APPLICATION OF MATHEMATICAL MODELLING IN INVESTIGATING COASTAL PHENOMENA

By

G. N. Wijesekara

A Thesis submitted to University of Moratuwa
for the Degree in Master of Engineering

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Research supervised

By

Dr. S. P. Samarawickrama

Professor S. S. L. Hettiarachchi

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF MORATUWA
MORATUWA
SRI LANKA

ABSTRACT

With the evolvement of Information Technology, the simulation of physical theories on real matter in order to envisage the behavior of man-made structures and its impact on earth resources have "spread its wings" from scaled models to highly sophisticated virtual reality computer models where all elements can be viewed in 2D/3D in graphic user interfaces.

Particularly the study in Coastal wave mechanics and simulation of such uncertainty with man-made structures, have proven the value of technology and it has been much effective with cost and time.

With the current research that had been carried so far, commercially used in-house wave models were studied and a whole new design and analysis of a computer simulated numerical model for Sediment Transport Modelling was carried out.

Case study on Hambanthota describes the coastal processes that has been undertaken in order to investigate the wave climate, wave induced currents and sediment movement for the proposed fishery harbour at Hambathota in Sri Lanka.

Various components of an available wave modelling suite ("Halcrow") were applied to evaluate the nearshore wave climate for design purposes, for optimization of the harbour configuration, for examination of wave penetration and for the input to the beach evolution model. The wave modelling shows that there is no significance wave penetration for the proposed fishery harbour. In addition, Wave-induced current modelling and investigation of beach evolution of the existing bay has been undertaken.

The proceedings of a final year project discussed on environmental impact on ecological and social environment with several proposed alternatives for a fishery harbour in Negombo Lagoon were considered for a case study using a commercial wave model to examine the significance impact of the wave climate for the nearshore region and structures proposed to be located in Negombo Bay. Several components of "Halcrow" wave model are used in order to validate the first alternative and modifications required are suggested herewith.

Most important of all, a sophisticated numerical model is designed and analyzed with the use of paradigms of software engineering for the simulation of Alongshore

Sediment Transport. Equations by Kamphuis (1992) based on empirical co-relations and dimensional analysis of properties have been used and followed through the whole design. Theories and equations integrated from research carried out by Dr. Saman Samarawickrama were used in deriving solutions for the numerical model of which the design is based on many GIS (*Geographical Information System*) functionalities.

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

ACKNOWLEDGMENT

I offer my most heartfelt gratitude to Prof. Samantha Hettiarachchi and Dr. Saman Samarawickrama for the extravagant assistance and perfect guidance held upon my research. The inspiring work on several government projects funded by international funding organizations was possible with their precious directions and absolute collaboration and involvement towards guiding my research.

I was privileged to conquer this opportunity with the absolute co-operation of National Science Foundation with their funding during my course of research, and I warmly appreciate their efforts to do so, without them this research would not be a possibility. I would also like to thank the Vice Chancellor, Dean of Engineering Faculty and the Senate Research committee, Head, Department of Civil Engineering, Director, Postgraduate Studies of University of Moratuwa for their favorable arrangements.

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

I'm grateful to consultants/engineers of Halcrow's Group of companies and Applied Science Association Inc. for the collaboration with their expensive resources and guidance.

My sincere gratitude is also offered to Dr. Ranjith Galappaththi and the rest of the staff at Lanka Hydraulic Institute for their wonderful collaboration towards my research work.

My warm gratitude is for my parents and my sister who always stood by me during difficult moments and for nourishing my mind with hope.

DECLARATION

This thesis is a report of research carried out in the Department of Civil Engineering, University of Moratuwa, between August 2001 and December 2003. Except where references are made to other work, the contents of this thesis are original and have been carried out by the undersigned. The work has not been submitted in part or whole to any other university. This thesis contains 173 pages.

G. N. Wijesekara
Department of Civil Engineering
University of Moratuwa
Sri Lanka

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Supervisor
Prof. S.S.L. Hettiarachchi
Department of Civil Engineering
University of Moratuwa
Sri Lanka

Supervisor
Dr. S. P. Samarawickrama
Department of Civil Engineering
University of Moratuwa
Sri Lanka

