Performance Evaluation of Asphalt Mixtures and Rigid Pavements in Intensively Loaded Urban Public Transport Stop Areas

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Abstract: - This study evaluates the performance of asphalt mixtures and rigid pavement solutions in public transport stop areas subjected to heavy traffic. These areas experience frequent stopping and starting, which can make the pavement deteriorate faster. The researchers studied asphalt mixtures, polymer-modified mixtures, and cement concrete pavements through laboratory tests. Pavement deformation was evaluated under repeated loading and unloading up to 10,000 times. Air void content, stiffness modulus at 20 °C, and rut depth development were also considered. The results showed that polymer-modified asphalt mixtures performed better than unmodified ones in resisting deformation and rutting. Flexible pavements can still deform under heavy loading conditions in urban transport stops. Cement concrete pavements showed little rutting, handled heavy loads, and performed better under environmental factors such as moisture and freezing and thawing. Overall, the study compared the drawbacks of each pavement solution to support the selection of durable systems and reduce maintenance needs.

Key-Words: - urban transport stops areas, flexible and rigid pavement systems, asphalt mixtures, performance assessment under repeated loading, permanent deformation resistance, long-term durability.

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1 Introduction

Urban public transport stop areas are really tough on the roads. They have to deal with a lot of use, which is different from other parts of the road. Buses and trains are always. Starting and that puts a lot of stress on the pavement. This leads to the pavement getting damaged faster and not lasting long. In these areas, how well the pavement holds up affects how much it costs to maintain the roads, and it also affects how safe it is for people to use the roads. It even affects how well the whole transportation system works, [1], [2]. When you have many heavy vehicles stopping and starting the usual kind of pavement does not work very well. Even though it is easy to build and does not cost a lot at first, it can get damaged easily. This is why people are looking for options, like special kinds of asphalt or concrete pavement. These might be able to withstand the use better. So, when we are choosing what kind of pavement to use in these areas, we need to know how the different materials will work. We need to compare them and see which one is best. This study is looking at how different kinds of pavement work, in public transport stop areas. We are looking at how the asphalt holds up and also how well the concrete pavement works. We want to know if it is strong and if it can withstand the water and the cold. Some other research [3] that we did earlier looked at how the pavement works in these areas. We wanted to know why the asphalt was getting damaged quickly.

That study analyzed the primary causes of rutting [4], [5], [6] in flexible pavements, considering traffic characteristics, material properties, and environmental influences specific to public transport stations located along major urban corridors.

Building upon these findings, the present paper advances the research from a predominantly descriptive and exploratory level toward a comparative, performance-oriented evaluation of pavement solutions. The emphasis is shifted from identifying distress mechanisms to assessing and comparing the structural performance of conventional asphalt mixtures, polymer-modified asphalt mixtures [7], [8], [9], and rigid pavement alternatives under conditions representative of urban public transport stop areas.

In practical terms, conventional flexible pavement solutions are frequently applied in urban transport infrastructure due to their constructability and initial cost advantages.

Flexible pavement systems are really common in city roads because they are easy to build and do not cost a lot. When these roads have to handle a lot of heavy traffic, such as near bus stops, they can get damaged quickly. This means they can become uneven and need to be fixed.

So, people are looking for options like special kinds of asphalt that have polymers in them and roads made of solid concrete because these can handle heavy traffic better and last longer. Flexible pavement systems, like these, are still important. Polymer-modified asphalt mixtures and rigid pavements are also good choices.

The present study compares the performance of flexible and rigid pavement solutions used in urban public transport stop areas under realistic loading conditions, [10], [11]. The analysis focuses on permanent deformation in asphalt mixtures and includes the evaluation of cement concrete pavements in terms of strength, impermeability, abrasion resistance, and durability under freeze–thaw conditions.

The study aims to support performance-based decision-making in pavement design and rehabilitation for intensively loaded urban public transport infrastructure, [12], [13].

The outcomes of this research are intended to contribute to the optimization of pavement structures in public transport stop areas by providing technically grounded recommendations for material selection and structural configuration. Through this approach, the paper supports the development of more durable, reliable, and sustainable pavement solutions tailored to the specific operational demands of urban public transport networks, [13], [14].

2 Materials and Experimental Methods

2.1 Research Scope

This study adopts an experimental and comparative approach to evaluate pavement solutions used in urban public transport stop areas subjected to intensive loading conditions. The analysis focuses on pavement structures exposed to repetitive heavy axle loads, frequent braking and acceleration, and prolonged stationary traffic, which are characteristic of public transport operations, [12], [13]. The experimental program was designed to compare the performance of flexible and rigid pavement systems using indicators relevant to urban transport infrastructure, [12], [13], [14].

2.2 Asphalt Mixtures

Two asphalt mixtures commonly applied in urban pavements were investigated:

1. conventional asphalt mixture (MAS 16);
2. a polymer-modified (PM) asphalt mixture (MAS 16 PM).

In order to better describe the composition and properties of the materials used in the experimental program, the physical and technical characteristics of the polymer-modifying additive SUPERPLAST [15] are presented. These characteristics, provided by the Technical Approval documentation [16], are summarized in Table 1. The visual appearance and physical form of the SUPERPLAST additive are illustrated in Figure 1. This information supports the understanding of the role of the polymer modifier in improving the performance of the asphalt mixture MAS 16 PM. The main physical characteristics of the polymer-modifying additive (Figure 1) used in the study are presented in Table 1.

Table 1. Characteristics of the PM–SUPERPLAST

No. crt.	Characteristics	Value
1	Appearance	granules
2	Color	shades of black-grey
3	Bulk density at 25 °C (g/cm³)	0.4–0.6
4	Softening point (°C)	160–180

Source: [15]

The material properties meet the requirements for use in asphalt mixtures exposed to heavy urban traffic and improve both workability and resistance to permanent deformation.

The mixtures were produced in the laboratory following the relevant technical specifications.

Fig. 1: SUPERPLAST polymer-modified (PM)
Source: created by the authors.

The experimental evaluation focused on resistance to permanent deformation, which represents the dominant distress mechanism in urban public transport stop areas. The testing program enabled a direct comparison of the deformation behavior of conventional and modified asphalt mixtures under representative loading conditions.

The gradation of the mix was chosen to meet MAS 16 standards for asphalt used in city roads. Figure 2 shows that all mixes are within the required limits.

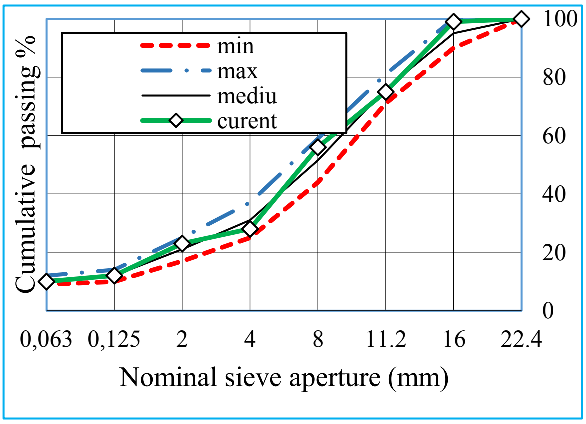

Fig. 2: Aggregate gradation curves for MAS 16 asphalt mixtures (conventional and polymer-modified).
Source: created by the authors.

The mixture composition and component dosages are given in Table 2. In addition, the laboratory program included preliminary verification of material conformity and consistency with the technical specifications required for urban pavement applications.

Table 2. Material composition and dosage

No. crt.	Material Name	Component dosage per 1 ton of asphalt mixture (%)	
		MAS16	**MAS16 PM**
1	Crushed stone 8–16 mm fraction – Turcoaia Quarry, Romania	41.3	41.3
2	Crushed stone 4–8 mm fraction – Turcoaia Quarry, Romania	27.2	27.2
3	Crushed sand 0–4 mm fraction – Turcoaia Quarry, Romania	14.1	14.1
4	Inactive mineral powder (filler) – "Liormax" LLC	11.3	11.3
5	Road petroleum bitumen 50/70 – Lukoil, Bulgaria	5.7	5.7
6	Interfiber C (Interchimica)	0.5	0.5
7	Polimer (Superplast), 4,5% Interchimica Spa	-	3,0

Source: created by the authors

The laboratory program included a preliminary check of material conformity with the required specifications for urban pavement applications. All materials were conditioned before mixing to maintain stable temperature and moisture conditions during specimen preparation. This helped reduce variability between specimens and improve the repeatability of the results. The asphalt mixtures were prepared under laboratory conditions (Figure 3) using a laboratory mixer to ensure homogeneous distribution of aggregates, binder, and the polymer additive, where applicable. Figure 4 illustrates the laboratory mixing equipment used during mixture preparation. Slab specimens were prepared under controlled laboratory conditions using a dedicated compaction device to ensure a uniform internal structure and repeatability of the test results. Rutting resistance was evaluated by means of a wheel-tracking test.

