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Flow Profile on Urban Road Intersection Based on The Longitudinal Slope

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Abstract

The rapid growth of the city population, as a consequence of urbanization, had impacted on the provision of facilities and infrastructure, i.e. housings, office buildings and shopping malls, roads, schools, and other public facilities. The availability of pervious land in urban area will decrease, as the impacts of development. This causes the reduction of the soil's ability to absorb the rain water, so that the drainage load and the peak discharge will increase, and the peak time of runoff is getting short. Unfortunately, the increase of the drainage load is not followed by an improvement of the drainage system capacity. On every rainy season, in almost all major cities in Indonesia experienced inundation with an average depth 20-40 cm. Inundation especially occurs on the main road sections and residential streets caused by the backwater effect as a result of the joining of two or more surface flow at a road intersection with different longitudinal slope. It is necessary to analyze the flow profile at a road intersection with a major review on the longitudinal slope factor. The study design consists of field observations and analytical activities, as follows: determination of the independent variables (i.e. rainfall intensity, longitudinal slope of roads) and the dependent variable (i.e. inundation depth); field measurements and data collection; simulation of flow profiles with various return period of rainfall using Hydraulic Model HEC-RAS; verification of the simulation result of flow profiles using observation data. This research results the relationship between the ratio of the longitudinal slope to the inundation depth at a road intersection and to a non-dimensional number, i.e. Froude Number. The relationship can be well expressed by exponential regression functions, y = 0.5749e0.8965x (x = inundation depth); and y = 0.8371e1.7523x (x = Froude Number). The ratio of the longitudinal slope is the comparison between the slopes of the roads that intersecting. The result also show that the optimum slope ratio is 0.75 where the inundation depth is still going on an allowable limit, and the rain with a return period of 2-year had already resulted an inundation depth exceeding the allowable limit.

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Keywords: Road intersection; longitudinal slope; backwater

1. Introduction

1.1. Structure

The rapid growth of the city population, as a consequence of urbanization, had impacted on the provision of facilities and infrastructure, i.e. housings, office buildings and shopping malls, roads, schools, and other public facilities. The availability of pervious land in urban area will decrease, as the impacts of development. This causes the reduction of the soil's ability to absorb the rain water, so that the drainage load and the peak discharge will increase, and the peak time of runoff is getting short. Unfortunately, the increase of the drainage load is not followed by an improvement of the drainage system capacity. In rainy season, almost all major cities in Indonesia experienced inundation with an average depth 20-40 cm. This condition interferes with the activity of society and cause discomfort, especially for road users. From the preliminary study conducted on some major roads in the city of Malang East Java, inundation usually occurs on roads with lower elevation and the road at the intersection. At every intersection, inundation does not always occur,

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but from some initial observations that have been made, at the junction with the differences of longitudinal slope are quite large, always occur the inundation higher. The condition is thought as a backwater effect that resulted from the joining of two or more of surface flow at the road intersection. During heavy rains, road can serve as a floodways [1]. Floodways are sections of roads which have been designed to be overtopped by floodwater during relatively low average recurrence interval (ARI) floods [2]. A roadway across a shallow depression subject to flooding, specifically designed to overtop and constructed to resist the damaging effects of overtopping [3]. The type of road pavement [4], the road network [5], spatial development change [6], and road rain pump [7] influence the inundation depth and the reduction of the runoff quantity. To assess where on the road most water from the surroundings will assemble, and how water will flow over the road after heavy rainfall by the use of a Laser Mobile Mapping System (LMMS) which, at high measuring rate, captures dense and accurate point clouds [8]. Maximum ponding depth on the road does not depend significantly on longitudinal grade, but the location of maximum ponding depth is very sensitive to longitudinal grade [9]. There was no study that investigated the inundation model at a road intersection. It is therefore hoped that the current research would find out the inundation model in urban road intersection based on the longitudinal slope as a part of storm water management. This model could be used to estimate the road inundation and runoff based on the slope data.

