Comparison Of Concrete and Modular Storage Ponds for Flood Control (Case Study Catchment Area Of Taman Ratu Channel)

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ABSTRACT

Taman Ratu Housing Area which is included in the drainage area of the Taman Ratu connecting channel is almost always flooded with a height variation of 30-60 cm at the peak of the rainy season. One solution of the flood control system according to the principle of sustainable drainage is the utilization of storage ponds. The availability of land, which is dominated by residential areas, motivates the placement of below ground pools with 2 different models, known as concrete pond and modulars. The placement of below ground ponds is also intended to fulfill public facilities into green open space areas. Therefore, this study was conducted to determine the comparison of cost budget plans related to the dimensions of the planned pond. The method that will be used through three stages of research includes hydrological analysis to calculate planned rainfall and planned runoff discharge, followed by hydraulic analysis for the design on the total land area of the development plan of 2015.88 m^2, the maximum storage volume obtained with dimensions of 45×45×1.5 m is 421.84 m^3 for a 5-year rain return period. The preparation of work unit prices refers to the Minister of PUPR Regulation No.8 of 2023 so that a budget value of Rp 6,256,025,595.86 for concrete pond and Rp 10,518,367,732.62 for modular pond is obtained.

Keywords: Flood; Storage Pond, Concrete construction model; Modular construction model, RAB

1. INTRODUCTION

Population displacement because of socio-economic development in urban areas reaching 141 people/km^2 reduces the ability of land to process hydrological systems [1]. Land use change due to the intervention of residential buildings that change the surface and sub surface geological characteristics such as increase in runoff from the soil pressure has the potential to trigger flooding [2][3].

The limited ability to pass water into the soil makes the infiltration rate low so the runoff rate is close to zero and increase peak discharge factor, which is linear with the total flood volume in a shorter peak period [4][5][6]. Data recorded by the West Jakarta water resourced department shown flooding can reach 60 cm with a duration of 3-5 hours because inundation.

To prevent flooding in the future continues, Jakarta government through the guidelines of the Minister of PUPR No.12 of 2014, one of the solution is utilizing storage techniques to hold flood discharge temporarily placed in subsurface to support the succeed of sustainable project construction which is targeted to be completed in 2025, precisely in Bandung regency, Gedebage, succeeded in optimizing flood reduction from the Cinambo, Cipamulihan and Cilameta Rivers by 70.56%, 57.81%, 30.60% respectively [7][8].

Using module panels as a innovation and implementation of sustainable project is the answer to problems in conventional construction related to delays in work time and losses due to material defect [9] the advantages of modular techniques such as work speed, not affected by weather, effectiveness, and high productivity and environmentally friendly are things that will be compared to conventional techniques [10].

In this research, a comparative study was conducted to determine each cost budget plan related to material prices and workers wages based on the construction method between conventional and modular. This research is expected to provide answers related to the utilization of land availability in the middle of residential centers.

2. THEORY AND METHODS

2.1 Theory

The maximum rainfall value of the plan uses the thiessen polygon method or the weighted average method with the calculation of the proportion of the division of the catchment area to the rain station. With the following equation:

$$P = \frac{P_1A_1 + P_2A_2 + P_3A_3 + \cdots + P_nA_n}{A_1 + A_2 + A_3 + \cdots + A_n} \quad (1)$$

Statistical calculations of average rainfall are necessary because the variable rainfall values are not homogeneous [11]. Here is the equation for dispersion testing:

$$S = \sqrt{\frac{\sum_{i=1}^{n} (Xi - \underline{X})^2}{n-1}} \quad (2)$$

$$Cs = \frac{n \sum_{i=1}^{i} (Xi - \underline{X})^3}{(n-1)(n-2)(S)^3} \quad (3)$$

$$Ck = \frac{n \sum_{i=1}^{i} (Xi - \underline{X})^4}{(n-1)(n-2)(S)^4} \quad (4)$$

