Dam-break Problems, Solutions and Case Studies

Editors:

D. de Wrachien
State University of Milan, Italy

&

S. Mambretti
Politecnico Di Milano, Italy

WIT PRESS Southampton, Boston
# Contents

Introduction xv

## Chapter 1 Dam failures

1 Dam classification 1
2 Embankment dams 6
  2.1 Loading conditions and related failures in embankment dams 7
  2.2 Mechanisms of failure 12
3 Concrete dams 23
  3.1 Concrete as dam material 26
    3.1.1 RCC 27
  3.2 Structural damage of concrete dams 29
    3.2.1 Ageing of concrete 29
    3.2.2 Early-age cracking 30
    3.2.3 Concrete swelling due to alkali-aggregate reaction (AAR) 32
    3.2.4 Erosion of concrete 33
  3.3 Failures of concrete dams 37
    3.3.1 The collapse of Gleno dam 38
4 Stability of rock foundations of dams 40
  4.1 Geological and rock mechanics studies 40
  4.2 Stability computations 43
    4.2.1 Limit equilibrium methods 43
    4.2.2 Statistical and parametrical analysis 44
    4.2.3 Numerical methods 45

## Chapter 2 Laboratory experiments

1 Introduction 51
2 Physical models 52
  2.1 Similarity and scaling laws 52
  2.2 Distorted models 56
  2.3 Physical model layout and construction 57
  2.4 Flow conditioning 58
3 Depth measurements 59
  3.1 Twin-wire probes 59
Chapter 3 Dam-break wave routing 85

1 Introduction 86
2 Clear-water wave routing 86
   2.1 Governing equations 87
   2.2 Initial and boundary conditions 89
      2.2.1 Initial conditions 89
      2.2.2 Boundary conditions 91
   2.3 Cross-sections 92
   2.4 2D flow models 93
   2.5 Hybrid models 93
3 Debris-flow routing 93
   3.1 Flow profile 94
   3.2 Rheological models 95
      3.2.1 Non-Newtonian fluid models 95
      3.2.2 GVF model 97
      3.2.3 Multi-layer models 98
   3.3 Governing equations 99
3.3.1 One-phase model 100
3.3.2 Two-phase mathematical model 102
  3.3.2.1 Non-stratified (mature) flows 102
  3.3.2.2 Stratified (immature) flows 104
3.3.3 Numerical model 106

4 Numerical models and solvers for dam-break shock waves 110
  4.1 Numerical solutions 112
  4.2 Homogeneous conservation laws 112
  4.3 Riemann solvers 113
    4.3.1 Local Lax–Friedrichs (LLF) Riemann solver 113
    4.3.2 Roe's approximate Riemann solver 114
    4.3.3 Harten–Lax–van Lier–Einfeldt (HLLE) Riemann solver 115
  4.4 Inhomogeneous conservation laws 116
    4.4.1 Linearized conservative implicit (LCI) solver 116
    4.4.2 Symmetric LCI solver 118
    4.4.3 Monotonic upstream scheme for conservation laws (MUSCL) LCI solver 118
    4.4.4 McCormack–Jameson solver 119

5 Sediment concentration of the mixtures 120
  5.1 Fundamental parameters of sediment particles 121
    5.1.1 Size 121
    5.1.2 Shape of sediment particles 122
    5.1.3 Sediment concentration 122
    5.1.4 Fall velocity 122
  5.2 Sediment concentration distribution 122
  5.3 Hydraulic-based routing modelling 123
    5.3.1 Governing equations 123
    5.3.2 Sediment concentration profile 125
  5.4 Stochastic approach 126
    5.4.1 Maximum entropy principle 127
    5.4.2 Equilibrium sediment concentration 128
  5.5 Gradual earth-dam failure 128

6 General remarks 130

Chapter 4 Dam-break flood routing 141

1 Introduction 141
2 Governing equations 144
  2.1 Sediment transport model 145
  2.2 Finite-element discretization 146
  2.3 Explicit time-stepping scheme 148
  2.4 Stability analysis 151
3 Numerical treatment of dry bed 154
4 OpenMP parallelization 154
5 Testing RiverFLO-2D model 155
Chapter 5 Dam-break flow against obstacles and through river bed singularities

1 The presence of a natural lake
2 The presence of a downstream artificial lake
3 Presence of a sand bar at the mouth of the river
4 The problem of debris
   4.1 Composition of debris
   4.2 Debris blockage
   4.3 Loading caused by debris
   4.4 Debris and the dam-break wave
5 Influence of ice
   5.1 Hydraulic considerations
   5.2 Ice cover mechanics
   5.3 Dam response
6 The presence of a downstream dam
7 Presence of a bridge on the river
8 Presence of an embankment with or without a culvert
9 The presence of an isolated obstacle or a high density of obstacles
   9.1 Isolated obstacle
   9.2 Groups of obstacles

