EPS test embankment on Highway E18 at Muurla

Leena K. Korkiala-Tanttu
Professor (fixed time) Soil Mechanics and Foundation Engineering
Aalto University, School of Engineering
Department of Civil and Environmental Engineering, Geoengineering Group
Rakentajanaukio 4, PO Box 12100, 00076 AALTO, FINLAND
GSM + 358 50 312 4775
leena.korkiala-tanttu@aalto.fi

Markku Juvankoski
Senior research Scientist
VTT Technical Research Centre of Finland
Markku.Juvankoski@vtt.fi

Harri Kivikoski
Senior Research Scientist
VTT Technical Research Centre of Finland
Harri.Kivikoski@vtt.fi

Abstract

The Muurla EPS embankment is one of the test sites of the EPStress research programme, which was funded by the Alliance of the Finnish Plastic Industry. The research was done by the Technical Research Centre of Finland and the test embankment was constructed by the Finnish Road Enterprise. The aim of the research was to study, how an EPS embankment without a concrete plate works under a heavy traffic loading. The service life of the road, where the EPS embankment was situated, was originally planned to be only ten years, for it was part of a temporary road connection. Another aim was to develop better design methods for the EPS embankments.

The length of the EPS embankment was 170 m, its thickness varied from 500 mm to 1 000 mm and its width was approximately 18 m. To stabilize the upper part of the pavement a steel grid was installed to the subbase layer for the length of 80 m. The base layer was a cement stabilized layer (180 mm). The ground was a clay deposit, which depth was around 15 m. The EPS embankment was designed so, that settlements during the design service life of 10 years would be tolerable.

The temporary road connection was in use for 4.5 years. During that time the performance of the EPS embankment has followed the designed. Surprisingly, the section where the steel grid reinforcement had been installed had a lower performance than the section without a steel grid. All in all it can be said that the EPS embankment can be used without the covering concrete plate, if the pavement is carefully designed and the service life of the pavement is considered.

1.0 BACKGROUND

The Muurla EPS test embankment is one of the test sites of the EPStress research program [1]. The Muurla site is situated near Salo. The test site was located on a short road connection, which was from 2003 to 2008 part of the temporary traffic arrangement of High Way E18. This full scale test was one of the tests of the EPSstress research program. The other test sites have been streets. The Muurla site was selected, because it had high traffic intensity, the amount of heavy traffic was relatively high and the design life of the road was short, with a maximum of 10 years. The average daily traffic intensity was 9000 vehicles/day, with a heavy traffic amount of approximately 15 %. The equivalent single axel load (ESAL) during the design life of 10 years was calculated to be 6 200 000 ESALs [2].

The major problem of using the EPS embankments has been so far shortcomings and lack of proper design parameters, requirements, methods and tools. The goal of the EPStress program was to improve the design of EPS structures as well as to activate and improve the competitiveness of the use of EPS products. The aim of the EPS test embankment was to study, how an EPS embankment without a concrete plate works under a heavy traffic loading. Another aim was to develop better design methods for the EPS embankments. The idea of the structure was to stiffen the upper part of the pavement structure to compensate the low bearing capacity of EPS. In this case a thick bound base layer was constructed below the asphalt concrete. One half of the structure was reinforced with a steel grid in the subbase layer. The research was done by the Technical Research Centre of Finland and the test embankment was constructed by the Finnish Road Enterprise.

2.0 DESIGN OF THE TEST STRUCTURE

The test site was situated on a temporary single line connection (Figure 1) between the new motorway part and a single line road. The EPS test embankment was installed between alignments numbering of 1180-1350, therefore the total length of the structure was 170 meters. The steel grid was installed between alignments numbering of 1260 – 1350. In both ends of the structure, where the embankment was narrow and its width changed, more flexible expanded clay aggregate was used as lightweight material [2].

