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ASPHALT PAVEMENT INTERLAYER SYSTEMS FOR STRUCTURAL PERFORMANCE ENHANCEMENT AND FATIGUE REDUCTION

Martynas KARBOČIUS*, Audrius VAITKUS

Road Research Institute, Vilnius Gediminas Technical University, Linkmenų g. 28, LT-08217 Vilnius, Lithuania

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Abstract. One of the possible alternatives to extend the service life of the pavement, reducing the maintenance costs of the pavement and possibly the thickness of the overlay, is the use of grids as a reinforcing interlayer of newly installed asphalt layers. Laboratory studies and the very limited amount of visual observation data from real use cases of grids partially substantiate the effectiveness of this measure in neutralizing the formation of reflecting cracks, but there is a lack of quantitative data on the performance of the renewed pavement structure distressed with fatigue cracking. This article presents the results of periodic structural monitoring of a pavement structure with a stress absorbing membrane interlayer (SAMI) and grid-reinforced overlay. The test section consists of 3 subsections, where SAMI and two different types of grid were installed on the distressed asphalt base layer and overlaid with a conventional asphalt binder course and wearing course. Measurement of the bearing capacity of the pavement structure with a falling weight deflectometer and visual survey of the pavement condition were used to investigate the performance of the renewed pavement structure. The interim results of the 3-year observation show a good structural condition of rehabilitated pavement.

Keywords: falling weight deflectometer, bearing capacity, geogrid, overlay reinforcement, pavement, pavement rehabilitation.

JEL Clasification: 030.

Introduction

The most widely used pavement rehabilitation strategy, where the existing asphalt pavement is partially removed and replaced with a new asphalt layer(s), is not always effective. In the case of fatigue cracks formed through all asphalt layers, even after sealing these cracks, they are soon reflected in the overlay. Thus, in essence, the fatigue life is extended and the rapid structural deterioration is prevented only for a relatively short time. The reason for this is the phenomenon of stress concentration in the area of existing cracks, which leads to transfer of critical stresses to the new asphalt layer.

One of the possible alternatives to extend the fatigue life of the pavement, reducing the maintenance costs of the pavement and possibly the thickness of the overlay, is the installation of an overlay reinforced with grid. It is not a new concept, but is still applied in very individual cases and to very different extents in individual regions or countries. The functional purpose of the grid as an asphalt pavement interlayer is defined by two mechanisms, i.e. stress relief/strain absorption and reinforcing effect (Al-Qadi et al., 2008). The concept of these mechanisms requires fundamentally different properties of the grid and may seem contradictory.

The phenomenon of stress relief is defined as a process in which the deformation of the grid dissipates a large part of the energy required for crack propagation (Barksdale, 1991). In this way, the crack is temporarily stopped at the interface of the asphalt layer and the grid, and the grids are used as a means of preventing reflective cracking. In order for the stress relief mechanism to be mobilized, the grid must have relatively low stiffness, i.e. be able to absorb relatively large deformations. For this reason, grids, which are normally used to prevent reflective cracking, are believed to not contribute to pavement bearing capacity and are not an option to reduce the thickness of asphalt layers. The reinforcing effect is defined as an increase in the bearing capacity of the structure leading to an extension of fatigue life, as well as a possible reduction in the thickness of the asphalt layers (Zofka et al., 2017b). In this case, the grid should reduce the deflection of the pavement and the tensile strain in the asphalt layer. To achieve the reinforcing effect, the grid must be relatively stiff, i.e., stiffer than asphalt layers.

* Corresponding author. E-mail: *martynas.karbocius@vilniustech.lt*

Regardless of the purpose for which the grid is used, research and practical experience have shown that the essential factor determining the effectiveness of grids is their adhesion to the asphalt layers and the quality of the installation work. Safavizadeh and Kim (2014) numerical analysis of the strain contour of cyclically bent asphalt beams showed that when bituminous emulsion was used under the grid, the strains were evenly distributed along the entire length of the specimen. In samples without bitumen emulsion, a higher concentration of strain was determined. Several researchers who have analyzed the effectiveness of grids in preventing reflective cracks have noted that the use of grids increases the risk of delamination (Monismith & Coetzee, 1980; Majidzadeh, 1976). Therefore, special attention and care must be given to surface preparation and the entire work technology in general. In addition, grids should also be carefully selected, since the mesh size, presence of nonwoven backing, and pre-coating with bituminous emulsion help to ensure better bonding with the asphalt layers. The position of the grid is also one of the essential factors that ensures the effectiveness of the grid. Asphalt has a relatively low tensile strength and fatigue cracks initiates at the bottom of the asphalt layer, where the maximum tensile strains occur under load. Therefore, the grid as a means of extending the fatigue life of the pavement must be installed in the tensile zone of the reinforced asphalt layer, as far as possible from the neutral axis.

To date, various types of geosynthetic products have been tested in both the field and laboratory tests to determine their effect on the durability of the pavement structure. Some results of grid-reinforced asphalt research are presented in Table 1. Since for a long time the main field of use of geosynthetics has been the prevention of reflective cracks in asphalt overlay, most long-term field monitoring data are related to the reflective cracks as well. Laboratory studies of the effect of grids as an asphalt interlayer on the durability of a pavement structure include fatigue, stiffness, crack initiation, and propagation tests. It is important to note that it is complicated to accurately and unambiguously assess the effectiveness of grids. Results vary greatly due to different grid properties, position in the structure, installation/sample fabrication aspects, and test conditions. However, in general, all studies have demonstrated the benefits of grids in reinforcing the pavement and preventing of reflective cracking. Interestingly, research shows a certain contradiction between the traditional functional classifications of grids in terms of the structural performance of the pavement. The prevailing opinion is that to increase fatigue life, a stiff reinforcing grid of low elongation and high tensile strength should be used. However, the results of some laboratory tests show that relatively low stiffness reinforcing grids could potentially also be applied to increase the fatigue resistance of asphalt layers.

One of the techniques to mitigate reflective cracking is a stress-absorbing membrane interlayer (SAMI) constructed bellow the overlay. It is a dense interlayer of very fine graded asphalt mixture with a high amount of bitumen. The thickness of the interlayer is usually up to 25 mm and in some cases up to 50 mm (Quintus, 2009). Due to its relatively low stiffness, it is capable of withstand high strain levels and allows vertical and horizontal displacements of the asphalt layers below (Ogundipe, 2011). Ogundipe et al. (2013) distinguished that efficiency depends on temperature, mechanical properties, and thickness of the interlayer. In laboratory tests, it was found that the effectiveness of SAMI in mitigating reflective cracks decreases with decreasing temperature and thickness of the interlayer, increasing load and thickness of the overlay. Although the technology is known and has been used since the early 1980s, compared to geogrids, it is much less documented by studies quantifying its effectiveness and is more of a practical technology than a subject of scientific research. Most of the existing information is related to the practical application of SAMI and insights into the performance of rehabilitated pavements. One of the first applications was at an international airport in Arizona (USA), where a heavily deteriorated runway pavement with extensive shrinkage and fatigue cracks was rehabilitated by constructing a SAMI layer and asphalt overlay. The runway with SAMI after 9 years of operation was characterized by significantly less extensive cracking and lower deflection compared to the runway rehabilitated without SAMI (Quintus, 1983). Loria et al. (2008) reported excellent performance of SAMI interlayer in Nevada (USA) Department of Transportation projects 3 years after construction regardless of traffic level and previous pavement condition prior to rehabilitation.

This article presents intermediate results and a discussion from a planned long-term study involving structural performance monitoring in a test section where the pavement was rehabilitated using different types of grids and stress-absorbing membrane interlayer (SAMI). The results of the study will allow for a more complete assessment of the benefits of grids in increasing the fatigue life of rehabilitated pavements and gain experience for their practical use.

1. Research scope and methodology

The study includes an evaluation of the performance of the rehabilitated pavement structure, where the double-layer overlay is reinforced with SAMI/grid, under real operating conditions. To evaluate performance of the pavement, a visual analysis of pavement condition and bearing capacity measurements were carried out.

1.1. Materials

Taking into account the results of previous studies, glass fibre and polyethylene terephthalate fibre grids with different geometries and mechanical properties were

Table 1. Examples of grid as asphalt interlayer studies

Reference	Grid type	Testing method		Main findings
(Arsenie et al., 2017)	Fiberglass (TS 100 kN/m)	L	4PB-PR	Fatigue life N_f increased by 50–62%, strain at 10^6 loading cycles ε_6 increased by 10.52%.
(Correia & Zornberg, 2018)	Polyvinyl alcohol fiber (TS 50 kN/m)	L	Pavement model	Tensile strain reduced by 50% and the rate of strain increase is limited.
(DeBondt, 2012)	–	F	Visual surface inspection	5 to 6 times earlier appearance of cracks in unreinforced pavements. 30% up to 12 times smaller area of cracked surface in reinforced pavements.
(Graziani et al., 2014)	G1 – fiberglass/carbon fiber (TS 111 kN/m, ε 3/4,5%) G2 – fiberglass (TS 211 kN/m, ε 3%)	F	FWD	G1 reduced tensile strains by 65% while G2 had no noticeable effect. G1 and G2 increased the stiffness of the pavement by 50% and 25%, respectively.
(Ingrassia et al., 2020)	G1 – fiberglass (TS 40 kN/m, ε 6%) G2 – polyester/fiberglass (TS 35 kN/m, ε 30%) G3 – fiberglass (TS 40 kN/m, ε 4%)	L	3PB-PR	G1, G2, and G3 increased the amount of energy required for crack propagation by 3, 8, and 4 times, respectively.
(Islam et al., 2012)	Fiberglass (TS 100 kN/m)	L	4PB-PR	Fatigue life N_f increased by 3.4 times and the stiffness modulus by 12.35%.
(Lee et al., 2019)	–	F	Visual surface inspection	After 3–8 years of renewal, the area of cracks in reinforced pavements was 2–3 times smaller.
(Lesueur et al., 2021)	Fiberglass (TS 100 kN/m, ε 3%)	L	3PB-PR	Strain at 10^6 loading cycles ε_6 increased by 45%.
(Nguyen et al., 2013)	Fiberglass (TS 100 kN/m)	F	Accelerated pavement testing, FWD, visual surface inspection	After 0.8 mill. load cycles, no significant deflection difference between the reinforced and unreinforced pavement, the area of cracked pavement was 0% and 13%, respectively. After 1.2 mill. load cycles, the cracked pavement area was 0% and 70% in reinforced and unreinforced overlay, respectively. After 3.3 mill. load cycles, the cracked pavement area was 10% and 100% in reinforced and unreinforced overlay, respectively.
(Safavizadeh & Kim, 2014)	Fiberglass (TS 115 kN/m, ε 2.5%)	L	4PB-PR	Fatigue life N_f increased by 82% when bitumen emulsion was used and 24% when bitumen emulsion was not used
(Shafabakhsh et al., 2020)	Polypropylene fiber (TS 50 kN/m, ε 11%)	L	4PB-PR	Fatigue life N_f increased up to 3 times. Efficiency decreases with increasing strain level.
(Virgili et al., 2009)	G1 – fiberglass (TS 100 kN/m, ε < 3%) G2 – polyester and fiberglass (TS 110 kN/m, ε < 3%) G3 – geomembrane with fiberglass (TS 40 kN/m, ε < 5%)	L	4PB-PR	G1, G2 and G3 increased the fatigue life Nf by 49%, 23% and 34% respectively. G1 and G2 become effective only at higher stresses or when the crack reaches the grid.
(Walubita et al., 2020)	G1 – polyester (TS 30 kN/m) G2 – polyester (TS 75 kN/m)	L	4PB-PR	G1 and G2 increased the fatigue life Nf by 3.5–6.4 and 7.8–12.8 times, respectively, depending on the position of the grid in the specimen.
(Zofka et al., 2017a)	G1 – fiberglass G2 – carbon fiber	L	3PB-PR	G1 and G2 increased the amount of energy required for crack propagation by 2 and 4 times, respectively.
		L	4PB-PR	G1 and G2 reduced the deflection by 1.5 and 2 times, respectively.

