INVESTIGATION OF EFFECTIVE ON-SITE DETENTION POND DESIGN USING VARIOUS METHODS

SHIRLINE LEONG AI LIN

B. ENG(HONS.) CIVIL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor Degree of Civil Engineering

____

(Supervisor's Signature)

Full Name : DR. JACQUELINE ISABELLA ANAK GISEN

Position : SUPERVISOR

Date : 14 JANUARY 2019

STUDENT'S DECLARATION

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

____

(Student's Signature)

Full Name : SHIRLINE LEONG AI LIN

ID Number : AA15289

Date : 14 JANUARY 2019

INVESTIGATION OF EFFECTIVE ON-SITE DETENTION POND DESIGN USING VARIOUS METHODS

SHIRLINE LEONG AI LIN

Thesis submitted in fulfillment of the requirements
for the award of the
Bachelor Degree in Civil Engineering

Faculty of Civil Engineering and Earth Resources
UNIVERSITI MALAYSIA PAHANG

JAN 2019

DEDICATION

Every challenging work requires self-efforts and perennial love from individuals close to our hearts. My humble effort I dedicate to both of my parents that love, encourage and pray for my success and honor.

Invaluable guidance from my supervisor had made it possible for me to complete this work. I respectfully dedicate this thesis to Dr. Jacqueline Isabella Anak Gisen.

ACKNOWLEDGEMENTS

Firstly, I would like to express my sincere gratitude to Faculty of Civil Engineering & Earth Resources, Universiti Malaysia Pahang for giving me this opportunity to undertake my Final Year Project. Throughout my Final Year Project completion journey, assistance provided by various parties have helped me tremendously and without these endorsements my Final Year Project might not have been a success.

Next, I would like to express my very great appreciation to Dr. Jacqueline Isabella Anak Gisen, for her advice and perennial care offered to me. Valuable lessons and advices given to me have guided me throughout this Final Year Project. Without Dr Jacqueline acting as the backbone of my Final Year Project, I would not have completed this Final Year Project within this short period of time.

Ultimately, my special thanks are extended to my family members, who are supporting me all the way from home. I am more than glad to have warm companionship with my family members throughout my Final Year Project completion journey. I am certain that supports and prayers from both of my parents have played a significant role in my success.

ABSTRAK

Banjir kilat dan banjir monsun adalah bencana yang sangat umum disebabkan oleh pengurusan air ribut yang tidak wajar. Oleh itu, kolam tahanan air hujan memainkan peranan penting dalam usaha pengurusan air ribut untuk mengurangkan kebarangkalian kejadian banjir. Sebelum merancang kemudahan penahanan air hujan, pengumpulan data hujan siri masa yang mencukupi dan analisis data hujan memainkan peranan yang sangat penting dalam memastikan ketepatan reka bentuk kemudahan kolam tahanan. Dalam kajian ini, data hujan siri masa untuk 30 tahun yang lalu telah dikumpulkan dan data hujan yang hilang telah dianggar menggunakan kaedah Arithmetic Mean dan konsistensi data hujan dinilai melalui kaedah Mass Curve. Dari analisis konsistensi, didapati bahawa tapak pembangunan Pekan mempunyai konsistensi data hujan tertinggi diikuti oleh tapak pembangunan Kuantan dan tapak pembangunan Jerantut. Selain itu, ciri-ciri sistem penahanan air hujan di tapak bergantung kepada prestasi lengkung IDF yang memberikan intensiti hujan yang bersamaan dengan pelbagai tempoh ribut dan ARI. Lengkung IDF yang disediakan dalam MSMA 2 tidak mengambil kira data hujan sehingga tahun semasa. Oleh itu, dalam kajian ini, lengkung IDF telah dibuat menggunakan Gumbel Type I distribution untuk stesen hujan terdekat kepada setiap tapak pembangunan. Difahamkan bahawa perbezaan antara kurva IDF baru dan kurva MSMA 2 IDF kajian adalah kecil untuk 60 minit pertama tempoh hujan dan meningkat secara beransur-ansur apabila tempoh hujan melebihi 60 minit. Ini disebabkan data hujan yang dipertimbangkan dalam membuat kurva IDF baru hanya sehingga 60 minit. Selain itu, penggunaan kaedah reka bentuk kemudahan kolam tahanan menentukan keberkesanan kos dan kegunaan kemudahan kolam tahanan. Kolam tahanan yang direka akan diklasifikasikan sebagai ‘under designed’ jikalau ia mempunyai keberkesanan yang rendah dalam mengurangkan risiko kebanjiran manakala kolam tahanan yang diklasifikasikan sebagai ‘over designed’ akan menyebabkan risiko kebanjiran dikurangkan tetapi tidak kos effektif. Oleh itu, dalam kajian ini, kolam tahanan di tiga kawasan pembangunan dianalisis dengan menggunakan dua kaedah iaitu Kaedah Simplified dan Kaedah Modified Puls. Dari hasil kajian, didapati Kaedah Modified Puls menghasilkan reka bentuk yang lebih kos efektif berbanding Kaedah Simplified. Akhirnya, hasil kajian telah memberikan industri kejuruteraan awam satu kefahaman mengenai kaedah reka bentuk kos efektif kolam tahanan untuk menghalang kerugian kewangan dalam pembinaan kolam tahanan yang teelalu besar.

