Estonian guideline for pavement geosynthetics

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ABSTRACT: One of the biggest problems of asphalt pavements are cracks along with rutting and ravelling. Studies have shown that relatively rigid asphalt pavements which withstand well permanent deformations are often prone to cracking – these are usually induced by temperature or caused by fatigue. In cold climate frost heave cracks are also very common. In these cases, just an overlay to restore pavement condition index would last usually from one to few years depending on the cause of the cracks and thickness of the new layer until reflective cracks appear. Many solutions have proposed and tested against reflective cracks like SAMI layers, but countries with cold climate have to also consider frost heave where latter is not effective. The aim of the work was to create a guideline for choosing the appropriate solution using geosynthetics for long lasting overlay over distressed pavement for cold climate conditions. The guideline is based on the results from different test sections over Estonia where variety of products and solutions were used. Also experiences from other countries with cold climate were considered along with published data from the literature.

Keywords: Pavement rehabilitation, reflective cracking, frost heave, geosynthetics

1 INTRODUCTION

Pavement geosynthetics (paving fabrics, reinforcing grids, geocomposites etc.) have been used worldwide for many years to extend pavement life. Most common usages are delaying or in best cases even preventing the development of reflective cracks in asphalt layers. Studies have shown that asphalt geosynthetics can extend the fatigue life and therefore maintenance intervals of rehabilitated (but also new) asphalt pavements. Experiences and presented lab studies in the literature along with manufacturers recommendations have encouraged more extensive usages of pavement geosynthetics in road rehabilitation works in Estonia. Due to vast variety of products (different raw materials along with product types) national recommendations choosing the appropriate product along with description of best practices for installation was needed.

2 ROAD NETWORK AND PAVEMENT GEOSYNTHETICS IN ESTONIA

The total length of Estonian national roads is approx.16,500 km and every year since 2008 approx. 500 km of pavements have been rehabilitated. First higher volumes of pavement geosynthetics were used in years 2004 and 2005 after which it decreased and started to slowly increase again between 2011 to 2014. Table 1 shows relevant data between years 2014 and 2017, where it can be noticed that usages of pavement geosynthetics increased rapidly in years 2015 and 2016 considering volume in square meters per rehabilitated km of pavement.

Main reasons for using asphalt geosynthetics have been delaying reflective (transverse and longitudinal) cracks, avoiding frost heave damage and widening the roads. In recent years most commonly used raw materials and product types has been PET and glass fibre composite grids or grids with installation aid. To some extent (mainly for testing purposes) also paving fabrics, high profile PP grids, steel grids/meshes and fibre modified chip seal SAMI layers with polymer modified emulsions.

Experiences with pavement geosynthetics in Estonia has been somehow controversial concerning both designing and installation. It can be seen in table 1 that pavement geosynthetic volumes have dropped significantly in 2017 and the partly reason for that is negative experiences due to lack of knowledge and poor installation skills.

In order to clarify the subject, many test sections and installation sites were analysed which will be explained in following paragraphs.

Table 1. Pavement rehabilitation (km) compared to usages of pavement geosynthetics (m^2)

	Year 2014	Year 2015	Year 2016	Year 2017
Main + supporting roads*	305 km	399 km	243 km	259 km
Secondary roads	177 km	247 km	260 km	198 km
Pavement geosynthetic volume	ca. 100´000 m^2	ca. 400´000 m^2	ca. 250´000 m^2	ca. 100´000 m^2
Ratio (main + support road)	328 m^2/km	1003 m^2/km	1029 m^2/km	386 m^2/km
Ratio (roads summarized)#	207 m^2/km	619 m^2/km	497 m^2/km	219 m^2/km

* pavement geosynthetics are mostly used in main and support roads
# for comparison secondary roads were also included

2.1 *Test sections in 2004 and 2005 – frost heave damage and reflective cracking, part I*