1.2. Problem Statement

The urban drainage system in Malang and its surroundings areas is overwhelmed with a number of problems. In spite of the fact that Malang is a plateau region, in every rainy season on some areas especially the road intersections are always flooded 40 cm in average that exceed the permitted depth is 30 cm [1]. This condition is thought to be the impact of backwater flow. Problems to be studied in this research are as follows:

1. How is the inundation profile on the road intersection?
2. How is the relation between the ratio of longitudinal slope with the runoff discharge and the inundation depth?
3. How is the relation between the ratio of longitudinal slope and the non-dimensional Froude Number?

1.3. Objectives

The main objective of this study is to determine the flow profile at a road intersection with a major review on the longitudinal slope factor. To achieve the main objective, this study also was designed with several specific objectives as follows:

1. To know the inundation profile on the road intersection.
2. To know the relation between the ratio of longitudinal slope with the runoff discharge and the inundation depth.
3. To know the relation between the ratio of longitudinal slope and the non-dimensional Froude Number.

2. Material and Method

2.1 Study Area

Study area is located at Bhumi Purwantoro Agung, Malang City, along Sulfat Highway. The total number of observation points or road intersection is ten points, located in Taman Sulfat Housing which is the outlet of runoff in the study area. The ten road intersections are defined as TS1, TS3, TS5, TS7, TS9, TS11, TS13, TS15, TS17, TS19. The major land covering at the study area are building houses, roads are equipped with drainage channels, but there are several roads without drainage, as well as a small part in the form of an open space area. Formerly, the housing in the study area was farmland. Along with the development of the city, then the area converted into residential areas with medium density.

2.2 Methodology

The research method is analytic observational study, consist of observation and data collection in the field, as well as the analysis of flow profiles using a hydraulic model. The modelling results will be verified by using the results of field observations on certain conditions in accordance with rain events. This research was conducted by using flow in open channels approach with a wide cross-section. Geometrical data of road that includes a cross-sectional and longitudinal slope obtained through direct measurements in the field. Whereas the flow profile caused by the backwater phenomenon that includes the data of flow velocity and flow height obtained using HEC-RAS hydraulic model version 4.0. Verification is done by using the data model of water level observations at several rain events. Road intersection observed is the intersection of a meeting between a residential street to the main road in Bhumi Purwantoro Malang Housing which is an outlet of surface runoff.

2.3 Data Collection

Primary data. The primary data consist of topographic maps, road geometry and inundation depth. Topographic map scale 1: 10,000 of the study area was not available so that it was made by direct measurement. Measurements was using theodolite for mapping the study area. The data of road geometry include cross and longitudinal section. Cross-section measurements performed on each interval of 20 m. Measurement of cross and longitudinal profile was performed using waterpass. Water level data was obtained by direct measurements at points of observation that were experiencing inundation during the rainy season in the study period. Secondary data. The secondary data is daily rainfall data from three rainfall stations, namely Abdul Rahman Saleh Station, Ciliwung Station and UB Station. Rainfall intensity data is determined from the maximum daily rainfall data analyses.

2.4 Simulation of Flow Profile

Simulation of inundation profiles using hydraulic model HEC-RAS version 4.1 was conducted in order to determine the flow profile at the point of observation on the various return period rainfall and the various longitudinal slope of road intersection in the study area. This step is also used to find out the length of backwater curve from the intersection to the upstream, so that it can be seen spreading inundation that occur at various return period rainfall and various longitudinal slope.

This activity consists of several stages. First, the geometric data preparation and flow rate at various return period rainfall; data input; and running the program to achieve the defined boundary conditions. The second is the processing of hydraulic model test data to obtain inundation depth occurred at the road intersection in a various of return period rainfall. The third is the determination of the calibration factor using field measurement data and water level observations. This activity is intended to ensure that the data used can be running with HEC-RAS software, and in case of deviations can be adjusted using the calibration factor. The lastly is viewing the results. Several output features are available under the view option from the main window. These options include: cross section plots; profile plots; rating curve plots; X-Y-Z perspective plots; tabular output at specific locations (Cross Section Table); tabular output for many locations (Profile Table); and the summary of errors, warnings, and notes. Boundary conditions are required in order to perform the calculations. If a subcritical flow analysis is going to be performed, then only the downstream boundary conditions are required. If a supercritical flow analysis is going to be performed, then only the upstream boundary conditions are required. If a mixed flow regime calculation would be performed, then both upstream and downstream boundary conditions are required (Anonymous, 2010b).

