

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

**by**

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# TABLE OF CONTENTS

ACKNOWLEDGEMENTS .....	ii
TABLE OF CONTENTS .....	iii
LIST OF TABLES .....	vii
LIST OF FIGURES .....	ix
LIST OF SYMBOLS.....	xiv
LIST OF ABBREVIATIONS .....	xviii
ABSTRAK .....	xix
ABSTRACT .....	xxi
CHAPTER 1 INTRODUCTION .....	1
1.1 Background.....	1
1.2 Problem statement .....	1
1.3 Research Goal.....	2
1.4 Research Objective .....	3
1.5 Scope of Research .....	3
1.6 Research Organization.....	4
CHAPTER 2 LITERATURE REVIEW .....	6
2.1 Introduction .....	6
2.2 Siphon Spillway.....	7
2.2.1 Hydraulic Design Considerations .....	17
2.2.1.1 Discharging Capacity .....	18
2.2.1.2 Cavitation.....	20
2.2.1.3 Discharge Coefficient .....	20
2.2.1.4 Siphon Operation.....	21
2.2.1.5 Deflector .....	22
2.2.1.6 Pool sill.....	23

2.3	Flow regimes on a stepped chute.....	26
	2.3.1.1 Nappe flow regime .....	28
	2.3.1.2 Energy dissipation for nappe flow.....	29
	2.3.1.3 Transition flow .....	31
	2.3.1.4 Skimming flow .....	31
	2.3.1.5 Air Entrainment .....	32
	2.3.1.6 Flow resistance in skimming flows .....	34
	2.3.1.7 Energy dissipation in skimming flow .....	36
2.5	Summary of literature review .....	43
CHAPTER 3 RESEARCH METHODOLOGY .....		44
3.1	Introduction .....	44
3.2	Dimensional Analysis.....	44
	3.2.1 Buckingham II Theorem.....	45
3.3	Laboratory Experiments .....	51
	3.3.1 Siphon spillway setup .....	57
	3.3.2 Free surface measurement .....	64
	3.3.3 Velocity measurement in the upstream of the siphon spillway .....	66
	3.3.4 Velocity measurement in the downstream of the siphon spillway .....	67
	3.3.5 Pressure measurement .....	69
3.4	Numerical modeling .....	70
	3.4.1 Computational Fluid Dynamic (CFD).....	71
	3.4.2 Flow-3D software .....	73
	3.4.3 Mesh Boundaries .....	76
	3.4.3.1 Volume of Flow Rate (VFR) boundary condition.....	76
	3.4.3.2 Wall shear boundary conditions .....	76
	3.4.3.3 Internal obstacle boundaries .....	77
	3.4.3.4 Specified pressure boundary conditions .....	78
	3.4.3.5 Outflow boundary conditions .....	78
	3.4.4 Governing equations of fluid dynamic .....	83
	3.4.4.1 Continuity equation .....	84
	3.4.4.2 Momentum equation.....	85
	3.4.4.3 Reynolds average Navier-Stokes equation (RANS).....	86
	3.4.5 Turbulence models.....	87

3.4.5.1	Two-equation turbulence models .....	88
3.4.6	Pressure-Velocity Solvers.....	89
3.4.7	Bubble and void region models .....	90
CHAPTER 4 RESULTS AND DISCUSSIONS .....		93
4.1	Experimental Laboratory Test.....	93
4.1.1	Siphon spillway operation .....	93
4.1.2	Discharge coefficient .....	99
4.1.3	Velocity distribution .....	101
4.1.3.1	Velocity distribution at the siphon outlet .....	101
4.1.3.2	Velocity distribution in upstream of siphon spillway....	102
4.1.4	Pressure.....	107
4.1.5	Basic flow pattern on stepped chutes.....	109
4.1.6	Energy Dissipation.....	112
4.1.6.1	Flow resistance in skimming flows .....	117
4.2	Computational Model Results .....	118
4.2.1	Verification tests .....	118
4.2.1.1	Siphon spillway operation .....	119
4.2.1.2	Water surface elevation comparison.....	122
4.2.1.3	Velocities comparison .....	123
4.2.1.4	Pressures comparison .....	129
4.2.1.5	Flow regimes comparison.....	130
4.2.2	Results of numerical models.....	131
4.2.2.1	Flow regimes on stepped chutes.....	132
4.2.2.2	Energy dissipation .....	133
4.2.2.3	Effective parameters on energy dissipation.....	134
4.2.2.4	Optimum slope of stepped chute and step numbers .....	139
4.2.2.5	Effect of width on rate of energy dissipation .....	142
4.2.2.6	Optimum width of stepped chute.....	143
4.3	Summary of results and finding .....	144
4.3.1	Comparison of the siphon spillway outlet conditions.....	144
4.3.2	Siphon spillway with stepped chute outlet .....	145
4.3.3	Numerical model .....	145

