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Hydraulic Capacity Analysis and Design of Road Culvert Drainage for Spillway Outflow in an Industrial Area in Pekalongan, Central Java, Indonesia

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ABSTRACT

The development of industrial areas significantly increases surface runoff by expanding impervious surfaces, potentially exceeding the capacity of existing drainage systems and increasing flood risk. In many industrial zones, stormwater management infrastructure must also accommodate additional discharge from retention pond spillways, which can further burden road drainage systems. In the study area, spillway outflow from a retention pond is conveyed into the road drainage network, requiring an adequately designed culvert system to accommodate the flow safely. This study aims to analyze the hydraulic capacity and design an appropriate road culvert drainage system to convey spillway outflow in an industrial area. Secondary data on design flood discharge were obtained from previous studies that conducted rainfall frequency analysis, flood discharge estimation using the Nakayasu Synthetic Unit Hydrograph method, and spillway routing analysis. The results show that the design flood discharge for the 100-year return period (Q100) is 8.68 m^3/s. A hydraulic analysis using the Manning equation was performed to determine the culvert dimensions required to convey the design discharge safely. The analysis indicates that the proposed culvert system is hydraulically adequate. A culvert with a diameter of 2.0 m is installed in the upstream section to accommodate concentrated inflow from the spillway outlet. In comparison, two parallel culverts with a diameter of 1.3 m are installed along the middle-to-downstream sections on both sides of the road. This configuration provides a total discharge capacity of 8.752 m^3/s, exceeding the design flood discharge. The results demonstrate that the proposed design improves drainage Reliability in industrial areas and contributes to flood mitigation by regulating runoff discharge, thereby reducing potential flood risk in downstream residential areas. These findings provide practical guidance for infrastructure planning and policy strategies to integrate industrial drainage systems with regional flood mitigation efforts.

INTRODUCTION

The development of industrial areas has led to a significant increase in surface runoff due to the expansion of impervious surfaces, which substantially alters the natural hydrological response of a catchment (Chow, 1965, 1968; "Hydrology and Floodplain Analysis," 1990; Mashuri et al., 2022; Peters, 2012). The conversion of permeable land into built-up areas reduces infiltration capacity and increases peak discharge, runoff volume, and flow velocity (Ahadi et al., 2020; Clark et al., 1980; J. Gribbin, 2002; J. E. Gribbin, 2007; Leopold, 1968). To control peak discharge, retention ponds and spillways are generally constructed as flow control systems before water is discharged into downstream drainage channels (Ansori et al., 2023; Brunner, 2020; Haan et al., 1994; US Army Corps of Engineers, 2010; USACE, 1995).

However, in many cases, existing drainage channels are not designed to accommodate additional discharge generated by spillway outflow under extreme flood scenarios (Dingman, 2023; Henderson, 1966; Salmasi & Abraham, 2023; Sukerta et al., 2022). The hydraulic capacity of a channel must be evaluated based on peak discharge, flow regime, and boundary resistance to prevent overtopping and structural instability (Castro-Orgaz & Sturm, 2018; Chow, 1959; Maini, 2024b, 2024a; Saputra & Maini, 2025; Subramanya, 1982).

In the studied industrial area, the spillway pond outlet discharges into a roadside drainage channel originally designed solely to convey road surface runoff. Currently, the channel functions as a multipurpose drainage system, conveying both road runoff and spillway outflow before discharging into the nearest river. This condition significantly increases flow velocity, depth, and bed shear stress, which may trigger erosion and structural degradation, particularly in unlined earth channels (Bathurst et al., 1981; Knighton, 2014; Porter et al., 2012; Simons & Sentirk, 1976). The existing channel geometry was not designed based on routed flood discharge from extreme events, potentially resulting in hydraulic inadequacy (Biedenharn et al., 1998; Chanson, 2004).

During a 100-year return period flood event, the discharge obtained from spillway routing may exceed the hydraulic capacity of the existing channel cross-section. Flood routing analysis is essential for determining the temporal variation in outflow discharge from storage structures (Haan et al., 1994; McCuen, 2004; USACE, 1995). If the channel capacity is lower than the routed peak discharge, overtopping, bank erosion, and drainage failure may occur (Castro-Orgaz & Sturm, 2018; Chow, 1959; Maini, Kironoto, Rahardjo, et al., 2024; Maini & Susanti, 2019). It indicates that the existing channel dimensions were not determined using an integrated hydrologic–hydraulic approach (Peters, 2012).

Previous research by Maini & Susanti (2025) calculated the regional design flood discharge and conducted spillway routing analysis for a 100-year return period. Nevertheless, that study did not assess whether the routed peak discharge could be safely conveyed by the roadside drainage channel based on hydraulic capacity analysis and flow regime evaluation. Thus, a research gap exists in determining channel geometric dimensions directly based on spillway outflow discharge resulting from extreme flood routing.