CONTENTS

1.0 Introduction 01

2.0 Literature Review 03

2.1 Hydrodynamics and Sediment Transport Modeling 04

2.1.1 Hydrodynamics 04

2.1.2 Sediment Transportation 06

3.0 Coastal Sediment Transport Modelling 08

3.1 Introduction 09

3.2 Literature Review 12

3.2.1 Alongshore transport formulae 12

3.2.2 Wave Breaking 15

3.2.3 One-line models 16

3.2.4 The cross-shore distribution of alongshore transport 17

3.2.5 Multi-Line (N-Line) models 21

3.3 Sediment Transport Model Development 22

3.3.1 Calculation of Wave Heights for the solution domain 22

3.3.2 Calculation of Wave angles for the solution domain 26

3.3.3 Calculation of Wave Height (H_{sb}) and Wave Angle (α_b) at breaking 26

3.3.4 Correction for Combined refraction and diffraction behind a structure 26

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

3.3.5 Groyne By-passing and Permeability 27

3.3.6 Alongshore Sediment Transport Rate 29

3.3.7 Alongshore Sediment Transport Rate - Kamphuis, 1991a 29

3.3.8 Distribution of the Alongshore Sediment Transport Rate Across the Surf Zone 32

3.3.9 The Cross- Shore Distribution of Alongshore Sediment Transport Rate, Perlin & Dean, 1983 32

3.4 Design of Along Shore Transport Model (*SandPro*) – Design and Details 35

3.4.1 Wave Climate Transformation 38

3.4.2 Calculation of wave-directional gradient 46

3.4.3 Correction for combined refraction and diffraction behind a structure 51

3.4.4 Implementing the Sediment Balance 53

3.4.5 Implementing the flow distribution 55

3.4.6 Main Algorithm 63

3.4.7 Technical guidelines for the development of *SanPro* 65

4.0 Numerical Modelling –Case Study – Proposed Harbour at the Negombo Lagoon 69

4.1 Introduction 70

4.1.1 Need for Development 70

4.1.2 Introduction to Alternatives 72

4.1.3 Alternative: Construction of Breakwaters and Associated Facilities at Morawala 72

4.2 Data Review and Analysis 73

4.2.1 Data collection 73

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

4.3 Model Basis 83

4.4 Regional Wave Modelling 83

4.4.1 Wave Penetration Modelling 87

4.4.2 Wave Model Setup for Regional Model 89

4.5 Local Wave Modelling 95

4.5.1 Wave Model Setup for Local Model 95

5.0 Application of Mathematical Modeling in the Design of Proposed Hambanthota Fishery Harbour. 100

5.1 Data Review and Analysis 101

5.1.1 Data collection 101

5.2 Wave Modelling 113

5.2.1 Model Basis 113

5.2.2 Local Wave Modelling 118

5.2.3 Wave- Induced Current Modelling 122

5.3 Modelling of Sediment Movements 124

5.3.1 General 124

5.3.2 Alongshore Drift 124

5.3.3 Cross-shore Modelling 126

6.0 Conclusions 133

6.1 Design of Sediment Transport Model 134

6.2 Proposed Fishery Harbour at Hambantota Bay 136

6.3 Proposed Fishery Harbour at Negombo 138

Bibliography 139

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

References 161

Appendix 164

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

LIST OF FIGURES

Figure	Description	Page No.
2.1	*Schematization of range of application of Tidal Modelling, showing relations to other areas of modelling activity*	06
3.1	*Classification of beach change prediction models - after Kraus (1983)*	11
3.2	*Diffraction approximation near groyne - after Kamphuis (1992)*	25
3.3	*Refraction-diffraction approximation near groyne - after Kamphuis (1992)*	27
3.4	*Grid space for bathymetry*	35
3.5	*Structures defined alongshore*	36
3.6	*Bathymetry Space with the Grid with structures defined with the shoreline*	37
3.7	*Grid formats for beach slope calculation and to identify shoreline*	39
3.8	*Diffraction approximation near groyne - after Kamphuis (1992)*	45
3.9	*Identifying points of diffraction*	45
3.10	*Considered Angle for Calculations*	46
3.11	*Calculating shoreline gradient*	47
3.12	*Calculating gradient at middle points along shoreline*	47

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

3.13	*Influence zone under diffraction*	48
3.14	*Considered Angle from Incident Angle for Diffraction Calculations*	48
3.15	*Angles derived for Diffraction Calculations*	48
3.16	*Two cases for the correction of combined refraction and diffraction*	51
3.17	*Calculating sediment flow for intermediate cells of the grid*	53
3.18	*General Case*	56
3.19	*Corner starting middle cell*	56
3.20	*Corner Starting Lower Cell*	56
3.21	*Corner Middle Lower Cell*	57
3.22	*Structure for Flow_Distributig_Array*	57
3.23	*Specifications and Grid Layout Considered for development of SandPro*	67
4.1	*Proposed Fisheries Harbour at Morawala*	72
4.2	*Wave rose produced from Galle 70m offshore wave data.*	85
4.3	*Bathymetry for Regional wave modeling and wave climate transformation*	86
4.4	*Regional Model Setup*	89

