

*Ain Shams University
Faculty of Engineering*

HYDRAULIC JUMP CONTROLLED BY JETS

By

NAHLA M. ABDELHAMID ABOUL ATTA

(M.Sc. Civil Eng. - Ain Shams University)

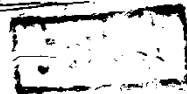
A Thesis Submitted in Fulfillment
of The Requirements of The
Ph.D.DEGREE
IN CIVIL ENGINEERING

(VOLUME I)



33643

33723



627.52
N. M

Supervised by

Prof. Dr. **MOHAMED WAFIE ABDELSALAM**

Professor of Irrigation Designs
Faculty of Engineering - Ain Shams University

Dr. **ABDELKAWI MOKHTAR KHALIFA**

Assoc. Professor, Irrigation and Hydraulics Dept.
Faculty of Engineering - Ain Shams University

Dr. **MAHMOUD ABDELLATEEF MOHAMED**

Assoc. Professor, Irrigation and Hydraulics Dept.
Faculty of Engineering - Ain Shams University

CAIRO - EGYPT

1990

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

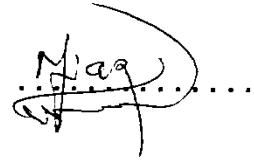


To
MY PARENTS
MY HUSBAND
MY SONS

BOARD OF EXAMINERS

Signature

1. Prof. Dr. Mohamed El-Niazi Hammad
Professor of Irrigation Designs,
Vice Dean, Faculty of Engineering,
Ain Shams University

Handwritten signature of Prof. Dr. Mohamed El-Niazi Hammad, consisting of stylized initials and a surname, followed by a dotted line.

2. Prof. Dr. Royal H. Brooks
Professor of Civil Engineering,
Colorado State University

Handwritten signature of Prof. Dr. Royal H. Brooks, written in a cursive script, followed by a dotted line.

3. Prof. Dr. Mohamed Wafaie Abdelsalam
Professor of Irrigation Designs,
Faculty of Engineering,
Ain Shams University

Handwritten signature of Prof. Dr. Mohamed Wafaie Abdelsalam, written in a cursive script, followed by a dotted line.

STATEMENT

This dissertation is submitted to Ain Shams University for the degree of Ph.D. in Civil Engineering.

The work included in this thesis was carried out by the author in the Hydraulic and Irrigation Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt, and in the Civil Engineering Department, The Pennsylvania State University, U.S.A., from June 1987 to September 1990.

No part of this thesis has been submitted for a degree or a qualification at any other University or Institution.

Date : 7/10/1990

Signature : *Nahla M. Aboul Atta*

Name : Nahla M. Aboul Atta

ACKNOWLEDGEMENT

I wish to express my deepest gratitude to all my supervisors for their supportive guidance during my staying at The Pennsylvania State University in the U.S.A. and after my return to Ain Shams University in Cairo, Egypt.

I am deeply indebted to Professor Dr. Mohamed Wafaie Abdel Salam, Professor of Irrigation Design, Faculty of Engineering, Ain Shams University, Cairo, Egypt, for his guidance, useful suggestions and valuable comments for this study.

I wish to express my thanks to Dr. Abdel Kawi Khalifa, Associate Professor of Irrigation Design, Faculty of Engineering, Ain Shams University, Cairo, Egypt, for his constructive advices, valuable discussions and useful revision of this work.

I also wish to express my gratitude to Dr. Mahmoud Abdel Lateef, Associate Professor of Irrigation Design, Faculty of Engineering, Ain Shams University, Cairo, Egypt, for his generous assistance, fruitful encouragement and constant guidance throughout this whole work.

Many thanks are also due to Professor Dr. Joseph Reed, Professor of Civil Engineering at The Pennsylvania State University, in the U.S.A., for his supervision and valuable discussions and revision of this work during my staying at The Pennsylvania State University.

Thanks are also due to the staff of the Hydraulic Laboratory, The Pennsylvania State University, for their contribution in the achievement of this work.

ABSTRACT

This study investigates the characteristics of the free and submerged jump controlled by floor jets.

In the theoretical study continuity and momentum principles are used to develop expressions relating the main characteristics of the flow and the hydraulic jump over floor jets. The energy equation was used to obtain the jump energy loss.

Experiments are conducted in a rectangular flume with a perforated bed. Each type of the hydraulic jump is investigated experimentally under different flow conditions and different jets arrangements and positions.

Statistical analysis is used to analyze the experimental data and regenerate the necessary characteristics design equations for the perfect, repelled and submerged jump controlled by jets. From these equations the relative jets position, the angle of inclination of the jets, and the relative jet diameter which is optimum from both the hydraulic and the economic points of view were obtained.

Finally the experimental data is used for the verification of the theoretical equations, also an evaluation of the study is presented and practical applications are discussed.

