ANALYSIS OF PLUNGE POOL SCOUR HOLE FORMATION BELOW A CHUTE SPILLWAY WITH FLIP BUCKET USING A PHYSICAL MODEL

Sokchhay Heng[1], Tawatchai Tingsanchali[2], and Tadashi Suetsugi[3]

[1]Interdisciplinary Graduate School of Medicine and Engineering, University of Yamanashi, Yamanashi, Japan, Tel: +81 80-36902013, e-mail: heng_sokchhay@yahoo.com

[2]Nakhon Pathom Rajabhat University, Nakhon Pathom, Thailand and Asian Institute of Technology, Pathumthani, Thailand, Tel: +66 81-9396846, e-mail: tawatch_t@hotmail.com

[3]University of Yamanashi,Yamanashi, Japan, Tel: +81 55-2208524, e-mail: tsuetsugi@yamanashi.ac.jp

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Abstract

Plunge pool scouring due to water jet impingement from flip bucket spillways is a major concern for stabilization of hydraulic structures and their downstream channel. The objectives of this study are to select an appropriate movable riverbed material for reproducing scour hole in the physical model and to analyze the characteristics of its formation using the selected material. The whole tasks were carried out using Nam Ngum 3 Spillway Physical Model constructed with an undistorted scale of 1:75. Different types of movable riverbed material were tested and the most appropriate one was then selected in order to conduct the scour study. Based on a set of criteria, cohesive movable riverbed material of Sand (40): Cement (1): Water (5) was found to reproduce more reliable scour hole than non-cohesive material of 25 mm graded gravel. Utilizing the selected material, the overall model test demonstrated that spillway operation, river morphology and natural topography of the plunge pool are the main factors governing irregular trend of scour development. Scour hole tends to develop toward the left bank and the maximum scour depth, about 74 m deep below the original riverbed, is located approximately 252 m downstream of the spillway's bucket lip.

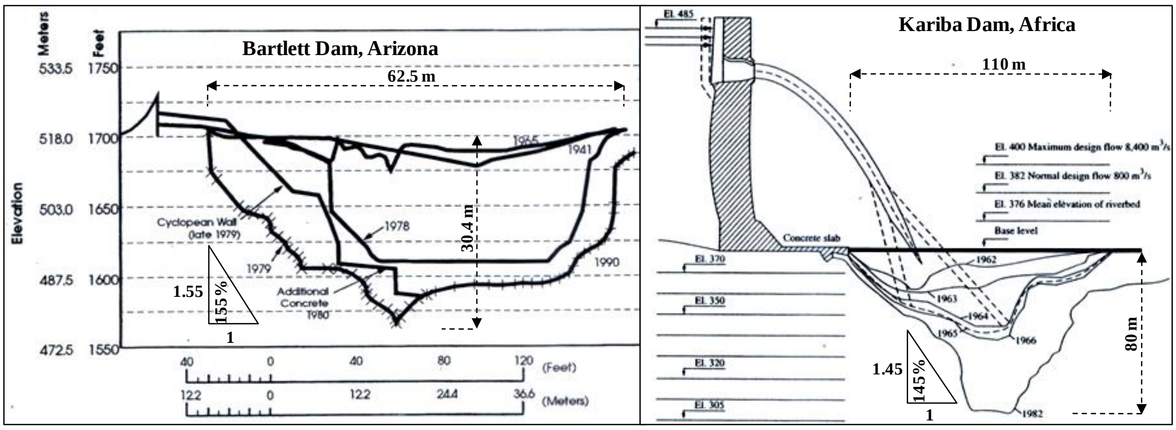
Keywords: Chute spillway, Nam Ngum 3, Physical model, Plunge pool, Scour hole

Introduction

Hydraulic structures spilling excess water from dams/spillways have been a major engineering concern for a long time. The discharge of water to downstream of such infrastructures may scour their foundation in case capacity of the spilled water exceeds the strength of existing riverbed. Long term of the scour process which produces gradually scour depth may endanger the stability of the dam and downstream bank and lead to structural failure. Three major effects of scouring are (i) the endangering of structure's stability itself by structural failure or increased in seepage, (ii) the endangering of the stability of downstream riverbed and its side slopes, and (iii) the formation of a mound of eroded material which could raise tailwater level at the structure [1].

For instances, a model study of Wirtz Dam (Texas) showed that ultimate scour depth extended into the foundation of structure [2]. After construction of Bartlett Dam (Arizona) in 1939, floods provoked a significant scour hole just downstream of the outlet spillway;

after that, scouring continued further downstream and scour hole reached about 30.4 m deep [3]. Likewise, high discharge of water caused a remarkable scour hole of about 80 m deep in the plunge pool of Kariba Dam (Africa) due to scouring of gneiss in 1982. Figure 1 shows the development of scour hole in the plunge pool of Bartlett Dam (1941-1990) and Kariban Dam (1962-1982). Moreover, a scour depth of 102.66 m was predicted to occur at downstream of the Three Gorges Dam in China [4].