Note: Gi – grid denotation (in case 2 or more grids are studied); TS – maximum tensile strength; ε – elongation at maximum tensile strength; L – laboratory testing; F – field testing; 4PB-PR – 4-point bending fatigue/stiffness test; FWD – measurement of bearing capacity with a falling weight deflectometer; 3PB-PR – 3-point bending (fracture energy) test.

chosen for the study. The fiberglass grid (FGG) is made of fiberglass yarns combined with an ultra-light nonwoven fabric and coated with bitumen emulsion (at least 60% bitumen). The grid has relatively high stiffness, as the elongation at maximum tensile strength reaches up to 3%. These properties correspond to those required by the typical definition of a reinforcing mechanism. Polyethylene terephthalate fiber grid (PETG) is made of high modulus polyester yarns combined with an ultra-light nonwoven fabric and coated with bitumen emulsion (at least 60% bitumen). The grid has a relatively low stiffness, since the elongation at the maximum tensile strength is 4 times higher compared to the FGG grid. Such a grid is typically considered effective in preventing reflective cracks in the overlay. The main characteristics of the grids used in the study are presented in Table 2. Both grids used in the study are presented in Figure 1. A fine-grained (largest particle size 5 mm) asphalt mixture with polymer-modified bitumen PMB 25/55-60 was used for the stress-absorbing membrane interlayer.

The selected grids were used to renew the pavement structure in the section of Justiniškių Street in Vilnius. It is a fairly heavily trafficked street, where the total average annual daily traffic volume is 12856 veh./day. The volume of heavy traffic is 689 veh./day, of which public transport is 421 veh./day. In the first traffic lane, on average, about 0.28 million ESAL's are accumulated per year, and in the second traffic lane about 0.03 million ESAL's.

In 2020, the 650-m-long street section was rehabilitated by milling a part of the asphalt pavement and laying the asphalt binder course and asphalt wearing course. The test section is divided into 3 subsections according to the asphalt pavement interlayer type, which are presented in Table 3. In the first subsection, SAMI layer was installed on the existing asphalt base layer, which, compared to grids, is more common solution in Lithuania as a means of preventing reflective cracking and fatigue cracking when renewing old and designing new pavements. In the second and third subsections, the FGG and PETG grids were installed on the existing asphalt base layer, respectively. In these subsections, the milling depth and thickness of the new asphalt layers were selected separately for the first and second traffic lanes, taking into account different traffic loading and the level of pavement deterioration. Before the installation of the SAMI layer/grids, the milled surface of the existing asphalt base layer was sprayed with bituminous emulsion, thus ensuring adhesion of the layers.

