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To cite this article: Michał Gołos and Piotr Mazurowski 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1202** 012024

PAVEMENT OPTIMISATION WITH AGGREGATE BASE OR ASPHALT LAYERS STABILISED WITH HEXAGONAL GEOGRIDS

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Received day month year; accepted date (use style Received dates, or Alt + Ctrl + R)

Abstract. The use of hexagonal geogrids in pavement structures results in the increase of the life of designed structure. This offers the possibility to reduce the thickness of layers without reduction of pavement life, or to increase the traffic capacity of a pavement without the need to increase its thickness. This way of using geogrids in pavements design was introduced to the pavement industry by one producer of hexagonal geogrids as a Pavement Optimisation (PO) concept. It can be transformed into both economic and environmental benefits, and obviously results in savings of natural resources and reduction of carbon footprint of a project. PO with geogrids can be used both in the newly designed pavement structures, and in the asphalt overlays of the existing old pavements. Asphalt overlays enhancement with a geogrid either increases the fatigue life of overlays or allows the reduction of overlays thickness to achieve the same pavement life. In new pavements, stabilisation of aggregate base with geogrids increases the stiffness of aggregate, which increases the performance of a whole pavement. This paper presents several tests results, which confirm beneficial effects of using hexagonal geogrids in asphalt overlays and aggregate base layers, from laboratory to full scale accelerated pavement tests. Also, modifications of Mechanistic-Empirical pavement design method, which allow to implement the geogrid benefits into the design process, are discussed. Finally, case studies of pavements – newly designed and reconstructed – optimised with hexagonal geogrids are presented.

Keywords: pavement design, hexagonal geogrid, geocomposite incorporating hexagonal grid, pavement optimisation, pavement tests, fatigue life increase, asphalt overlay

Introduction

Different types of geogrids or geocomposites are used in pavement structures for a relatively long time. Typically, they are used in two main applications: improvement of soft soil bearing capacity under new pavements, or protection against reflective cracking in asphalt overlays on existing pavements. However, in both these cases the design with geogrids do not address the fatigue life of the pavement itself.

One producer of stiff, punch and drawn hexagonal proposed new approach to the use of geogrids in pavement structures. It is to take the influence of geogrids into account in calculation of pavement life, thus enabling to deliver more economic and environmentally friendly designs. The use of such geogrids in pavement layers improves parameters of these layers, and it affects the life of a whole pavement. This offers the possibility to reduce the thickness of layers without reduction of pavement life, or to increase the traffic capacity of a pavement without the need to increase its thickness. While improvement of soft soil and protection against reflective cracking remain main and important part of geogrids applications in pavement, this new concept, named "Pavement Optimisation" (PO), offers new opportunities to pavement designers.

In US the concept of using geosynthetics in new pavements to reduce its thickness or increase its life is covered within AASHTO R50-09 Standard. According to it: "Geosynthetics are used in the pavement structure for structural support of traffic loads over the design life of the pavement. The geosynthetic is expected to provide one or both of these benefits: (1) improved or extended service life of the pavement, or (2) reduced thickness of the structural section".

Two different approaches to PO with geogrids concept are presented in this paper. First is to use hexagonal geogrid to stabilise aggregate base or sub-base layer of new pavement. Second is to use geogrid in asphalt layers, mostly in asphalt overlays of existing pavements. Both enable designers to design pavements which are either thinner (thus cheaper) or offer a substantial increase of pavement life compared to traditional pavements without geogrids.

1. Pavement Optimisation of new pavements

Aggregate layer stabilised with hexagonal geogrid has increased parameters compared to non-stabilised layer. This increase has been confirmed by laboratory and field tests. Kwon et al. (2012) observed a modulus increase of 5% to 20% when testing stabilized and non-stabilized silty gravel samples in a test conducted with combination of AASHTO

T307 and NCHRP 598. In-situ resilient modulus tests performed with Automated Plate Load Tests (APLT) exhibited 5% to 30% modulus increase of geogrid stabilized sections compared to non-stabilized (White 2014a, White 2014b). Increased stiffness on aggregate layer(s) enhances the performance of a whole pavement. This can be utilized in two ways: to increase the life of a pavement compared to typical, non-stabilised section, or to reduce thickness of layer(s) – the stabilised layer, or other, including asphalt.

