LIGHT-WEIGHT ROAD EMBANKMENTS WITH GEOFOAM (EPS-BLOCKS) FOR THE BELGRADE BY-PASS PROJECT ON THE E70/E75 HIGHWAY CROSSING

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Abstract: The paper describes the Belgrade by-pass project on the E70/E75 highway crossing, the first large-scale implementation of light-weight road embankments in South-East Europe. Due to the use of EPS-blocks (geofoam) the total length of the bridges was reduced by more than 700 m in comparison with the preliminary design. In addition, issues of terrain relative soft spots and high embankments at locations of multi-level intersections of road routes and railroads in the area of future interchange "Batajnica" have been resolved. Simultaneously, the total project costs have been reduced by 50 %. Ever since the 1970s, this methodology has been applied in the developed countries and is meant to provide for minimum disturbance of natural equilibrium after the construction of infrastructural facilities. The utilized EPS blocks are composed by 98 % of air, they are durable, natural stone aggregates are saved, and due to inert properties of EPS there is no pollution of surrounding soil whatsoever. By implementing this advanced design technology one can find solutions that can tackle causes appearing either at locations with soft spots or on unstable slopes (being more relevant for Serbia) rather than mitigating the symptoms, which has been the case for previous solutions.

Keywords: EPS geofoam, embankment, road, settlement, dam

INTRODUCTION

The soil bearing capacity on the location of the future interchange "Batajnica" at the position where the motorway from Novi Sad and the Belgrade by-pass (two biggest cities in Serbia) cross is relatively limited. In the previous version of preliminary design this problem was solved with increased lengths of the bridge structures which started at the height of 4.83 m or 5.50 m above ground in case of E75 basic alignment and at 4.3 m to 5.0 m height with other road routes. Such limited starting heights on one hand and grade separated Belgrade-Novi Sad railway crossings on the other implied an extrem long bridge structure of 1730 m for the basic alignment only. Preliminary calculations, however, showed that such approach was not economically justifiable compared to the usage of light-weight structures with EPS-blocks which have become available in the meantime thanks to Dutch-Serbian technological cooperation. In this project, InfraDelft, Republic of Sebia Roads and the Highway Institute of Serbia had crucial roles actively supported by the relevant ministries of the Netherlands and of Serbia. EPS means **E**xpanded **P**oly**s**tyrene foam.

REASON FOR IMPLEMENTING LIGHT-WEIGHT STRUCTURES

In the new version of "Batajnica" interchange preliminary design, calculating with the implementation of ultra-light EPS-blocks (bulk density 15-35 kg/m³ when dry), bridge structures have been significantly shortened by increasing road finished level in their starting points. In that way, the designed bridge structure on the north side of the basic alignment starts at the height of 8.71 m from the natural ground and increases up to 9.02 m on the north-east side where the I. category road passes over the railway. In table 1, actual values of the previous and in the latest version of preliminary design (reduced), lengths of bridge structures and the heights of embankment and bridge crossing points for all the routes pertaining to the interchange are given. As it can be seen in the given table, the realization of high access embankments without increasing soil load (and thus settlement) by applying contemporary design methodology and EPS-blocks on the sections marked on figure 1 will enable overall reduction of lengths of (expensive) bridge structures in the amount of 718 m within the interchange.

The previous discussion did not include branches 1 and 2 of the basic alignment, although the reduction of vertical soil load by using EPS-blocks is significant for another reason. Two pipelines pass under the anticipated embankment slope 2 m deep in the ground and in a distance of 13 m between each other on the west side on these embankments. If the slope gradient would remain 1:3, both pipelines would lie entirely or partially in the zone of road structure weight impact. Since slope gradient 1:2 will be used for light-weight embankments, only the “more east” pipeline will be exposed to possible settlements which therefore have to be minimized. For that purpose, thicker package of EPS-blocks will be placed locally and the own weight of the embankment will be additionally reduced in order to exclude the risk of significant deformation of the present gas pipeline after the interchange has been realized.