1.2. Methodology

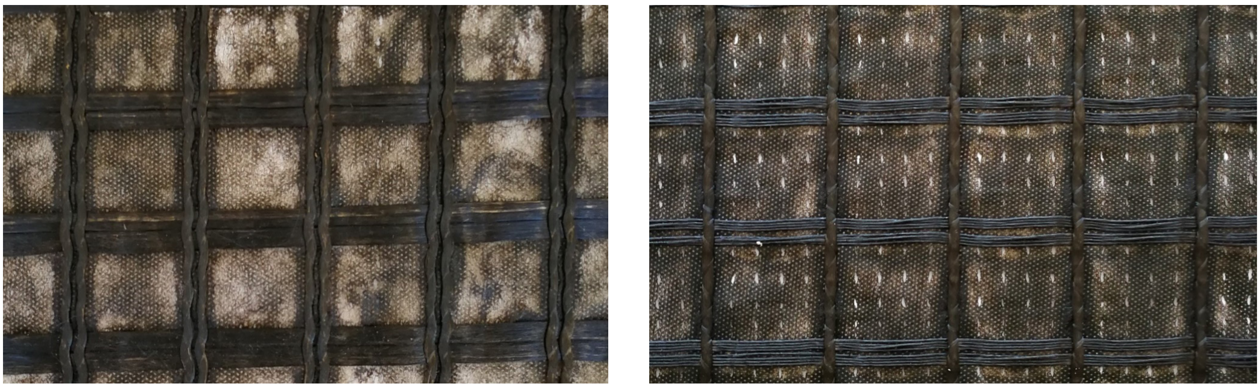
Every year since pavement rehabilitation, the test section performs a visual assessment of pavement distress, a measurement of bearing capacity and traffic loading. The same tests were also carried out before rehabilitation.

A visual inspection of the condition of the pavement was carried out in the spring of 2020 before the renovation of the pavement structure, as well as in the spring of 2021 and in the autumn of 2022. During visual inspection, pavement distresses are recorded and classified, the degree of their development, and the possible causes are determined.

The bearing capacity of pavement structures are evaluated by non-destructive method – Falling Weight Deflectometer (FWD). The method is based on the transfer of a dynamic load to the surface of the pavement and the registration of the elastic deformation (deflection). The load is transmitted through a circular plate with a diameter of 30 cm, simulating the effect of

Table 2. Properties of grids used in study

Denotation	Material	Tensile strength (kN/m)	Elongation at max. tensile strength (%)	Mesh size (mm)	Mass (g/m^2)
FGG	Fiberglass	100	≤3	30×30	600
PETG	Polyethylene terephthalate	50	≤12	40×40	270



a) b)

Figure 1. Fiberglass grid (a) and polyethylene terephthalate grid (b)

Table 3. Pavement composition in test section

Lane	Layer type	Subsection					
		SAMI (length 250 m)		FGG (length 200 m)		PETG (length 200 m)	
		Material	Thickness (cm)	Material	Thickness (cm)	Material	Thickness (cm)
1	Asphalt wearing course	SMA 8 S (PMB 25/55-60)	3.0	SMA 11 S (PMB 25/55-60)	3.5	SMA 11 S (PMB 25/55-60)	3.5
	Asphalt binder course	AC 22 AS (PMB 25/55-60)	7.0	AC 22 AS (PMB 25/55-60)	8.5	AC 22 AS (PMB 25/55-60)	8.5
	Interlayer	SAMI 05 (PMB 25/55-60)	2,0	FGG	–	PETG	–
	Old asphalt base course	Varies	~7	Varies	~7	Varies	~7
2	Asphalt wearing course	SMA 8 S (PMB 25/55-60)	3.0	SMA 11 S (PMB 25/55-60)	3.5	SMA 11 S (PMB 25/55-60)	3.5
	Asphalt binder course	AC 22 AS (PMB 25/55-60)	7.0	AC 16 AS (PMB 25/55-60)	4.5	AC 16 AS (PMB 25/55-60)	4.5
	Interlayer	SAMI 05 (PMB 25/55-60)	2.0	FGG	–	FGG	–
	Old asphalt base course	Varies	~7	Varies	~11	Varies	~11

a heavy vehicle wheel. During the measurement, the pavement is loaded with 50 kN, corresponding to the load of one wheel of an equivalent standard axle weighing 10 t. Deflection is measured at the centre of the load transfer plate and by sensors placed at different distances from the plate centre up to 210 cm. In this way, the deflection basin of the pavement structure is obtained, according to which the load-bearing capacity of the individual layers of the pavement structure can be evaluated. Falling weight deflectometer measurements were performed in the spring of 2020 before the renovation of the pavement structure, as well as in the autumn of 2020, the spring of 2021 and the autumn of 2022 after the rehabilitation of the pavement structure. Measurement locations are placed on wheel path of each traffic lane in 25 m increments. Each subsection has 14–20 measurement locations.