Most previous studies tend to separate hydrological analysis (design flood estimation using frequency analysis, such as the Gumbel or Log-Pearson Type III distribution) from hydraulic channel design (Chow, 1968; Maini, 2024a). In practice, channel dimensions are often determined under steady, uniform flow conditions using the Manning equation, without explicitly verifying capacity limits against the actual routed peak discharge (Chow, 1959; Henderson, 1966; Maini & Susanti, 2025; Saputra & Maini, 2025). This separation may lead to an underestimation of hydraulic risk in multipurpose industrial drainage systems.

The novelty of this study lies in directly designing drainage channel dimensions based on the peak discharge obtained from 100-year return period spillway routing, using hydraulic capacity optimization through the Manning equation (Bonetti et al., 2017; Cheng, 2017; Maini et al., 2025; Maini, Kironoto, Istiarto, et al., 2024; Strohmeier et al., 2014). The study specifically focuses on determining cross-sectional geometry (width, depth, and bed slope) capable of safely conveying the design discharge without overtopping, thereby producing an adaptive channel design suitable for multipurpose drainage systems in industrial areas. However, previous studies have generally emphasized flood discharge estimation and spillway routing. In contrast, the hydraulic design of downstream drainage structures, particularly road culverts that convey spillway outflow, has received relatively limited attention. In industrial areas, inadequate culvert capacity may reduce the effectiveness of flood control ponds and increase the risk of local flooding. Therefore, this study aims to analyze the hydraulic capacity and design an appropriate road culvert drainage system to convey spillway outflow in an industrial area. The design is based on the 100-year return period flood discharge (Q100) of 8.68 m^3/s derived from previous hydrological analyses (Maini & Susanti, 2025), ensuring that the proposed drainage system can safely accommodate extreme flows and operate with adequate hydraulic performance.

RESEARCH METHODS

Research Approach

This study uses secondary data from a previous study by Maini and Susanti (2025), which analyzed the hydrological characteristics and performance of the pond storage and spillway system in an industrial area in Pekalongan Regency, Central Java, Indonesia. The rainfall data used in the previous study consisted of daily rainfall records for 10 years from 2015 to 2024 obtained from a rainfall station in Pekalongan Regency. Based on the hydrological analysis conducted in that study, the pond storage and spillway structure were designed to safely accommodate and convey the flood discharge corresponding to a 100-year return period. The spillway outflow discharge from this analysis is used in the present study as the design discharge for evaluating the drainage culvert's hydraulic capacity (Maini & Susanti, 2025).

The initial stages of this research adopt the results of the previous analysis, including the collection of rainfall data, hydrological analysis, and determination of the spillway outflow discharge. These results provide the primary input for the subsequent hydraulic analysis. In addition, this study incorporates existing land-use data for the industrial area, obtained through field surveys, to identify site characteristics, including surface conditions, existing drainage systems, and road geometry, where the culvert drainage system will be installed.

Based on these data, a hydraulic capacity analysis of the culvert was conducted to evaluate its ability to convey the design discharge generated from the spillway outflow. The analysis was then used to determine the optimal culvert dimensions to ensure the drainage system safely and efficiently conveys the flow without causing overflow or flooding in the industrial area.

Accordingly, the primary focus of this research is to evaluate the hydraulic capacity of the existing drainage channel and to redesign its geometric dimensions based on the peak discharge resulting from 100-year return period spillway routing.

Secondary Data of Flood Discharge and Spillway Routing

The design flood discharge data and spillway routing analysis results used in this study were entirely adapted from research conducted by Maini and Susanti (2025). In this study, a comprehensive hydrological analysis was conducted, beginning with rainfall frequency analysis to determine design rainfall for various return periods. This statistical analysis aims to estimate the magnitude of extreme rainfall representing specific return periods, including the 100-year return period commonly used in flood control infrastructure planning.

The resulting design rainfall was then used as input in calculating the design flood discharge using the Nakayasu Synthetic Unit Hydrograph (SUH) method. The method was chosen because it can represent the watershed response as a synthetic hydrograph based on watershed morphometric characteristics and time of concentration. The resulting design flood hydrograph was further analyzed using level-pool routing (storage-indication method) to simulate flood propagation through the retention pond and spillway system, yielding an outflow hydrograph.

Based on the research results, the peak discharge of runoff through the spillway for a 100-year return period (Qout,100) has been determined and used as the design discharge in this study. Therefore, this study does not recalculate the hydrological analysis or flood tracking; instead, it directly uses the peak discharge from the routing results as the main input for hydraulic planning. This approach is taken to maintain consistency with previous studies and focus the research on the dimensional design and hydraulic performance evaluation of the drainage channel system.

Determination of Circular Channel Design Dimensions

The design dimensions of a circular drainage channel (culvert) are determined based on the design flood discharge. In open channel hydraulics, discharge (*Q*) is defined as the product of the wetted cross-sectional area (*A*) and the average flow velocity (*V*), as expressed in Equation (1):

$$Q = A.V \tag{1}$$

The flow velocity can be calculated using the Manning equation, originally introduced by Manning (1891) and widely presented in hydraulic references such as Chow (1959). The Manning equation is given in Equation (2):

$$V = \frac{1}{n} R^{2/3} S^{1/2} \tag{2}$$

where:

n = Manning roughness coefficient,

R = hydraulic radius (*A*/*P*),

S = energy slope (approximated by the channel bed slope for uniform flow conditions).

The Manning roughness coefficient (n) depends on the surface characteristics of the channel material, such as concrete, steel, or natural earth, and its value can be obtained from standard Manning roughness tables Chow (1959). The energy slope (*S*) is determined from field measurements, typically based on the longitudinal slope of the channel bed or the water-surface slope (difference in upstream and downstream water-surface elevations), which can be measured using a theodolite.

In the study area, a circular culvert is already available in the field. Therefore, if the drainage channel is designed using a circular cross-section flowing full, the culvert diameter (*D*) can be determined by substituting Equations (1) and (2) For a full-flowing circular pipe (Saputra & Maini, 2025):

Cross-sectional area:

$$A = \frac{\pi D^2}{4} \tag{3}$$

Wetted perimeter:

$$P = \pi D \tag{4}$$

Hydraulic radius:

$$R = \frac{A}{P} = \frac{\frac{\pi D^2}{4}}{\pi D} = \frac{D}{4} \tag{5}$$

Substituting these parameters into Equation (1):

$$Q = V \cdot A$$

$$Q = \frac{\pi D^2}{4} \frac{1}{n} \left(\frac{A}{P}\right)^{2/3} S^{1/2} \tag{6}$$

Substituting $R = \frac{D}{4}$:

$$Q = \frac{\pi D^2}{4} \frac{1}{n} \left(\frac{D}{4}\right)^{2/3} S^{1/2} \tag{7}$$

Rearranging:

$$Q = \frac{\pi}{4}\frac{1}{n}D^2\left(\frac{1}{4}\right)^{2/3} D^{2/3}\, S^{1/2} \tag{8}$$

$$Q = \left(\frac{1}{4}\right)^{5/3} \pi\, \frac{1}{n} D^{8/3}\, S^{1/2} \tag{9}$$

Rearranging to isolate $D^{8/3}$:

$$D^{8/3} = \frac{Q}{\left((1/4)^{5/3}\, \pi \frac{1}{n} S^{1/2}\right)} \tag{10}$$

Finally, solving for the culvert diameter:

$$D = \left[\frac{Q}{\left((1/4)^{5/3}\, \pi\, \frac{1}{n} S^{1/2}\right)}\right]^{3/8} \tag{11}$$

Equation (11) indicates that the diameter of a circular drainage channel (*D*) is primarily influenced by the design discharge (*Q*), the Manning roughness coefficient (*n*), and the channel slope (*S*). An increase in the design discharge (*Q*) results in a larger required diameter, as a greater flow capacity must be accommodated by the conduit. Similarly, a higher Manning roughness coefficient (*n*) increases the required diameter because greater surface roughness reduces flow velocity, requiring a larger cross-sectional area to convey the same discharge. In contrast, a steeper channel slope (*S*) reduces the required diameter, as a greater slope increases flow velocity and enhances the channel's hydraulic capacity. This analytical formulation provides a direct and practical method for determining the required design diameter of a circular drainage channel under uniform full-flow conditions.

Evaluation of Existing Channel Hydraulic Capacity

The calculated discharge capacity of the existing channel (Q_{design}) was then compared with the routed peak outflow discharge corresponding to the 100-year return period flood ($Q_{out,100}$), which was obtained from the spillway routing analysis. If the condition $Q_{design} < Q_{out,100}$ is satisfied, the channel is classified as hydraulically inadequate. In such a case, the existing geometry cannot safely convey the design flood without overtopping, indicating the need for geometric redesign. The redesign process focuses on modifying key hydraulic dimensionssuch as channel width, depth, and slope to ensure that the upgraded channel capacity meets or exceeds the required design discharge.

RESULTS AND DISCUSSION

Description of secondary data

Secondary data, in the form of design flood discharges for various return periods, were obtained from the study by Maini & Susanti (2025). As presented in Figure 1, the analysis indicates that the estimated flood discharges potentially entering the pond for return periods of 5, 10, 20, 25, 50, and 100 years are 19.53 m^3/s, 22.98 m^3/s, 26.29 m^3/s, 27.34 m^3/s, 30.57 m^3/s, and 33.78 m^3/s, respectively. The increasing trend of discharge values with longer return periods reflects rainfall events with lower probabilities of occurrence but higher rainfall intensity and runoff volume.

This simulation provides essential quantitative information regarding the maximum potential flood inflow to the pond for each return period. These data serve as the basis for spillway routing analysis and for evaluating the pond's storage capacity in attenuating peak discharge, thereby playing a significant role in flood risk management within the industrial area.

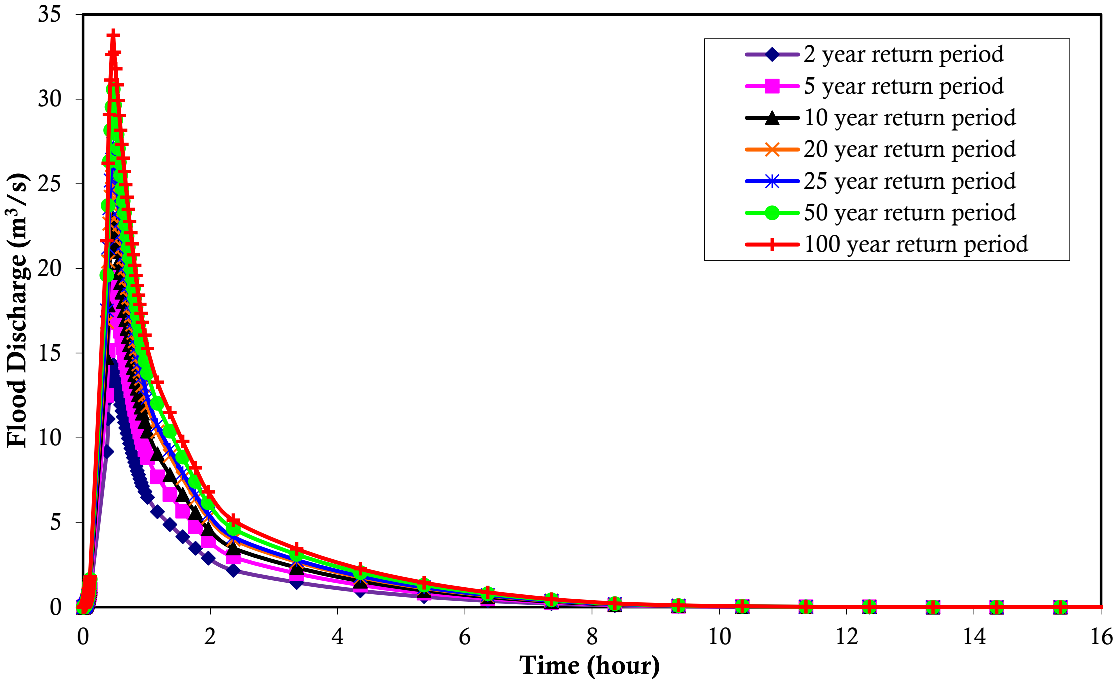

Figure 1. Flood Discharge of Various Recurrence Periods in the Pond System in the Shoe Factory Industrial Area, Pekalongan Regency, Central Java Province (Source: Maini & Susanti, 2025)

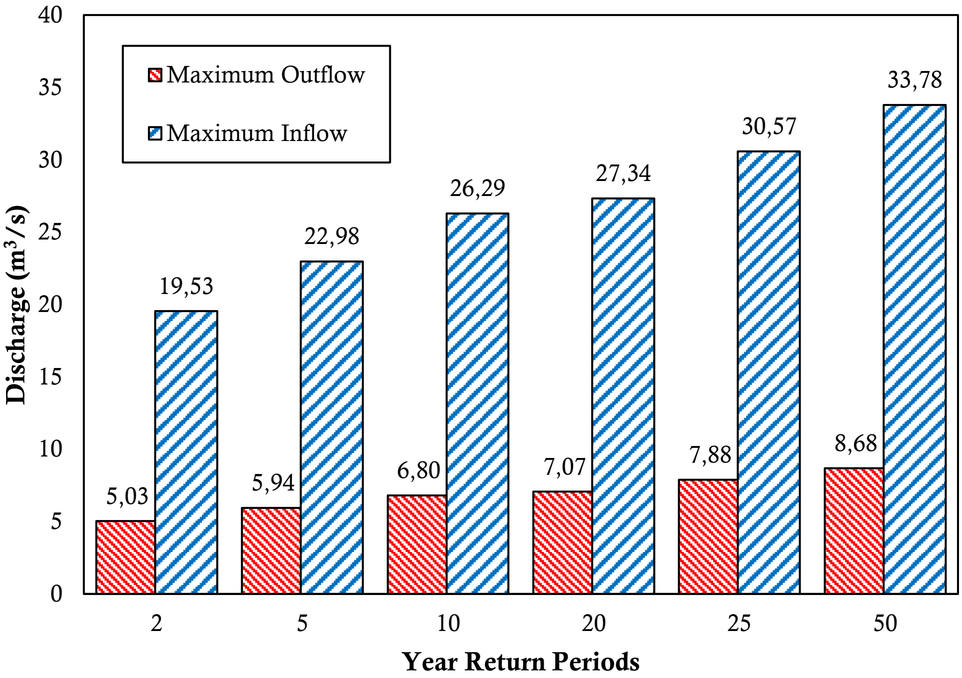

Figure 2. Inflows and outflows of various return periods

Furthermore, the spillway routing results, also conducted by Maini & Susanti (2025), show significant variations in outflow discharge corresponding to the analyzed return periods. The resulting outflow discharges for the 5-, 10-, 20-, 25-, 50-, and 100-year return periods are 5.03 m^3/s, 5.94 m^3/s, 6.80 m^3/s, 7.07 m^3/s, 7.88 m^3/s, and 8.68 m^3/s, respectively (see Figure 2). These results indicate that the pond effectively reduces peak inflow discharge before releasing it downstream.

Based on these secondary data, the drainage channel in this study was designed using the maximum outflow discharge as the design condition, namely 8.68 m³/s corresponding to the 100-year return period. This approach ensures that the designed drainage channel has sufficient hydraulic capacity to accommodate the highest spillway outflow, thereby minimizing the risk of overflow and inundation within the industrial area.

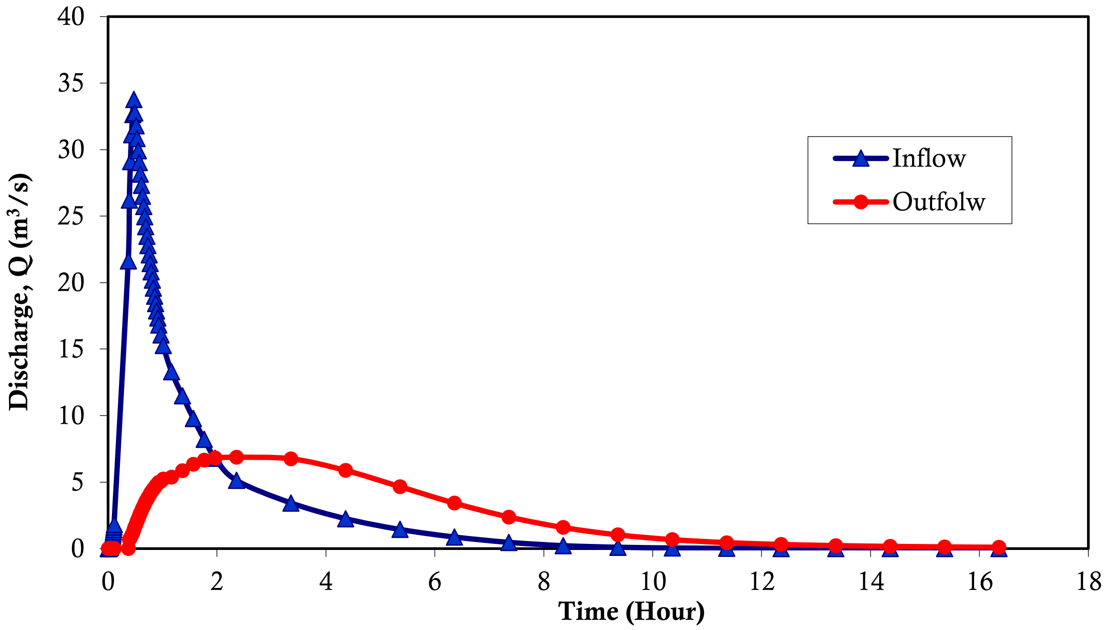

Figure 3. Inflow Hydrograph of 100-Year Return Period Flood and Outflow Spillway in Pond System in Shoe Factory Industrial Area, Pekalongan Regency, Central Java Province (Source: Maini & Susanti, 2025)

Channel Design

Secondary data indicate that the spillway routing outflow discharge for the 100-year return period (Q_{100}) is 8.68 m³/s, as reported by Maini and Susanti. The planned energy slope (S) is 0.007, and the channel lining is concrete, resulting in a Manning roughness coefficient (n) of 0.012.

Using Equation (9), the required diameter of the circular culvert is determined as:

$$D = \left[\frac{Q}{((1/4)^{5/3}\,\pi\,(1/n)\,S^{1/2})}\right]^{3/8}$$

Substituting the design parameters:

$$D = \left[\frac{8.68}{\left((1/4)^{\frac{5}{3}} \times 3.14 \times\ (1/0.012)\ \times 0.007^{1/2}\right)}\right]^{3/8}$$

D = 1.681 m

Although the calculated hydraulic diameter is 1.681 m, a freeboard is required to accommodate discharge fluctuations and ensure hydraulic safety. A freeboard of 25% of the calculated diameter is adopted:

Freeboard = 25% × 1.681 = 0.252 m

Thus, the design diameter becomes:

D_design = 1.681 + 0.252 = 1.933 m rounded using a diameter of 2 m

The corresponding design cross-sectional area is:

$$A_{design} = \frac{1}{4}\pi D^2$$
$$A_{design} = \frac{1}{4} \times 3.14 \times (2)^2 = 3.142 \text{ m}^2$$

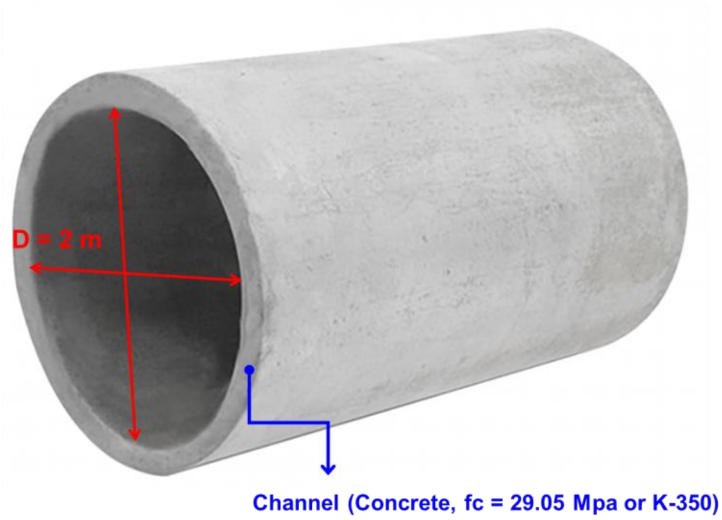

Figure 4. Culvert Type Channel Dimension Design (Diameter 2 m)