ABSTRACT

Flash flood and monsoon flood are very common disasters that caused by improper stormwater management. Hence, on-site detention facility plays an indispensable role in stormwater management efforts to reduce probability of flood occurrences. Prior designing on-site detention facility, collection of sufficient time series precipitation data and rainfall data analysis play indispensable role in ensuring the accuracy of on-site detention facility design. In this study, time series rainfall data for the past 30 years were collected and rainfall data gaps were approximated using the Arithmetic Mean method and the consistency of the gap filled rainfall data was evaluated using the Mass Curve method. From the consistency analysis, it was found that Pekan development site has the highest rainfall data consistency followed by Kuantan development site and Jerantut development site. Moreover, the characteristics of on-site detention system is depending on the IDF curve performance which gives the magnitude of rainfall intensity corresponding to various storm duration and ARI. The IDF curves provided in MSMA 2 was not up to the current year. Thus, in this study, IDF curves were developed using Gumbel Type I distribution for the nearest rainfall station to each development site. It was noticed that difference between the study's IDF curve and MSMA 2 IDF curve appeared to be small for the first 60 minutes of storm duration and gradually increased when the storm duration greater than 60 minutes. This was due to rainfall data considered in developing new IDF curve was only up to 60 minutes. Furthermore, the adoption of on-site detention facility design method determines the cost effectiveness and usefulness of the on-site detention facility. An under designed on-site detention facility has low effectiveness in reducing flood probability whereas an over designed on-site detention facility is not economical. Thus, in this study, on-site detention facility of three development areas were analysed using two methods namely, the Simplified Method and the Modified Puls Method. From the study outcome, it was found that the Modified Puls Method produced more economical design compared to the Simplified Method. Ultimately, the study outcome has provided the civil engineering industry an insight on the cost effective design method of on-site detention facility to prevent monetary losses in construction of oversized on-site detention facility.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

$\bar{P}$	Average Rainfall Depth
Pi	Rainfall at The ith Rain Gauge Station
N	Total Number Of Rain Gauge Station
β	Scale Parameter Of Gumbel Distribution
μ	Location Parameter Of Gumbel Distribution
$\bar{X}$	Arithmetic Mean Of Observations
S	Standard Deviation Of The Observations
K_T	Frequency Factor
T	Return Period
I	Rainfall Intensity
λ	Coefficient Of Power Law
K	Coefficient Of Power Law
θ	Coefficient Of Power Law
η	Coefficient Of Power Law
d	Rainfall Duration
Q	Peak Flow
C	Runoff Coefficient
A	Area Of Catchment
C_{avg}	Weighted Runoff Coefficient
C_j	Runoff Coefficient Of Segment j
A_j	Area Of Segment j
m	Total Number Of Segments
t_c	Time Of Concentration
t_o	Time Taken For Overland Flow
n	Horton Roughness
S	Overland Slope
L	Length Between Highest Point And Lowest Point
t_d	Time Taken For Channel Flow
n	Manning's Roughness Coefficient
S	Channel Slope
L	Length Of Channel From The Highest Point To The Outlet
R	Wetted Perimeter
V_S	Preliminary Detention Storage Required
Q_o	Outflow Discharge Limit

