Flood Risk Reduction Strategy With Vertical Drainage In Medan City, Indonesia

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Abstract. As the population of a city increases, there will be excessive exploitation of nature, uncontrolled land use change, and a decrease in the environment's carrying capacity. These impacts cause flood disasters to increase in quantity and quality. Floods are still difficult to predict and avoid. Medan City is still haunted by the same problem as other cities in Indonesia, namely flooding. The government has focused on flood management by building a horizontal drainage network system, normalizing rivers, building embankments, but flooding still occurs frequently. Therefore, vertical drainage is needed for flood management. Vertical drainage drains surface water directly into the soil layer that horizontal drainage cannot accommodate. This research aims to study the ability of vertical drainage in Medan City to reduce flood risk. Based on the test results, vertical drainage has a discharge of 0.812 liters/second. Based on technical calculations, vertical drainage can distribute potential rainwater collected on the surface and with the addition of possible water from other sources at the research site within 9 minutes 1 second until it runs out as much as 440 liters. As a result, one vertical drainage system can effectively accommodate an area of 25 m².

1. Introduction

The number of Indonesians living in urban areas was 15.9% of the 97.09 million population during the first post-independence population census; today, the number of people living in urban areas in Indonesia is 49.8% of the total population [1]. The increase in population in this urban area cannot be separated from the imbalance between development in urban and rural areas [2]. This causes urbanization, or the movement of people from rural to urban areas. According to the World Bank, there are currently 151 million Indonesians living in urban areas, with predictions that this number will rise to 220 million by 2045, accounting for 70% of the country's population [3].

With the increasing number of residents in a city, there will be excessive exploitation of nature, uncontrolled land use changes, and a decrease in the environment's carrying capacity. These various effects lead to a tendency to increase flood disasters in quantity and quality [4]. Flooding is a problem for the community because it causes property and life losses, health problems, and damage to various facilities and infrastructure, among others. Urbanization hurts urban hydrological conditions, such as accelerating the speed of runoff flow and increasing flow from upstream [5]. Urbanization significantly influences changes in river systems and structures, which usually cause increased flood risk [6, 7]. Floods can occur due to natural conditions and phenomena (topography, rainfall), geographical conditions, and human activities that impact spatial planning or land use in an area [8]. Floods occur due to changes in land use, waste disposal, erosion and sedimentation, slum settlements along rivers, inappropriate flood control systems, river physiography, rainfall, land subsidence, the influence of tides, water structures, and damage to flood control facilities [9]. Floods can also occur if people need to consider their ability to use space and develop at a rate that exceeds the capacity of the land [8]. Floods have been difficult to predict and avoid until now [10].

Currently, Medan is still haunted by the same problem as other cities in Indonesia, namely flooding. Even the floods in December 2020 have caused five people to die [11]. Most of the floods in Medan City occurred along the Deli River, starting from the Bukit Barisan mountains with a height of 1725 m above sea level to the coast of the Malacca Strait with a length of 75.8 km, flowing through the city of Medan, which is in the downstream part of the Deli watershed with a height of 75.8 km. About 0-40 m above sea level and has an area of 481.62 km. This river is the primary channel that supports the drainage of the city of Medan, with an area of about 51% [12].

For years, the government has focused on flood prevention by building a horizontal drainage network system, normalizing rivers, constructing embankments, and others, but floods still occur frequently. Floods in Medan City, which often occur and are of higher intensity and frequency, significantly impact the quality of life of the affected people. The quality of life of flood victims decreased significantly, especially women and the elderly [13].

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As a result, it requires a breakthrough to prevent flooding, namely the use of vertical drainage. After the DKI Jakarta government began carrying out vertical drainage work, many people have become interested in using vertical drainage as an alternative to flooding. The DKI Jakarta Government constructed a vertical drainage system with a diameter of 100 cm and a depth of 270 cm.

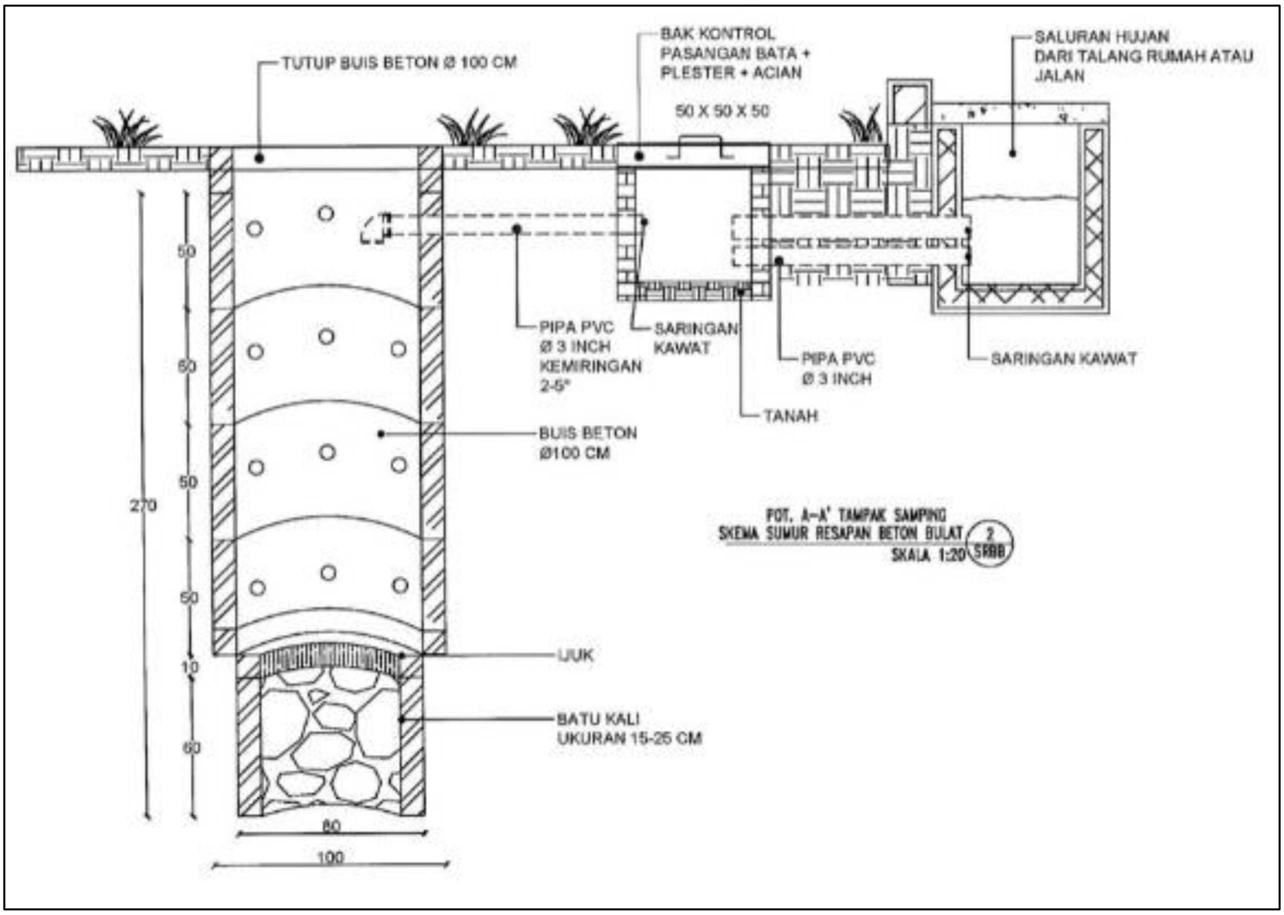

Fig. 1. DKI Jakarta Vertical Drainage

The authors of this study constructed a vertical drainage system in Medan's North Sumatra University Campus area. This vertical drainage work, on the other hand, is very different in concept, material, and technique from the vertical drainage built by the DKI Jakarta Government. The inability of horizontal drainage to accommodate the amount of water discharge causes flooding on the North Sumatra University Campus. This study aims to determine how well one vertical drainage system can deliver water to the soil aquifer layer while reducing flooding.