Source: Modified from Annandale (2006) [1]

Figure 1. Scour hole development in the plunge pool of Bartlett Dam, Arizona (1941-1990) and Kariba Dam, Africa (1962-1982)

Yildiz and Üzücek (1994) present the effect of scouring in plunge pools of various dams/spillways in many countries [5]. During the operation at low discharge of the Keban Dam/Spillway in Turkey between 1983 and 1986, scouring demolished the concrete protection blocks. Another phenomena occurred at the Karakaya Dam in the same country is that the rocky river bed was scoured until 30 m deep and without any protections, scouring developed towards the left bank. At Tarbela Dam in Pakistan, scour hole occurred in the plunge pool widening towards the right bank and performing in joint expansion and the development of fractures in the drainage gallery. A remarkable 36,900 m^3 of deposited material occurred at downstream of the Picote Dam in Portugal after 5 years of operation; this trouble was a consequence of a released discharge between 1,000 m^3/s and 7,000 m^3/s.

Annandale (2006) stated that “the design of plunge pool scour protection should be technically and economically feasible” [1]. Consequently, the estimation of scour extent is very important for this purpose. Adequate data are not often available to accurately analyze the behavior of the scour effect. In addition, the present empirical methods can be used to estimate only maximum scour depth and the mathematical model is yet unavailable. Thus, only scour study using physical model can demonstrate confidently how the scour hole is formed in the plunge pool. A common problem related to the physical model study of scouring is the use of movable riverbed material.

Hence, the objectives of this study are (1) to select an appropriate movable riverbed material for reproducing scour hole in the physical model and (2) to analyze the characteristics of its formation using the selected material. The remaining section of this paper is broken down as follow: (i) model characteristics, (ii) methodology including selection of the trial movable riverbed materials, (iii) results and discussion, and (iv) conclusions.

This research is, therefore, an important step forward in designing the protection facility against plunge pool scouring. It focuses on estimation of scour extent and characteristics based on the constructed physical model and plunge pool pit. Moreover, the study considered only cement mortar (cohesive material) and gravel (non-cohesive material) as the trial movable riverbed materials. Analysis of the water jet characteristics and sediment transport are beyond the scopes of this study. Scour development tests were carried out with steady flow ranging between 1,000 m^3/s (minimum discharge) and 8,182 m^3/s (maximum discharge) following Nam Ngum 3 Spillway operation. All dimensions in the paper refer to prototype, unless specifically stated.

Model Characteristics

Throughout the spillway, free surface flow exists and dynamic similitude between the model and prototype is based solely on Froude's Law of Similarity, which assumes gravity and inertia to be the dominant forces. Based on available laboratory space and pump capacity, the spillway model was constructed at an undistorted geometric scale of 1:75. Using subscripts "*m*" and "*p*" to denote model and prototype respectively, the equal Froude number between model and prototype can be presented as:

$$F_m = F_p \quad or \quad \frac{V_m}{\sqrt{g_m L_m}} = \frac{V_p}{\sqrt{g_p L_p}} \tag{1}$$

Where	F	: Froude number	
	V	: Mean flow velocity	[m/s]
	L	: Characteristic length	[m]
	g	: Gravitational acceleration	[9.81 m/s^2]

Following the Froude number similarity, the scale relationships between model and prototype are shown in Table 1.

Table 1. Model Scale Relationships

Parameter	Scale Relation	Scale Ratio
Length, L	$L_r = \frac{L_p}{L_m}$	75.00
Velocity, V	$V_r = L_r^{1/2}$	8.66
Discharge, Q	$Q_r = L_r^{5/2}$	48,713.93
Pressure head, h	$h_r = L_r$	75.00
Time, t	$t_r = L_r^{1/2}$	8.66

The prototype section shown in Figure 2 was constructed in the Hydraulic Laboratory of Asian Institute of Technology, Thailand, as a physical model (1:75, undistorted scale). The model composes of three main parts: (i) the upstream head pond including forebay and spillway approach channel; (ii) the control structure consisting of inlet piers, radial gates, dam and chute spillway with flip bucket; and (iii) the downstream boundary covering plunge pool and downstream riverbed channel.

