

Structural and Functional Comparison of Flexible and Rigid Pavements for Expressway Projects

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ABSTRACT: The selection of pavement type is a critical factor influencing the performance, durability and cost efficiency of highway and expressway projects. This study presents a comparative analysis of flexible and rigid pavements based on their structural behavior and functional performance under varying traffic loads and environmental conditions. Flexible pavements, composed of bituminous layers, distribute loads through a layered system and depend on subgrade strength, whereas rigid pavements, made of cement concrete, distribute loads over a wider area due to their high flexural strength.

Key parameters such as load distribution, durability, maintenance requirements, construction cost, service life, and resistance to rutting and cracking are evaluated. The findings indicate that flexible pavements have lower initial costs and are easier to maintain but require frequent repairs and offer a shorter service life. In contrast, rigid pavements involve higher initial investment but provide greater durability and reduced maintenance over time. Life cycle cost considerations suggest that rigid pavements can be more economical in the long run. The study emphasizes selecting pavement type based on traffic, climate, subgrade conditions, and economic factors to achieve sustainable infrastructure development.

KEYWORDS: Flexible pavement, Rigid pavement, Pavement design, Load distribution, Life cycle cost, Durability, Highway engineering etc.

I. INTRODUCTION

Transportation infrastructure is a key driver of economic growth, with highways and expressways playing a vital role in the efficient movement of goods and passengers. The increasing traffic volume, higher axle loads, and varying environmental conditions have made pavement design a critical aspect of highway engineering. Among the most important decisions in this field is the selection of an appropriate pavement type, which significantly affects performance, durability, maintenance, and overall cost.

Pavements are broadly classified into flexible (bituminous) and rigid (cement concrete) types, each exhibiting distinct structural behavior. Flexible pavements distribute loads through layered systems and depend largely on subgrade strength, while rigid pavements transfer loads over a wider area due to their high flexural strength and slab action. These fundamental differences influence their performance under traffic and environmental stresses.

This study presents a comparative evaluation of flexible and rigid pavements for expressway applications, considering key factors such as load distribution, durability, service life, maintenance requirements, and life cycle cost. The objective is to provide a clear understanding of their relative advantages and support informed decision-making for sustainable and cost-effective pavement design.

II. LITERATURE SURVEY

Numerous studies have explored the comparative performance, cost implications, and suitability of flexible and rigid pavements under varying traffic and environmental conditions. Ahmad Rois Abid et al. (2023) conducted a case study in Gresik Regency, Indonesia, and reported that although flexible pavements offer lower initial costs and shorter construction time, rigid pavements are more economical in the long run due to reduced maintenance and higher durability. Similarly, Andri Kurniawan et al. (2025) emphasized that rigid pavements perform better under heavy urban traffic, exhibiting lower life-cycle costs and higher resistance to rutting and deformation, while flexible pavements remain advantageous in terms of initial investment and construction speed.

Ziar et al. highlighted that flexible pavements can be more cost-effective depending on the design method adopted, with the Asphalt Institute method showing the lowest cost among flexible pavement designs. Uljarevic and Supic demonstrated that pavement selection becomes critical under heavy vehicle loading, where rigid pavements provide structural advantages despite higher construction complexity. Mohod and Kadam noted that flexible pavements are widely preferred due to ease of construction and staged development, whereas rigid pavements offer superior durability and longer service life.

Recent studies by Kumar and Sharma introduced the concept of perpetual flexible pavements, showing that they can outperform rigid pavements in terms of life-cycle cost and environmental impact. Jain et al. and Taher et al. further confirmed that while flexible pavements are economical initially, rigid pavements prove more cost-effective over time due to lower maintenance requirements. Additionally, Liu et al. highlighted the growing importance of composite pavements, combining the advantages of both systems to enhance performance and durability.

Overall, the literature indicates that pavement selection should be based on life-cycle performance, traffic conditions, environmental factors, and economic considerations rather than initial cost alone.

II. METHODOLOGY

The present study adopts a systematic and comparative approach to evaluate flexible and rigid pavements for expressway applications. The methodology focuses on assessing structural behavior, functional performance, and economic efficiency under varying traffic loads and environmental conditions.

Initially, a detailed study of pavement types is carried out, including flexible pavements (bituminous) and rigid pavements (cement concrete), to understand their design principles and structural characteristics. Subsequently, material properties are analyzed through standard laboratory tests. For aggregates, tests such as crushing, impact, abrasion, and water absorption are considered. Bitumen is evaluated using penetration, ductility, softening point, and flash point tests, while concrete properties are assessed through compressive strength, slump, setting time, and flexural strength tests.

A structural comparison is then performed based on parameters such as load distribution mechanism, layer thickness, elasticity, joint behavior, and construction aspects. This is followed by a functional comparison considering riding comfort, maintenance requirements, initial cost, service life, and ease of repair.

Finally, the results are analyzed to identify the most suitable pavement type for expressway projects. Conclusions and recommendations are drawn based on traffic intensity, subgrade conditions, climatic factors, and economic feasibility, along with suggestions for future research and improvements.

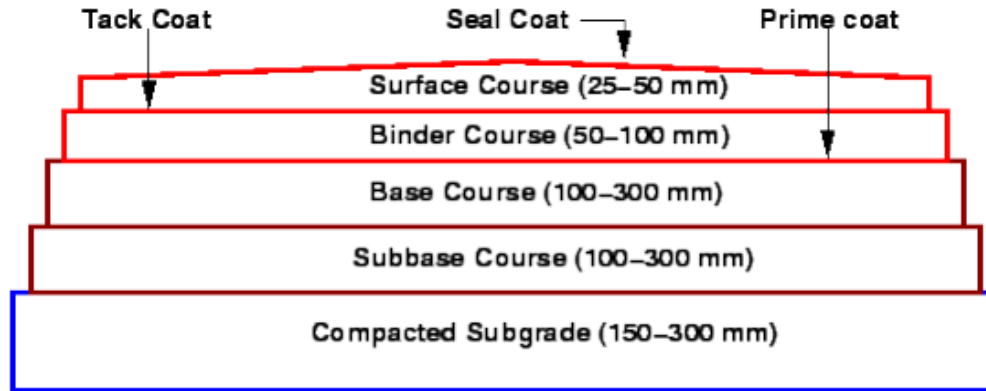


Fig. a) Typical Cross Section of Flexible Pavement

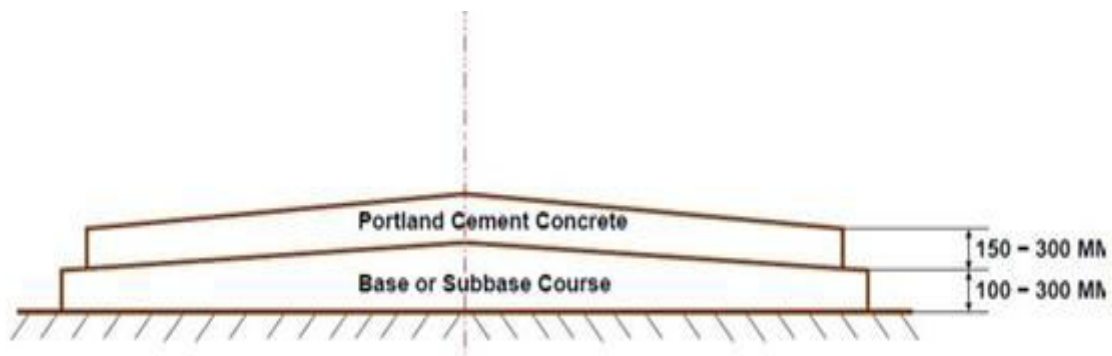


Fig. b) Typical Cross Section of Rigid Pavement

Materials Used

• Flexible Pavement Materials:

- Bitumen (Binder)
- Coarse aggregates
- Fine aggregates (sand)
- Mineral fillers

• Rigid Pavement Materials:

- Cement
- Coarse aggregates
- Fine aggregates
- Water
- Reinforcement steel (if required)

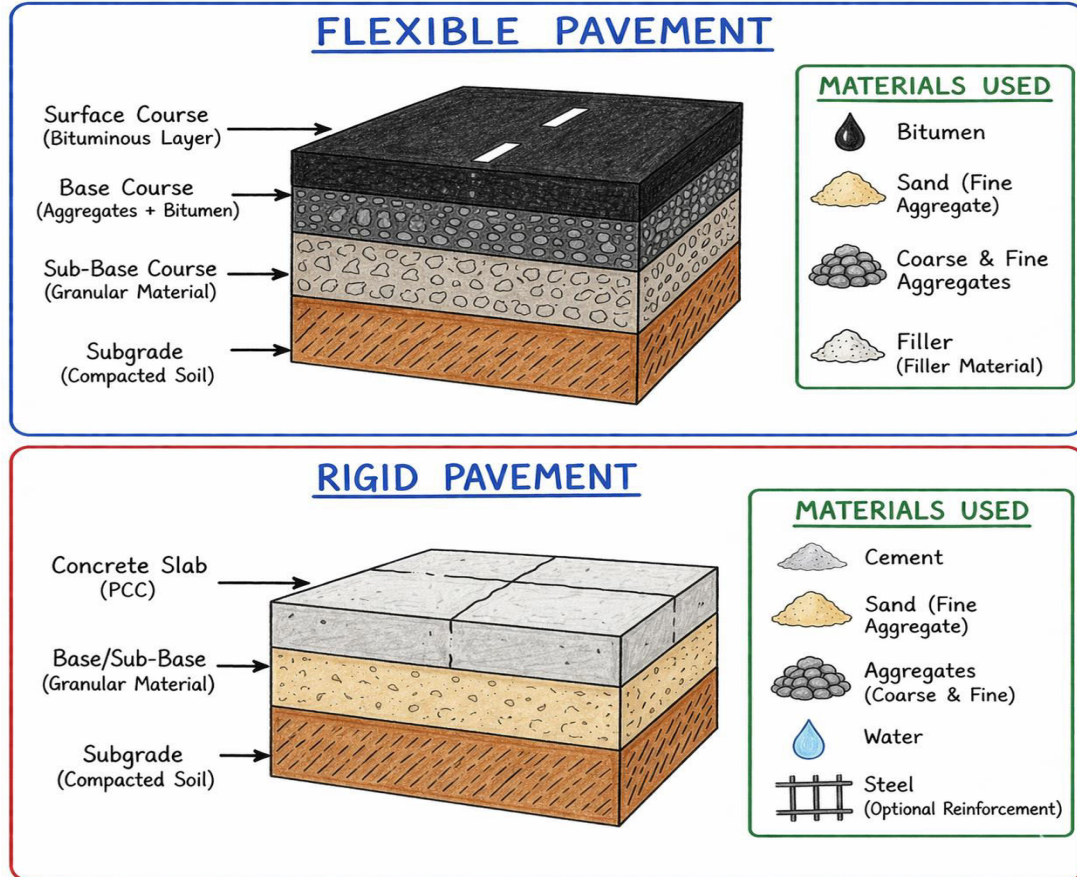


Fig. c) Typical Material Used in Rigid Pavement and Flexible Pavement

Table. 1 Observation Table of Abrasion Test on Aggregate

Sr. No.	Details	Sample 1	Sample 2	Sample 3
1	Weight of empty measuring cylinder, W_1 (g)	970.1	970.1	970.1
2	Weight of aggregate with cylinder, W_2 (g)	1407.7	1384.5	1398.6
3	Weight of empty 2.36 mm sieve, W_4 (g)	328.6	328.6	328.6
4	Weight of aggregate retained with sieve, W_s (g)	557.3	570.6	572.7
5	Weight of aggregate passing sieve, W_3 (g)	208.9	172.4	184.4
6	Aggregate Impact Value (%)	47.74%	41.60%	43.04%
7	Average Aggregate Impact Value (%)	44.13%	44.13%	44.13%

