PERPETUAL PAVEMENTS FOR SOUTHERN AFRICA

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ABSTRACT

This technical paper explores the concept of perpetual pavements and its applicability in Southern Africa. Beginning with a historical overview of the development of perpetual pavements, the paper examines their successful application in America, Europe, and other regions. The focus then shifts to the potential implementation of perpetual pavements in Southern Africa, considering regional factors and proposing typical concept pavements suited to the unique challenges and conditions of the area. Based on the insights gathered, recommendations for the implementation of perpetual pavements in Southern Africa include the use of Enrobé à Module Élevée (EME) asphalt as a base layer with either a granular or cemented subbase supporting layer, optimized to ensure initial pavement failure is located in the surfacing layer. Emerging technologies, such as advanced asphalt mix formulations and nano technology, have the potential to further enhance the performance and sustainability of perpetual pavements.

1. INTRODUCTION

The development of sustainable and resilient infrastructure is a global imperative, and perpetual pavements emerge as a promising solution for achieving longevity and minimizing maintenance costs. Originating from the need to address the perpetual cycle of pavement deterioration and rehabilitation, perpetual pavements present a paradigm shift in the way we conceive and construct road infrastructure.

Southern Africa, with its diverse climatic conditions, increasing traffic loads, and reduced material availability, stands at the threshold of a significant evolution in pavement design. Existing design manuals have not been updated (for example, TRH 4 dating back to 1996) or does not cater for loading in excess of 100 million standard axle loads (Rolt et al., 2023). This paper aims to delve into the concept of perpetual pavements, trace its historical development, and explore its successful implementations worldwide. With a focus on Southern Africa, we seek to understand the challenges unique to the region and propose tailored concept pavement solutions for sustainable and enduring road infrastructure.

1.1 Aim and Scope of the Paper

The primary objectives of this technical paper are as follows:

- To provide an overview of the concept and history of perpetual pavements.
- To examine the successful application of perpetual pavements in the America, Europe, and other regions, drawing lessons and best practices.
- To assess the challenges and opportunities in implementing perpetual pavements in Southern Africa, considering regional factors.

- To propose typical concept pavements suited to the specific conditions of Southern Africa.

The scope of this paper encompasses a thorough review of literature, analysis of case studies, and the formulation of recommendations for the design and implementation of perpetual pavements in Southern Africa. The intention is to contribute valuable insights to the field of pavement engineering.

1.2 Concept and History of Perpetual Pavements

1.2.1 Definition and Characteristics

Perpetual pavements, as a concept, refer to a design philosophy and construction approach aimed at creating road surfaces with an extended lifespan and minimal maintenance requirements (PIARC, 2009). Unlike traditional pavements that undergo cycles of deterioration and rehabilitation, perpetual pavements are engineered to withstand the effects of traffic loads, climate variations, and material aging over an extended period.

Key characteristics of perpetual pavements include a multi-layered structure that accommodates gradual distress and redistributes stresses, ensuring the sustained performance of the pavement system. These pavements typically consist of a flexible surface layer, a stable intermediate layer, and a strong, resilient and rut resistant base layer, each serving specific functions in the overall design (Newcomb et al., 2001).

The defined perpetual pavement in terms of the paper is a flexible pavement. Although the pavement layers might have cement stabilised characteristics with high stiffness, the pavement is not rigid, and no concrete layers are included. The pavement structure would typically be able to carry more than 100 Million Equivalent Standard Axles (MESA) and has been balanced in terms of stress distribution to ensure that failure would be located in the top surfacing layer. This would ensure that any maintenance action over the design life would only require treatment of the top surfacing layer.

1.2.2 Development Over Time

The development of perpetual pavements can be traced back to the mid-20th century, with significant advancements in pavement engineering and materials science. Initial experiments focused on understanding the factors contributing to pavement fatigue and distress, leading to the realization that the traditional approach of thicker asphalt overlays was not a sustainable solution (Willis et al., 2009).

In the 1960s and 1970s, seminal research by institutions such as the American Association of State Highway and Transportation Officials (AASHTO) laid the foundation for the perpetual pavement concept. The idea gained momentum in the following decades as more research institutions, government agencies, and industry stakeholders recognized its potential benefits.

The 1980s and 1990s witnessed the implementation of perpetual pavements in various states in America (Newcomb et al., 2001), with successful outcomes and documented performance. Europe also embraced the concept (Nunn, 1997; Litzka, 2006), adapting it to local conditions and establishing it as a viable alternative to traditional pavement designs.

1.2.3 Key Principles and Design Factors

The design principles of perpetual pavements revolve around achieving structural integrity, flexibility, and resistance to fatigue and environmental factors. Some key principles include:

Layered Structure: Perpetual pavements consist of multiple layers, each designed to withstand specific stresses and strains as indicated in Figure 1. This layered structure facilitates gradual distress and load distribution.

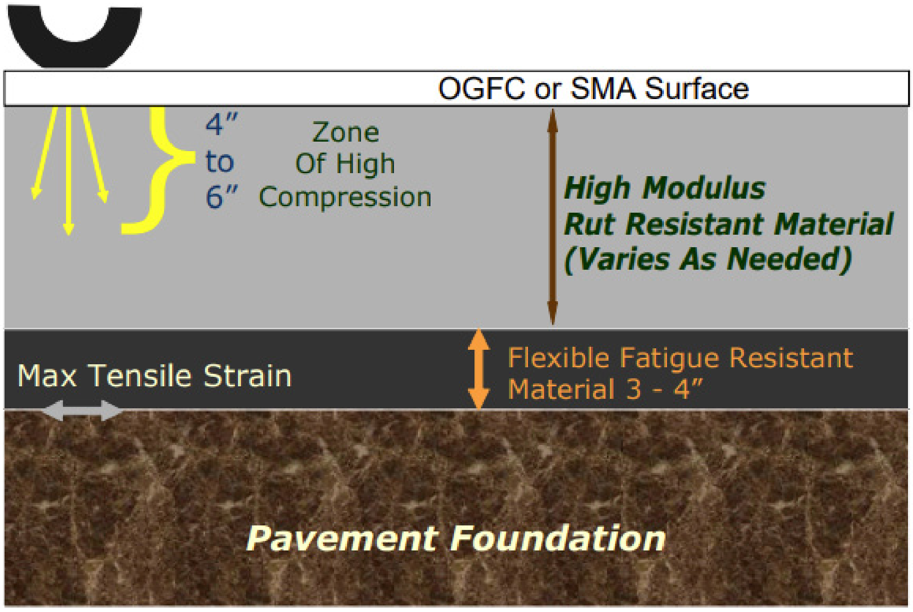


Figure 1: Perpetual pavement concept (Willis et al., 2009)