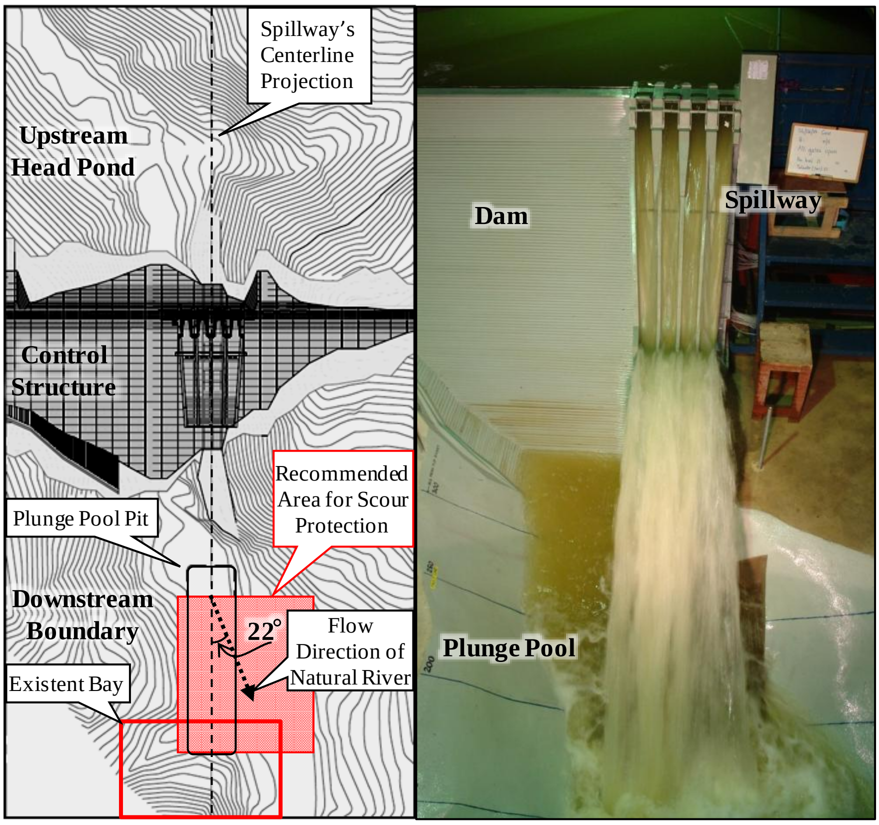


Figure 2. Prototype section constructed as physical model of 1:75 undistorted scale. Layout plan (left) and physical model (right)

Upstream Head Pond

The upstream model boundary extends up to a distance of about 300 m upstream of the main dam axis and covers a total width of around 400 m across the spillway's central axis. The upstream head pond reproduces the upstream topography starting at an elevation of 530 m MSL along the river thalweg up to the maximum topographic elevation defined by the model boundary. The topography was reproduced using cement mortar over compacted sand.

To ensure full dissipation of the turbulent flow from feeding conduit, a forebay of 1.5 m long and fully independent from the upstream model boundary was included in the upstream head pond. Flow dampener was utilized to ensure that full potential flow free from any vortices will prevail in the upstream boundary as the flow enters the model structures.

Control Structure

The main roller-compacted concrete dam including the stepped spillway along the dam downstream face was fabricated using steel. In order to eliminate leakages especially at the stepped spillway joint, all steel surfaces and joints were sealed and coated with epoxy paint. It is difficult at a scale of 1:75 to reproduce a hydraulic surface smooth enough to represent the prototype concrete spillway chute and bucket. The best possible material for spillway model construction is PVC plastic because this material can be easily fabricated with smooth curves.

Downstream Boundary

The downstream boundary reproduces the natural flood valley of the river over a length of about 600 m downstream from the edge of the spillway flip bucket. The plunge pool area was built as a hollow pit without bed material. For succeeding tests on scour development, the actual morphological conditions along the downstream boundary were reproduced. A flap gate at the downstream end was installed to adjust tailwater levels according to the rating curve.

In the model, a plunge pool pit (Length = 300 cm, Width = 120 cm, Depth = 100 cm, model dimension) was pre-excavated for scour development study. For each test, the plunge pool pit is filled with the trial material that the surface elevation is set according to the natural topography. It is remarked that the spillway's centerline projection forms an angle of 22° with the existing river flow direction as displayed in Figure 2.

Roughness

The PVC material used in the construction of spillway control structure and chute has a typical Manning's roughness coefficient (*n*) of 0.009. Based on a Froudian scale, this roughness has a prototype equivalent of 0.018 - higher than the typical spillway concrete surface roughness of 0.014. Therefore, it is apparent that the spillway model would result in an underestimation of the discharge capacity.

A previous study (Damle, 1952) comparing the discharge capacities between high coefficient model weirs (at different scales) and its prototype equivalent indicated that in most cases with high spillways, the error was not more than 1% [6]. However, the depth of overflow should always be more than 15 mm to eliminate the effect of capillary and surface tension. Accordingly, minor scale effects associated with boundary roughness in this model study are acceptable.

Methodology

Trial Movable Riverbed Materials

The most common method of representing bed rock in plunge pool scour hole reproduction in the models is the use of non-cohesive or cohesive material as movable bed. Physical model using gravel as non-cohesive bed material is practical for scour hole geometry studies [7]. In this study, the prototype bed material investigated at downstream of the spillway is boulder and its diameter ranges between 2 m and 3 m which are respectively about 26.67 mm and 40.00 mm in the model. Because it is difficult to find the material within this range, 25 mm graded gravel was used as the first trial material.

Recommended by Aswegen et al. (2001) and Suppasri (2007), the use of cohesive materials, mixing of sand, cement and water, could provide more realistic scour holes and this kind of material is the most available, cheap and easy to work with [8,9]. Therefore, this material was also tested as the second trial material. Based on past experience of similar hydraulic model study (Nam Ngum 2 Spillway), the ideal proportion that gave realistic scour holes and demonstrated repeatability in the model was Sand (32): Cement (1): Water (4), unit is bucket [9]. Because the maximum model discharge of the present study (168 l/s) is less than that of Nam Ngum 2 (363 l/s), the material should be less cohesive. Consequently, the mixing of Sand (40): Cement (1): Water (5) was taken into account. In order to produce consistency of strength of the cement binder, the trial mixture was allowed to cure for 48 hours prior to the tests.