2. Theoretical Review

2.1. Flood

Floods are waves of water flowing downstream of a river system that interacts with rising estuary water levels due to storms. Floods are divided into two types so that the definition of flood is not limited to high river water discharge above the river surface so that the trough does not accommodate it and causes inundation in the downstream part of the river [14]. The occurrence of floods is closely related to precipitation [15, 16] and the magnitude of rainfall directly influences the severity of flood disasters [17].

Elevation and slope have a significant effect on the occurrence of flash floods [18]. Generally, a negative correlation exists between flood and elevation. The steeper the slope, the faster the water flows downward under gravity. Therefore, low-lying areas are more susceptible to flooding. *Aspect* is defined as the direction of the steepest slope of the topographic surface, which contributes to the moisture retention and vegetation cover in an area [19, 20].

2.1.1 Aquifer Layer

An *aquifer* is a subsurface rock layer that stores and releases significant amounts of water (permeable layer). There are several aquifers: confined aquifers, semi-confined aquifers, semi-unconfined aquifers, and unconfined aquifers. Confined aquifer, semi-confined aquifer, semi-unconfined aquifer, and unconfined aquifer [21]. An aquifer is a layer, formation, or group of permeable geological unit formations, both consolidated (e.g., clay) and unconsolidated (sand) under water-saturated conditions, and has a hydraulic conductivity (K) which functions to store groundwater in large quantities so that can carry water (or water can be extracted) in economic quantities [22, 23]. As a result, an aquifer is essentially a water compartment in the ground. Delivering water to the aquifer layer can speed water flow into the soil [24].

2.2. Vertical Drainage

Vertical drainage is unsuitable for soils with a high secondary compression ratio, such as highly plastic clays and peat, because vertical drainage cannot control the secondary consolidation rate [25]. Vertical drainage drains water on the surface directly to the soil layer that horizontal drainage cannot accommodate. In addition, vertical drainage also functions as a means of conserving groundwater, which can increase the water discharge in the soil aquifer layer [22, 23].

2.2.1 Conventional Vertical Drain

This is the classic type that has been widely used. The material used is graded material or sand (sand drain). It generally consists of sand or gravel that has high permeability. The traditional method of making a vertical drain is to drill a borehole in the clay layer and backfill it with graded sand to a diameter of about 200 - 400 mm, and the drainage channel is made more than 30 m deep [26].

2.2.2 Synthetic Vertical Drain

The advantages of synthetic vertical drains are minor soil disturbance due to installation, lighter installation tools, and elimination of sand quality control in the field. The quality of synthetic vertical drains is more uniform [27]. Flood risk management is essential to protect urban areas from flood threats and manage natural resources effectively. Flood mitigation approaches consist of structural and non-structural measures, depending on whether engineering or policy interventions are used [27].

METHODOLOGY

The data collection stage of the research begins with physical observation of the research area, a literature review, and a hydrogeological survey using the geoelectric survey method. The resistivity/geoelectrical estimation method is a geophysical method for presenting data on the arrangement of subsurface rock units based on the rocks' electrical properties. By flowing direct electric current into the earth, the Schlumberger electrode arrangement system is used to explore geoelectrical estimation [28].

The condition of the subsurface rock layers vertically will be described using field data interpretation. Numerous aspects can be interpreted according to requirements using the electrical properties of this rock. Estimates of the vertical and horizontal arrangement of subsurface rocks, as well as estimates of water-bearing rocks, are among them (aquifers).

The research continues with vertical drainage construction work after the stages of data collection at the research site have been completed. The ability of the vertical drainage work to flow water to the vertical drainage will then be tested, and the flow of water flowing to the vertical drainage will be calculated. Following the acquisition of performance data, technical calculations are performed to determine (1) the Volume of water delivered to the aquifer layer via vertical drainage and (2) the Time required to deliver all of the water to the vertical drainage.

$V = (CH + BK)$……. (1)

V represents the Volume of water that will be sent to the underground Aquifer layer via vertical drainage, CH represents the amount of rainfall, and BK represents the projected flooding delivery (estimated)

$W = V/KDV$........... (2)

W is the Time required to deliver all the water to the vertical drainage. At the same Time, KDV is the vertical drainage capability, and V is the Volume of water sent to the underground aquifer layer through vertical drainage.

3. Results and Discussions

3.1. Geoelectrical Survey

The Schlumberger electrode arrangement model was used to conduct hydrogeological investigations using the geoelectric method. Current (I) and potential (P) cable ranges are adjusted as needed. The current and potential cable ranges are 600 and 50 meters (l/2 = 1.50 – 300 meters and a/2 = 0.50 – 25 meters, respectively). Subsurface rock penetration depth is theoretically 1/3 the cable span length, in this case 600 meters. So 1/3 X 600 meters = 200 meters is the depth/thickness of rock layers that can be calculated.

When viewed from the grouping of the actual vertical rock resistivity, the subsurface rock layers are not varied or relatively homogeneous at the research location. The tendency of subsurface rocks is less compact to somewhat compact. At the top (soil cover) visible rock from alluvial units. Meanwhile, the analysis of subsurface rocks in general for measuring ducks is as follows:

At a depth of 0.0 – 1.80 meters with a vertical resistivity of the actual rock of 21 and 23 m, in the form of topsoil. At a depth of 1.80 – 10.40 meters with actual rock vertical resistivity of 25 and 27 m, it has an excellent porosity level; physically less compact rock can act as a shallow aquifer or medium-high water nest. At a depth of 10.40 –≥ 25.10 – 35~ meters with a vertical resistivity of 35 and 34 m, the actual rock is a rock with excellent porosity, less compact physical rock with medium–high nesting, and can act as a productive shallow aquifer; the accumulation of water between grains/pores. For drilling, it is estimated that the aquifer (water-carrying layer) consists of sandstone and gravel from the Medan Formation (Qpme).