First documented pavement reinforcement usage was in 2004 on a main road where 5.6 km of steel grid (steel B500K, 6 mm rib, aperture 100x100 mm) and 2.28 km of PET grid (50 kN/m with paving aid) were used against frost heave damage. The road was originally widened between 1955…1959 without removing or homogenizing the old embankment which caused 2…3 (in some places up to 10) cm frost heave cracks to appear nearly in every winter until year 2004, thus demanding constant maintenance works. With rehabilitation works the pavement was levelled with milling and placing the levelling course to provide smooth surface, reinforcement was placed and paved with 5+4 cm of AC concrete. In 2012 and 2013 wearing course was renewed with hot in-place recycling.

Table 2 shows summarized info about inventoried defects data from 2011 and 2017. Especially interesting is info about narrow longitudinal cracks in the middle of the road as these are assumed to be caused by frost heave action. It can be seen that with reinforcement not all the cracks have been eliminated, but nevertheless the extent is relatively low compared to the original situation in 2004 as see in the figure 1, also crack widths are considerable narrower compared to previous situation. Some of the cracks have been sealed with patching thus this distorts the data. When compared alligator crack amount and patches, noticeable difference can be seen between polyester and steel grid sections from where it can be concluded that latter has been more effective. Difference, although not too considerable, can be seen also from FWD data: polyester grid section average d_0 deflection was 173 µm and SCI parameter 41.8, in steel grid section respectively 169 µm and 32.1. For comparison from previous and following unreinforced sections in average d_0 = 272 µm and SCI = 78.1 was measured.

Table 2. PMS info about inventoried defects averaged to one kilometre

	Transverse cracks (pcs/km)	Narrow longitudinal cracks (m/km)	Alligator cracks (m^2/km)	Edge cracks (m/km)	Patches (pcs/km)
PET grid sections 2011	1.32	26.33	0.88	8.78	-#
Steel grid sections 2011	2.14	20.55	2.68	0.00	-
PET grid sections 2017*	13.60	35.98	10.53	1.76	53.53
Steel grid sections 2017	20.37	25.02	1.43	5.36	19.66

* wearing course was renewed in 2012…2013 with hot in place recycling
# no info

Figure 1. Longitudinal frost heave crack before rehabilitation, installation of PET and steel grid, longitudinal frost heave crack 7 years after roadworks [photo courtesy: Enno Vahter]

Second pavement geosynthetic usages in the era was done in 2005 on a main road where 140 g/m^2 paving fabric, 50 kN/m PET grid (with paving aid) and 50 kN/m glass fibre grid (with glass fibre filament paving aid) were used against severe extent of transverse cracks in different sections. With rehabilitation works the reinforcement was placed on a milled surface and paved with 5+4 cm of AC concrete. Levelling course was used in glass fibre section. Table 3 shows length of different sections and average transverse crack per kilometre before, 4 and 10 years after rehabilitation. It can be clearly seen that pavement geosynthetics have successfully delayed, but not prevented reflective cracks. Among these sections glass fibre grid has been the most effective.

Table 3. PMS info about inventoried defects averaged to one kilometre

	Section length, km	Transverse cracks (pcs/km) before rehabilitation	Transverse cracks (pcs/km) in 2009	Transverse cracks (pcs/km) in 2015
Paving fabric section 1	1.1	97.3	0.9	7.3
Paving fabric section 1	6.3	114.3	4.9	15.7
Paving fabric section 1	1.2	92.5	0.8	13.3
PET grid section	2.5	126.0	2.0	20.4
Glassgrid section	1.1	13.6	0	2.7