Analytical Approaches

A material is considered to be acceptable for representing the prototype riverbed material for scour hole reproduction in the model in case the slope of scour hole is steep or near vertical at equilibrium phase [8]. Due to unavailable data of scour hole in the prototype (project is under study stage) and to show how steep the scour hole is, the slopes of model scour hole (resulted from maximum discharge) should be steeper than 150% which is the average front slope of scour hole occurred at downstream of Bartlett Dam in Arizona (155%) and Kariba Dam in Africa (145%) as illustrated in Figure 1. Moreover, the maximum scour depth and impact location should match with that of some empirical formulas. Maximum scour depth is a height difference between tailwater and bottom scour hole elevation. Impact location is a distance measured from bucket lip of spillway to the point of maximum scour depth. If steep scour hole occurs, maximum scour depth and impact location will be further checked; otherwise, the trial material is automatically considered inappropriate.

From extensive literature review, there are 28 and 3 empirical equations developed by different authors for predicting the maximum scour depth and impact location, respectively. For maximum scour depth estimation, all methods developed before 1985 were summarized by Mason and Arumugam (1985) and others can be found in Mason (1989) coupled with Evrine (1976), Hoffmans (1998), Liu (2005) and Suppasri (2007) [10,11,12,13,4,9]. For impact location prediction formulas, Taraimovich (1978) for submerged jet was coupled alternately with Elevatorski (1959), Kawakami (1973) and USBR (1977) for non-submerged jet [14,15,16,17]. All of these formulas were employed to evaluate the performance of the trial materials. Empirical methods were basically developed using data collected from different geographical areas. This kind of methods is also known as regional approach. In consequence, comparison of maximum scour depth and impact location resulted from the model with those yielded from the empirical formulas could be considered as an evaluation tool.

While testing each trial materials, maximum scour depth was measured at each 30 minutes (model dimension) until scour process was not further observed. This measurement is important for equilibrium phase study of scour development. Time of equilibrium is the duration that the riverbed is being scoured. After this period, scouring would not be so significant or have no further effect on the riverbed because energy of the falling jet is fully dissipated. Time of equilibrium was then considered as a testing duration of a particular scour hole formation of a specific discharge.

A rate of change in scour depth with time was used as an indicator for equilibrium phase analysis [18]. If this ratio is equal or approximate to zero, equilibrium phase is considered to be reached.

Results and Discussion

Non-Cohesive Material of 25 mm Graded Gravel

As shown in Figure 3, the scour hole profile resulted from a discharge of 8,182 m^3/s (maximum discharge) confirms that non-cohesive material of 25 mm graded gravel is not appropriate for reproducing scour hole because its front slope is not steep which is about 50% and it is much less steep than the set criterion (150%). It is also apparent that the scour hole is large and shallow which does not represent the reality and scouring also occurred at the non-impinged areas because the materials were collapsed (no based binder). Moreover, downstream deposition occurred next to the plunge pool pit blocked the scour process as the materials are in big size and dense, and cannot be transported further downstream with flowing water.

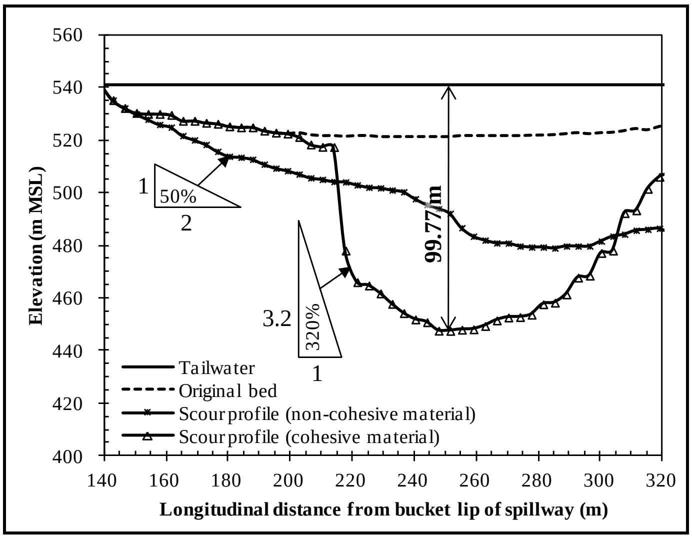


Figure 3. Longitudinal scour hole profiles (at maximum depth location) resulted from a discharge of 8,182 m^3/s (maximum discharge) using non-cohesive material of 25 mm graded gravel and cohesive material of Sand (40): Cement (1): Water (5)

Using smaller size of gravels as another alternative for trying to reproduce steep scour hole, all materials are expected to be removed from the pit and scour hole would be larger because the material has no base binder. The disadvantage of using movable bed material without base binder is that scouring also occurs at the nearby areas of impact location even water does not impinge at those places. The binder can be made using cement mortar but its strength would be high and may cause less scour effect.

In conclusion, the scour test using gravels as movable bed material resulted in an unrealistic and inaccurate scour hole as it represents. The use of non-cohesive material of 25 mm graded gravel was then ruled out from this study.