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS .....	147
5.1 Introduction .....	147
5.2 Conclusion.....	147
5.3 Recommendation for Future Works .....	149
REFERENCES .....	150
LIST OF PUBLICATIONS.....	155
APPENDIX 1	
APPENDIX 2	

<b>LIST OF TABLES</b>		Page
Table 3.1	The types of stepped chute	54
Table 3.2	The size of the multi-block mesh	75
Table 3.3	Comparison of simulated total head ( $H_t$ ) at upstream and water depth at the toe of stepped chute ( $y_1$ ) with experimental data for different cell sizes	82
Table 3.5	The size and numbers of the cells in the multi-block mesh	83
Table 4.1	Water surface elevation in upstream and outlet of siphon spillway	94
Table 4.2	Equations of the effective head-discharge curves	98
Table 4.3	Discharge coefficient for siphon spillway	99
Table 4.4	Observed flow regimes for stepped chutes	109
Table 4.5	Flow characteristic in downstream of stepped chutes	111
Table 4.6	Comparison of the upper limit of nappe flow for present study with the previous researchers	112
Table 4.7	Equations of energy dissipation with critical depth in stepped chutes with different widths (0.50, 0.32, and 0.14 m)	113
Table 4.8	Comparison of Experimental water surface elevation	122
Table 4.9	Computational configurations of the stepped chutes	132
Table 4.10	Simulated flow regimes on the stepped chutes	133
Table 4.11	Simulated total head $H_t$ for siphon spillway with stepped chutes	134
Table 4.12	Model summary	136
Table 4.13	Analysis of variance (ANOVA) for dependent variable	136
Table 4.14	Coefficients for dependent variable $\Delta H / H_t$ for nappe flow	137

Table 4.15	Model summary	138
Table 4.16	Analysis of variance (ANOVA) for dependent variable	138
Table 4.17	Coefficients for dependent variable $\Delta H / H_t$ for skimming flow	138



<b>LIST OF FIGURES</b>		Page
Figure 2.1	Main type of overflow structure: a) frontal, b) side, c) shaft overflow, and d) Siphon spillway (Vischer et al., 1998)	6
Figure 2.2	Siphon spillway (Morris and Wiggert, 1972)	7
Figure 2.3	Standard overflow spillway (Khatsuria, 2004)	8
Figure 2.4	Flow rate head relation with (1) weir regime, (2) siphon regime (Vischer et al., 1998)	9
Figure 2.5	Comparison of the head-discharge for the siphon spillway and the weir (Houichi et al., 2009)	10
Figure 2.6	Head-discharge relation for the siphon model (Fenocchi and Petaccia, 2014)	11
Figure 2.7	(a) General view of an air-regulated siphon spillway (b) Head - discharge curve (Babaeyan-Koopaei et al., 2002)	13
Figure 2.8	Prettyjohn's experiments with novel arrangement of air regulated siphon (Prettyjohns and Markland, 1989)	14
Figure 2.9	Typical stage curves for (a) conventional and (b) air regulated siphon (Vischer et al., 1998)	15
Figure 2.10	Discharge characteristics of an air regulated siphon. (Ackers et al. 1975)	16
Figure 2.11	Discharge characteristic of the siphon at increasing aeration (Dornack and Horlacher, 1999)	17
Figure 2.12	Siphon spillway of Burgkhammer dam in Germany (Khatsuria, 2004)	19
Figure 2.13	Variation of discharge coefficient with dimensionless head (Tadayon and Ramamurthy, 2012)	21
Figure 2.14	Deflector shapes tested (Hardwick et al. 1997)	23
Figure 2.15	Type air regulated siphon spillway (Vischer et al., 1998)	23
Figure 2.16	Siphon spillway in O'Shaughnessy Dam (Zipparro et al., 1993)	25
Figure 2.17	Flow regimes on stepped spillways (Khatsuria, 2004)	27

