EFFECTS OF STEPPED CHUTE IN SIPHON SPILLWAY OUTLET ON THE PERFORMANCE OF SPILLWAY

by

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LIST OF SYMBOLS

(A_x, A_y, A_z)	Fractional flow areas
(G_x, G_y, G_z)	Body acceleration
$AFB_{i,j,k}$	Friction area A_y for flow in y direction at $j+0.5$ cell-face
$AFR_{i,j,k}$	Friction area A_x for flow in x direction at $i+0.5$ cell-face
$AFT_{i,j,k}$	Friction area A_z for flow in y direction at $k+0.5$ cell-face
B	Width of the siphon throat
C_d	Discharge coefficient
C_v	Velocity coefficient
l	Length of the steps
h	Height of the steps
N	Step numbers
D	Height of the siphon throat
D_H	Hydraulic diameter
D_{out}	Height of the siphon outlet
d	Flow depth perpendicular to the edge of last step
R	Radius of curvature
R_1	Radius of curvature at the siphon crest
R_2	Radius of curvature at the siphon crown
R_{CL}	Radius of centreline of the siphon throat
ρ	Fluid density
μ	Dynamic viscosity

Fr_1	Froude number at toe of the step
F_h	Froude number defined of step roughness height
F	VOF function
$F^n_{i,j,k}$	Fluid fraction at center of cell (*i*,*j*,*k*) at time level n
g	Acceleration due to gravity
G_T	Turbulence production caused by buoyancy effects
G_x	Gravitational, rotational, and general non-inertial accelerations in the x-direction (similarly for y- and z- direction)
f	Darcy-Weisbach friction factor
H_{out}	Height of the siphon outlet
H_0	Upstream head above the crest
H_1	Residual head at the toe of stepped chutes
H_{dam}	Height of the siphon crest
H_e	Effective head
H_s	Height of stepped chute
H_t	Total head
H_{at}	Atmospheric pressure
ΔH	Head loss
$\Delta H / H_t$	Rate of energy dissipation
k	Roughness produce by step
L_i	Length of inception point
$\frac{\Delta P}{L}$	Pressure drop per length

p	Pressure into the siphon
p_t	Total pressure in Pitot tube
p_s	Static pressure in Pitot tube
Q	Flow rate
q	Flow rate per unit width
Q_{design}	Design flow rate
Re_1	Reynolds number at toe of the step
$TLEN$	Maximum length scale
T_T	Time scale
τ	Average of shear stress
θ	Slope of the stepped chutes
u', v', w'	Fluctuating (turbulence) part of the velocity
u_*	Shear velocity
u_{inner}	Velocity distributions in the inner region
u_{in}	Velocity of inflow
$\overline{u'v'}$	Cross correlation of turbulent stream wise and wall normal velocity components, i.e. Reynolds shear stress apart from the water density
u	Component of velocity in x direction
V	Magnitude of velocity
v	Component of velocity in y direction
v_0	Velocity at the edge of last step
v_1	Velocity at the toe of stepped chutes
V_F	Fractional volume open to flow

$VF_{i,j,k}$	Fractional volume for flow at center of cell
V_{fa}	Volume of fluid in each cell
W	Width of the steps
W_f	Width of the flume
W_0	Half of the width of flume
w	Component of velocity in z direction
y_c	Critical depth
y_0	Flow depth perpendicular to pseudo bottom at the edge of last step
y_1	Flow depth at the toe of stepped chutes
y_i	Flow depth of inception point
Z	Distance from the outlet bottom to the Pitot tube head
β	Dimensionless pressure gradient
γ	Specific weight of water
ε	Turbulence dissipation
ν_T	Turbulent kinematic viscosity
ϕ	Depth-averaged non-hydrostatic energy coefficient
ψ	Depth-averaged non-hydrostatic momentum coefficient

