View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Repository@USM

PHYSICAL HYDRAULICS MODEL AND COMPUTATIONAL FLUID DYNAMICS OF SG. BELIBIS PUMP SUMP

MUHAMMAD KHAIRI BIN A. WAHAB

UNIVERSITI SAINS MALAYSIA

2017

PHYSICAL HYDRAULICS MODEL AND COMPUTATIONAL FLUID DYNAMICS OF SG. BELIBIS PUMP SUMP

by

MUHAMMAD KHAIRI BIN A. WAHAB

Thesis submitted in fulfillment of the

requirements for the degree of

Master of Science

February 2017

ACKNOWLEDGEMENTS

In The Name of ALLAH swt, The Most Beneficent, The Most Merciful...

May ALLAH swt Guide Us All To Truth and Keep Us On The Straight Path…

I wish to express my sincere appreciation and gratitude to my supervisor, Dr. Mohd Remy Rozainy bin Mohd Arif Zainol for his guidance since my final year project in undergraduate until now, master degree. I would also like to thank to my co-supervisor, Professor Dr. Ismail bin Abustan. I would like to gratitude NAHRIM especially to Hydraulic and Laboratory Instrumentation for giving me the opportunity to do my research there. Also, I would like to thanks the staff of Hydraulic Laboratory, Mrs. Nurul and other staff of the School of Civil Engineering for their co-operation during my research. In addition, not to forget my other co-laboratory-mates and friends, Zulhillmi, Firdaus, Rais, Azraie, Dr.Haitham and Dr. Neeraj in for the stimulating discussions, for helping me during my research and for all the fun we have had. Finally I must express my very profound gratitude to my dearest parents, Mr. A.Wahab bin Yaakob and Mrs. Sarida binti Ismail and my dear siblings for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. May *ALLAH swt* blessed and grant/guide us to *Jannatul Firdous !*

TABLE OF CONTENTS

		Page
ACKNOWLEDGEMENTS		ii
TABLE OF CONTENTS		iii
LIST OF TABLES		ix
LIST OF FIGURES		x
LIST OF SYMBOLS		xx
LIST OF ABBREVIATIONS		xxii
ABSTRAK		xxiv
ABSTRACT		xxvi
CHAPTER ONE: INTRODUCTION		
1.1	Background of the study	1
1.2	Problem statement	2
1.3	Objectives of the Study	4
1.4	Scope of the Research	5
1.5	Advantages of the Research	6
1.6	Thesis structure	7
CHAPTER TWO: LITERATURE REVIEW		
2.1	Introduction	8
2.2	Pump intake structure	8
2.3	Froude number	13
2.4	Reynold’s number	14
2.5	Model similitude	15

2.6 Problems encountered in pump intake 16
2.6.1 Free surface vortices 17
2.6.2 Subsurface vortex 19
2.6.3 Cavitation 21
2.7 Modified design of sump intake 22
2.7.1 Floating raft and submerged raft 23
2.7.2 Fillets and splitters 24
2.7.3 Curtain wall 26
2.7.4 Inlet piers. 26
2.7.5 Flow deflector beam 27
2.7.6 Conical vortex breaker 27
2.7.7 Formed suction inlet (FSI) 28
2.7.8 Three symmetrically thin vertical cylinders 29
2.8 Computational fluid dynamics (CFD) 30
2.8.1 Application of CFD in model of pump sump 31
2.9 Validation numerical analysis and experimental measurement 33
2.10 Gap of knowledge 34

CHAPTER THREE: EXPERIMENTAL SETUP

3.1 Introduction 36
3.2 Physical model test 38
3.2.1 Model Description 38
3.3 Pump sump design 39
3.4 Dimensionless Parameters 43
3.4.1 Reynolds number 43

