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Comparative Analysis of Cost and Time Between Rigid and Flexible Pavements on the Pilang–Sawocangkring Road Section, Sidoarjo Regency

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ABSTRACT:
Agricultural infrastructure plays a crucial role in supporting regional food security, particularly in highly productive zones such as Wonoayu District, Sidoarjo Regency. However, inadequate road conditions often hinder the smooth flow of agricultural logistics, thereby emphasizing the urgent need for sustainable infrastructure development. This study aims to conduct a comparative analysis of cost and construction time between rigid and flexible pavement types on the Pilang–Sawocangkring road segment. Utilizing traffic projections based on ESA5 and JSKN for the years 2035 and 2055, the analysis encompasses pavement dimensioning, construction cost estimates, and life-cycle cost evaluations. The findings indicate that rigid pavements, although requiring a higher initial investment and longer construction duration, provide significantly greater structural durability and reduced maintenance costs over the long term. In contrast, flexible pavements offer advantages in terms of faster implementation and lower upfront costs, yet they tend to underperform under continuous heavy agricultural traffic due to higher susceptibility to deformation and more frequent maintenance requirements. The study also highlights the importance of considering subgrade conditions, such as CBR values, as well as economic and project timeline constraints in pavement selection. Overall, this comparative study provides a data-driven foundation for informed decision-making in rural infrastructure planning. It concludes that rigid pavement is more suitable for long-term agricultural development due to its higher performance and cost-efficiency over time. The insights gained from this analysis are expected to contribute to more effective rural road planning, ensuring sustainability, budget optimization, and improved access for local agricultural communities.

Keywords: Rigid Pavement, Flexible Pavement, Construction Cost, Time Efficiency, Agricultural Infrastructure, ESA5, JSKN

INTRODUCTION

Sidoarjo Regency is one of the strategic areas in East Java Province that has great potential in the agricultural sector, especially in Wonoayu District (Pratiwi et al., 2018). This area is a food buffer for the surrounding regions because it has a significant amount of technical agricultural land. However, the major challenge faced is the inadequate condition of the road infrastructure, which hinders the optimal distribution of agricultural products. Roads are a vital element in the land transportation system; as stated by Kodoatie & Syarief (2010), roads play an important role in social and economic connectivity. In the context of agriculture, roads serve as the main routes for mobilizing production tools and harvests, so their feasibility greatly determines the sustainability of the agrarian sector.

Unfortunately, road infrastructure in many agricultural areas still consists of dirt roads or single-layer asphalt with low durability. According to Nasution (2003), roads like these cannot withstand heavy vehicle loads, especially during the harvest season. This results in increased operational costs and a higher risk of damage to agricultural products. Improving road quality can be done using two main pavement options: rigid pavement and flexible pavement. Rigid pavements generally use cement concrete, have a long service life, and are resistant to heavy loads (Setiawan, 2017; Aditiya & Siswoyo, 2020).

In contrast, flexible pavements are cheaper and faster to implement because they use asphalt as the dominant layer. However, their service life is shorter, and they are more susceptible to deformation due to high loads and temperatures (Asidin, 2021; Assa et al., 2022).

According to the 2017 Road Pavement Design Manual from the Ministry of PUPR, rigid pavements have lower long-term maintenance costs than flexible pavements. This aligns with the findings of Woro Sukarno (2022), which show that although the initial cost is higher, rigid pavements are more economical overall. Several studies, such as those conducted by Prasojo & Narendra (2023) and Kamil et al. (2023), emphasize that the selection of pavement types must consider environmental, traffic, and budget factors. The right choice will have a direct impact on the efficiency of agricultural product distribution and regional budget savings.

In addition, social aspects must also be taken into account. Poor road quality makes it difficult for rural communities to access basic services. This was also highlighted by Mahardika et al. (2021), who emphasized that road construction must reach all levels of society, especially in disadvantaged areas. In a study by Lelepadang et al. (2020), a cost comparison between flexible and rigid pavements showed that flexible pavements are cheaper but less durable. Rigid pavements are recommended for areas with heavy traffic and less stable soil conditions.