Q_i	Inflow Peak Discharge
t_i	Total Duration Of Hydrograph
I(t)	Inflow Rate
O(t)	Outflow Rate
S(t)	Volume Of Water Stored at t
Q	Discharge Of Orifice
H_o	Effective Head Of Orifice
A_o	Orifice Cross Sectional Area
C_o	Orifice Flow Coefficient
g	Gravitational Constant

LIST OF ABBREVIATIONS

DID	Department Of Irrigation And Drainage
FAA	Federal Aviation Administration
GCM	Global Climate Modelling
IDF	Intensity – Duration – Frequency
LCW	Lai Chi Wo
MBJB	Majlis Bandaraya Johor Bahru
MRM	Modified Rational Method
MSMA	Manual Saliran Mesra Alam
OSD	On – Site Detention
PSD	Permissible Site Discharge
SSR	Site Storage Requirement
STP	Sewage Treatment Plant
USM	Universiti Sains Malaysia

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Extreme events such as flash flood and monsoon flood are induced by either improper or insufficient storm-water management. Improper storm water management tends to increase the probability of flood occurrence. For a small development area located at the upstream region of a catchment produces minimal runoff volume to be managed. Although the small volume might seem to be negligible but when the runoff volumes from several development areas are accumulated downstream, yielding an uncontrollably high peak discharge during heavy rainfall event which consequently causing flood to occur. The condition is worsened by rapid urbanization as the change in land uses from forest cover to build up areas increase the percentage of the land imperviousness.

Rainfall runoff from the land surface is drained into the conveyance facilities before it is discharged into a river system. When the peak discharge is extremely high, the river tends to overflow. In the effort to reduce the peak discharge, comprehensive drainage design for flood prevention is necessary. For this reason, it is essential to construct a detention pond at the downstream part of the development area. In many developed countries such as Australia, Canada and Japan, implementation of on-site detention system (OSD) has been made mandatory along with their massive development for decades. The effectiveness of a detention pond is highly depending on the accuracy of the design. Ineffective design of on-site detention facility may not able to perform satisfactorily and is non cost effective.

The implementation of OSD has been made mandatory for new development area in the Pahang State after the serious flood during the end of year 2013. There are two types of OSD namely the above ground storage and the below ground storage. The maintenance for below ground storage is more difficult than the above ground storage. Hence, the above ground storage is more favourable and commonly used.

Storm-water management structures can be very costly especially when unpredictable construction faults occurred which increase the cost needed to remedy the situation. Thus, it is very important to evaluate the optimum specifications of OSD in accordance to the Malaysian guidelines. There are few methods available to design detention systems, for instance hydrological modelling, hydrological routing, and empirical design method. In Malaysia, the guidelines for OSD design is based on the Urban Stormwater Management Manual for Malaysia (MSMA 2). In this study, two methods were used to design the OSD which are the conventional hydrological routing (MSMA 2: Chapter 7) and simplified empirical design method (MSMA 2: Chapter 5). The conventional hydrological routing adopted is the Modified Puls Method which involves the routing of inflow hydrograph to obtain the resultant outflow hydrograph. Meanwhile, the simplified empirical design method is solely based on the OSD characteristics tables which are classified by region of development, terrain, and percentage of imperviousness. Nevertheless, no matter which design method is adopted, over-designed system will affect the construction process financially. Therefore, optimum design of OSD is important to ensure cost effectiveness of a development project.

1.2 PROBLEM STATEMENT

Detention system is meant to delay and reduce post development peak discharge through temporary storage. Improperly designed detention system can be costly when over-designed, and unable to cater high discharge when under-designed. Construction industry demands efficient, effective and cost effective designs. Thus, the optimum design of OSD storage is crucial. However, there are many methods and guidelines available for the design of detention system. In this study, two methods provided in MSMA 2 were compared to investigate the most cost effective method.