Material Selection: Perpetual pavements are usually designed based on the endurance limit property of bound pavement materials, which is the critical stress or strain below which the material can be subjected to a finite number of load repetitions without causing fatigue failure (Beriha et al., 2019). The choice of materials, including high-quality asphalt mixes, plays a crucial role in the performance of perpetual pavements. Emphasis is placed on durability and resistance to aging and deformation. The top asphalt layer or wearing course is designed to be crack and wearing resistant and thus has a high binder content. The next, intermediate asphalt layer would be highly resistant to deformation and stiff. This layer typically has lower binder content and larger in size interlocked aggregates. A third, lower asphalt layer is designed to be fatigue resistant. At this location in the pavement structure the horizontal strains peak and high dosages of modified binders would typically be included in this layer. The pavement foundation should typically also be stiff to protect the subgrade from deforming. Increased stiffness is generally obtained by stabilising this layer with cement.

Balanced Structural Design: Achieving a balance in the structural design ensures that no single layer bears excessive loads, preventing premature failures and extending the pavement's life.

Regular Maintenance: While perpetual pavements are designed to minimize maintenance, regular inspections and minor repairs are essential to address localized issues and prevent them from escalating. Asphalt surfacings, being exposed to oxidation, precipitation and tyre wear have a limited functional life and require replacement and typically 10-year intervals. These mill and overlay special maintenance actions would typically constitute the most extensive operating expenditure on perpetual pavements (Newcomb et al., 2001).

In summary, the concept and development of perpetual pavements signify a progressive shift toward sustainable and resilient road infrastructure. The evolution of this approach reflects a commitment to longevity, cost-effectiveness, and environmental sustainability in pavement engineering.

The following essential design factors have to be considered during the development of a perpetual pavement (Lee et al, 2018):

Design traffic loading: Typical design traffic loads varies between 30 (Michigan, America) up to 200 (India) ESA. This represents a typical design life of 50 years.

The strain criteria: The criteria might vary but typically 70 micro strain for asphalt layers and 200 micro strain for subgrade is applied. The total asphalt thickness varies between 280mm and up to 560mm but typically 380mm is used.

2. APPLICATION OF PERPETUAL PAVEMENTS

2.1 Perpetual Pavements in North America and Canada

America has been at the forefront of adopting and implementing perpetual pavements, showcasing numerous successful projects across the country. Notable examples include the Illinois Toll way System and Texas IH 35 PP sections, where perpetual pavements have demonstrated exceptional durability and longevity (Lee et al., 2018). The Long-Term Pavement Performance (LTPP) program, initiated by the Federal Highway Administration (FHWA), has been instrumental in monitoring and evaluating the performance of perpetual pavements over extended periods.

The Texas perpetual pavement concept was initially proposed based on the Texas Department of Transportation memorandum (TxDOT, 2001) recommending the use of full-depth asphalt pavements on heavy truck trafficked highways where the 20-year estimate was in excess of 30 MESA. The memorandum included the material-layer type and the proposed minimum layer thickness. The material for each layer was chosen to withstand the specific stresses and strains expected in that layer. The surface layer(s) are required to resist oxidation/weathering, thermal cracking, and rutting. Below the surfacing, a load-carrying layer composed of a mix with a nominal maximum aggregate size of 20mm was specified as a transitional layer with low-moisture susceptibility. The main structural load-carrying layer is a rut-resistant layer with a minimum thickness of 200mm to ensure adequate structural capacity in terms of the load spreading capability. Below the rut-resistant layer, a rich asphalt layer is specified to create a fatigue-resistant layer. A treated subgrade material with typically 3 to 6 percent lime is placed above the subgrade to provide the working platform during construction and the stable pavement foundation.

Lee et al. (2018) compared the practices of other agencies for perpetual or full depth pavements to the Texas perpetual pavement structure and found that the Texas perpetual pavement required the thickest asphalt layers using premier mixtures amongst the states and countries reviewed. It was further found that the perpetual pavement sections that used thinner asphalt layers than Texas, showed good field performance and therefore there is room for optimisation of the Texas perpetual pavement structures.

In Canada, Golder Associates (2010) designed a perpetual pavement for the new four-lane Red Hill Valley Parkway in Hamilton, southern Ontario. The pavement consisted of 370 mm of subbase, 150 mm of granular base and then several lifts of asphalt. For the lowest lift, Golder Associates developed a new Rich Bottom Mix (RBM), laid 80 mm thick, which gives excellent fatigue endurance. Above that a 70 mm course of Superpave 25, then 50 mm of Superpave 19 and finally, a 40 mm Stone Mastic Asphalt (SMA) surface course were constructed. The mechanistic properties of the asphalt mixes were determined by laboratory testing at the mix design stage and Golder Associates developed six special specifications for the mix types. Due to the excellent performance observed at this site, more perpetual pavements are being constructed in Ontario and Alberta, Canada.

2.2 Perpetual Pavements in Europe

The UK defined long-life roads as pavements that are expected to last at least 40 years without the need for structural strengthening. TRL Report 250 reported that the M65 extension bear Blackburn was constructed on a trial basis using the essential elements of long-life asphalt pavement design methodology (Nunn et al., 1997). The trial was designed to determine whether construction using the proposed long-life design is feasible and to examine any difficulties that might occur. Two test sections were constructed that included thin surfacing materials, high modulus base using 15 penetration grade bitumen (HMB15) and heavy-duty macadam (HDM). Two proprietary surfacing materials were chosen by the Contractor. The pavement structures are illustrated in Figure 2.