To be able to include the geogrid in the pavement design process, it is necessary to modify pavement design methods. The development of these modifications should not be based on theoretical considerations only. According to AASHTO R50-09: "Because the benefits of geosynthetic reinforced pavement structures may not be derived theoretically, test sections are necessary to obtain benefit quantification" [AASHTO 2009]. ARA suggests a number of laboratory and field tests, including full scale Accelerated Pavement Tests: "The purpose of the Accelerated Pavement Testing (APT) is to gather the data needed for developing the design inputs described in the previous sections (i.e., adjusted modulus and transfer function coefficients)" [Lee 2017].

A series of APTs with Heavy Vehicle Simulator (HVS – Figure 1) device were performed at U.S. Army Engineer Research and Development Center (ERDC) facility to quantify the benefits of one type of hexagonal stabilisation geogrid [Jersey et al. 2012, Norwood et al. 2014, Robinson et al. 2017]. In total, 8 sections were tested. Test sections dimensions were 2.44 m (8 ft) by 15.2 m (50 ft). The subgrade made of locally available clay was prepared to achieve a bearing capacity of either 3% or 6% CBR. The granular base layer consisted of either 15 cm or 20 cm of crushed aggregate, on four of the sections base was stabilized with hexagonal geogrids. Six sections had surfacing of 5, 7.5 or 10 cm of dense-graded hot mix asphalt (HMA), and two sections had a surfacing of double bituminous surface treatment (DBST).

Figure 1. HVS device in ERDC hangar during the test

All sections with base stabilised with hexagonal geogrids heavily outperformed their non-stabilised counterparts. Five to ten higher number of axle loads was applied to stabilised sections to reach the same critical rut depth (12.5 mm) compared to non-stabilised sections.

Results of these tests were a basis of modifications of both empirical and mechanistic-empirical pavement design methods. In case of mechanistic-empirical design, the influence of geogrid on a pavement is taken into account by two mechanisms, used simultaneously. First is the increase of elastic modulus of aggregate layer(s) stabilised with geogrid. Second is to apply a Life Shift Factor to calculated life of a pavement. The development of these modification and discussion of tests results are discussed by Mazurowski at al. [2019].

Another confirmation of hexagonal geogrid influence on pavement life was obtained in research conducted by Nevada Department of Transportation [2016]. A series of cycling loading tests of pavement sections constructed in 1.8 m diameter tank was performed (Figure 2). Six sections were tested: two control, two with biaxial geogrids and two with triaxial geogrids. Sections consisted of 7.6 cm thick asphalt layer and 30 or 40 cm thick aggregate base layer. 3 mln 40 kN load cycles were applied to each section by an actuator and 305 mm diameter steel plate.

Figure 2. Tank and steel loading plate used in Nevada DOT test

Test results are presented on Figure 3. After 3 mln load cycles rut depth on sections with hexagonal geogrids (marked T16 and T12 of Figure 3) was ~30% lower compared to control section (C16 and C12) and ~17% lower compared to section with biaxial geogrid (B16 and B12).

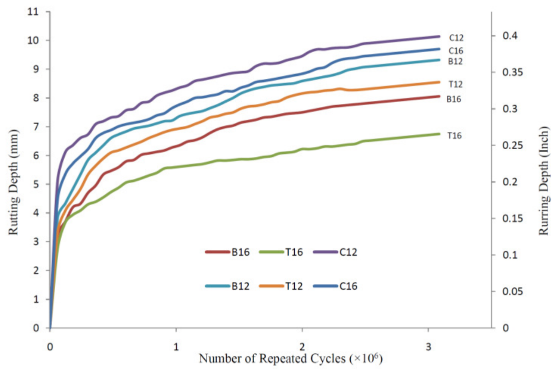

Figure 3. Results of Nevada DOT test

2. A Pavement Optimisation of new pavement Case Study: the Voivodeship Road 507 Braniewo – Pieniężno, Poland, 2018-2019

The Voivodeship Road 507 is located in the north of Poland, along Polish – Russian border (with Kaliningrad), a few kilometres from Vistula Lagoon and Baltic Sea. Reconstruction of 29 km long section of this road, between towns Braniewo and Pieniężno, started in 2018. The project was divided into two parts: reconstruction of the first part (15 km) was finished in 2019, reconstruction of the second part (14 km) is planned to be finished in 2021.