Rutting resistance was evaluated by means of a wheel-tracking test, simulating the effect of repeated loading typical of stationary and slow-moving heavy urban traffic. The laboratory preparation of asphalt mixtures, specimen compaction procedure, and the wheel-tracking testing setup used for permanent deformation assessment are illustrated in Figure 2, Figure 3 and Figure 4. The laboratory preparation of asphalt mixtures was performed using a controlled-temperature mixer to ensure homogeneous binder–aggregate distribution and repeatability of the test conditions (Figure 4).

a) MAS16 sample MAS16 PM sample

Fig. 3: Laboratory samples of asphalt mixtures.
Source: created by the authors.

Fig. 4: Laboratory mixer used for the preparation of asphalt mixtures under controlled temperature and pressure.
Source: created by the authors.

Slab specimens were compacted under controlled temperature and pressure to reproduce field-representative density and internal structure prior to rutting testing (Figure 5).

Fig. 5: Compacted slab specimen prepared for rutting testing.
Source: created by the authors.

Permanent deformation resistance was evaluated using a wheel-tracking device capable of applying repeated loading under controlled temperature conditions (Figure 6).

Fig. 6: Wheel-tracking apparatus used for permanent deformation evaluation.
Source: created by the authors.

2.3 Cement Concrete Pavement - CCP

In addition to flexible pavement solutions, a CCP was analyzed as an alternative structural solution for highly loaded stopping zones.

A special concrete mix was made for road sections like bus stops. Tests were done to check how well it handles, including its strength, water resistance, wear and tear, and ability to withstand freezing and thawing. These are factors for how well it performs over time in heavy city traffic and various weather conditions.

2.4 Comparative Evaluation Framework

The comparison between asphalt and rigid pavement was done using a framework that focuses on performance. Asphalt mixes were mainly evaluated on how they resist permanent deformation. The rigid pavement solution was assessed on its ability to handle static and repeated loads and its durability against environmental damage.

The adopted methodology supports a structured comparison of pavement systems and the identification of optimized solutions for urban public transport stop areas.

2.5 Applicability to Urban Conditions

The experiments were based on real-life conditions seen at city transport stops along major roads. This approach makes sure the results are relevant and can be applied to city environments with lots of public transport activity.

3 Results and Discussion

3.1 Performance of Asphalt Mixtures under Permanent Deformation

Asphalt mixtures have a problem with permanent deformation, also known as rutting. This issue is critical in areas where buses and trucks stop often. Heavy vehicles, braking, and acceleration cause stress on the asphalt, leading to irreversible damage. When it's hot outside, the asphalt gets softer, making it more prone to deformation. In these conditions, how well asphalt mixtures resist rutting is crucial for the pavement's lifespan.

Figure 7 illustrates the laboratory-prepared slab specimen and the wheel-tracking test configuration adopted to simulate repeated loading conditions representative of urban public transport stop areas, forming the experimental basis for the rutting performance evaluation presented in this section.

Fig. 7: Placement of fresh concrete during pavement construction.
Source: [17].

The results of lab tests on rutting are in Table 3. We compared asphalt mixtures (MAS16) with mixtures made from polymer-modified asphalt (MAS16 PM). The tests show differences in how the mixtures behave under stress.