Prestipation is part of the hydrological cycle whose quantity cannot be predicted [11]. The frequency and probability analysis are intended to show the value of the rainfall return period T years with the following equation:

$$X_T = \underline{X} + S\,K \quad (5)$$

$$LogX_T = \underline{Log\ X} + SLogX\ K_T \quad (6)$$

$$X_T = \underline{X} + Z\,S \tag{7}$$

$$LogX_T = \underline{Log\,X} + S\,K_T \tag{8}$$

The goodness of fittest test is used to look at the fit of the frequency sample to the predicted distribution. with the Chi-Squared and Smirnov Kolmogorov test equations as follow:

$$X_h^2 = \sum_{i=1}^{G} \frac{(O_i - E_i)^2}{E_i} \tag{9}$$

$$DK = K - (P + 1) \tag{10}$$

Simply put, rain intensity is the amount of rain discharge against the length of time in the catchment area [12]. The calculation of rain intensity uses the Mononobe equation, with the following formula:

$$I = \frac{R_{24}}{24} \times \frac{24^{\frac{2}{s}}}{t} \tag{11}$$

Runoff occurs when rainwater cannot be absorbed and pools on the ground surface. With the runoff discharge equation as follows:

$$Qp = \frac{1}{3{,}6} \left(\frac{A \times Re}{0{,}3 \times Tp \times T_{0,3}}\right) \tag{12}$$

Inundation or flood tracing is one part of hydrological and hydraulics analysis that uses inflow discharge (the amount of water flowing into the pool in seconds) and outflow (the amount of water flowing out through the pipe). With the Nakayasu Hydrograph runoff discharge equation as follows:

$$C_0 = \frac{\Delta t / K}{2 + (\frac{\Delta t}{K})} \tag{13}$$

$$C_1 = C_0 \tag{14}$$

$$C_2 = \frac{2 - \Delta t / K}{2 + (\frac{\Delta t}{K})} \tag{15}$$

Cost planning is generally done to estimate the price of work packages and/or sub-works [13] through the stages of collection and calcification before the total cost value can be informed. With the following calculation equation:

$$HSP = Koefisien \times Harga\,Satuan \tag{16}$$

$$RAB = Volume \times HSP \tag{17}$$

2.2 Methods

Research Location

The research was conducted at locations in the Taman Ratu connecting channel catchment area, especially the location points in the Taman Ratu Housing which often experience inundation and even flooding such as Ratu Mawar, Ratu Melati, and Ratu Dahlia Street. The catchment area served by the Kedoya Taman Ratu pump house and the Sekertaris River is 32.4 ha as shown in Figure1.

Figure 1. Research location.

Method Of Collecting Data

Researchers used secondary data sources of rainfall data from BMKG for the Kemayoran, Tanjung Priok and Tangerang rain stations for the last 10 years (2013-2022); Map of channels and flow streams from the Water Resources Department; Soil data type; as well as PUPR guidance literature.

Data Analysis Methods

To simplify the research process, several stages that must be carried out are as follows:

1. Analyzing hydrological data of average rainfall, dispersion testing, distribution models, calculating rain intensity and planned runoff discharge.
2. Hydraulic analysis which includes creating a flood hydrograph and flood routing to determine the dimensions the pond required.
3. Preparation the work unit price according to the standards of PUPR Ministerial Decree No. 8 of 2023 and cost budget plan in accordance with the calculated volume.

3. RESULTS AND DISCUSSION

3.1 Average Rainfall

The prosess of planning and determining the design of the catchment pond utilizes rainfall data from three rainfall stations that affect the research catchment area, namely the Kemayoran Rain Station, Tanjung Priok Rain Station, dan Tangerang Rain Station. The results of the recapitulation of average maximum rainfall data can be seen in Table 1.

