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RESEARCH PAPER

Drainage system evaluation and control of inundation in campus and housing areas of ITS, Surabaya

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Abstract. The campus area of Sepuluh November Institute of Technology (Institut Teknologi Sepuluh Nopember/ITS) and its housing complex are usually inundated during heavy rain. It is because the slope of the land of the campus area is generally flat. Moreover, some of the existing drainage channels also contain sediment thus reducing the optimum capacity of the channels. Hence, an evaluation of ITS's drainage system needs to be conducted. This evaluation was undertaken in stage with the following steps: identification of the existing problems, collection of primary and secondary data, literature review, calculation of the capacity of the existing channels, calculation of run-off, and analysis of the existing retention ponds. The primary data included the flow direction, the slope and dimensions of the channels, and thickness of sediment in the channels. The secondary data comprised rainfall intensity, ITS master plan, and land use. The calculation included the engineering design, the bill of quantity (BOQ), and budget. A standard operating procedure for drainage system maintenance to make the channels optimum was also suggested. From the analysis, it is shown that the maximum daily rainfall is 136.09 mm/day for a 5 year-rainfall return period and 159.19 mm/day for a 10 year-rainfall return period. Inundation around ITS is resulted from some channels which are not connected to each other making drainage water unable to flow easily to the receiving water body (river). Another cause of such inundation is the slope of some channels that were not made properly. The inundation of some roads occurs because of the absence of street inlets, resulting in the water unable to flow to the side channels. It can be concluded that in some areas, the number of secondary channels and box culverts needs to be added, the slope of some channels needs to be rearranged, and a total of 288 street inlets must be constructed along the planning area.

Keywords: design; drainage; inundation; street inlet

1. Introduction

The term *drainage* means to stream, drain, or throw some excess water. In general, drainage can be defined as a technique to decrease the quantity of excess water. It also can

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be defined as to control the quality of groundwater in relation to salinity. In another definition, drainage can be defined as a water construction that functions to decrease excess water in some areas in order that the ground/land can be used optimally (Suripin, 2004). Another function of drainage is to control water resources, including to control maintenance of groundwater surface elevation (Masduki, 1988).

ITS's campus area and its housing complex are usually inundated when heavy rain happens. It is because the slope of land of the campus area is generally flat (see Figure 1). Moreover, some of the existing drainage channels also contain sediment thus making the capacity of the channels unable to be used optimally. Hence, an evaluation of ITS's drainage system needs to be conducted.

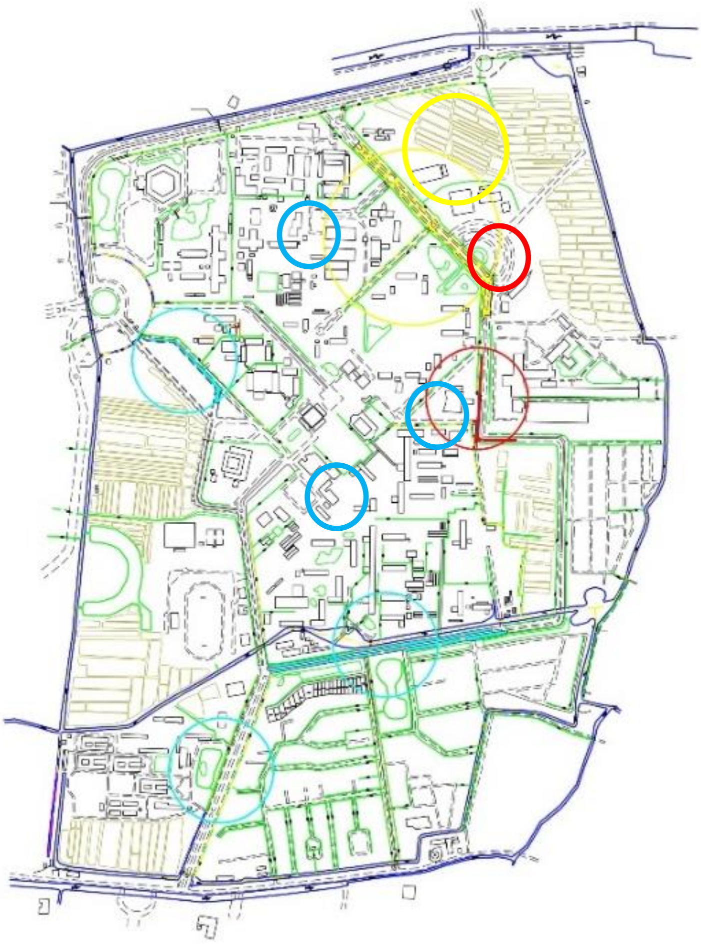

Figure 1. Areas of inundation in ITS

From field observation, these are the areas of inundation. The blue, yellow, and red circles indicate the duration of inundation. Blue circles show that it lasts for about 1-4 hours, yellow circles show that it lasts for 4-8 hours, and red circles show that it lasts for 8-12 hours. There are actually more inundation areas, but the inundation is lower and lasts for shorter duration.