Before designing the OSD system, rainfall data analysis has to be performed. The relationship between the rainfall intensity, storm duration and flood frequency is illustrated by IDF curves. IDF curve provided by MSMA 2 is not updated to the current year. Thus, the development of updated IDF curve based on the up to date rainfall data is required for the design purpose. Total of 30 years rainfall data is available for analysis but these data contains a lot of missing data. In the effort of filling the rainfall data, arithmetic mean method was used. Data filling is important to ensure the accuracy of the developed IDF curves and subsequently the accuracy of stormwater management structure designs.

1.3 OBJECTIVES

The objectives of this study are stated as follow:

1. Perform rainfall data consistency analysis.

2. Develop new Intensity Duration Frequency curve for designated study areas.

3. To investigate the most effective method to design on-site detention pond.

1.4 SCOPE OF STUDY

In this study, three project development sites located in the Kuantan District, Pekan Town and Jerantut Town have been selected. Each project development site selected has a limited total area of less than 5 Hectares. All the project areas selected representing different topographic characteristics including low-lying terrain, mild terrain and steep terrain. The development layout drawings of the selected areas were collected from a local consultant firm for the boundary extraction and levelling information. For the time series precipitation data of 30 years, they were acquired from the Department of Irrigation and Drainage. Since the main factor that govern the accuracy of the study is the time series rainfall data, missing precipitation data has been filled by using the Arithmetic Mean Method. For the development of IDF curve, Gumbel Type I Extreme Value Distribution was used and the relationship between the rainfall intensity, duration and return period was established via Power Law empirical approach. Prior to the design of the OSD system for each development site, inflow hydrograph was derived through the Rational Hydrograph Method. The design outputs obtained through Simplified Method and Modified Puls Method in accordance to MSMA 2 were compared and the most cost viable design was identified.

REFERENCES

Aravinda, P., Balakrishna, H., Jayaramu, K. 2015. Identification of Potential Sites for Detention Ponds along the Vrishabhavathi River. International Conference on Water Resources, Coastal and Ocean Engineering (ICWRCOE 2015) 585-592.

Ariff, N., Jemain, A., Ibrahim, K., Zin, W. W. (2012). IDF Relationships Using Bivariate Copula for Storm Events in Peninsular Malaysia. Journal of Hydrology. 470-471: 158-171.

Benjamin, N. (2017). The Star Online. Retrieved from The Star Online: https://www.thestar.com.my/metro/community/2017/06/02/efforts-to-mitigate-flash-floods-council-to-remove-silt-rubbish-and-sand-from-retention-ponds/

Caldera, H., Piyathisse, V., Nandalal, K. (2016). A comparison of Methods of Estimating Missing Daily Rainfall Data. Engineer. XLIX(04): 1-8.

Farahmand , T., Fleming , S. W., Quilty, E. J. (2007). Detection and Visualization of Storm Hydrograph: An Impulse Response Approach. Journal of Environmental Management. 85(1): 93-100.

Guo, & J. C. (1999). Detention Basin Sizing For Small Urban Catchment. ASCE J. of Water Resoures Planning and Manangement, Vol 125, No.6, Nov.

Herget, J., Meurs, H. (2010). Reconstructing Peak Discharges for Historic Flood Levels in the City of Cologne, Germany. Global and Planetary Change. 70(1-4): 108-116.

Jamaluddin, A. F., Hassan, Z. A., Ghani, A. A. (2011). Effectiveness of Aman Lake as Flood Retention Ponds in Flood Mitigation Effort: Study Case at USM Main Campus, Malaysia. 3rd International Conference on Managing Rivers in the 21th Century: Sustainable Solutions for Global Crisis of Flooding, Pollution and Water Scarcity. 1-7

Kalantari, Z., Lyon, S. W., Folkeson, L., French, H. K., Stolte, J., Jansson, P.-E., Sassner, M. (2014). Quantifying the Hydrological Impact of Simulated Changes in Land Use on Peak Discharge in a Small Catchment. Science of the Total Environment. 466-467: 741-754.

Kuichling, E. (1889). The Relation between the Rainfall and the Discharge of Sewers in Populous Places. Transactions of the American Society of Civil Engineers. 20: 1-60.