Existing pavement was in very bad condition, with a lot of different damages, and the Designer, with the approval of the Client, decided to design its complete demolition and construction of a new one for the whole section. A new pavement with base made of Recycled Asphalt with bitumen emulsion and cement mix (RAP) was chosen to reduce costs and utilize recycled materials.

On the first, 15 km long section, about 8 km of the road had poor ground conditions, with high plasticity clay of estimated bearing capacity of E2 = 15 MPa directly under the pavement. Pavement design on this section has been optimised with the use of hexagonal geogrids.

Typical pavement for prognosed medium traffic category KR3 and stiff clay subgrade designed according to Polish Catalogue of Typical Flexible and Semi-Rigid Pavement Structures is as follows:

- 12 cm of asphalt;
- 20 cm of RAP base;
- 24 cm of CBR 60% aggregate subbase;
- 40 cm of CBR 20% aggregate capping layer.

The catalogue does not cover the cases of subgrade consisting of high plasticity cohesive soils and requires individual design in such situation. For this project an additional capping layer has been added: 15 cm of in-situ chemically stabilised layer. The full structure of the conventional pavement on high plasticity clay for this project is presented in Figure 4, the left side.

Then Pavement Optimisation with hexagonal geogrid was done for this project. It allowed for substantial reduction of thickness of pavement. Asphalt layers thickness was reduced by 1 cm, RAP base by 2 cm, and CBR 20% aggregate capping layer by 20 cm. It was also possible to remove whole 15 cm in-situ chemically stabilised layer. This optimisation resulted in savings of about 2.5 mln PLN (~0,55 mln euro) on the first section.

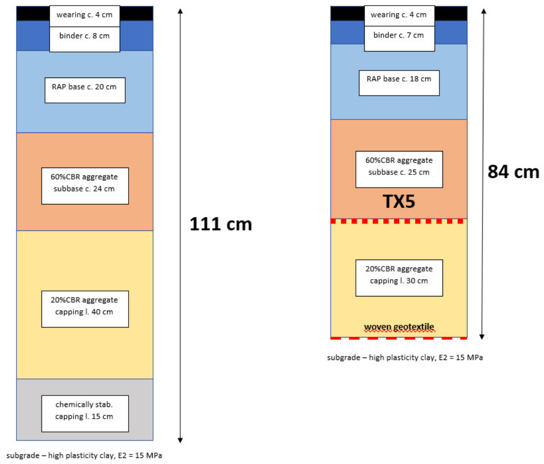

Figure 4. Comparison of catalogue and optimised with geogrid pavement sections on road no. 507

Figure 5. Installation of hexagonal geogrid on road no. 507

3. Asphalt interlayers development. Geocomposites

3.1 Geocomposite incorporating stiff monolithic grids

Pavement Optimisation is usually used in design of new pavement structures. There is, however, a second way of optimizing pavements by the use of geocomposites in the new asphalt overlays on existing pavements. In this approach the asphalt overlays are enhanced by a geocomposite, which either (1) increases the fatigue life of asphalt overlays of or (2) allows for reduction of asphalt overlays thickness to achieve the same pavement life as a thicker overlay not incorporating geocomposite. Geocomposites, also known as asphalt interlayers, are a proven solution for extending the life of the repaired and reconstructed pavements.

The process of manufacturing asphalt interlayers based on a stiff monolithic grids and geocomposites incorporating such grids has been developed within the last decades. The initial laboratory tests and several site applications incorporated a biaxial grid alone. A stiff, monolithic polypropylene grid punched and stretched in two directions was used. After some years of its application the process has been modified and the biaxial grid has been mounted on a paving fabric to create a geocomposite. There have been a massive and successful applications of this product, which is available in two versions: as a both large (65x65 mm) and small (39x39 mm) square aperture size grids (see Figure 6).

Recently the interlayer system has been further developed, which resulted in creation of new type a geocomposite, based on a triaxial grid, with triangular apertures, whilst the stiff and monolithic structure of a grid itself remained unchanged. The idea of using multiaxial isotropic grid to strengthen the asphalt bound layers has been transmitted from the concept of using the similar type of a grid for unbound granular layers, which is present on the market for more than a decade.

The paving hexagonal grid is orientated in three directions such that the resulting ribs have a high degree of molecular orientation which continues through the area of the integral node. Ribs in all directions - longitudinal and transverse - have a rectangular cross section. This stiff hexagonal grid is thermally bonded to a paving fabric backing, and the resultant product is then called a geocomposite (see Figure 7).

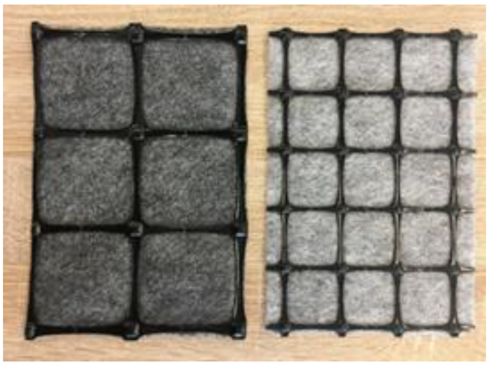

Figure 6. Geocomposites incorporating biaxial grids. Large version of 65x65 mm (left) and small version of 39x39 mm aperture size (right)

Figure 7. Geocomposite incorporating triaxial grid with the hexagonal pitch of nominal value of 80 mm

3.2 Functions of geocomposite and its components

The fabric is a polypropylene non-woven needle punched geotextile, which has an adequate residual bitumen retention to absorb the bitumen once the underlayment is sprayed with either straight run bitumen or bitumen emulsion. According to EN 15381:2008 the minimum bitumen retention to assure installation integrity should be not less than 0.9 kg/sqm. The primary role of the fabric when used in conjunction with bitumen tack coat is to stick it enough to the underlayment and hold the grid in place during paving operations. Once installed and fully saturated with bitumen, the fabric functions as a stress relief system (STR) and interlayer barrier (B). Stress Relief is a function of an asphalt interlayer provided by a bitumen saturated fabric which allows for slight differential horizontal movements between two layers of asphalt (under and overlays) and thus provides the stress relief, which delays or stops (arrests) crack propagation in the asphalt overlay. The Interlayer Barrier is also a function provided by a fabric, which acts as a barrier to the ingress of water (EN 15381:2008). Thus, both functions provided by a bitumen saturated fabric prevent or delay the deterioration of the entire pavement. In turn, the performance of a stiff Polypropylene (PP) geogrid in asphalt overlay is based on two main principles, i.e.:

1. The mechanism of interlocking particles of an asphalt mixture within the hexagonal apertures of a monolithic grid, taking over the horizontal tensile stresses after initial decay of the bitumen (Andrews, 2013). This creates the lateral confinement of bitumen bound particles, by which structure of the hexagonal grid restrains the asphalt mixture;
2. The high fatigue resistance, increasing designed pavement life (Andrews, 2013). Distribution of wheel load in all directions in the plane of geocomposite of the bitumen bound particles of an asphalt overlayer improves the fatigue performance by increasing the isotropy of the resulting composite structure (asphalt overlay + geocomposite).

Due to its stiff and monolithic structure as well as because it is typically used at lower structural level, under base course and binder course, this material is also called a *structural grid* or *structural geocomposite*. Therefore, the main range of structural geocomposite's applications in asphalt is an increasing of the fatigue life of pavement and delaying the cracking occurrence in a new asphalt overlay.

3.3 Inter-layer bonding concept with geocomposite

As both STR and B functions are important from the geocomposite's performance perspective, it means that - if the stress relief is to occur between the under bound layers and asphalt overlays - the control de-bonding of these layers is needed. It has been observed that the use of a geocomposite in the asphalt overlay causes reduction in shearing strength and inter-layer bonding. However, it does not mean that the asphalt overlay reinforced with geocomposite will be susceptible to its pre-mature distress. The maximum horizontal shear force in pavement, which may occur during e.g. emergency braking of heavy vehicles, is about 0.25 ÷ 0.3 MPa (Jaskuła & Rys, 2017; Jaskuła, 2018). If the shearing strength of the inter-layer bonding within the asphalt layers is at least this high, then the pre-mature distress will not happen, even if the shearing strength at the plane of geocomposite would be lower compared to shearing strength between asphalt layers only.

