THE APLICATION OF EPS IN GEOTECHNICAL PRACTICE: A CASE STUDY FROM SERBIA

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Abstract: *During the last few years, the development of Serbian infrastructure was based on the improvement and the expansion of the existing road network. Significant efforts have been undertaken in order to develop the major design projects in compliance with all aforementioned requirements. At the same time many problems concerning stability, bearing capacity and excessive roadbed settlements have been overcome using a modern construction technology which includes the utilization of certain byproducts, such as fly-ash, polystyrene etc. This paper is revealing some of the experience from geotechnical practice in Serbia, concerning the application of expanded polystyrene (EPS).*

Two important design solutions (one of which was implemented) will be discussed:

1. *The main design for the Motorway E-75, at the interchange „Batajnica";*
2. *The main design for the rehabilitation and improvement of the Main road M-21, at the bypass of Valjevo.*

INTRODUCTION

The construction within the scope of problematic terrains, in the last few decades is the subject matter of scientific and professional investigation, and represents the real challenge. These refer to the terrains made of soils, being insufficiently resistant to shear force, prone to large, fast and sudden deformations: unconsolidated soils, peat-bogs, dumps, waste-dumps, unstable slopes and rubbish dumps. Investigation efforts had two basic routes: firstly to establish constitutive models of soils which depict their behaviour in the best way, and secondly to find out the techniques meant to improve the soils.

The utilization of light-weight materials such as geofoam (EPS-blocks) and extruded polystyrene provide for considerable techno-economic advantage in relation to other techniques for soil improvement, requiring extensive experience and technical facilities at hand.

The text will review here-in-after the experience attained in Serbia regarding the utilization of EPS-blocks. The examples exposed represent the crucial events of their implementation in Serbia. Professionally, one had to acquire the knowledge on advanced methods of computation and constitutive models of soils thus to improve the understanding of behavior of polystyrene and soil as well.

THE BEGINNING OF THE DESIGN WITH POLYSTYRENE (2005) „LIGHT-WEIGHT EMBANKMENT FOR BATAJNICA INTERCHANGE, ON BELGRADE BY-PASS"

Batajnica interchange is anticipated to be located at the crossing of motorway from Novi Sad and Belgrade by-pass, i.e. at the intersection of motorways E70/E75 [1],[2],[3]. It is the integral part of Pan-European Road Corridor 10, being the most relevant and demanding infrastructural project in Serbia in the last few years.

The area wherein the interchange has been anticipated to be set belongs to Srem region, loess flat plateau and therefore it is an extension of Zemun township loess flat plateau. Average height of loess plateau amounts to 77.00 -85.50 m of altitude.

It is characterized by slightly rolling terrain with pronounced morphological forms – sags and uplifted blocks.

As regards the geologic structure of terrain there are Quaternary sediments, i.e. Pleistocene sediments, originating from different sedimentation and climatic conditions. They are represented by several genetic and lithologic types, as follows:

- Loess sediments – the thickness of these deposits varies within the range from 20.0 to 25.0 m, and are distingished with low plasticity, prevailingly medium compressibility and medium water permability;
- Alluvial-marshy sediments, represented by clayey-sandy clays, whose substratum is made of loess deposits originating from the earliest phases of Pleistocene. Thicknesses vary from 10.0 to 20.0 m. They belong to medium or less compressible soils with medium water permability.
- Fluvial-lacustrine deposits, represented by clayey sands with scattered interbeds and lenses of sandy clays whch make up the basis of terrain, with age corresponding to younger divisions of older Pleistocene and is in transition from lower to middle Pleistocene. They are distinguished with good compactness, good to medium water perviousness and water saturation.
- Scattered filling over the natural ground has been carried out, mainly with processed loess silty-sandy material, rubble and organic residues. The embankments within the framework of existing road and rail transport facilities were built under control and technically processed.

Figure 1: Aerial photo of „Batajnica“ interchange with all road routes and marked light-weight structures made of EPS-blocks

In accordance with hydro-geologic features there are two milieus:

- elevated semi-pervious milieu, made of „loess“ package and alluvial-marshy sediments;
- water-bearing milieu, made of fine grained to medium grained clayey sands.

Free level ground water accumulation has been created within the elevated semi-pervious layer.

As regards the hydro-dynamic aspect, it does not have the characteristics of an aquifer. Horizontal motion of ground water is negligible comapered to the vertical one, and is conditioned by climatic and anthropogenous factors.