2.5 Verification of Simulation Result

Verification is conducted to ensure that the model is representative of the entire existing parameters corresponding to the basic theory. in this research, verification is done by using the data model of water level observations at several rain events. Road intersection observed is the intersection of a residential street and the main road in Taman Sulfat Housing, Malang City, which is an outlet of surface runoff.

3. Result and Discussion

3.1. Discharge of Road System

Based on the condition of the road network in the study area, then the road system is made as shown below. Discharge of road system is determined by adding the discharge runoff captured by each road, correspond to the lane of road network.

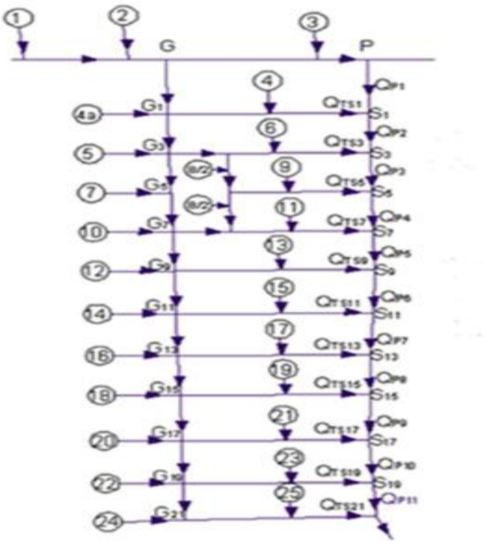

Fig. 1. Road system at the study area

3.2. Simulation Result

Figure shown below is the cross section plot of the road intersection at the downstream of the road network, and the long section plots of the inundation profile on the main road.

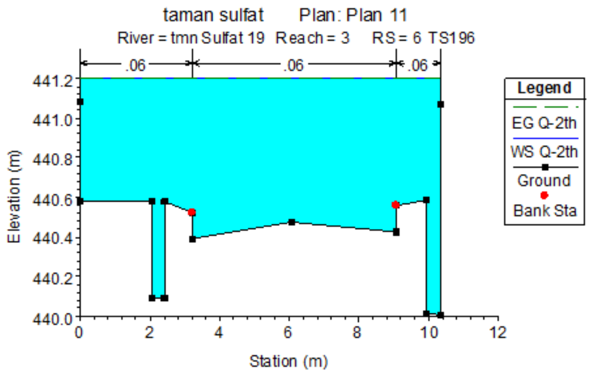

Fig. 2. Cross section plot of the road intersection at the downstream

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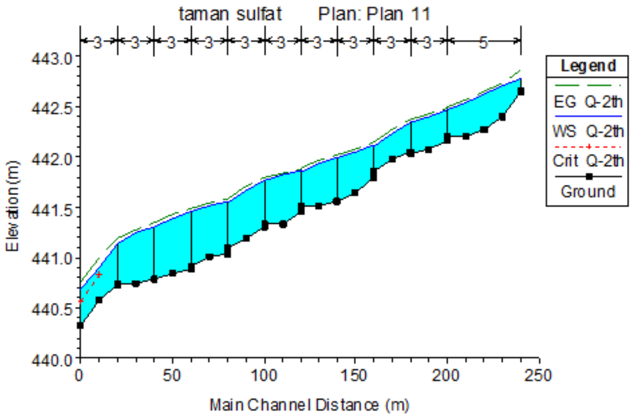

Fig. 3. Long section plot at the main road

3.3. Field Observation Result

Field observation results consist of inundation depth measurement data, and the picture of the backwater phenomenon in maximum runoff condition.

Fig. 4. Backwater flow in stormwater runoff condition

3.4. Verification and simulation result

Verification result is shown in Table 3 below:

Table 3. Calculation of the differences beetween inundation depth observation and simulation

Date	Rainfall Depth (mm)		Inundation Depth (mm)								Accu-ration (%)
			S13		S15		S17		S19		
	Obs	Calc	Obs	Sim	Obs	Sim	Obs	Sim	Obs	Sim	
13-03-14	118	100	270	320	370	430	350	400	250	300	82.74
30-02-14	95	100	250	320	350	430	330	400	230	300	74.37
26-12-13	80	100	230	320	320	430	320	400	210	300	64.66

The table above shows that the simulation results provide inundation depth data is relatively higher than the data of observation. The accuracy of those data between the range of 64.66% - 82.74% or the average is 73.93%. It can be concluded that the simulation model gives results closer to the observations.