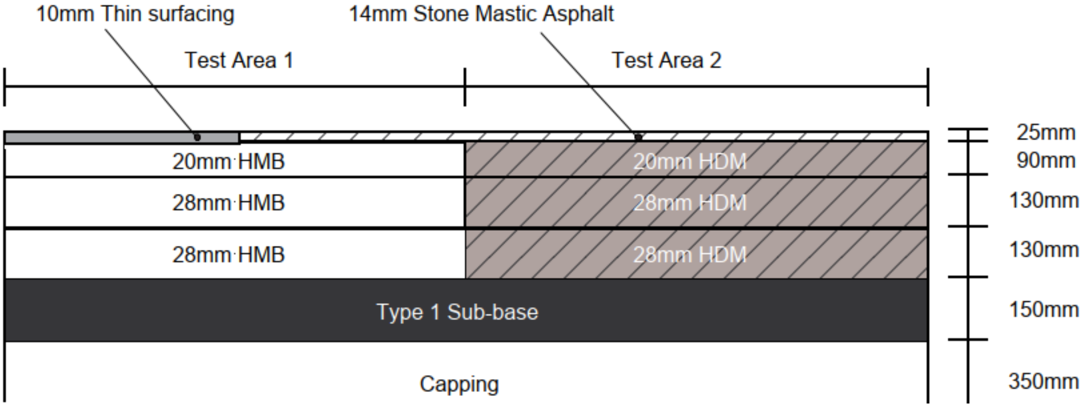


Figure 2: Construction thicknesses for M65 trial (Nunn et al., 1997)

The following conclusions were drawn from the trial (Nunn et al., 1997):

1. Additional site testing will ensure that all pavement layers have good performance related properties, and that the pavement is unlikely to deteriorate prematurely.
2. High modulus base is an alternative material for the structural layers.
3. Thin surfacing can meet the current texture requirements for wearing course. A road resistant to surface rutting can be produced when a thin surfacing or well-designed hot mix asphalt is laid in combination with a very stable base.
4. Overall, the trial demonstrated that Long Life Pavement Design is practicable and that considerable benefits can be expected from its introduction.

Furthermore, the study by Nunn et al. (1997) indicated that no evidence of structural deterioration due to fatigue or cracking of the asphalt base, or deformation originating deep within the pavement structure, has been found in existing roads that conform with the criteria for long-life. Additionally, the report concluded that the traditional concept of critical conditions based on pavement deflection doesn't apply well to thicker and well-built flexible pavements. This impacts how long-life pavements are designed and assessed, with the key change being the reduction of the reliance on pavement deflections to predict pavement life. To guide future actions and research in this area, the European Long-Life Pavement Group (ELLPAG) under the umbrella of the Forum of European Highway Research Laboratories (FEHRL) was established (Ferne et al., 2004). ELLPAG's best practice guidelines suggested the following steps to producing of long-life design methodologies and construction standards:

1. Determine how existing fully-flexible pavements perform.
2. Diagnose the cause of good or bad performance.
3. Update the design method or construction standards as required.
4. Adopt these revised methods and standards.
5. Monitor the benefits from these changes.

In (2001), Nunn et al. reviewed all available information to produce a design method and strategy for condition assessment for roads expected to last at least 40 years without the need for structural maintenance. The report highlighted that in the United Kingdom, flexible roads can maintain structural serviceability for a significant time if they exceed a certain strength threshold. However, it's crucial to detect and address non-structural deterioration such as surface-initiated cracks and deformation promptly to avoid compromising road integrity. Additionally, for long-term durability, the pavement must be well-constructed using high-quality asphalt and a good foundation to prevent deterioration due to construction or material deficiencies.

Ferne et al. (2004) conducted a cost-benefit analysis where improving and maintaining a 10,000km heavily trafficked road network over a decade using long-life pavement designs was compared to conventional ones. The analysis showed savings of approximately €120M in construction and maintenance costs for new pavements, and €220M for maintaining the existing network. This totals to nearly €350M or around 10% of the total construction and maintenance budget for the period. These substantial savings highlight the potential benefits of adopting long-life pavement designs for heavily trafficked road networks, not even factoring in potential environmental benefits.

In 2008, a research program called SPENS was conducted near Warsaw in Poland to test various pavement structures. The program, led by the Polish research institute IBDiM, constructing and testing four different pavements using a Heavy Vehicle Simulator (HVS). The focus was on validating the benefits of using asphalt concrete with high stiffness modulus, which had been experimentally used on the Polish network since 2004. Achieving the required stiffness modulus and fatigue resistance involved using harder bitumen and optimizing the mixture design with low air voids content and high binder content. There were concerns about potential low temperature cracking due to the stiff bitumen used. Stiffness and fatigue tests were conducted using four-point bending tests on specimens. One of the tested pavements aimed to create a perpetual asphalt pavement with a high fatigue-resistant asphalt course at the bottom which was an asphalt mixture with fine aggregate grading and a relatively high content of highly polymer-modified binder. The pavement structures and the results of the fatigue behaviour of the four pavement types after the HVS tests are illustrated in Figure 3 below.