2. Results analysis and discussion

2.1. Visual assessment of pavement condition

A visual inspection of the test section prior to rehabilitation indicated that the condition of the pavement was generally poor due to the predominant structural distress resulting from the cumulative effect of long-term loading and other distress related to pavement aging and hardening. It provides an opportunity to test selected reinforcing systems under challenging conditions. It was established that fatigue, transverse, longitudinal, and block cracks dominate the section. The severity of fatigue cracks varied from low, which can be identified as longitudinal cracks in the wheel path (Figure 2a), to high, where the cracks form a fine pattern (Figure 2b). An extremely advanced fatigue phase was indicated by the fact that high-severity fatigue cracks in most cases are combined with structural deformations.

a)

b)

Figure 2. Fatigue cracks: a) low severity; b) high severity

a)

b)

Figure 3. Transverse (a) and longitudinal (b) cracks

Asphalt aging was indicated by extensive transverse (Figure 3a) and longitudinal (Figure 3b) cracks. The dense arrangement of transverse cracks (2–20 meters) and longitudinal cracks, in some locations connecting to each other and forming blocks, showed an advanced process of pavement hardening. In most cases, transverse cracks were accompanied by secondary or multiple parallel or branching cracks, especially in the wheel paths.

Visual inspections, carried out after pavement rehabilitation, determined that during approximately 2.5 years, during which the first and second traffic lanes accumulated 0.651 million and 0.075 million ESAL, respectively, no distress was formed in the pavement, related to loads, material properties, or poor condition of the old asphalt layers below. The only distress observed is a local longitudinal crack in the longitudinal joint of the asphalt wearing course, which is technological in origin.

2.2. Bearing capacity of pavement structures

For the initial evaluation of pavement structural performance, the average deflection basins are presented in Figure 4. The deflections basins are provided from measurements taken before rehabilitation and periodic measurements taken after rehabilitation, linked to the accumulated number of equivalent standard axle loads. At this stage of the study, only the measurement data of the first traffic lane are analyzed, since the second traffic lane is about 19 times less loaded, and therefore, in terms of bearing capacity, more important observations can be made in the later stages of the study.

From Figure 4a, it can be seen that the bearing capacity of all subsections before pavement rehabilitation was equivalent. The correspondence of the deflection basins shows that the asphalt layers, as well as the base layers and subgrade, are in similar condition, which allows one to compare the performance of the pavement structures with different interlayer systems after pavement rehabilitation. The greatest increase in bearing capacity was found in the FGG grid subsection, where the deflection directly under load, representing the total strength of the structure, decreased by almost 33% (Figure 4b). In the PETG subsection, the deflection decreased by 23%. The relatively minor reduction in deflection in the SAMI subsection, which reaches 10%, indicates that the SAMI interlayer does not significantly affect the initial strength of the pavement structure. Another important aspect is the change in the shape of the entire deflection basin in the FGG and PETG subsections. In the FGG subsection, the deflection in the zone characterizing the structural performance of the asphalt layers decreased by 29% and in the zone of the unbound base layers and the subgrade by an average of 21%. In the PETG subsection, the influence on the asphalt layers is slightly less, where the deflection has decreased by 24%. However, a similar effect to the FGG subsection is seen in the area of unbound base layers and subgrade, where the deflection has decreased by almost 20%. In the SAMI subsection, although it is relatively small, the reduction in deflection, equal to 9%, is visible only in the asphalt layers zone. In the zone of unbound base layers and subgrade, the deflection decreased on average by only 5%. This could indicate the positive effect of grids to redistribute stresses in the pavement structure and reduce the impact of loads on the base layers below.