3.5. Hydraulic characteristics of flow at the road intersection

From the result of hydrological analysis and simulation of flow profile, it could be seen that the rainfall with two year return period has caused inundation of water level exceeds the allowable. The result also shows that at several road intersections especially at the downstream part in the study area occur backwater phenomena, which indicated by a rise in water level at the downstream end of the road, and the lower flow velocity in the area around the intersection. The relation between the flow velocity and the inundation depth can be well expressed by exponential regression functions, $y = 0.7997e^{-2.7219x}$ (x: flow velocity; y: inundation depth), with determination coefficient of 47.54%.

3.6. Relation between inundation depth and ratio of longitudinal slope

The intersection between the discharge curve and the ratio curve occur in inundation depth of 0.2 meters. This depth is smaller than the maximum water level condition that is allowed on the road. Therefore it can be concluded that the optimum ratio of longitudinal slope in the study area is 0.75. It also shows that the ratio of the longitudinal slope has a relationship and a positive influence, not too tightly, against the water level, which is expressed by exponential regression functions, $y = 0.5749e^{0.8965x}$ (x: inundation depth; y: ratio of the longitudinal slope), with determination coefficient of 14.15% and 1.32 F test results; while the runoff discharge has a negative effect relationship and fairly close to the water level, which is expressed by exponential regression functions, $y = e^{-1.702x}$ (x: inundation depth; y: runoff dischrage), with determination coefficient of 37.12% and amounted to 4.72 F test results.

3.7. Relation Between The Ratio of the Longitudinal Slope and the Inundation Depth with Froude Number

Analysis of the relation between the ratio of the longitudinal slope and a non-dimensional number (Froude Number) is intended to generate a formula without the need to pay attention to the road geometric data and the amount of runoff discharge. By knowing the ratio of Froude Number of two flows at a road intersection, it could be known the magnitude of slope ratio.

The ratio of Froude Number has a positive relation and fairly close to the inundation depth which is expressed by logarithmic regression functions $y = 0.2194\ln(x) + 1.2472$, (x:ratio of Froude Number; y:inundation depth), with determination coefficient of 85.09% and F-test result of 5.54.

The ratio of the Froude Number has a positive relation and fairly close to the ratio of the longitudinal slope which is expressed by exponential regression functions, $y = 0.8371e^{1.7523x}$ (x:ratio of Froude Number; y:the ratio of the longitudinal slope), with determination coefficient of 29.46% and F-test result of 3.34.

4. Conclusions and reccomendations

Rainfall with two year return period has resulted in a inundation depth in the study area exceeding the allowable. At several road intersections occur backwater flow. It is characterized by the rise in water level at the downstream end of all roads at Taman Sulfat Housing (TS1, TS3, TS5, TS7, TS9, TS11, TS13, TS15, TS17, TS19) which is the meeting point with the main road. The flow velocity has a negative relationship to the inundation depth, which is expressed by exponential regression functions, $y = 0.7997e^{-2.722x}$. The ratio of the longitudinal slope has a positive relation to the water level, which is expressed by exponential regression functions, $y = 0.5749e^{0.8965x}$; while the runoff discharge has a negative relation and fairly close to the water level, which is expressed by exponential regression functions, $y = e^{-1.702x}$. The ratio of the longitudinal slope

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has a positive relation and fairly close to the non-dimensional Froude Number which is expressed by exponential regression functions, y = 0.8371e1.7523x. The optimum slope ratio at Taman Sulfat Housing in Malang City is 0.75, with a water level that occurred still meet the requirements of permissible water level occurred on residential roads. The research results can be used as a basis for determining the slope criteria and the capacity of the drainage channel with inundation depth within allowable level. For a more optimal result which gives a clearer overview the relation between the main observation variables, further research needs to be done at the location where the longitudinal slope more varied. It is needed to study more specific road characteristic, i.e. road without and with drainage channels, to minimize the influence of other variables outside the model.

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