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

4.5	*Wave Rose for Negombo-Inshore wave data after transformation*	92
4.6	*Local Model Setup*	95
4.7	*Local Model Critical Cases Run no 1*	96
4.8	*Local Model Critical Cases Run no 2*	97
4.9	*Local Model Critical Cases Run no 3*	98
4.10	*Local Model Critical Cases Run no 4*	99
5.1	*Regional Wave Model Bathymetry for Southern Coast of Sri Lanka*	114
5.2	*Layout Options*	118
5.3	*Typical wave penetration model result*	121
5.4	*Typical wave-induced current pattern*	123
5.5	*Typical alongshore model result*	126
5.6	*Hambatota Harbour Optimization Modelling Existing Bay – SW Monsoon*	128
5.7	*Hambatota Harbour Optimization Modelling Existing Bay – NE Monsoon*	129
5.8	*Hambatota Harbour Optimization Modelling Option 1 – SW Monsoon*	130
5.9	*Hambatota Harbour Optimization Modelling Option 1 – NE Monsoon*	131

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

5.10 *Hambatota Harbour Optimization Modelling Option 1a SW Monsoon* 132

Bibliography

Figure	Description	Page No.
1.1	*Log-log plot of S44 3rd and 4th Editions.*	148
1.2	*Log-log plot of SMA implementation of S-44*	151
1.3	*Log-log plot of USACE standards, and S44 4th Edition Special Order*	153
1.4	*Log-log plot of Proposed LINZ worst-case sector / IMCA depth uncertainty, and S44 4th Edition Special Order*	157
1.5	*Compilation of all depth uncertainty standards from s 1 to 4.*	160

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

LIST OF TABLES

Table	Description	Page No.
3.1	*General characteristics of currently available models*	11
4.1	*Tide level Vs Predicted Water Level*	74
4.2	*Percentage distribution of CCD-GTZ overall wave data by direction sector*	76
4.3	*Percentage distribution of CCD-GTZ overall wave data by wave period*	77
4.4	*Percentage distribution of CCD-GTZ overall wave data by direction for SW monsoon*	79
4.5	*Percentage distribution of CCD-GTZ overall wave data by direction for NE monsoon*	80
4.6	*Percentage distribution of CCD-GTZ overall wave data by direction for IM1 monsoon*	81
4.7	*Percentage distribution of CCD-GTZ overall wave data by direction for IM2 monsoon*	82
4.8	*Percentage distribution of CCD-GTZ overall wave data by direction*	84
4.9	*Summary of MWAVE_REG model runs undertaken*	87
4.10	*Probability analysis of transformed wave data*	90
4.11	*Probability Analysis of wave height from direction 180 - 210*	93
4.12	*Probability Analysis of wave height from direction 210 - 240*	93
4.13	*Probability Analysis of wave height from direction 240 - 270*	93
4.14	*Probability Analysis of wave period from direction 180 - 210*	93

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

4.15	*Probability Analysis of wave period from direction 210 - 240*	94
4.16	*Probability Analysis of wave period from direction 240 - 270*	94
4.17	*Inshore critical wave regions*	94
5.1	*Tide level Vs Predicted Water Level*	101
5.2	*Percentage distribution of CCD-GTZ overall wave data by direction sector*	103
5.3	*Percentage distribution of CCD-GTZ overall wave data by wave period.*	104
5.4	*Percentage distribution of CCD-GTZ overall wave data by direction for SW monsoon*	106
5.5	*Percentage distribution of CCD-GTZ overall wave data by direction for NE monsoon*	107
5.6	*Percentage distribution of CCD-GTZ overall wave data by direction for IM1 monsoon*	108
5.7	*Percentage distribution of CCD-GTZ overall wave data by direction for IM2 monsoon*	109
5.8	*Percentage distribution of Kudawella overall wave data by direction sector for the SW monsoon*	111
5.9	*Percentage distribution of Kudawella overall wave data by direction sector for the SW monsoon*	111
5.10	*Percentage distribution of overall wave data by direction sector for the SW monsoon at Kirinda*	112
5.11	*Percentage distribution of overall wave data by direction sector for the NE monsoon at Kirinda*	112
5.12	*Summary of MWAVE REG model runs undertaken*	115
5.13	*Percentage distribution of nearshore wave data at H1 by direction sector*	116
5.14	*Extreme Wave Heights predicted for nearshore point H1*	117

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Bibliography

Table	Description	Page No.
1.1	*Summary of Minimum Standards for Depth Uncertainties from S44 4th Edition (IHO, 1998)*	147
1.2	*The Swedish implementation of S-44*	150
1.3	*USACE depth uncertainty standards (2001 draft version)*	153
1.4	*Proposed LINZ Depth uncertainty specifications*	156
1.5	*Proposed IMCA Depth Measurement Uncertainty Standards*	157

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk