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Annotated Bibliography on

Long Life (Perpetual) Pavements

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Introduction:

The construction of long-lasting hot mix asphalt pavements has been practiced for a number of decades in different parts of the world. Full-depth (asphalt courses used for all layers above subgrade) and deep-strength (asphalt surface and asphalt base over a minimal aggregate base above subgrade) pavements were originally designed for 20-year life expectancies. One of the primary advantages to these designs was that the total pavement sections were thinner when compared to conventional designs of asphalt over thick aggregate bases. As these full-depth and deep-strength pavements performed beyond their design lives, the vast majority only required surface restoration such as a thin overlays or mill and overlay. This practice of replacing only the surface offers a number of rehabilitation advantages in terms of speed of construction (user delay costs) and construction costs. The challenge for today is to obtain a longer surface life on a long-lasting asphalt support structure. Recent efforts in materials selection, mixture design, performance testing, and pavement design offer a methodology which may be employed to obtain very long-term performance from asphalt pavement structures (greater than 50 years) while periodically (approximately every 20 years) replacing the surface (top 25 to 100 mm) of the pavement. This concept has been proposed for use in Europe and it is rapidly gaining acceptance in the United States. The common theme in these approaches is to combine a rut resistant, impermeable, and wear resistant top structural layer with a rut resistant and durable intermediate layer and a fatigue resistant and durable base layer.

This annotated bibliography contains articles' abstracts from 2020-2022.

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Articles' Abstract:

1. Mikhailenko, P., Piao, Z., Kakar, M. R., Bueno, M., Athari, S., Pieren, R., et al. (2022). Low-noise pavement technologies and evaluation techniques: A literature review. *International Journal of Pavement Engineering, 23*(6), 1911-1934. **Abstract:** Traffic noise is the perpetual form of environmental pollution adversely affecting human health in urban environments. This literature review, intended for pavement researchers and professionals, looks at the continuously evolving low-noise asphalt pavement technologies and the techniques which can be used to evaluate them. Test methods for determining the acoustical properties of asphalt pavements are reviewed, in both the laboratory and field environments. The Close-Proximity (CPX) method is the most commonly used field test for pavement acoustics, followed by the Statistical Pass-By (SPB) and On-Board Sound Intensity (OBSI) methods. SPB seems is the most comprehensive methods, while the CPX is more practical. Methods for measuring the acoustical properties in the laboratory include the impedance tube for sound absorption and laboratory pavement noise simulators; with only the larger drum methods being able to produce conditions similar to in-situ. Methods for noise-relevant non-acoustical characteristics like surface texture, porosity and airflow resistivity were also reviewed. Optimizing surface texture at the macro-scale was found to be important in reducing tire/road noise. For pavement types, porous asphalt concrete (PAC) and its variants result in low-noise properties the most reliably, while having some drawbacks in durability and maintenance. Finally, various acoustical performance prediction models were discussed.

2. Wang, G., Li, J., Saberian, M., Massarra, C., Buckhalter, C., Farrington, J., et al. (2022). Use of COVID-19 single-use face masks to improve the rutting resistance of asphalt pavement. *Science of the Total Environment, 826*, 154118. **Abstract:** Today, the world faces an enormous increase in plastic waste pollution caused by the emergence of the COVID-19 pan-demic. Plastic pollution has been already one of the greatest threats to our planet before the Coronavirus outbreak. The disposal of millions of personal protective equipment (PPE) in the form of face masks has significantly contributed to the generation of plastic waste and has exacerbated plastic pollution. In an

attempt to mitigate pollution caused by the excess PPE waste, an innovative way was developed in this research to reduce pandemic-generated wastes by using the shredded face mask (SFM) fibers as an additive to hot mix asphalt (HMA) to enhance rutting resistance. Rutting or per-manent deformation is one of the major distresses of asphalt pavement. Since the SFM behaves as a semi-liquid be-tween 115.5 and 160 degrees C, which is in the range of HMA mixing and paving temperature, it can function as a binding agent to glue the aggregates. When the pavement is cooled down to ambient temperature, the hardened SFM can pro -vide stability and stiffness to HMA. Based on the results of this study, the modified mixes exhibited excellent resistance to permanent deformation under the Asphalt Pavement Analyzer (APA), as rutting depth values were reduced from 3.0 mm to 0.93 mm by increasing the SFM content from 0% to 1.5%. From the rutting test results and premature dis-tress mechanism study, the appropriate addition of SFM modifiers could improve the high-temperature properties of HMA that can be used to strengthen high-compression and shearing zones in the pavement structure.

3. Richmond, C. M., Archilla, A. R., & Adey, B. T. (2022). Are current design service lives for asphalt concrete pavements suboptimal? an analytic argument for longer design service lives. *Sustainable and Resilient Infrastructure, 7*(2), 130-152.
Abstract: One would expect the service life to be treated as an endogenous variable to be optimized in design procedures, but this is often not the case. This article provides a solution to the net-benefit maximizing choice of the design service life as a closed form equation. Using the 1993 AASHTO Design Equation, it is shown that for real discount rates under 4%, design service lives over 72 years are net-benefit maximizing given constant traffic loads. For lower discount rates, optimal service lives are considerably longer. This finding is consistent with perpetual pavement design as well as with optimal maintenance strategies involving multiple resurfacing cycles. Discounting is shown to be a key driver of the solution. Additionally, a simple method is shown on how to calculate an economically maximum pavement thickness that is independent of physical parameters. A methodology to simplify the AASHTO equation for use in analytic modelling is shown.

4. Tutu, K. A., & Timm, D. H. (2022). Asphalt fatigue endurance limit estimation and impact on perpetual pavement design. *International Journal of Pavement Engineering, 23*(4), 1239-1247.

   Abstract: The National Cooperative Highway Research Program (NCHRP) Project 9-38 developed a method for estimating asphalt fatigue endurance limit (FEL) which employs bending beam fatigue (BBF) lives. Another project, NCHRP 9-44A, used BBF test data to formulate a healing-based FEL prediction model. Both procedures were evaluated in this study by utilising data from the National Center for Asphalt Technology Pavement Test Track. The estimated FELs were used in perpetual pavement design to investigate their impact on asphalt thickness. The NCHRP 9-44A-predicted FELs increased with longer rest periods, but largely stabilised after 8 s, which agreed with the NCHRP 9-44A researchers' conclusion that no healing occurs after a rest period of 5-10 s. Overall, the NCHRP 9-38 method yielded greater FELs. Without binder modification and/or high binder content, both methods provided similar FELs, if a rest period longer than 5 s was entered in the NCHRP 9-44A model. Generally, the NCHRP 9-44A-predicted FELs produced thicker layers. However, for conventional asphalt mixtures, both sets of FEL yielded similar thicknesses, if the NCHRP 9-44A model applied a rest period exceeding 5 s. The NCHRP 9-44A model's predictive capability will increase if it is recalibrated with mixtures containing modified binder and/or higher binder contents.

5. van Blerk, P. G. L., Costello, S. B., & Henning, T. F. P. (2022). Design and construction of a new mechanised cement bound macadam (MCBM). *Construction and Building Materials, 336*, 127542.

   Abstract: The paper describes the development and implementation of a new heavy-duty pavement design and construction technique. The pavement structure consist of a very densely packed and interlocked, mainly single sized large aggregate skeleton, combined with a low cement and fines void filler. The small percentage of cemented finer particles specific to the gradation ensures optimal void fill is achieved without causing separation of the inter-locked large stone particles. This enables direct load transfer to take place between the interlocked large stone particles. The heavy-duty pavement is modelled on the

original macadam pavement philosophy with specific reference to cement-bound macadam. However, the advances in modern day construction equipment, and an increased focus on productivity, resulted in the demise of this traditional labour-intensive method. The greatest challenge, therefore, was to mechanise the cement-bound macadam concept, while also ensuring consistent aggregate gradation production and placement. This was achieved through the innovative use of modern recycling equipment and aggregate blending plants. Performance testing of in-situ core and beam cut test samples shows the strength characteristics achieved are similar to lean mix and conventional concrete. The cost of a mechanised cement bound macadam (MCBM) layer is approximately a third to a quarter of an equivalent thickness structural asphalt layer in New Zealand. It is therefore a viable design alternative to structural asphalt, delivering performance more akin to rigid lean-mix pavements, at significantly reduced cost.

6. Walubita, L. F., Martinez-Arguelles, G., Polo-Mendoza, R., Ick-Lee, S., & Fuentes, L. (2022). Comparative environmental assessment of rigid, flexible, and perpetual pavements: A case study of texas. *Sustainability, 14*(16), 9983.
   Abstract: Unlike conventional pavements with a service life of 20 similar to 30 years, perpetual pavements (PPs) are designed to have a 50-year service life without requiring major maintenance and rehabilitation (M&R) activities. In this way, PPs are more cost-effective than conventional rigid pavements (CRPs) and conventional flexible pavements (CFPs). Nonetheless, even though the economic and mechanical aspects of PPs have been widely studied and well documented, the literature is limited regarding the environmental assessment of PPs. Consequently, this research estimated the environmental burden associated with five pavement structures (one CRP, one CFP, and three PP structures) through the life-cycle assessment (LCA) methodology. Notably, the PaLATE computational tool was used to carry out the LCAs. The results indicated that for CFP, most of the environmental impacts are generated by the M&R activities. Otherwise, for CRP and PP structures, the most impact occurred during the initial construction stage. The study results also revealed that materials production is the sub-stage that most contributed to the generation of environmental detriments. Overall, this comparative case study

concluded that the pavement alternative with the slightest environmental damage is the PP structure.

7. Kulkarni, S., & Ranadive, M. S. (2022a). The parametric comparison of perpetual pavements with respect to life-cycle cost and greenhouse gas emissions. *Materials Today-Proceedings, 52,* 1147-1152.
   Abstract: The Present Study does parametric comparison of perpetual pavements designed as per IRC 37 (2018) guidelines. The comparison is executed among various combination of flexible pavement mentioned in IRC guidelines designed with perpetual pavement concept. The comparison is carried out on the grounds of checking the effect of change in thickness of sub base and base layers of pavement compositions with respect to overall thickness, life cycle cost assessment and carbon dioxide emissions. IITPAVE software was used to design perpetual pavements. The results were then verified using the KENPAVE software. The study concludes that change in thickness of sub base and base layers in case of various combinations of perpetual pavement results in considerable change in overall pavement thickness, total lifetime cost and CO2 emission. Results also show that deep strength perpetual pavement is proven to be most economical and eco-friendly option.

8. Kulkarni, S., & Ranadive, M. (2022b). Effect of soil stabilization on design of conventional and perpetual pavement in india. *Gradevinar*, *74*(9), 779-787.
   Abstract: The present study compares conventional pavement and perpetual pavement in the case of ground-granulated blast-slag-stabilized black cotton soil. Ground-granulated blast slag (GGBS) can be used for pavement over weak subgrade. We added slag to soil in proportions of 10 %, 20 %, 30 %, and 40 %. After determining the engineering properties of the soil and GGBS, modified Proctor compaction and California bearing ratio tests were performed. After determining these values, six combinations for conventional pavements and perpetual pavements with treated and non-treated subgrades were designed using a mechanistic-empirical methodology. The pavements were designed using IITPAVE software. The relevance of perpetual pavements was justified based on life-cycle cost assessment and carbon dioxide emissions for a duration of 50 years. The present study

concludes that for the implementation of perpetual pavements in a developing country such as India, there is a need for further study in the domain of soil stabilization as well as usage of high-stiffness base materials considering the rising cost of bitumen.

9. Ghazavi, M., Abdollahi, S. F., & Kutay, M. E. (2022). Implementation of NCHRP 9-44A fatigue endurance limit prediction model in mechanistic-empirical asphalt pavement analysis web application. *Transportation Research Record*, *2676*(6), 696-706. **Abstract:** One of the essential components of various design methods for perpetual (or long-life) flexible pavements is elimination (or minimization) of bottom-up fatigue cracking. For this purpose, the concept of the fatigue endurance limit (FEL) is used. The FEL is defined as a strain threshold below which fatigue damage does not accumulate for any number of load repetitions. Different ranges of FEL values have been reported in the literature. Recent studies have showed that FEL is not a single value and depends on several factors. The NCHRP 9-44A project resulted in an FEL prediction model based on the micro-crack healing concept and stiffness, both of which can fluctuate throughout the service life of a pavement. In this study, NCHRP 9-44A FEL prediction model was implemented in the Mechanistic-Empirical Asphalt Pavement Analysis (MEAPA) web application to investigate the effect of fluctuating FEL on bottom-up fatigue cracking prediction in three typical road sections (low, medium, and high traffic) in Michigan. The critical bottom-up fatigue strains, predicted FEL, and predicted fatigue cracking for each road section have been compared. The results revealed that implementation of FEL is critical for accuracy in the prediction of fatigue cracking in relatively thick pavements that are subjected to high traffic loading. The effect of FEL, however, was minimal in thin pavements with low traffic levels. Therefore, given that the mechanistic-empirical pavement design methods are typically used while designing highly trafficked pavements (e.g., highways, arterials, etc.), proper implementation of the FEL concept in pavement design is very important.

10. Yang, Z., Wang, L., Cao, D., Li, R., & Yang, H. (2022). Test and evaluation for performance of composite pavement structure. *Proceedings of the 8th International*

Conference on Civil Engineering, , 282-297.

Abstract: Perpetual pavement has become an important research field of highway development in China. Reasonable selection of pavement structure and ensuring the durability of the structure are one of the necessary measures to build perpetual pavements. The inverted asphalt pavement structure can not only provide high strength and good bearing capacity of semi-rigid base, but also make use of the graded crushed stones for restraining the reflection cracks of semi-rigid base. This paper presented a study on three pavement structures are, namely, a semirigid asphalt pavement and two inverted asphalt pavements. The performances of the three pavement structures after one million loading repetition are obtained. Taking rutting depth, deflection and dynamic response as evaluation indexes, the feasibility of inverted asphalt pavement structure as perpetual pavement structure is evaluated. It is found that the composite asphalt pavement structure with permeable asphalt mixture of large particle size as base and cement stabilized macadam as subbase has the best performance as perpetual pavement.

11. Zhang, R., Tang, N., Deng, X., Zhu, H., Su, C., & Xi, Y (2022). Erosion mechanism of sea salt solution on the performance of SBS-modified asphalt mixtures. *International Journal of Pavement Engineering*,

Abstract: Investigation of the erosion mechanism of sea salt solution on properties of asphalt pavement has important implications for the perpetual asphalt pavement construction in the coastal region. This paper intends to explore the performance deterioration mechanism of styrene-butadiene-styrene (SBS)-modified asphalt and mixture eroded by sea salt. The mixed sea salt solutions were prepared, and salt erosion dry-wet and freeze-thaw cycle tests were conducted for the simulation of the sea salt erosion environment. Multiple stress creep recovery (MSCR) tests, force-ductility tests (FDT), splitting tests and mass accumulation analysis were executed to study the performance deterioration mechanism of asphalt binder and asphalt mixture. The results indicate that the elastic recovery, high-temperature permanent deformation, rutting resistance and stress sensitivity of asphalt were improved after sea salt erosion, which proved the improvement of high-temperature rheological properties, while the stability of asphalt binder was

damaged. Moreover, the low-temperature crack resistance of asphalt binder was significantly damaged. Meanwhile, the mass accumulation rate of asphalt mixture eroded by sea salt increased, indicating that the salt migrated into asphalt mixture specimens in mixed salt solution after sea salt erosion, which was also confirmed by the appearance of salt crystallisation phenomenon and the observation results of frost. Therefore, the splitting tensile strength and splitting tensile strength ratio (TSR) of the asphalt mixture specimens were reduced, resulting in serious damage to moisture stability. Finally, it is confirmed that the concentration of the mixed salt solution and the number of cycles exerted a significant effect on the properties of the asphalt and asphalt mixture.

12. Zhu, J., Sargand, S., Khoury, I., Tarawneh, D., Ma, T., & Chen, F. (2022). Dynamic load responses of perpetual pavement test roads on US 23: Full-scale instrumentation and evaluation. *Construction and Building Materials*, *331*, 127326.

    a. **Abstract:** Perpetual pavement experimental roads of varying asphalt concrete thicknesses (28 cm, 33 cm & 38 cm) were constructed and instrumented on U.S. Route 23 in Delaware County, Ohio. Controlled Vehicle Load (CVL) testing was performed to obtain dynamic load responses under vehicular load and to evaluate influence of vehicle speed, tire pressure and axle configuration. CVL tests were conducted in November 2012 and July 2013 to evaluate temperature effects on pavement responses. A linear elastic finite element model program, OpenPave was used to obtain layered elastic solutions of load responses with time history to validate measured results. Paired t-tests were performed to compare mean difference between measured and calculated strain responses. Factorial ANOVA test was performed to evaluate significance of truck speed and tire pressure on measured strain responses. It was found that the calculated strain responses were overall in good agreement with the measure values. A uniquely designed strain gage rosette was installed to obtain vertical strain in the pavement and was found to be effective. However, significant differences existed between measured and calculated strain responses in summer test due to unaccountability of the FE program for viscoelasticity of asphalt concrete materials. 33 cm section with

stabilized subgrade performed the best with lowest strain responses. Tandem axle truck produced strains lower than single axle truck even though total weight was heavier. Transverse strain tends to increase as lateral wheel offset increases.

13. Fang, Y., Zhang, Z., Wang, S., Yang, J., & Li, X. (2022). Determination of minimum dynamic modulus (E*) of high modulus asphalt concrete applied to semirigid base asphalt pavement. *Journal of Materials in Civil Engineering*, *34*(1), 04021378. **Abstract:** In order to mitigate the serious rutting disease of the semirigid base asphalt pavement (SBAP), measuring the settings of a high modulus asphalt concrete (HMAC) layer in the SBAP structure was proposed in this study. In this paper, the mechanical structure model was established according to the typical structure in the perpetual pavement (PP) design, and the mechanical response of pavement structure was analyzed, and then, the reasonable calculation points, critical failure axle load, and minimum E* value of HMAC applicable to the PP structure were demonstrated. On this basis, referring to the design concept and analysis process of the PP structure, the reasonable calculation points, critical failure axle load, and minimum E* value of HMAC applicable to the SBAP structure were determined, and then, the antirutting behavior of HMAC was analyzed and discussed. The results show that under the vehicle load, the SBAP structure shows different mechanical responses with the PP structure. For the PP structure, the center of wheel gap should be used as the calculation control point; differently for the SBAP structure, the center of wheel gap, the center of the load action and the edge of the load action should be respectively taken as the analysis points of antifatigue, vertical compressive stress, and shear strain. Also, the critical failure axle load of the two pavement structures was both determined as 130 kN. In order to achieve the design goal of pavement durability, the minimum E* value of HMAC applicable to the PP structure should not be less than 14,000 MPa (20 degrees C, 10 Hz); while for the SBAP structure, the minimum E* value of HMAC should not be less than 13,000 MPa (20 degrees C, 10 Hz). In addition, setting the high modulus layer (HMAC) in the middle and lower surface layer of SBAP structure can effectively reduce the shear deformation and the vertical deformation of the structure layer, thus improving the rutting resistance of pavement structure. (C) 2021 American Society of Civil Engineers.

14. Franesqui, M. A., & Gallego, J (2022). Inspection and depth sizing of surface-initiated cracking for preventive maintenance of asphalt pavements. *International Journal of Pavement Engineering,*

Abstract: Adequate monitoring and timely treatment of partial-depth, surface-initiated cracks are essential in order to prolong the life cycle of pavement structures. Therefore, methodologies to precisely identify and assess the progression of top-down cracking (TDC) depth are fundamental. For this purpose, a calibrated model for ultrasound inspection of various types of bituminous mixtures for paving (semi-dense asphalt concrete AC-S, stone mastic asphalt SMA, and porous asphalt PA) is proposed to assess the depth and extent of top-down propagated macro-cracks in asphalt pavements. Extensive laboratory measurements were recorded on specimens of the different materials, thicknesses, temperatures and distances between sensors, with varying crack depths. The laboratory results were compared with in situ tests and with the theoretical approach. The application of the calibrated model allowed an appraisal of the depth of TDC with sufficient precision for a routine practical application regarding pavement maintenance. This non-destructive, inexpensive and easy-to-implement methodology for on-site identification and evaluation of TDC depth in asphalt pavements ensures straightforward implementation on non-prepared surfaces and provides sufficient reliability in the laboratory and on in-service pavements.

15. Franesqui, M. A., Yepes, J., & Gallego, J. (2022). Mechanical performance under dynamic loading of rubberized asphalt mixtures with highly-porous vesicular aggregate. *Scientific Reports, 12*(1), 19973.

Abstract: In volcanic regions, the use of certain abundant aggregates of scoriaceous nature with high porosity to manufacture bituminous paving mixtures is a major problem due to the excessive heterogeneity, absorption and limited strength of these aggregates. Consequently, the properties of the mixtures often do not meet technical specifications. The aim of this research is to study the improvement of the mechanical performance of asphalt mixtures with these residual volcanic aggregates by using binders modified with rubber from end-of-life tyres, since environmental and economic requirements make it necessary to reuse both types of waste. Laboratory studies determining the compactability, dynamic stiffness, fatigue resistance and elastic constants have made it possible to

characterise the mechanical performance of these mixtures during production and in service, and to compare them with conventional mixtures. It was found that the use of tyre rubber modified bitumen makes compaction somewhat more difficult, but reduces the particle size degradation of the porous aggregates and improves the mixture performance and durability, showing higher stiffness moduli and increased resistance to fatigue.

16. Gallego, J., Gulisano, F., Contreras, V., & Paez, A. (2021). The crucial effect of re-compaction energy on the healing response of hot asphalt mortars heated by microwaves. *Construction and Building Materials, 285*, 122861.
Abstract: Microwave heating treatments for assisted self-healing of asphalt mixtures have been investigated over the last years. However, the only heating treatment does not permit to recover the entire original strength of the asphalt mixtures. The experimental results of this investigation show that the combination of heating and re-compacting of the pavement (thermomechanical treatment) can overcome these limitations, restoring the original tensile strength of the mixtures. During the investigation, an innovative type of mold for the gyratory compactor has been developed. The peculiarity of the mold is that it can be longitudinally opened and closed through the use of hex screw heads. Thanks to this two-parts mold, the previously broken specimen can be easily reintroduced into the mold to be subjected to new cycles of re compaction with the kneading effect of the gyratory compactor. The experiment done in this investigation was carried out on asphalt mortars with steel fibers or electric arc furnace slag. The results showed that the additives and the re-compaction technique reduce drastically the heating energy necessary to assist self-healing of the mortars. This thermomechanical treatment could be implemented in the field by heating the deteriorated pavement with a microwave generator, and then re-compacting the pavement with a rolling compactor, which can promote the healing process thanks to its kneading action on the heated pavement. (c) 2021 Elsevier Ltd. All rights reserved.

17. Gopinath, P., & Kumar, C. N. (2021). Performance evaluation of HMAC mixes produced with gilsonite modified bitumen for heavily trafficked roads. *Materials Today-Proceedings, 43*, 941-946.
Abstract: The structural distresses in the flexible pavements due to exponential increase in traffic volume, heavily loaded vehicles and changes in climatic conditions are decreasing

the performance of the pavement and leading to premature failure. These structural distresses lead to increase in maintenance cost, decreases residual life of the pavement and cause delay to the road users due to lane closures. The concept of Perpetual pavements can be adopted as a solution to addresses these issues because of its enhanced design life with minimum traffic-disrupting reconstruction or maintenance. High modulus layer used in the perpetual pavement can be produced with hard grade bitumen. In this study Gilsonite is used as stiffening additive for modifying VG 30 to produce hard grade bitumen. The physical test results of modified bitumen with different percentages, show that 15% (by weight of VG 30) of gilsonite is the optimum percentage to produce hard grade bitumen according to the specifications of EME2 method. The results of resilient modulus and rutting test on High Modulus Asphalt Concrete (HMAC) mixes show that the modulus value is increased by 2.4 times and rut depth is decreased by 4 mm with conventional mixes. A pavement section for a design traffic of 300 msa has been designed for both conventional and HMAC mixes as per IRC:37-2018 guidelines. Based on the analysis, the thickness of DBM layer with Gilsonite modified bitumen has been decreased by 65 mm in comparison with conventional bitumen, because of which investment of money and use of natural resources like mineral aggregates will be saved. (C) 2020 Elsevier Ltd. All rights reserved. Selection and peer-review under responsibility of the scientific committee of the International Conference on Advanced Materials Behavior and Characterization.

18. Guo, X., & Hao, P. (2021). Influential factors and evaluation methods of the performance of grouted semi-flexible pavement (GSP)-A review. *Applied Sciences-Basel, 11*(15), 6700. **Abstract:** Featured Application This review provides guidance for the future studies of this new pavement technology, which may be of concern in many fields of road construction, such as heavy-duty pavement, perpetual pavement, reclaimed asphalt pavement, and new airport runway. Grouted Semi-flexible Pavement (GSP) is a novel pavement composed of open-graded asphalt concrete grouted with high-fluidity cement mortar. Due to its excellent load-bearing and anti-rutting performance, it has great potential as anti-rutting overlay and surface in road construction. However, the understanding of GSP performance remains limited and pertinent findings are inconsistent. This article aims to provide a systematic literature review for the articles which were published between 2000 and 2020 on GSP, explore the problems in the recent research, identify knowledge

gaps, and deliver recommendations for future research. The influential factors and the relative evaluation methods of GSP performance are summarized and discussed in this article.

19. Hu, C., Mai, Y., Cannone Falchetto, A., & Tartari, E. (2021). Experimental investigation on the use of selenice natural bitumen as an additive for pavement materials. *Materials, 14*(4),

    Abstract: As a good asphalt modifier, natural asphalt has been the focus of more attention because of its low price and ability to improve the performance of modified asphalt. In this paper, the incorporation of a natural asphalt binder in the production of bituminous materials for pavement application in China was experimentally investigated to evaluate the feasibility of such a process and its potential benefits in terms of performance. For this purpose, an asphalt binder conventionally used in the south of China was blended with various percentages of a hard natural binder obtained from the region of Selenice in Albania. The content of Selenice natural bitumen (SNB) was 80.5%, having high molecular weight and the advantages of good stability and compatibility with virgin asphalt. The physical, rheological, and mechanical properties, as well as the modification mechanism of the binder and corresponding asphalt mixture, were evaluated in the laboratory. It was observed that the hard binder improved the response of the binder blend at high and intermediate temperature; this reflected a better stability, improved moisture susceptibility, and enhanced rutting resistance of the mixture. Fluorescence microscopy showed that after dissolving, the size of the SNB modifier became smaller and its distribution was uneven, presenting three forms, granular, agglomerated, and flocculent properties. Chemical test results showed that the modification mechanism of SNB was mainly related to the enhancement of hydrogen bonds and Van der Waals forces caused by sulfoxide and carbonyl along with the stress concentration caused by silica particles. Molecular composition revealed that the proportion of middle molecules has reduced while the proportion of large molecules has increased. It is considered that SNB is a promising low-priced natural modifier with excellent rutting resistance properties. Future research will be focused on the economic analysis, pavement life cycle assessment of SNB modified asphalt, and its application in perpetual pavements.

20. Isied, M. M., Souliman, M., I., Zeiada, W. A., & Bastola, N. R. (2021). Predictive artificial neural network laboratory fatigue endurance limit model for asphalt concrete pavements based on the volumetric properties and loading conditions. *Transportation Research Record, 2675*(8), 630-642.

Abstract: Asphalt concrete healing is one of the important concepts related to flexible pavement structures. Fatigue endurance limit (FEL) is defined as the strain limit under which no damage will be accumulated in the pavement and is directly related to asphalt healing. Pavement section designed to handle a strain value equivalent to the endurance limit (EL) strain will be considered as a perpetual pavement. All four-point bending beam fatigue testing results from the NCHRP 944-A project were extracted and utilized in the development of artificial neural network (ANN) EL strain predictive model based on mixture volumetric properties and loading conditions. ANN model architecture, as well as the prediction process of the EL strain utilizing the generated model, were presented and explained. Furthermore, a stand-alone equation that predicts the EL strain value was extracted from the developed ANN model utilizing the eclectic approach. Moreover, the EL strain value was predicted utilizing the new equation and compared with the EL strain value predicted by other prediction models available in literature. A total of 705 beam fatigue lab test data points were utilized in model training and evaluation at ratios of 70%, 15%, and 15% for training, testing, and validation, respectively. The developed model is capable of predicting the EL strain value as a function of binder grade, temperature, air void content, asphalt content, SR, failure cycles number, and rest period. The reliability of the developed stand-alone equation and the ANN model was presented by reasonable coefficient of determination (R-2) value and significance value (F).

21. Vasquez-Varela, L. R., & Garcia-Orozco, F. J. (2021). An overview of asphalt pavement design for streets and roads. *Revista Facultad De Ingenieria-Universidad De Antioquia*, (98), 10-26.

Abstract: Pavements constitute a geotechnical problem since they are built on the ground and with materials obtained from it: untreated, such as soils and rocks, and processed as hydraulic and bituminous binders; consequently, a geotechnical framework is useful to describe their constitutive elements. The design of asphalt pavements for streets and roads evolved from empiric to mechanistic-empiric (M-E) procedures throughout the 20th

century. The mechanistic-empiric method, based on layered elastic theory, became a common practice with the publication of separate procedures by Shell Oil, Asphalt Institute, and French LCPC, among others. Since its origin, the M-E procedure can consider incremental pavement design but, only until the beginning of the 21st century, the computational power became available to practicing engineers. American MEPDG represents the state-of-the-art M-E incremental design procedure with significant advantages and drawbacks, the latter mainly related to the extensive calibration activities required to assure a proper analysis and design according to subgrade, climate, and materials at a particular location and for an intended level of reliability. Perpetual pavements are a subset of M-E designed pavements with a proven history of success for the conditions where they are warranted. No design method, either the most straightforward empirical approach or the most elaborated incremental mechanistic one, is appropriate without proper knowledge about the fundamental design factors and calibration of the performance models for each distress mode upon consideration.

22. Yang, Z., Wang, L., Bin, X., Cao, D., Li, J., & Zhao, K (2021). Performance of SBS modifier-crumb rubber composite modified asphalt used as an anti-wear layer of perpetual pavement. *International Journal of Pavement Engineering,*
Abstract: Perpetual pavement has become an important research area of highway development in China. Ensuring the durability of materials is an essential measure to achieve the goal of perpetual pavement construction. This paper documents a study on how to prepare SBS modifier/crumb rubber composite-modified asphalt (SRA) by testing based on an orthogonal experimental design to obtain the optimum proportion of crumb rubber, SBS modifier, and compatible stabiliser. We used needle penetration, ductility, softening point, 60 degrees C dynamic viscosity and segregation as evaluation indexes to obtain optimal ratios. Then, we analysed the performance of SRA and compared it with that of other asphalts, such as base asphalt, SBS-modified asphalt, rubber asphalt and high-viscosity-modified asphalt. We considered that rubber powder and SBS modifier compound-modified asphalt can form a cross-linked stable structure in asphalt and greatly improve the rheological and antifatigue properties of asphalt. Further, we conducted a comparative experiment to study the performance of asphalt mixtures, and we concluded

that SRA has better road performance and can be used as an anti-wear layer of perpetual pavement.

23. Feng, D., Wang, D., Yi, J., & Zhang, F. (2020). Designation principle and method for functionally graded composite pavement. *Chinese Science Bulletin-Chinese, 65*(30), 3270-3286.

Abstract: Pavement is the main structure of road engineering, which consists of multiple structural and functional layers. During the service period, pavement should simultaneously meet the requirements of durability, driving safety and comfort under the combined effects of vehicle load, water and environment temperature. Normally, the design lives for asphalt pavement and concrete pavement are 12-15 and 20-30 years separately. The concept of perpetual pavement had been proposed in recent twenty years, which requires that pavement can resist structural fatigue distress for a long time (at least 50 years). Therefore, the service life and performance of the present asphalt pavement is far from meeting the requirements of perpetual pavement. The reason is not only the raw material and construction quality issues, but also that the existing design theory and design index cannot meet the needs of perpetual pavement design. In addition, the integrating design principles of material-structure-construction had also not been effectively implemented during the pavement design and construction. At present, as to the short design life, the requirements of mechanical properties and fatigue lives of existing pavement materials within the effect of repeated loading can be easily qualified. In order to achieve the perpetual pavement's design life, a new theoretical framework of pavement design may provide the potential solution. Therefore, in this study, the concept of the functionally graded composite pavement was proposed based on the definition of functionally graded materials, which consisted of structural layers with various stiffness. The functionally graded composite pavement could be realized by eliminating the weak adhesion between layers and optimizing the structural response of pavement. Firstly, the types and mechanisms of asphalt pavement cracking were analyzed based on the structural damage characteristics and developments of asphalt pavement, and the effects of the pavement material composition characteristics and the layered structural interfacial state on the cracking mechanisms were then clarified. Secondly, different from the popular elastic layered theory of asphalt pavement, the design theory and design method of the

functionally graded composite pavement were proposed. The structural combination and design process of the functionally graded composite pavement were also recommended. Then the technical solutions, which include the development of high-performance functional composite materials and the good layered treatment to eliminate the interface effects, were proposed in order to realize the functionally graded composite pavement. Finally. bridge deck pavements on field concrete bridge and steel bridge were introduced to be as the case study of the functionally graded composite pavement. By employing new pavement materials and improving the interfacial mechanical behaviors. the functionally graded composite pavement on the concrete and steel bridge deck performs well in the service life. When comes to the future of the functionally graded composite pavement, as to the development and widely application of 3D printing technology, the functionally graded pavement with multiple functional, interfaceless and continuous stiffness graded layers could be more easily realized. It can be expected that a potential Chinese solution to realize the perpetual pavement could be presented and the service life of the pavement will be prolonged as to the application of the functionally graded pavement.