3.4.2 Froude number 44

3.5 Modification proposed to eliminate undesired flow in pump sump 45

3.5.1 Buffer block wall 46

3.5.2 Positioning of buffer wall, fillet wall and floor splitter 48

3.6 Data collection 50

3.6.1 Flow rate measurement 50

3.6.2 Velocity measurement 51

3.6.3 Swirl meter rotation 55

3.6.4 Dye tracer 56

3.7 Summary 57

CHAPTER FOUR: COMPUTATIONAL FLUID DYNAMICS

4.1 Introduction 58

4.2 Description of the CFD model 58

4.3 Process of simulation 58

4.4 Pre-Processing 60

4.4.1 Geometry of computational model. 61

4.4.2 Geometry and grid generation 61

4.5 Numerical simulation 63

4.5.1 The FLUENT™ model 63

4.5.2 Governing equations 63

4.5.3 Solution control 65

4.6 Post-Processing 68

4.7 Planes for CFD analysis 68

4.8 Summary 69

CHAPTER FIVE: RESULTS AND DISCUSSION

5.1 Introduction 70

5.2 Physical experiment results and discussions 70

5.2.1 Velocity distribution 70

5.2.1.1 Velocity contour at water level of 0.3 m with 25 L/s (Case 3) 71

5.2.1.2 Velocity contour at water level of 0.2 m with 25 L/s (Case 6) 73

5.2.1.3 Velocity contour at water level of 0.18 m with 25 L/s (Case 9). 75

5.2.1.4 Velocity contour at water Level of 0.18 m with 25 L/s (Buffer Block Wall) (Case 10) 77

5.2.1.5 Velocity contour at water level of 0.18 m with 25 L/s (Wall fillet and floor splitter) (Case 11) 78

5.2.1.6 Velocity Contour at Water Level of 0.18 m with 25 L/s (Combination of buffer block wall and wall fillet and floor splitter) (Case 11) 80

5.2.2 Swirl Meter Measurements 81

5.2.3 Visual Observations 83

5.3 Numerical simulation results and discussions 92

5.3.1 Grid sensitivity analysis 92

5.3.2 Velocity vector (Flow visualization) 96

5.3.2.1 Velocity vector (Flow visualization) at water level of 0.3 m with 25 L/s (Case 3) 96

5.3.2.2 Velocity vector (Flow visualization) at water level of 0.2 m with 25 L/s (Case 6) 102
5.3.2.3 Velocity vector (Flow visualization) at water Level of 0.18 m with 25 L/s (Case 9) 108
5.3.2.4 Velocity vector (Flow visualization) at water Level of 0.18 m with 25 L/s (Buffer block wall) (Case 10) 114
5.3.2.5 Velocity vector (Flow visualization) at Water Level of 0.18 m with 25 L/s (Wall fillet and floor splitter) (Case 11) 119
5.3.2.6 Velocity vector (Flow visualization) at water level of 0.18 m with 25 L/s (Combination of buffer block wall and wall fillet and floor splitter) (Case 12) 124
5.3.3 Velocity and pressure contour result 129
5.3.3.1 Velocity contour result 130
5.3.3.2 Pressure contour result 137
5.4 Comparison between Experimental and Simulation Results in Velocity Profile 144
5.5 Comparison of visualization between experimental and simulation 147
5.6 Simulation at high flow rate 150
5.6.1 Water level of 0.18m with flow rate of 40L/s (Buffer block wall). 150

CHAPTER SIX: Conclusions

6.1 Conclusions 156

6.2 Experimental 156

6.3 Computational fluid dynamic (CFD) modelling 157

6.4 Recommendations for the future works 158

REFERENCES 160

APPENDICES

APPENDIX A (Display Input of FLUENT™)

APPENDIX B (Results CFD for Water Level of 0.18m with Flow Rate of 40 L/s (Buffer Block Wall))

LIST OF PUBLICATIONS

LIST OF AWARDS

LIST OF TABLES

		Page
Table 2.1	Recommended dimensions for Figures 2.1 and 2.2 (American National Standard for Pump Intake Design, ANSI/HI 9.8-1998)	11
Table 2.2	Recommended Dimensions of Pump Sump	12
Table 2.3	Accuracy based on relative error	33
Table 2.4	Comparison the advantages of each modification	35
Table 3.1	The operational of pump	37
Table 3.2	The Reynolds number at different water levels	38
Table 3.3	The Reynolds number at different water levels and flow rates	39
Table 3.4	The parameter values for modification test	49
Table 4.1	Cases of study, turbulence kinetic energy, k and turbulence dissipation rate, ε	65
Table 4.2	Properties of water	65
Table 5.1	Result of swirl angle	82
Table 5.2	Visual observation in the pump sump	84
Table 5.3	Meshing details for 3, 5 and 7 cases with three different flow rates	94
Table 5.4	Comparison of visualization between experimental and simulation	149