Figure 2.18	Cross-section of stepped spillway with nappe flow regime (Salmasi, 2004)	29
Figure 2.19	characteristics of skimming flow on stepped spillway (Chanson, 1994c)	32
Figure 2.20	Skimming flow above a gated stepped spillway (Chanson, 1994c)	33
Figure 2.21	Darcy friction factor of skimming flows on stepped chute ( $\theta > 20^\circ$ ) (Chanson et al., 2002)	36
Figure 2.22	Darcy – Weisbach friction factor for data of Thorwarth and Köngeter (2006, 2008) and Felder and chanson (2009 and 2013)	36
Figure 2.23	Change of relative energy dissipation with relative step height. (a) $\theta = 5.73^\circ$ , (b) $\theta = 19^\circ$ , (c) $\theta = 55^\circ$ (Yasuda, 2004)	38
Figure 2.24	Energy dissipation for the 12-step and 23-step models (Roshan et al., 2010)	40
Figure 3.1	Sketch of siphon spillway with stepped chute outlet	47
Figure 3.2	Primary simulation of the siphon spillway outflow	53
Figure 3.3	The research flow chart	56
Figure 3.4	Electromagnetic flow meter	57
Figure 3.5	The siphon spillway details	58
Figure 3.6	The air vent pipe with the PVC ball valve	60
Figure 3.7	Locations of the piezometer taps	61
Figure 3.8	The siphon spillway with the pool sill	62
Figure 3.9	Three main types of stepped chute with different slopes: (a) $14^\circ$ , (b) $26.6^\circ$ , and (c) $31^\circ$	63
Figure 3.10	Two types of stepped chutes with adjustable widths: (a) S1-2-1 and (b) S3-3-2	63
Figure 3.11	Sketch of siphon spillway without stepped chute outlet	64

Figure 3.12	Image of (a) point gauge mounted on a carrier and (b) scale part of the point gauge with a vernier	65
Figure 3.13	Measuring flow depth at the outlet by point gauge	65
Figure 3.14	ADV downward-pointing head with four recovers	66
Figure 3.15	Locations of the velocity measurements by A.D.V in upstream	67
Figure 3.16	Image of (a) Prandtl Pitot tube and (b) a water manometer	68
Figure 3.17	Locations of the velocity measurements by Pitot tube at the outlet	69
Figure 3.18	Manometer board with glass monometer	70
Figure 3.19	Computational 3D Mesh and Geometry	75
Figure 3.20	Boundary Conditions for simulation of siphon spillway operation	79
Figure 3.21	FAVOR blocked cell with obstacle boundary is (a) parallel to cell sides and (b) inclined toward the cell sides (Flowsience, 2010)	80
Figure 3.22	FAVORized geometries of 14° stepped chutes with nested mesh sizes (a) 10mm, (b) 7.5 mm, and (c) 5 mm	83
Figure 4.1	Total head-discharge for the siphon spillway	96
Figure 4.2	Effective head-discharge curve for siphon spillway	97
Figure 4.3	Developed effective head-discharge curve	97
Figure 4.4	Variation of discharge coefficient with dimensionless heads	100
Figure 4.5	Velocity distribution at a discharge of 5.7 L/s at the siphon outlet for	102
Figure 4.6	Velocity magnitude contours in the upstream of spillway with (a) free outlet and (b) submerged outlet	104
Figure 4.7	Streamlines and velocity magnitude contours at the upstream surface of spillway with (a) free outlet and (b) submerged outlet	105

