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Hydrological-Based Design of Road Surface Drainage Channels Using SNI 03-3424-1994: Case Study on the Jepara–Keling Road Section

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Abstract

Effective road surface drainage plays a crucial role in maintaining the structural performance and service life of flexible pavement systems. Inadequate drainage causes rainwater to stagnate or flow along pavement edges, accelerating pavement deterioration under repeated traffic loads. This study focuses on redesigning the dimensions of road surface drainage channels along the Jepara–Keling Road section, where the existing drainage system remains natural and is prone to sedimentation and vegetation growth. The planning process follows the Indonesian standard SNI 03-3424-1994 concerning procedures for road surface drainage design. Daily rainfall data over ten years were analyzed to determine design rainfall, rainfall intensity, time of concentration, runoff coefficient, and flood discharge. The calculated design discharge was subsequently used to determine appropriate channel dimensions. The results indicate that a concrete drainage channel with a base width of 70 cm, an effective flow depth of 35 cm, and a freeboard height of 41 cm is sufficient to safely accommodate the design flood discharge. The proposed design is expected to improve drainage performance, reduce water-related pavement damage, and support the planned service life of the road.

Keywords: Road surface drainage; Hydrological reanalysis; Drainage design; Rainfall analysis; Surface drainage.

1. Introduction

Rainwater runoff is widely recognized as one of the primary external factors contributing to the deterioration of flexible pavement structures[1,2]. From a pavement engineering perspective, water weakens the mechanical properties of pavement layers by reducing inter-particle bonding, decreasing shear strength, and increasing pore water pressure within the subgrade[3,4]. When surface water is not promptly conveyed away from the pavement, it infiltrates through surface cracks or joints and accumulates within the pavement system, accelerating various forms of distress such as cracking, rutting, stripping, and pothole formation. These detrimental effects are further intensified under continuous traffic loading, as saturated or weakened pavement layers experience faster structural fatigue, ultimately leading to a significant reduction in pavement service life. Effective surface drainage, therefore, plays a fundamental role in pavement performance by controlling moisture exposure within the pavement structure[5,6]. The primary function of road surface drainage is to rapidly collect and convey runoff away from the pavement before infiltration or prolonged ponding can occur. Inadequate drainage performance commonly results in water stagnation along pavement edges and

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shoulders, which are structurally vulnerable zones due to lower support capacity and frequent load concentration. Over time, these conditions promote edge failures and longitudinal cracking that often propagate into the main traffic lanes.

In practice, however, many road sections, particularly secondary and regional roads, still rely on natural or semi-natural drainage channels with limited hydraulic capacity. Such channels are highly susceptible to sediment deposition, vegetation growth, and irregular channel geometry, all of which increase hydraulic roughness and reduce the effective flow area[7,8]. As a result, the ability of these channels to convey runoff during rainfall events is significantly diminished, leading to water ponding, overtopping, or uncontrolled flow along pavement shoulders. These conditions not only accelerate pavement deterioration but also pose risks to road user safety and driving comfort[9]. The Jepara–Keling road section exhibits conditions consistent with these challenges. Field observations indicate that the existing surface drainage system remains largely natural and is partially obstructed by vegetation growth along the channel alignment. During rainfall events, runoff is not efficiently conveyed, resulting in localized water accumulation along the pavement edge and shoulder. If such conditions are left unaddressed, prolonged moisture exposure is likely to progressively undermine pavement integrity, accelerate surface distress, and increase the frequency and cost of maintenance interventions[10,11].