This research aims to evaluate the drainage system, design a system for eliminating inundation in ITS, calculate the bill of quantity (BOQ) and budget plan for implementing the designed system, and review the operation and maintenance of the drainage system.

2. Planning framework

The planning framework began with problem identification, followed by literature review and data collection to gather primary data and secondary data. Primary data included the direction and velocity of the flow along the channels, the slope and dimensions of the existing channels, sediment formed along the channels, the capacity of retention ponds, height, area, and duration of inundation. The secondary data included data on rainfall, ITS map, and Surabaya drainage master plan. The next step was analysing the existing channels, creating standard operating procedures (SOP) for operation and maintenance, and drawing conclusions and giving recommendations.

3. Design analysis

The rainfall data were obtain from a rain station in Keputih Village since it is located very close to the research site (UPT PSAWS, 2016). The calculated maximum daily rainfall is 136.09 mm/day for a 5-year return period and 159.19 mm/day for a 10-year return period. These values will be used for calculating rainfall intensity.

Calculation of the flow coefficient

The average flow coefficient refers to a number that shows the comparison between the amount of drained water with the amount of total rainfall. Soil permeability and the ability of land to collect water determine the value of the flow coefficient (C). The average C can be calculated using the following formula (1).

$$C_{Average} = \frac{(C_1 \times A_1) + (C_2 \times A_2) + (C_3 \times A_3) + \cdots (C_n \times A_n)}{A_1 + A_2 + A_3 + \cdots + A_n} \qquad (1)$$

Where, C is the flow coefficient and A is the catchment area (km^2). In this research, there were four categories that determine the value of C, they are building, green space, road, and pond. Each category has its own C-value according to the table of flow coefficients (Arsyad, 2006).

Calculation of time of concentration

Time of concentration is calculated by accumulation of the flowing time of water in each existing channel. If there is a junction between two channels, the longest time of concentration is used. For areas of inundation, this is calculated when inundation is not happening, which is approached using equations (2), (3) and (4).

$$t_o = 1.44 \left(n \frac{L_o}{\sqrt{S_o}} \right)^{0.467} \qquad (2)$$

$$t_f = \frac{Ld}{V} \qquad (3)$$

$$t_c = t_0 + t_f \qquad (4)$$

Where t_o is time of concentration (minute), n is the roughness coefficient, Lo is travel length (meter), So is slope, Ld is the longest watercourse length (meter), and V is velocity (m/min).

Calculation of the existing flow

Existing Flow is the amount of the flow of rain water runoff and the flow of grey wastewater. The flow of rain water can be calculated using the following formula:

$$Q_{runoff} = 0.278 \; x \; C \; x \; I \; x \; A \quad (5)$$

where Q is the flow of rainfall (m^3/sec), I is rainfall intensity (mm/hour), C is rainfall runoff, A is service-block area (km^2), and grey wastewater can be calculated based on the flow of clean water from each building multiplied by 70%, as shown in the following formula (6).

$$Q_{grey\ water} = Q_{clean\ water} \; x \; 70\% \quad (6)$$

when Q of clean water is known by the account of water used by each building and housing, then the factor of 0.7 (70%) known from the factor clean water become waste water (Eddy et al., 2013). The existing flow can be calculated using the following formula:

$$Q = Q_{runoff} + Q_{grey\ water} \quad (7)$$

Then, by examining the existing channel dimensions, it can be determined whether a channel has a sufficient capacity to mediate the existing flow by calculating the dimensions of the exisiting channel itself. There are some channel shapes such as trapezoidal and rectangular ones. Results of the calculation show that some channels do not have a sufficient capacity to flow the existing flow, as shown in Table 1.

Changing the capacity of channels

From Table 1, it is revealed that some channels cannot deliver the existing flow properly, which results in inundation. Some modifications have been made to these channels in order that the existing flow can be fit to the channel dimensions as can be seen in Table 2.