Table 1. Average Maximum Daily Rainfall Calculation

Year	Rain Station			Catchment Area			Max. Rainfall
	Kemayoran	Tanjung Priok	Tangerang	Kemayoran	Tanjung Priok	Tangerang	
2013	81.1	39.3	27.8				198.9
2014	62.0	94.7	27.8				223.6
2015	116.4	82.4	26.1				284.8
2016	52.2	37.6	25.6				181.6
2017	75.4	49.6	23.6	62.48	49.69	36.83	206.7
2018	43.9	43.2	19.3				164.0
2019	37.9	43.5	31.4				163.6
2020	116.4	51.9	29.3				261.4
2021	39.5	30.5	20.9				159.0
2022	85.5	44.9	20.8				214.5

Source: Calculation Results

3.2 Frequency and Probability Testing

Several types of statistical distributions used to determine the amount of planned rainfall such as the Gumbell, Log Pearson III, Normal, and Log Normal. But the use of these distributions must meet the requirements of the calculation parameters presented in Table 2.

Table 2. Statistical Test Parameters

No	Rainfall	$(Xi – Xaverage)^2$	$(Xi – Xaverage)^3$	$(Xi – Xaverage)^4$
1	284.8	6239.1	492809.7	38925929.0
2	261.4	3092.3	171960.1	9562473.6
3	223.6	317.1	5647.9	100582.1
4	214.5	75.3	653.7	5672.8
5	206.7	0.8	0.7	0.6
6	198.9	48.1	-333.7	2315.0
7	181.6	586.3	-14195.4	343714.9
8	164.0	1750.6	-73245.5	3064607.9
9	163.6	1784.1	-75358.2	3183031.3
10	159.0	2185.4	-102165.3	4776077.1
Σ	**2058.0**	**16079.2**	**405773.8**	**59964404.1**
Nilai Rata-Rata		205.80		
Standar Deviasi		40.09		
Cv		0.19		
Cs		0.87		
Ck		3.23		

Source: Calculation Results

Based on the dispersion factors above, the distribution model that can be used can be determined as in Table 3.

Table 3. Statistical Parameter Test Results

Distribution	Dispersion Requirements		Result
	Terms	Count	
Gumbel	Cs = 1.14	Cs = 0.87	Does not meet
	Ck = 5.4	Ck = 3.23	
Normal	Cs = 0	Cs = 0.87	Does not meet
	Ck = 3	Ck = 3.23	
Log-Normal	$Cs = Cv \times 3 + 3 \times Cv$	Cs = 0.87	Does not meet
	$Ck = Cv^8 + 6Cv^6 + 15Cv^4 + 16Cv^2 + 3$	Ck = 3.23	
Log-Pearson III	Selain dari nilai distribusi lainnya	Cs = 0.87	Meet
		Ck = 3.23	

Source: Calculation Results

3.3 Frequency Match Testing

There are two types of fit test methods, namely Chi Square and Smirnov Kolomogorov, with the aim of supporting the selection of distribution models from dispersion testing, so that the resulting rainfall return period values are valid. Fit test result can be seen in Tabel 4.

Table 4. Fit Test Calculation Results

Distribution	Chi Square		Smirnov Kolmogorov	
	DK	ΔDK	DK	ΔDK
Gumbel	5.99	0.80	0.41	0.29
Log-Pearson III	5.99	0.78	0.41	0.06
Log-Normal	5.99	7.41	0.41	1.43
Normal	5.99	0.60	0.41	0.12

Source: Calculation Results

Referring to the results of the data distribution test which shows that if the Log Pearson III model is appropriate plus the empirical confidence degree value is below that required for DK 0.05 in the Table 4, then the Log Pearson III distribution can be continued for the planned return period calculation.

3.4 Rainfall Distribution with Log Pearson III Model

Referring to the total catchment area and the selection of the storage pond as a flood control media, the rainfall return period used is in 5 years. Therefore, it is necessary to know thw planned rainfall for a 5-year period based on the previously known average rainfall.

