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Stormwater Drainage Design (Case Study: UTHM Campus)

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Abstract: The impervious surface has risen as a result of development is growing rapidly. Impervious surfaces are considered to have poor water permeability as the surface prevents water from penetrating it which can lead to increased surface runoff. The rise of surface runoff at impervious area such as paved road and parking area will be far more severe especially when there is no existing drain nearby at Jalan Kolej in UTHM Campus. Along with the condition of road chambers that have slope to drain surface runoff to the road shoulder also may increase the surface runoff drastically in that area as the water will accumulate more due to slow infiltration rate. Therefore, the objective of this case study is to determine runoff problem at impervious area that may cause flash flood as well as to propose a good design for new storm water drainage. In this study, the rational method and Manning's equation were applied. Rational method was used to determine the peak runoff in the study area and Manning's equation was used to ensure that the stormwater drainage designed were able to accommodate peak surface runoff. As a result, it was discovered that the poor infiltration rate in the study area was also a contributing factor to increasing impervious surface runoff. The lowest infiltration rate discovered in UTHM Campus was 9.78 mm/hr. In order to decreased surface runoff on impervious surfaces while minimising the risk of flash floods, the designed stormwater drain should be able to accommodate peak flow. The peak discharge at the study area was at sub-catchment 3 with 1.723 m^3/s while the designed stormwater drainage capacity was 4.119 m^3/s. By doing this study, runoff problems were identified and a stormwater drain was developed to mitigate the problem in the study area.

Keywords: Surface runoff, stormwater drain, rational method, manning's equation

1. Introduction

In this urbanization era, development is growing rapidly especially in urban areas. There are many new developments of buildings everywhere similar to road construction where more paved roads are being built in line with the increasing number of vehicles on the road to facilitate the users. All roads, walkways, and parking areas that have significant paved surfaces that are covered by substances such as asphalt, concrete, brick, and stone are referred as impervious area. However, impervious areas have very low water permeability which rigid surfaces prevent water from penetrating and causing it to surface runoff. Problems start to arise during rainy days, as it can cause an increase in surface runoff on the road as well as cause flooding. Impermeable infrastructure is one of the primary causes of flash floods in metropolitan areas [1].

Flash floods can occur rapidly in impervious areas especially during heavy rains. Floods are becoming more common in impervious environments, where the soil cannot absorb large volumes of water in a brief period of time [2]. The phase of urbanization, which has altered the initial form of the ground surface, has raised the possibility of flooding at the development site even further. In this case, floods can also occur if the existing drains are not able to withstand the excessive volume of rainwater and runoff in a short period of time. Flooding may be unpleasant and inconvenient for motorists and residents. This is due to the fact that flooding can cause losses and damage to buildings and infrastructure.

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Therefore, the objective of this study is to the determine runoff problem at impervious area that may cause flash flood and to propose a good design for stormwater drainage. The study location is at Jalan Kolej in UTHM Campus (Universiti Tun Hussein Onn Malaysia). The study area is near to student residential colleges, parking lots, and paved roads, which most of the areas are constituted as water impermeable area. The average annual rainfall in this area is high which ranging between 2250 and 2600 mm [3]. However, because of a massive low infiltration rate at the study area, the surface runoff rate might increase when rainfall is high at one time. Accordingly, stormwater drainage is designed to mitigate the surface runoff and reduce the risk of flash flooding. The stormwater drainage was design by referring to Urban Stormwater Management Manual (SWMM 2^{nd} edition) as guideline. The hydraulic parameter used in this study is rainfall intensity and peak runoff discharge. In this study, the rational method and Manning's equation were applied. Rational method was used to determine the peak runoff in the study area and Manning's equation was used to ensure that the stormwater drain designed were able to accommodate peak surface runoff.

2. Literature Review

2.1 Runoff Effect on Impervious Surface

The growth in human population necessitates the urban development as a requirement for a pleasant livelihood [1,4]. The development of UTHM, which has been formed as a large institution as the population of Parit Raja has grown faster than surrounding area may due to increasing the number of students, upgrading facilities and others [5]. Rapid growth on the UTHM campus has transformed the existing pervious soil surface to an impervious layer which resulted in increasing surface runoff [6]. It has long been acknowledged that impervious surfaces can increase the amount of runoff during heavy rains due to a lack of water that able to permeate into the soil along with the minimum quantity of water lost through evaporation [7]. A study has shown that approximately about 50% of precipitation will penetrate and 10% will become runoff for natural unaltered soil contrarily with impervious surface which up to 55% may become runoff [1].