At the time of investigation (October – November 2005), the ground water level has been established in lower terrain parts (<81.5 m of altritude) at the depths of 0.6 – 4.6 m, i.e. within the range of absolute spot levels from 81.5 to 95.0 m of altitude, whereas in upper terain parts it has been established at the depths of 8.5 –

12.9 m (spot levels from 76.9 to 78.4 of altitude). The ground water level oscillations has been established to be in the order of 0.5 to 1.5 m.

Based upon the exploratory works, it has been established that the soil on future interchange location at the spot of intersection of respective motorways from Novi Sad and and Belgrade by-pass, is *soft soil*. In the previous version of Preliminary design, this issue was solved by an extended bridge structure which initiated at the height, from 4.83 or 5.50 above the terrain, in the case of E-75 motorway basic alignment, and for other routes the overbridging height amounted to 4.3 or 5.0 m. These limiting initial heights on one side, and flyover intersections with roads and railroad Belgrade – Novi Sad, on the other, implied a very long bridge structure of 1730 m. Preliminary estimated bill of quantities, however, indicated that such an approach, is not economically viable compared with the utilization of light-weight constructions with EPS blocks.

In the previous considerations the legs N^o1 & N^o2 within the basic alignment have not been taken into account, yet there it is essential to decrease vertical load upon the soil by resorting to EPS-blocks for an additional reason. Namely, on the westward side of the embankmemts the gas pipe-line tubes are set at the depth of 2 m and with mutual distance of 13 m under the anticipated embankment slope. Should the slope remain 1:3, then both gas pipe-lines would lie entirely, or partially, within the zone of weight impact of the road structure. Since the ratio 1:2 shall be applied for light-weight embankments, thus only the eastward pipe would be exposed to potential subsidence which must be minimized. For that purpose a thicker package of EPS-blocks would be set locally, and therefore reduce additionally the weight of embankment, in order to exclude the risk of relevant deformation on the gas pipe-line after the interchange completion.

In the process of dimensioning the embankment made of EPS-blocks and sand, the following boundary conditions and reference marks have been utilized as guidelines:

a) Maximum allowable overall subsidence, for the embankment of E-75 basic alignment, and main road M22 and the 1st rank road transport facility, out of which boundary consolidated subsidence (from the interchange opening for traffic operation), amounts to 15 cm,
b) Maximum allowable vertical load, upon the soil ensuing from the constructed road structures of „Batajnica“ interchange, amounts to 50 kPa, which is in accordance with allowable subsidence as per the results arising from field investigation, laboratory testing and computations,
c) Pavement structure for basic alignment, its legs, as well as for main road M22 and the 1st rank road transport facility, has been determined on the basis of anticipated road traffic volume. Pavement structure own weight is part of the allowable vertical load and as such exerts the direct impact onto the designed layers of light-weight road embankment;
d) Designed gradient of the embankment slope is not conditioned by land property limits along the corridor, neither by urban planning conditions, but only by the stability of available local dredged flushing sand (with grain size distribution of 20% of grains 0.63 μm-0.5 mm, and 80 % of grains 0.5-2 mm, $\gamma > 17 kN/m^3$, $\varphi > 25^0$);
e) The standard material (dredged flushing sand) is utilized in the lowest part of the embankment, and the danger of high ground waters and consequently the appearance of uplifting, within the lowest part of EPS-blocks, by the thrust of water force at the interchange site is negligible;
f) After boundary conditions, the construction costs represent the critical criterion for design optimization of road embankment within the scope of „Batajnica“ interchange;

g) The dimensions of EPS-blocks and thus the thicknesses of layers within the package, are determined by taking into account the available building equipment, training level of operators, rather economical labour force at hand, normal working conditions (maximum weight to be carried by building workers, etc.);

h) In other words, economic criterion determines the type, i.e. specific weight of implemented EPS;

i) Design structural life-cycle of the interchange embankment, exceeds 30 years, even under minimum conditions of maintenance, with the only exception referring to the wearing course of asphalt.

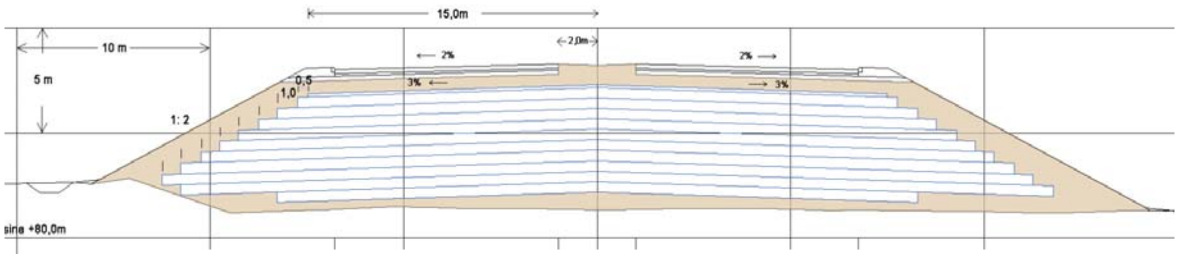

Figure 2 – Cross-section profile of designed light-weight structure with EPS-blocks at the chainage km:187+050 of „Batajnica" interchange basic alignment

Critical cross-section of „Batajnica" interchange basic alignment, has been modelled and analyzed by finite elements method (*FEM*), as staged constructed structure. For that purpose *PLAXIS* program package [4] has been utilized, in which process for modelling and analysis a basic alignment road structure 8.5 m high, has been selected with two alternative structural solutions: a) standard embankment made of sand; b) light-weight structure made of EPS-blocks. Actually such a situation, in fact, exists at the chainage km: 188+450 on basic alignment. Computation results pertaining to subsidence, vertical deformations and input data of materials are shown in *Fig. 3*, and *Table* $N^0 1$. Computed settlements of the emabankment made of standard materials – sand, is almost thee times higher, than it is the case for light-weight structure made of EPS-blocks., amounting 0.51m for standard embankment, and less than 0.14 m for light-weight structure.

It is important to point outm, that if one would resort to EPS blocks, instead of bridge structure and high embankment made of standard materials (> 6 m), the financial savings could amount to over 50% by utilizing light-weight material compared to mentioned alternative solutions.

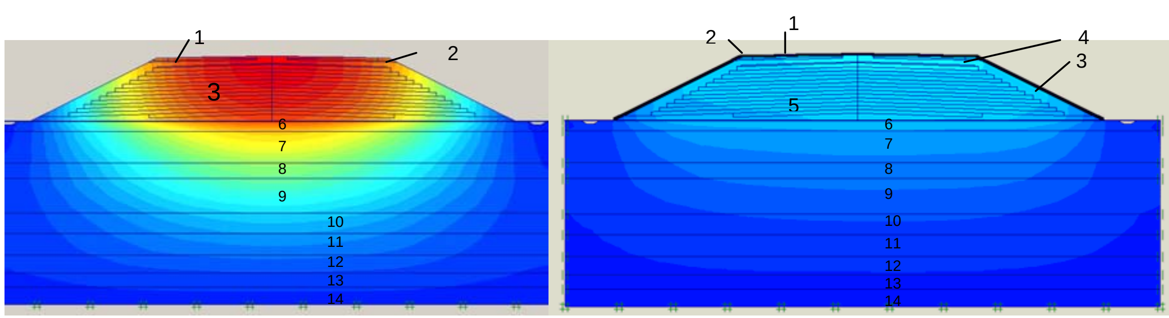

Figure 3 –Resulting vertical deformation, under road structure's own weight obtained by PLAXIS- model analysis of typical cross-section at km 188+450 at the interchange Batajnica basic alignment, with the

a) embankment made of classical materials- sand, on the left side

b) embankment made of lightweight materials-EPS blocks, on the right side

Table 1–Material properties of soil layer, EPS blocks and other utilized materials in FEM analisys

No.	Material	γ_{unsat} kN/m^2	γ_{sat} kN/m^2	$k_x=k_y$ m/day	E_{ref} MN/m^2	υ -	c_{ref} kN/m^2	φ °
1	asphalt	24,0	24,0	1,0	7500	0,35	-	-
2	stone aggre.	22,0	22,0	1,0	600	0,35	-	-
3	sand	17,0	18,0	0,100	100	0,30	1	30
4	concrete	24,0	24,0	0,000	25000	0,35	-	-
5	EPS 100	0,2	0,5	1,0	8	0,10	-	-
6	loess	15,4	26,6	0,100	1,6	0,34	8	24
7	loess	15,4	26,6	0,100	4,6	0,33	12	23
8	sand/clay	14,6	26,4	0,002	8	0,33	13	25
9	loess	15,2	26,5	0,100	6,5	0,33	5	25
10	sand/clay	14,7	26,4	0,002	8,7	0,33	12	23
11	loess	14,9	26,5	0,100	11,2	0,33	12	23
12	sand/clay	15,9	26,4	0,002	9,2	0,33	12	23
13	loess	15,4	25,2	0,100	13,9	0,33	12	22
14	sand/clay	15,9	26,6	0,002	13,9	0,33	7	25