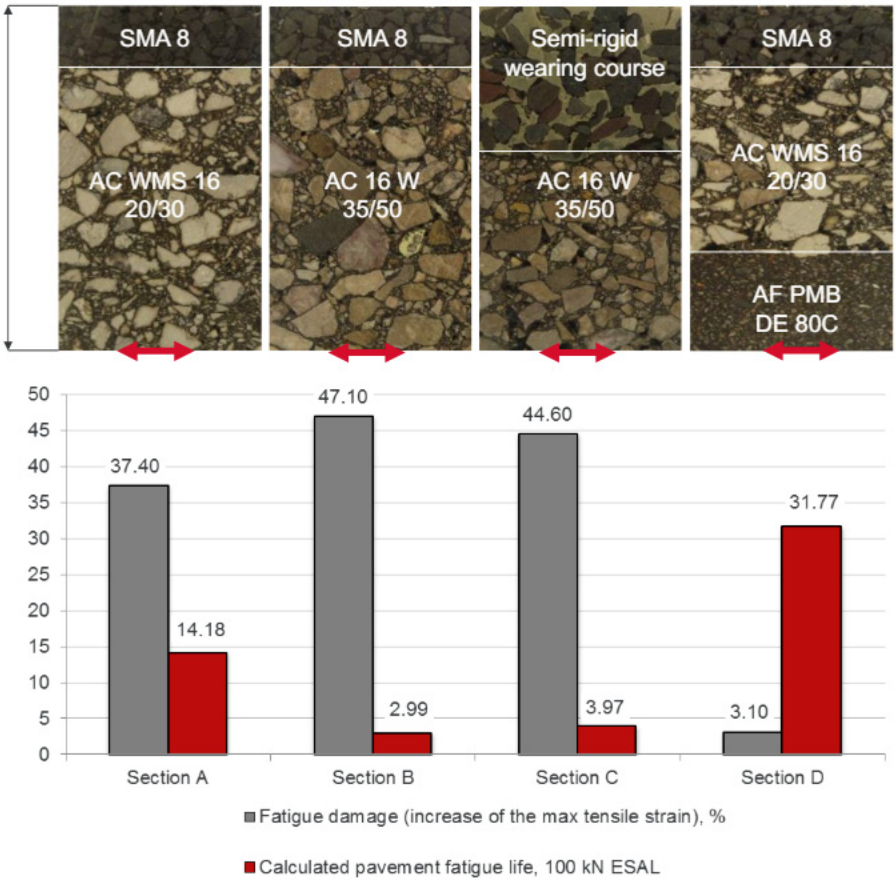


Figure 3: Results of fatigue behaviour of four pavement types after HVS tests (Ruttmar et al., 2016)

The accelerated testing results using HVS (refer to Figure 3) showed that the pavement with a high modulus asphalt base course (AC WMS) had significantly better fatigue life compared to pavements with traditional asphalt concrete base courses. However, the pavement with an anti-fatigue (AF) course, featuring a high content of highly modified binder at the bottom of the asphalt pavement, exhibited the best fatigue behaviour. Although the perpetual pavement type (section D) showed higher deflection on the pavement surface and strain at the bottom of the asphalt layer compared to section A, the fatigue damage of the perpetual pavement increased very slowly over time, indicating a practically unchanged condition. This suggests that the material at the bottom of the asphalt layers significantly improved the pavement's fatigue life.

Between 2012 and 2013, the TPA research laboratory in Pruszków conducted an extensive testing program focusing on assessing the functional properties of asphalt mixtures for base and binder courses, aiming to identify the optimal and most durable solution for pavement structures in Poland's climate. Through analysing various combinations of materials and layer thicknesses, they determined that employing stiffer material at the upper part of the asphalt layer and more flexible material at the bottom provided the highest calculated fatigue life for the pavement. This supported the concept of perpetual asphalt pavement with an anti-fatigue course at the bottom. Furthermore, a comprehensive assessment of life cycle costs, and an evaluation of the benefits for public investors (in terms of Net Present Value) of perpetual pavements in comparison to traditional pavement structures, clearly demonstrated the profitability of investing in perpetual pavements (Ruttmar et al., 2016). The economic analysis resulted in the S8 expressway in Poland to be constructed in 2014 using the concept of perpetual pavements.

2.3 Perpetual Pavements in Other Parts of the World

The adoption of perpetual pavements is not limited to America and Europe; it has gained recognition in various parts of the world. However, global implementation faces challenges related to varying climatic conditions, material availability, and local construction practices. Successful projects in regions such as Australia, South America, and Asia demonstrate the adaptability of the perpetual pavement concept on a global scale.

Case studies from diverse regions showcase the versatility of perpetual pavements. In Australia, for example, the Pacific Highway in New South Wales has benefited from perpetual pavement design principles (Sullivan, 2015).

China started to design, construct and test perpetual pavements such as the Yan Jiang Expressway, Xu Wei Expressway and Binzhou test road in 2004 and 2005 (Sultan et al., 2016). Chinese pavement designers tried to build on their long-time experience with long-life semi-rigid pavement structures that has been the main pavement structure in China since 1997 for their heavily trafficked highways. Their long life semi-rigid pavements consisted of asphalt pavements with 90% of the pavement structure comprising of a semi-rigid (cement stabilised granular) material. Figure 4 compares typical perpetual pavements to conventional pavements with a semi-rigid base in China.