Table. 2 Observation Table of Aggregate Crushing Value Test

Sr. No.	Grading	No. of Steel Balls	Weight of Charge (g)	Number of Revolutions
1	A	12	5000 ± 25	500
2	B	11	4584 ± 25	
3	C	8	3330 ± 20	
4	D	6	2500 ± 15	
5	E	12	5000 ± 25	1000
6	F	12	5000 ± 25	
7	G	12	5000 ± 25	

Table. 3 Observation Table of Abrasion Test on Aggregate

Sr. No.	Grading	No. of Steel Balls	Weight of Charge (g)	Number of Revolutions
1	A	12	5000 ± 25	500
2	B	11	4584 ± 25	
3	C	8	3330 ± 20	
4	D	6	2500 ± 15	
5	E	12	5000 ± 25	1000
6	F	12	5000 ± 25	
7	G	12	5000 ± 25	

Table. 4 Observation Table of Water Absorption Test

Sr. No.	Details	Sample 1	Sample 2	Sample 3
1	Weight of saturated surface-dried sample, A (g)	2400	2380	2401
2	Weight of oven-dried sample, B (g)	2404	2375	2486
3	Water Absorption = $(\frac{A - B}{B} \times 100)$ (%)	0.208%	0.210%	0.201%
4	Average Water Absorption (%)	0.206%	0.206%	0.206%

Table. 5 Observation Table of Compressive Strength Test

Sr No	Cube No	Load at Failure (kN)	Area (mm ²)	Compressive Strength (N/mm ²)
1	1	620	22500	27.55
2	2	640	22500	28.44
3	3	600	22500	26.66

Table. 6 Observation Table of Compressive Strength Test

Sr No	Beam No	Load at Failure (kN)	Span (mm)	Flexural Strength (N/mm ²)
1	1	18	600	3.20
2	2	20	600	3.55
3	3	19	600	3.38

III. EXPERIMENTAL RESULTS

The comparative analysis of flexible and rigid pavements highlights distinct differences in their structural and functional performance under varying traffic and environmental conditions. Flexible pavements are found to be more economical in terms of initial construction cost and are suitable for low to medium traffic conditions. Their layered structure allows ease of construction and quick repair; however, they are more prone to distresses such as rutting, fatigue cracking, and deformation due to repeated loading and temperature variations. Consequently, they require frequent maintenance, which increases long-term costs.

In contrast, rigid pavements demonstrate superior performance under heavy traffic loads due to their high flexural strength and slab action, which enable effective load distribution over a wider area. They exhibit higher durability, better resistance to deformation, and significantly lower maintenance requirements over their service life. These characteristics make rigid pavements particularly suitable for expressway applications and high-volume traffic corridors.

Despite these advantages, rigid pavements involve higher initial investment and require skilled construction practices and proper joint design to prevent cracking due to temperature stresses.

Overall, the results indicate that while flexible pavements are advantageous for short-term and low-budget projects, rigid pavements offer better long-term performance and cost efficiency. Therefore, the selection of pavement type should be based on traffic intensity, design life, economic considerations, and environmental conditions.

VI. CONCLUSION

This study presents a comparative evaluation of flexible and rigid pavements based on their structural performance, functional characteristics, and economic considerations. The analysis indicates that flexible pavements are cost-effective and suitable for low to medium traffic conditions due to their lower initial cost and ease of construction and repair. However, their susceptibility to rutting, temperature variations, and frequent maintenance limits their long-term performance.

In contrast, rigid pavements demonstrate superior performance under heavy traffic loads, offering higher durability, better load distribution, and reduced maintenance requirements. Although they involve higher initial investment and demand skilled construction practices, their longer service life and lower maintenance costs make them more economical over the pavement life cycle, particularly for expressway applications.

Therefore, the selection of pavement type should be based on a balanced consideration of traffic intensity, design life, budget constraints, and environmental conditions. A well-informed choice can ensure the development of durable, cost-effective, and sustainable road infrastructure.

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