REPAIR OF UNSTABLE EMBANKMENT, THE FIRST POLYSTYRENE STRUCTURE IMPLEMENTED IN SERBIA AND SOUTH EAST EUROPE (2010)

Unstable terrain, is located on the south-eastern part of Valjevo township by-pass, on main road M21, section:Valjevo-Kosjerić, at km:2+000 [5]. At the exit from the township, thereof there is a bridge structure over Petnička St., while the approach ramp, after the bridge was set on the embankment of variable height ranging from 4 to 5m. The embankment was built on the rolling slope with slight and steep gradient ranging from 3 to 10^0, while Petnička St. (around the street and bridge) is densely populated.

Sags, cracks and twisting of the asphalt course within the bridge zone have been established by visual inspection. Traffic operation was endangered seriously along the stretch of 35 m. Open drain channel from the hillside, was found to be out of function, covered with vegetation, while the water was discharged onto the pavement without control, instead of flowing freely through the drain channel. The bridge structure was found to be without visual damages, sags and deformations, thus indicating that it is in stable conditions, while the embankment was in unstable conditions. Gradually due to abundant precipitation, new motions and collapses of embankment slopes appeared, along with setting into motion of the concrete retaining wall

Figure 5. –Labile embankment location next to the bridge-viaduct

which supporting the right slope near the bridge head. The purpose of the wall was to provide space for free traffic operation through Petnička St., under the bridge. By setting the wall into motion, part of the street under the bridge, in time, became potentially endangered.

In-situ and laboratory investigation determined the geologic composition of the terrain to be as follows:

- Embankment, made of wet, clayey-silty soil, dappled with interbeds of sand, gravel and waste material. It is incoherent to mediium compacted and wet. Its height amounts to 4-5m. It is classified into CH clays, and partly into silts denominated as ML;
- Embankment subsoil, is made of silty-clayey and muddy soil, mixed with sand and gravel. It is classified into the group of CH-CL clays and ML silts. Its consistence ranges from medium hard to soft. Its thickness amounts to 2 – 2.5 m and it is of dilivial origin;
- Under that layer there are marly clays (LG) being a transitory zone towards the marls. The clay is medium hard and tenacious, CH. It is cracked and is divided by fissures and cracks. It is water saturated and quite wet. Its thicnkess amounts to 2.5 – 3.5 m;
- Terrain substratum is made of soft marl rock (L). It is massive and is divided into blocks, with exiguous compressibility and perviousness.

Ground water has been established to be at the depth of 5.5 to 6 m from terrain surface within the zone of contact between subsoil and marly clays.

Based upon all investigation carried out, the causes of embankment instability have been established as follows:

- Humidity of material is higher than optimal, due to unserviceable channel and lack of measuers for controlled outlet of rainwater services. Surface water was discharged onto the pavement and thus soaking the slopes and penetrating into the embankment body. The water from there drained very quickly both horizontally and vertically and carrying away fine grain particles.
- This embankment did not fulfill all technical requirements. Its subsoil is of poor geotechnical quality for direct support of the facility, so it had to be repaired, prior to any type of works. Marl rock mass, marly clay and subsoil made of clays and silts are poor water pervious layers, thus the water remained in low parts and softened the embankment. Its slopes were built in accordance with gradient ratio 1:1.5 and 1:1 which is in contrast with regulations prescribed for the embankments of such height. Building materials were of poor quality and insufficiently compacted, with uneven content of clayey fraction within the upper level, and likewise in clayey-marly-muddy content within the lower level.
- Retaining wall supporting the slope next to the bridge head was insufficently founded.

By recognizing the factors and causes of instability, it has been determined that the entire existing embankment must be substituted by a new one, and to improve its subsoil by adequate repair measures. The substitution of unstable embankment with a new one, lightened by expanded polystyrene, set over gravelled pad/mattresses in the zone of contact with subsoil appeared to be a convincing measure, being adopted and discussed here-in-after.