Cohesive Material of Sand (40): Cement (1): Water (5)

Based on scour hole profile resulted from the maximum discharge as illustrated in Figure 3, the cohesive material of Sand (40): Cement (1): Water(5) was considered as an appropriate material for reproducing scour hole because:

- The front slope of scour hole is very steep or nearly vertical (320%). It is also steeper then the set criterion (150%). In addition, this slope characteristic is the same as mentioned by Aswegen et al. (2001) who mentioned that the accurate scour hole should be steep or near vertical [8].
- The maximum scour depth of 93.77 m is approximately equal to that obtained from the empirical formula of Machado (1980), Mason-A (1985), Mirskhulava-A (1967) and SOFRELEC (1980) which are 94.41 m, 93.80 m, 97.92 m and 94.52 m, respectively, with an absolute percentage error less than 5%. The detail of these equations is presented in Table 2.
- The impact location of 251.60 m matches with that obtained from the coupled formula of Taraimovich (1978) and Kawakami (1973) which is about 248.64 m with an absolute percentage error of 1.2%. This combined equation is shown in Table 2.

Table 2. Good Performing Empirical Formulas

Name	Equation	Definition of Parameters	Source
Machado (1980)	$D_S = 1.35 \frac{q^{0.50} H^{0.3145}}{d^{0.0645}}$	*d*, d_m, d_{90}: Characteristic particle size of bed material D_S: Maximum scour depth measured from tailwater surface *g:* Gravitational acceleration *h:* Tailwater depth h_0: Difference between bucket lip and tailwater level *H:* Head drop between reservoir and tailwater level k_0: Coefficient related to air resistance L_S: Impact location *q:* Discharge per unit width *Q:* Discharge u_0: Flow velocity at the end of flip bucket θ_0: Angle of flip bucket θ_T: Jet impact angle	[10]
Mason-A (1985)	$D_S = 0.14N - 0.73\frac{h^2}{N} + 1.7h$ $N = \left(Q^3 H^{1.5} / d_m^2\right)^{1/7}$		[10]
Mirskhulava-A (1967)	$D_S = \left(\frac{0.97}{\sqrt{d_{90}}} - \frac{1.35}{\sqrt{H}}\right)\frac{q \sin\theta_T}{1 - 0.175\cot\theta_T} + 0.25h$		[10]
SOFRELEC (1980)	$D_S = 2.30 q^{0.60} H^{0.10}$		[10]
Taraimovich (1978) and Kawakami (1973)	$L_S = \frac{1}{g k_0^2}\ln(1 + 2k_0 u_{0X}\alpha) + (h_0 + D_S)\tan(90 - \theta_T)$ $\alpha = \tan^{-1}(k_0 u_{0Y})$ $u_{0X} = u_0 \cos\theta_0$		[14] [16]

Therefore, the scour hole was considered to be accurate and realistic and the mixing ratio by volume of Sand (40): Cement (1): Water (5) was selected as an ideal material for scour hole reproduction in the model. The study of scour hole characteristic was then carried out using this mixing ratio and the results are presented in the following sections.

The mixing ratio by volume of the ideal mix, Sand (40): Cement (1): Water (5), unit is bucket, is proportional to the ratio by percentage of volume, Sand (87%): Cement (2%): Water (11%).

Equilibrium Phase of Scour Process

As presented in Figure 4, scouring is so significant at Primary Scour period, from the beginning until 30 minutes. At Intermediate Scour period, from 30 minutes to 60 minutes, the scour depth is moderately increased. Plus, the rate of change in scour depth with time is very small at Secondary Scour period after 60 minutes because equilibrium phase is nearly approached and the energy of water jet is dissipated at maximum at the bottom of scour hole. To facilitate the testing and avoid long time running of each test, equilibrium phase of scour process was considered to occur at 60 minutes after starting experiment because scouring was not so significant after that time. Moreover, some tests compose of many cases and take time for running; so, in case of using cement mortar as bed material, its characteristic could be changed very much due to submergence. Therefore, one hour was carried out for scour hole study of a particular discharge.

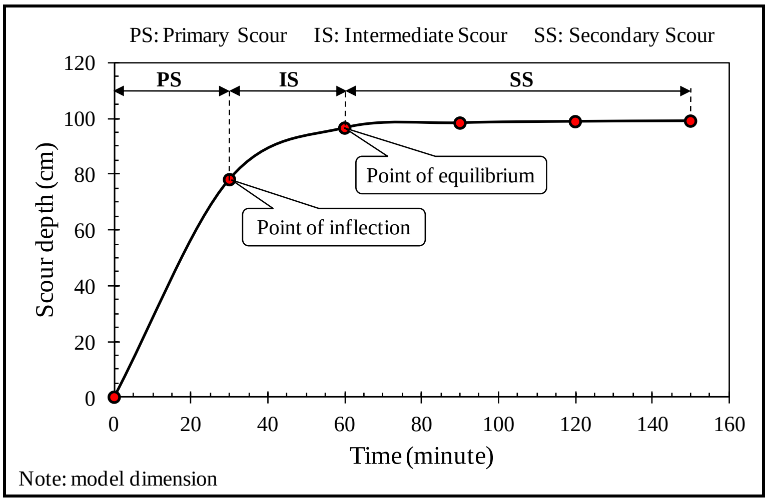


Figure 4. Change in model scour depth with time resulted from a discharge of 8,182 m^3/s (maximum discharge) using cohesive material of Sand (40): Cement (1): Water (5)