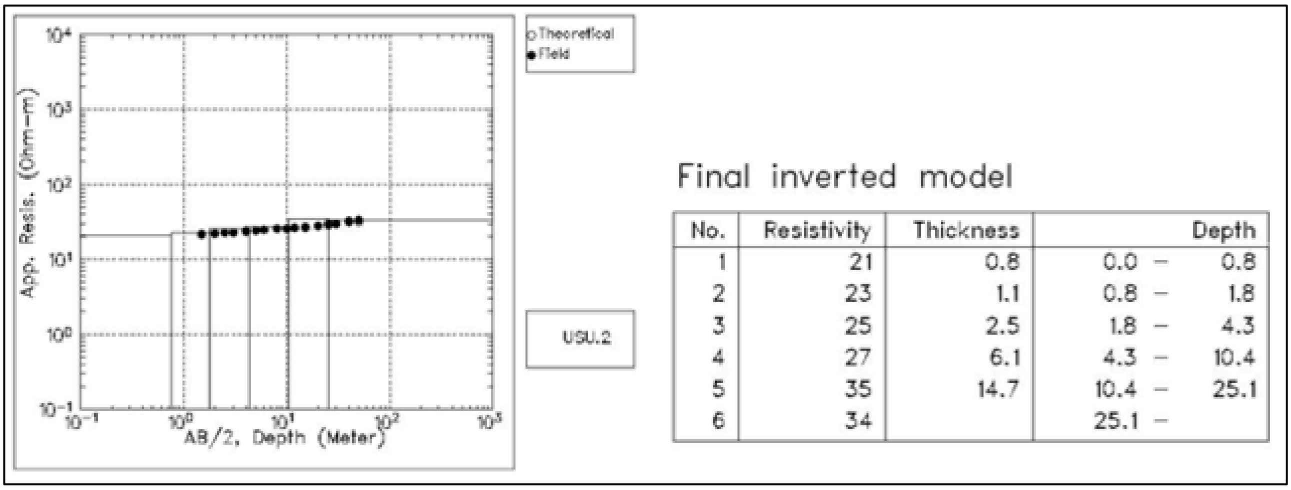

Fig. 2. Geoelectrical Survey Data

Table 1. Geoelectrical Survey Result

Layer Thickness (m)	**Depth (m)**	**Resistivity (Ωm)**	**Formation (Lithological Estimation)**	**Explanation**
0,80	0,00-0,80	21	Top Soil	
1,00	0,80-1,80	23	Form Medan (Qpme)	Suspected shallow aquifer
2,50	1,80-4,30	25	Form Medan (Qpme)	Suspected shallow aquifer
6,10	4,20-10,40	27	Form Medan (Qpme)	Suspected shallow aquifer
14,70	10,40-25,10	35	Form Medan (Qpme)	Suspected shallow aquifer
	25,10 - ~	34	Form Medan (Qpme)	Suspected shallow aquifer

The soil layer factor plays a crucial role in soil permeability so that drainage can work well or not [18]. A lot of vertical drainage is needed to control the amount of water on the surface so it does not stagnatee [24].

3.2. Vertical Drainage Construction

After the hydrogeological conditions were obtained through a hydrogeological survey using the geoelectric method, the construction phase of the vertical drainage works was carried out. The following is a vertical drainage design concept the research team formulated.

Fig. 3. Vertical Drainage Construction

The vertical drainage construction took four days with the help of four well-drilling specialists. Drilling is carried out until it reaches the soil aquifer layer, which, according to the geoelectric survey, can be reached at a depth of 9 meters. Stages of work start from drilling and inserting a 10-inch pipe as a casing as deep as 3 meters. Then, the drilling is continued to a depth of 12 meters or up to the aquifer layer, and a 6-inch pipe is inserted into the vertical drainage. As a means of getting water into and out of the drainage, the 6-inch pipe is sliced on several sides.

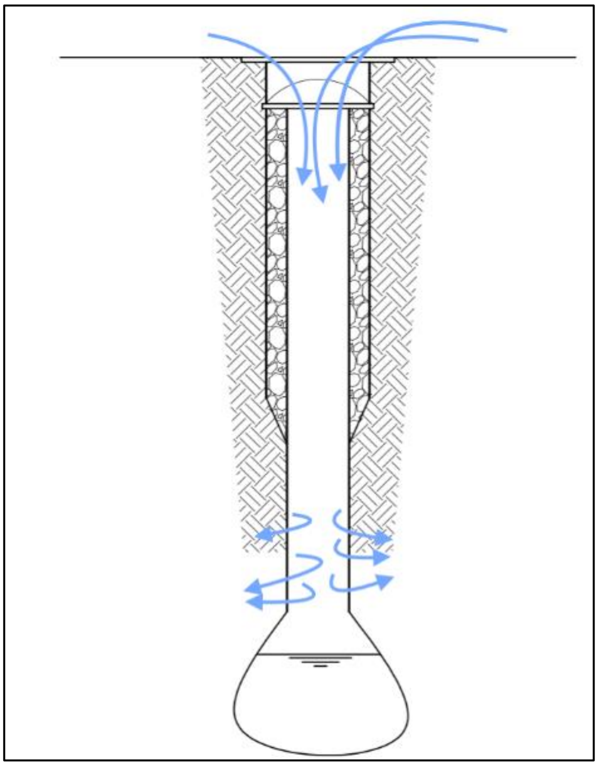

Fig. 4. Vertical Drainage Design

Then, between the 6-inch and 10-inch pipes, gravels are inserted to act as a filter against contaminants such as mud or garbage that could disrupt the vertical drainage performance. As a result, after the drainage work is finished, the task is to create an oval vertical drainage cover that acts as a sewage barrier.

