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FLOOD MODELING OF DAM BREAK WITH CONSIDERATION OF CLIMATE CHANGE

SAAD SHAUKET SAMMEN

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By

SAAD SHAUKET SAMMEN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

To

My Parents

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

FLOOD MODELING OF DAM BREAK WITH CONSIDERATION OF CLIMATE CHANGE

By

SAAD SHAUKET SAMMEN

December 2017

Chairman : Professor Thamer Ahmad Mohammed Ali, PhD
Faculty : Engineering

In this study, the failure of cascade dams in a tropical region is simulated using mathematical models. The simulation is considering the climate change impact. Three cascade dams for hydropower generation on the Perak River were taken as case studies. The three dams are of different designs, ages and heights which make a unique complex dam system. The proposed models were categorized as dam breach parameters model, hydrological model and hydrodynamic models. The dam breach parameters model is based on generalized regression neural network, GRNN while the hydrological model and hydrodynamic models are Mike 11 (NAM sub-model), 1-D Mike 11 and 2-D Mike 21.

The GRNN was used to estimate the dam breach parameters. Dam breach parameters such as breach width, breach height and breach formation time are the key variables to estimate the peak discharge during dam break. Because of the high nonlinear relationships in dam breach parameters and their variation with time, the estimation of these parameters is considered very complex. The training and testing of GRNN models were conducted using records of more than 140 failed dams around the world in order to estimate dam breach parameters. The results obtained from GRNN models for dam breach parameters were compared with the results obtained from the existing methods. The computed value of Mean Relative Error, MRE for GRNN models were found to be ranged from 0.11 to 0.17 while values of MRE for the existing methods were founded to be ranged from 0.15 to 0.33 for dam breach width estimation. For dam failure time estimation, the values of MRE were found to be ranged from 0.08 to 0.16 for GRNN model results and from 0.34 to 0.57 for the existing methods' results.

In this study, the hydrological model was developed using Mike 11 (NAM sub-model). The Mike 11 (NAM sub-model) is a lumped conceptual model which forms part of the rainfall-runoff (RR) module of the MIKE 11 river modeling system. Time series of rainfall, evaporation and streamflow data for the Temenggor catchment were used to calibrate and validate the hydrological model for the Temenggor dam (the largest dam in the studied dam system). The developed model was applied to predict the probable maximum flood, PMF. Also, the impact of climate change on value of PMF was considered by estimation the PMF value for two future period which include future 1 period (2031 – 2045) and future 2 period (2061 – 2075). The values of PMF were found to be 2887.53 m^3/s, 4299.43 m^3/s and 6427.89 m^3/s for periods (2001 – 2015), (2031 – 2045) and (2061 – 2075) respectively.

The 1-D Mike 11 hydrodynamic model was calibrated and validated using recorded water levels and streamflow for Perak river. Then the model was applied to determine simulated maximum peak outflow from Temenggor, Bersia and Kenering dams for four scenarios. By using the PMF for the period from 2061 to 2075, the maximum peak outflow for the above dams was found to be 272602.59 m3/s, 217984.96 m^3/s and 184922.01 m^3/s respectively. Also, flood routing for Perak river, flood hydrograph and water level hydrograph at different sections were simulated.

The 2 – D Mike 21 hydrodynamic model was used to routing the flood that will result from the simulated maximum peak outflow from Temenggor, Bersia and Kenering dam failures for four scenarios. Flood arrival time, maximum water depth and time to maximum water depth were estimated for different selected villages downstream of the three dams above. Additional, the flood inundation maps were found for different scenarios.

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PEMODELAN BANJIR DISEBABKAN EMPANGAN PECAH DENGAN MENGAMBIL KIRA IMPAK PERUBAHAN IKLIM

Oleh

SAAD AHAUKET SAMMEN

Disember 2017

Pengerusi : Profesor Thamer Ahamed Mohammed Ali, PhD
Fakulti : Kejuruteraan

Dalam kajian ini, kegagalan empangan lata di sebuah kawasan tropika disimulasi menggunakan model matematik. Simulasi tersebut mempertimbangkan impak perubahan iklim. Tiga empangan lata untuk penjanaan kuasa hidro di Sungai Perak telah diambil sebagai kajian kes. Ketiga-tiga empangan tersebut yang berbeza reka bentuk, umur dan ketinggian menjadikan ini suatu sistem empangan kompleks yang unik. Model yang dicadangkan dikategorikan sebagai model parameter empangan pecah, model hidrologi dan model hidrodinamik. Model parameter empangan pecah adalah berdasarkan kepada rangkaian neural regresi umum, GRNN manakala model hidrologi dan model hidrodinamik ialah Mike 11 (sub-model NAM), 1-D Mike 11 dan 2-D Mike 21.