Comparison between the Experimental and Computed Results

In order to strongly conclude the consistent results between the experiment and the good performing empirical formulas in Table 2, a comparison of the whole range of discharge was carried out. Figure 5 depicts the scatter plots of the experimental versus computed results (D_S and L_S) of the empirical formulas. From minimum to maximum discharge, both results were found consistent with determination coefficient (R^2) greater than 0.990 for D_S and equal to 0.940 for L_S. The experimental D_S were commonly smaller than the computed ones of Machado (1980), Mason-A (1985) and SOFRELEC (1980) formula but larger in case of Mirskhulava-A (1967). Moreover, the bias decreased with increase in discharge for D_S; in case of L_S, it was smaller at low and high flow but larger at medium flow. This could be due to the effect of data range used for developing the empirical methods. In short, the experimental results of both D_S and L_S fit approximately well with those obtained from the empirical equations for the whole range of discharge.

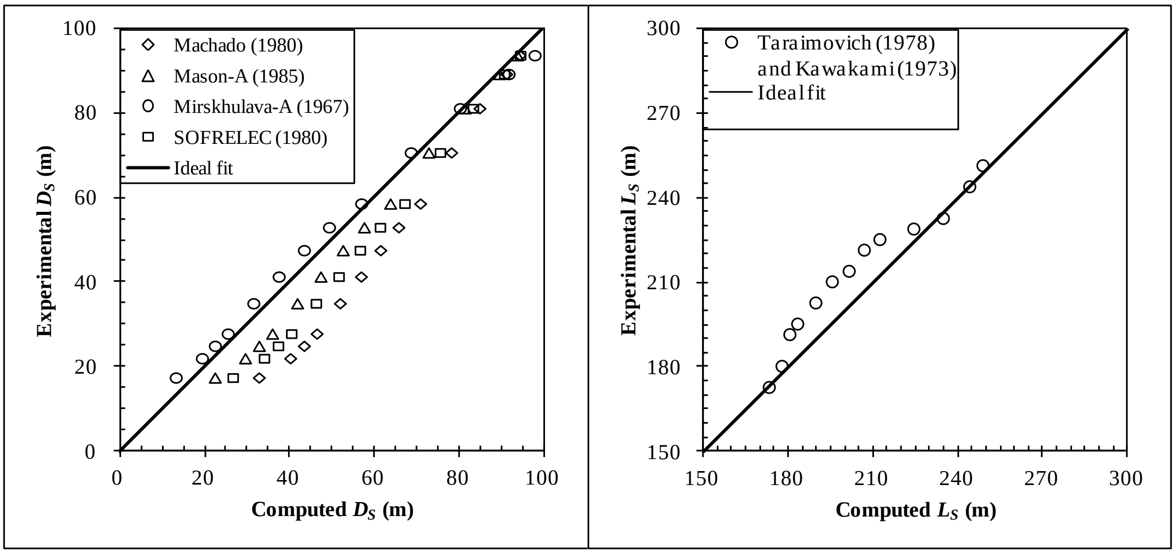


Figure 5. Scatter plot of the experimental versus computed results: maximum scour depth, D_S (left) and impact location, L_S (right)

Scour Characteristics

Scour characteristics are governed by the pattern of the oblique submerged impinged jet and submerged hydraulic jump on an adverse slope in the scour pit [4] as schematized in Figure 6. At the area of impact between the submerged jet and pit bottom (the latter called impacting zone), the flow velocity decreases rapidly while the pressure increases sharply; this region is the main zone of scouring. At the submerged hydraulic jump zone, the flow diffuses rapidly along the adverse slope and a recirculating region is formed in the surface water zone of the scour pit.

Based on the experimental investigation, jet thickness at the point of impingement decreased with increase in discharge. The same trend was considered for the length of the impacting zone and it was indicated by the shape of scour hole shown in next section. The larger jet thickness at low flow was because the water jet was broken up by air drag prior to its fall in the plunge pool. With lower jet velocity (corresponding to lower discharge), air drag has more influence and thus larger jet thickness. In the experiments, length of the submerged hydraulic jump (L_j) was determined by the recirculating region observed on the water surface. L_j increases generally with discharge. In this study, it could not extend farther downstream from discharge greater than 3,500 m^3/s because of the existent bay located in front of the spillway as marked in Figure 2. As a consequence, scour process was bounded at that area. In case of no protection, the mentioned bay would be scoured in the future after long term operation.