Alternative further plan

To accomodate the existing flow, new channels and street inlets must be built. Moreover, a water pump must be installed to the pond in order that the pond can function well. The dimensions of channels, street inlets, and the pump are listed below.

Table 1. Condition of the existing secondary and tertiary channels

Channel	Q. Existing (m^3/sec)	Dimensions of the Existing Channels: Shape (channel)	b. up (m)	b. down (m)	h (m)	*Z* (m)	Slope of Water Surface (*S*)	*n*	*A* (m^2)	(A) Existing with Sediment (m^2)	P (m)	V.Channel (m^3/sec)	Q. Channel (m^3/sec)	Remarks
Secondary														
II3-II2	0.132	Trapezoidal	1.05	0.57	0.40	0.60	0.00062	0.02	0.324	0.233	2.82	0.237	0.055	Unsafe
II4-II5	0.100	Rectangular	0.40	0.40	0.50	0.00	0.00159	0.02	0.200	0.172	1.40	0.493	0.085	Unsafe
Tertiary														
3.5-3.6	006008	Trapezoidal	0.80	0.35	0.55	0.41	0.0002	0.02	0.316	0.264	1.97	0.186	0.049	Unsafe
3.9-3.10	0.04080	Trapezoidal	0.70	0.50	0.60	0.17	0.00003	0.02	0.360	0.310	1.53	0.091	0.028	Unsafe

Table 2. Changing the capacity of secondary channels

Channel	Q. Existing (m^3/sec)	Dimensions of the Existing Channels: Shape (channel)	b. up (m)	b. down (m)	h (m)	Z (m)	Slope of Water Surface (S)	Dimensions of Planning Channels: b. up (m)	b. down (m)	h (m)	Z (m)	Slope of Planning Water Surface (S)	*n*	*A* (m^2)	*P* (m)	V.channel (m/s)	Q. Channel (m^3/s)	Remarks
Secondary																		
II3-II2	0.132	Trapezoidal	1.05	0.57	0.40	0.60	0.00062	1.10	0.60	0.50	0.50	0.00062	0.02	0.425	2.6	0.372	0.158	Safe
II4-II5	0.100	Rectangular	0.40	0.40	0.50	0.00	0.00159	0.40	0.40	0.55	0.00	0.00159	0.02	0.220	1.5	0.554	0.122	Safe
Tertiary																		
3.5-3.6	0.060	Trapezoidal	0.80	0.35	0.55	0.41	0.00020	0.80	0.40	0.55	0.36	0.00020	0.02	0.330	2.08	0.207	0.068	Safe
3.9-3.10	0.041	Trapezoidal	0.70	0.50	0.60	0.17	0.00003	0.70	0.60	0.60	0.08	0.00003	0.02	0.390	1.47	0.113	0.044	Safe

New secondary channels

The dimensions of a typical trapezoid-shaped channel are utilized. The designs of the new channels are presented in Table 3.

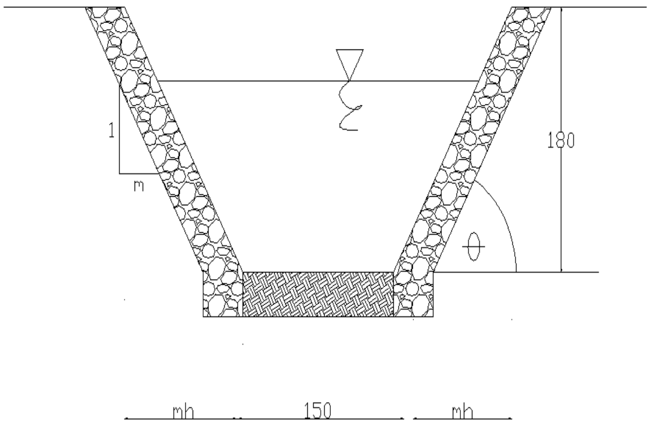

Figure 3. Typical Secondary Channels

Table 3. Addition of secondary channels

Location	Code	Shape	Ld (m)	B (m)	b (m)	h (m)
Block J - Minimarket	A	Trapeziodal	226	1.3	1	1
Pound 8	B	Trapeziodal	95	1.3	1	1
Block R	C	Trapeziodal	137	1.3	1	1
FTK - TI	D	Trapeziodal	171	1.3	1	1
RC - FTK	E	Trapeziodal	192	1.3	1	1
BPPT	F	Trapeziodal	22	1.3	1	1
NASDAC-Primer	G	Trapeziodal	435	1.3	1	1

These are the initial measurements: free board = 0.3 m, h = 1 m, b = 1 m, Ld = 226 m, B = 1.3. B pair of bricks, volume of excavation, and volume of stone are calculated as follows.