LIST OF ABBREVIATIONS

CFD	Computational fluid dynamic
VOF	volume of fluid
FAVOR	fractional area/volume obstacle representation
RNG	Re-Normalisation Group

KESAN TANGGA DI SALURAN KELUAR ALUR LIMPAH SIFON KE ATAS PRESTASI ALUR LIMPAH

ABSTRAK

Limpahan sifon adalah sejenis alur limpah saluran tertutup yang dibina di dalam empangan kecil dan rangkaian pengairan untuk menyalurkan limpahan dengan cepat dari takungan. Aliran keluar dari limpahan sifon memasuki kolam-kolam empang di hilirnya supaya tenaga dapat diserakkan. Kolam empang yang bertempat di hilir alur limpah akan menenggelamkan salur keluar sifon lalu memberikan kesan yang negatif terhadap operasi sifon. Kajian ini bertumpu pada kesan penenggelaman ini terhadap operasi sifon dan cara menambahkan serakan tenaga dengan menggantikan kolam empang dengan pelongsor bertangga. Pelongsor bertangga adalah sejenis binaan penyerak tenaga yang bercirikan rintangan aliran dan penyerakan tenaga yang nyata dengan penggunaan tangga. Dalam kajian ini, beberapa susunan pelongsor bertangga yang sederhana cerun digunakan pada salur keluar limpahan sifon. Aliran air diukur bagi setiap susunan dan hasilnya dibentangkan dalam bentuk aturan aliran, ketinggian permukaan air, halaju huluan dan salur keluar, serakan tenaga, dan rintangan aliran. Simulasi berangka, termasuklah pembinaan model ciri-ciri aliran di dalam, di hulu dan di hilir alur limpah, aturan aliran pada pelongsor bertangga, dan ketinggian permukaan air di hilir pelongsor bertangga, dilakukan untuk menentukan kecerunan, lebar pelongsor, dan bilangan tangga yang optimum. Berdasarkan hasil ujian eksperimen dan model berangka ini, pelongsor bertangga yang berkecerunan 14°, mempunyai 4 anak tangga, dan berukuran 0.14 m lebar didapati mencapai kadar penyerakan tenaga yang tertinggi, iaitu sehingga 92%, tanpa kesan yang negatif terhadap operasi limpahan sifon. Berdasarkan ujian pengesahan pada model-model berangka, model golakan k-ε

didapati lebih memuaskan berbanding dengan model RNG apabila mensimulasikan operasi sifon.

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ABSTRACT

A siphon spillway is a type of spillways with a closed conduit that is constructed in small dams and irrigation networks for rapid evacuation of overflow in a reservoir. The outflow from siphon spillways enters to pool sills at downstream for energy dissipation. Using pool sills at downstream of spillways will cause submergence of siphon outlet, and this has a negative effect on siphon operations. The present study focuses on the effect of submergence on the siphon operation and increases energy dissipation by replacement of the pool sill with the stepped chutes. The stepped chute is a type of energy dissipation structure, which is characterized by significant flow resistance and energy dissipation via the steps. In this study, several stepped chute configurations with moderate slopes were applied to the siphon spillway outlet. Water flow measurements were carried out for each configuration and results were presented in terms of flow regimes, water surface elevation, upstream and outlet velocity, energy dissipation, and flow resistance. Numerical simulations, including the modeling of the flow characteristics inside, upstream and downstream of the spillway, the flow regimes on the stepped chutes, and water surface elevation at downstream of stepped chutes were performed to determine the optimum slope, width of stepped chute, and number of steps. Based on the results of experimental tests and numerical models, the stepped chute with a slope of 14°, 4 step numbers, and width of 0.14 m achieves the highest energy dissipation up to 92%, and had no negative effect on the operation of the siphon spillway. Based on the verification tests in numerical models, the k-ε turbulence model is more satisfactory than the RNG model to simulate siphon operation.

CHAPTER 1
INTRODUCTION

1.1 Background

Standard siphon spillway with rectangular cross sections is used when a large flow rate is required in a very small changing in water head without the use of acting gates.