4. Delay of fatigue cracking propagation and fatigue life improvement by using asphalt geocomposites

4.1. Pavement surface deterioration

According to (Code of Practice for Geosynthetics and Steel Meshes, 2012) deterioration of the pavement surface is mainly caused by weathering, movement, and fatigue (caused by a failure under trafficking), accelerated by the asphalt's susceptibility to bottom-up cracking leading to ingress of water, then to potholes and a finally, total breakdown of the surface (Figure 8).

Figure 8. The process of crack development under wheel loading. Model of cracking caused by bending mechanism

The fatigue life of asphalt layers is defined as a number of standard axle loads which can be applied before a given percentage of a pavement surface area will be covered with cracks. In mechanistic-empirical design approach it is calculated with the help of an appropriate Transfer Function. Fatigue cracking development depends on the magnitude of horizontal tensile strain at the bottom of lowest asphalt layer. This approach is used for a bottom-up mode of fatigue cracking.

4.2 Mechanism of asphalt fatigue cracking

Fatigue cracking (called also as *alligator cracking*) is a series of cracks caused by fatigue failure of the asphalt surface under repeated traffic loading. Cracking begins at the bottom of the lowest asphalt layer, where both tensile stress and strain are the highest under wheel loading. They propagate to the surface - initially as a series of parallel longitudinal cracks - and later they connect, forming sharp-angled pieces (less than 0.5m on the longest side) that develop a pattern resembling the skin of an alligator. At the highest severity of its development fatigue cracking creates well defined pieces which are spalled at the edges. Some of them may rock under trafficking (ASTM D 6433-07). Another negative effect of deterioration process is water penetration throughout the cracking network and its freezing within the voids created by the cracks. This process is presented on the scheme illustrated in Figure 9. (Błażejowski & Wójcik-Wiśniewska, 2016).

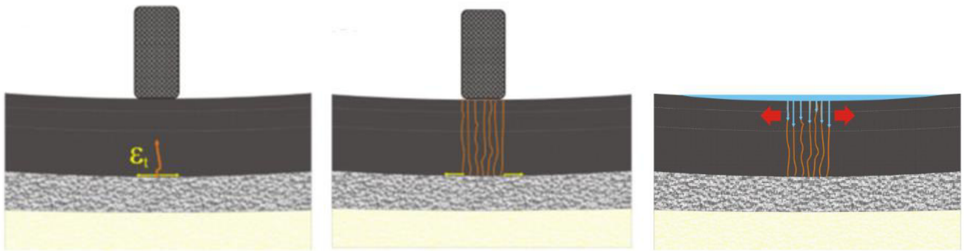

Figure 9. Fatigue cracking process of creating and developing

4.3 Two approaches of using geocomposites for fatigue life increase

It is important to provide efficient performance of an interlayer between existing pavement and a new asphalt overlay package to arrests and delay fatigue crack propagation and to provide a barrier to the ingress of water. Hexagonal geocomposite was developed for those purposes and may ideally solve the issue. In this approach the asphalt overlay is reinforced by a geocomposite, and the asphalt interlayer either increases the fatigue life of this overlay or allows to reduce the overlays thickness, while achieving the same pavement life as thicker overlay not incorporating the geocomposite. This approach is illustrated on the Figure 10:

- Section no. 1: Typical section with new asphalt overlay (H) which is not strengthened by any geocomposite designed for a respective fatigue life of a pavement (N0);
- Section no. 2: Section with new asphalt overlay (H same as in Section no.1) strengthened by hexagonal geocomposite gives a massive benefit of an increased fatigue life of a pavement (N >> N0);
- Section no. 3: Section with new asphalt overlay (h) strengthened by hexagonal geocomposite designed for at least the same fatigue life as a Section 1 ($N \geq N0$) gives a benefit of a thinner overlay thickness ($h < H$).

