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Design Planning for Road Pavement Upgrading Using Rigid Pavement on the Gotri–Damarjati Road Segment

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Abstract

The Gotri–Damarjati road section experiences various problems, including structural deterioration, resulting in uneven, undulating, and pothole-ridden pavement conditions. Therefore, an alternative pavement system with greater structural durability is required. This study adopted the Directorate General of Highways (Bina Marga) Pd T-14-2003 guideline with a 20-year design life and included drainage dimension planning. The results indicate that: (1) the average daily traffic reached 3,269.7 passenger car units/day, with a peak traffic volume of 3,284 vehicles/hour on Monday mornings, dominated by motorcycles and passenger cars; (2) the rigid pavement design employed Jointed Plain Concrete Pavement (JPCP) with a 25 cm concrete slab thickness, using concrete with a flexural strength of 3.5 MPa, a 10 cm lean concrete subbase with a 28-day compressive strength of 5.5 MPa placed over the existing pavement layer, tie bars of deformed steel (Ø16 mm, 70 cm length, 75 cm spacing), and dowel bars of plain steel (Ø36 mm, 450 mm length, 300 mm spacing); and (3) the drainage design, based on the Pd. T-02-2006-B Road Drainage System Planning Guideline produced a discharge capacity of 0.51 m^3/s with planned channel dimensions of 0.9 m width and 0.45 m depth, providing a channel area of 0.405 m^2 and a discharge capacity of 0.6 m^3/s. The side drains were designed using concrete rectangular channels or 60 × 80 cm U-ditch sections.

Keywords: Rigid pavement; road pavement upgrading; Jointed Plain Concrete Pavement (JPCP); traffic analysis; pavement design; drainage design; road infrastructure rehabilitation.

1. Introduction

Roads are one of the primary transportation infrastructures that enable mobility from one location to another and play a vital role in supporting the movement of people, goods, and services[1,2]. Compared with water and air transportation, road transportation is the most widely used mode for daily activities and for supporting economic, social, tourism, and cultural development[3,4]. The increasing economic activities in Jepara have led to significant growth in traffic volume and loading intensity. As a result, the flexible pavement along the Gotri–Damarjati road section has experienced structural deterioration due to the continuous increase in traffic demand. This condition has caused surface deformation, uneven pavement, and potholes, particularly during the rainy season.

Several maintenance and rehabilitation efforts have been carried out using flexible pavement repairs at selected locations [5]. However, these measures have not been sufficient to overcome the recurring damage caused by the high intensity of heavy vehicle and freight traffic along the road segment. The increasing traffic volume has continuously raised the load carried by the flexible pavement structure, accelerating pavement deterioration over time. Considering

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these conditions, an alternative pavement system with greater structural durability is required for the Gotri–Damarjati road section. Therefore, this study proposes the application of rigid pavement as a more durable and sustainable solution to improve road performance and service life [6].

The objective of this study is to design a rigid pavement structure and support drainage system capable of accommodating long-term traffic loads and improving road functionality. The contribution of this study lies in providing a technical reference for sustainable road rehabilitation planning that enhances driving comfort, safety, and reliability while supporting regional economic activities, particularly for the communities in Jepara.

2. Material and Methods

2.1. Research Object and Data Collection

This study was conducted on the Gotri–Damarjati road section located in Margoyoso Village, Kalinyamatan District, Jepara (see Figure 1). The road segment has a width of 6 m and a total planned length of 1 km (STA 0+00 to STA 1+00). The research focused on the planning and design of rigid pavement improvement and roadside drainage systems to address the structural deterioration of the existing flexible pavement. The study employed both primary and secondary data. Primary data were collected through direct field surveys and investigations, including traffic volume surveys, subgrade soil investigations using Dynamic Cone Penetrometer (DCP) tests, road elevation measurements, and rainfall data collection. Traffic surveys were conducted for seven consecutive days at three observation periods each day: morning (06:00–08:00), midday (12:00–14:00), and afternoon (16:00–18:00). Vehicle classifications were converted into passenger car units (PCU) based on the Indonesian Highway Capacity Manual (MKJI 1997). Secondary data were obtained from related agencies, technical guidelines, previous studies, and relevant standards. The rigid pavement design referred to the Directorate General of Highways (Bina Marga) Pd T-14-2003 guideline, while the drainage design followed the Pd. T-02-2006-B Road Drainage System Planning Guideline.