2.2 Soil Type Affect Infiltration Rate

Apart from the impervious surface factor which can lead to slow infiltration rate, the type of soil has a very significant impact on the rate of infiltration. The type of soils is one of the factors that leading to flood occurrences [3]. UTHM was found to have a thick layer of clay underlying soil which may indicate a poor infiltration rate. Clay soils are characterised by fine-grained particles, poor permeability, high compressibility, and low strength [8]. As the proportion of clay in the soil increases, soil infiltration will decrease [3]. In relation with that, soils with low infiltration rate will result in an increase in quantity of surface runoff.

2.3 Stormwater Drainage

In these impervious regions, stormwater drains seem to have high effectiveness in overcoming runoff concerns [9]. The drainage system at UTHM has also had to deal with extremely severe situations, such as floods in 2006 that flooded part of the UTHM campus. This situation came as a result of poor drainage system around the campus [5]. Moreover, due to lack of proper drainage system can lead to flash flood [10]. Other than that, due to smaller capacity of stormwater drainage systems to accommodate the quantity of rainfall and runoff intensity also can causes flash floods occur in urban areas [11]. Therefore, stormwater drainage is known as an approach to drain excess water from roadways, walkways, rooftops, buildings, and other surfaces [1]. Drainage systems play an important role in a development to manage surface runoff when it rains [12].

3. Materials and Methods

Data such as catchment area, rainfall intensity, and peak runoff in the study area are required for the design of this stormwater drainage. Rational method was used to determine the peak runoff in the study area and Manning's equation was used to ensure that the stormwater drain designed were able to accommodate peak surface runoff.

3.1 Calculation of Catchment Area

The catchment area was calculated using Google Earth Pro application. The total catchment area obtained was 9 hectares. The land use in this particular area is for residential purposes. Therefore, the catchment area is consists of residential buildings, paved road, parking lots and etc. Furthermore, the catchment area is segmented into several sub-catchments based on its land use. The sub-catchments division at the study area is illustrate as in Fig. 1 and the area for each sub-catchment is shown in Table 1. The sub-catchment areas were divided based on its land-use. According to Li C et al. (2020), sub-catchment division approach that takes into consideration land-use types. Sub-catchments 1 and 3 were divided by the land use purpose, which is for residential uses. However, land use for sub-catchment 2 and 4 were open space with grass cover.

Fig. 1 - The sub-catchments division at the study area

Table 1 - Area for each sub-catchment

Sub-catchment	Area (Hectare)
1	3.390
2	0.990
3	3.180
4	1.480

3.2 Estimation of Rainfall Intensity

Rainfall intensity is an important factor to consider while designing stormwater drainage. Estimation of rainfall intensity was made by referring to Stormwater Management Manual for Malaysia (SWMM). It was calculated by pertaining at the nearest rainfall station to the study location, which is at Setor JPS Batu Pahat Station. The value obtained was ranging between 102.71 – 216.54 mm/hr. It was calculated by using the following equation,

$$i = \frac{\lambda T^{k}}{(d + \theta)^{\eta}} \qquad (1)$$

Where,
i = Rainfall intensity (mm/hr)
T = Average recurrence interval (ARI)
d = Storm duration (hours)
k, θ, η = Fitting constants dependent on rain gauge location

According to Stormwater Management Manual for Malaysia (SWMM), the value of storm duration from the equation above is equal to the time of concentration for catchment area less than 80 hectares [13]. Other than that, by referring to minor system from the table in SWMM [13], the minimum ARI for this area is 10 years.
Setor JPS Batu Pahat fitting constants,
$\lambda = 64.099$
$k = 0.174$
$\theta = 0.201$
$\eta = 0.826$

3.3 Rational Method

Rational method is the most used method in Malaysia. Rational method is used to estimate the peak runoff as well as the amount of discharge at study area. Peak flow is the most significant factor in deciding the size of stormwater drain. However, rational method is not recommended to be used when the catchment area is greater than 80 hectare. The peak runoff estimation may be generated using the following equation.

$$Q = \frac{CiA}{360} \qquad (2)$$

Where,
Q = Runoff in m^3/sec
C = Runoff coefficient
i = Rainfall intensity in mm/hr
A = Area in hec

From the following equation, C which indicates as runoff coefficient can be referred to Table 2.5 in MSMA [13]. The most important part in using Rational Method is to choose value of runoff coefficient, C. Runoff coefficient is depending on the land use at the area and type of surface. Runoff coefficient for numerous land use can be calculated using the following equation.

$$C_{avg} = \frac{\sum_{j=1}^{m} C_j A_j}{\sum_{j=1}^{m} A_j} \qquad (3)$$

Where,
C_{avg} = Average runoff coefficient
C_j = Runoff coefficient of segment
A_j = Area of segment (ha)
m = Total number of segments