Chapter 6 Dam-break risk management and hazard mitigation
3.2.1 Visual inspections 227
3.2.2 Instrumentation 227
3.2.3 Data collection 228
3.2.4 Data evaluation and management 229
3.3 Decision at the dam site 229
3.4 Notification system 230
3.5 Warning the population at risk 231
  3.5.1 Introduction 231
  3.5.2 Public warnings 233
  3.5.3 Personal notification 234
  3.5.4 Television or radio broadcast notification 235
3.6 Evacuation of the population at risk 235
4 Final remarks 237

Chapter 7 Economic evaluation of dams for flood protection: an integrated safety approach 241

1 Introduction 241
  1.1 Motivations for integrated catastrophe management 243
  1.2 Integrated risk management approach 245
2 Ethical goals and constraints 246
  2.1 Spatiotemporal heterogeneities 247
    2.1.1 Temporal 247
    2.1.2 Spatial and social 248
  2.2 Multiagent aspects 248
  2.3 Safety constraints 249
  2.4 Discounting 250
  2.5 Assessment versus robust solutions 251
3 Integrated management of catastrophic losses 252
  3.1 Catastrophe modelling as integrated assessment model 252
    3.1.1 The technique 253
    3.1.2 Integrated catastrophe model 253
    3.1.3 The output 255
  3.2 Integrated catastrophe management modeling 256
4 Spatial adaptive Monte Carlo optimization 257
5 Case studies 258
  5.1 Background 258
  5.2 Structure of the integrated catastrophe-management model 260
    5.2.1 Remark 261
6 Discounting and robust decisions 262
7 Risk communication, public perception and participation 264
  7.1 Intertemporal inconsistency of discounting 265
  7.2 Commitment to actions 266
8 Some guidelines and conclusions for policy evaluations 267
Chapter 8  Case histories: a worldwide view

1 Failures and incidents: general aspects
   1.1 Failures in concrete and masonry dams
      1.1.1 Failures caused by shortcomings in dam design and construction phases
         1.1.1.1 The failure of Bouzey dam
         1.1.1.2 Vega de Tera dam
      1.1.2 Failures caused by problems in the foundations
         1.1.2.1 Malpasset dam
         1.1.2.2 St. Francis dam
      1.1.3 Failures caused by overtopping
         1.1.3.1 Sella Zerbino dam
   1.2 Failures in embankment dams
      1.2.1 Failures caused by internal erosion in the dam body
         1.2.1.1 Teton dam failure
      1.2.2 Failures caused by internal erosion in the foundation
         1.2.2.1 Baldwin Hills dam failure
         1.2.2.2 The arch cofferdam of the Kariba Dam in Rhodesia
      1.2.3 Failures caused by overtopping
         1.2.3.1 Belci dam failure
         1.2.3.2 Tous dam collapse
         1.2.3.3 The failure of Taum Sauk upper dam
      1.2.4 Failures of natural embankment (landslide and rockslide) dams
         1.2.4.1 La Josefina landslide dam
         1.2.4.2 The Val Pola rockslide dam
         1.2.4.3 The Lake Sarez and Usoi landslide dam
      1.2.5 Quake lakes case histories
         1.2.5.1 The Iwate-Miyagi Nairiku earthquake (communication of Prof. Matsumoto to ICOLD)
         1.2.5.2 The Wenchuan earthquake (communication of Dr. Xu Zeping to ICOLD)
         1.2.5.3 Some remarks on quake lakes failure
   1.3 Failures involving the watershed banks instability: the Vajont Dam case history
   1.4 Failures caused by deliberate human actions
      1.4.1 Dam failures during World War II years (1939–1945)
         1.4.1.1 The two destructions of Dnjeprstroj dam (Russia)
         1.4.1.2 The bombing of Mohne, Eder and Sorpe dams (Germany)
         1.4.1.3 The blasting of Peruća dam (Croatia)
         1.4.1.4 Other known cases
1.5 Lessons learned from dam failures, remedial measures, fall-out on legislation and improvement of safety criteria

1.5.1 Overtopping and hydraulic problems due to inadequate spillways and outlet capacity

1.5.2 Shortcomings in the dam foundation

1.5.3 Surveillance of dams
   1.5.3.1 Visual inspections
   1.5.3.2 Monitoring

1.5.4 Landslide and rockslide dams: general remarks and remedial measures

1.5.5 Malevolent actions against dams: remedial measures
   1.5.5.1 Interagency Forum for Infrastructure Protection in USA
   1.5.5.2 Department of Homeland Security in USA
   1.5.5.3 European Programme for Critical Infrastructures Protection