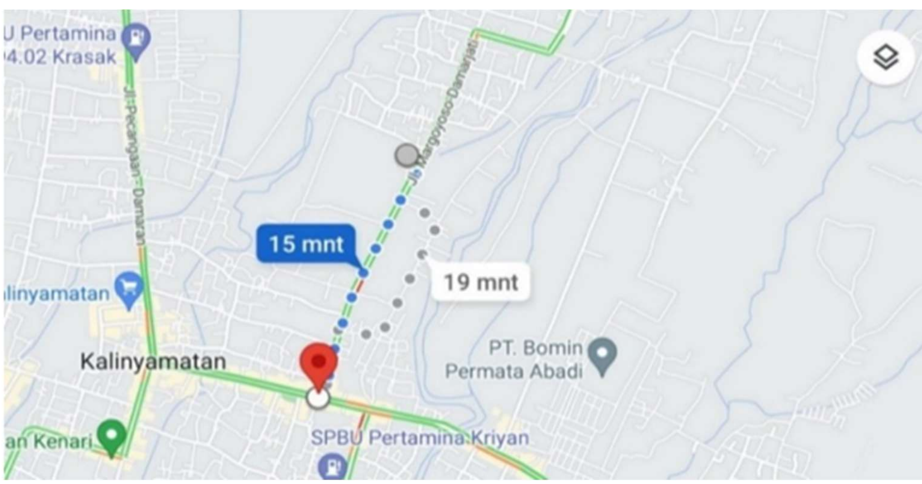

Figure 1. Location of the study

2.2. Data Analysis Procedure

The analysis included traffic evaluation, subgrade assessment, rigid pavement thickness design, and drainage system design. Traffic analysis was performed to determine the average daily traffic (ADT), peak-hour traffic volume, road capacity, degree of saturation, and traffic growth rate. The degree of saturation was evaluated to determine whether road widening was necessary. Subgrade conditions were evaluated using CBR values obtained from DCP testing along the road section. The effective CBR value was then used to determine the required subbase thickness. Rigid pavement thickness design was carried out using the Bina Marga 2003 method, considering traffic loading, cumulative axle repetitions, concrete flexural strength, fatigue analysis, and erosion analysis. The pavement system selected in this study was Jointed Plain Concrete Pavement (JPCP). The drainage analysis included rainfall intensity calculations, runoff coefficient determination, concentration time analysis, discharge calculations, and hydraulic design of roadside drainage channels. The drainage dimensions were designed to ensure that the channel discharge capacity exceeded the design runoff discharge

3. Results and Discussion

3.1. Analysis Data

The traffic survey results showed that the Gotri–Damarjati road section had an average daily traffic volume of 3,269.7 PCU/day. The peak traffic volume occurred on Monday morning between 06:00–07:00, reaching 3,284 vehicles/hour or 936.85 PCU/hour, dominated by motorcycles and passenger vehicles. The calculated road capacity was 2,229.32 PCU/hour, while the degree of saturation value was 0.42, which is below the critical threshold of 0.75. Therefore, road widening was not required for the planned design period. Traffic growth analysis indicated a continuous increase in vehicle volume, which contributed significantly to pavement deterioration. Subgrade investigation results showed that the average CBR value was 9.63%, with a design CBR value of 8.11%. Based on the Bina Marga guideline, a 10 cm lean concrete subbase layer with a compressive strength of 5.5 MPa was selected to improve the effective subgrade support condition. The rigid pavement design adopted a Jointed Plain Concrete Pavement (JPCP) system with a concrete slab thickness of 25 cm and a concrete flexural strength of 3.5 MPa. Fatigue and erosion analyses demonstrated that the pavement design satisfied the required structural performance criteria, with cumulative damage values remaining below the allowable limit of 100%.