Table 1. Road routes, chainage, road and terrain finished levels, maximum embankment heights on crossing points with the bridges and corresponding lengths of bridge structures for all routes pertaining to "Batajnica" interchange within the present preliminary design with light-weight structures and the previous version with standard embankments

Road route	Chainage	Road level	Terrain level	Max height embankment	Bridge length
According current preliminary design with light-weight structures					
E75 basic alignment	187+084.94 188+440.11	88.20 84.83	81.18 76.12	7.02 8.71	1355
M22/1-k2	1+469.26 1+726.91	87.64 89.10	79.20 82.60	8.44 6.50	258
I. category road	0+636.55 0+828.55	85.97 88.02	78.32 79.00	7.65 9.02	192
According previous preliminary design with sand embankments					
E75 basic alignment	186+950 188+680	88.20 82.33	82.60 77.50	5.60 4.83	1730
M22/1-k2	1+385 1+809	84.65 86.58	79.65 82.30	5.00 4.28	424
I. category road	0+557 0+925	82.75 83.30	78.45 79.00	4.30 4.30	368

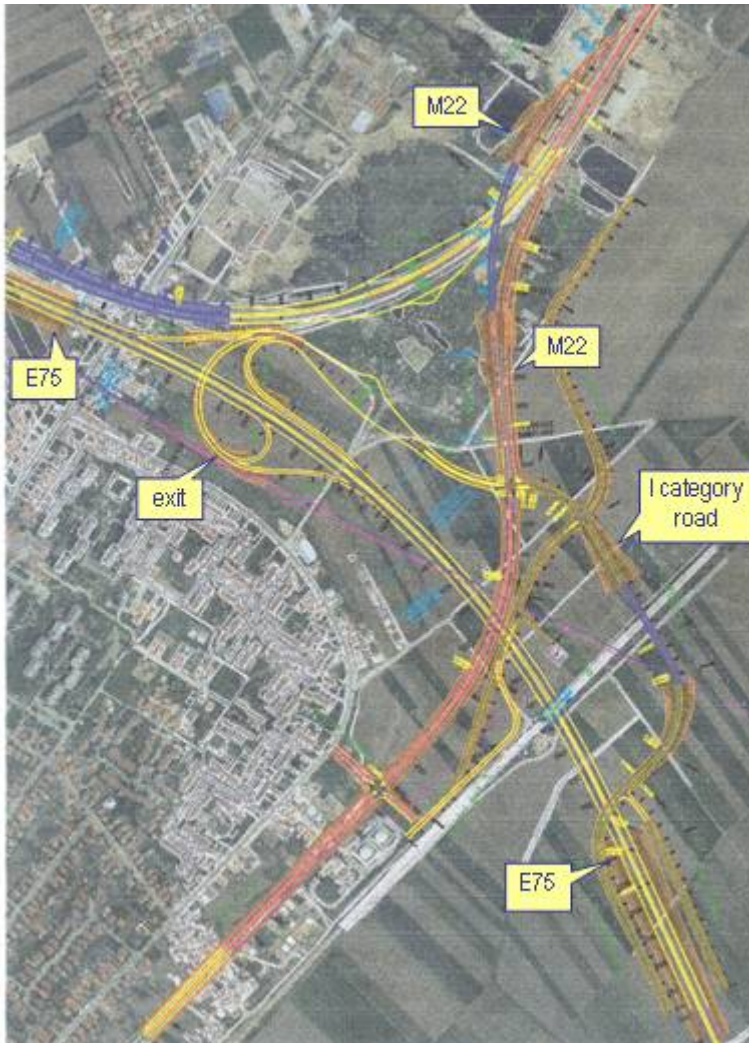

Figure 1. Aerial photo of "Batajnica" interchange with all road routes and indicated light-weight structures made of EPS blocks

BOUNDARY CONDITIONS AND STARTING POINTS

When dimensioning the embankment composed of EPS-blocks and sand, the following boundary conditions and starting points acted as guidelines:

a) Maximum allowed settlement for embankment of E75 basic alignment, M22 main road and I. category road is 20 cm, out of which ultimate consolidation settlement (from the moment of opening interchange for traffic) is 15 cm;
b) Maximum allowed vertical soil load as a consequence of the realization of "Batajnica" interchange road structures is 50 kPa, which is in accordance with the allowed settlements pursuant to the results of field researches, laboratory tests and calculations;
c) Carriageways for the basic alignment and its branches, as well as for M22 road and I. category road are determined according to the expected traffic volume; own weights of these carriageways constitute a part of the allowed vertical load and as such directly impact the designed layers of light-weight road embankment;
d) Design slope gradient of embankments is not conditioned with ownership borders along the corridor or with urban planning rules, it is conditioned only with the stability of the available local drudged sand (with size distribution of 20% of particles 0,63 μm-0,5 mm and of 80% of particles 0,5-2 mm, bulk density >17 kN/m³, angle of internal friction > 25°);
e) Since the lowest part of the embankment is realized with standard material (drudged sand), the hazard of high groundwater and thus caused lifting of the lowest EPS-blocks with water thrust at the location of "Batajnica" interchange can be ignored;
f) Concerning the novelty of implementing light-weight road structures in the region and complete lack of contractors' experience with using EPS-blocks (Geofoam) in road construction, maximum attention has to be paid on well-known contractor's mistakes/inaccuracies when dimensioning; this refers, first of all, to the construction phase when heavy civil engineering machinery performs the transport, filling and compaction of sand layer and stone aggregate in upper embankment layers above EPS-block packages;
g) After ultimate criteria, construction costs are a relevant criterion for optimizing design of road embankments within "Batajnica" interchange;
h) Dimensions of EPS-blocks and thus the thickness of layers in package are determined by paying attention on aspects of realization including the available machinery, (non)trained machine operators, relatively cheap and available manpower, at all times implying normal working conditions (maximum weight which construction workers can carry, etc.);
i) Economic criterion also determines the type, or specific weight of the applied EPS;
j) Design structural life cycle of interchange road embankments exceeds 30 years even in the conditions of minimum maintenance (which is more a rule than an exception in this region); the only exception is upper (wearing) asphalt layers;
k) Protection of EPS-blocks with impermeable foil from the contact with (dissolving) oil derivatives will be applied on the entire embankment of the basic alignment because of the high importance of the motorway for national economy; concerning the very low possibility of oil-tanker turning over or a similar accident on one hand, and relatively simple reparation of easily accessible embankments on the other, the remaining road embankments within "Batajnica" interchange will remain unprotected because of savings while the concrete layer on top will guarantee sufficient impermeability.

APPLIED DESIGN PRINCIPLES FOR LIGHT-WEIGHT STRUCTURES

The stated ultimate criteria were strictly observed in the final selection of material and dimensioning of light-weight road structures and the starting points were adopted as far as possible. Practically, this came down to the following actual interpretations:

- Thickness of EPS-block packages is conditioned with ultimate criteria a), b) and c) i.e. maximum own weight including adequate weights of carriageways plus chosen layers above EPS-packages and lower layer of sand up to the natural terrain finished level;
- For design slope gradient of embankments, the gradient 1:2 (instead of 1:3) was consequently applied since the planned drudged sand pursuant to ultimate criterion d) is not unstable concerning the stated effective angle of internal friction of 25°; economic advantages (pursuant to the ultimate criterion g)) of the adopted gradient are smaller capture of areas and reduced amounts of material (both of EPS-blocks and sand); additional functional advantage in case of branches 1 and 2 of the basic alignment is also the increased distance from the pipelines;
- Having in mind the starting point f) i.e. the novelty of light-weight structures in the region and the need for protecting relatively less robust embankment core consisting of EPS-blocks from constructing machinery during the construction activities, as well as the securing of favourable bed for the compaction of the specified bearing layers consisting of loose stone aggregate and sand, concrete layer with light reinforcement will be cast directly over EPS-packages (figure 2); further functional advantages of concrete layer are minimizing negative impact of possible gaps between blocks (caused by careless fitting and/or local settlements) and practical impermeability for fluids; concrete layer thus eliminates the need for protecting EPS-packages with impermeable foils on the upper side against possible contact with dissolving oil derivatives (starting point k) in case of incidents (turning over of oil tankers, etc.);

Figure 2. Example of concrete layer with light reinforcement over EPS blocks, above which the roadbase courses are subsequently followed by asphalt layers