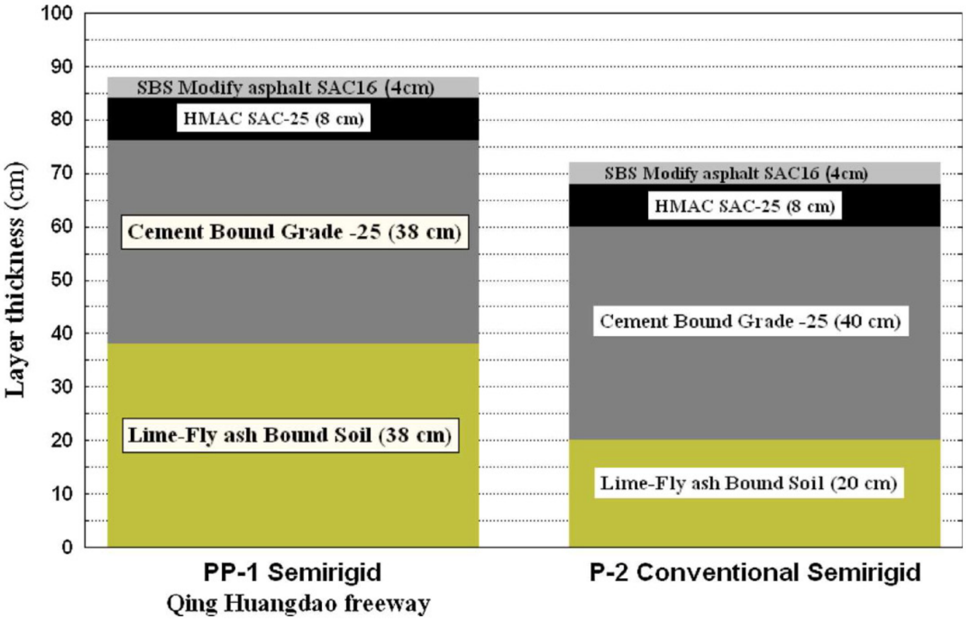
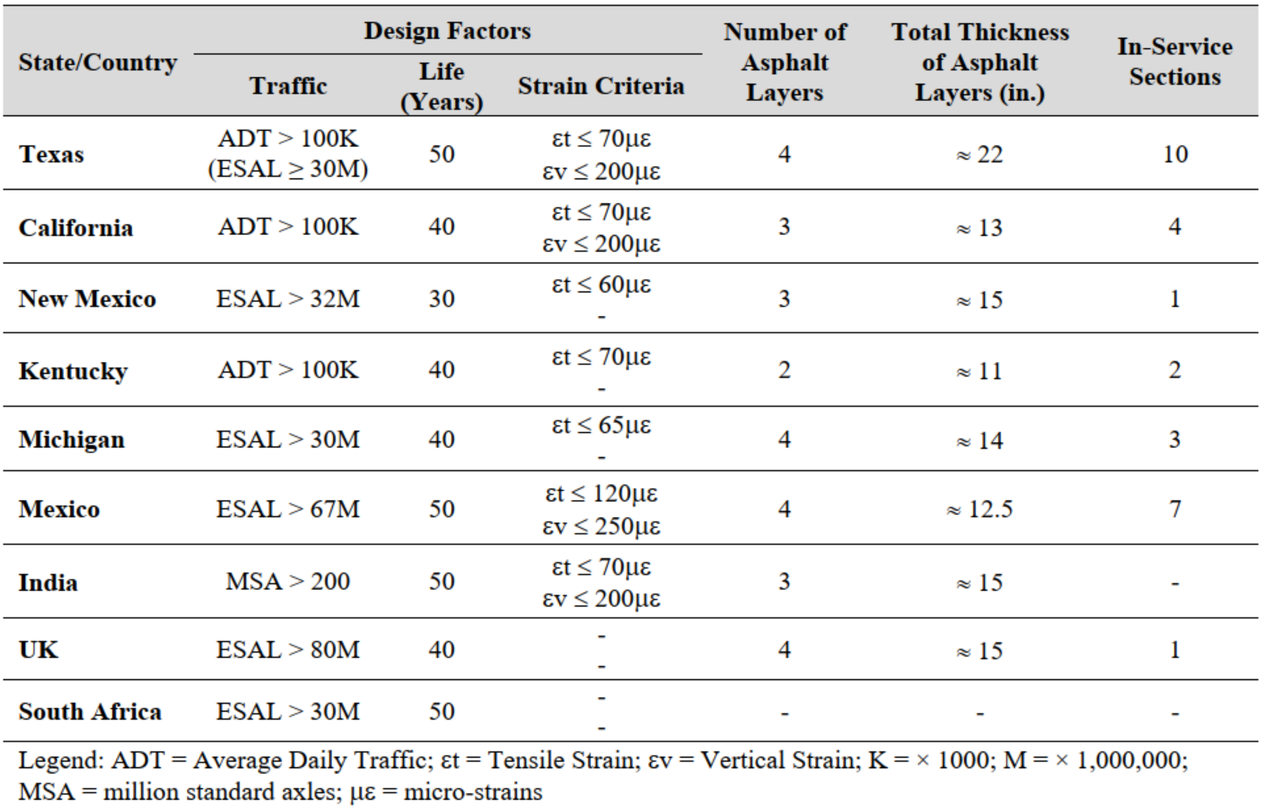


Figure 4: Perpetual and conventional asphalt pavements with a semi-rigid base layer in China (Sultan, et al., 2016)

South America has also witnessed successful implementations, with countries like Brazil incorporating perpetual pavements in their infrastructure development. Polo-Mendoza et al. (2023) conducted a case study in Barranquilla city (Colombia) to estimate the environmental burdens and monetary costs associated with the life cycle over a 50-year period of three pavement alternatives, i.e., a perpetual pavement, a conventional flexible pavement, and a conventional rigid pavement as decisions in terms of economic-environmental sustainability are especially important in developing countries. It was found that perpetual pavements generate less environmental impact and higher profitability than conventional pavements. Therefore, implementing perpetual pavements in Barranquilla (and in the rest of the northern region of Colombia) was found to be a feasible approach to pursuing sustainable development goals.

A comparative analysis of perpetual pavement projects worldwide reveals commonalities and distinctions. Factors such as material selection, design considerations, and maintenance practices vary based on regional preferences and challenges. Understanding these variations contributes to a more comprehensive global perspective on perpetual pavements. Lee et al (2018) collected data from various states in America and countries in the world and their data is presented in Table 1.

Table 1: Global data related to perpetual pavements (Lee et al., 2018)



State/Country	Design Factors			Number of Asphalt Layers	Total Thickness of Asphalt Layers (in.)	In-Service Sections
	Traffic	Life (Years)	Strain Criteria			
Texas	ADT > 100K (ESAL ≥ 30M)	50	$\varepsilon t \leq 70\mu\varepsilon$ $\varepsilon v \leq 200\mu\varepsilon$	4	≈ 22	10
California	ADT > 100K	40	$\varepsilon t \leq 70\mu\varepsilon$ $\varepsilon v \leq 200\mu\varepsilon$	3	≈ 13	4
New Mexico	ESAL > 32M	30	$\varepsilon t \leq 60\mu\varepsilon$ -	3	≈ 15	1
Kentucky	ADT > 100K	40	$\varepsilon t \leq 70\mu\varepsilon$ -	2	≈ 11	2
Michigan	ESAL > 30M	40	$\varepsilon t \leq 65\mu\varepsilon$ -	4	≈ 14	3
Mexico	ESAL > 67M	50	$\varepsilon t \leq 120\mu\varepsilon$ $\varepsilon v \leq 250\mu\varepsilon$	4	≈ 12.5	7
India	MSA > 200	50	$\varepsilon t \leq 70\mu\varepsilon$ $\varepsilon v \leq 200\mu\varepsilon$	3	≈ 15	-
UK	ESAL > 80M	40	- -	4	≈ 15	1
South Africa	ESAL > 30M	50	- -	-	-	-

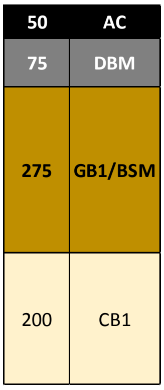
Legend: ADT = Average Daily Traffic; εt = Tensile Strain; εv = Vertical Strain; K = × 1000; M = × 1,000,000; MSA = million standard axles; με = micro-strains

This section underscores the global relevance of perpetual pavements while recognizing the need for region-specific adaptations and considerations in their application.