The pavement joints were reinforced using tie bars with a diameter of 16 mm, length of 70 cm, and spacing of 75 cm, while dowel bars with a diameter of 36 mm, length of 450 mm, and spacing of 300 mm were applied at transverse joints. The drainage design analysis produced a runoff discharge of 0.51 m^3/s. Based on hydraulic calculations, the planned drainage channel dimensions were 0.9 m in width and 0.45 m in depth, resulting in a channel discharge capacity of 0.6 m^3/s. Since the channel capacity exceeded the design runoff discharge, the proposed drainage system was considered hydraulically adequate. Table 1 presents the Average Daily Traffic (ADT) data for the Gotri–Damarjati road section based on a seven-day traffic survey. The results indicate that motorcycles were the dominant vehicle type throughout the observation period, with the highest traffic volume recorded on Monday (8,938 vehicles/day). Passenger vehicles, including sedans, jeeps, and wagons, also contributed significantly to the traffic flow, while heavy vehicles such as light two-axle trucks, medium two-axle trucks, and three-axle trucks were observed in lower quantities but still contributed to pavement loading. The traffic volume tended to be higher on weekdays compared to weekends, reflecting the influence of daily economic and transportation activities in the study area. Among the surveyed days, Monday recorded the highest overall traffic volume, whereas Sunday showed the lowest traffic intensity. The presence of freight vehicles and commercial transportation indicates that the road segment experiences substantial axle loading, which contributes to the deterioration of the existing flexible pavement structure. These traffic characteristics were used as the basis for determining the rigid pavement design requirements and evaluating the long-term structural performance of the proposed pavement system.

Table 1. Average Daily Traffic (ADT) on the Gotri–Damarjati Road Section (vehicles/day)

No.	Vehicle Type	Monday AADT	Tuesday AADT	Wednesday AADT	Thursday AADT	Friday AADT	Saturday AADT	Sunday AADT
1	Motorcycle	8,938	8,743	8,815	8,639	7,938	7,654	3,176
2	Sedan, Jeep, Wagon	462	403	423	474	385	419	408
3	Combi, Minibus	81	67	72	75	79	61	69
4	Pickup Truck, Delivery Vehicle	179	156	162	193	145	185	204
5	Small Bus	0	0	0	0	2	0	1
6	Large Bus	3	4	0	2	1	5	1
7	Light Two-Axle Truck	212	193	198	237	147	204	198
8	Medium Two-Axle Truck	42	52	42	34	24	31	36
9	Three-Axle Truck	4	6	7	11	3	6	9

Table 2 summarizes the Monday traffic survey results for the Gotri–Damarjati road section based on hourly traffic observations. The results show that motorcycles were the dominant traffic component throughout the observation periods, indicating the high dependence on two-wheeled transportation in the study area. The highest traffic volume occurred during the morning peak hour between 06:00–07:00, reaching 3,284 vehicles/hour or 937 PCU/hour. This peak-hour traffic condition reflects intense commuter and economic activity during the early morning period. In addition to motorcycles, light vehicles and heavy vehicles also contributed to the overall traffic flow. Although the number of heavy vehicles was relatively lower compared to motorcycles, their axle loads significantly influenced pavement deterioration and structural performance. Another notable traffic increase occurred during the afternoon period between 16:00–17:00, with a total traffic volume of 2,645 vehicles/hour or 823 PCU/hour, indicating substantial evening traffic activity. Overall, the total daily traffic volume reached 9,921 vehicles/day or 3,269.7 PCU/day. These traffic characteristics demonstrate that the Gotri–Damarjati road section experiences considerable traffic loading, which must be taken into account in the rigid pavement design to ensure adequate structural capacity and long-term pavement performance.

Table 2. Summary of Monday Traffic Survey Results on the Gotri–Damarjati Road Section

Time Period	Motorcycle (MC) (veh/h)	Light Vehicles (LV) (veh/h)	Heavy Vehicles (HV) (veh/h)	Total Traffic Volume (veh/h)	Total Traffic Volume (PCU/h)
06:00–07:00	3,137	119	28	3,284	937
07:00–08:00	841	101	36	978	354
12:00–13:00	722	117	73	912	385
13:00–14:00	595	104	68	767	334
16:00–17:00	2,438	175	32	2,645	823
17:00–18:00	1,205	106	24	1,335	436
Total	**8,938**	**722**	**261**	**9,921**	**3,269.7**