GRNN telah digunakan untuk menganggarkan parameter pecahan empangan. Parameter pecahan empangan seperti lebar pecahan, ketinggian pecahan dan masa pembentukan pecahan adalah pembolehubah utama untuk menganggarkan pelepasan puncak semasa pecahan empangan. Kerana hubungan tak lurus yang tinggi bagi parameter pecahan empangan dan variasinya dengan masa, anggaran parameter-parameter ini dianggap sebagai sangat rumit. Latihan dan ujian model GRNN telah dijalankan menggunakan rekod lebih daripada 140 empangan yang gagal di seluruh dunia untuk menganggarkan parameter pecahan empangan. Keputusan yang diperolehi daripada model GRNN untuk parameter pecahan empangan dibandingkan dengan keputusan yang diperolehi daripada kaedah-kaedah sedia ada. Nilai dikira Ralat Relatif Mean, MRE untuk model GRNN telah didapati berjulat antara 0.11-0.17 manakala nilai MRE untuk kaedah-kaedah yang sedia ada didapati berjulat antara 0.15-0.33 untuk anggaran lebar pecahan empangan. Untuk anggaran masa kegagalan empangan, nilai MRE telah didapati antara 0.08-0.16 untuk keputusan model-model GRNN dan 0.34-0.57 untuk keputusan kaedah sedia ada .

Dalam kajian ini, model hidrologi dibangunkan menggunakan Mike 11 (sub-model NAM). Mike 11 (sub-model NAM) ialah model konseptual tergumpal yang merupakan sebahagian daripada modul larian air hujan (RR) daripada sistem pemodelan sungai MIKE 11. Siri masa hujan, penyejatan dan data aliran sungai untuk kawasan tadahan Temenggor digunakan untuk menentukur dan mengesahkan model hidrologi untuk empangan Temenggor (empangan terbesar di sistem empangan yang dikaji). Model yang dibangunkan telah digunakan untuk meramalkan banjir maksimum yang mungkin, PMF untuk senario yang berbeza termasuk impak perubahan iklim. Nilai-nilai PMF didapati 2887.53 m^3/s, 4299.43 m^3/s dan 6427.89 m^3/s untuk tempoh (2001 - 2015), (2031 - 2045) dan (2061 - 2075) masing-masing. Model hidrodinamik 1-D Mike 11 telah ditentukur dan disahkan menggunakan paras air dan aliran sungai yang direkodkan untuk sungai Perak. Kemudian model tersebut telah digunakan untuk menentukan aliran keluar puncak maksimum yang disimulasi dari empangan Temenggor, Bersia dan Keering untuk empat senario. Dengan menggunakan PMF bagi tempoh 2061 ke 2075, aliran keluar puncak maksimum bagi empangan-empangan di atas didapati ialah 272602.59 m^3/s, 217984.96 m^3/s dan 184922,01 m^3/s masing-masing. Juga, penghalaan banjir sungai Perak, hidrograf banjir dan hidrograf paras air di bahagian-bahagian yang berbeza telah disimulasi.

Model hidrodinamik 2 - D Mike 21 digunakan untuk penghalaan banjir yang akan terhasil daripada aliran keluar puncak maksimum yang disimulasi dari kegagalan empangan Temenggor, Bersia dan Kenering untuk empat senario. Masa Banjir tiba, kedalaman air maksimum dan masa untuk kedalaman air maksimum dianggarkan untuk kampung terpilih yang berbeza di hiliran daripada tiga empangan di atas. Selain itu, peta banjir telah didapatkan untuk senario yang berbeza.

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Thamer Ahmad Mohammad Ali, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Abdul Halim Ghazali, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Ir. Azlan Abdul Aziz, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Lariyah Mohammed Sideq, PhD
Professor, Ir
University Tenaga Nasional
Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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Name and Matric No: Saad Shauket Sammen, GS41659

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Signature: ______________________
Name of Chairman of Supervisory Committee: Thamer Ahmad Mohammad Ali

Signature: ______________________
Name of Member of Supervisory Committee: Abdul Halim Ghazali

Signature: ______________________
Name of Member of Supervisory Committee: Azlan Abdul Aziz

Signature: ______________________
Name of Member of Supervisory Committee: Lariyah Mohammed Sideq