Other studies by Putri Zayu et al. (2022) and Sutapa et al. (2022) emphasize the importance of accurate pavement thickness design based on existing conditions and projections of future traffic loads, such as ESA5 and JSKN. A comparative study of costs and service life conducted by Ibrahim & Narendra (2023) showed that a combination of accurate design and material selection can reduce the regional fiscal burden in the long term. On the other hand, Austroad (1987) and AASHTO (1993) provide a more comprehensive planning approach, taking into account daily traffic loads and local economic growth.

The government, through Government Regulation No. 34 of 2006, has also determined the importance of roads as part of the national transportation system that must support sustainable development (Government of the Republic of Indonesia, 2006). Rigid pavements are generally superior in agricultural areas with heavy truck traffic, as found by Ridwan & Romadhon (2019) in their study in Kediri. However, flexible pavements remain relevant for areas with limited accessibility and urgent needs.

In terms of technical design, guidelines from the Department of Settlement and Regional Infrastructure (2002, 2003) are the main references for determining the thickness and structure of road layers according to local conditions. Hardiyatmo (2015) mentions the importance of soil investigations to determine the bearing capacity and stability of the foundation layer so that the selected pavement can function optimally in the long term. The existence of a project on the Pilang-Sawocangkring road section, Sidoarjo, provides an opportunity to analyze this comparison directly. This location has shown serious damage due to increased agricultural traffic and inadequate road age. Research by Adhita Maharani (2018) and Diantoro (2023) also emphasizes the importance of combining technical and social analysis in regional road planning.

In conditions of limited regional budgets, cost and time efficiency are crucial in determining the type of pavement. Firmansyah et al. (2022) showed that material selection must consider local soil, traffic, and weather conditions. A study by Prasetya et al. (2023) stated that agricultural road projects must be designed based on LHR and DCP data to determine an efficient design. The formulation of the problem from this background leads to the need to determine the best road pavement method on the Pilang-Sawocangkring section based on ESA5 and JSKN projections until 2055. This includes an analysis of the required thickness, estimated construction and maintenance costs, and the implementation time of rigid and flexible pavement projects. With a data-based approach, this study is expected to provide recommendations for selecting efficient and sustainable pavement types to optimally support agriculture in Sidoarjo Regency.

METHOD

Using traffic projections (ESA5 and JSKN) for 2035 and 2055, pavement dimensions were calculated based on the 2017 Road Pavement Design Manual (flexible) and Pd T-14-2003 (rigid). This research was conducted on the Pilang-Sawocangkring road section located in Wonoayu District, Sidoarjo Regency, East Java. This location was chosen because it is the main route for agricultural product distribution and has experienced structural damage due to heavy traffic loads. The research lasted for three months, from January to March 2025. During this period, field observations, primary data collection, and laboratory analysis were carried out. The Pilang-Sawocangkring road section is approximately 1.4 km long with an existing condition in the form of a single-layer asphalt pavement 8 cm thick. This suboptimal road condition is the basis for selecting the location because it requires an efficient and sustainable construction solution. The time of the research was adjusted to weather conditions and planting cycles so as not to interfere with agricultural activities. Field observations were carried out to record the type of damage, daily traffic, and subgrade conditions.

This study used primary and secondary data collected systematically. Primary data was obtained through average daily traffic (ADR) measurements, soil testing using the DCP (Dynamic Cone Penetrometer) method, and documentation of existing road conditions. Meanwhile, secondary data was obtained from related agencies such as the PUPR Office of Sidoarjo Regency, BPS, and relevant previous studies. Both types of data were used for pavement dimension analysis and construction cost calculations. Data collection was carried out triangulating to ensure the reliability of the research results. Traffic data was converted into ESA (Equivalent Single Axle Load) and JSKN (Number of Commercial Vehicle Axles) values based on projections for 2035 and 2055. Soil data was analyzed to determine the bearing capacity and determine the required foundation layer. All data was collected, validated, and used in calculating pavement dimensions and estimating budget costs.

Pavement planning was carried out using two approaches, namely the 2017 Road Pavement Design Manual (MDPJ) method for flexible pavements and Pd T-14-2003 for rigid pavements.

The MDPJ method considers the average daily traffic factor, the CBR value of the subgrade, and the design age of the road. Meanwhile, the Pd T-14-2003 method considers the stiffness of the concrete, environmental factors, and the thickness of the concrete slab required. Both methods have been commonly used in technical practice in Indonesia and are in accordance with national standards. The planning steps include calculating the equivalent traffic load (ESA), selecting the layer thickness based on graphs and standard formulas, and evaluating the efficiency of the pavement structure. For flexible pavements, the AC-WC, AC-BC, and AC-Base surface layers are used. In rigid pavements, the structure consists of a concrete slab, a subbase layer, and subgrade. This process ends with a comparison between the two alternatives based on structural and economic efficiency.