The issue of embankment stability and foreacast of embankment behavior in case of polystyrene blocks has been discussed in a standard way and with FEM *(Plaxis)* as staged constructed structure *(Fig.6)*.

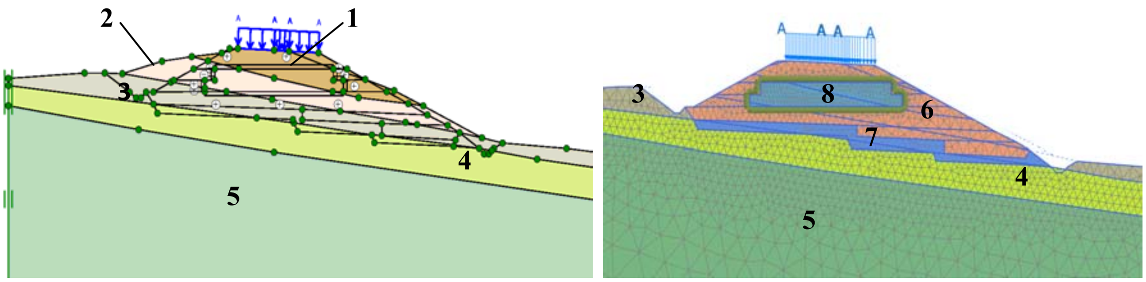

Figure 6. – Embankment model for stability back analysis on the left, and model for forecaste behaviour of new embankment by EPS geofoam blocks utilization on the right, by FEM analysis

Soil layers of which the embankment is made (new and old), have been modelled as elastic-ideally plastic, while the soil under the embankment (subsoil and layers as per depth), as elastic-plastic with hardening *(Hardening soil),* and according to *Mohr-Coulomb* failure condition. The hardening is twofold, shearing and compressible. Within the scope of analyses with light-weight materials, EPS-blocks are modelled as linear-elastic material. Elasticity module *(E)* of EPS is considerably smaller in comparison with other building materials, concrete, timber and soil. It depends on polystyrene density, and yet a discord has been noticed amongst the researchers regarding its constant value. Prescribed values can be obtained on the basis of testing results according to EN 826, and are valid only for the elastic part of stress-deformation curve. In this paper the value has been adopted in accordance with papers [6], [7], and [8], i.e. equation: $E_t=(0.45\cdot\rho-3)$MPa, represent the solution on the safe side. On the contact between EPS-blocks and embankment (soil), interactive thin linear elements have been adopted, with the purpose to describe mutual impact of styrene and soil. As regards *Plaxis* this relationship is entered through the dimension $R_{int.}$. Adopted value R_{int} = 0.6 – 0.8, which is usually adopted in the analysis of geosynthetic materials and it is on the safe side. At the contact styrene-styrene these elements are not introduced since the friction is higher here, and EPS-blocks are mutuallly linked with metal plates. Gravel pads/mattresses, are wrapped with non-woven geotextile, which does not have a structural role, but an intercepting one, and therefore it is not modelled. The review of relevant input values of soil materials and styrene are presented in *Table N^{0}3*, whereas the simulated phases of computation are given in *Table N^{0}2*.

Table 2. – List of calculation phases

Ph No.	Phase indetification	Calculation	Loading input	Time, day
1	Initial phase	Gravity loading	Staged construction	0
2	Calculation of weight	Plastic analysis	Total multipliers	0
3	Construction of first layer	Consolidation analysis	Staged construction	2
4	Construction of second layer	Consolidation analysis	Staged construction	2
5	Construction of third layer	Consolidation analysis	Staged construction	2
6	Use-phase of embankment with traffic load of 15kN/m^2	Consolidation analysis	Staged construction	2920
7	Use-phase of embankment with traffic load of 25kN/m^2	Consolidation analysis	Staged construction	1465

Ph No.	**Phase indetification**	**Calculation**	**Loading input**	**Time, day**
8	Global stability of embankment	Safety	Incremental multipliers	0
9	Removal of olde embankment	Consolidation analysis	Staged construction	3
10	Construction of gravel matress and first layer of new embankment	Consolidation analysis	Staged construction	1.5
11	Construction of second layer of new embankment - placing EPS blocks	Consolidation analysis	Staged construction	2
12	Construction of third layer of new embankment with EPS blocks	Consolidation analysis	Staged construction	1
13	New embankment with EPS blocks in use-phase with traffic load of $15kN/m^2$	Consolidation analysis	Staged construction	720
14	New embankment with EPS blocks in use-phase with traffic load of $15kN/m^2$	Consolidation analysis	Staged construction	1825
15	Global stability of new embankment with EPS blocks	Safety	Incremental multipliers	0