TABLE OF CONTENTS

	PAGE
CHAPTER (1) —	
INTRODUCTION	1
CHAPTER (2)	
LITERATURE REVIEW	5
2.1. Hydraulic Jump on Smooth Horizontal Floors .	5
2.1.1.Length of Jump	5
2.1.2.Water Surface Profile and Sequent Depths	8
2.1.3.Energy loss	14
2.2. Hydraulic Jump on Roughened Beds	17
2.2.1.Control of Jump by Sills, Baffles and Weirs	17
2.2.2.Control of Jump by Roughness	25
2.2.3.Control of Jump by Jets	29
2.3. Uniqueness of Present Study	32
CHAPTER (3)	
THEORETICAL APPROACH	33
3.1. The Free Hydraulic Jump	34
3.1.1.The Relative Depth	35
3.1.2.The Relative Energy Loss	44
3.2. The Submerged Jump	48
3.2.1.The Inlet Depth Ratio	49
3.2.2.The Relative Energy Loss	57
CHAPTER (4)	
EXPERIMENTAL STUDY	61
4.1. Experimental Equipment	61
4.1.1.The Flume	61
4.1.2.The Sluice Gate	65
4.1.3.The Tail Gate	65
4.1.4.The Measuring Carriage	65

4.2. Methods of Measuring and Instruments	67
4.2.1. Discharge Measuring	67
4.2.2. Measurement of Depths and Water Surface Profile	67
4.3. The Perforated Bed	69
4.4. Test Procedure	70
4.4.1. Free Hydraulic Jump on Smooth Bed	70
4.4.2. Free Hydraulic Jump on Perforated Bed	72
4.4.2.1. Perfect Jump	72
4.4.2.2. Repelled Jump	76
4.4.3. Submerged Hydraulic Jump on Perforated Bed	78
4.5. Experimental Data	82

CHAPTER (5)

ANALYSIS AND DISCUSSION OF THE EXPERIMENTAL DATA	85
5.1. Free Jump	85
5.1.1. Free Jump on Smooth Bed	85
5.1.2. Perfect Jump	86
5.1.2.1. Water Surface Profile	86
5.1.2.2. The Relative Jump Length	99
5.1.2.3. The Relative Depth	111
5.1.2.4. The Relative Energy Loss	123
5.1.2.5. The Relative Discharge	135
5.1.2.6. Optimum Stilling Basin	146
5.1.3. Repelled Jump	148
5.1.3.1. Water Surface Profile	148
5.1.3.2. The Relative Jump Length	161
5.1.3.3. The Relative Depth	173
5.1.3.4. The Relative Energy Loss	185
5.1.3.5. The Relative Discharge	197
5.1.3.6. Optimum Stilling Basin	208
5.2. Submerged Jump	210
5.2.1. Water Surface Profile	210
5.2.2. The Relative Jump Length	233
5.2.3. The Inlet Factor	250

5.2.4.The Relative Energy Loss	270
5.2.5.The Relative Discharge	288
5.2.6.Optimum Stilling Basin	305
 CHAPTER (6)	
VERIFICATION, EVALUATION AND APPLICATION OF THE STUDY	307
6.1. Verification of the Study	307
6.1.1.Perfect Jump	307
6.1.2.Repelled Jump	309
6.1.3.Submerged Jump	310
6.2. Evaluation of the Study	311
6.3. Application of the Study	313
6.3.1.Design Procedure	313
6.3.2.Illustrative Example	314
 CHAPTER (7)	
CONCLUSIONS AND RECOMMENDATIONS	316
6.1. Conclusions	316
6.2. Recommendations	320
 REFERENCES	321
APPENDIX I (AI) Figures.....	330
APPENDIX II Tables	420
APPENDIX III Computer Programs	565

LIST OF FIGURES

Figure No.		Page
(3.1)	Free Jump Definition Sketch	36
(3.2)	Evaluation of Q_3 for Free Jump	39
(3.3)	Definition Sketch for Submerged Jump	50
(3.4)	Evaluation of Q_4 for Submerged Jump	54
(4.1)	The Testing Flume	63
(4.2)	A Longitudinal Section in the Testing Flume	64
(4.3)	Details	66
(4.4)	Calibration Chart	68
(4.5)	The Distribution of Floor Jets	71
(4.6)	Relation Between H and Q	75
(5.1) to (5.12)	Water Surface Profiles for Perfect Jump	86 - 98
(5.13) to (5.15)	Relation Between L_b/Y_1 and L_j/Y_2 for Perfect Jump	101 - 103
(5.16) to (5.18)	Relation Between θ and L_j/Y_2 for Perfect Jump	104 - 106
(5.19) to (5.21)	Relation Between D/Y_2 and L_j/Y_2 for Perfect Jump	108 - 110
(5.22) to (5.24)	Relation Between L_b/Y_1 and Y_2/Y_1 for Perfect Jump	113 - 115
(5.25) to (5.27)	Relation Between θ and Y_2/Y_1 for Perfect Jump	116 - 118
(5.28) to (5.30)	Relation Between D/Y_2 and Y_2/Y_1 for Perfect Jump	120 - 122