Average value (Log X) = 2.306
Standar deviation (Sx) = 0.086
Skewness coefficient (Cs) = 0.000018
The price of K referring to the value of Cs = 0.000018 at the 5-year rainfall return period is 0.842
LogR value = 2.378
R value = 238.92 mm

Table 5. 5-Year Rain Return Period Daily Rainfall

Return Period (year)	Rainfall (mm)	Return Period (year)	Rainfall (mm)
2	202,1	25	286,2
5	238,9	50	303,8
10	260,8	75	312,3
20	277,5	100	320,9

Source: Calculation Results

3.5 Determination of Intensity Duration Frequency (IDF) Curve

Rainfall intensity analysis uses data from the Log Pearson III distribution model. The rain intensity calculation process utilizes the Mononobe equation formula approach, so that the results can be seen in the intensity duration frequency (IDF) graph as shown in Figure 2.

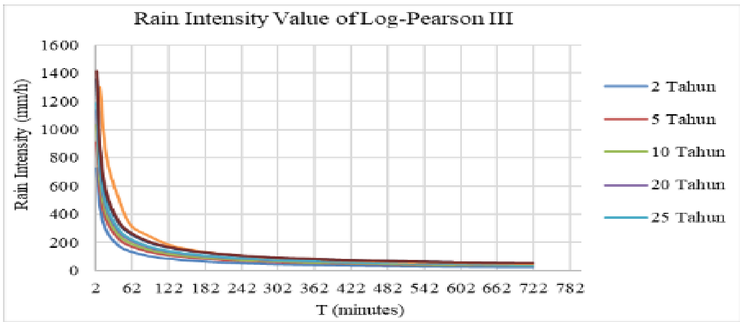

Figure 2. IDF curve of Log Pearson III distribution

3.6 Determination of Runoff Discharge Plan

The stage that must be done before determining the value of runoff discharge or flood plan is to know the rainfall intensity number for the 5-year rain return period first. This is because the value of rain intensity determines the amount of runoff discharge plan. The data amount of runoff discharge plan. The data parameters needed are:

Catchment area (A) = 32.4 ha
Channel length (L) = 1600 m
Channel slope (i) = 0.45

Table 6. Runoff Discharge Plan

Channel (m)	Coefficient			T1 (minute)	T2 (minute)	T3 (minute)	Qp (m^3/sec)
	Nd	S	V				
1600	0.142	3%	1.50	4.66	17.78	22.44	163,89

Source: Calculation Results

3.7 EPA SWMM 5.2 Simulation

The drainage network mode display based on the results of running model simulations for the Taman Ratu connecting channel catchment area, obtained a con tenuity error of 0.44%. the running simulation results are acceptable because the continuity error value is less than 10%. The drainage model can be seen in Figure 3 and simulation result in Figure 4.