Lundberg, K., Carling, M., Lindmark, P. (1999). Treatment of Highway Runoff: A Study of Three Detention Ponds. Science of The Total Environment. 235(1-3).

Martínez-Carreras, N., Hissler, C., Gourdol, L., Klaus, J., Juilleret, J., Iffly, J. F., Pfister, L. (2016). Storage Controls on the Generation of Double Peak Hydrograph in a Forested Headwater Catchment. Journal of Hydrology. 543(B): 255-269.

Mei, Y., Anagnostou, E. N. (2015). A Hydrograph Separation Method Based on Information from Rainfall and Runoff Records. Journal of Hydrology. 523: 636-649.

Mélèse, V., Blanchet, J., Molinié, G. (2018). Uncertainty Estimation of Intensity-Duration-Frequency Relationships: A Regional Analysis. Journal of Hydrology. 558: 579-591.

Mohamadi, M. A., Kavian, A. (2015). Effects of Rainfall Patterns on Runoff and Soil Erosion in Field Plots. International Soil and Water Conservation Research. 3(4): 273-281.

On-site Stormwater Detention Handbook, Third edition. (1999). Upper Parramatta River Catchment Trust.

Perumal, E., Tan, V. (2015). THE STAR ONLINE. Retrieved from https://www.thestar.com.my/metro/community/2015/08/19/77-floodprone-areas-in-selangor-poorly-kept-drains-and-retention-ponds-cause-of-flash-floods/

Qian Xu, Ji Chen, Peart, M. R., Ng, C.-N., Hau, B. C., Law, W. W. (2018). Exploration of Severities of Rainfall and Runoff Extremes in Ungauged Catchments: A case study of Lai Chi Wo in Hong Kong, China. Science of the Total Environment. 634: 640-649.

Raj, R. (2017). The Malay Mail Online. Retrieved from http://www.themalaymailonline.com/malaysia/article/rm40m-retention-ponds-to-overcome-kl-floods

Rupa Chandra, U. S. (2015). Model and Parameter Uncertainties in IDF Relationships Under Climate Change. Advances in Water Resources. 79: 127-139.

Simonovic, S. P., Schardong, A., Sandink, D., Srivastav, R. (2016). A Web-Based Tool for the Development of Intensity Duration Frequency Curves under Changing Climate. Environmental Modelling & Software. 81: 136-153.

The Straits Time Asia. (2018). Retrieved from http://straitstimes.com/asia/se-asia/nearly-5000-evacuated-from-pahang-floods

Timbuong, J. (2017). THE STAR ONLINE. Retrieved from https://www.thestar.com.my/news/nation/2017/02/12/postflood-dangers-still-lurk-receding-waters-leave-vectorborne-diseases-in-their-wake/

Urban Stormwater Management Manual for Malaysia, MSMA2nd Edition. (2012). Department of Irrigation and Drainage.

Wei Li, Maren, D. v., Wang, Z., Vriend, H. J., Wu, B. (2014, May). Peak Discharge Increase in Hyperconcentrated floods. Advances in Water Resoures. 67: 65-77.

Y.S, L., Z., S., Ghani, A. A., A.Ab, G., N.A, Z. (2012). Performance of a Dry Detention Pond: Case Study of Kota Damansara, Selangor, Malaysia. Urban Water Journal. 9(2): 129-136.

Yao Ming, H. (2007). Numerical Simulation of Laboratory Experiments in Detention Pond Routing with Long Rainfall Duration. International Journal of Sediment Research. 23(3): 233-248.

Yao Ming, H., Naichia , Y., Jen-Yan , C. (2006). The Simplified Method of Evaluating Detention Volume for Small Catchment. Ecological Engineering. 26(4): 355-364.

Yao-Ming, H. (2008). Numerical Simulation of Laboratory Experiments in Detention Pond Routing with Long Rainfall Duration. International Journal of Sediment Research. 23(3): 233-248.

Yao-Ming, H. (2010). Experimental Evaluation of Design Methods for In-Site Detention Ponds. International Journal of Sediment Research. 25(1): 52-63.