Fig. 5. Vertical Drainage Cover

3.3. Vertical Drainage Test

After the drainage works are completed. After that, a drainage test determines how a vertical drainage can deliver water to the aquifer layer. The stages of drainage testing include:

- Prepare a cone to pour water by the diameter of the pipe in the vertical drainage to accommodate the amount of water to be poured with overflowing conditions.
- Water is poured into the cone until the overflow/maximum condition is reached.
- Calculate how long it will take to finish pouring the water. The ability of vertical drainage to transmit flood water into the aquifer layer is measured using this Time.

In this case, the test was carried out by pumping water into a vertical drainage through a cone that the research team had prepared. (1) Robin RTG 300 LH brand water pump; (2) Funnel for pouring water; (3) Pipes; (4) 3-inch water hose; (5) Bucket; (6) Stopwatch is among the tools provided..

Water is pumped at a speed of 200 liters per minute from the water source to the vertical drainage until the vertical drainage overflows with a total volume of 0.1 cubic meters or 100 liters. After three tests, the average Time to spend the water was 123 seconds, with a flow speed of 0.812 liters per second. With this speed, 48.72 liters of water can be delivered into the soil aquifer layer in one minute.

Table 2. Vertical Drainage Test Result

	Volume	Time	Flow rate
Test 1	100 liter	122 sec	0,819 liter/ sec
Test 2	100 liter	126 sec	0,793 liter/ sec
Test 3	100 liter	121 sec	0,826 liter/ sec

3.4. Technical Calculation

The following is Medan City's average rainfall data obtained through the Central Bureau of Statistics (2019) data, which is 179.79 mm per month and 5,615 mm per day [30]. The unit of measurement for rainfall is millimeters. The Volume of rainwater divided by the area of the base is what is known as rainfall. The formula for calculating the number of liters of rainwater stored in the catchment area of the research location is as follows:

V = CH x CA

Information:
V= Volume of rainwater
CH= Daily rainfall (mm)
CA= Catchment area (length x width area)

V = CH x CA
V = 0.0056 m x 25 m²
V = 0.14 m3
V = 140 liters

So, on average, in one day, the rainwater at the research location with a catchment area set at 25 m2 is 140 liters. After the rainfall data is obtained, then to get a technical calculation, an estimate of how much water will be accommodated in the vertical drainage is:

V = (CH + BK) (1)
Information:
V = Volume of water to be delivered to the underground Aquifer layer, through vertical drainage
CH = The amount of rainfall

BK = Amount of Shipment Flood (Possible)

V = (CH + BK)
V= (140 liters + 400 liters)
V= 440 liters

Based on these calculations, the amount of water that must be accommodated by vertical drainage on average per day is 440 liters. With the vertical drainage capacity to deliver water of 48.72 liters/minute, the calculation is as follows:

W= V/ KDV (2)
Information:
V = Volume of water to be delivered to the underground Aquifer layer, through vertical drainage
KDV = Vertical Drainage Capability
W = Time taken to deliver all the water to the vertical drainage

W= V/ KDV
W= 440 liters/ 0.812 liters/second
W= 541.87 seconds or 9 minutes 1 second

Thus, vertical drainage can deliver rainwater storage and possible flooding at the research site within 9 minutes 1 second until it runs out.

4. Conclusion

The ability of vertical drainage has a positive effect on delivering water into the aquifer layer. Based on the author's test results, vertical drainage can deliver rainwater and the possibility of floodwater delivery at the research location with a time of 9 minutes 1 second with the calculation of the average daily rainfall of Medan City and the assumption of the possibility of the number of flood shipments at the research location. As a result, one vertical drainage system can be accommodated effectively in every 25 m² area. The vertical drainage system has worked well, but the test results have not been optimal or as expected. The vertical drainage work has been completed for now, but more experiments are needed to maximize the vertical drainage abilities to improve the results.

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