However, based on the existing conditions at the project site, the drainage system is planned to be constructed along two channels located on the left and right sides of the road. Therefore, the previously planned drainage diameter of 2.0 m is divided into two parallel conduits, each with a diameter of 1.0 m. This configuration consists of two parallel drainage culverts that function simultaneously to convey the flow discharge through both sides of the road. With this arrangement, the total drainage system flow capacity is expected to remain sufficient to accommodate the design flood discharge. Furthermore, to ensure that each 1.3 m-diameter culvert has sufficient hydraulic capacity, discharge capacity was verified. The discharge capacity of the drainage culvert was calculated using the Manning equation as follows:

$$Q = A \cdot V$$
$$Q = \frac{1}{4}\pi D^2 \cdot \frac{1}{n}\left(\frac{A}{P}\right)^{2/3} S^{1/2}$$
$$Q = \frac{1}{4}\pi D^2 \cdot \frac{1}{n}\left(\frac{\frac{1}{4}\pi D^2}{\pi D}\right)^{2/3} S^{1/2}$$

Substituting D = 1.3 m, n = 0.012, and S = 0.007 results in:

Q (single culvert) = 4.376 m^3/s

With two culverts:

Q (2 units) = 4.376 × 2 = 8.752 m^3/s

The total culvert capacity (8.752 m^3/s) is greater than the 100-year return period discharge (Q_{100} = 8.68 m^3/s), indicating that the proposed dual 1.3 m diameter culvert configuration satisfies the hydraulic capacity requirement. However, considering the hydraulic conditions along the drainage alignment and the availability of construction materials on site, a variation in culvert diameter is applied along the channel reach.

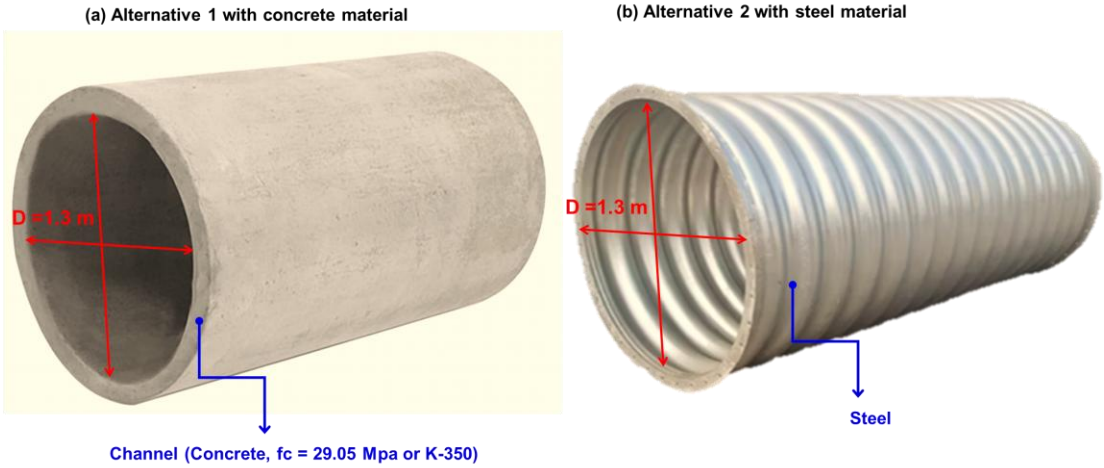

Figure 5. Culvert Type Channel Dimension Design (Diameter 1.3 m): (a) alternative 1 with concrete material, (b) alternative 2 with steel material

In the upstream section, a culvert with a diameter of 2.0 m (see Figure 4) is installed to accommodate the higher inflow concentration and to ensure adequate hydraulic conveyance at the inlet section. Field observations indicate that this upstream area functions as the primary entry point for runoff originating from the spillway outlet and surrounding impervious surfaces within the industrial area. During high rainfall events, flow concentration in this section increases significantly, potentially leading to local inundation if drainage capacity is insufficient. Therefore, installing a larger culvert in the upstream section is necessary to reduce hydraulic head losses and ensure smooth flow into the downstream drainage system.

Meanwhile, in the middle to downstream sections, two culvert units with a diameter of 1.3 m (see Figure 5) are installed in parallel on the left and right sides of the road (see Figures 6 and 7). This configuration reflects the actual field constraints, where the road alignment and limited construction space restrict the installation of a single large-diameter conduit. The use of dual culverts distributes flow through two channels, thereby reducing the risk of flow concentration and potential overtopping during peak discharge. From a flood risk perspective, this arrangement also improves the hydraulic stability of the drainage system by providing redundancy in case partial blockage occurs in one of the conduits due to sediment or debris transport, which is commonly observed in drainage systems within industrial areas.