- The placement of relatively light (and thus cheaper) EPS100 type (mark pursuant to the new European Standard) is not a problem because of the presence of concrete layer, pursuant to the starting point i), which has an important positive economic effect on the necessary investment because of the significant scope of works;
- Pursuant to the stated existing soil bearing capacity at the location of the future interchange and on light-weight sections, a part of the embankment will consist of drudged sand (total thickness about 1.75 m) because in that way the amount of more expensive EPS geofoam is reduced in accordance with the starting point i). At the same time, the ultimate criteria for the allowed own weight of the structure is observed;
- Using the allowed presence of the abovementioned sand layer, carriageway is structurally strengthened with the placement of ≥ 0,5 m of sand between the concrete layer and the bearing layer composed of loose stone aggregate; this sand is actually the moved layer from the lowest part of the embankment, which practically means that in this way the total own weight (and price) of the structure remains unchanged, and we significantly strengthened the carriageway and provided the required design bearing capacity of the sand subgrade.
- Pursuant to the starting point f), a functional very important consequence of placing sand layer of ≥ 0.5 m over the concrete layer above EPS is that the realization of drainage and placement of road furniture in the upper part can be conducted in a usual manner for contracting enterprises in the region; the abovementioned drastically decreases the possibility of mistakes and/or inaccuracies, which is always present when applying new methods of work for the first time;
- Paying attention to the following three aspects: 1) the possibility of relatively equal reduction/increase of EPS-package thickness and thus precise monitoring of terrain, i.e. the realization of adequate transitional structures in longitudinal section, 2) the possibility of designing EPS-packages which is followed by slope gradient in the cross-section of light-weight embankments without too big rises and 3) usage of blocks with dimensions and thus weights which can be easily placed manually (with two workers) in accordance with the starting point c), all layers in EPS-packages of the light-weight structures have the same thickness of 0.5 m;
- The presence of the sand layer in the lowest part of the embankment enables feasible creation of adequate working platform without any problems (flat and with designed gradients) at the bottom of EPS-packages; the second advantage is by default excellent drainage and frost insusceptibility;
- For the calculations of vertical soil load as a consequence of embankment's own weight, bulk densities of materials with critical moisture expected in engineering practice were used.

LIGHT-WEIGHT ROAD STRUCTURE FOR E75 BASIC ALIGNMENT

Drawings of characteristic profiles based on the previous calculations are given in figure 3 and 4. Not shown in these figures is the impermeable HDPE (High Density Polyethylen) foil covering the EPS-blocks on the side for protection of contact with oil derivatives that dissolve EPS. As well as the chance for a full oil tanker to turn over exactly on the section with light-weight embankment may be minimal, we cannot exclude it. Such risk is eliminated because of the importance of the E75 basic alignment for regional economy. As it has already been stated, concrete offers sufficient protection on the upper side. Example of placing the foil is illustrated in figure 5. Most important are impermeable seams between adjoining foils. The entire protection makes no sense without total impermeability of seams. Of course, there is no need for protection from the lower side.

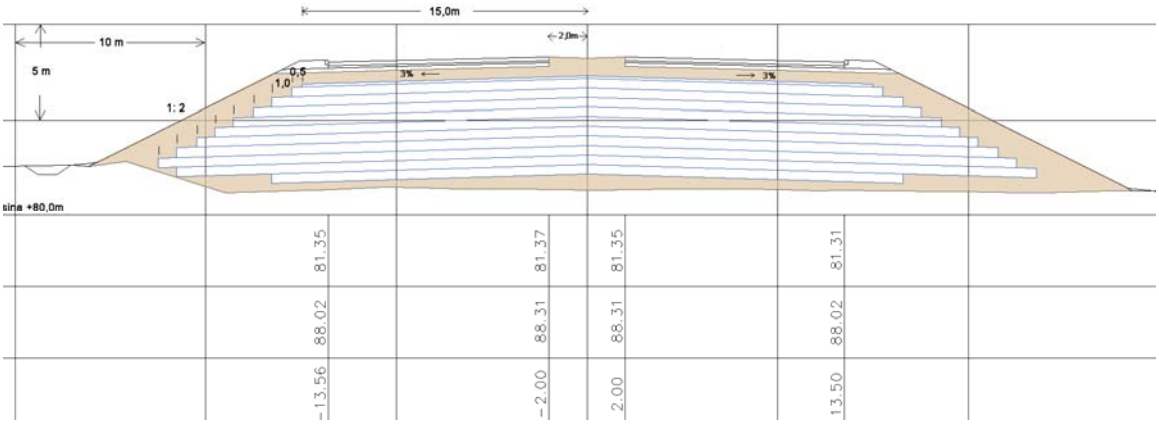

Figure 3. Cross-section profile of the designed light-weight structure with EPS blocks at km 187+050 of interchange "Batajnica" basic alignment