Subsequent measurements show that between 0.092 mill. ESAL and 0.231 mill. ESAL the pavement consolidation phase, which is characteristic of newly constructed pavements, continued, as the deflection of the studied subsections remained similar or decreased (Figure 4c). In SAMI and FGG subsections, the change was not significant and reached up to 5%. A rather significant reduction in deflection is observed in the PETG subsection, where it was 12%. After the studied section accumulates 0.652 mill. ESAL, an increase in deflection is visible (Figure 4d). In the SAMI, FGG, and PETG subsections, the deflection in the asphalt layers zone increased by 8%, 15% and 18%, respectively. Although the change of deflections between measuring periods were least of SAMI subsection, it should be noted that the absolute deflection values are only 3% lower than those measured before rehabilitation. In the FGG and PETG subsections,

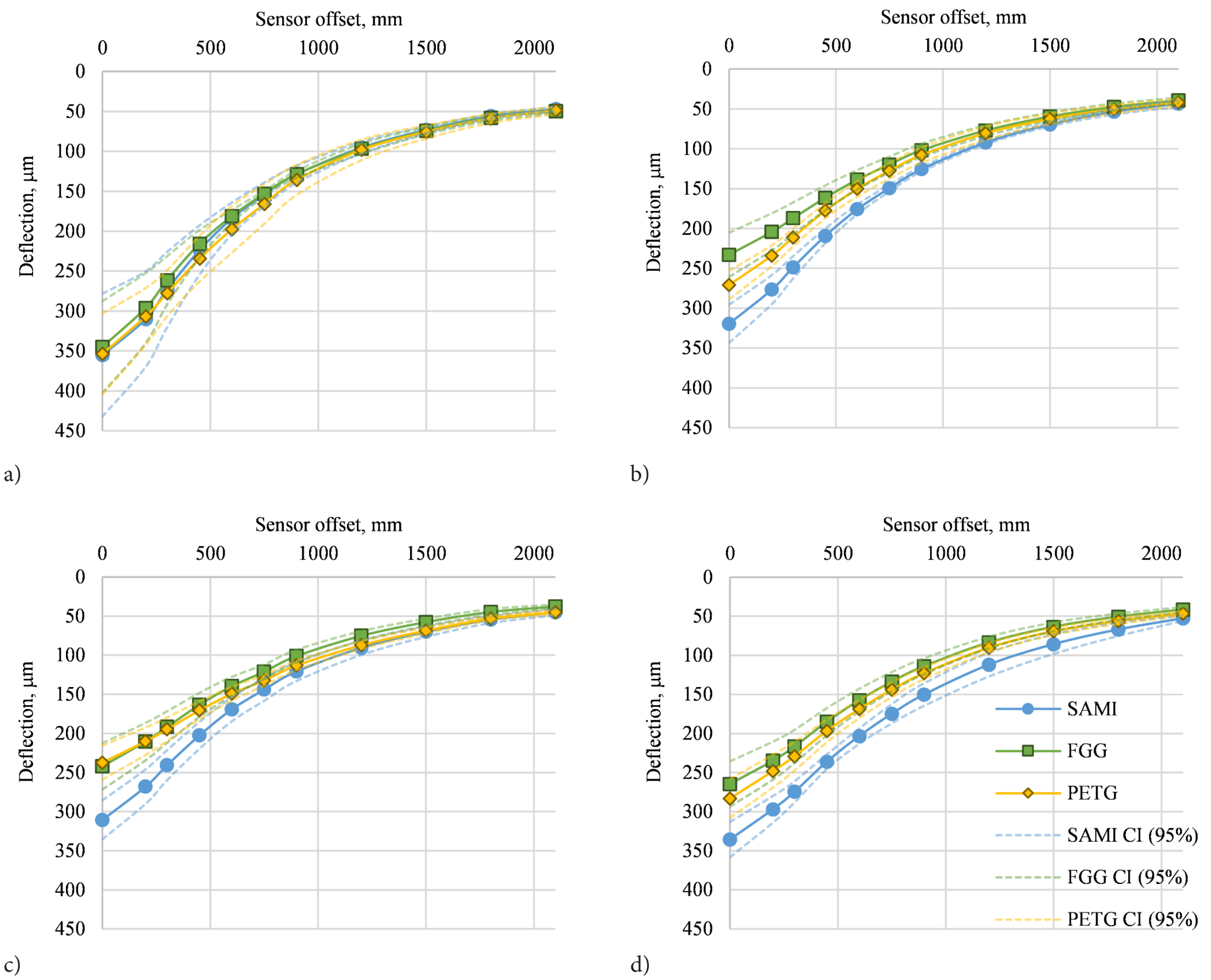


Figure 4. Average deflection basins: a) before rehabilitation; b) after rehabilitation (AR), 0.092 mill. ESAL accumulated; c) AR, 0.231 mill. ESAL accumulated; d) AR, 0.652 mill. ESAL accumulated

they are 23% and 19% lower, respectively, indicating a higher efficiency of rehabilitation. A clear separation between SAMI and subsections containing grids can be seen when analysing the deflections in the base layers and the subgrade zone. Here, it can be seen that in the SAMI subsection, the deterioration of the base layers was not neutralized by rehabilitation for a long time, as the deflection is on average 14% higher than the deflection of the old pavement. Meanwhile, the deflection is 14% and 10% lower in the FGG and PETG subsections, respectively, indicating a slowed down deterioration process of the base layers.

Conclusions

This article presents the first interim results of an ongoing long-term study focused on the influence of different asphalt pavement interlayer systems on the structural performance of the pavement structure. The study is based on the measurement of the bearing capacity and visual assessment of pavement condition in a test section where a stress-absorbing membrane interlayer, fiberglass grid, and PET grid were used as a rehabilitation solution for structurally deteriorated pavement.