3. CHALLENGES AND OPPORTUNITIES IN SOUTHERN AFRICA

Very little has been published in terms of long-life pavements in Southern Africa. Jones et al (2008) reported on the long-life performance of the N12. The pavement was not specifically designed as a perpetual pavement and experienced only in the order of 50 MESA loadings. The recently updated Roadnote 31 (Rolt et al., 2023), that has been adopted (previous 1993 version of Roadnote 31) in many African countries, has a long-life pavement option that can carry up to 80 MESA. Figure 5 shows their climate resilient pavement structure that is specified for traffic where super single tyres are expected to be prevalent. They advise that an EME binder should be used to enhance climate resilience, as well as the addition of a surface treatment on top of the asphalt wearing course.

TRH4 (1996) proposes two long life pavement options (up to 100 MESA). They include a granular base pavement (only for moderate to dry regions) and an asphalt base pavement as indicated in Figure 6. These structures were developed for lower pavement contact stress (520kPa) and under higher stresses (typical to higher tyre pressures) (De Beer et al., 2013), less than 50 MESA life can be expected. Concerns with reflective cracking from the C3 subbase on the asphalt base option can be addressed with the incorporation of either a Stress Absorbing Membrane Interlayer (SAMI) layer or asphalt grids between the base and subbase layers.



Note:
AC – Asphalt wearing course
DBM – Dense Bitumen Macadam
GB1 – Graded crushed stone
BSM – Bitumen Stabilised Material
CB1 – Hydraulically bound material

Figure 5: Roadnote 31 long life pavement (S5 subgrade - > 15% CBR)

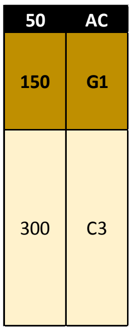
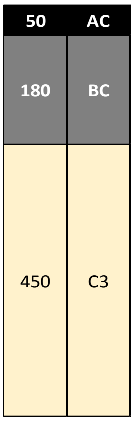
Granular base – Moderate or Dry region	Hot-mix asphalt base – All regions	
		Note: AC – Asphalt wearing course BC – Asphalt base course G1 – Graded crushed stone C3 – Cement stabilised gravel
20 MESA – failure in C3 layer	40 MESA – Asphalt base failure	

Figure 6: TRH4 long life pavements

4. TYPICAL CONCEPT PAVEMENTS FOR SOUTHERN AFRICA

4.1 Adaptations to Local Conditions

Designing perpetual pavements for Southern Africa requires careful consideration of the unique environmental, climatic, geological and traffic conditions prevalent in the region. The pavement structure should be adapted to withstand high temperatures. In the region, only Lesotho experiences sub-zero temperatures (below 0° centigrade), but their low traffic volumes do not necessitate a perpetual pavement strategy. The main risk of high temperatures remains asphalt rutting, that is typically addressed through the asphalt mixture design procedure and not considered during pavement structural design.

Variable rainfall patterns occur throughout the region, ranging from arid desert conditions in the Kalahari, to high rainfall areas near the tropics. Granular layers are affected by moisture the most and increased thicknesses and a protective cover are typically required.

Traffic loading, and particularly the volume of loading, is probably the single most important factor leading to the need for long-life pavements in Southern Africa. Traffic loading conditions are highly variable and overloading control is typically absent leading to high load equivalency factors (Pinard, 2010). The use of super single tyres has increased significantly (Lema, 2013), even in South Africa, that also contribute to higher load equivalency factors. In addition, there has been a continuous shift from rail to road freight, due to the deterioration of the freight rail system (Erasmus, 2023).

4.2 Material Selection and Design Considerations

Material selection is a critical aspect of perpetual pavement design for Southern Africa. The use of high-quality bituminous materials, well-graded aggregates, and innovative binders can contribute to pavement durability and cost-effective designs. Design considerations should include an optimal layer configuration that balances the stresses imposed by heavy traffic loads and the underlaying subgrade conditions. Typical asphalt base mixtures to consider include the standard Bitumen Treated Base (BTB) asphalt and the recently introduced Enrobé à Module Élevée (EME) or high modulus asphalt mixtures.

A theoretical exercise was conducted where a number of pavement structures were developed that would provide a design life of 100MESA with failure located in the top surfacing layer. The mechanistic analysis was performed using Rubicon toolbox software (Modelling and Analysis Systems, 2024) and the transfer functions listed in Table 2 were implemented.

Table 2: Failure modes and transfer functions used during the analysis (Modelling and Analysis Systems, 2024)

Layer	Failure Mode	Transfer Function
Asphalt surfacing (AC)	Horizontal tensile strain	Shell asphalt fatigue (SF=5)
Asphalt Base (BTB)	Horizontal tensile strain	RSA thick asphalt base, Category A
EME base	Horizontal tensile strain	EME fatigue
Granular subbase/selected (G5, G7)	Shear stress safety factor	RSA granular shear, Category A
Cemented subbase (C3)	Horizontal tensile strain	RSA cemented fatigue, Category A
Bitumen treated material subbase (BSM)	Deviator stress ratio	BSM Stellenbosch, Category A
Subgrade	Vertical compressive strain	RSA subgrade rut, 10mm, Category A

The following matrix of pavement layer materials was used:

- Surfacing: Asphalt wearing course
- Base: EME and BTB
- Subbase: a granular material (G5 quality), a cement stabilized material (C3), a bitumen stabilised material (BSM1 quality) and a combination of C3/BSM1 materials.

The pavement structures were modelled on a G9 quality (CBR > 7%) subgrade with a single 150mm G7 (CBR > 15%) selected/capping layer. In addition, the parameters defined in Table 3 were used, that were considered to be representative of typical material properties and loading conditions in Southern Africa.

Table 3: Mechanistic modelling parameters

Parameter	Value
Climate	Moderate
Tyre pressure	750 kPa
Wheel load	20kN
Wheel configuration	Dual
Wheel spacing	350mm
AC stiffness; poison ratio	3,000MPa; 0.40
BTB stiffness; poison ratio	7,000MPa; 0.40
EME stiffness; poison ratio	12,000MPa; 0.40
G5 stiffness; poison ratio	180MPa; 0.35
G7 stiffness; poison ratio	120MPa; 0.35
C3 stiffness; poison ratio	1,500MPa; 0.25
BSM1 stiffness; poison ratio	700MPa; 0.35

Figure 7 summarises the layer thickness required considering a 40mm asphalt wearing course. It is interesting to note that the pavement structures designed with an EME base has significantly higher strain levels than the 70 micro strain asphalt, and 200 micro strain subgrade strain limits referred to in the literature for perpetual pavements, as shown in Figure 8. However, the mechanistic analysis indicates that both the EME base and the subgrade are able to carry more than 100 MESA. The strain criteria therefore seems to be dependent on the type of material and climate of the area and differs from region to region as noted by the National Research Council (1973) and Kingham (1973). The EME base pavement use significantly lower volumes of asphalt and are accordingly appreciably more economical as indicated in Figure 9. The cost ratio’s shown in Figure 9 were based on the rates provided in Table 4.