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H_d	Dam height
B_{avg}	Average breach width
H_w	Depth of water above the bottom of the breach
V_w	Reservoir volume at the time of failure
V_{er}	Volume of material eroded from the dam embankment
B^*_{avg}	Dimensionless average breach width
S^*	Dimensionless reservoir storage
C_b	Reservoir volume coefficient
B	Breach width
K_o	Coefficient related to dam failure mode
g	Gravitational acceleration
H_b	Breach hight
d_i	The computed distance
σ	Spreading factor or smoothing factor
Q	Discharge
h	Water depth
α	Velocity distribution coefficient
t	Time
x	Stationing
A	Area of wet cross-section
C	Chezy number
R	Hydraulic radius

P	Wet perimeter
E	Reservoir's water surface elevation
E_s	Water surface elevation in the breach,
v_1	Reservoir's flow velocity
ζ_{in}	Head loss factor for inflow contraction
A_s	Flow area in the breach
A_1	Reservoir flow area.
y_s	Breach's water depth
U, V	Depth-averaged Cartesian velocity components,
K_{xx}, K_{yy}	eddy viscosities
U_S, V_S	Velocities at the source
X	Standardized value of X_i
X_{min}	Minimum value of data
X_{max}	Maximum value of data
X_o	Observed values
X_p	Predicated values
$\bar{X}_o$	The average of observed predicted values
$\bar{X}_p$	The average of predicted values
X_o	Observed values
X_p	Predicated values
X_o	Mean value of the recorded rainfall
σ_X	Standard deviation of the recorded rainfall
P	Occurrence probability
y	Dimensionless variable

T	Return period
X_T	Estimated event magnitude
Q_{simi}	The simulated discharge during time i
Q_{Obsi}	The observed discharge during time i
$\bar{Q}_{Obs}$	The average observed discharge,
$\bar{Q}_{Sim}$	The average simulated discharge
C_R	Courant number
c	Wave celerity or maximum velocity (m/s)
Δt	Time step (sec)
Δx	Grid spacing (m)
τ_o	The wall shear stress
η	The eddy viscosity
$\partial u^{-}/\partial z$	The changes in mean horizontal velocity along the depth

CHAPTER 1

INTRODUCTION

1.1 History of Dams Failure

Water is the vital liquid to support all forms of life on the earth. It is an essential element of the environment. Although 70% of the Earth is covered with water, a significant portion of the world population suffers water shortage. This is because 96.5% of the water resources are salt water found in oceans (Gleick, 1993). On the other hand, 98.8% of the earth's freshwater is in the forms of ice and groundwater and only a small portion is in rivers and lakes. As a result of the expanding world population and economic growth, the demand for water has increased the importance of freshwater resources. Therefore, it is essential to collect and store the available freshwater water resources on the earth. Dams are built for storing freshwater in large quantities to overcome the water shortage.

As can be witnessed in the historical record, dam building is as old as man's civilization. Elsewhere, India, Mesopotamia and Egypt are old civilization were dams existed. On record, the old dam in the world is Egyptian Saddle-Kafara dam which was built around 2600 BC as a diversion dam for flood control, but it was destroyed by heavy rain during construction or shortly afterward (Kok, 1987).

Dams can usually be classified into two different groups: concrete and earthen/rock. Concrete dams can usually be classified into gravity, arch, or buttress. Almost 80% of the world's major dams are constructed from natural erodible earthen materials (US Committee on Large Dams, 1975). In the United States, about 11,000 dams were constructed in the mid-twentieth century (Caldwell, 2009). Given the cheaper cost often associated with earth dam construction in developing countries, this percentage is likely higher on a global scale.

Despite the efforts to promote dam safety, but the huge water volume that is retained in the reservoir can produce a serious flood and threat the properties and population in the downstream if a sudden released of the stored water may occur (Razad et al., 2013). There are many factors that may increase the potential of dam failure by overtopping and piping such as changes in the patterns of global climatic, the insufficient discharge capacity of the spillway and lack of maintenance of the embankment dams. Therefore, the study of dam break is considered significantly necessary in order to determine the peak outflow to assess economic, social and environmental impacts downstream and to prepare the emergency response plan. Over the past years, the need to predict, model and understand the characteristics of dam break has become an important subject. Therefore, many physically and numerically techniques have been developed for dam break analysis.