RESULTS AND DISCUSSION

Traffic Load Projection Results and Pavement Thickness

Based on the results of the Average Daily Traffic (ADR) survey and vehicle load analysis, the ESA5 and JSKN projection values for 2035 and 2055 were obtained. The calculation shows that the volume of commercial vehicles will increase significantly over the next 30 years. The ESA5 value for 2035 is estimated to reach 11,372,340 and for 2055 it will reach 23,002,026. This data is the basis for calculating the road pavement structure.

From this projection, the thickness of the pavement layer is calculated for flexible and rigid pavement types. Using the MDPJ 2017 method, the total thickness of the flexible pavement is 52 cm consisting of AC-WC, AC-BC, and aggregate foundation layers. Meanwhile, using the Pd T-14-2003 method, the thickness of the rigid pavement required is 29.5 cm using unreinforced concrete slabs. This thickness refers to existing subgrade data and projected traffic load volume.

Tabel 1. CESA5 10th Calculation

No.	Category	Type of Vehicle	LHR (Vehicle/Day)	VDF 5 (Factual)	ESA5 (Normal)	ESA5 (Factual)	ESA5 (2025-2035)
1.	6a	Medium Truck (Two Axles Four Wheels)	288	0,50	0,50	52.560	616.602
2.	6b	Large Truck (Two Axles Four Wheels)	112	9,20	5,10	376.096	2.445.855
3.	7a2	Large Truck (Two Axles Four Wheels)	332	19,00	5,60	2.302.420	7.961.017
						2.731.076	11.023.474
	ESA5 (Factual)						**2.731.076**
	ESA5 (Normal)						**11.023.474**
	ESA5 10th						**13.754.550**

The analysis also considers the existing condition of the pavement layer in the field which is only 8 cm thick and shows structural damage in most sections. This shows that increasing the capacity of the road structure is very necessary to support agricultural traffic. In addition, the condition of the subgrade tends to be soft at several points adds to the urgency of strengthening the pavement structure. Therefore, proper structural planning is a sustainable solution. As part of the technical verification, a DCP test was conducted to determine the strength of the subgrade and the CBR value. The test results showed an average subgrade CBR value of 6%, which indicates the need for a thick aggregate foundation layer on flexible pavements. In rigid pavements, this value remains a concern in planning the subbase for concrete slabs. This data is also input in calculating the thickness of each layer.

Cost Estimation Results and Implementation Time

Based on the calculation results of the volume of work and unit price, the estimated construction costs for both types of pavements were obtained. The construction cost of flexible pavement for a 10-year design life is Rp 9,496,433,067.65, while for a 30-year design life it is Rp 19,179,534,874.91. Meanwhile, the construction cost of rigid pavement for a 10-year design life is Rp 5,063,381,285.08, and for a 30-year design life it is Rp 7,636,616,864.03. These data show that rigid pavement is much cheaper in terms of total construction costs compared to flexible pavement, both for the medium and long term. The project implementation time also shows a significant difference between the two methods. Flexible pavement is estimated to require 18 working days for a 10-year design life and 22 working days for a 30-year design life. In contrast, rigid pavements require a much longer time, namely 97 days for a 10-year design life and 104 days for a 30-year design life due to the concrete curing process. Weather factors, material availability, and labor also affect the estimated completion time, making flexible pavements more suitable for projects with short deadlines

The long-term maintenance costs of flexible pavements are generally higher because they require periodic resurfacing. Although not explicitly stated in the document, based on the 5-year maintenance standard, the total maintenance cost of flexible pavements can far exceed that of rigid pavements. Rigid pavements only require minor maintenance such as joint cleaning and crack patching, which are more cost-efficient. This strengthens the argument that rigid pavements are more economical in the maintenance of life cycle.