Table 3. Performance indicators for permanent deformation (asphalt mixtures)

No crt	Measured parameter	MAS 16	MAS16 PM
	Air voids at 10 and 80 gyrations, V10G/V80G (%)	13.1/ 4.6	12.2/ 3.9
1	Strain rate at 50 °C (µm/cycle)	0.632	0.299
2	Permanent deformation at 50 °C after 10,000 Cycles (µm)	15,447	9,754
3	Stiffness modulus at 20 °C, 124 ms (MPa)	4,623	5,622
4	Rutting rate at 60 °C (mm/1,000 cycles)	0.245	0.063
5	Rut depth, RD_air (mm)	4.23	2.64
6	Proportional rut depth, PRD_air (%)	9.1	4.8

Source: created by the authors

The rutting-related performance indicators obtained from laboratory testing are summarized in Table 1 for the conventional and polymer-modified asphalt mixtures. Air void content at 10 and 80 gyrations (V10G/V80G) were determined in accordance with EN 12697-31 [18], providing a volumetric characterization of the mixture and its compacted internal structure, which is directly related to susceptibility to permanent deformation. Dynamic creep parameters, including the strain rate at 50 °C and the accumulated permanent deformation after 10,000 load cycles, were measured following EN 12697-25 [19] (Method B), allowing the assessment of the mixtures' resistance to time-dependent plastic flow under sustained loading conditions representative of stationary heavy urban traffic.

The stiffness modulus at 20 °C and 124 ms loading time was determined according to EN 12697-26:2023 (Annex C) [20], offering an indicator of load distribution capacity and structural stability of the asphalt mixtures at an intermediate temperature.

The wheel-tracking test was used to see how well the material could stand up to rutting. This test was done with a device, and it followed the rules set out in EN 12697-22, [21]. From this test, we got some numbers: the rutting rate, the rut depth, and the proportional rut depth at 60 °C.

These numbers tell us a lot about how the material behaves when it's under a lot of stress and heat, like what you would see in a busy city where buses and trains stop.

We looked at all the numbers from the tests, including the ones about volume and how the material flows, and the ones about rutting. This helps us compare the asphalt to the kind that has polymer added to it. We want to make sure we are comparing them in a way and that our results are relevant to what happens in real life, especially in areas where a lot of buses and trains stop.

The numbers in Table 3 show that the polymer-modified asphalt is better at resisting damage from use. It does a job, then the regular asphalt, and this is shown by the lower strain rates, the less deformation that happens over time, the higher stiffness, and the better rutting indicators when it is hot.

3.2 Influence of Polymer Modification on Mechanical Behavior

The comparison of asphalt and asphalt with polymers added to it shows that the polymers have a big effect on how the asphalt behaves when it is under a lot of stress. When polymers are added to asphalt, the air holes in the asphalt get smaller. The asphalt becomes denser and more stable. This makes the asphalt better able to handle being loaded and unloaded without getting damaged.

Tests that applied a lot of heat to the asphalt showed some differences between the two types of asphalt. The asphalt with polymers added to it was better able to handle being loaded and unloaded times without getting damaged compared to the regular asphalt. This means that the polymer asphalt will perform better when it is under a lot of stress for a time. This behavior confirms the role of polymer modification in limiting the accumulation of irreversible strains under conditions representative of stationary heavy urban traffic. The stiffness modulus at intermediate temperatures supports this observation.

The asphalt with polymers added to it was also better at spreading the load and staying stable compared to the regular asphalt. This is important for areas where buses and trains stop often, like city bus stops, because the asphalt has to be able to handle the stress of vehicles stopping and starting in the same place. Asphalt, with polymers added to it, is better able to handle this kind of stress. The polymer-modified asphalt mixture is more stable. Can handle the repeated stopping and starting of vehicles.

Rutting resistance evaluated by wheel-tracking testing confirmed the superior performance of the polymer-modified mixture. Lower rut depth and deformation rates were recorded for the MAS 16 PM mixture, indicating improved resistance to permanent deformation under repeated loading at elevated temperatures.

The combined results from volumetric, rheological, and rutting-related tests show improved durability and structural performance of asphalt mixtures under intensive urban traffic conditions.

3.3 Implications for Pavement Design in Public Transport Stop Areas

The observed performance differences between conventional and polymer-modified asphalt mixtures underline the limitations of standard flexible pavement solutions when applied in intensively loaded urban transport zones. While MAS 16 mixtures may perform satisfactorily under normal traffic conditions, their behavior under stationary heavy loads is characterized by rapid accumulation of permanent deformation.

The superior rutting resistance of MAS 16 PM mixtures support their use in urban public transport stop areas as an optimized flexible pavement solution. Flexible pavement systems can still deform under extreme and repetitive loading, especially in areas with prolonged stationary traffic, even with polymer modification. In such conditions, rigid pavements are more suitable, as traffic and operating conditions may exceed the capacity of flexible systems.