LIST OF FIGURES

		Page
Figure 2.1	Recommended intake structure layout (American National Standard for Pump Intake Design,ANSI/HI 9.8-1998))	10
Figure 2.2	Filler wall details for proper bay width (American National Standard for Pump Intake Design,ANSI/HI 9.8-1998)	10
Figure 2.3	Free surface vortex form at pump suction bell entrance (Hirata et al., 2011)	18
Figure 2.4	The formation of free surface vortices (Source : Ibrahim, 2011)	19
Figure 2.5	Classification of vortices (Source : Shabayek, 2010)	20
Figure 2.6	Shows the classification of boundary-attached subsurface vortex (Source : Rishel, 2002)	21
Figure 2.7	Cavitation damage on the impeller blades at the discharge (Binama et al., 2016)	22
Figure 2.8	(a) floating (b) submerged raft (Novák, 2004)	24
Figure 2.9	Modified Pump Cell Design : (a) Plan; (b) Profile (Source : BHRA, 1997)	25
Figure 2.10	Methods to reduce subsurface vortices : (a) wall splitter plate (b) floor splitter plate (c) floor cane (Source : The New Hydraulic Institute Pump Intake Design Standard, 1999)	25
Figure 2.11	A curtain wall in the pump sump	26

Figure 2.12	A flow straightening piers at the entrance to the pump bay. (Source : The New Hydraulic Institute Pump Intake Design Standard,1999)	27
Figure 2.13	A conical vortex breaker under suction intake (Source : Ahmad et al, 2011)	28
Figure 2.14	FSI model (Source : Zheng and Werth, 2008)	29
Figure 2.15	Three symmetrically thin vertical cylinders placed under suction intake (Source : Ciocanea, 2013)	30
Figure 2.16	Two-dimensional velocity contour in pump sump (source : Kim, 2014)	32
Figure 2.17	Three-dimensional flow pattern in pump intake (source : Khan, 2012)	33
Figure 3.1	Flow Chart of the overall study	37
Figure 3.2	Location plan of NAHRIM (source: NAHRIM)	38
Figure 3.3	Self-contained circulation system of pump sump	39
Figure 3.4	(a) Plan view (b) Side view A-A (c) Front view B-B (d) Three dimensional view of model	42
Figure 3.5	(a) Suction of intake in Bay 1 and 2 (b) Suction of intake in Bay 3 and 4 (in cm)	42
Figure 3.6	(a) Details of buffer block wall (b) Perspex of buffer block wall	47
Figure 3.7	(a) Plan view the location of buffer block wall (b) Side view the location buffer block wall	48
Figure 3.8	The dimension of the modified model (a) front view (b) side view (c) plan view	49

Figure 3.9	Flow rate measurement equipment for pump sump model	51
Figure 3.10	ADV measurement probe	52
Figure 3.11	The example of readings taken by Vectrino Software	53
Figure 3.12	Probe retrieve the data in model	53
Figure 3.13	Nixon Streamflo measurement probe	54
Figure 3.14	(a) (b) The location of the measurement points	55
Figure 3.15	Swirl meters installed in physical models	56
Figure 3.16	Illustrates Dye tracer technique in physical model	57
Figure 4.1	Boundary condition for the model	59
Figure 4.2	CFD Modelling Overview	60
Figure 4.3	The computer model generated by using pre-processor	62
Figure 4.4	Grid location in the sump (Upper- plan view plane, lower – vertical plane)	69
Figure 5.1	Contour of velocity distribution for Bay 2 at water level of 0.3 m with 25 L/s (Case 3) (a) level 1 (b) level 2 (c) level 3	72
Figure 5.2	Contour of velocity distribution for Bay 3 at water level of 0.3 m with 25 L/s (Case 3) (a) level 1 (b) level 2 (c) level 3	73
Figure 5.3	Contour of velocity distribution for Bay 2 at water level of 0.2 m with 25 L/s (Case 6) (a) level 1 (b) level 2 (c) level 3	74
Figure 5.4	Contour of velocity distribution for Bay 3 at water level of 0.2 m with 25 L/s (Case 6) (a) level 1 (b) level 2 (c) level 3	75
Figure 5.5	Contour of velocity distribution for Bay 2 at water level of 0.18 m with 25 L/s (Case 9) (a) level 1 (b) level 2 (c) level 3	76