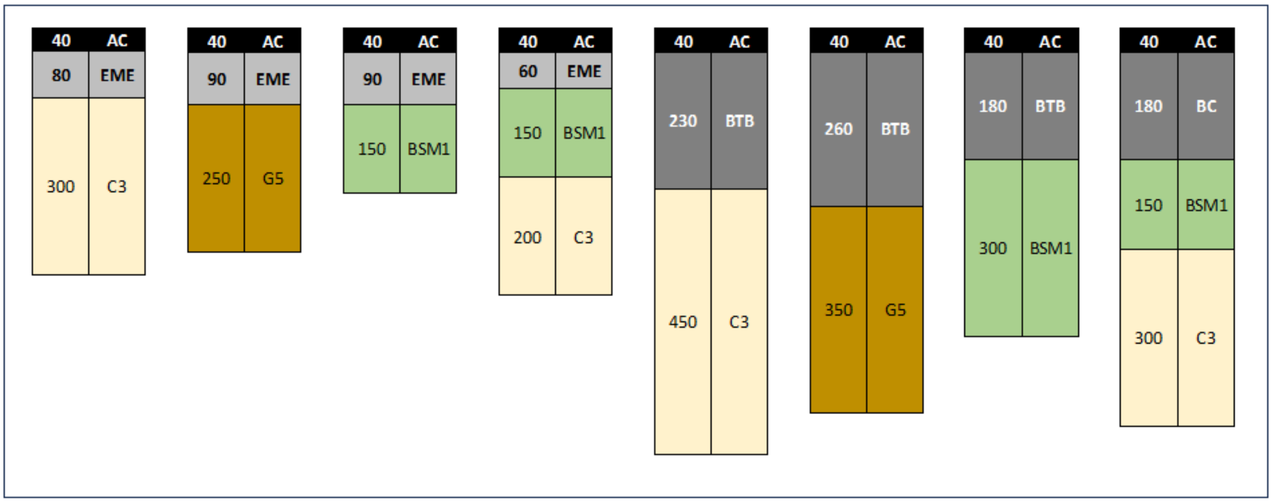


Figure 7: Theoretically developed perpetual pavement designs

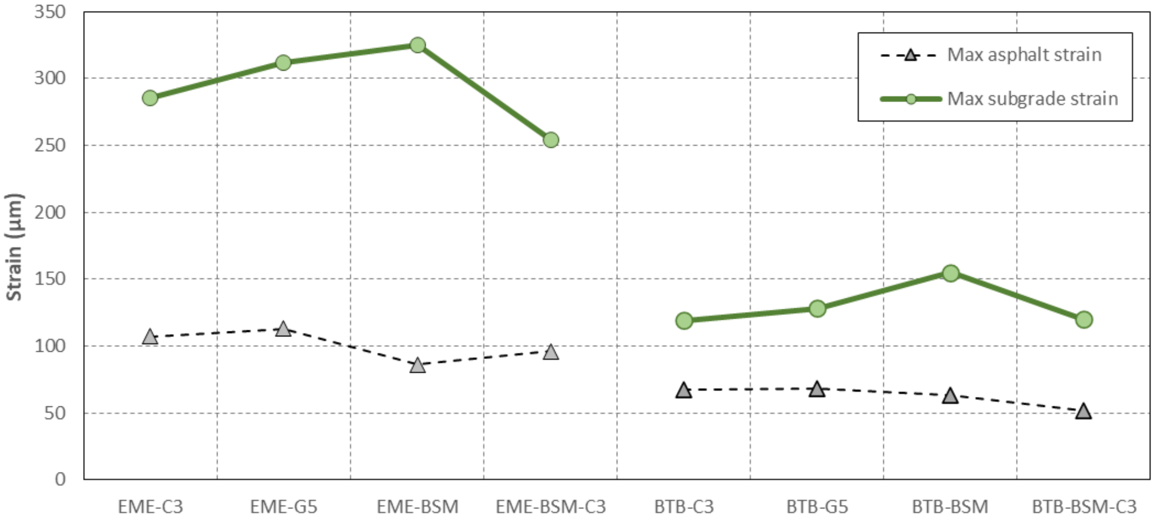


Figure 8: Calculated maximum strain levels for different perpetual pavement designs

Table 4: Typical cost rates

Material	Rate per m^3 (2024)	Material	Rate per m^3 (2024)
AC	R5,200	EME	R4,430
BSM1	R1,800	G1	R850
BTB	R3,200	G4	R600
C2	R850	G5	R420
C3	R600	G7	R75
Concrete	R3,000	Steel	R15000/ton

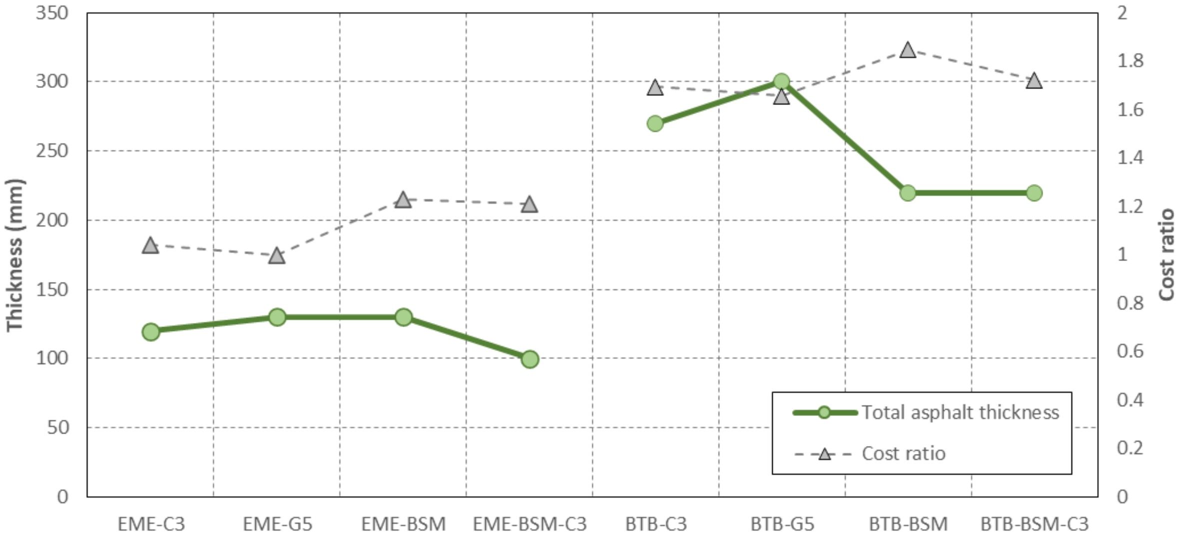


Figure 9: Total asphalt thickness and cost ratio's for theoretically developed perpetual pavement structures