Despite the acknowledged importance of surface drainage, the application of standardized drainage planning methods in practical road improvement projects remains limited. Many drainage systems are designed without sufficient integration of hydrological analysis, runoff estimation, and pavement performance considerations. In particular, applied studies that explicitly implement SNI 03-3424-1994 for redesigning road surface drainage channels under real field conditions are still scarce, especially for road sections characterized by natural drainage systems and recurring maintenance problems. In response to these challenges, this study focuses on redesigning the dimensions of the road surface drainage channel along the Jepara–Keling road section by applying the procedures specified in SNI 03-3424-1994. The study integrates rainfall analysis, time of concentration estimation, runoff discharge calculation, and hydraulic channel design to develop a drainage solution that is technically adequate and practically feasible. The proposed drainage channel is expected to improve runoff conveyance capacity, minimize water-related pavement damage, and enhance long-term pavement performance. Furthermore, the findings of this study provide a practical reference for engineers and practitioners involved in road drainage planning and rehabilitation, particularly in regions with similar hydrological conditions and roadway characteristics.

2. Material and Methods

This study employed a quantitative hydrological engineering approach to redesign the dimensions of road surface drainage channels along the Jepara–Keling road section in accordance with SNI 03-3424-1994. The research stages were systematically structured to analyze rainfall characteristics, estimate runoff discharge, and determine appropriate channel dimensions capable of safely conveying surface runoff, improving drainage performance and supporting pavement durability.

2.1. Research Object and Data Collection

The research object of this study is the road surface drainage system along the Jepara–Keling road section, which serves as an important transportation corridor in the Keling District. This road segment was selected due to the recurring drainage-related problems observed during rainfall events, including water accumulation along the pavement edge and limited runoff conveyance caused by the use of natural drainage channels. The drainage planning process was carried out using a combination of primary and secondary data to ensure a comprehensive understanding of both field conditions and hydrological characteristics. Primary data were obtained through direct field observations and measurements, focusing on the geometric and physical characteristics of the existing drainage system. These observations included the longitudinal slope of the drainage channel, the current condition of the channel alignment, and the presence of sedimentation or vegetation that may affect hydraulic performance. Secondary data consisted of daily rainfall records for the Keling District, which were obtained from the local public works and water resources authority. The rainfall data represent long-term hydrological conditions and were used to analyze rainfall characteristics, determine design rainfall values, and estimate rainfall intensity for drainage planning purposes. By integrating field-based observations with long-term rainfall data, this study ensures that the proposed drainage channel design reflects actual site conditions while remaining consistent with regional hydrological patterns.

2.2. Rainfall Data Analysis

Daily maximum rainfall data spanning ten years were analyzed to determine the design rainfall for a selected return period. Statistical parameters, including mean rainfall and standard deviation, were calculated to estimate the rainfall magnitude corresponding to the design return period. The resulting design rainfall value was then used as the basis for hydrological analysis.

2.3. Time of Concentration and Rainfall Intensity

The time of concentration (Tc) was calculated to represent the time required for runoff to travel from the farthest point of the catchment area to the drainage channel. The analysis considered runoff paths across pavement surfaces, shoulders, and drainage channels. Using the calculated Tc, the maximum rainfall intensity was determined to represent the critical condition for runoff generation.

2.4. Runoff Discharge Calculation

The design flood discharge was estimated using the rational method, which incorporates rainfall intensity, runoff coefficient, and contributing drainage area. The drainage area included half of the pavement width, road shoulders, and adjacent land extending up to 100 m from the road edge. The calculated discharge served as the basis for determining the required hydraulic capacity of the drainage channel.

2.5. Drainage Channel Dimension Design

Based on the calculated design discharge, the drainage channel dimensions were determined in accordance with SNI 03-3424-1994. A concrete channel was selected to ensure structural stability, resistance to erosion, and long-term hydraulic performance. Channel dimensions were designed to safely convey the design discharge while providing adequate freeboard to prevent overtopping.

3. Results and Discussion

3.1. Hydrological Analysis

The rainfall data analysis produced an average daily maximum rainfall of 191.2 mm, with a standard deviation of 56.29 mm, as described in Table 1. For a five-year return period, the design rainfall was estimated at 245.64 mm. The calculated time of concentration was 4.40 minutes for surface runoff and 3.33 minutes for flow within the drainage channel, resulting in a maximum rainfall intensity of 333.90 mm/h. The procedure for processing daily rainfall data is described as follows:

Table 1. Results of daily rainfall data analysis

Year	Max Rainfall (mm) (Xi)	Daily Average Rainfall ($\bar{x}$)	Deviation ($Xi - \bar{x}$)	$(Xi - \bar{x})^2$
2012	132	191,2	-59,2	3504,64
2013	137	191,2	-54,2	2937,64
2014	280	191,2	88,8	7885,44
2015	164	191,2	-27,2	739,84
2016	143	191,2	-48,2	2323,24
2017	79	191,2	-28,2	795,24
2018	163	191,2	-28,2	795,24
2019	164	191,2	-27,2	739,84
2020	298	191,2	106,8	11406,24
2021	169	191,2	-22,2	492,84
2022	183	191,2	-8,2	67,24
Total	**191.2**			**31687,44**

Further, the runoff coefficient was determined as 0.45, reflecting the combined surface characteristics of pavement, shoulders, and adjacent areas. Using these parameters, the design flood discharge was calculated as 0.36 m^3/s. This discharge value represents the maximum runoff that must be safely conveyed by the drainage channel during the design rainfall event. Hydraulic analysis indicated that a channel cross-section with a base width of 70 cm and an effective flow depth of 35 cm provides a wetted area of 0.241 m^2, which is sufficient to convey the design discharge. A freeboard height of 41 cm was incorporated to accommodate flow fluctuations and ensure operational safety during extreme rainfall events. Compared to the existing natural drainage, the proposed concrete channel offers significantly improved hydraulic capacity and durability. The smooth channel surface reduces flow resistance, while the defined geometry minimizes sediment accumulation and vegetation growth. Consequently, the redesigned drainage system is expected to enhance runoff conveyance efficiency and reduce the risk of pavement damage caused by prolonged water exposure. Figure 1 illustrates the design of the road surface drainage channel, highlighting the proposed channel geometry and dimensions intended to ensure effective runoff conveyance and ease of field implementation.

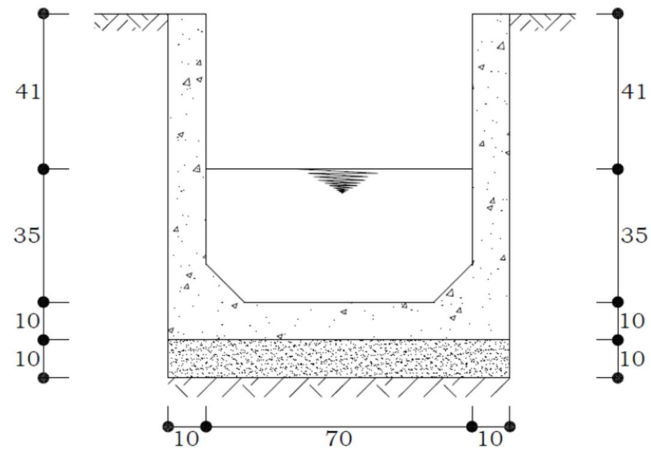

Figure 1. Road surface drainage channel design

3.2. Discussion

The hydrological analysis results demonstrate that rainfall characteristics in the Jepara–Keling road area impose substantial demands on the surface drainage system. The relatively high average daily maximum rainfall and corresponding five-year design rainfall indicate that drainage channels along this road segment must be capable of accommodating intense short-duration rainfall events. The calculated short time of concentration reflects the predominance of impervious pavement surfaces, which generate rapid runoff and reduce the opportunity for natural infiltration. Under such conditions, inadequate drainage capacity can quickly result in surface water accumulation along pavement edges.

The estimated maximum rainfall intensity confirms that runoff is generated rapidly and reaches peak discharge within a short time interval. This finding highlights the importance of designing drainage channels with sufficient hydraulic capacity to safely convey runoff without causing overtopping or backflow. The selected runoff coefficient value appropriately represents the combined surface conditions of pavement, shoulders, and adjacent areas, ensuring that runoff estimation reflects realistic field conditions rather than idealized assumptions. The calculated design flood discharge of 0.36 m^3/s serves as a critical parameter in determining channel geometry. The hydraulic analysis indicates that the proposed channel dimensions, comprising a base width of 70 cm and an effective flow depth of 35 cm, provide an adequate wetted cross-sectional area to convey the design discharge safely. The inclusion of a freeboard height of 41 cm is particularly important, as it enhances operational safety by accommodating flow fluctuations during extreme rainfall events and reducing the risk of overtopping. When compared to the existing natural drainage system, the proposed concrete channel design offers notable improvements in hydraulic performance and durability. Natural channels are inherently vulnerable to sediment accumulation, vegetation growth, and irregular geometry, all of which increase flow resistance and reduce effective capacity over time. In contrast, the smooth surface and well-defined geometry of the concrete channel reduce hydraulic roughness, promote efficient runoff conveyance, and minimize maintenance requirements. These improvements are expected to significantly reduce water stagnation along pavement edges, thereby limiting moisture infiltration into pavement layers.

From a pavement performance perspective, improved surface drainage plays a vital role in mitigating water-related deterioration mechanisms. By rapidly removing runoff from the pavement surface, the redesigned drainage channel helps preserve the structural integrity of pavement layers, reduces the likelihood of edge failures, and contributes to extending pavement service life. Consequently, the proposed drainage design not only satisfies hydraulic requirements but also supports long-term pavement durability and cost-effective road maintenance. The results confirm that the hydrological-based drainage channel design developed in accordance with SNI 03-3424-1994 is technically adequate and practically feasible for the Jepara–Keling road section. The findings reinforce the importance of integrating rainfall analysis, runoff estimation, and hydraulic design in addressing drainage deficiencies commonly encountered on regional road networks.

4. Conclusions

Based on the drainage planning analysis conducted in accordance with SNI 03-3424-1994, the redesigned road surface drainage channel for the Jepara–Keling road section has been demonstrated to satisfy the hydraulic requirements associated with the selected design rainfall. The hydrological analysis, which integrated rainfall characteristics, time of concentration, runoff estimation, and hydraulic capacity assessment, indicates that the proposed channel geometry is capable of safely conveying the design flood discharge without overtopping. The recommended channel dimensions, comprising a base width of 70 cm, an effective flow depth of 35 cm, and a freeboard height of 41 cm, provide sufficient hydraulic capacity while maintaining operational safety during high-intensity rainfall events.

The adoption of a concrete drainage channel with well-defined geometry is expected to significantly enhance surface runoff management along the road corridor. Compared to existing natural drainage conditions, the proposed design offers improved hydraulic efficiency, reduced flow resistance, and greater resistance to sediment accumulation and vegetation growth. These improvements contribute to minimizing prolonged water exposure at the pavement edge, which is a critical factor in preventing moisture-induced pavement deterioration such as edge cracking, rutting, and surface distress. As a result, the redesigned drainage system is anticipated to support the planned service life of the pavement and reduce long-term maintenance requirements.

Furthermore, the results of this study provide a practical and implementable reference for road surface drainage planning, particularly for regional and secondary roads experiencing similar drainage deficiencies. The methodology and findings may be applied to other road sections with comparable hydrological conditions, traffic characteristics, and drainage constraints, thereby supporting more sustainable and effective road infrastructure management practices.

5. Declarations

5.1. Author Contributions

Conceptualization, M.I.K. and K.U.; methodology, N.H.; software, M.I.K.; validation, M.I.K., K.U. and A.F.K.K.; formal analysis, M.I.K.; investigation, N.H.; resources, N.H.; data curation, M.I.K.; writing—original draft preparation, K.U.; writing—review and editing, A.F.K.K.; visualization, A.F.K.K..; supervision, N.H.; project administration, N.H. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding

Funding information is not available.

5.4. Acknowledgements

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5.5. Conflicts of Interest

The authors declare no conflict of interest.

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