Figure No.		Page
(5.31) to (5.33)	Relation Between L_b/Y_1 and E_L/E_1 for Perfect Jump	125 - 127
(5.34) to (5.36)	Relation Between θ and E_L/E_1 for Perfect Jump	128 - 130
(5.37) to (5.39)	Relation Between D/Y_2 and E_L/E_1 for Perfect Jump	132 - 134
(5.40) to (5.42)	Relation Between L_b/Y_1 and $Q_J/Q_T\%$ for Perfect Jump	136 - 138
(5.43) to (5.45)	Relation Between θ and $Q_J/Q_T\%$ for Perfect Jump	140 - 142
(5.46) to (5.48)	Relation Between D/Y_2 and $Q_J/Q_T\%$ for Perfect Jump	143 - 145
(5.49)	Relation Between F_1 and Y_2/Y_1 for Optimum Stilling Basin	147
(5.50)	Relation Between F_1 and L_J/Y_2 for Optimum Stilling Basin	147
(5.51)	Relation Between F_1 and E_L/E_1 for Optimum Stilling Basin	147
(5.52) to (5.63)	Water Surface Profiles for Repelled Jump	149 - 160
(5.64) to (5.66)	Relation Between L_b/Y_1 and L_J/Y_2 for Repelled Jump	163 - 165
(5.67) to (5.69)	Relation Between θ and L_J/Y_2 for Repelled Jump	166 - 168
(5.70) to (5.72)	Relation Between D/Y_2 and L_J/Y_2 for Repelled Jump	170 - 172
(5.73) to (5.75)	Relation Between L_b/Y_1 and Y_2/Y_1 for Repelled Jump	175 - 177
(5.76) to (5.78)	Relation Between θ and Y_2/Y_1 for Repelled Jump	177 - 179

Figure No.		Page
(5.79) to (5.81)	Relation Between D/Y_2 and Y_2/Y_1 for Repelled Jump	182 - 184
(5.82) to (5.84)	Relation Between L_b/Y_1 and E_L/E_1 for Repelled Jump	187 - 189
(5.85) to (5.87)	Relation Between θ and E_L/E_1 for Repelled Jump	190 - 192
(5.88) to (5.90)	Relation Between D/Y_2 and E_L/E_1 for Repelled Jump	194 - 196
(5.91) to (5.93)	Relation Between L_b/Y_1 and $Q_J/Q_T\%$ for Repelled Jump	198 - 200
(5.94) to (5.96)	Relation Between θ and $Q_J/Q_T\%$ for Repelled Jump	202 - 204
(5.97) to (5.99)	Relation Between D/Y_2 and $Q_J/Q_T\%$ for Repelled Jump	205 - 207
(5.100)	Relation Between F_1 and Y_2/Y_1 for Optimum Stilling Basin	209
(5.101)	Relation Between F_1 and L_3/Y_2 for Optimum Stilling Basin	209
(5.102)	Relation Between F_1 and E_L/E_1 for Optimum Stilling Basin	209
(5.103) to (5.124)	Water Surface Profiles for Submerged Jump	211 - 232
(5.125) to (5.127)	Relation Between L_b/Y_1 and L_{sJ}/Y_1 for Submerged Jump	235 - 237
(5.128) to (5.133)	Relation Between θ and L_{sJ}/Y_1 for Submerged Jump	239 - 244
(5.134) to (5.139)	Relation Between D/Y_2 and L_{sJ}/Y_1 for Submerged Jump	245 - 250
(5.140) to (5.142)	Relation Between L_b/Y_1 and Y_3/Y_1 for Submerged Jump	254 - 256

Figure No.	Page
(5.143) to (5.148)	Relation Between θ and Y_3/Y_1
	for Submerged Jump 257 - 262
(5.149) to (5.154)	Relation Between D/Y_2 and Y_3/Y_1
	for Submerged Jump 264 - 269
(5.155) to (5.157)	Relation Between L_b/Y_1 and E_L/E_1
	for Submerged Jump 272 - 274
(5.158) to (5.163)	Relation Between θ and E_L/E_1
	for Submerged Jump 275 - 280
(5.164) to (5.169)	Relation Between D/Y_2 and E_L/E_1
	for Submerged Jump 282 - 287
(5.170) to (5.172)	Relation Between L_b/Y_1 and $Q_J/Q_T\%$
	for Submerged Jump 289 - 291
(5.173) to (5.178)	Relation Between θ and $Q_J/Q_T\%$
	for Submerged Jump 293 - 298
(5.179) to (5.184)	Relation Between D/Y_2 and $Q_J/Q_T\%$
	for Submerged Jump 299 - 304
(5.185)	Relation Between F_1 and Y_3/Y_1
	for Optimum Stilling Basin 306
(5.186)	Relation Between F_1 and L_{sj}/Y_2
	for Optimum Stilling Basin 306
(5.187)	Relation Between F_1 and E_L/E_1
	for Optimum Stilling Basin 306
(6.1)	Verification of Theoretical
	Equation for Perfect Jump 308
(6.2)	Verification of Theoretical
	Equation for Repelled Jump 309
(6.3)	Verification of Theoretical
	Equation for Submerged Jump 310
(6.4)	Comparision Between Different
	Type of Stilling Basins 311