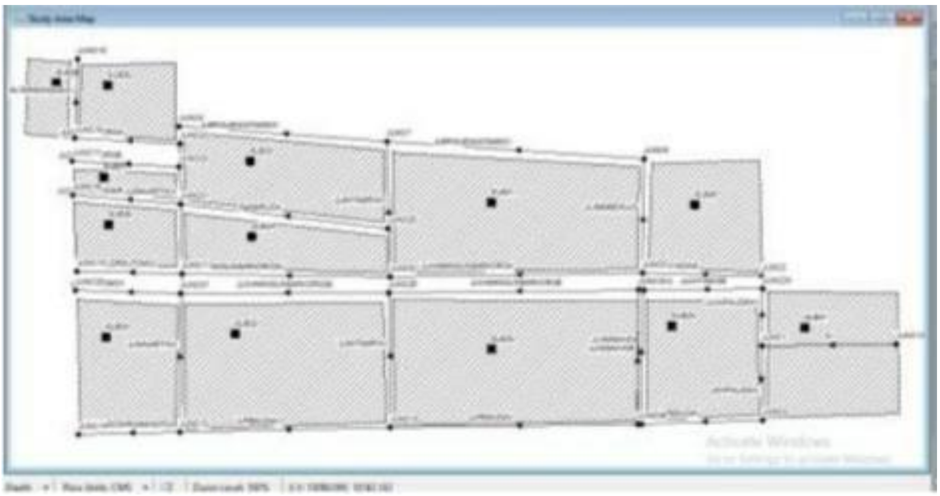

Figure 3. Drainage network model

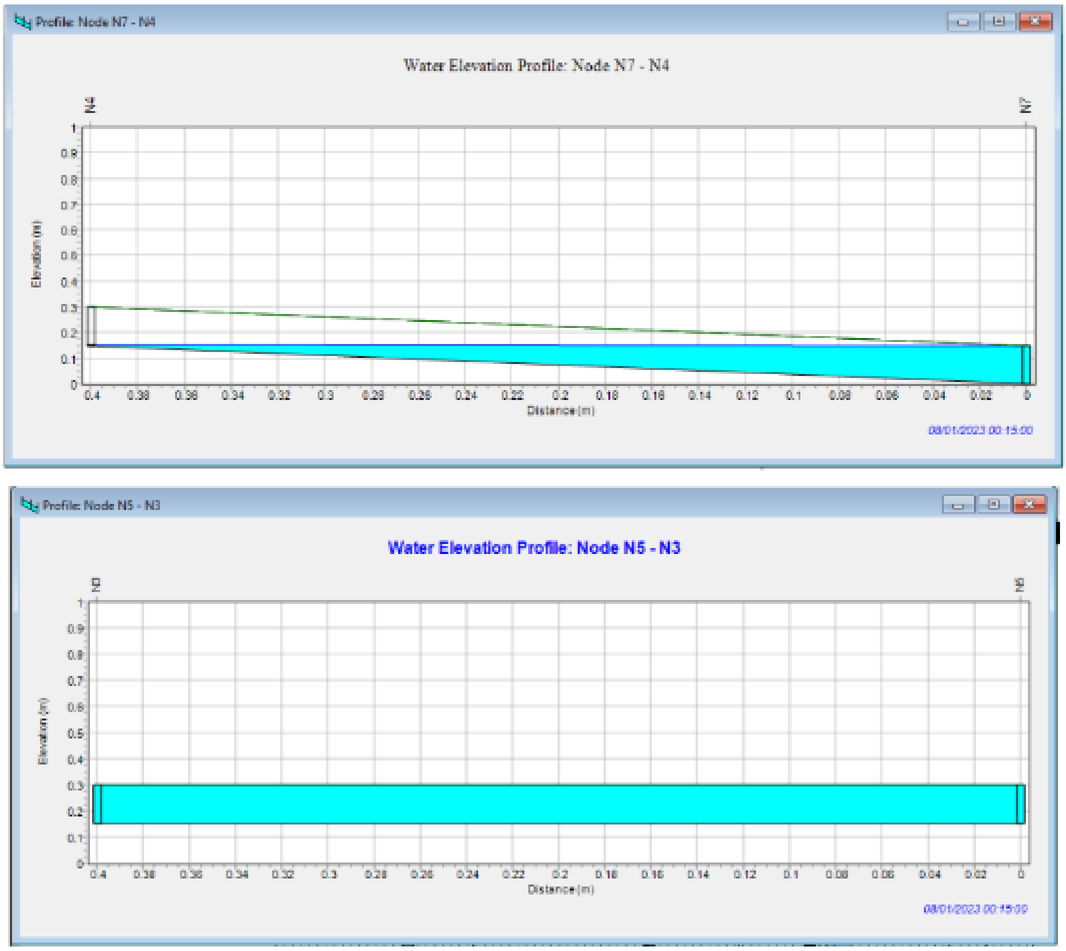

Figure 4. Simulation running results

Referring to the running results in the figure above is an example of a channel that experiences overflow at hour 1 due to the value of rain intensity reaching peak values. As the hours increase, the runoff discharge begins to recede because the rain intensity decreases. Some channels that experience overflow are no longer able to accommodate runoff discharge due to rain, because the channel dimensions can no longer accommodate rain of high intensity. Channels that receive runoff loads from Ratu Teratai, Ratu Melati, Ratu Dahlia, Ratu Kemuning, Ratu Kamboja, and Ratu Mawar Streets experience overflow during simulation hours. Based on the summery results, it can also be seen that the planned flood discharge, the largest of which occurs in the Ratu Melati channel at 16.605 m^3/second. 5-year rain return period hydrograph can be seen in Figure 5.

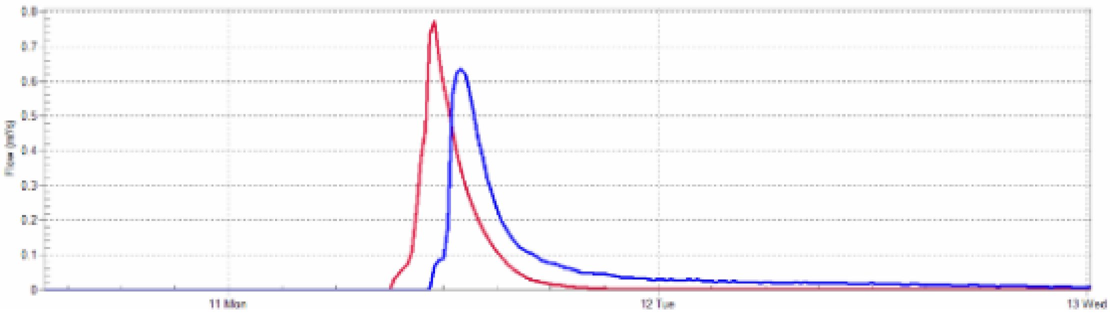

Figure 5. 5-year rain return period hydrograph

The planned storage pond is 1 pond in the middle of the Taman Ratu housing area. Based on the principle of sustainable drainage, pond water can be utilized during the dry season. Simulations are carries out using the storage unit function in EPA SWMM 5.2 with the type of inlet and outlet in the form of an orifice, the pond is planes to have dimensions of 45×45 m with a depth of 1.5 m, adjusted to the available land of 2014.88 m². It has a maximum volume inflow and outflow of 0.1208 and 0.1160 m^3/sec with the highest elevation of 0.70 m. The pond routing has maximum operational performance of runoff discharge is 4 hours on capacity of 421.85 m^3.

3.9 Cost Budgeting Plan

The comparative study on the construction of a detention pond is on the type of materials used. The selection of concrete with a quality of fc' – 31.2 Mpa or K-350 as the main material for making conventional ponds is based on guidelines issued by PUPR for drainage system work, due to its impermeable nature with normal – high values. The selection of panel material for modular construction was chosen based on the technical specifications from piping and water system company. Furthermore, after the pond building model and dimensions have been determined, working drawings was prepared with the help of AutoCAD software. Longitudinal view of the concrete structure can be seen in Figure 7 and cross section of modular structure in Figure 8.

