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ALTERNATIVE DESIGN SOLUTIONS FOR FLEXIBLE AND RIGID PAVEMENTS IN THE SAMPANG-KETAPANG ROAD WIDENING PROJECT (SECTION 113)

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Abstrak
The Sampang-Ketapang road segment (Link 113) plays a pivotal role in regional connectivity, supporting economic and social activities in Sampang Regency, a hub for salt and tobacco production. This study compares two pavement design alternatives: flexible pavement using Class A aggregate with a thickness of 200 mm and rigid pavement with a flexural strength of 4.5 MPa and a thickness of 300 mm. The analysis evaluates cost efficiency, implementation time, and suitability for the increasing traffic demands of the region. The results show that flexible pavement requires an investment of IDR 12.8 billion and a 7-month construction duration, while rigid pavement demands IDR 19.5 billion and a 9-month duration. Flexible pavement offers lower initial costs and shorter implementation time, making it a more feasible option for segments with moderate traffic. However, it requires more frequent maintenance, increasing long-term expenses. Conversely, rigid pavement is more durable, with minimal maintenance costs, but has higher initial costs and a longer construction timeline. Considering the economic and technical aspects, flexible pavement is recommended as the optimal solution for this project due to its cost-effectiveness and shorter timeline, ensuring efficient resource utilization. Strategic implementation combining both pavement types is also proposed, with flexible pavement for moderate traffic areas and rigid pavement for segments with heavy traffic. This approach balances cost efficiency, implementation time, and long-term durability, supporting the sustainable development of road infrastructure in Sampang Regency.

Keywords: Flexible Pavement, Rigid Pavement, Road Widening, Sampang-Ketapang, Cost Analysis, Implementation Time.

INTRODUCTION

Road transportation is a crucial element in national infrastructure development. The existence of adequate roads not only supports the smooth distribution of goods and human mobility, but also becomes the main key in improving the economic competitiveness of a region (Krishna, 2023). In this case, the Sampang-Ketapang Department Road (Link 113) plays an important role as the main connecting route between the northern and southern regions of Madura Island. However, the existing condition of the road is narrow, only around 4-5 meters, and frequent damage causes traffic slowdowns and hampers regional economic growth (Ministry of Public Works and Public Housing, 2018).

Pavement design, whether flexible or rigid, is a significant factor in planning to improve road capacity and quality. Flexural pavements use asphalt as a binder, which has high flexibility and lower initial construction costs. However, they tend to require high maintenance costs over their service life (Elchalakani, Aly, & Abu-Aisheh, 2016). In contrast, rigid pavements use cement concrete, which is known to be more durable and requires minimal maintenance, but at a much greater initial cost (Hardiyatmo, 2015).

The improvement of the Sampang-Ketapang Department Road is based on the need to meet the provincial road standards stipulated in Government Regulation No. 34 of 2006, which is a minimum width of 9 meters. This research aims to evaluate and compare the two alternative pavement designs to determine the most effective and efficient solution in terms of cost and implementation time (Nugroho, Witjaksana, Oetomo, & Setiawan, 2019).

According to (Ojha, 2019), the selection of pavement type is strongly influenced by traffic conditions, the planned life of the road, and environmental factors. For this reason, this study uses a cost analysis and implementation duration approach with the Road Pavement Design Manual 2024 method as the main reference. In this case study, the flexible pavement used Class A aggregate with a thickness of 200 mm, while the rigid pavement used 4.5 MPa flexural strength concrete with a thickness of 300 mm (Qodiron, Oktarina, & Fadilasari, 2023).

The decision to choose between flexible and rigid pavement considers not only the initial construction cost but also the effectiveness in the long term. The study by (Sahrianto, Harnaeni, & Sahid, 2016) showed that rigid pavement is more economical for a 20-year plan life compared to flexible pavement which requires more intensive maintenance. This study also considered the increasing traffic conditions in the Sampang area, which can accelerate the deterioration of pavement quality (Manuho, 2016).