The hydraulic analysis shows that this configuration results in a total culvert capacity of 8.752 m^3/s, which is slightly greater than the design flood discharge for the 100-year return period ($Q100 = 8.68\ m^3/s$). It indicates that the proposed drainage system satisfies commonly applied drainage design standards for industrial areas, where the design flood typically ranges from 25-year to 100-year return periods, depending on the required level of flood protection. By adopting the 100-year return period discharge as the design basis, the proposed culvert system provides a higher level of hydraulic safety. It significantly reduces the risk of flooding in downstream areas, which are characterized by residential areas and road infrastructure.

It is important to note that the proposed design differs significantly from the existing drainage condition in the field. Currently, the drainage channel along the road consists of an earth channel with a standard roadside drainage dimension of approximately 0.6 m × 0.6 m. Such dimensions are generally intended to accommodate local surface runoff from road drainage and are not designed to convey additional discharge originating from the spillway outlet. Consequently, during high rainfall events, the existing drainage capacity is likely insufficient to safely convey the design flood discharge, leading to overflow and localized flooding along the drainage path and in surrounding areas.

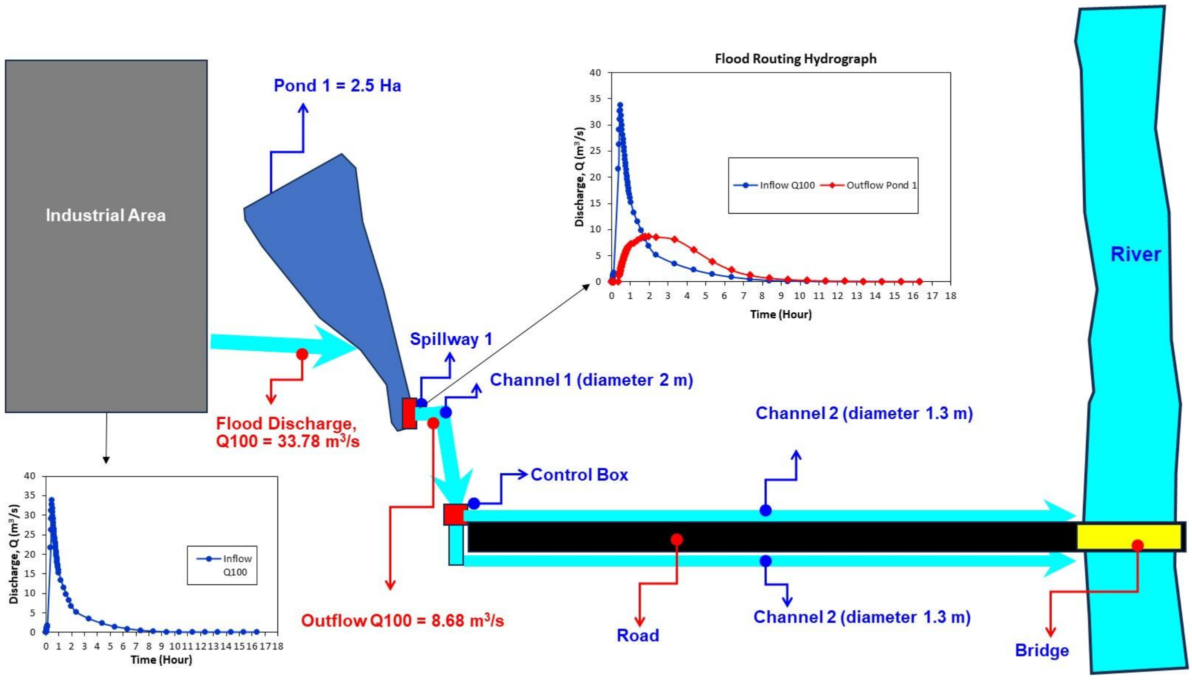

Figure 6. schematic drainage design

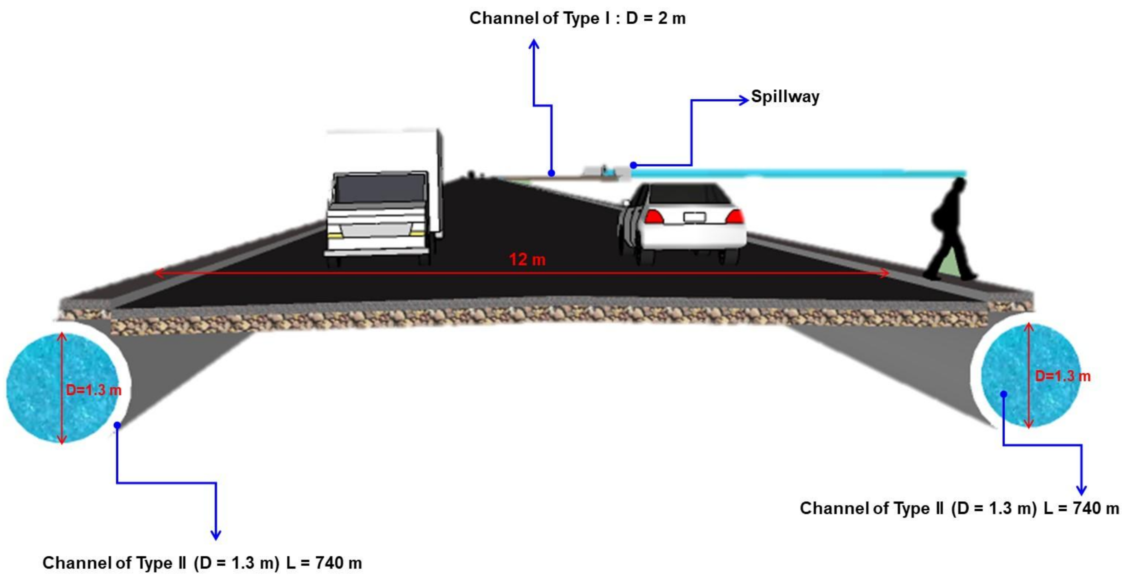

Figure 7. 3D design of the road drainage culvert installation with a diameter of 1.3 m

Therefore, the implementation of the proposed culvert system not only increases the hydraulic capacity of the drainage infrastructure but also represents a significant improvement compared with the existing drainage system. In addition, the use of reinforced culvert structures with available 1.3 m-diameter steel or concrete pipes in the middle to downstream sections ensures compatibility with on-site construction materials while maintaining hydraulic reliability. This approach satisfies both hydraulic safety requirements and construction feasibility, making the proposed drainage design technically applicable and effective for mitigating flood risks in the industrial area.

Overall, the proposed culvert system represents a significant improvement over the existing drainage condition. The current earth channel, approximately 0.6 m × 0.6 m, was originally designed solely to accommodate local roadside runoff and is not capable of conveying additional discharge from the spillway outlet. By replacing this limited-capacity drainage channel with a culvert system designed based on the 100-year return period flood discharge, the hydraulic capacity of the drainage infrastructure is substantially increased. This improvement not only ensures the safe conveyance of extreme runoff but also helps reduce the potential risk of flooding in downstream areas, particularly in residential zones near the industrial drainage network.

Comparison with Previous Studies

Several previous studies have investigated the hydraulic design and capacity analysis of drainage channels and culvert structures in urban and industrial areas. In general, these studies emphasize the importance of accurately estimating design flood discharge and ensuring that drainage structures have sufficient hydraulic capacity to convey runoff safely and prevent flooding.