In this study, efforts to prevent the siphon spillway outlet from submergence and increase the energy dissipation at the downstream by using various stepped chute configurations has been model. The investigation was conducted via experimental tests and numerical modelling. The experimental tests and numerical models were evaluated for two outlet conditions, submerged and free outlets. In the submerged outlet condition, the pool sill was considered at the siphon spillway outlet. In the free outlet condition, the siphon spillway was tested with stepped chute and without stepped chute at the outlet. In the numerical modeling, Flow-3D was used to simulate the experimental results.

1.2 Problem statement

The outflow from a siphon spillway generally enters a pool sill in the downstream. The pool sill prevents the re-entry of air into the conduit with submerging of the siphon outlet. In addition, the outflow of a siphon spillway has high energy, which the pool sill must dissipate before the discharge returns to the downstream channel (Aisenbrey et al., 1983).

The discharge in a siphon spillway is governed by the relationship for a closed conduit $Q \propto H_e^{1/2}$, where H_e is the effective head from the upstream to the tail water level. Therefore, tail-water depth has a significant effect on the spillway operation.

Outlet submergence at the pool sill causes a reduction of the actual head and, consequently, discharge of the spillway. In addition, the water level in the upstream of the spillway rises with constant discharge during outlet submergence, which may cause the reservoir to overflow and damage the dam and hydraulic structure downstream (Vischer et al., 1998).

Although Babaeyan-Koopaei et al. (2002) and Musavi-Jahromi (2011) have mentioned the negative effects of a submerged outlet on a siphon spillway as increase of total head in reservoir and reduce of maximum discharge. Moreover, the results indicate that there is a lack of information about the effect of a submerged outlet on the outflow velocity, the flow velocity in the upstream, and the rate of energy dissipation in the downstream of the spillway.

1.3 Research Goal

The main goal of this research is to prevent the siphon spillway outlet from submerging and increase siphon operation by removing the pool sill. Two problems occur with this removal: first, air may re-enter the conduit and prevent priming action; second, outflow with high energy enters the downstream. The first problem is solved by using a deflector inside the conduit. A deflector is one of the various devices used to obtain rapid priming of the siphon spillway (Khatsuria, 2004). This study focuses on the second problem and applies a dissipation structure at the outlet of the siphon spillway.

The stepped chute is a type of energy dissipation structure, which is characterized by significant flow resistance and energy dissipation via the steps. The previous studies only focus on the stepped chute separately. The novelty of this study is using the stepped chute as an energy dissipation structure in the siphon spillway outlet. In addition, the outlet of siphon spillway with stepped chute will be free.

1.4 Research Objective

The present study is the first of its kind in terms of using stepped chute in the siphon spillway outlet to prevent the siphon outlet from submergence, increase flow efficiency and the rate of energy dissipation in downstream of siphon spillway.

To objectives of the present study are as follows:

1) To investigate the effect of using a stepped chute in the siphon outlet during the siphon operation, priming and depriming action;
2) To determine the rate of energy dissipation in the siphon spillway with a stepped chute outlet and compare it with the pool sill outlet;
3) To determine the effect of various stepped chute configurations on the rate of energy dissipation and obtain the optimum configuration (i.e. slope of chute, number of steps, and chute width);
4) To simulate the siphon operation using the Flow-3D solver and evaluate the numerical modelling results by comparing them with experimental data.

1.5 Scope of Research

As previously mentioned, the aim of this study are to improve siphon spillway operation, increase the rate of energy dissipation, and flow efficiency using different stepped chute configurations. Experimental tests and numerical modelling were performed for several stepped chute configurations. The effect of stepped chute slope, number of steps, and stepped chute width were investigated to find the optimum configuration.

In the experimental section, two main outlet cases were tested and compared: the pool sill outlet and a stepped chute outlet. In the stepped chute outlet, the effect