Figure 5.6	Contour of velocity distribution for Bay 3 at water level of 0.18 m with 25 L/s (Case 9) (a) level 1 (b) level 2 (c) level 3	77
Figure 5.7	Contour of velocity distribution for Bay 4 at water level of 0.18 m with 25 L/s (Buffer Block Wall) (Case 10) (a) level 1 (b) level 2 (c) level 3	78
Figure 5.8	Contour of velocity distribution for Bay 4 at water level of 0.18 m with 25 L/s (Wall Fillet and Floor Splitter) (Case 11) (a) level 1 (b) level 2 (c) level 3	79
Figure 5.9	Contour of velocity distribution for Bay 4 at water level of 0.18 m with 25 L/s (Combination of Buffer Block Wall and Wall Fillet and Floor Splitter) (Case 12) (a) level 1 (b) level 2 (c) level 3	81
Figure 5.10	Formation of surface vortex Type 5 at the back wall (Case 6	85
Figure 5.11	Formation of surface vortex Type 5 at the back wall (Case 8)	86
Figure 5.12	(a) Formation of surface vortex Type 5 at the back wall (b) Formation of subsurface vortex Type 2 under the suction intake (Case 9)	87
Figure 5.13	Flow distribution from the entrance bay to suction intake (Case 9)	87
Figure 5.14	Formation of surface vortex Type 2 at the back wall (Case 10)	89

Figure 5.15	Flow distribution from the entrance bay to suction intake (Case 10)	90
Figure 5.16	Formation of surface vortex Type 2 at the back wall (Case 11)	90
Figure 5.17	Formation of surface vortex Type 1 at the back wall (Case 12)	91
Figure 5.18	Flow distribution from the entrance bay to suction intake (Case 12)	91
Figure 5.19	Enlarged views of grid : (a) Coarser grid (b) Medium grid (c) Finer grid	93
Figure 5.20	0.18 WL with 15 L/s flow rate	95
Figure 5.21	0.2 WL with 20 L/s flow rate	95
Figure 5.22	0.3 WL with 25 L/s flow rate	96
Figure 5.23	No vortex at the upper level of the sump intake at water level of the 0.3 m for Bay 2 and 3	98
Figure 5.24	(a) No vortex at the middle level of the water (0.15m) of Bay 2 and Bay 3 (b) vertical plane at the elevation of 0.15 m	99
Figure 5.25	(a) Surface at the elevation of 0.05 m at water level 0.3 m of Bay 2 and Bay 3 (b) vertical plane at the elevation of 0.05 m (under suction intake)	99
Figure 5.26	Surface at the elevation of 0 m at water level 0.3 m of Bay 2 and of Bay 3	100
Figure 5.27	No vortex at the back wall at water level of 0.3 m (back view)	101

Figure 5.28	Velocity vector magnitude at the wall of sump intake at water level of 0.3 m (side view)	101
Figure 5.29	Case 3(a) surface dimple (b) no subsurface vortex	102
Figure 5.30	Subsurface vortex at the upper level of the sump intake at water level of the 0.3 m for Bay 2 and 3	103
Figure 5.31	(a) Surface vortex at the middle level of the water (0.10 m) of Bay 2 and Bay 3 (b) vertical plane at the elevation of 0.10 m	104
Figure 5.32	(a) Surface at the elevation of 0.05 m at water level 0.2 m of Bay 2 and Bay 3 (b) vertical plane at the elevation of 0.05 m (under suction intake))	105
Figure 5.33	Surface at the elevation of 0 m at water level 0.2 m of Bay 2 and of Bay 3	106
Figure 5.34	Subsurface vortex at the back wall at water level of 0.2 m (back view)	107
Figure 5.35	Velocity vector magnitude at the wall of sump intake at water level of 0.2 m (side view)	107
Figure 5.36	Case 6 (a) no surface vortex (b) no subsurface vortex	108
Figure 5.37	Subsurface vortex at the upper level of the sump intake at water level of the 0.18 m for Bay 2 and 3	109
Figure 5.38	(a) Surface vortex at the middle level of the water (0.09 m) of Bay 2 and Bay 3 (b) vertical plane at the elevation of 0.09 m	110