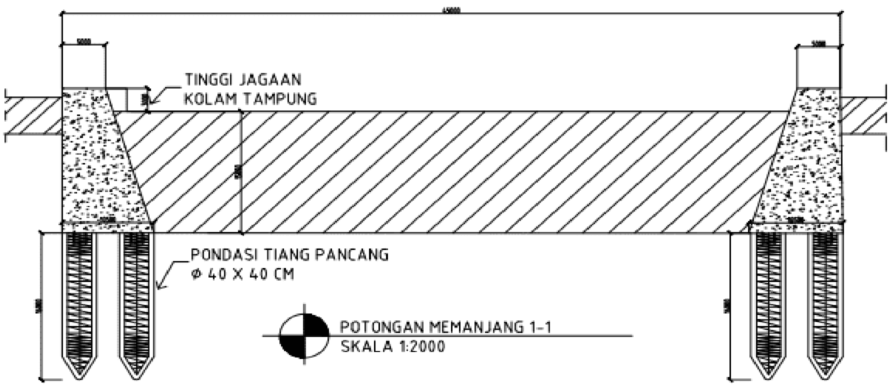

Figure 7. Section of concrete storage pool

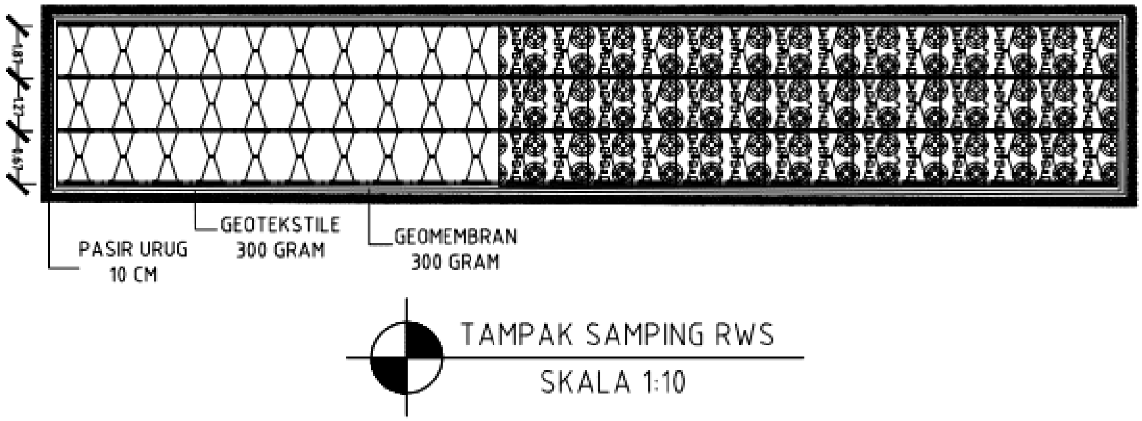

Figure 8. Section of modular storage pond

Work breakdown structure is a flowchart of the scope of work as a management control and quality control tool prepared according to Ministry Regulation of PUPR No.8 of 2023 in the field of Water Resources. The work breakdown structure for concrete structure can be seen in Figure 10 and for modular structure in Figure 11.