In the latter half of the twentieth century, several major embankment dams failed. In the Netherlands, in February 1953, a high–tide storm caused the highest water levels observed up to date and breached the dikes in more than 450 places, causing the death of nearly 1,900 people as well as enormous economic damage (Gerritsen, 2005). The Baldwin Hills Reservoir near Los Angeles failed in 1964, destroying 277 homes and killing 5 people after discharging 1 million m^3 of water from the reservoir and causing an additional 73 million CAD (12M USD in 1971) in property damage (Hamilton and Meehan, 1971). The Teton Dam in Idaho failed in 1976 and is considered one of the most well-known dam failures in the world; 14 people were killed and over $1 billion in damages were caused (Solava and Delatte, 2003). But the world's worst dam disaster occurred in Henan province in China, in August 1975, when the Banqiao Dam and the Shimantan Dam failed catastrophically due to the overtopping caused by torrential rains. Approximately 85,000 people died from flooding and much more died during subsequent epidemics and starvation; millions of residents lost their homes (Qing, 1997). This catastrophic event is comparable to what Cherno and Bhopa represent for the nuclear and chemical industries (McCully, 1996). Additionally, between 1985 and 1994, there have been more than 400 dam failures in the United States alone. The amount of life loss will depend on a number of different factors including: the water depth, geographical distribution of the population, warning time to reach the population, and how easy it is to warn them. Therefore, if advanced warning messages are delivered to the population, lives can be saved.

Dam failures do not always result in loss of life, however, as many have been constructed far away from populated centers. Massive ecological damage is also possible. When the Aznalcollar tailings pond dam in Spain failed in 1998, a great quantity of toxic material spilled out into the river system, causing devastating ecological damage which threatened a nearby national park (Coleman et al., 2002). Similarly, when the Opuha Dam in New Zealand failed in 1997 while it was under construction, it caused significant economic and environmental damage (Coleman et al., 2002).

1.2 Problem Statement

Malaysia has not experienced any dam break incident. As the dams in Malaysia get older, the scenario of dam break should be considered in order to take relevant safety measures. Flooding due to dam break leads to greater peak discharge magnitudes compared to any flood that resulting from rainfall. Moreover, it will often have catastrophic consequences if there are human developments found downstream of the dam. To evaluate the flood damage resulting from a dam break, one has to predict not only the mode and possibility of a dam break but also the flood waves' propagation and the volume of floodwater that the dam breach will release.

The most important factors in the dam break analysis are hydrological parameters (peak outflow and time failure) and dam breach geometry (breach width and breach height). Therefore, the development of simple and precise approaches to deal with estimation of these parameters has been the focus of many contributions published in the last decades (Wahl 2010; Bentaher 2013; Froehlich 1995; Xu and Zhang 2010). The statistical approaches that use regression analysis are considered as traditional approaches for predicting dam breach parameters. In this approaches, reservoir characteristics such as depth and volume of water were taken as the dependent variables to obtain the best-fit equations for estimation of peak outflow and dam breach parameters (USBR 1988; Von Yhun and Gillette 1990; Froehlich 1995a, 2004, 2008; Xu and Zhang 2010). More accurate equations can be obtained when the database of dam failure cases are well documented (Xu and Zhang 2010).

Wahl (2004) and Pierce (2010) criticized the quality of the data for the case studies that were used in the formulation of regression analysis methods and the accuracy of predictions from these methods. Black-box models is an alternative approach if the suitable database exists. In the black-box models, the inputs and targets are mapped directly inside the model without detailed consideration of the internal structure of the physical process (Hakimzadeh et al., 2014). Artificial Neural Network (ANN) is considered as a black-box model which have usefulness exceed traditional statistical models such as free-pattern of forecasting model, toleration to data inaccuracy and their data-driven nature (Azmatullah et al., 2005). In addition to its simplicity, capability and accuracy. Artificial Neural Network (ANN) has been adopted and commonly used to model various problems in the field of water resources engineering. Forever, it has not been used specifically for estimating dam breach parameters.

Climate change is an important issue that has gained increasing attention in recent years. Climate change may involve changes in the length and time of weather variation or changes in mean weather conditions (Carnesale & Chameides, 2011). Most of the dams in Malaysia are designed for estimated life more than 100 years. However, Malaysia is affected by climate change and the period included climate change studies, particularly for dam break analysis, should consider the dam life. Despite the climatic changes that are expected in Malaysia, there have been no studies that carried out on the effect of climatic changes on dam break analysis. Therefore, analysis of flow depth, peak outflow and inundation maps that results from dam failure with different scenario under current and future climatic changes is considered very important and necessary for dam safety in Malaysia.