3.4 Computation of Stormwater Drainage Size

Manning's equation is widely applied in hydraulic design. Manning’s equation is mostly applied for uniform flow in an open channel [14]. There are several assumptions made for a uniform flow channel such as that the bottom slope is parallel to the slope of the energy grade line and the water surface slope. The Manning equation is used to calculate the peak flow of a new proposed stormwater drain. To overcome and reduce the problem of surface runoff, the peak flow of the designed drain must be greater than the peak runoff at the site. Manning's Roughness Coefficient depends on the roughness of the channel or friction on the flow. The Manning’s Equation are as follows:

$$Q = \frac{AR^{2/3}S^{1/2}}{n} \qquad (4)$$

Where,
Q = Drain discharge in m^3/s
V = Velocity of flow in m/s
R = Hydraulic radius in m
S = Slope of channel
n = Manning’s Roughness Coefficient
A = Area of the channel in m^2

4. Results and Discussion

4.1 Runoff Problem at the Study Area

Based on research by Arish previous research [15], UTHM was discovered to have silty clay soil. Silty clay is known to have a very slow infiltration rate. Therefore, data from previous studies on infiltration rate for silty clay soils were collected. Fig. 2 shows the result of infiltration rate for silty clay at UTHM Campus.

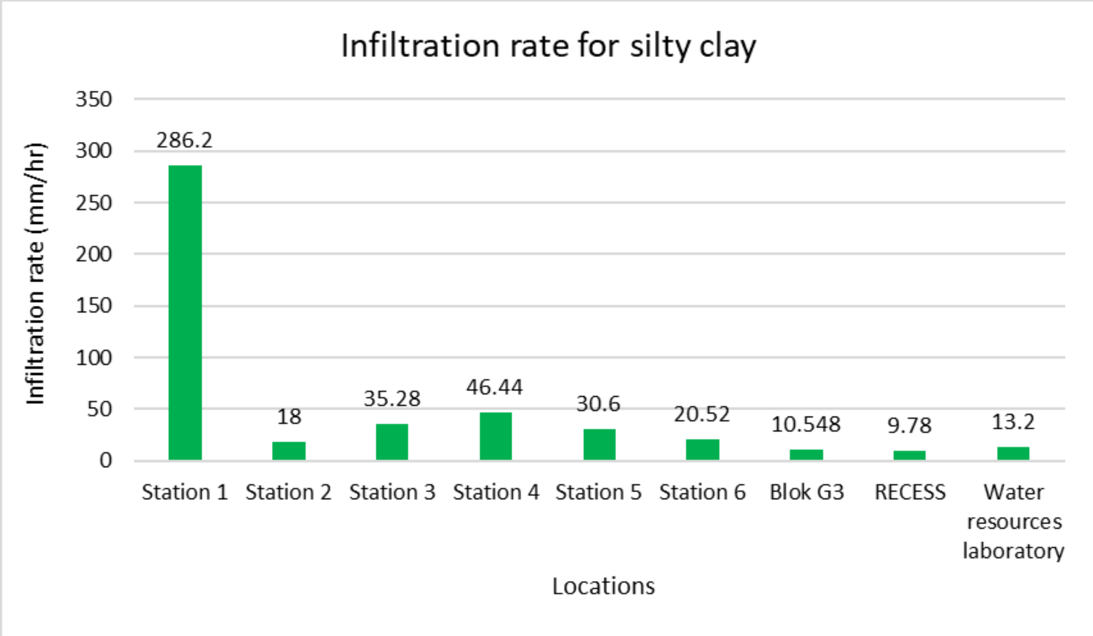

Fig. 2 - The result of infiltration rate for silty clay at UTHM Campus

According to the graph, the majority of the locations have a low rate of infiltration. This demonstrates that silty clay has a low rate of infiltration. This might be the cause of the problem of excess surface runoff especially during the rainy season as most areas are unable to infiltrate water quickly. The lowest infiltration rate is at Research Center for Soft Soil (RECESS) with 9.78 mm/hr. Due to the poor infiltration rate, surface runoff will accumulate significantly during heavy rains which may lead to flash floods, especially in areas without an adequate drainage system.

4.2 Estimation of Peak Runoff

First and foremost, average runoff coefficient must be calculated for various type of land use. Table 2 shows the average runoff coefficient for each sub-catchment and Table 3 shows peak discharge at the study location using Rational Method.