24. Zheng, J., Lu, S., & Liu, C. (2020). Technical system, key scientific problems and technical frontier of long-life pavement. *Chinese Science Bulletin-Chinese, 65*(30), 3219-3227. **Abstract:** The development of long-life pavement is the most effective means to reduce the resource consumption of road construction and maintenance. It can also relieve the traffic congestion which is caused by large and medium scale maintenance of pavement, and impmve the road capacity and mad network transportation efficiency. In this paper, the basic characteristics of long-life pavement were illustrated, and the current technology system of long-life pavement was introduced. The key technical problems and main scientific problems of the long-life pavement structure design, the design and development of durable pavement materials, and the pavement maintenance management and large and medium scale maintenance were analyzed. The results indicated that the pavement structure is a large scale spatial three-dimensional structure although it is simple in geometry. It is necessary to select three-dimensional elastic mechanics theory or even more complicated mechanical theory to analyze its mechanical response. The pavement materials exhibit the viscoelastic plastic characteristics, because most of the pavement

materials use asphalt as binder. Therefore, only the visco-elasticplastic mechanics theory can accurately describe the mechanical behavior of the pavement. Moreover, under the multiphysics coupling effects of temperature, humidity, ultraviolet rays and ice, snow, water, steam, the scientific problems inherent in the pavement structure are very complex. The material used for pavement is a kind of mixture with multi-phase, multi-scale, multi-component features. The micro-structure characteristics inside material, the micro-mechanism of load and load transfer, the damage evolution occurred and developed inside material, along with the corresponding relationship between them and the structural macro-performance parameters are extremely complicated. The performance characteristics of pavement material should be scientifically described as the guidance for the scientific design of the pavement material and the scientific analysis of the pavement structure. For this regard, some suggestions were proposed for the method of mechanical analysis, pavement structure design, the development of durability of road materials, and long-life pavement maintenance. For mechanical analysis and pavement structure design, the following researches could be conducted in future: (1) Constitutive theory of the multi-phase, multi-scale, multi-component materials; (2) strength theory and failure criterion of pavement materials under three-dimensional stress state; (3) fatigue failure criterion of pavement materials in three dimensional state; (4) spatiotemporal response characteristics and its evolution patterns of pavement structure performance under the coupling action of multiple physical fields; (5) robustness of sub-grade stiffness field and its relation to the mechanical behavior of pavement structure; (6) real time perception and information analysis of mechanical response characteristics of pavement structure during full scale test. As to the development of durability of mad materials, the most efforts should be put into the modification of mix proportion design method of mixture, improvement of the durability of binder, and the study and development functional pavement materials. As to the long-life pavement maintenance, the most efforts should be put into theory and method about the timely perception, reflection and inversion of pavement structure performance, theory and technology about the fast perception of pavement performance, long term performance of pavement and the evolution model of the long term perfomance of pavement, the evaluation, prediction and intelligent decision-making of pavement performance, and technical principle and method of efficient utilization of reclaimed

asphalt pavement. These researches provided direction for the development of perpetual pavements.

25. Amin, M. S. R., Tamima, U., & Amador, L. (2020). Towards resilient roads to storm-surge flooding: Case study of bangladesh. *International Journal of Pavement Engineering*, *21*(1), 63-73.

Abstract: Operating roads are critical during emergency operations at a disaster area. Prolonged inundation of pavements accelerates rapid deterioration of pavements and increases maintenance cost. The upgrade of vulnerable pavements with a raised subgrade and gabion walls is proposed as the means to increase the resiliency of strategic roads vital during the emergency attention in the aftermath of a cyclone. Hence, optimal pavement management can be used to allocate upgrade and maintenance and rehabilitation (M&R) operations to reduce the damage and mitigate the geo-physical risk and community vulnerability before the disaster even occurs. A case study is presented for regional highways, arterial and collector roads of Barguna district in Bangladesh that is frequently affected by cyclones and storm surges. The geo-physical risk and vulnerability (GEOPHRIV) index of each road segments is estimated by integrating the geo-physical risk; community, structure and infrastructure vulnerabilities; and damage indices. Dynamic linear programming is applied to optimise M&R strategies and the conversion of strategic roads into resilient perpetual pavements. The same budget required to optimise roads condition is also used to guide the conversion of roads into perpetual pavements, therefore increasing the overall network resiliency. As expected, the results show that most of the annual budget is equally expended into the conversion or the resurfacing of pavements. The decision-making approach herein proposed is very useful to roads agencies around the world, because it provides them with the ability to increase the resiliency of their strategic network ex-ante any flooding disaster.

26. Garcia-Gonzalez, C., Yepes, J., & Franesqui, M. A. (2020). Geomechanical characterization of volcanic aggregates for paving construction applications and

correlation with the rock properties. *Transportation Geotechnics*, *24*, 100383. **Abstract:** In volcanic terrains and in particular island regions, the aggregates come from the mechanical crushing of lava rocks and pyroclastic deposits. This study offers an experimental database of the geomechanical characteristics of different volcanic rock lithotypes and the aggregates obtained from these rocks. For this purpose, 971 aggregate samples and 643 rock samples of 11 different common volcanic lithotypes (including basalts, trachybasalts, trachytes, phonolites, ignimbrites and pyroclasts) were tested. These represent the majority of stone materials found in volcanic islands. Furthermore, correlations between the different properties of the aggregates (volumetric, geometric and mechanical properties) have been established, as well as between certain aggregate properties and the source rock. This allows an estimation of the foreseeable characteristics of the aggregates based on their origin. The results show that the aggregates from massive lithotypes provide superior resistance, partly due to their high density. These generally comply with the standard specifications although the particle shape may present an excessive flakiness index. However, the most abundant volcanic aggregates come from very porous rocks with a vesicular or scoriaceous structure, non-cubic particles, low resistance and high absorption, though they provide good drainage capacity. The high statistic dispersion of the geomechanical properties is due to the different viscosity of the magmas, degrees of explosiveness of the volcanic eruption and random spatial distribution. Even the abundant vesicular and scoriaceous volcanic aggregates, generally considered as marginal materials, may offer adequate quality and properties for certain construction applications. In this sense, the use of these aggregates might contribute to the development of infrastructures in these regions and thus a sustainable utilization of this natural material.