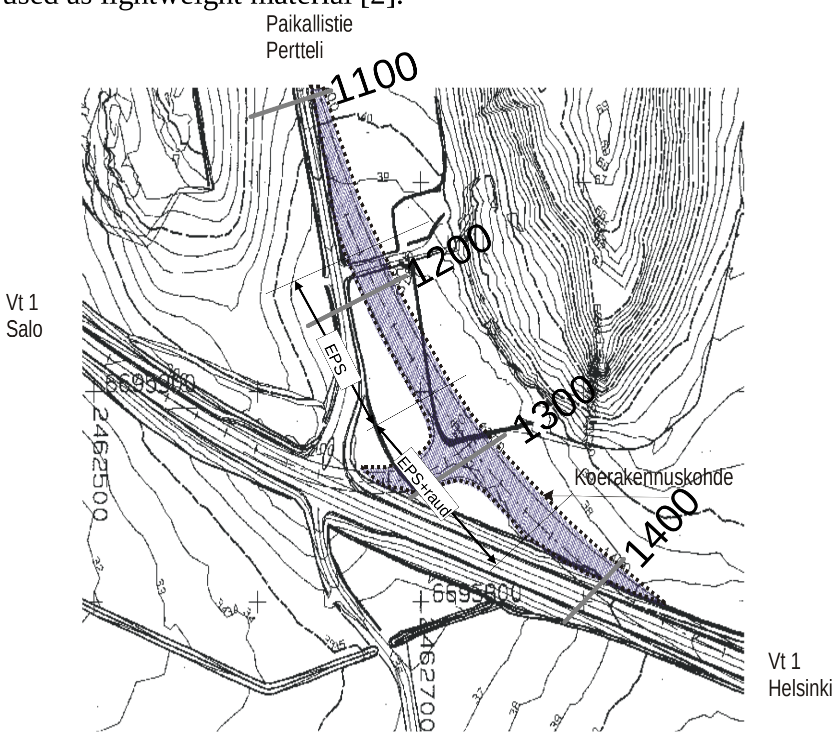

Figure 1. The test site (blue area) and the alignment numbering [3].

The EPS blocks and the sub-base layer had already been constructed in 2001. The base layer and the asphalt layer had been constructed in 2002. The traffic had been changed to the temporary connection in 2003, which was immobilized when the complete motorway was ready in 2008 [3].

The test site was situated on a clay deposit, which thickness varied from 14.5 m to 16.5 m. The upper part of the deposit was a dry crust layer, which thickness varied from 0.8 – 1.7 m. The clay layer consisted mainly of very fine clay, which downwards gradually changed to silty clay. The undrained shear strength (vane test) of the clay was between 9 – 20 kPa. The clay was normally consolidated or slightly overconsolidated.

The preliminary calculations proved that the factor of safety in the area was below the required level of 1.5 with a minimum level of 1.3. The expected consolidation settlements were estimated to be 400 – 500 mm during 10 years, when the weight of the embankment p was supposed to be 32 kPa. Therefore a lightweight embankment was considered to be the most economical solution. The reduction of the embankment weight (compensation) was designed to be only partial (p = 15 kPa), so that the expected consolidation settlements were around 180 – 250 mm during 10 years. Some settlement could have been accepted in this case, but the idea was to minimize the differential settlements. The site was located on a national highway with a crossing (see Figure 1) in the design area. For the total compensation, the dry crust layer should have been removed in some areas. The partial compensation was also better, because only a thin layer of humus (200 mm) was removed from the surface. With the partial reduction of embankment weight the factor of safety increased to be over 1.9.

Table 1. The pavement layers and their calculation parameters.

Name of the layer	Nominal thickness (mm)	Material	Back-calculated elastic modulus MPa
Upper surface	40	Asphalt concrete 20/100	4106
Lower surface	60	Asphalt concrete 22/150	4106
Upper base	150	Stabilized composite of Foam Bitumen and 1 % cement	2013
Lower base	50	Crushed rock max. grain 31 mm	280
Steel grid	-	6/6 - 150/150 (B500K/F30)	-
Subbase	400	Crushed rock max. grain 90 mm	150
Covering layer	0 - 300	Fine crushed rock max. grain 16 mm	-
Geotextile		Specification profile 4*	-
Coating plastic	0,2 mm	Polyethene	-
EPS 0.5 x 1.2 x 3.0 m^3	750 - 1250	Compression strength 100 kPa with 5 % strain	7 - 15
Sand for levelling	100 - 200	-	-
Geotextile	-	Specification profile 3*	-
Subgrade	-	Dry crust clay	20

*specification profile after NorGeoSpec[4]

The cross section of the EPS embankment is presented in Figure 2 and the nominal thickness in Table 1. The minimum thickness of the granular layers above EPS was 700 mm to avoid skidding due to ice formation on the road surface during winter time. To stiffen the upper part of the structure the upper part of the base layer (150 mm) was chosen to be a composite stabilized crushed rock layer.

The design of the pavement layers was based on the bearing capacity requirements on the surface of the final pavement. The parameters of the calculations are presented in Table 1. The deformations and stress on the upper part of EPS were calculated by using the Plaxis finite element code with ideally elastic material models. With the standard wheel load of 50 kN the vertical stress in the upper part of EPS was 23 kPa and the strain was 0.1 %. Preliminary tests [1] had shown that the EPS acts elastically up to strains of 0.4-0.5 %, so the ideally elastic assumption was acceptable. The fatigue calculation tool APAS was used to calculate the stress and strains in granular pavement layers. The thickness of the layers was varied to find the optimum structure. Therefore, to stiffen the upper part of the structure, the upper part of the base layer (150 mm) was a composite stabilized crushed rock layer. There were no suitable material models for the composite material, so a conservative model was chosen. The service life of the composite layer was calculated to be only 4.5 years, but it was accepted for this temporary structure. [2]

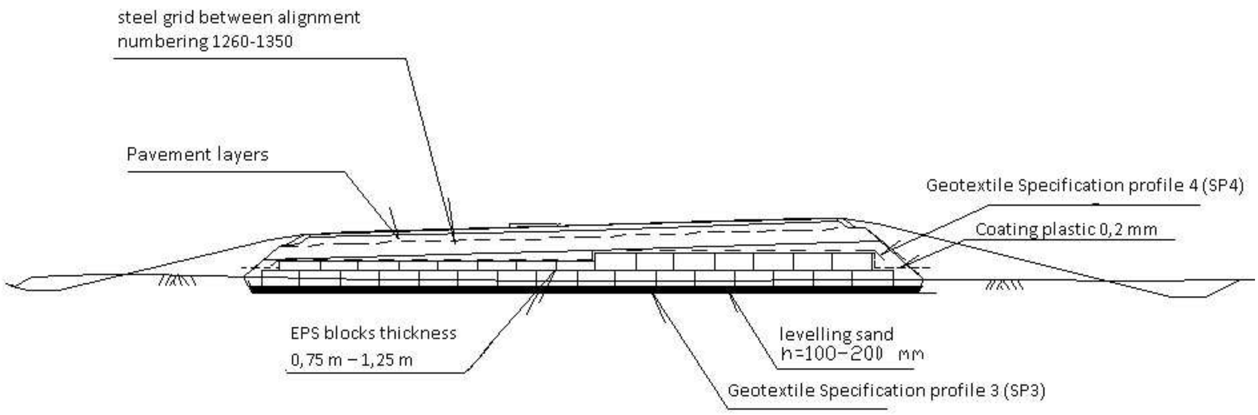

Figure 2. The cross section of the EPS embankment [2].

3.0 CONSTRUCTION OF THE EMBANKMENT

The embankment was constructed in two phases: in the first phase all preparing work was done with the construction of the EPS embankment up to the top of the sub base layer in autumn 2001. The base and asphalt layers were constructed in the second phase during 2002. The used EPS blocks had the sizes 0.5 x 1.2 x 3.0 m^3 and 0.25 x 1.2 x 3.0 m^3. The blocks were installed on the levelled sand (Figure 3) and they were connected to each other with toothed plate connectors. The blocks were covered with a covering plastic, which thickness was 0.2 mm as well as with a geotextile (specification profile 4) to protect the plastic. The protection structure was relatively simple, because the service life of the embankment was short. The covered EPS blocks were again covered with a crushed rock layer, which grain size varied from 0 to 16 mm and thickness from 0 to 300 mm (Figure 4). The layer was shaped to follow the surface of the whole structure. The thick parts of the layer (over 200 mm) were compacted with a vibratory plate. [2]

The sub base layer (400 mm) was constructed in the first phase, but it was compacted only in spring 2002. The steel grid was installed on top of it. Details of steel are presented in Table 1. The grid was installed, so that it was overlapped only cross wards. The upper part of the base layer (150 mm) was stabilized in-situ with a composite of foam bitumen and concrete. There were some problems with loosening of steel rods during the stabilization. Therefore the stabilization was restricted in the remaining areas to 120 mm. [2]

Figure 3. The preparation of levelling sand [2].

Figure 4. The covering of EPS blocks [2].

The quality of the construction was followed by measuring the surface of each layer with 2D and 3D measurements, bearing capacity and compaction tests. The quality of the construction was relatively good. The biggest deviations were found in the thickness of the base layer that varied from 86 mm to 316 mm. The measured bearing capacities (Plate loading and Falling weight Deflectometer FWD) for the pavement layers of EPS, expanded clay aggregate (EC) and reference (Ref.) structures are presented in Table 2. The bearing capacities of E2 for the base layer do not fulfil the requirements. The reason for the low values was that the strengthening process of stabilized base was still going on when the measurements were done. [2]

Table 2. The bearing capacities of different layers and areas [2].

Layer	Area	E_2 MPa	E_2 MPa requirement	E_2 deviation MPa	E_2/E_1	E_2/E_1 requirement
Subbase (Plate loading)	EPS	28	39 (Odemark)	4	1,6	< 2,2
	EC	61	-	6	2,19	<2,2
	Ref.	202	110	57	1,9	<2,2
Base (Plate loading)	EPS	80	129 (Odemark)	10	1,8	<2,0
	EC	126	-	22	2,0	<2,0
	Ref.	180	230 (unbound)	19	1,9	<2,0
Asphalt concrete (FWD)	EPS	289	274 (Odemark)	54	-	-
	EC	521	-	149	-	-
	Ref.	533	-	52	-	-

The FWD test showed that the shape of the deflection bowl in the EPS structure area was very shallow, meaning that there were not so much tensile stresses in the pavement layers as expected. Therefore also the performance of the structure can be expected to be longer than it would have been expected by the total deflection. The service life expectancy was established by using measured values to be 10 years as designed. [2]

4.0 POST MORTEM TESTS

4.1 The EPS Blocks

The EPS test structure was partly dismantled after the new road connection was taken into use during 2008. Test samples were taken from the blocks from four cross sections. The 0.5 m blocks had compressed from 0 – 6 mm (0-1.2% of the nominal thickness) and the 0.25 m blocks from 6 to 9 mm (2.4 – 3.6% of the nominal thickness). The average compression varied from 0.4 – 1.2%. The volumetric water content in the upper part of EPS blocks were low, nearly 0%, increasing downwards so that the water content in the lower 150 mm varied from 3.2% to 6.9% (see Figure 5). It is also important to note that the water contents in the block interface area were higher, by maximum 2%, showing that the water moved also into the interface. [3]

The average volumetric water content varied between 1.1 – 1.7%. The wet densities of the blocks varied between 0.30 – 0.40 kN/m^3 so that the upper part varied between 0.20-0.26 kN/m^3 and the lower part between 0.38-0.49 kN/m^3.

The strength properties were tested with compression tests from test samples of 100 × 100 mm. The short-time compression strengths with 10% deformation (σ_{10}) were defined from this tests and the long-term compression strengths with 2% deformation (σ_2) were calculated from them according to equation 1 [5]

$$\sigma_2 = 0.25\times\sigma_{10} \qquad (1)$$

The short-time compression strength σ_{10} varied from 117 to 153 kPa and the long-time compression strength from 29 to 38 kPa. The nominal required compression strength of the used material was 100 kPa, so all the samples exceeded this clearly. [3]