Table 2 - Average runoff coefficient

Sub-catchment	Area (ha)			Runoff coefficient			Area weighted C
	Developed area		Undeveloped area	Developed area		Undeveloped area	
	Paved road	Building		Paved road	building		
1	1.12	0.38	1.89	0.95	0.8	0.4	0.59
2	0.15	0.22	0.62	0.95	0.65	0.4	0.54
3	0.28	1.38	1.52	0.95	0.8	0.4	0.91
4	0.3	0.16	1.02	0.95	0.65	0.4	0.54

The runoff coefficient was different for each sub-catchment due to differ in type of land use. There are residential buildings, paved roads, and open spaces with grass cover around the catchment area. The value of runoff coefficient can be referred from Stormwater Management Manual for Malaysia (SWMM). After the value of the runoff coefficient is obtained, the peak flow is calculated using the rational method as in equation 2.

Table 3 shows the runoff flow at the study location calculated using Rational Method. The maximum discharge to be accommodate by proposed stormwater drain is 1.723 m^3/s.

Table 3 - Peak discharge at the study location using Rational Method

Sub-catchment	Total area (ha)	Σ CA	Tc (min)	I (mm/hr)	Runoff flow, Q (m^3/s)
1	3.390	2.000	10.3	216.54	1.203
2	0.990	0.534	43.0	102.71	0.152
3	3.180	2.887	10.5	214.86	1.723
4	1.480	0.796	36.1	114.66	0.254

4.3 Stormwater Drainage Design

Stormwater drainage may minimise surface runoff at impervious area as well as reducing flash floods. In order to ensure the effectiveness of proposed of stormwater drainage, the drain must be able to accommodate the peak runoff at the study location ($Q_{designed} > Q_{peak}$). Manning's equation was used to compute the amount of discharge for designed stormwater drainage. Table 4 shows the design detail for stormwater drainage and Table 5 shows the comparison of peak flow value.

Table 4 - Design detail for stormwater drainage

sub-catchment	Channel size (mm)				Slope (1:S)	Manning's roughness, n	Drainage area, A (m2)	Wetted perimeter	Hydraulic radius, R	Q designed
	b	h	C	fb						
1	1200	600	1075	50	300	0.015	1.114	2.914	0.382	2.258
2	600	600	300	50	300	0.015	0.365	1.871	0.195	0.473
3	1200	1200	1075	50	300	0.015	1.834	4.114	0.446	4.119
4	600	600	300	50	300	0.015	0.365	1.871	0.195	0.473

Table 4 shows the detail of the design for stormwater drain. Manning's equation formula was used in order to obtain the discharge for the designed drain as shown in equation 4. Manning's roughness coefficient with value of 0.015 for concrete drain with smooth surface was proposed for this stormwater drainage. The drainage area and wetted perimeter were calculated by referring to the channel size. The channel size are design by refferting to standard size for precast concrete box culvert drain with dry weather flow. Dry weather flow channels may considerably accomodate more flow rate. A dry weather flows drainage system provides comprehensive pretreatment of polluted runoff in the area. The system will efficiently remove rubbish, debris, and silt from the runoff before it is transported to the other watershed. 1:300 bed slopes usually provide appropriate flow velocities, allowing liquids to flow easily and particles to be transported without clogging.

Table 5 - Comparison of peak flow value

Sub-catchment	Q_{peak}	$Q_{designed}$	Remark
1	1.203	2.258	ok
2	0.152	0.473	ok
3	1.723	4.119	ok
4	0.254	0.473	ok

According to table 5, the value for peak runoff (Q_{peak}) is smaller than the amount of discharge from drain ($Q_{designed}$) for all sub-catchments. This show that the designed stromwater drain are capable to accommodate the surface runoff at the study location. Therefore, stormwater drainage is proven to be able to reduce surface runoff problems on impervious surfaces and able to manage stormwater effectively.

5. Conclusion

The rising population in UTHM has resulted in further development, including buildings, paved roads, parking lots, and walkways and others. The rise in development corresponds to the rise in impervious surfaces. Redundant impervious surfaces have resulted in flash floods, particularly during the rainy season. Accordingly, these flash floods can be more severe in the area if there is lack of a proper drainage system. This is due to the fact that surface runoff cannot infiltrate through impervious surfaces, causing a large amount of runoff to accumulate. Furthermore, UTHM was found to have silty clay soil with low infiltration rate which also contributes to increased surface runoff at impervious surface during heavy rain. 9 hectares catchment area was divided into 4 sub-catchments based on the land use. Due to small catchment area, Rational Method was used to calculate the peak runoff. The peak runoff obtained was 1.741 m^3/s. Subsequently, stormwater drainage was designed using Manning's Equation. The channel sizes are design by referring to standard size for precast concrete box culvert drain with dry weather flow. Dry weather flow channels may considerably accommodate more flow rate. From the design, it can be concluded that stormwater drainage can accommodate the peak runoff at the study area which as well can reduce the surface runoff at impervious surface.

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