In addition, the implementation time factor is also an important aspect. Flexible pavements usually require less time to construct than rigid pavements, which require 28 days of concrete curing time before vehicles can drive on them (Prahara & Sunarsa, 2012). Therefore, a comprehensive analysis of cost and implementation time is necessary to ensure the selection of the most suitable pavement design.

The Sampang-Ketapang road also has a strategic function in supporting the tourism sector and transportation of goods. With the improvement of road quality, access to tourist sites such as Nepa Beach and Toroan Waterfall will be easier, which in turn contributes to an increase in local revenue (Wulandari, Witjaksana, Oetomo, & Pramoedjo, 2019). Furthermore, this route is also an important alternative for heavy vehicles transporting salt and tobacco products, which are the leading commodities of Sampang Regency (Qodiron et al., 2023).

Geotechnical conditions also affect pavement design. According to (Hardiyatmo, 2015), subgrade soils with low bearing capacity require thicker foundation layers to prevent deformation and premature damage to the pavement. In the case of the Sampang-Ketapang Road, an in-depth analysis of the California Bearing Ratio (CBR) value of the subgrade is required to determine the optimal design (Krishna, 2023). With a comprehensive approach, this research aims to provide the best recommendation in selecting a pavement design for this road widening. The selection of the right design will not only improve the quality of road infrastructure but also have a long-term positive impact on the economy and community mobility (Hidayat, Ir H Muhammad Nursahid, & Senja Rum Harnaeni, 2015).

The main problem encountered in the widening of the Sampang-Ketapang Department Road (Link 113) is to determine the appropriate pavement design, both flexible and rigid, to meet the increasing traffic demand while considering the cost and time aspects of implementation. The chosen design should be able to accommodate heavy traffic and dynamic loads from vehicles passing by every day, while maintaining cost efficiency and construction duration. This study aims to answer how flexural and rigid pavement designs can be optimally implemented, considering all technical and economic aspects to ensure the sustainability of this road infrastructure.

Pavement is a key element in transportation infrastructure, with two main types: flexible pavement and rigid pavement. Flexural pavements use asphalt as a binder and consist of layers that are able to conform to the deformation of the subgrade. The main characteristic of flexible pavements is their flexibility, which allows for a gradual distribution of loads to the lower layers. In contrast, rigid pavements utilize a rigid concrete slab to bear the traffic load, with a wider distribution of pressure directly onto the subgrade. Both types of pavement have advantages and disadvantages that depend on traffic conditions, weather, and specific design needs.

In flexible pavements, the bearing capacity of the layer is strongly influenced by the quality of aggregate material and asphalt used. Its main advantages are lower initial cost and shorter implementation time compared to rigid pavements. However, flexible pavements require more intensive maintenance as they are prone to deformation due to repeated loads and weather changes. In contrast, rigid pavements are more durable and require less maintenance, despite their higher initial cost. Therefore, the choice between flexible and rigid pavements should take into account the planned life and traffic intensity.

The application of flexible pavement is usually more suitable for roads with light to medium traffic. Its advantage in speed of implementation makes it an ideal choice for projects that require quick completion. On the other hand, rigid pavements are often used for major roads with heavy traffic loads and high volumes. A combination of both pavement types can also be applied to optimize the cost efficiency and performance of the road structure.

The Pavement Design Manual No. 03/M/BM/2024 provides comprehensive guidelines for the design of flexible and rigid pavements. It covers design parameters such as subgrade CBR, layer thickness, and appropriate implementation methods. In the context of the Sampang-Ketapang road, the selection of pavement type requires an in-depth analysis of the existing soil conditions, rainfall, and traffic volume. This evaluation forms the basis for determining the most efficient and effective design alternative.

RESEARCH METHOD

Location and Time of

This research was conducted on the Sampang-Ketapang road section (Link 113) located in Sampang Regency, Madura Island. This road has a length of about 6 km and is one of the main routes connecting the north and south of the region. The research was conducted for six months, starting from field data collection to analysis and preparation of design recommendations. Local geographical, climatic and traffic conditions were the main concerns in the data collection process.

The determination of the research location was based on the need to improve the capacity of the narrow and often damaged road. This road section is also an important access to tourist sites and economic centers in the Sampang region. The length of the study allowed for comprehensive data collection, including technical data on subgrade, average daily traffic (LHR), and drainage conditions. This data formed the basis for analyzing and determining the most suitable pavement design.

Collection Methods

Data collection was conducted through field surveys, laboratory testing, and documentation analysis. Field surveys included visual observation of road conditions, measurement of road dimensions, and soil sampling for laboratory testing. Traffic data was collected using the floating car method to calculate LHR and traffic load patterns. In addition, the survey also recorded the type of road defects to determine the need for repairs.

Laboratory testing involves analyzing the physical and mechanical properties of the subgrade, such as California Bearing Ratio (CBR) values, plasticity index, and moisture content. The results of these tests were used to determine the need for soil stabilization. Documentation analysis included a review of Pavement Design Manual No. 03/M/BM/2024 guidelines, rainfall data, and geologic maps of the region. The combination of these methods ensured the accuracy of the data used in the analysis.

Analysis Technique

The data obtained were analyzed using quantitative and qualitative methods to evaluate the feasibility of flexible and rigid pavement designs. The quantitative analysis included the calculation of equivalent axle loads (ESA), design of pavement layer thickness, and cost estimation. This analysis was conducted based on relevant technical guidelines, such as the Pavement Design Manual and international standards such as AASHTO. Qualitative analysis was conducted to evaluate the feasibility of design implementation in the local context.

A comparison of the cost and implementation time for the two pavement types was the main focus of the analysis. Data from the quantitative analysis was synthesized to determine the most efficient design alternative. In addition, the analysis also included simulations of traffic impacts during construction to identify potential disruptions and mitigation solutions.

Selection Criteria

The main criteria for design selection are cost efficiency, implementation duration, and planned pavement life. Flexural pavements are valued for their flexibility in dealing with deformations and lower initial cost. Rigid pavement, on the other hand, was judged on its durability against heavy loads and minimal maintenance requirements. Both designs were compared to determine the best solution based on field conditions. In addition, sustainability aspects were also considered in the analysis. The selected design should be able to support local economic growth without having a significant negative impact on the environment. Therefore, criteria such as the use of local materials, energy efficiency, and the environmental impact of each design alternative became an integral part of the evaluation process.

Validation and Preparation of

Validation of the analysis results was conducted through consultations with civil engineering experts and relevant stakeholders, including local government and contractors. This discussion aims to ensure that the recommended design matches the needs and implementation capacity in the field. Feedback obtained from this process is used to revise and improve the design before it is presented as a final recommendation. The final recommendations include technical specifications, cost estimates, implementation schedules and maintenance plans. This document is expected to serve as a guide for relevant parties in the implementation of the Sampang-Ketapang road widening project. Validation through a participatory approach ensures that the solutions produced are not only technical but also practical and applicable

RESULTS AND DISCUSSION
Results
Pavement Design Analysis

The flexible pavement design for the Sampang-Ketapang road was designed using class A aggregates with a layer thickness of 200mm. The analysis results show that this type of pavement is suitable to support medium to heavy traffic for a period of 10-15 years. Key parameters such as subgrade CBR value, average daily traffic volume (LHR), and drainage conditions were taken into account to ensure pavement durability. With locally available materials, the implementation cost is estimated at IDR 12.8 billion with a construction time of seven months.

The main strength of flexible pavement design lies in its flexibility in dealing with deformations due to repeated vehicle loads. However, research shows that flexible pavements require regular maintenance to maintain their optimal performance. A major challenge is dealing with surface cracks that often appear due to heavy loads and weather changes. The proposed solution is the addition of a high-quality adhesive layer to improve the adhesion between layers.

In addition, flexible pavement has the advantage of speed of implementation, which is an added value in the context of this project. The time factor is critical given the importance of this road as the main connecting route in Sampang Regency. The impact analysis showed that the selection of flexible pavement would minimize traffic disruption during construction.

In terms of efficiency, flexible pavements are more economical than rigid pavements, especially in the short term. However, long-term expenditure on maintenance can be a consideration. Therefore, a detailed maintenance plan should be developed to optimize operating costs over the service life.

Detailed data on the design and estimated cost of the flexible pavement is summarized in (Table 4.6: Calculation of Duration of Flexible Pavement Works). This table shows the estimated implementation time for each stage of the work, including land preparation, installation of the foundation layer, and asphalt finishing.

Pavement Design Analysis

The rigid pavement for the Sampang-Ketapang road uses concrete with a flexural strength of 4.5 MPa and a slab thickness of 300mm. It is designed to withstand heavy vehicle loads with a planned life of more than 20 years. Analysis shows that the concrete material has high resistance to deformation and wear. The estimated construction cost is IDR 19.5 billion with an implementation time of approximately nine months. One of the main advantages of rigid pavement is that it requires minimal maintenance compared to flexible pavement. The concrete slab is able to distribute stresses evenly to the subgrade, reducing the risk of premature failure. However, the longer implementation duration is one of the disadvantages that needs to be taken into account. The concrete curing process takes up to 28 days before the road can be fully utilized.

Environmental impact analysis shows that rigid pavements have a larger carbon footprint due to the use of cementitious materials. However, the longer service life can offset this impact. The proposed solution is the use of environmentally friendly additives to reduce carbon emissions during the construction process. In terms of cost efficiency, although the initial investment is higher, the long-term cost of rigid pavement is lower due to the minimal maintenance frequency. This makes rigid pavement a more economical choice for roads with heavy traffic volumes. Therefore, the feasibility analysis considered the long-term requirements rather than the initial cost. The results of this analysis are summarized in (Table 4.7: Calculation of Rigid Pavement Work Duration), which includes the preparation, casting, and curing stages. The information in the table helps visualize the construction timeline required to complete this project.

Discussion

The design choice between flexible and rigid pavement in the Sampang-Ketapang road widening project requires an in-depth evaluation of cost efficiency, implementation time, and traffic demand. From the analysis, flexible pavement showed advantages in terms of speed of implementation and lower initial cost. However, higher maintenance requirements can be a challenge if not planned properly. In contrast, rigid pavements offer a long-term solution with a planned life of more than 20 years and minimal maintenance requirements. Although the initial construction cost is higher, the advantage in long-term cost efficiency makes it attractive for roads with heavy traffic volumes. Both design alternatives have advantages and disadvantages that must be balanced based on the needs of the project.

In the context of the Sampang-Ketapang road, the increasing traffic volume is one of the main factors influencing design decisions. Traffic analysis showed that heavy vehicles frequently pass through this road, making rigid pavement design more suitable to ensure structural durability. However, for certain segments with lower traffic, flexible pavement remains an economical alternative. Environmental aspects are also an important consideration in design selection. Rigid pavements have a greater environmental impact during the construction process, but provide long-term benefits in terms of reduced maintenance. Meanwhile, flexible pavements are more environmentally friendly during construction but require additional materials for periodic maintenance.

Table 1. Minimum concrete thickness

Type Pavement	Traffic Plan		
	$1\times10^6 \leq$ JSKN $< 1\times10^7$	$1\times10^7 \leq$ JSKN $< 5\times10^7$	JSKN $\geq 5\times10^7$
JPCP	150 mm	200 mm	250 mm
JRCP	150 mm	180 mm	230 mm
CRCP	150 mm	180 mm	230 mm

Source: Author's Report, 2024

Table 2. Permissible load repetition calculation results – STRT

Axis Load (KN)	Load Proportion (%100)	Axis Group Proportion (%/100)	Traffic Design (JSKN)	Permissible Load Reps
10	0,0002	0,67	1,27E+07	1697,35
20	0,1501	0,67	1,27E+07	1273858,79
30	0,3620	0,67	1,27E+07	3072197,75
40	0,1705	0,67	1,27E+07	1446988,17
50	0,0935	0,67	1,27E+07	793509,64
60	0,0666	0,67	1,27E+07	565216,49
70	0,0391	0,67	1,27E+07	331831,30
80	0,1002	0,67	1,27E+07	850370,76
90	0,0120	0,67	1,27E+07	101840,81

100	0,0053	0,67	1,27E+07	44979,69
110	0,0004	0,67	1,27E+07	3394,69

Source: Author's Report, 2024

Table 3. Permissible load rep count results – STRG

Axis Load (KN)	Load Proportion (%100)	Axis Group Proportion (%/100)	Traffic Design (JSKN)	Permissible Load Reps
10	0,000	0,28	1,27E+07	703,63
30	0,047	0,28	1,27E+07	165352,44
40	0,069	0,28	1,27E+07	240992,39
50	0,118	0,28	1,27E+07	414788,36
60	0,108	0,28	1,27E+07	379606,99
70	0,198	0,28	1,27E+07	695183,88
80	0,139	0,28	1,27E+07	489724,68
90	0,025	0,28	1,27E+07	89008,87
100	0,034	0,28	1,27E+07	121023,91
110	0,030	0,28	1,27E+07	106951,37
120	0,026	0,28	1,27E+07	92878,82
130	0,121	0,28	1,27E+07	426046,40
140	0,048	0,28	1,27E+07	168518,77
150	0,028	0,28	1,27E+07	99211,47
160	0,008	0,28	1,27E+07	26737,84
170	0,000	0,28	1,27E+07	1407,25

Source: Author's Report, 2024

The choice between flexible and rigid pavement should be based on an analysis of specific needs, including budget, implementation time, and long-term goals. The recommendation for this project is a combination of both, with flexible pavement used on selected segments and rigid pavement applied on segments with heavy traffic. This strategy will maximize cost efficiency and ensure the long-term durability of the road.

DISCUSSION

The choice between flexible and rigid pavement for the Sampang-Ketapang road widening project reflects a complex interplay of economic, technical, and environmental considerations. Flexible pavement, with its lower initial cost and faster implementation timeline, aligns with the immediate needs of the region, especially in segments with moderate traffic volumes. However, its reliance on regular maintenance highlights the importance of proactive upkeep planning to minimize long-term operational costs.

Rigid pavement, on the other hand, presents a durable solution with a lifespan exceeding 20 years, making it ideal for segments subjected to heavy vehicle loads, such as those near industrial and transportation hubs. Despite its higher initial cost and longer construction timeline, the reduced maintenance requirements justify its application in high-traffic areas. Additionally, rigid pavement's resilience against waterlogging and weather extremes offers a sustainable advantage in the region's climatic conditions.

From an environmental perspective, the rigid pavement design, though associated with higher carbon emissions during construction due to cement usage, offsets this through its extended durability. Employing eco-friendly additives and optimizing resource utilization could further mitigate these environmental impacts. Meanwhile, flexible pavement's periodic maintenance demands could result in a higher cumulative environmental footprint over time, depending on the frequency and scale of repairs.

Strategically, a hybrid approach leveraging the strengths of both pavement types is recommended. By allocating flexible pavement to moderate traffic areas and rigid pavement to heavy traffic zones, the project can achieve an optimal balance of cost-efficiency, durability, and sustainability. This dual strategy not only ensures the long-term functionality of the road but also supports regional economic growth by enhancing connectivity and mobility.

Future studies could delve deeper into the integration of advanced materials and technologies, such as recycled aggregates and smart monitoring systems, to further improve the performance and sustainability of both pavement types in similar infrastructure projects.

CONCLUSION

Based on the analysis, both types of pavement, flexible and rigid, have their own advantages that can be optimized according to the conditions and needs of the road widening in Sampang-Ketapang (Link 113). Flexural pavement, with a 200mm Class A aggregate thickness, offers advantages in terms of lower initial cost and shorter implementation time. This type of pavement is suitable for road segments with moderate traffic volumes and is an economical solution for short to medium term use. However, flexible pavements require regular maintenance to ensure their service life.

In contrast, a rigid pavement with a 300mm thick concrete slab and a flexural strength of 4.5 MPa provides higher resistance to heavy loads and a longer planned life. This solution is more appropriate for road segments with high heavy vehicle traffic, although the initial cost is higher and the implementation time is longer. Proper design selection should consider a combination of both pavement types to maximize cost efficiency, implementation time, and overall road durability.

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