OVERTOPPING RISK AND UNCERTAINTY ANALYSIS OF EMBANKMENT DAMS

EHSAN GOODARZI

FK 2010 65
OVERTOPPING RISK AND UNCERTAINTY ANALYSIS OF EMBANKMENT DAMS

EHSAN GOODARZI

DOCTOR OF PHILOSOPHY
UNIVERSITY PUTRA MALAYSIA
2010
OVERTOPPING RISK AND UNCERTAINTY ANALYSIS
OF EMBANKMENT DAMS

By

EHSAN GOODARZI

Thesis submitted to the school of graduate study, Universiti Putra Malaysia, in
Fulfillment of the Requirements for the Degree of Doctor of Philosophy.

October 2010
DEDICATION

I dedicated this thesis to my parents. I hope that this achievement will complete the dream that they had for me all those many years ago when they choose to give me the best education that I could.
Abstract

The main objectives of this study are the evaluation of overtopping risk in conjunction with uncertainty for two embankment dams in the south of Iran (Fars province) and north of Iran (Mazandaran province). Dams are one of the most significant structures that contribute to the survival of the human race. The main benefits of this structure for human society are; flood controlling, generation of hydro-electric power, and supply water for different purpose such as agriculture, irrigation, recreation, and tourism attraction. Annually, natural disasters like earthquake, flood, drought, and thunders
happen in different parts of the world. Malfunctioning of a dam can result in serious economic damage to the owners, and environmental problems such as pollution, sedimentation in the downstream areas and can also result in the loss of human lives. Iran is one of the ten foremost countries sensitive to the unexpected phenomena and natural disasters. Flooding is one of the most important disasters in Iran and losses during 1951-2000 exceeded more than 11,500 people. So, constructing new flood control structures and assessment safety of existing dams are essential.

There is main gap with regards to apply new statistical tools and techniques for overtopping risk analysis and assessment the safety of dams. Furthermore, considering various events such as wind in conjunction with flood which increase the probability of failure is a crucial task of hydrosystem engineers. Hence, this research presents the application of risk and uncertainty analysis to dam overtopping. A flood frequency analysis of annual maximum discharge was done for the Doroudzan and Meijaran dams applying the General Extreme Value (GEV) probability distribution. Risk of overtopping were calculated for six extreme floods taking into consideration inflow hydrograph, initial water level, discharge coefficient of spillway, and the reservoir geometry as uncertain variables. The reservoir routing technique was used to compute the highest water levels and the Monte Carlo simulation (MCS) and Latin hypercube sampling (LHS) were applied for uncertainty analysis. To consider the effect of wind speed on the overtopping risk, frequency analyses were performed on the wind data and consequently extreme wind speeds, highest wind set-up and wave run-up were calculated. The maximum risk considering the effects of wind speeds in the study was 1.5 to 3.5 times
larger than the risk of overflowing due to only floods using Latin hypercube sampling (LHS) and Monte Carlo simulation (MCS) approaches, respectively. The results of this study show that, initial water level, and inflows to reservoir have significant effects on the overtopping probability of the Doroudzan and Meijaran dams. Overtopping risk increases with increase in magnitude of stated parameters. Trends of computed risks for the Doroudzan dam indicate that calculated probabilities with Latin hypercube sampling were slightly higher than the Monte Carlo simulation, while in the Meijaran dam, there was no any specific trend between the MCS and LHS results.

The major findings and main contributions of this study are; solving the flood model (reservoir routing) in uncertain conditions, estimating wind set-up and wave run up to solve the wind model with considering uncertainties, estimating the probability of failure due to overtopping under different hydrologic conditions, and compare the results based on two applied uncertainty models (MCS and LHS) for two mentioned dams.
Abstrak Tesis Yang Dikemukakan Kepada Senat Universiti Putra Malaysia Sebagai Memenuhi Keperluan Untuk ijazah Doktor Falsafah

ANALISIS RISIKO DAN KETIDAKPASTIAN PARAS TERLAMPAU TINGGI EMPANGAN BENTENG

Oleh

EHSAN GOODARZI

October 2010

Pengerusi: Prof Lee Teang Shui, PhD

Fakulti: Kejuruteraan

terkorban. Jadi, pembinaan struktur baru untuk mengawal banjir dan penilaian keselamatan empangan yang sedia ujud adalah diperlui.

dan Meijaran. Risiko paras terlampau tinggi kian tambah selaras dengan tambahan magnitud parameter tersebut. Risiko dikira untuk empangan Doroudzan menunjukkan kebarangkalian dikira dengan LHS lebih tinggi dibandingkan dengan MCS, akan tetapi untuk empangan Meijaran, tidakpastinya bandingan keputusan MCS dan LHS.

Penemuan utama dan sumbangan terpenting kajian ini adalah; menyelesaikan model banjir (penghalalan takungan) didalam keadaan taktentu, penaksiran kenaikan paras air tertinggi dan panjang gelombang kerana angin dengan mengambilkira ketidakpastian, penaksiran kebarangkalian kegagalan disebabkan paras terlampau tinggi dalam keadaan hidrologi berbeza, dan membandingkan keputusan berdasarkan dua model ketidakpastian (MCS dan LHS) bagi dua empangan tersebut.
ACKNOWLEDGEMENTS

Praise belongs to God who has been the source of inspiration, strength and confidence throughout my life and especially during the postgraduate program.