The pavement was cored in each sections in order to evaluate the situation visually. According to the visual inspection of the cores, some of the cracks have appeared on the same place where they used to be previously (crack continued in the old pavement) and some of them where new (crack was found only on top of the pavement geosynthetic). Also different crack ages were noticed – some of them were already widened and repaired, some were narrow and unsealed (figure 2). All of this indicates that at least some of the cracks are originated from top layer which suffers temperature induced top-down cracking rather than reflective cracking. Aavik *et al*. 2015 studied bituminous binders used in Estonian market and concluded that most of them does not meet to the needed requirements to withstand winter negative temperatures especially considering reversible ageing thus our pavements are susceptible to temperature induced transverse cracking. It was also discussed that changes in pavement stiffness (e.g. existence of old crack) could promote new top-down crack to appear to the same place. Thus SAMI layers are ineffective against this kind of mechanism and reinforcement is needed to strengthen the areas where old cracks used to be, but even more importantly, top layer properties need to be chosen carefully in order to avoid cracks caused by its insufficient performance.

Positive effect from stiff reinforced layer was seen on glass fibre grid section where only 3 transverse cracks were found. All of these were concentrated to the same small area where also significant rutting was observed. Coring revealed problems with layer bonding (Figure 3). The same problem with glass fibre materials has been described by Nguyen *et al.* 2013 based on the literature review, but afterwards it was concluded that problems with glass fibre rises mainly when installation has been executed poorly and otherwise glass fibre grids significantly improve the fatigue life.

Figure 2. Transverse cracks in different stages – one is repaired and has appeared to the same location as it used to be and second one is new, unrepaired. In both cases paving fabric was used.

Figure 3. Bonding problems between glass fiber grid and pavement was noticed.

Based on the information from 2004 and 2005 test sections it was concluded that in cold climate regions stiffer (and stronger) reinforcement is needed in order to gain the hoped results. Although other factors, especially pavement resistance to cold temperatures, its reversible ageing properties and geosynthetic installation have a great influence on pavement performance.

2.2 *Test sections in 2009 (SAMI), 2010 (reinforcement) and 2013 (reinforcement) – frost heave damage and reflective cracking, part II*

As results from 2004 and 2005 test sections were not analysed nor published, it was decided to continue with testing starting from 2009 with SAMI – Fiberdec and SAMI – Modiseal technologies which report was published by Tükk 2013. Test sections were built on a support road which pavement suffered from alligator, block, narrow transverse and longitudinal cracks. One section was chip sealed using polymer modified bitumen emulsion (“Modiseal”) and other using glass fibre additive (“Fiberdec”) after which it was paved with 4 cm of asphalt concrete. First transverse cracks reappeared after 1.5 years and within 2.5 years all of the transverse cracks were visible again; the same occurred with longitudinal joint reflection cracks. Both technologies were effective against alligator, block (no areas reappeared within monitoring period) and narrow longitudinal cracks (74% of cracks did not appear within monitoring period).

Second test section was built on a main road in 2010 and report was published by Truu 2015. Test section was divided into three reinforced subsequent sections (150 m each) where 100 kN/m glass fibre composite with 130 g/m^2 PP geotextile, 50 kN/m PET grid with paving aid and 40x50 kN/m steel mesh were installed. Geosynthetics where installed on a milled surface, steel mesh was attached with fasteners. Products were covered with 11 cm of asphalt concrete (AC) in two layers. First frost heave cracks were discovered on sections with glass fibre composite and PET grid in 2012 and on steel mesh section in 2013. Core samples revealed that the geosynthetics were intact. It can be concluded that in this case frost heave cracking was not eliminated nor reduced with reinforcement. Rehabilitation was effective against transverse cracking and narrow longitudinal cracks in the wheel path, but there was no difference in any sense (including FWD data) between different geosynthetics, between reinforced and unreinforced section. Unfortunately, there is very limited data about installation as this could influence significantly the performance of reinforcement. According to some photos from final report and workmen’s explanations, installation did not go well as steel mesh was ripped too loose during paving and tack coat amount was not enough for synthetic products. Also, these were not tightened and smoothen which is essential in order to be successful against frost heave action.