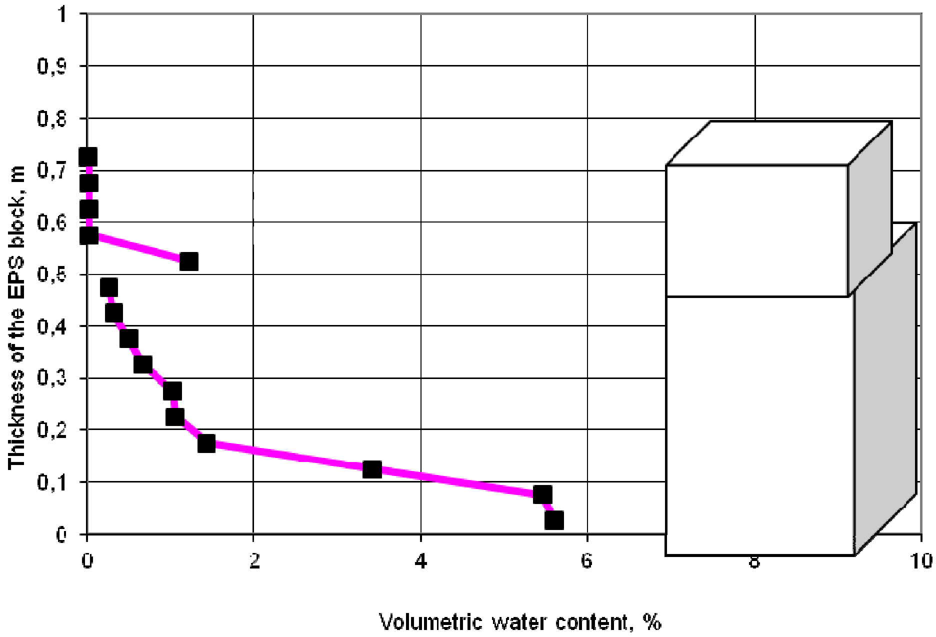

Figure 5. The volumetric water contents of EPS blocks on cross section 1197 to Turku [3].

4.2 Pavement layers

The thickness of pavement layers was defined from two cross section width test pits. The measured values are presented in Table 3, where also the designed thickness is presented. Table 3 shows that in the EPS blocks have happened some permanent deformations. Also the stabilized layer thickness is somewhat smaller than the designed thickness. On the other hand the asphalt layer seems to be a little thicker than it was designed. [3]

Table 3. The measured and designed pavement layer thickness of two cross sections [3].

Layer	Designed thickness, mm	Normal EPS embankment section 11997, mm		Steel grid area section 1267, mm	
		Average	min. – max.	Average	min. – max.
Bound asphalt layers	100	107	98 - 120	113	100 - 120
Stabilized base*	150	123	95 - 150	128	112 - 140
Lower base and subbase	450	510	469 - 558	439	360 - 565
Covering layer	0 - 300	272	170 - 435	246	205 - 310
EPS-blocks	750 - 1250	-	744 - 996	-	741 - 994

* Stabilized thickness in steel grid area was 120 – 130 mm

The water content of unbound pavement layers was measured with Troxler. The dry densities varied in section 1197 from 1863 to 2030 kg/m^3 (on average 1924 kg/m^3) and in section 1267 from 1843 to

2060 kg/m^3 (on average 1980 kg/m^3). The corresponding water contents in section 1197 were between 1.9 – 3.3 % (on average 2.4 %) and on section 1267 between 2.2 – 4.7 % (on average 3.1 %).

4.3 Performance of the structure

The evenness of the surface was measured four times during the service life of the structure: 24.9.2004, 22.10.2005, 12.9.2007 and 6.6.2008. The defined values were IRI, IRI4 and rut depths. In average the IRI had increased from 1.3 mm/m in 2004 to 1.7 mm/m in 2008 on the area without steel grid. On the area with steel grid the corresponding change was clearly higher from 1.6 mm/m to 2.7 mm/m. To the same extent the IRI4 values had increased from 0.7mm/m to 1.3 mm/m and on the area with steel grid from 1.0 mm/m to 1.7 mm/m. The rut depths for different test areas are presented in Figure 6. It is important to note that in both lanes the reference structure without EPS embankment have rutted less. Also the rut depths seem to be smaller for all areas in the lane to Helsinki, where the pavement layers were thicker than on the lane to Turku. The annual rut depth growth was 2.1 mm/year in the reference area, 2.3 mm/a in the EPS-embankment area and 2.4 mm/year in the steel grid area. Like the rut depths also the damages were remarkably lower on the lane to Helsinki. Even some alligator crack type damages were detected on the lane to Turku. On the steel grid area the cracking was clearly bigger than on the area without. [3]