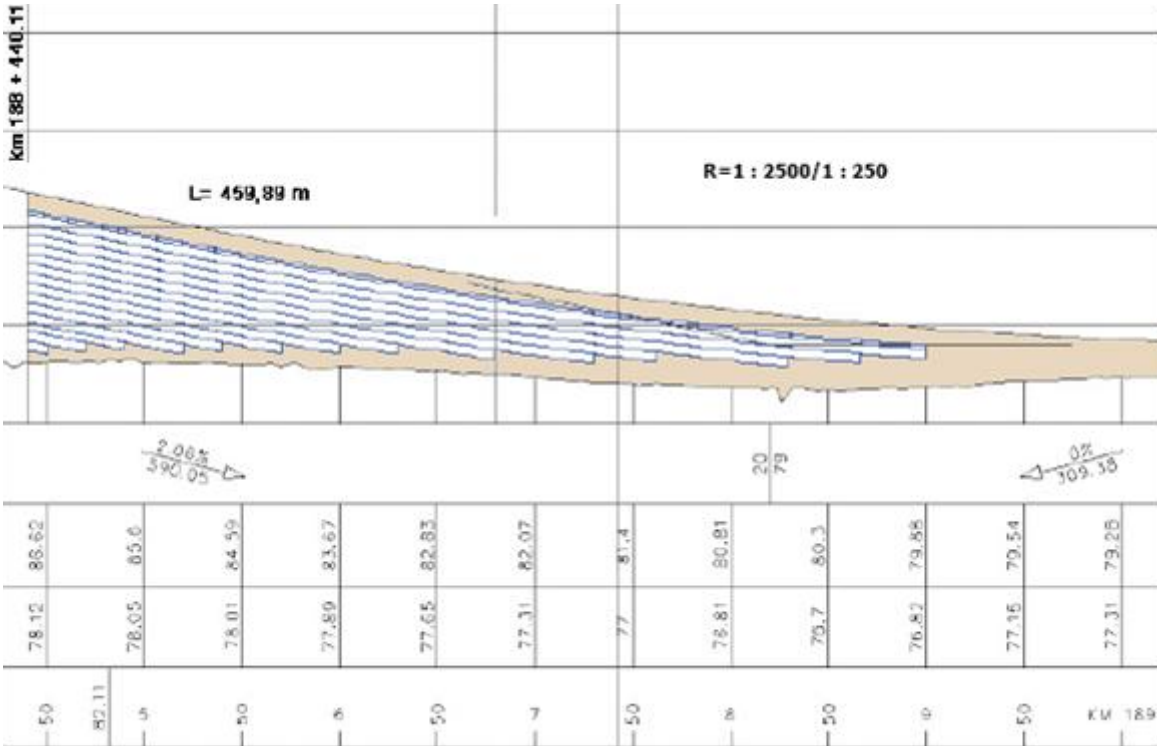

Figure 4. Longitudinal profile of the designed light-weight structure with EPS blocks between km 188+440 and km 189+000 of interchange "Batajnica" basic alignment

Figure 5. Example of the protection of EPS blocks on the embankment side with HDPE impermeable foil

Figure 6. Example of light-weight structure with concrete course above EPS blocks with longitudinal profile and crossfall.

COMPARISON OF CONSTRUCTION COSTS

Most important conclusions of construction cost estimation and mutual comparison of light-weight embankments and alternative bridge structures for road routes within "Batajnica" interchange are the following:

- By far the most important conclusion is that the cost of 6.7 m high light-weight structure with EPS-package (consisting of layers 4.5 m thick in total) is significantly lower than half the price of bridge structure for 30 m wide motorway constructed in a conservative way.
- By reducing the width of the median from 4.0 m to say 2.0 on light-weight sections of the basic alignment, it is possible to achieve savings of about 15% without any reduction of functionality and/or long-life. Such significant savings are possible since the widths of all layers in EPS-package are directly reduced for the assumed 2 m.

ANALYSIS OF ROAD STRUCTURES WITH PLAXIS

Critical cross-section of "Batajnica" interchange basic alignment was modelled and analysed with method of finite elements. The analysis was done with the program PLAXIS for a 8.5 m high road structure of basic alignment with the following two alternative structural solutions: a) standard sand embankment and b) light-weight structure with EPS-blocks. In reality, this situation exists at km 188+450 of the basic alignment. Results of settlement and vertical deformation calculations are shown in figures 7 (EPS embankment) and figure 8 (sand embankment). The calculated settlements are less than 0.14 m for the EPS embankment and over 0.51 m for standard sand embankment.