The following section therefore extends the analysis toward the performance of CCP solutions in comparison with asphalt-based structures.

3.4 Comparative Performance of Asphalt and CCP Solutions

The study of rigid pavement solutions shows they work differently in areas with a lot of public transport stops and heavy traffic. Polymer-modified asphalt mixtures hold up better against lasting damage than asphalt. Flexible pavement systems can still get damaged underweight, especially where traffic stops for a long time and it's hot outside, [22], [23].

CCP was tested as an option for areas with traffic that stop often. It resists lasting damage well. Doesn't get rutted from repeated braking, speeding up, and stationary traffic. Tests in the lab found that the road concrete mix made has strength, doesn't let much water through, and resists wear on the surface and freezing-thawing cycles. These qualities help it perform over time in cities with a lot of traffic and tough conditions.

Table 4 presents the performance of the analyzed pavement solutions in urban public transport stop areas.

Table 4. Comparative performance of pavement solutions for urban public transport stop areas

Performance criterion	MAS 16	MAS 16 PM	CCP
Resistance to permanent deformation	Low	Moderate–High	Very high
Rutting susceptibility	High	Reduced	Negligible
Deformation rate under repeated loading	High	Reduced	Very low
Durability under intensive loading	Moderate	High	Very high
Sensitivity to temperature variations	High	Moderate	Low
Resistance to wear and abrasion	Moderate	High	Very high
Maintenance frequency	High	Moderate	Low
Initial construction cost	Medium	High	High

Source: created by the authors

Cement concrete is less affected by moisture and temperature changes, making it suitable for public transport stop areas where maintenance is difficult.

CCP offers a longer service life and requires less maintenance than asphalt, especially under extreme loading. They cost more at first. Need careful planning and design. When choosing pavement, consider how much traffic it will get, how often vehicles stop, the environment it will be in, and the costs over its entire life.

4 Conclusion

The experimental results show that polymer modification improves the performance of asphalt mixtures, especially in terms of resistance to permanent deformation. The MAS 16 PM mixture showed lower rut depth, reduced deformation, and better mechanical stability compared to the conventional mixture. Polymer additives also improve binder–aggregate interaction and increase mixture stiffness, leading to better resistance to plastic deformation under elevated temperatures and repeated loading typical of urban public transport conditions. Flexible pavement systems can still deform under severe loading, even with polymer modification, especially in areas with prolonged stationary traffic. Rigid pavement solutions are therefore more suitable for heavily loaded urban transport stop areas. The comparative assessment shows that CCP performs better under intensive loading.

Polymer-modified asphalt mixtures have stiffness and better durability. They are also less affected by moisture and temperature changes. This makes polymer-modified asphalt mixtures suitable for urban public transport stop areas. You see, urban public transport stop areas are pretty tough on the pavement. This is because of all the stopping, braking, and high axle loads. These things create demanding conditions. Limit maintenance. So, when we pick a pavement, we should think about how it will perform. We need to consider things like traffic intensity, loading conditions, and environmental exposure. We also have to think about construction constraints and life-cycle costs. We cannot just think about the costs. The results show that polymer-modified asphalt mixtures are good for moderate loading conditions. On the other hand, rigid pavements are better for heavily loaded areas. This is because rigid pavements support the long-term performance of the pavement.

5 Future work

Future work will focus on the long-term behavior of pavement systems used in urban public transport stop areas under intensive loading. The study will include the development of numerical models to describe stress–strain response and deformation in both flexible and rigid pavements under realistic traffic and environmental conditions.

Finite element analysis will be applied to evaluate the effects of repeated loading, temperature variations, and material properties on pavement performance. This will support a better understanding of deformation processes and improve the assessment of pavement durability.

The research will also include in situ monitoring, allowing continuous observation of pavement behavior under real traffic conditions and providing data for model validation.

Real-time monitoring of rutting development and structural response under actual traffic conditions will provide essential field data for validating laboratory results and numerical predictions.

The integration of laboratory testing, numerical analysis, and field monitoring is expected to contribute to the development of a **performance-based framework** for the design, evaluation, and maintenance of pavement structures in urban public transport infrastructure, with the objective of improving long-term durability, operational reliability, and sustainability.

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