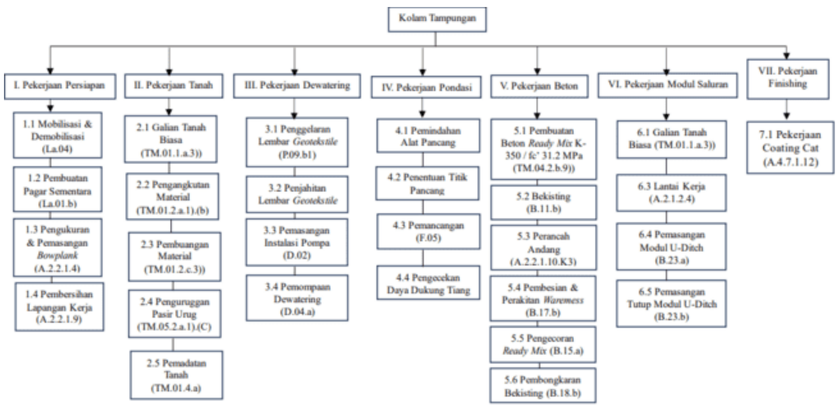

Figure 10. Work breakdown structure of concrete pond

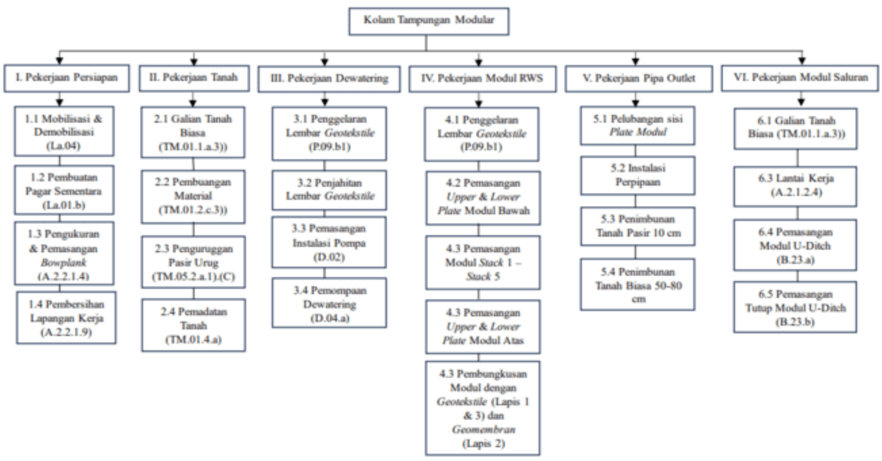

Figure 11. Work breakdown structure of modular pond

Other parameters used in the comparative study process besides the type of material are the price of materials, rental and/or purchase of equipment, and labor wages that are adjusted according to the standards of Jakarta Province and its surroundings. Recapitulation budget plan for concrete structure can be seen in Table 7 and budget plan for modular structure in Table 8.

Table 7. Recapitulation Budget Plan of Conventional Construction

No	Job Descriptions	Total Price (Rp)
I	Pekerjaan Persiapan	143,114,746.23
II	Pekerjaan Tanah	149,136,610.49
III	Pekerjaan Dewatering	134,238,619.04
IV	Pekerjaan Pondasi	1,398,481,453.57
V	Pekerjaan Beton	3,431,413,617.76
VI	Pekerjaan Saluran Modul Drainase	276,526,467.90
VI	Pekerjaan Finishing	154,384,481.25
	Jumlah	5,687,295,996.24
	PPN (10%)	568,729,599.62
	Jumlah Total	6,256,025,595.86

Source: Calculation Results

Table 8. Recapitulation Budget Plan of Modular Construction

No	Job Descriptions	Total Price (Rp)
I	Pekerjaan Persiapan	143,114,746.23
II	Pekerjaan Tanah	149,136,610.49
III	Pekerjaan Dewatering	134,238,619.04
IV	Pekerjaan Pondasi	1,398,481,453.57
IV	Pekerjaan Modul RWS	2,440,020,022.32
V	Pekerjaan Pipa O*utlet*	5,020,634,564.66
VI	Pekerjaan Saluran Modul Drainase	276,526,467.90
	Jumlah	9,562,152,484.20
	PPN (10%)	956,215,248.42
	Jumlah Total	10,518,367,732.62

Source: Calculation Results

The results of the study showed a different in the calculation of the cost of building a concrete storage pond of Rp 6,256,025,595.86 and Rp 10,518,367,732.62 for a modular storage pond. There is a difference in the cost budget of Rp 4,262,345,136.76 with a percentage difference of 25.84%. although the concrete construction budget is more affordable, the manufacture of modular storage pond is considered more economical referring to the process of mobilizing panel materials, ease of assembly, and shorter work duration until 1 week.

4. CONCLUSIONS

According to the simulation process using EPA SWMM 5.2 and listing for budget plan, it can be concluded that:

1. The highest rainfall intensity occurs at hour 1 and then gradually decreases of the following hours, with maximum intensity values for 5-years rain return period is 560.31 mm/hour. In addition, the highest planned flood discharge occurs is the Taman Melati Street channel with peak discharge is 16.605 m^3/second.
2. The dimensions of the storage pond of 45 45 1.5 m are considered capable of accommodating the highest volume of 421.84 m^3 with the peak rainfall in the 4^{th} hours.

3. The calculation results of budget plan for each model construction is Rp 6,256,025,595.86 and Rp 10,518,367,732.62 with percentage different 25.84%

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