Third test section was built on support road in 2013 which report was published by Sillamäe 2017. Existing pavement was severely cracked – there were many transverse and longitudinal cracks as well cracks caused by frost heave (Figure 4). It was decided to use three different products – steel mesh bound to slurry seal, 100 kN/m glass fibre composite with 130 g/m^2 PP geotextile and 120/200 kN/m glass fibre grid with glass fibre filament paving aid between ribs. The road was levelled by milling and levelling course, the aforementioned products were installed and whole process was monitored very carefully, after what 4+4 cm asphalt concrete (AC) followed. There were no wrinkles during the placement of the products, adhesion between geosynthetic and pavement was adequate according to Leutner test. Frost heave damage did appear on the reference section (with 4+4 cm asphalt overlay) in 2016, but no defects has been found on reinforced sections. Monitored test section was followed by pavement where only 4 cm of overlay was placed to the existing road. First cracks (both transverse and longitudinal) appeared to that section approx. 2.5 years after rehabilitation works.

Figure 4. Defects found in third test section before rehabilitation works.

3 INSTALLATION

Very, if not the most, important aspect about pavement geosynthetics is the installation process. This has been emphasized in many publications by mentioning among the important role of adhesion. Latter is the most problematic aspect in Estonia, but it has also brought to attention by Shukla & Yin 2006 where it is stated that according to one study, approx. 75% of pavement geosynthetic related failures are caused by insufficient tack coat.

The important role of sufficient amount of tack coat was seen among many others in one site constructed 2015. Reason for using pavement reinforcement was to avoid potential longitudinal crack caused by road widening. Geosynthetic was supposed to be placed under 4 cm wearing course which was supported by the base course asphalt concrete (AC) layer. The construction was finished in autumn at temperatures around +5 ^{0} C. Next year defects started to appear and the situation in 2017 is shown in figure 5 along with two different core samples. Damaged sections and areas were cored in order to inspect asphalt concrete quality and adhesion between geosynthetic by Leutner test. Latter was not possible as cores did not stay intact and after curing it was seen that geotextile has not been saturated with bitumen and white spots which were not covered by bitumen, were noticed (Figure 5 left core sample). In contrast, cores were taken from sections where no damages appeared, the cores were intact. On the previously mentioned undamaged sections another kind on reinforcement product was used and it was properly adhered between asphalt layers and it was possible to see that needed amount of tack coat is present (Figure 5 right core sample).

Figure 5. Left core sample was taken from damaged (shown below) and right undamaged section

Analysis of the described project's documentation showed that contractor used tack coat according to manufacturer recommendations, although in the reality it was not enough as base layer was relatively porous (air voids content approx. 10%) thus allowing emulsion to seep into the base couse layer. Placing thin layer of surface course asphalt layer during cold weather did not have enough residual heat to attract bitumen to rise up in order to saturate the textile for sufficient saturation and adhesion. So, there would have been a need for more tack coat, even greater amount what manufacturer had suggested. From this conclusion another problem arises: when contractor uses more tack coat, under paving machinery bitumen usually penetrates geotextile thus sticking to the truck tyres which starts to tear up and buckle the placed geotextiles and this is the main reason why workmen limit the tack coat dosages.

These kind of problems and failures are one of the main reasons why pavement geosynthetic volumes have dropped rapidly in year 2017 as seen in table 1. Also this is one of the main reasons why national guidelines are needed, where all locally occurred problems can be taken into account. It needs to be mentioned that on previously described test sections, which was designed and installed properly among with numerous other sites, have proved beneficial impacts of pavement geosynthetics.

4 ESTONIAN GUIDLINE FOR PAVEMENT GEOSYNTHETICS

In the guideline, usages of pavement geosynthetics is focused on rehabilitation works, not on new pavements although design principles, installation requirements and recommendations are applicable also there. The guideline along with all the needed explanations was done by Sillamäe 2017.

