 34, pp. 9-15, August 2016.

4. Le Van Nghi, Nguyen Quoc Huy, Doan Thi Minh Yen, Conditions for formation and transformation the status flows in downstream of the stepped spillway with large angles , Journal of Water Resources Science and Technology, No. 25, pp. 44-51, February 2015.

5. Le Van Nghi, Nguyen Quoc Huy, Doan Thi Minh Yen, Patent "The structure of stepped spillway creates the integration of surface – bottom – submerged 3 whirlpools in the downstream of floodgate", No. 1-2015-03470, On 21/9/2015, Decision No. 68818 / QD-SHTT of the National Office of Intellectual Property - Ministry of Science and Technology approved the application of Decision No. 68818 / QĐ-SHTT, dated 03/11/2015.