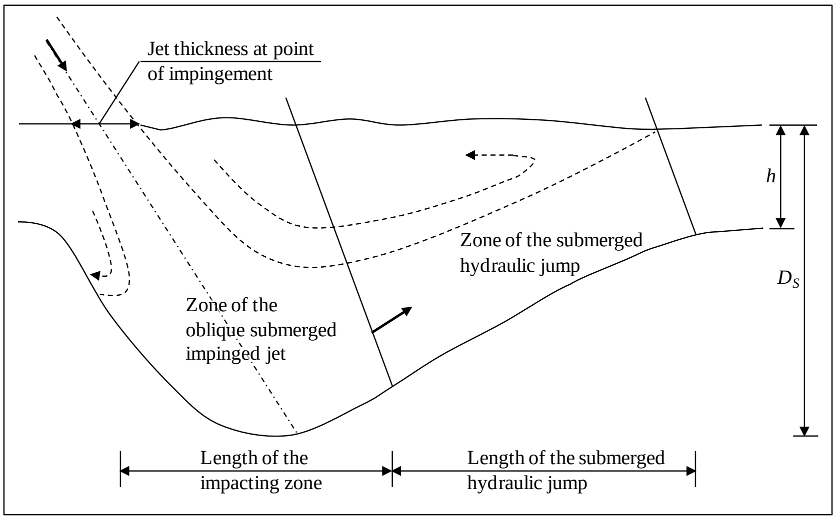


Figure 6. Oblique submerged impinged jet and submerged hydraulic jump on an adverse slope in the scour pit

Characteristics of Scour Hole Formation

The overall model tests demonstrated that scour hole develops toward the left bank as shown in Figure 7. For the discharges of 1,000 m^3/s, 1,500 m^3/s and 1,750 m^3/s, the maximum scour depths occurred on the right side of the spillway's centerline projection about 3.75 m because the high ground level of the left bank reflected the jet impingement to the opposite site. For the discharges of 2,000 m^3/s, 2,500 m^3/s and 3,000 m^3/s, the maximum scour depths were on the spillway's centerline projection. For higher discharges between 3,500 m^3/s and 8,182 m^3/s, the maximum scour depths developed toward the left bank because the water jet impinged on the right bank and reflected lateral hydraulic forces directing to the left side.

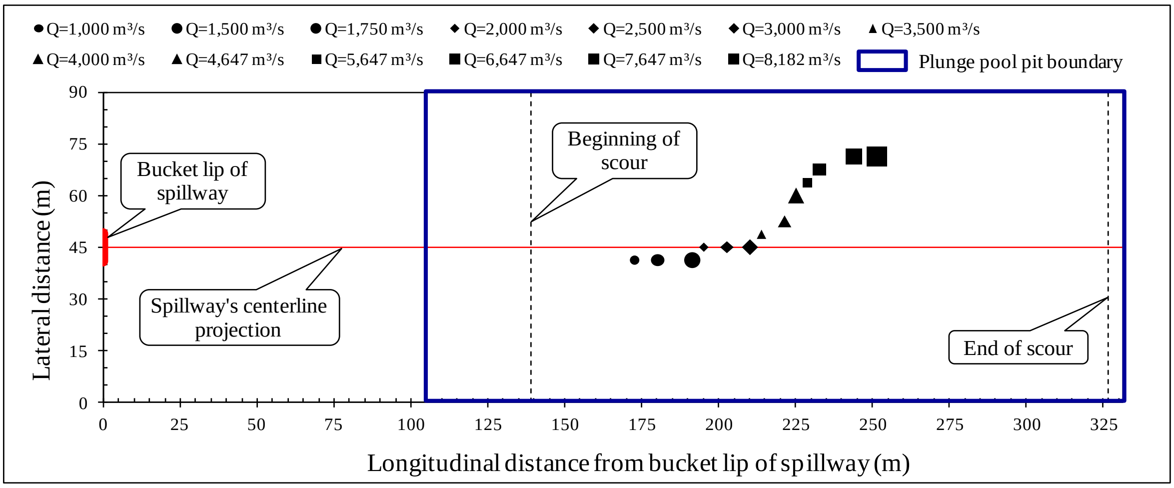
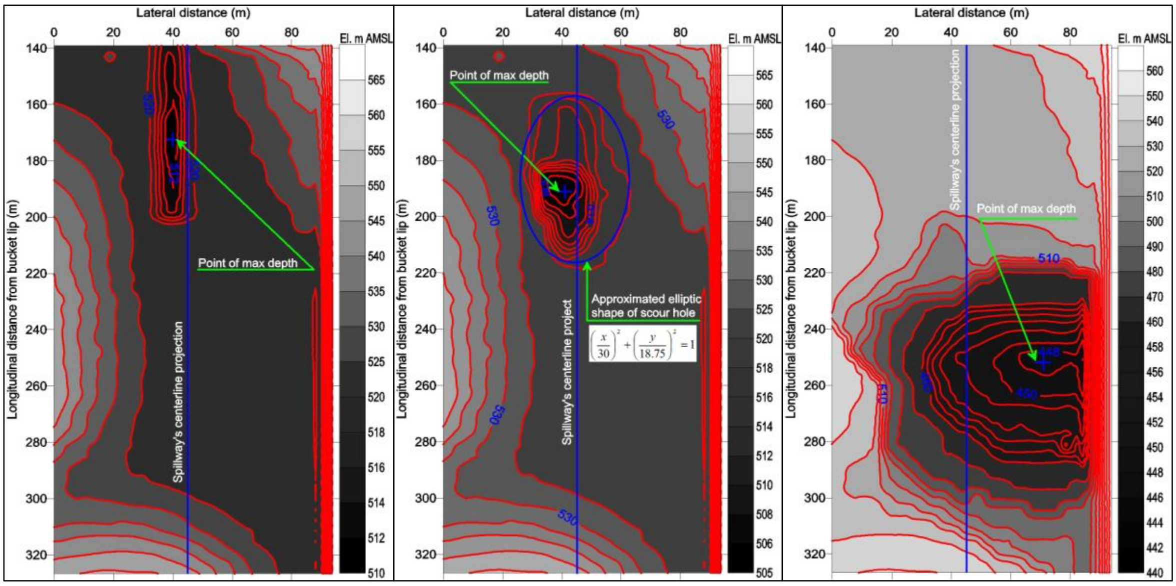


