


Tan Weiyan



**SHALLOW WATER
HYDRODYNAMICS**



ELSEVIER OCEANOGRAPHY SERIES

D III 203

DK 551.511.32

Elsevier Oceanography Series, 55

SHALLOW WATER HYDRODYNAMICS

Mathematical Theory and Numerical Solution
for a Two-dimensional System of
Shallow Water Equations

Tan Weiyao

*Nanjing Research Institute of Hydrology and Water Resources
Nanjing 210024, China*

281/3493 INSTITUT
FÜR METEOROLOGIE U. KLIMATOLOGIE
UNIVERSITÄT HANNOVER
HERRENHAUSER STR. 2 • 3000 HANNOVER 71



Water & Power Press
Beijing, China



Elsevier
Amsterdam

1992

CONTENTS

FOREWORD	V
PREFACE	VII
LIST OF SYMBOLS	K
ABBREVIATIONS	X
CHAPTER 1 BACKGROUND IN MECHANICS	1
1.1 Physical objects	1
1.2 System of fluid-dynamics equations for homogeneous isotropic incompressible flows	3
1.3 Two-dimensional system of shallow-water equations (2-D SSWE)	17
1.4 Physical meanings of various terms in 2-D SSWE	26
1.5 Various forms of 2-D SSWE	38
CHAPTER 2 PROPERTIES OF 2-D SSWE	60
2.1 Conceptual mechanical behavior	60
2.2 Dimensional analysis of 2-D SSWE	66
2.3 Basic mathematics for systems of first-order quasilinear hyperbolic equations	72
2.4 Geometric theory of characteristics	84
2.5 Riemann invariants	93
2.6 Theory of nonlinear wave propagation	100
CHAPTER 3 PROPERTIES OF THE SOLUTIONS OF 2-D SSWE	107
3.1 Initial and boundary conditions for well-posed problems	107
3.2 Behavior of solutions	121
CHAPTER 4 DISCONTINUOUS SOLUTIONS OF SSWE	130
4.1 Isentropic-flow simulation of SSWE and its limitations	130
4.2 Discontinuous Solutions of 1-D first-order hyperbolic systems	135
4.3 Introduction to 2-D discontinuous solutions	150
4.4 Mathematical conditions of shock waves for 2-D SSWE	155
CHAPTER 5 PRELIMINARY REVIEW OF FINITE DIFFERENCE METHODS	161
5.1 General description	161
5.2 Basic performance of a difference scheme	168
5.3 Basic difference schemes for first-order hyperbolic systems in one space dimension	187
5.4 FDMs for the computation of 1-D unsteady open flows	193
CHAPTER 6 DIFFERENCE SCHEMES FOR 2-D SSWE	206
6.1 FDMs for the solution of 2-D SSWE in nonconservative form	206
6.2 FDMs for the solution of 2-D SSWE in conservative form	215
6.3 Fractional-step methods and splitting-up algorithms	219
6.4 Fractional-step difference schemes for 2-D unsteady flow computations	223
6.5 FDMs for curvilinear meshes	234
6.6 Finite volume method (FVM)	241
CHAPTER 7 NUMERICAL SOLUTIONS USING FINITE ELEMENT METHODS	245
7.1 Related principles in variational calculus	245
7.2 Piecewise approximation of plane problems and convergence of FEM solutions	251
7.3 FEM for 2-D unsteady open flows	264
7.4 Several classes of special FEMs	272
CHAPTER 8 TECHNIQUES FOR THE IMPLEMENTATION OF ALGORITHMS	283
8.1 Computational mesh	283
8.2 Classical techniques for improving computational stability and accuracy	308
CHAPTER 9 NEW DEVELOPMENTS OF DIFFERENCE SCHEMES FOR 2-D FIRST-ORDER HYPERBOLIC SYSTEMS OF EQUATIONS	334
9.1 General description	334
9.2 Two-dimensional methods of characteristics	342
9.3 Characteristic-based splitting	347

9.4 Riemann approach	360
9.5 Approximate factorization of implicit schemes	366
9.6 FCT algorithms and TVD schemes	369
9.7 Square conservation schemes	382
CHAPTER 10 STABILITY ANALYSIS AND BOUNDARY PROCEDURES	388
10.1 Mathematical definitions of stability for difference schemes	388
10.2 von Neumann linear stability analysis	390
10.3 Nonlinear instability	395
10.4 Boundary procedures and their influence on numerical solutions	400
10.5 Stability theory for mixed problems	413
CHAPTER 11 CONCLUDING REMARKS	418
11.1 Requirements for an ideal finite-difference scheme	418
11.2 Comparison of performance, merits and drawbacks between FDM and FEM	419
11.3 Brief introduction to other algorithms	420
11.4 Towards a truly 2-D algorithm	424
INDEX	431