Dam failure can lead to significant downstream disaster. This is especially true for a valley that has cascade reservoirs, which would intensify the extent of the disaster. Numerous experimental and computational studies concerning dam-break flows have been conducted over the past decades. However, the focus of majority of these research studies is on flood that results from the failure of a single dam due to overtopping failure mode only (Bellos et al. 1991; Gracia-Navarro, 1999; Zhou et al. 2005; Al-Taiee and Rasheed, 2009; Dewals et al. 2010; Xiong, 2011; Cao et al., 2011; Mungkasi et al. 2013; Ehsan and Marx 2014; Sun et al. 2014; George and Nair, 2015; Wang et al., 2016; Andrew, 2016). There is scarce quantitative research about cascading dam-break flows despite the fact that cascading dam-break floods are significantly more disastrous since they can progressively destroy a series of dams.

The present study includes a more accurate technique for estimation of dam breach parameters. Also, the hydrological modeling for estimation of maximum probable flood considering climate change impact. While the hydrodynamic modeling for dam break modeling will consider different dam failure mode including overtopping and piping for a selected cascade dams in Malaysia.

1.3 Research Objectives

The main objective of the present study is to model the dam break for a cascade dams which include (Temenggor, Bersia and Kenering) dams located in the state of Perak, Malaysia with consideration of climate change impact. The specific objectives of this study are:

1. To propose the generalized regression neural network (GRNN) as a new method that can accurately estimate the dam breach parameters.
2. To estimate the maximum probable inflow hydrograph into Temengor reservoir using MIKE 11 (NAM – Submodel) hydrological model with consideration of climate change impact.
3. To investigate the possible scenarios of dam failure such as overtopping and piping for cascade dams using 1D and 2D hydrodynamic models.
4. To produced predicated inundation maps at the Temenggor, Bersia, and Kenering catchment due to dam break with consideration of climate change impact.

1.4 Significance of the Study

This study is concerning the simulation of dam break for cascade dams (Temenggor, Bersia and Kenering) located at Perak state, Malaysia with consideration of climate change impact.

Data related to failed dams around the world were used to build Generalized Regression Neural Network (GRNN) models for accurately estimating dam breach parameters (dam breach width and dam failure time). The available methods used for estimation of dam breach parameters are based on regression analysis and suffer from uncertainty in their predictions.

In this study, the dam break modeling was conducted by considering the impact of climate change on the probable maximum flood (PMF). The impact of climate change was not considered before in dam break studies in Malaysia. Also, a different mode of failure including overtopping and piping were considered in this study. However, most of the dam break studies were considered the overtopping failure mode only.

The consideration of cascade dams in dam break modeling is one of the main significance of the present study. Perak dam system which consists of three dams (Temenggor dam, Bersia dam and Kenering dam) was taken as a case study. Almost all the studies on dam break in Malaysia was focused on a single dam only.

The inundation depth maps are the main output of the present study. These maps will help to prepare the emergency action plan for the affected areas in order to reduce human and economic losses.

Also, the flood due to single dam break has a catastrophic consequences if the human development was found downstream of the dam. But this consequence will be more sever when more than one dam founded on the same river (cascade dam). Therefore, this study was conducted in order to investigate the flood due to the failure of the series dam. While most of the previous dam break studies were focused on modeling of dam break due to the single dam.

1.5 Scope and Limitations

This study was conducted to model dam failure by taking (Temenggor, Bersia and Kenering) located at Perak State, Malaysia as a case study. The simulation includes estimation of dam breach parameters using Generalized Regression Neural Network technique and data of 140 failed dam around the world. Due to a limitation in data, 85% of the data is used for training while the remaining 15% is used for testing.

The study also includes the hydrological modeling to forecast the inflow hydrograph for the catchment of Temengor dam. Mike 11 (NAM – Submodel) is used for this purpose. The data was acquired from respective Government authorities in Malaysia. Data on streamflow is derived using water balance concept. Also, there is no meteorological station found in the catchment of the study area, so the evaporation is taken from the nearest station.

The hydrodynamic modeling include the simulation of flood wave resulted from a dam break. Mike 11, Mike 21 are used to simulate flood wave at (Temenggor, Bersia and Kenering) catchment. Limited data is available to be used in the modeling process. The available data for streamflow and water level are from January 1980 to June 1983 and these data were used for calibration and validation for Mike 11. For Mike 21 model, existing values for the Manning coefficient of roughness for the floodplain are used in the model application. These values are ranging from 0.045 to 0.10 and taken from (TNB).

1.6 Thesis Layout

This thesis is organized into five chapters. Chapter one focuses on the introduction while Chapter two summarizes the published literature. The methodology and description of the study area are presented in Chapter three. Chapter four present the results that obtained from the study and their discussion. Finally, Chapter five present the main conclusions and the recommendations for the future research.

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LIST OF PUBLICATIONS

Published Paper

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Other Papers

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