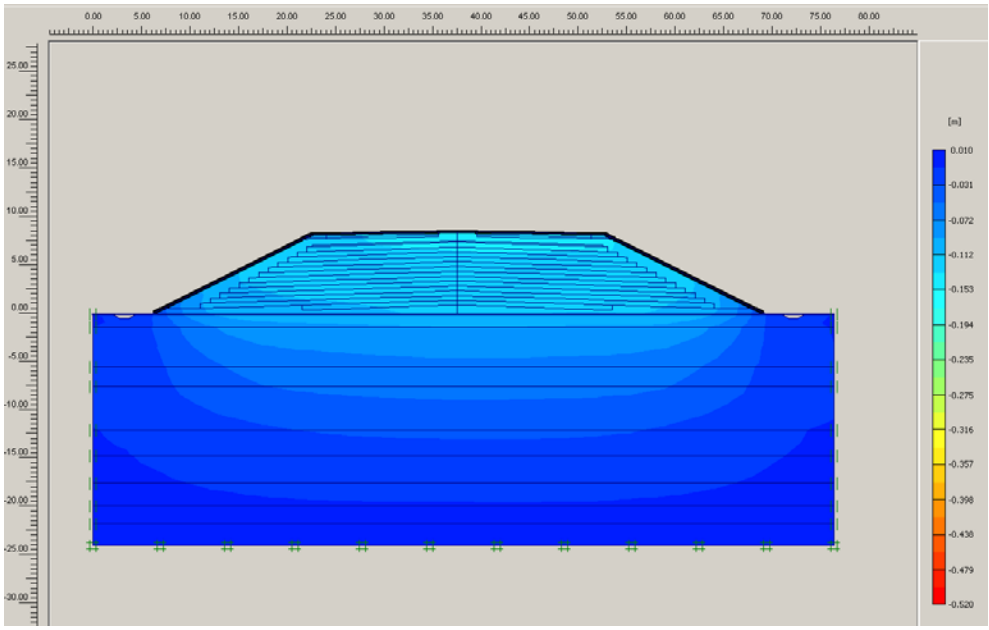

Figure 7. Resulting vertical deformation (including the settlement magnitude on the road finished level) under road structure's own weight with the embankment EPS-package (thickness 6.5 m) obtained by PLAXIS-model analysis of typical cross section the at km 188+450 at the interchange Batajnica basic alignment.

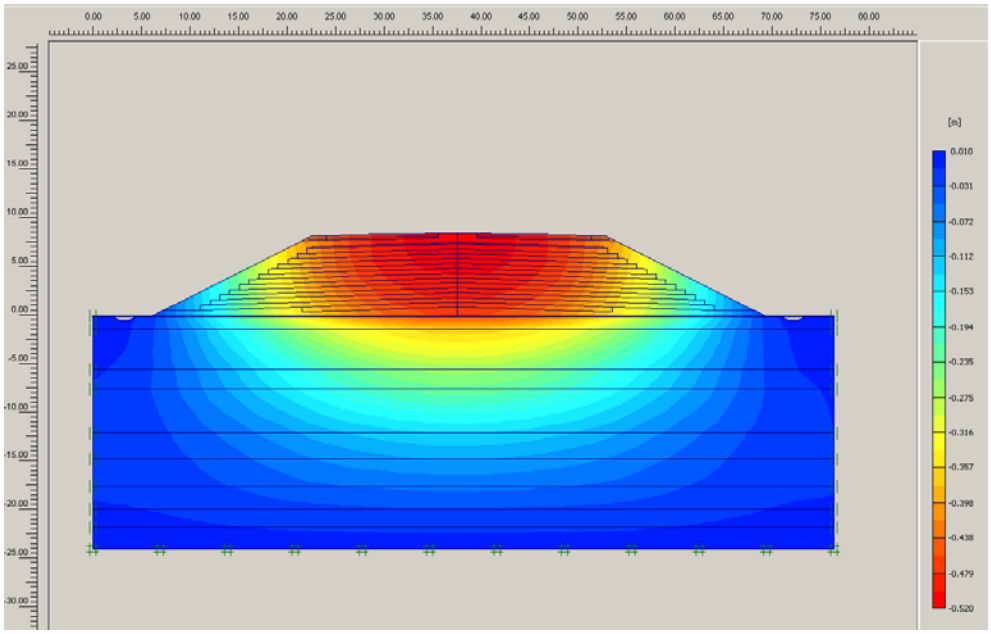

Figure 8. Resulting vertical deformation (including the settlement magnitude on the road finished level) under light weight structure's own weight with sand embankment obtained by PLAXIS- model analysis of typical cross-section at km 188+450 at the interchange Batajnica basic alignment.

FINAL COMMENT

The given example shows that the application of light-weight road structures with EPS-blocks (compared to standard methods and natural materials) has comparative advantages both in technological and in rational financial sense. This is a contemporary methodology which enables extremely cost-effective solutions for current problems in the modernization of Serbian infrastructure when roads are constructed with high embankments on terrains consisting a low bearing capacity where bigger settlements are possible and/or on unstable slopes where the disturbance of the natural equilibrium leads to the occurrence of landslides.

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