Table 3. – Material properties of soil, embankments and EPS blocks in FEM analysis

No	*Material layer*	*Material model*	*Drainage type*	γ_{sat} kN/m^3	γ_{sat} kN/m^3	k_x=k_y *m/day*	R_{int} -	K_o^{nc} -
1	Gravely and sandy layer of old embankment	MC	Drained	20.0	21.0	1.0	1.0	/
2	Clay layer of old embankment	MC	Undrained	19.0	20.5	0.0432	1.0	/
3	Subsoil layer made of clay and silt	HS	Undrained	19.0	19.0	0.0432	0.66	0.775
4	Clay Shale	HS	Undrained	18.5	19.5	0.005	1.0	0.758
5	Marl (soft rock)	HS	Undrained	20.0	21.0	0.005	1.0	0.577
6	New embankment made of sand and gravel	MC	Drained	20.0	21.0	1.0	0.66	/
7	Gravelly and sandy pad/mattress	MC	Drained	18.0	19.0	1.0	1.0	/

No	*Material layer*	*c* *kPa*	*φ* °	*ψ* °	E_{oed}^{ref} *MPa*	E_{50}^{ref} *MPa*	E_{ur}^{ref} *MPa*	*m* -	E_{oed} *MPa*	*υ* -
1	Gravely and sandy layer of old embankment	0.6	25	0	/	/	/	/	12.0	0.3
2	Clay layer of old embankment	10	15	0	/	/	/	/	3.5	0.3
3	Subsoil layer made of clay and silt	10	13	0	4.8	4.8	12.0	0.8	/	/
4	Clay Shale	10	14	0	6.8	6.8	20.0	0.7	/	/
5	Marl (soft rock)	22	25	0	7.2	7.2	21.3	0.5	/	/
6	New embankment made of sand and gravel soil	0.6	32	2	/	/	/	/	60	0.3
7	Gravelly and sandy pad/mattress	0.6	33	3	/	/	/	/	40	0.3

No	*Material layer*	*Material model*	*Drainage type*	γ_{sat} kN/m^3	γ_{sat} kN/m^3	k_x=k_y *m/day*	R_{int} -	E_{oed} *MPa*	*υ* -
8	Expanded polystyrene blocks (Geofoam)	LE	Non-pourous	0.30	1.0	0.0001	0.8	2.637	0.08

MC-MohrCoulomb, HS-Hardening Soil, LE-Linear Elastic

Based on the analyses, it has been confirmed that the most important layers for embankment stability, is the layer of marly clay and subsoil made of clay and silt. Determined lower geotechnical parameters of layers, thereof confirm previously mentioned facts indicating that the layers were softened by penetration and retaining of water, due to the lack of technical soundness pertaining to the embankment, i.e. the measures for elimination of water from embankment body and by utilizing less permeable clayey material in its lower part. The issue in time became even more complex due to the lack of maintenance of side channels and to a lesser extent, because of increased traffic volume, which altogether set the masses into motion. It is interesting to point out that, with FEM analyses, the values obtained were approximately 60% smaller (*Table N^0 4*) than those arising from standard analyses of settlements, due to the fact that there have been numerous assumptions which simplify the computation itself for practical reasons.

Forecast of embankment behavior after the repair due to the construction of a new lightened facility with styrene, appropriate processing of the subsoil, supply proofs that future embankment is going to be stable, while expected subsidence is going to be well below the maximum allowable.