My most earnest acknowledgment must go to my supervisor, Professor Ir. Dr. Lee Teang Shui, who continually and convincingly conveyed a spirit of adventure in regard to research and scholarship, and an excitement in regard to teaching. Without his guidance and persistent help this dissertation would not have been possible.

Thanks are also due to my committee members, Prof. Ir. Dr. Desa Bin Ahmad, and Prof. Dr. Assoc. Prof. Dr. Abdul Halim Ghazali, for their time and constructive criticisms.

My deepest appreciation belongs to my parents for their personal support, patience and tolerance during many years of my academic endeavour.

Lastly, there are a number of people in my everyday circle of colleagues who have helped me in various stages of this research. I would especially like to thank Mina, Majid, and Raeis for their support and help.
I certify that an Examination Committee has met on date of viva voce to conduct the final examination of Ehsan Goodarzi on his Doctor of Philosophy entitled “OVERTOPPING RISK AND UNCERTAINTY ANALYSIS OF EMBANKMENT DAMS” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the (PhD degree).

Members of the Examination Committee were as follows:

**Mohd Amin Mohd Soom**
Professor
Engineering
Universiti Putra Malaysia
(Chairman)

**Thamer Ahmed Mohamed, PhD**
Associate Professor
Engineering
Universiti Putra Malaysia
/Internal Examiner

**Badronnisa Yusuf, PhD**
Doctor
Engineering
Universiti Putra Malaysia
/Internal Examiner

**Kwok-wing Chau, PhD**
Associate Professor
Engineering
Hong Kong Polytechnic University
/External Examiner

**BUJANG BIN KIM HUAT, PhD**
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:
This thesis was submitted to the Senate of university Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

**Lee Teang Shui, PhD**  
Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Desa bin Ahmad, PhD**  
Professor  
Faculty Engineering  
Universiti Putra Malaysia  
(Member)

**Name of member 2, PhD**  
Title: Assoc. Prof. Dr. Abdul Halim Ghazali  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

---

**HASANAH MOHD GHAZALI, PhD**  
Professor  
School of Graduate Studies  
Universiti Putra Malaysia

Date:
DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or other institutions.

______________________________________________________

Ehsan Goodarzi

Date: 19/10/2010
TABLE OF CONTENTS

DEDICATION ii
ABSTRACT iii
ABSTRAK vi
ACKNOWLEDGEMENT ix
APPROVAL xi
DECLARATION xii
LIST OF TABLE xvi
LIST OF FIGURE xix
LIST OF ABBREVIATIONS xxii

CHAPTER

1 INTRODUCTION
1.1 Hydrosystem 1
   1.1.1 Risk-based hydrosystems engineering 2
1.2 Explanation of uncertainty 3
   1.2.1 Types and sources of uncertainty 3
   1.2.2 Measurement of uncertainty 4
1.3 Engineering Reliability and Risk Assessment 5
1.4 Statement of the problem 7
1.5 Objectives 8
1.6 Scope of work and limitations of the study 9
1.7 Significance of the study 10

2 LITERATURE REVIEW
2.1 Introduction 12
2.2 An overview of Probable Maximum Flood (PMF) 14
2.3 An Overview of Risk and Uncertainty 15
2.4 Analysis of Empirical Studies for Risk and Uncertainty 20
   2.4.1 Empirical studies of risk 20
   2.4.2 Empirical studies of uncertainty 27
2.5 Measuring Risk and Uncertainty 28
   2.5.1 An overview of uncertainty analysis techniques 29
      2.5.1.1 Analytical techniques 29
      2.5.1.2 Approximation techniques 32
2.6 An Overview of Reliability (Risk) Analysis Techniques
  2.6.1 Event Tree
  2.6.2 Fault tree
  2.6.3 Direct integration method
  2.6.4 First-order second-moment (FOSM) method
  2.6.5 Empirical studies of risk and uncertainty in hydro system

2.7 An overview of overtopping problem and spillway design
2.8 Empirical studies of overtopping failure
2.9 Data requirements in risk-based approach
2.10 Summary

3 METHODOLOGY
  3.1 Introduction
  3.2 Doroudzan Dam Description
  3.3 Meijaran Dam
  3.4 Overtopping Model in the Risk Analysis
    3.4.1 Solve routing equation
    3.4.2 Effect of uncertainty in the reservoir routing equation
  3.5 Risk Model
  3.6 Wind Model
    3.6.1 Importance of wind speed calculation
    3.6.2 Wind set-up and wave run-up calculation
    3.6.3 Wind set-up
  3.6.4 Wave run-up
  3.7 Computer Program (@Risk Microsoft Excel)
  3.8 Assessing Risk
  3.9 Approaches to Quantifying Risk
  3.10 Simulation
  3.11 @RISK Simulation Analysis
  3.12 Generation of Random Numbers (Sampling)
  3.13 Sampling in @RISK

4 RESULTS AND DISCUSSIONS
  4.1 Introduction
  4.2 Data Analysis of Doroudzan Dam
  4.3 Selection Annual Maximum Discharge
  4.4 Univariate Flood Frequency of Doroudzan Data