The pavement structures of the first and second lanes of the test section are designed for a load of 5.73 million ESAL and 2.14 million ESAL, respectively. During the first 28 months after rehabilitation, the first and second traffic lanes accumulated a load of 0.652 million ESAL and 0.075 million ESAL, respectively.

The preliminary results of the bearing capacity measurement show that the stress absorbing membrane interlayer does not have a significant impact on the structural performance of the rehabilitated pavement in the case of severely deteriorated original layers. The deflection in the centre of the load area right after rehabilitation in SAMI subsection was 320 µm (10% lower than before rehabilitation), and 336 µm (only 3% lower than before rehabilitation) after accumulating 0.652 million ESAL.

Relatively stiff fiberglass and less stiff polyethylene terephthalate fibre grids, which according to their functional purpose are usually assigned to the reinforcement and reflective crack preference categories, respectively, show a similar contribution to the performance of the pavement. The deflection in the centre of the load area right after rehabilitation in FGG and PETG subsections was 233 μm and 271 μm, respectively (33% and 23% lower than before rehabilitation, respectively). After accumulating 0.652 million ESAL, the deflection was 265 μm and 283 μm, respectively, or 23 and 19 percent lower than deflection before the rehabilitation, respectively.

During the observation period, a trend emerged that FGG and PETG grids inhibit the deterioration of the unbound base layers and subgrade, while SAMI does not affect it. After 0.652 million ESAL, the FGG and PETG subsections in the base layer zone had deflections 14% and 10% lower than before rehabilitation, respectively, while the deflection in the SAMI subsection was 14% higher compared to deflection before rehabilitation.

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Contribution

Conceptualization, A.V.; methodology, A.V. and M.K.; data curation, M.K.; writing – original draft preparation, M.K.; writing – review and editing, A.V. and M.K. All authors have read and agreed to the published version of the manuscript.

Disclosure statement

The authors declare no conflict of interest.

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