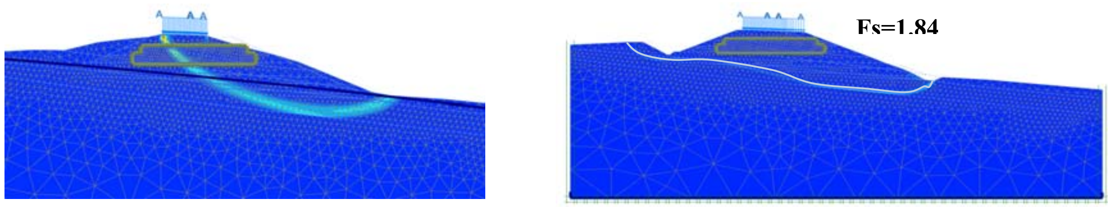

Figure 7. Global stability of old embankment, on the left, and stability of new embankment after rehabilitation measures by EPS blocks, on the right

Table 4. – Comparison of results by classical analysis and by Finite Element Method (Plaxis)

Old embankment settlement by classical analysis			
Settlements	20.32cm		
Back analysis of old embankment by FEM			
	Construction of third layer (Phase number 5)	Use-phase of embankment (Phase number 7)	Secondary settlements (7)-(5)
Settlements	12.82cm	20.98cm	8.16cm
New embankment with EPS blocks analysis by FEM			
	Construction of third layer (Phase number 12)	Use-phase of new embankment (Phase number 14)	Secondary settlements (14)-(12)
Settlements	13.34cm	15.27cm	1.93cm

Design criteria according to EUROCODE 7:

Based on interface effective stresses of the embankment made of styrene (Fig. 8), the behavior of materials has been checked in accordance with EUROCODE 7. It is implicit that there are three partial computations, which EPS-blocks must fulfill (EPS 160):

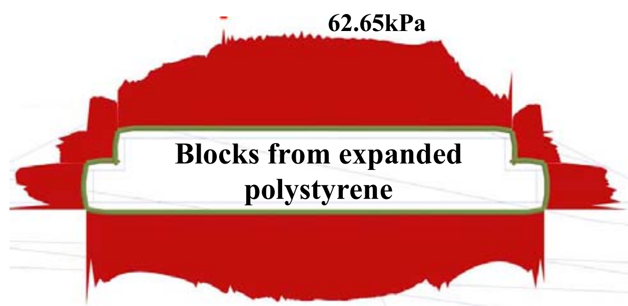

Figure 8. Interface effective normal stresses display

1. The first one refers to the compressive strength of EPS, under short-term load. It is considered that the compressive strength of EPS is the strength at deformations of 10%. This dimension with certain safety factor must be smaller than stresses acting upon the styrene.

- Compressive strength of styrene: $\sigma_{10,d} = \sigma_{10,d}/\gamma_m = 160/1.25 = 128kPa$
- Stresses from permanent load: $\sigma_{v,g} = (62.25\text{-}25) = 37.65kPa$
- Stresses from live load: $\sigma_{v,p} = 25kPa$

Overall stress of styrene according to EUROCODE 7:

σ = 1.35·(37.65)+1.50·25=88.32kPa, since $\sigma_y < \sigma_{10,d}$, the first prerequisite has been fulfilled.

2. The second one refers to the long-term behavior of EPS. Styrene under long stresses, like other materials, is exposed to the effects of creeping. As regards the latter, the deformations in styrene appear at an all-time high of 2% within the time horizon of 50 years, whereas its strength is declining down to the value 30-35% from original one.

- Compressive strength of styrene after 50 years: $\sigma_{10,per,d}$ = 0.35·160/1.25 = 44.80kPa
- Vertical stresses from permanent load, after 50 years: $\sigma_{y,g}$ = 1.35·(37.65) = 50.82kPa

Since $\sigma_y \approx \sigma_{10,per,d}$, one may consider that the second prerequisite has been fulfilled.

3. The third one provides that the deformations of EPS, under cyclic load, remain within the limits of 0,4%. Then the material shall behave with elasticity, without permanent deformations. According to the thesis of *Duškov* [9], [10] this prerequisite is going to be fulfilled provided that maximum stress would be under the limit of $0.35 \cdot \sigma_{10}$.

- Styrene strength under cyclic load: $\sigma_{10,cyc,d}$ = 0.35·160/1.25 = 44.80kPa
- Vertical stress originating from movable (traffic) load: $\sigma_{v,p}$ = 1.50·25 = 37.50kPa

Since $\sigma_{y,p} < \sigma_{10,cyc,d}$ so the third prerequisite has been fulfilled as well.

All three prerequisites have been met, and therefore styrene EPS160 fulfills the prerequisites pertaining to the behavior of materials according EUROCODE 7.