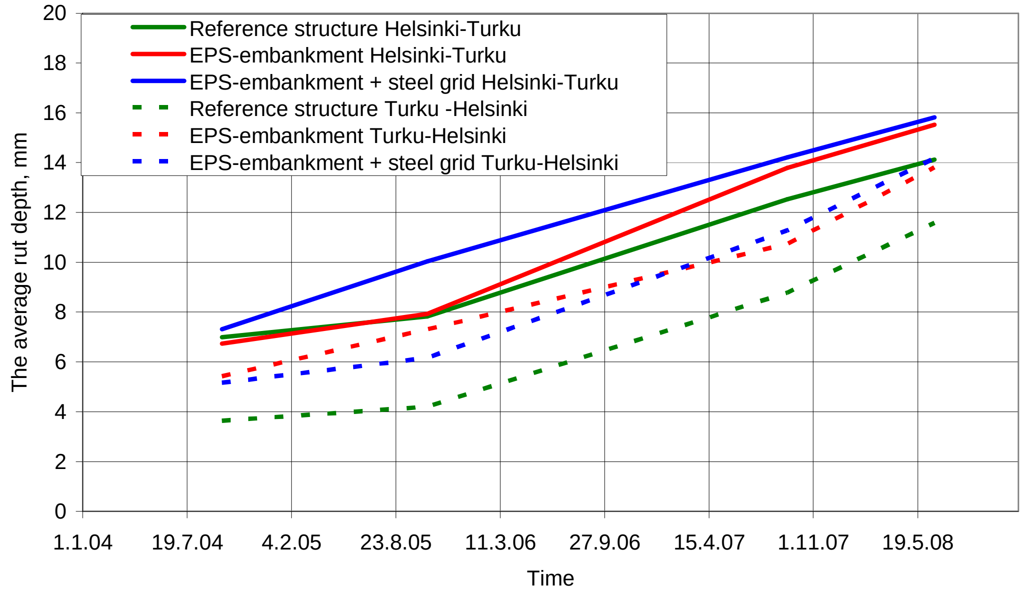

Figure 6. The average rut depths of lanes and areas [3].

5.0 CONSLUSIONS

The EPS embankment has performed almost as it had been estimated and designed. The designed service life of 10 years was achieved in the most parts of the structure. The exceptional area was the lane to Turku with steel grid and thinner pavement layers. In general it can be said that steel grids decrease rut depths and deterioration and do lengthen the service life of the structure. In this structure the steel grid did not work as it was expected - quite the contrary. Yet, no clear single factors were found to explain this. It might be the case that the steel grid was too stiff to work in cooperation with unbound materials. For the areas (mainly on the lane to Helsinki) the thickness of pavement layers was nearly 1 meter, the expected service life calculated from the measurements was at maximum 20 years.

The test results show that EPS embankments can be used without concrete slab. However, the recommendation would be to use it in low-volume roads or streets. It is important that the above layers have enough stiffness and thickness to strengthen the whole structure.

ACKNOWLEDGEMENTS

The authors want to thank Finnish Plastics Industries Federation, EPStress project, Finnish Road Administration and Finnish Road Enterprise for their financial support and contribution to the construction of the EPS embankment.

REFERENCES

1. Saarelainen, S. ”Paksun EPS kerroksen kuormituskestävyys”, in Finnish, final report of EPStress program, VTT internal report RTE50-IR-14/2003, VTT, in Finnish, http://www.eps-eriste.fi/doc/Loppurap_RTE50-IR-14_2003.pdf, 2003
2. Korkiala-Tanttu, L., “The design of Muurla EPS test embankment”, VTT internal report, 6.2.2003, in Finnish, 2003
3. Kivikoski, H. and Juvankoski, M, ” EPS test embankment in Muurla, light weight structure studies”, VTT report VTT-S-09017-08, in Finnish, www.**eps-**eriste.fi/doc/Loppurap_RTE50-IR-14_2003.pdf, 2008
4. Watn, A., Eiksund, G., Glåmen, M.G. and Rathmayer, H. “NorGeoSpec 2002, A Nordic system for specification and control of geotextiles in roads and other trafficked areas”, SINTEF, Norway, 2002
5. Rakennustieto, “INFRARYL 2006” Infrarakentamisen yleiset laatuvaatimukset, Osa 1 Väylät ja alueet, in Finnish, 2006