Figure 5.39	(a) Surface at the elevation of 0.05 m at water level 0.18 m of Bay 2 and Bay 3 (b) vertical plane at the elevation of 0.05 m (under suction intake)	111
Figure 5.40	Surface at the elevation of 0 m at water level 0.18 m of Bay 2 and of Bay 3	112
Figure 5.41	Subsurface vortex at the back wall at water level of 0.18 m (back view)	113
Figure 5.42	Velocity vector magnitude at the wall of sump intake at water level of 0.2 m (side view)	113
Figure 5.43	Case 9 (a) surface vortex Type 4 and 5 (b) no subsurface vortex	114
Figure 5.44	Subsurface vortex at the upper level of the sump intake at water level of the 0.18 m for Bay 4	115
Figure 5.45	(a) Surface vortex at the middle level of the water (0.09 m) of Bay 2 and Bay 3 (b) vertical plane at the elevation of 0.09 m	116
Figure 5.46	(a) Surface at the elevation of 0.05 m at water level 0.18 m of Bay 2 and Bay 3 (b) vertical plane at the elevation of 0.05 m (under suction intake)	117
Figure 5.47	Surface at the elevation of 0 m at water level 0.18 m of Bay 4	117
Figure 5.48	Subsurface vortex at the back wall at water level of 0.18 m (back view)	119
Figure 5.49	Velocity vector magnitude at the wall of sump intake at water level of 0.18 m (side view)	119

Figure 5.50	Case 10 (a) surface vortex Type 2 (b) no subsurface vortex	119
Figure 5.51	Subsurface vortex at the upper level of the sump intake at water level of the 0.18 m for Bay 2 and 3	121
Figure 5.52	(a) Surface vortex at the middle level of the water (0.09 m) of Bay 2 and Bay 3 (b) vertical plane at the elevation of 0.09 m	121
Figure 5.53	(a) Surface at the elevation of 0.05 m at water level 0.18 m of Bay 2 and Bay 3 (b) vertical plane at the elevation of 0.05 m (under suction intake)	122
Figure 5.54	Surface at the elevation of 0 m at water level 0.18 m of Bay 2 and of Bay 3	122
Figure 5.55	Subsurface vortex at the back wall at water level of 0.18 m (back view)	123
Figure 5.56	Velocity vector magnitude at the wall of sump intake at water level of 0.18 m (side view)	124
Figure 5.57	Case 11 (a) surface vortex Type 2 (b) no subsurface vortex	124
Figure 5.58	Subsurface vortex at the upper level of the sump intake at water level of the 0.18 m for Bay 4	126
Figure 5.59	(a) Surface vortex at the middle level of the water (0.09 m) of Bay 4 (b) vertical plane at the elevation of 0.09 m	126
Figure 5.60	(a) Surface at the elevation of 0.05 m at water level 0.18 m of Bay 4 (b) vertical plane at the elevation of 0.05 m (under suction intake)	127
Figure 5.61	Surface at the elevation of 0 m at water level 0.18 m of Bay 2 and of Bay 3	127

Figure 5.62	Subsurface vortex at the back wall at water level of 0.18 m (back view)	128
Figure 5.63	Velocity vector magnitude at the wall of sump intake at water level of 0.18 m (side view)	129
Figure 5.64	Case 12 (a) surface vortex Type 2 (b) no subsurface vortex	129
Figure 5.65	Plane location in the sump (plan view plane)	130
Figure 5.66	Case 3 (a) Plane A for velocity vector (b) Plane B for velocity vector	132
Figure 5.67	Case 6 (a) Plane A for velocity vector (b) Plane B for velocity vector	133
Figure 5.68	Case 9 (a) Plane A for velocity vector (b) Plane B for velocity vector	134
Figure 5.69	Case 10 (a) Plane A for velocity vector (b) Plane B for velocity vector	135
Figure 5.70	Case 11 (a) Plane A for velocity vector (b) Plane B for velocity vector	136
Figure 5.71	Case 12 (a) Plane A for velocity vector (b) Plane B for velocity vector	137
Figure 5.72	Case 3 (a) Plane A for velocity vector (b) Plane B for velocity vector	139
Figure 5.73	Case 6 (a) Plane A for velocity vector (b) Plane B for velocity vector	140
Figure 5.74	Case 9 (a) Plane A for velocity vector (b) Plane B for velocity vector	141