4.3 Maintenance Strategies and Life Cycle Costs

Establishing a robust maintenance strategy is essential for the success of perpetual pavements in Southern Africa. Regular inspections, instrumentation, and data collection contribute to a proactive approach to maintenance. Early intervention through crack sealing, surface treatments, and periodic rejuvenation can mitigate distress and ensure the longevity of the perpetual pavement system.

To establish whether the developed perpetual pavement structures could compare to a more traditional long life concrete pavement, a present worth of cost life cycle cost analysis was performed. The perpetual pavement options were compared to a Continuously Reinforced Concrete Pavement (CRCP) consisting of a 240 mm thick slab, reinforced with Y20 steel at 150mm spacing and placed on a 300 mm C2 subbase, as shown in Figure 10. The CRCP option was designed using cncPave software (Cement & Concrete SA, 2024) to carry 100 MESA over a 50-year design period with less than 3% shattered slabs at the end of its design life. For the perpetual pavement options, it was assumed that maintenance will involve asphalt overlays at 12-year intervals.

Using the rates provided in Table 4 and a discount rate of 8%, the EME base perpetual pavements would be between 19 to 32% more economical. However, at the current high bitumen costs, the BTB base perpetual pavements are less economical as indicated in Figure 10.

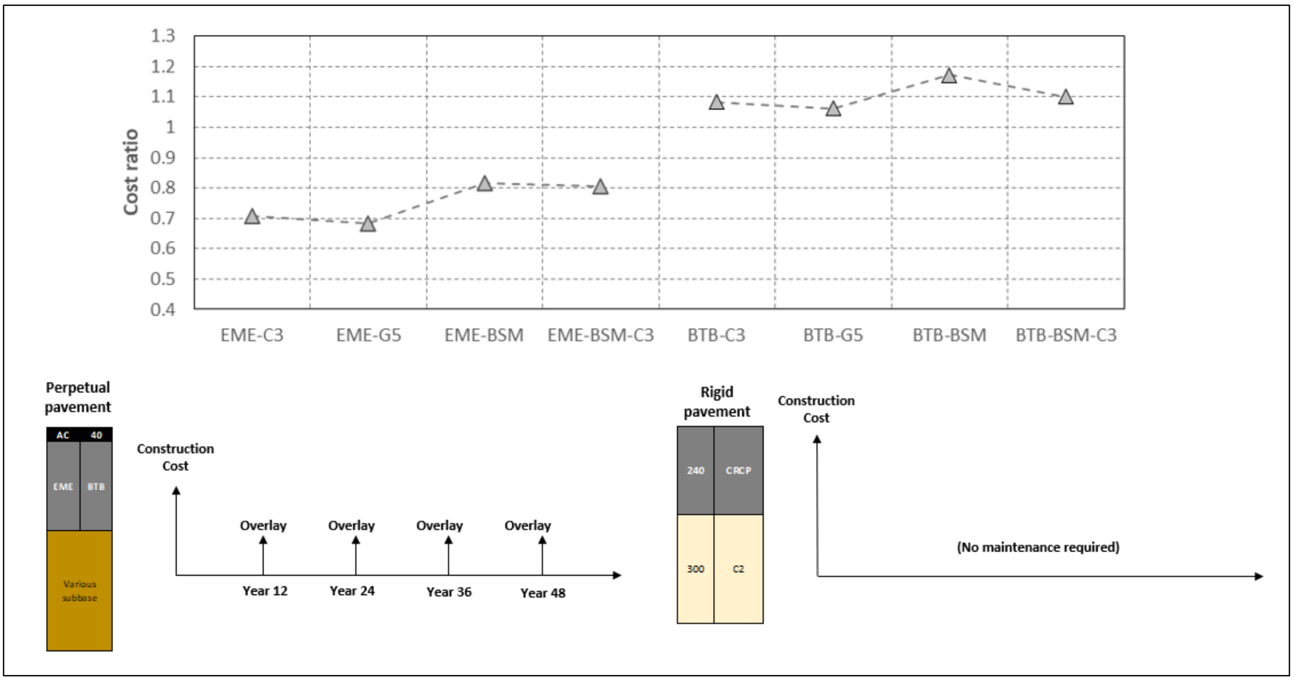


Figure 10: Life cycle cost comparison Perpetual vs Rigid pavement

5. CONCLUSION

This paper has provided an exploration of perpetual pavements, from their conceptualization to global applications and specific considerations for Southern Africa. Based on the insights gathered, recommendations for the implementation of perpetual pavements in Southern Africa include the use of EME asphalt as a base layer with either a granular or cemented subbase supporting layer, optimized to ensure initial pavement failure is located in the surfacing layer.

The future of perpetual pavements in Southern Africa holds exciting possibilities with ongoing innovations in design methodologies and materials. Emerging technologies, such as advanced asphalt mix formulations and nano technology, smart infrastructure monitoring, and environmentally friendly construction practices, have the potential to further enhance the performance and sustainability of perpetual pavements. Exploring these innovations will be crucial for staying at the forefront of pavement engineering in the region.

Identifying research gaps and areas for improvement is essential for advancing perpetual pavement design in Southern Africa. Research endeavours should focus on understanding the specific behaviour and specifically the endurance limits of regional materials, optimizing layer configurations, and developing more climate-resilient pavement solutions. Collaborative efforts between research institutions, government agencies, and industry stakeholders can address these gaps and contribute to the continuous improvement of perpetual pavements in the region.

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