Figure 7. Location of maximum scour depths resulted from different discharges using cohesive material of Sand (40): Cement (1): Water (5)

The scour hole is deeper and the impact location is farther with higher discharge. From minimum to maximum discharge, scour hole developed from 139.10 m to 326.60 m, downstream of the bucket lip of spillway as illustrated in Figure 7. It reached the right solid slope of the plunge pool pit only on the upper part but reached the left solid slope from the top to bottom due to narrow pit. In addition, the maximum scour depth measured from the original bed level is about 73.88 m and it is located about 251.60 m from bucket lip and 26.25 m on the left side of spillway's centerline projection. Only three scour hole's geometries were measured and they are presented in Figure 8.



(a) Q=1,000 m^3/s (min. discharge) (b) Q=1,750 m^3/s (c) Q=8,182 m^3/s (max. discharge)

Figure 8. Scour hole's geometries resulted from 3 different discharges using cohesive material of Sand (40): Cement (1): Water (5). (a) Scour hole shape cannot be assessed because of the model scale effect (surface tension and capillary effect) (b) Scour hole is approximated with elliptic shape (c) Scour hole shape cannot be assessed due to side wall effect of the plunge pool pit

Scour hole resulted from a discharge of 1,000 m^3/s (Figure 8a) has a long shape because water was not well distributed. This inconvenience is provoked by the model scale effect (surface tension and capillary effect) while the flow depth at spillway (8.79 mm) is less than 15.00 mm [6]. In case of a discharge of 1,750 m^3/s, an elliptic shape of scour hole (Figure 8b) approximated with Equation 2 was performed in the plunge pool bed and its major axis was on the direction of the spillway's centerline project. This scour hole characteristic is similar to a case study of Fort Peck Spillway conducted by Babb et al. (2002) [19]. For a discharge of 8,182 m^3/s, the scour hole shape cannot be assessed due to side wall effect of the plunge pool pit.

$$\left(\frac{x}{30}\right)^2 + \left(\frac{y}{18.75}\right)^2 = 1 \quad (2)$$

Where x : Longitudinal distance [m]
y : Lateral distance [m]

In brief, the characteristics of scour hole formation and its irregular development trend depend primarily on spillway operation, river morphology and natural topography of the plunge pool. In order to investigate the complete extent of scour hole for this particular case study, the plunge pool pit should be extended wider especially to the left because trend of the scour hole expands to that side. Based on the present result of scour hole formation and its development trend, it is recommended to provide extensive scour protection measure at the area as specified in Figure 2.

Conclusions

This study investigated on both cohesive and non-cohesive material for reproducing scour hole in the physical model. Only cohesive material, mixing of Sand (40): Cement (1): Water (5), provides reliable result because scour hole is steep in comparing with other similar prototypes, and the maximum scour depth and impaction location match with some empirical formulas. If the prototype data is available, the mixing ratio will be adjusted until it could reproduce the most accurate scour hole. Any types of cohesive material may provide similar or better result but the importance is that they must be able to provide a nearly vertical scour hole. Failure to do this, ideal scour hole will not occur because the bed materials would not be scoured or all materials would be removed from the plunge pool pit.

Physical model is the most effective method for reproducing a comprehensive scour hole formation and its characteristics in the plunge pool. The study using physical model is time consuming and costly. However, it could remain the most appropriate tool for scour hole prediction unless 3D mathematical model is initiated. Empirical formulas are able to foresee only ultimate scour depth and impaction location, not the full extent of scour formation. However, they are useful for plunge pool pit design in the model for further scour characteristic study.

The characteristics of scour hole formation are the most important information during design stage in order to secure the hydraulic structure and downstream channel. They depend mainly on spillway operation, river morphology and natural topography of the plunge pool. If axis of river and spillway are on the same direction, maximum scour depth is expected to occur on the spillway's centerline projection and the scour hole shape would be elliptic. This is the case of chute spillway with flip bucket. The result of this scour erosion test is considered as an essential finding to provide hydraulic data for further investigation of scour problems and improvement of control structures, bank and downstream channel protection.

The main findings of this research are (1) indication of reliable scour hole reproduction using the easily available material (cement mortar) for representing the movable riverbed material, (2) evidence of model scale effect on scour hole formation and (3) identification of factors governing irregular trend of scour development.

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