Embankment repair methodolgy by utilizing EPS expanded polystyrene

In view of the fact that EPS has been utilized, in some kind of earthen structure, for the first time in Serbia, the works by its scope and technical requirement called for particular attention, and certain phases had to be carried out carefully, especially the works as specified here-in-after under items 3 & 4:

1. In the first place the old embankment had to be dismantled on the whole by wide excavation of the road base. Excavated soil was loaded and hauled over to the waste dump. Existing unstable retaining wall was dismantled also in this phase;
2. Upon the completion of embankment and retaining wall dismantling, a new wall was built;
3. After retaining wall construction, the subsoil was excavated down to the depth of 1.5 m and followed by the placing of gravel pads/matresses throughout entire length and width. They were compacted in layers of 30-50 cm and were wrapped into non-woven geotextile made of polypropylene (PP). The mattress thickness was 50-100cm. At the lowest hypsometric point of the slope along the bridge pier, a drainage carpet 3 m wide and 0.8 high was placed. Through the drain, the water will move from the embankment subsoil into catchwater drain made of concrete. After the placement of gravel pads/matresses, the construction of embankment began up to the level where the placement of styrene was anticipated. When approaching this level, the works on grading the last layer of crushed stone aggregate of 0-60 mm were carried out manually, by measuring the levels on every single meter, thus to obtain appropriate evenness. Afterwards, the bedding layer made of crushed stone aggregate with fraction 0-2mm and 5 cm thick was carried out. The layer had to be even, thus to avoid unallowed spacing of EPS-blocks. The embankment was graded with screed boards and compacted with vibrating plates weighing 750 kg (Fig 9);

4. Styrene was lined up manually, and coupled with metal plates sizing 33 x 33 cm manufactured in the workshop (Fig.10). The first row of EPS was coupled with metal plates with cut-out edges and bent over on both sides in order to couple both plates. Plates were lined up in such a way, so that in every angle there was one plate, which afterwards coupled the styrene blocks, and one in the middle. The upper row of styrene was positioned so as to avoid the matching of edges of upper and lower block of styrene, and in this way prevent the appearance of weak structural spots. More precisely, the blocks were lined up as rows made of brick for a wall, i.e. not a single joint should match neither vertically nor horizontally (Fig.9). The last row of blocks, was coupled with the same metal plates, yet the edges were bent towards one side only.

Figure 9. Embankment grading with screed bords, prior to the seting of styrene blocks on the left, and mode of lining-up of styrene blocks on the right side

The most critical phases in the embankment construction, refer to the compaction of soil around styrene, and the compaction of layers above it. For the simple reason, one must admit that there is a lack of experience in the construction with styrene, in other words insufficient knowledge of its resilience, and consequently which kind of equipment to be utilized. At the beginning, the filling around styrene was carried out manually, while the first layer of 20 cm was compacted with vibrating plates of 750 kg. Being aware that in the course of compaction, when one approached the edges of styrene with vibrating plates, no changes of its shape occurred, then the operation continued with vibrating rollers of 5 tons, and later with 8 tons (Fig.10). When the last row level was reached, the soil was spread manually, while in the 20 cm thick layer the vibrating plates weighing 750 kg were utilized. No strain appeared after the passage of vibrating roller weighing 5 tons, and afterwards the comapction continued with it. After the completion of the second layer of 25 cm, module of compressibility was measured to be 80MPa. In that particular phase, heavy tipper truck with full load of crushed stone aggregate passed over. It was demonstrated that with material layer of 45 cm, styrene is able to sustain serious loads. Tipper truck vehicle capacity amounts to 25 tons.

Figure 10. Metal plate made in the workshop, which merged blocks of styrofoam, on the left and compaction of the first layer above stiropra roller 8t, at the right

FINAL COMMENT

The primary experience in utilizing the light-weight materials EPS is described in the first part of the paper. Cost-effective solutions have been provided for current geotechnical issues, high embankments on soft soil spots and within the framework of Serbian road network improvement, particularly on Belgrade by-pass.

The second part of the paper refers to the facility made of EPS for the first time in Serbia. It represents the turning point in attaining the experience and impetus for futher use and improvement. Some details and facts as regards the design stage and construction process have been presented.

FEM been used in both cases, being a powerful toolkit for reliable and extensive analyses of wide range of issues regarding the structural stability.

Initial high cost of styrene, does not necessarily mean high cost of a solution, but besides the fear of utilizing innovation, it was the main reason, why after so many years of the design with EPS, the first structure in Serbia, was built only in the year 2010

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