B pair of bricks = 1.3 m + 2(0.3 m) = 1.9 m

Volume of excavation is calculated as follows

$$v_{excavation} = \{0.5(B + (b + 0.6)) \times h \times Ld\} + \{(b + 0.6) \times 0.3 \times Ld\}$$

$$= \{0.5(1.9 + (1 + 0.6)) \times 1 \times 226\} + \{(1 + 0.6) \times 0.3 \times 226\}$$

$$= 504 \text{ m}^3$$

Volume of stone is calculated as follows

$$= 504\text{m}^3 - [\{0.5(1.3\text{m} + 1\text{m}) \times 1\text{m} \times 226\text{m}\} + \{1\text{m} \times 0.3\text{m} \times 226\text{m}\}]$$

= 504 m³ – (259.9 m³ + 67.8 m³)

= 176 m³

New street inlets

Figure 4 illustrates the design of street inlets. The distance between street inlets can be calculated using the following formula:

$$D = \frac{280}{W}\sqrt{S}$$

where D is the *distance* between *street inlets* (meter), S is *slope* (%), D $\leq$ 50 meters, and *W* is road width (meter).

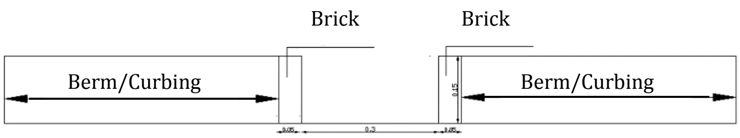

Figure 4. Typical street inlets

Table 4. Addition of Secondary Channels

Street	Street Length (m)	*w* (m)	Elevation Difference (m)	Slope	*D* (m)	P Street Inlet (m)	Number of Street Inlets
Block U - FTK (left)	110	9	0.057	0.0063	2.5	0.4	38
Block U - FTK (right)	85	5	0.034	0.0068	4.6	0.4	17
FTK - TC (left)	250	6.5	0.025	0.0038	2.7	0.4	81
FTK - TC (right)	248	8	0.010	0.0013	1.2	0.4	151
Total							288

Table 4 shows the list of locations and the number of street inlets. As many as 288 units of street inlets are needed. These street inlets will be placed at the locations shown in Figure 5. Moreover, Figure 5 also presents new seconday channels, with new channels shown in purple lines and street inlets shown in yellow lines.

New pump

A pump needs to be installed in the pond. The pump is used to pump water from the pond, to give more space for rainfall water to be collected in the pond during heavy rainfall. Therefore, the pumping is conducted before rain falls in order to empty part of the space in the pond. Data on the pond and the designed pump are as follow: pond capacity = 19,800 m³; water height = 4 m; excavation is set until water reaches 3 m in height; planned duration of pump operation = 2 hours; Known, Qin = 3.8 m³/minute. Based to the data, it can be concluded that in two hours, a total of 450 m³ of water can be collected. Therefore, the pond capacity will become: 19,800 m^3 +450 m^3 = 20,250 m^3. The capacity of a 3 m-high pond is 14,850 m^3. Therefore, the water volume needed to be pumped is: 20,250 m^3 – 14,850 m^3 = 5,400 m^3. In two hours, the pumping capacity is 2700 m^3/hour = 750 L/second