Table 3 presents the peak-hour traffic volume observed on the Gotri–Damarjati road section during the traffic survey period. The results indicate that the highest peak-hour traffic volume occurred on Monday between 06:00 and 07:00, reaching 3,284 vehicles/hour or 936.85 PCU/hour. This finding suggests that weekday morning periods experience the most intensive traffic activity, primarily associated with work, education, and commercial transportation movements. Traffic volumes remained relatively high from Tuesday to Friday, indicating consistent weekday transportation demand along the road corridor. On Thursday and Friday, the peak traffic periods shifted to the afternoon session (16:00–17:00), reflecting increased return-trip and distribution activities during the evening hours. In contrast, weekend traffic volumes were considerably lower, with Sunday recording the lowest peak-hour traffic volume at 938 vehicles/hour or 401.00 PCU/hour. The observed peak-hour traffic characteristics demonstrate that the Gotri–Damarjati road section is subjected to substantial daily traffic loading. These conditions contribute to the accelerated deterioration of the existing pavement structure and highlight the importance of implementing a more durable, rigid pavement system capable of sustaining long-term traffic demands and improving road service performance.

Table 3. Peak Hour Traffic Volume on the Gotri–Damarjati Road Section

Day	Peak Hour	Peak Traffic Volume (veh/h)	Peak Traffic Volume (PCU/h)
Monday	06:00–07:00	3,284	936.85
Tuesday	06:00–07:00	3,163	900.10
Wednesday	06:00–07:00	2,893	814.80
Thursday	16:00–17:00	2,565	850.80
Friday	16:00–17:00	2,645	817.10
Saturday	16:00–17:00	1,67	588.45
Sunday	16:00–17:00	938	401.00

3.2. Discussion

The results indicate that the existing flexible pavement system on the Gotri–Damarjati road section is no longer capable of accommodating the increasing traffic load, particularly from heavy vehicles and freight transportation. Repeated maintenance using flexible pavement overlays has been ineffective in preventing recurring pavement distress. Therefore, the implementation of rigid pavement provides a more durable alternative with higher load-bearing capacity and longer service life. The selected rigid pavement configuration demonstrated satisfactory structural performance based on fatigue and erosion evaluations. The use of a lean concrete subbase also contributed to improving load distribution and subgrade stability. Furthermore, the integration of an adequately designed drainage system is essential to minimize water infiltration and prevent accelerated pavement deterioration, especially during the rainy season.

4. Conclusions

Based on the analysis and design results, the Gotri–Damarjati road section requires the implementation of a more durable pavement system due to the continuous increase in traffic volume and axle loading, which have accelerated the deterioration of the existing flexible pavement structure. The current pavement condition, characterized by surface deformation, uneven pavement, and potholes, indicates that conventional flexible pavement rehabilitation is no longer capable of adequately sustaining the growing traffic demand, particularly from freight and heavy vehicles. These conditions not only reduce driving comfort but also increase the potential risks to road safety and transportation efficiency. To address these issues, this study proposed the application of a rigid pavement system using Jointed Plain Concrete Pavement (JPCP). The design results demonstrated that the selected pavement configuration, consisting of a 25 cm concrete slab combined with a 10 cm lean concrete subbase layer, fulfills the required structural performance criteria based on fatigue and erosion analyses. The use of rigid pavement is expected to provide greater structural strength, higher resistance to repeated axle loads, and a longer service life compared to the existing flexible pavement system. Furthermore, the incorporation of tie bars and dowel bars in the pavement joints enhances load transfer efficiency and minimizes the risk of joint-related distress.

In addition to the pavement structure, the study also emphasized the importance of an effective drainage system in maintaining pavement durability and preventing water-related damage. The designed roadside drainage channel demonstrated sufficient hydraulic capacity to safely accommodate the calculated runoff discharge, ensuring proper surface water management during rainfall events. Effective drainage performance is essential to minimize water infiltration into the pavement layers, which can weaken the subgrade and accelerate pavement deterioration over time. The proposed rigid pavement and drainage system design is expected to significantly improve road performance, driving comfort, and traffic safety along the Gotri–Damarjati road section. The improved infrastructure is also anticipated to enhance transportation reliability and reduce long-term maintenance requirements. Moreover, the successful implementation of this road improvement project will contribute to supporting regional mobility, facilitating the distribution of goods and services, and strengthening economic activities in Jepara.

5. Declarations

5.1. Author Contributions

Conceptualization, A.A.F. and D.R.; methodology, D.R.; software, A.A.F..; validation, D.R., N.H. and A.A.F.; formal analysis, N.H.; investigation, N.H.; resources, N.H.; data curation, A.A.F...; writing—original draft preparation, A.A.F.; writing—review and editing, A.A.F..; visualization, D.R..; supervision, D.R.; project administration, A. 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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