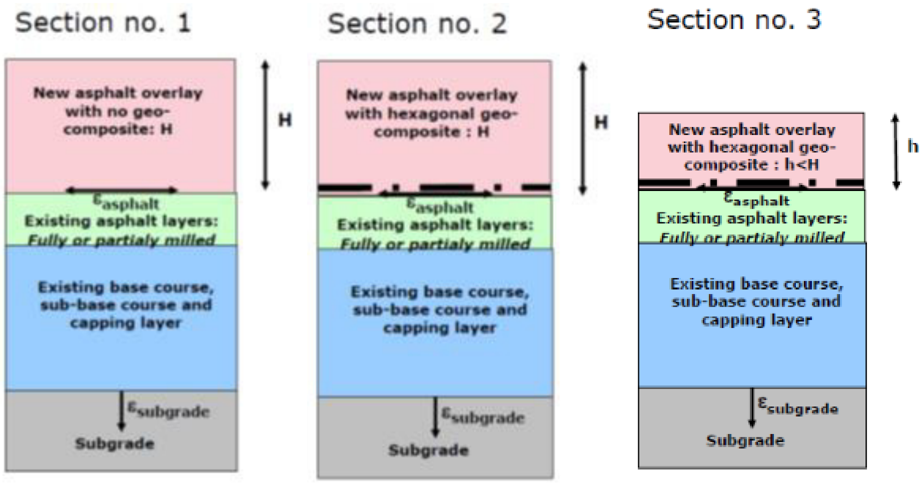

Figure 10. Fatigue life improvement approach. Comparison of three sections of reconstructed pavement

Additionally, to use a geocomposite as much efficiently as possible, it is important to locate it at the bottom of the lowest asphalt course, which usually is a bottom of the new asphalt overlay.

This approach has been already utilized in several applications, where the existing pavements required reconstruction and strengthening by new asphalt overlay. One of the case studies is presented below.

5. A Pavement Optimisation of asphalt overlay Case Study: the Aleksandra Caka Street, Riga, Latvia, 2020

After decades of service the surface of the Caka Street in Riga, Latvia, was in very poor condition. City Council's Transport Department needed a long-term solution to carry the heavy traffic by the reconstructed pavement with the new relatively thin asphalt overlay. It was finally decided to reconstruct approx. 2.5 km length of the street.

Aleksandra Caka Street is one of the main streets in the Riga centre. Investigations revealed structural and surface issues on the full length of the road, requiring reconstruction of the entire street section. There was an extensive network of cracking which were formed on the entire pavement surface with an intensive 'alligator cracking' mode close to the edges of the roadway. Ruts have been formed in some places of approx. 4 cm deep down with the part of the surface being pushed to the sides. The subgrade was in a good ground-water conditions, as it consisted of non-cohesive soils. The existing structure had a following cross section:

- existing asphalt layers, remaining after assumed milling depth of ~10÷12.5 cm, 5 cm;
- existing base layer of an unbound crushed aggregate, 25 cm;
- existing capping layer of a sand blanket, 70 cm;
- subgrade, non-cohesive soils of $E2 \geq 50$ MPa.

The design assumed restoration of the pavement structure to the existing width and to mill the existing surface in variable thickness (12.5 cm on average). In order to create a suitable crossfall of the pavement surface, a hot asphalt AC11 levelling course of min 2.5 cm thick was paved, on which the geocomposite with hexagonal grid was installed. It has been then overlaid with 2 layers of hot asphalt, i. e. binder course AC 22 of 6 cm and wearing course AC11 of 4 cm, respectively. Figure 11 illustrates the designed cross section.

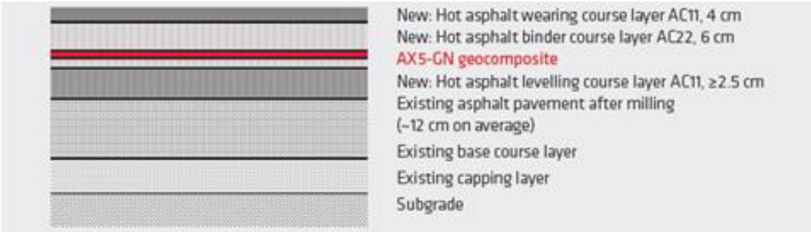

Figure 11. Cross section of the existing pavement overlaid by new asphalt enhanced with geocomposite

The designed traffic based on the investigation carried out and provided by the Client, was calculated as >34 mln ESALs of 100 kN axles. The main goals of the pavement reconstruction formulated by the Client were:

- to carry prognosed heavy traffic;
- to extend the fatigue life of a reconstructed pavement, and finally;
- to retard the reflective fatigue cracking to the asphalt surface.