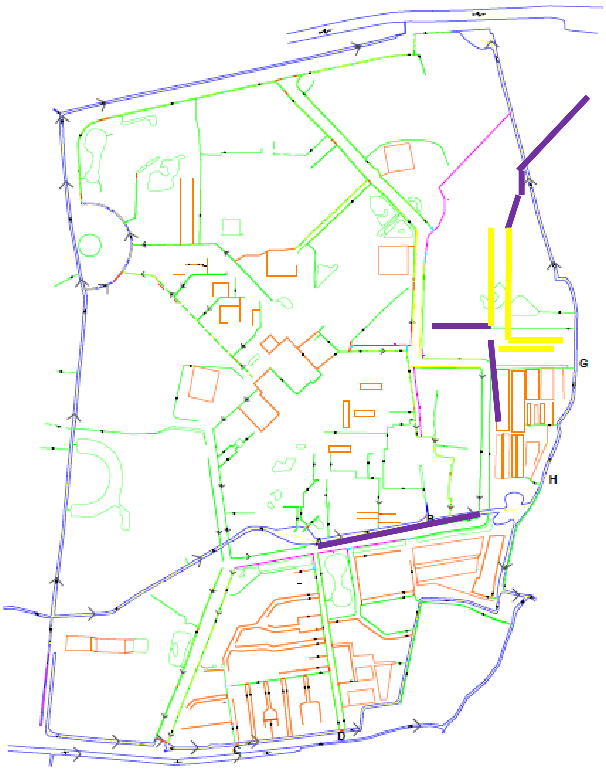

Figure 5. Locations for New Secondary Channels and Street Inlets to be Added

Operation and maintenance

There is no special treatment for the building drainage system. Some of the steps in the operation and maintenance of the system include putting the drainage system as the land use of the city and cleaning the buildings on a regular basis (Hartati, 2002).

- ***Performing excavation***
  In 2015, excavation was carried out in three retention ponds. Those three retention ponds have a capacity of 14,075 m^3. At least about 728 m^3 of sediment needs to be excavated every year.
- ***Cleaning street inlets***
  Based on field observation, ITS actually has a sufficient number of water inlets, but they are dirty and not well-maintained. Therefore, it is necessary to carry out regular inspection in order that rain water from the road can access channels easily.
- ***Removing water hyacinths and litter***
  Based on field observation, when water hyacinths are in bloom, they can attempt around 3,463 m^2, thereby slowing down the flow of water and reducing pump performance.

The calculation of the budget plan is presented in the following table.

Table 5. Addition of Secondary Channels

Activity	Unit	Value	Value of HSPK (IDR)	Price (IDR)
Addition of New Channels				
Drainage Excavation	m^3	2,850	87,550.00	249,512,247.00
Rock Installation Work	m^3	997	1,204,757.50	1,200,950,466.00
			Total	1,450,462,713.00
Box Culvert				
Unloading Paving Reused	m^2	76	7,560.00	570,780.00
Drainage Excavation	m^3	232	87,550,00	20,304596.00
Rock Installation Work	m^3	177	1,204,757.50	213,049,316.00
Reinforced Concrete (200 kg of Iron)	m^3	32	7,120,530.00	230,918,788.00
			Total	464,843,480.00
Street Inlets				
Unloading Paving	m^2	0.06	3,780.00	226.80
Ground Excavation for Construction	m^3	0.06	86,450.00	5,187.00
Installation of Red Bricks	Press	5.00	140,000.00	700,000.00
			Total	705,413.80
			Total 288 Street Inlets	203,159,174.40
Changing the Channel Capacity -Secondary Channel				
Drainage Excavation	m^3	42	87,550.00	3,654,787.00
Channel Excavation (manual)	m^3	340	82,809.60	28,157,866.00
Unloading the Wall of the Channel	m^2	78	117900.00	9,219,485.00
Rock Installation Work	m^3	1,789	1,204,757.50	2,155,876,706.00
			Total	2,196,908,844.00
Changing the Channel Capacity -Tertiary Channel				
Drainage Excavation	m^3	93	87,550.00	8,120,580.00
Channel Excavation (manual)	m^3	376	82,809.60	31,107,780.00
Unloading the Wall of the Channel	m^2	151	117900.00	17,801,761.00
Rock Installation Work	m^3	2,285	1,204,757.50	2,753,143,051.00
			Total	2,810,173,171.00
Operation and Maintenance				
Channel Cleaning	m^2	3,463	6,764.00	23,423,732.00
Channel Excavation (manual)	m^3	838	82,809.60	69,418,786.00
Channel Excavation (heavy equipment)	m^3	3353,18	91,014.00	305,185,938.00
Transport of Channel Cleaning	m^3	4191	93,948.00	393,780,195.00
			Total	768,384,919.00

Note: HSPK = the standard price of works in Surabaya established by the Government of Surabaya

4. Conclusions

Results of the evaluation of ITS's drainage system suggest that inundation in ITS results from, first, for some areas of inundation, some channels that are not connected to one another, thus requiring the addition of new channels and street inlets to provide water with access to enter channels. Second, some channel bottoms need to be excavated to make water flow to the direction as planned. Third, the addition of several secondary channels and a water tunnel is necessary to reduce inundation in some areas.

It costs approximately IDR 8,883,829,313.00 to implement the drainage system to prevent inundation. Ponds need to be excavated, the access of street inlets to channels needs to be cleaned, and water hyacinths and litter along the channels need to be removed in order to allow rain water to flow freely into the water body.

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