Chow (1959) emphasized that the hydraulic capacity of open channels and culverts can be evaluated using the Manning equation, which relates discharge capacity to channel geometry, slope, and roughness coefficient. This approach has been widely applied in drainage system design to ensure that channel dimensions can convey the design flood discharge.

Similarly, research by Kodoatie & Sugiyanto (2010) found that inadequate drainage capacity in rapidly developing areas often results from increased impervious surfaces, which significantly increase surface runoff. Therefore, hydraulic analysis and proper design of drainage infrastructure, including culverts, are essential to maintain drainage system performance.

Previous studies also focused on culvert design in road drainage systems. For example, Norman E. Jones demonstrated that culvert capacity must be carefully designed based on expected flood discharge and site-specific hydraulic conditions to prevent backwater and flow obstructions.

Compared with previous studies, this research specifically evaluates the hydraulic capacity of road drainage culverts designed to convey spillway outflow from a retention pond in an industrial area. The design incorporates a variation in culvert diameters along the drainage alignment, with a 2.0 m diameter culvert in the upstream section and dual 1.3 m diameter culverts in the middle to downstream sections. This configuration ensures sufficient discharge capacity while optimizing the use of available construction materials. Therefore, the study contributes to practical hydraulic design solutions for drainage systems affected by spillway discharge in industrial environments.

CONCLUSION

This study analyzed the hydraulic capacity and developed a design for road culvert drainage to convey spillway outflow in an industrial area safely. Based on secondary data obtained from previous studies, the design flood discharge for the 100-year return period (Q_{100}) was determined to be 8.68 m³/s from spillway routing analysis. The hydraulic evaluation was then conducted using the Manning equation to determine the required culvert dimensions capable of safely accommodating the design discharge.

The analysis results indicate that the proposed culvert system is hydraulically adequate to convey the spillway outflow. The design uses a variation in culvert diameters along the drainage alignment, with a 2.0 m-diameter culvert installed in the upstream section to accommodate the concentrated inflow near the spillway outlet. In the middle to downstream sections, two parallel culverts with a diameter of 1.3 m are installed on the left and right sides of the road. This dual configuration provides a total discharge capacity of approximately 8.752 m³/s, which exceeds the design flood discharge (Q_{100} = 8.68 m³/s).

These results confirm that the proposed culvert configuration can safely convey the spillway outflow without exceeding the drainage system's hydraulic capacity. In addition, the selected design optimizes the use of available construction materials while ensuring hydraulic safety and cost efficiency. Therefore, the proposed design can serve as a practical engineering solution for improving road drainage systems in industrial areas affected by spillway discharge.

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