Figure 5.75	Case 10 (a) Plane A for velocity vector (b) Plane B for velocity vector	142
Figure 5.76	Case 11 (a) Plane A for velocity vector (b) Plane B for velocity vector	143
Figure 5.77	Case 12 (a) Plane A for velocity vector (b) Plane B for velocity vector	144
Figure 5.78	Water level of 0.3m with flow rate of 25L/s (Case 3)	146
Figure 5.79	Water level of 0.2m with flow rate of 25L/s (Case 6)	146
Figure 5.80	Water level of 0.18m with flow rate of 25L/s (Case 9	147
Figure 5.81	Subsurface vortex at the upper level of the sump intake at water level of the 0.18 m for Bay 4	151
Figure 5.82	(a) Surface vortex at the middle level of the water (0.09 m) of Bay 2 and Bay 3 (b) vertical plane at the elevation of 0.09 m	152
Figure 5.83	(a) Surface at the elevation of 0.05 m at water level 0.18 m of Bay 4 (b) vertical plane at the elevation of 0.05 m (under suction intake)	152
Figure 5.84	Surface at the elevation of 0 m at water level 0.18 m of Bay 4	153
Figure 5.85	Subsurface vortex at the back wall at water level of 0.18 m (back view)	154
Figure 5.86	Velocity vector magnitude at the wall of sump intake at water level of 0.18 m (side view)	154
Figure 5.87	Case 10 with 40 L/s (a) surface vortex Type 2 (b) no subsurface vortex	155

LIST OF SYMBOLS

μ	Dynamic viscosity
$\cdot$	Inner product, a.b = a1b1 + a2b2 + a3b3
$c\mu$	k-ε model parameter (0.09)
D	Suction intake diameter
D_A	Suction intake diameter (bell mouth) for Bay 1 & 2
D_B	Suction intake diameter (bell mouth) for Bay 3 & 4
D_p	Internal diameter of the pump suction pipe (m)
F_r	Froude number
F_m	Froude model
F_p	Froude prototype
F_r	Froude ratio
g	Gravity
k	Turbulence kinetic energy
L	Length characteristic depending on water level
∇	Nabla operator
N_{rpm}	Number of rotations per minute
p	Pressure
Q	Flow rate
Q_r	Reynold's number
S	Submergence depth
t	Time
τ	Shear stress
TI	Turbulence

t_r	Time scales
U	Inlet velocity
u	Velocity
u'	Root-mean-square of the turbulence velocity fluctuations
U_r	Velocity scales
V	Velocity
ε	Turbulence dissipation
θ	Swirl angle
ν	Kinematic viscosity
ρ	Density

LIST OF ABBREVIATIONS

3D	Three Dimensional
ACIS	Andy, Charles & Ian's System
ADV	Acoustic Doppler Velocimeter
ANSI	American National Standard
ANSI/HI	American National Standard/Hydraulic Institude
BHRA	British Hydromechanics Research Association
CAD	Computer Aided Design
CFD	Computational Fluid Dynamic
FSI	Formed Suction Inlet
GUI	Graphical User Interface
h2O	Water-liquid
HI	The Hydraulic Institute
HWL	High Water Level
IGES	Initial Graphics Exchange Specification
JPS	Jabatan Pengairan dan Saliran
LCD	Liquid Crystal Display
MSMA	Urban Storm Water Management
NAHRIM	National Hydraulic Research Institute of Malaysia
NPSH	Net Positive Suction Head
PDE	Partial Differential Equations
PVC	Poly Vinyl Chloride
RANS	Reynols-average Navier Stokes
RKE	Realizable k-ε

RNG	Renormalization Group
SIMPLE	Semi Implicit Method for Pressure Linked Equations
SKE	Standard k-ε
SKW	Standard k-ω
SSTKW	Shear Stress Transport k-ω
TSS	Total Suspended Solids