The calculations based on the Mechanistic-Empirical design method have been carried out. The first approach assumed no grid nor geocomposite application within the asphalt overlay. Based on that the calculated pavement life was assessed as approx. half of a total assumed pavement life (>16 mln ESALs). The increase of the pavement life due to implementation of a geocomposite with a hexagonal grid has been incorporated to the method by a relevant fatigue improvement factor. It was based upon the results of Prof. S. F. Brown at the University of Nottingham in the UK in the mid of 80's last century which have been conducted for the bi-axial grids. In the laboratory conditions, (Brown et al., 1985) an increase of asphalt fatigue life by a shift factor of 10 in a strain-controlled beam testing at the grid positioned at the base of the asphalt layer was achieved. Based on this research and a long-term performance of projects incorporating geocomposites with stiff PP grid it was assumed that a fatigue improvement factor of between 2 and 3 of the relevant fatigue transfer function is acceptable and conservative (IB/Grid_Fatigiue, 2012).

Finally shift factor of 2.0 for hexagonal geogrid has been assumed for the Caka Street reconstruction project. As a result, the calculation for the 2-layered asphalt overlay reinforced by geocomposite with a structural hexagonal grid, delivered the anticipated fatigue life of a reconstructed pavement.

The works of milling the existing asphalt layer, paving the hot asphalt levelling course and installing the geocomposite started in August 2020. Rolls of 3.8 m width were mostly installed by the purpose-built interlayer installation machine, while some of them were installed also manually. Immediately after installation pressure with brooms or brushes was applied to geocomposite to get rid of the folds and wrinkles and – what is also important - to assist the fabric to be initially soaked with the bitumen. The bitumen spray rate of 1.2÷1.5 kg/m2 of residual bitumen was recommended by producer's installation guideline. As the Contractor used a bitumen emulsion with a bitumen solid content of ≥65%, the amount of freshly sprayed bitumen emulsion had to be within the range of 1.85÷2.30 kg/m2. Figures 12 and 13 illustrate the mechanical installation process which efficiently and successfully has been carried out between August and October 2020. The paving works were finished in November 2020. Figure 14 reflects the existing condition of A. Caka Street in Riga (January 2021).

Conclusions

The use of geogrids, in aggregate or asphalt layer(s), can help in optimisation of pavement structures, meaning reduction of pavement thickness or increase of pavement life. Such Pavement Optimisation offers a wide range of benefits for clients, designers and contractors, like: reduction of construction costs and time, construction traffic, maintenance costs, damage to access roads and construction risks, and an increased life of the pavement. Another important aspect, not discussed in this paper, are the environmental benefits associated with the use of geogrids. Use of geogrids in pavements can result in substantial savings in carbon emission compared to traditional technologies, especially cement and other hydraulically bound mixtures.

Modified pavement design methods, based on extensive research, are available to assist designers with designs of pavements incorporating hexagonal geogrid, both in aggregate base on new pavements and asphalt overlays of existing ones.

Figure 12. Process of geocomposite installing by the purpose-built asphalt interlayer installation machine

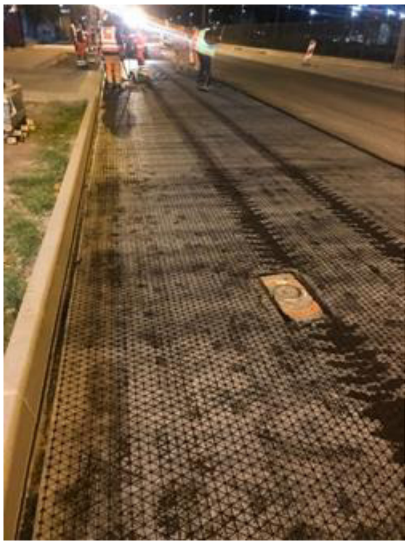

Figure 13. Geocomposite with hexagonal grid installed in place

Figure 14. Fully trafficked A. Caka Street. Section strengthened by asphalt overlay with a geocomposite, January 2021

Disclosure Statement

Authors declare that they have no competing financial, professional, or personal interests from other parties.

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