Many defects can be found on the old pavement – ravelling, potholes, ruts, different types and origin cracks:

- ravelling and potholes cannot be influenced by pavement geosynthetics if there is not enough bonding between geosythetic and layers. In fact, geosythetics could promote the defect to appear. Usually ravelling and potholes appear, when pavement is old and needs to be replaced or overlaid. In this case polyester grids would be useful since they are flexible and well suited against pavement fatigue. Also, SAMI layers would fit. Estonian experience shows that PET grids and SAMI layers works well if overlay is done over alligator, block cracking and narrow longitudinal cracks.
- Problem with ruts should be solved by proper selections of raw materials and asphalt mix design. The problem could arise when old pavement, which is prompt to permanent deformation, is being overlaid with new layer – it has been seen even with the usages of pavement reinforcement layer. Studies with high profile monolithic PP grids have shown highly beneficial effect against permanent deformation which is also supported by Estonian experience with lab tests and test section in heavily trafficked street. Studies in Finland (e.g. Korkiala-Tanttu *et al.* 2003) has shown that steel nets can reduce permanent deformation by 40…60% – it can also be classified as high profile monolithic grid although its physical properties are completely different compared to synthetic materials. High profile monolithic grids can also provide reinforcement through aggregate interlock and when accompanied with geotextile, create SAMI layer thus acting as a barrier layer working against reflective cracking.
- In order to restraint reflective cracks (whether temperature or frost heave induced), its movement needs to be considered. Montestraque *et al.* 2014 presented a methodology which kind of material and methodology to choose according to crack movement. Different solutions can be find in Russian manual ODM 218.5.001-2009 for cold climate regions and recommendations can also be found in manufacturers' materials (e.g. Tensar, Cidex, TenCate). Considering all previous references along with locally gathered knowledge, it was required that in the case of frost heave and temperature cracks, minimum of 100 kN/m glass fibre or PVA pavement grids are needed, but in some cases, stronger materials or solutions must be used (steel grid, over 100 kN/m glass fibre grid, sandwich solutions etc.).
- Polyester grids and composites are more suitable for non-moving cracks and to improve durability against fatigue.
- SAMI layers alone are suitable when old pavements have problems with alligator cracking.
- In the case of road widening, min. 100 kN/m pavement grid (can be with paving aid) is required.

Some special requirements for installation:

- minimum required overlay thickness should be 5 cm or more if it's stated in the manufacturer's guidelines. It is recommended to use two layer overlays (e.g. 5+4 cm);

- in case of glass fibre materials, it is required to use levelling course in order to protect the brittle material;
- it is crucial to achieve good adhesion between geosynthetics and layers, so right amount of tack coat is essential and Equation [1] according to Koerner 2005 is recommended to use. Before installation, small sized test section has to be done. In case of porous base layer (e.g. base course asphalt concrete with up to 12% porosity) it is recommended to apply tack coat in two layers – first layer fills up the pores and after it has cured, second layer can interact with geosynthetic, especially if composite materials are used.

$$Q_d = 0.36 + Q_s \pm Q_c, \quad (1)$$

where Q_d is required amount of bitumen binder, Q_s is geosynthetic bitumen retention and Q_c depends on base layer porosity (values are listed in the Koerner 2015 and in Estonian guideline). The equation has worked more precise than recommendations from manufacturers as latter states only recommended range and where contractors often choose inaccurately.

5 CONCLUTIONS

It can be concluded from the literature that pavement geosynthetics can be an effective way to extend pavements life expectancy. Results and experiences from Estonia have been contradictional and in some cases using the pavement geosynthetics have made the outcome even worse. At the same time there are many positive examples. Based on these experiences it was concluded that the main problems arise during the installation process – even when the design and choosing the product type is done correctly, many contractors have failed to install pavement geosynthetics properly which in turn has given the geosynthetics somewhat unreliable reputation.

Composed guideline along with needed explanations and examples hopefully clarifies the subject and helps to improve the life expectancy of the pavements in Estonia. Educating and informing designers, contractors and supervisors is in progress and situation is getting better.

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