Thus, the life cycle cost analysis shows that although the initial cost of flexible pavements is higher, it is not necessarily an economical choice in the long term. Rigid pavements for a 30-year life with a cost of IDR 7.63 billion have better efficiency and durability than flexible pavements with a total cost of IDR 19.17 billion. This striking difference makes it clear that structural durability and stability are important aspects in agricultural road construction. Therefore, project priorities and budget conditions should be the main considerations in selecting the type of pavement. Overall, the estimation data shows that the choice between the two types of pavement cannot be based solely on initial cost efficiency. It needs to be reviewed from the aspects of service life, resistance to traffic loads, and long-term maintenance needs. The combination of technical and economic efficiency is the main basis for sustainable road infrastructure planning. Therefore, decision making must be based on complete and relevant data.

The results of the study show that there is a significant difference in pavement thickness between flexible and rigid methods resulting from traffic load projections in 2035 and 2055. The flexible pavement thickness of 52 cm indicates the complexity of the layered structure and high material requirements. In contrast, rigid pavement with a thickness of 29.5 cm has a simpler design but requires higher material strength. This design difference is closely related to the structural characteristics and load distribution methods of each type of pavement. This emphasizes the importance of adjusting the design to local soil and traffic conditions.

In terms of cost, flexible pavement is superior in terms of initial cost efficiency with a difference of almost IDR 600 million compared to rigid pavement. However, when considering maintenance costs until 2055, the difference decreases drastically. The total cost of both types of pavements shows a difference of less than 5%, making the durability and service life aspects the main differentiating factors. In this case, rigid pavement provides advantages because it is more resistant to heavy loads and climate change. Long-term efficiency is a strong argument for considering rigid pavement in strategic projects.

The implementation time analysis shows that flexible pavement is completed faster, making it suitable for projects with urgent needs. This advantage is due to the absence of curing time as in concrete in rigid pavement. However, this implementation speed must be considered with the potential for higher premature damage. If the project is directed for intensive use such as agricultural roads, then durability becomes the main consideration. Therefore, the compromise between time and quality becomes important in choosing a method.

The results of this study are relevant to the first problem formulation related to the ESA and JSKN projections, where increased traffic requires a road structure that is able to support long-term loads. By using two national standard methods, this study provides a clear picture of the need for appropriate pavement thickness. The second problem formulation regarding optimal thickness can be answered with empirical data and simulations. While the third problem formulation related to costs and implementation time is answered through accurate estimates. This shows the integration between the analysis results and the problem formulation that has been set.

The research findings are also in accordance with the results of previous studies, such as those conducted by Prasojo & Narendra (2023), Firmansyah et al. (2022), and Lelepadang et al. (2020). The study shows the relative superiority of rigid pavements in terms of long-term efficiency and stability. Meanwhile, studies such as by Kurniawan & Djunaidi (2020) show the superiority of flexible pavements in terms of speed of implementation and initial cost. This comparison provides a basis for project decision-making according to local context and needs. Thus, the results of this study strengthen previous findings. Overall, the results and discussion show that there is no absolute solution that can be applied to all road conditions. The choice of pavement must be based on technical data, fiscal capacity, and infrastructure development objectives. In the context of agricultural roads such as the Pilang-Sawocangkring section, sustainability and durability are the main indicators. Therefore, although rigid pavements have higher initial costs, their long-term benefits make them a worthy option to consider. The final decision must refer to the results of a comprehensive analysis that considers all technical and economic aspects.

CONCLUSION

This study projects that traffic loads on the Pilang-Sawocangkring road will significantly increase by 2055, requiring optimal pavement thicknesses of 42 cm for asphalt and 38 cm for concrete to accommodate heavy vehicles and soft soil conditions. Although both flexible (asphalt) and rigid (concrete) pavements meet technical standards, rigid pavement demonstrates substantial advantages in cost efficiency and long-term maintenance despite a longer construction time (104 days versus 22 days for asphalt). Flexible pavement, with higher initial costs, may be suitable for projects prioritizing faster completion or budget limits if supported by ongoing maintenance. The study recommends rigid pavement as the sustainable solution for agricultural roads in Sidoarjo Regency, emphasizing the importance of periodic soil CBR data and traffic load updates to refine pavement design. It also highlights the need for routine condition evaluations, integration of technical, economic, and social considerations, and the standard use of predictive methods like DCP and LHR/ESA in planning. Future research should focus on developing adaptive pavement design frameworks that dynamically incorporate real-time traffic and environmental data to enhance durability and cost-effectiveness in agrarian infrastructure projects.

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