Figure 4.8	Experimental velocity magnitude for discharge 5.7 L/s in the upstream of siphon spillway with free and submerged outlet	106
Figure 4.9	Comparison of absolute pressure inside the siphon spillway at discharge of: (a) 5 L/s, (b) 5.7 L/s, (c) 6 l/s, and (d) 6.5 L/s	108
Figure 4.10	Flow patterns from top right to bottom left over stepped configurations for discharge 5.7 l/s: (a) skimming flows for S3-3-2 ( $\theta=31^\circ$ , $W=0.14$ m, and $N=5$ ); (b) Nappe flows for S1-1-1 ( $\theta=14^\circ$ and $W=0.50$ m, and $N=3$ ); (c) Nappe flows for S2-2-1 ( $\theta=14^\circ$ and $W=0.32$ m, and $N=3$ ); (d) Skimming flows with a jump to the third step in S3-1-2 ( $\theta=31^\circ$ and $W=0.5$ m, and $N=5$ ); (e) skimming flows for S1-3-1 ( $\theta=14^\circ$ and $W=0.14$ m, and $N=3$ )	110
Figure 4.11	Flow regimes on stepped chutes based on previous researchers	112
Figure 4.12	Variation of relative energy dissipation $\Delta H / H_t$ with $y_c / h$ for stepped chute with different widths: (a) 0.50 m; (b) 0.32 m; (c) 0.14 m	114
Figure 4.13	Variation of relative energy dissipation $\Delta H / H_t$ with $y_c / Nh$ for stepped chute with different widths: (a) 0.50 m; (b) 0.32 m; (c) 0.14 m	115
Figure 4.14	Comparison of relative energy dissipation for siphon spillway with the pool sill, without stepped chute, and configurations S1-1-	116
Figure 4.15	Comparison of Darcy – Weisbach friction factor for present study and data of Thorwarth (2006, 2008) and Felder et al. (2009 and 2013)	117
Figure 4.16	Comparison between the results of k- $\epsilon$ model and RNG turbulence model	120
Figure 4.17	Priming action stages for the S1-1-1 configuration with a 5.7 L/s discharge	121
Figure 4.18	Comparison between the experimental and computational velocity distribution at the siphon outlet for the S3-3-2 and the siphon spillway with the pool sill	123
Figure 4.19	Comparison between (a and b) Computational and (c) Experimental velocity magnitudes for S3-3-2 configuration	125

Figure 4.20	Comparison between (a and b) Computational and (c) Experimental velocity magnitudes for siphon spillway with pool sill	126
Figure 4.21	Comparison between Experimental and Computational (a) x-velocity, (b) y- velocity, and (c) z-velocity Components for configuration S3-3-2	127
Figure 4.22	Comparison between Experimental and Computational (a) x-velocity, (b) y- velocity, and (c) z-velocity Components for configuration siphon spillway with pool sill	128
Figure 4.23	Pressure distributions inside of the siphon with discharge 5.7 L/s for (a) S3-3-2 and (b) siphon with pool sill	129
Figure 4.24	Comparison between Experimental and Computational pressure inside of the siphon spillway with discharge of 5.7 L/s for configurations S3-3-2 and siphon spillway with pool sill	130
Figure 4.25	Comparison of Experimental and Computational flow regimes for the siphon spillway with discharge 5.7 L/s: (a) skimming flows for S3-3-2; (b) nappe flows for S1-1-1; (c) skimming flows for S1-3-1; (d) Skimming flows for S3-1-2 with a jump to third step	131
Figure 4.26	Variation in energy dissipation with dimensionless critical depths for stepped chutes of different widths: (a) 0.5 m; (b) 0.32 m; (c) 0.14 m	141
Figure 4.27	Variations of rate of energy dissipation with discharge for stepped chute configurations with N=4, and (a) $\theta=14^\circ$ ; (b) $\theta=26.6^\circ$ ; (c) $\theta=31^\circ$	142
Figure 4.28	Variations of relative energy dissipation with discharge for stepped chute configurations $\theta=14^\circ$ and N=3 and 4	143

## 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
$\rho$	Fluid density
$\mu$	Dynamic viscosity

$Fr_1$	Froude number at toe of the step
$F_h$	Froude number defined of step roughness height
$F$	VOF function
$F_{i,j,k}^n$	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
$\Delta H$	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
$\tau$	Average of shear stress
$\theta$	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
$\beta$	Dimensionless pressure gradient
$\gamma$	Specific weight of water
$\varepsilon$	Turbulence dissipation
$\nu_T$	Turbulent kinematic viscosity
$\phi$	Depth-averaged non-hydrostatic energy coefficient
$\psi$	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 limbah 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 limbah 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 hulu dan salur keluar, serakan tenaga, dan rintangan aliran. Simulasi berangka, termasuklah pembinaan model ciri-ciri aliran di dalam, di hulu dan di hilir alur limbah, 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  $14^\circ$ , 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.

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

## **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  $14^\circ$ , 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  $k-\varepsilon$  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