27. Garg, N., Li, Q., & Brill, D. (2020). Accelerated pavement testing of perpetual pavement test sections under heavy aircraft loading at FAA's national airport pavement test facility. *Journal of Testing and Evaluation*, *48*(1), 107-119. **Abstract:** Six flexible pavements were constructed for construction cycle 7 (CC7) at the Federal Aviation Administration (FAA) National Airport Pavement Test Facility in Atlantic City, New Jersey. Four test sections on the north side measure 200 mm (LFP-4), 250 mm (LFP-3), 300 mm (LFP-2), and 375 mm (LFP-1) that are made of hot mix asphalt (HMA) over an aggregate subbase (thickness varying between 850 and 1,025 mm) resting

on a subgrade with a California bearing ratio of 5.5. The fifth test section, LFC-5, is conventional flexible pavement with 125 mm of HMA over aggregate base and subbase, and the LFC-6 structure is the same as LFC-5 except that the crushed stone base layer is replaced with asphalt-stabilized drainable base. The objective of CC7 tests is to develop perpetual pavement design criterion and to validate or refine the fatigue model for HMA in airport pavement thickness design software FAARFIELD. The HMA fatigue model is based on the ratio of dissipated energy change (RDEC). Four fiber optic strain plates were installed to measure transverse and vertical strains at top and transverse strains at bottom within the HMA layer. Full-scale accelerated pavement tests were performed. Traffic test load parameters were six-wheel gear, 245-kN wheel load (gear load 1,470 kN), and 4-kmph speed. Pavement performance was monitored using crack maps, straight edge rut depth, and surface profile measurements. LFC-5 and LFP-4 showed significant fatigue cracks and rutting. LFP-1 and LFP-2 performed well with no signs of cracking. This article presents a discussion on the RDEC fatigue model, pavement thickness design, pavement material characterization test results, pavement instrumentation, accelerated pavement tests under heavy aircraft gear loads, and pavement responses measured using embedded sensors. The test section performance shows that, under loading conditions used in the study, by increasing HMA thickness from 25.4 to 30.5 cm, fatigue cracking was eliminated for the duration of testing (38,000 passes).

28. Islam, S., Sufian, A., Hossain, M., Miller, R., & Leibrock, C. (2020). Mechanistic-empirical design of perpetual pavement. *Road Materials and Pavement Design, 21*(5), 1224-1237.

    Abstract: Perpetual pavements use multiple, durable asphalt layers to produce a safe, smooth, long-lasting road. The pavement design begins with a strong, yet flexible bottom layer that resists tensile strain caused by traffic, and thus stops cracks from forming at the bottom of the pavement. Four perpetual pavement sections were designed and constructed in 2005 and currently are scheduled for rehabilitation for top-down surface cracking. These cracks have been confirmed by full-depth cores. This study revisited the design of these perpetual pavement sections using now available PerRoad and AASHTOWare Pavement ME Design software to investigate whether the design assumptions were correct. Fatigue lives of these sections were also evaluated based on bottom-up cracking. Layer moduli

were backcalculated from the falling weight deflectometer (FWD) deflection data using the EVERCALC software. Tensile strains at the bottom of the asphalt layer were then computed. Results showed that predicted strain values derived from the mechanistic response models were lower than the tensile strains computed using moduli from the FWD deflection data. The required asphalt thickness from PerRoad was relatively higher than the asphalt thickness obtained from the AASHTOWare Pavement ME Design software over a 50-year design period. The study identified the most successful perpetual pavement design as the one with a rich bituminous mix in the base layer.

29. Lee, S. I., Carrasco, G., Mahmoud, E., & Walubita, L. F. (2020). Alternative structure and material designs for cost-effective perpetual pavements in texas. *Journal of Transportation Engineering Part B-Pavements*, *146*(4), 04020071.
Abstract: Since the perpetual pavement (PP) concept was introduced, many countries and states, including Texas, have constructed PP roadways. To date, 10 PP sections in Texas have been in service since 2003. With the oldest section having a 15-year service life, there is an opportunity to review the existing design practice and field performance for enhancing the design procedures for cost-effectiveness. From reviewing comprehensive PP practices, the Texas PP design requires the thickest asphalt layers [533.4 mm (21 in:)], but other PP sections using thinner layers have comparably shown good field performance. To date, all Texas PP sections are in good condition with no major structural rehabilitations. Thus, the current Texas PP design procedure needs enhancement for cost-effectiveness. In this study, cost-effective PP design alternatives were proposed to improve design optimization, material quality, and constructability. The structural and economic validations indicated that the design alternatives analytically meet expected performance limits, which last for the 50-year design life without significant structural failures, with a total agency cost saving of up to 19% compared with the current design procedure. (C) 2020 American Society of Civil Engineers.

30. Nanjegowda, V. H., Silva, F., Sousa, J. B., Way, G. B., & Biligiri, K. P. (2020). Forensic approach to predict film thickness of reacted and activated rubber (RARX) modified asphalt mixtures. *Road Materials and Pavement Design, 21*, S19-S36. **Abstract:** The major objective of this study was to arrive at an optimum threshold asphalt binder film thickness,Tf*and developTf*predictive equation that includes materials and mixture properties, which could be used in all future forensic assessment of asphalt mixtures. Also, 18 field asphalt mixtures constructed as test sections were investigated for their field performance and correlated withTf*. Furthermore, the performance criteria set by Arizona department of transportation (ADOT) in the USA to assess the field mixtures were related toTf*established in this study. An optimumTf*of 12 mu was selected as the threshold magnitude for asphalt mixtures that incorporates activated crumb rubber modified products, termed RARX. It was found that with increase in the overall cumulative surface area (SA) of the mix matrix, the required binder content also increased, in turn decreasingTf*.Tf*predictive equation encompassing materials properties and associated volumetrics was established as a best-fit nonlinear regression model that had excellent statistical measures:R-2 = 99.8%; S-e/S-y = 0.0447. It is noteworthy that the predictive model was established using the robust concept that introduced utilisation ofSAof the whole mixture matrix, including, those that ofSAof aggregate fractions not estimated by current models. Based on the methodical approach followed in this study to calculateTf*, it is recommended that more amount of RARX be tried in other mixtures to enhance pavement performance. The current study involved only 18 field asphalt mixtures, amongst which six were without RARX. So, it is suggested that additional field sections be placed and monitored for their performance keeping in mind the volumetrics and specifically,Tf*, which can potentially be a quality control parametric assessor for field performance forensic evaluation, and that which becomes an integral characteristic in perpetual pavement design philosophy.

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