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Geotechnical zoning of the terrain along the first section of E-80 highway in Serbia – SEETO route 7

Zonage géotechnique du terrain le long du premier tronçon de l'autoroute E-80 en Serbie - SEETO route

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ABSTRACT: Part of E-80 highway that passes through Serbia (from the city of Nis to the administrative border Merdare) is 77 km long. The highway is divided into two sections: the first from Nis to Plocnik (39.4 km long) and the second from Plocnik to the administrative border with Kosovo. Compared to the total length of the first section, about 20 % is covered by appropriate structures (tunnels, bridges, overpasses), while on the rest of the section, the construction of numerous cuts is planned, and almost 45% of the route passes through alluvial relief of the Toplica River. Geotechnical zoning is performed based on numerous factors which are generally divided into three basic categories. In this way, the following were identified: A - „favourable“, B - „conditionaly favourable“ and C - „unfavourable“ sections, which are related to the complexity of the construction of planned structures on the highway route.

RÉSUMÉ: Une partie de l'autoroute E-80 qui traverse la Serbie (de la ville de Nis à la frontière administrative de Merdare) a une longueur de 77 km. L'autoroute est divisée en deux sections: la première de Nis à Plocnik (39.4 km) et la deuxième de Plocnik à la frontière administrative avec le Kosovo. Par rapport à la longueur totale de la première section, environ 20% sont couverts par des structures adéquates (des tunnels, des ponts, et des passages supérieurs), tandis que sur le reste de la section, de nombreuses coupures sont prévues et près de 45% du tracé passe au travers du relief alluvial de la rivière Toplica. La zonage géotechnique est réalisée en fonction de nombreux facteurs qui sont généralement divisés en trois catégories. Ainsi, nous identifions : A - des sections „favorables“, B - des sections „généralement favorables“ et C - des sections „défavorables“, liées à la complexité de la construction des structures prévues le long de la trace de l’autoroute.

Keywords: Highway; Geotechnical investigations; Zoning of the terrain;

1 INTRODUCTION

The highway E-80 (SEETO route 7), represents the traffic intersection of the Western Balkan and is part of the main regional transport network in Southeast Europe. Total length of the route is 77 km, and it is divided into two sections: the first one, 39.4 km long (ends at the Neolithic settlement Plocnik), and the second from Plocnik to Merdare (Figure 1). The most characteristic structures on the route are the bridge across the Toplica River (1020 m) and the tunnels „Bozurna“ (620 m) and „Racunkovo brdo“ (1225 m).

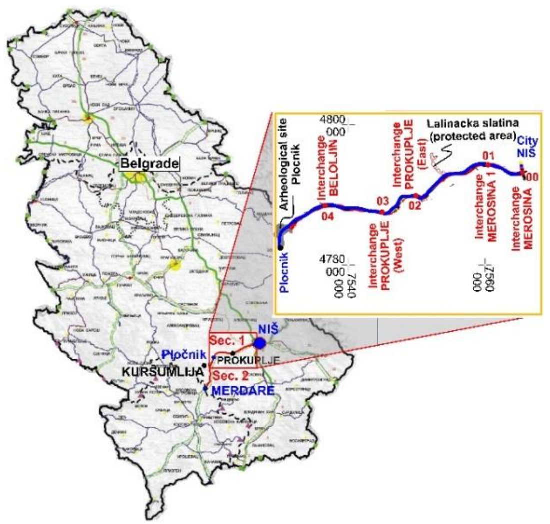

Figure 1. Highway route with characteristic details on the section Nis-Plocnik

Remarkable number of geotechnical laboratory and terrain investigations were carried out for Preliminary Design needs during 2016 and 2017: 121 exploration boreholes, 23 Cone Penetration Tests, 105 Standard Penetration Tests, 2 dilatometer tests, 277 samples of soil and rock were tested, 11 piezometer constructions were built in, geophysical investigations (68 geoelectrical sounds, 18 refraction profiles), mineralogical-petrological tests (Rakic, 2017). It is important to mention research related to wider area of highway route which enabled registration of large regional structures that are important for highway construction: photo-geological analysis of satellite images, study of rupture pattern and geomorphological occurrences with layout of instability occurrences, neotectonical and seismogeological analysis, determination of design parameters of seismicity for structures, forming of engineering geological map of limitations.

2 ENGINEERING GEOLOGICAL CONDITIONS IN THE ZONE OF HIGHWAY ROUTE

Regional rupture pattern indicates two systems of perpendicular structures that form a block structure of investigated terrain (Figure 2). The most prominent is the fracture zone in the central part of the route in Prokuplje area, general strike direction SW-NE (Rakic et al., 2018).

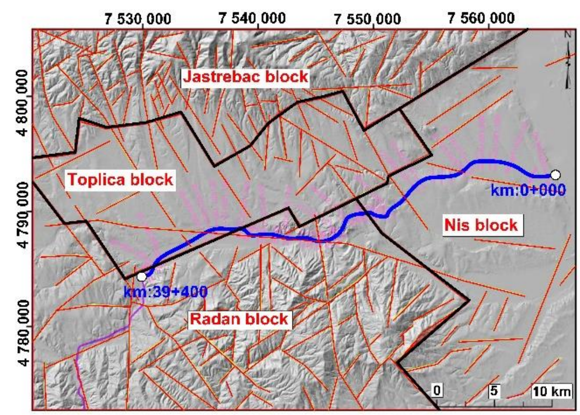

Figure 2. Regional rupture pattern - analysis of satellite images

Geological composition of terrain is very heterogeneous in the wider zone of the highway route. It is built of crystalline schists (fine grained gneisses dominate in Prokuplje area), Neogene sediments of foothills and Quaternary sediments in the valley of the Toplica River and its tributaries. Investigation results enabled the separation of three characteristic regions (Table 1). In the section 0-17.2 km, highway route crosses alluvial relief of the Toplica River tributaries and river terraces of smaller distribution (*al, pr,* t_1*,* t_2). In small streams there is a mixture of sands, gravel and rarely clays that are often muddy and saturated, but can be well drained. River-terraced plateaus are outside the influence of the Toplica River flow and they are completely stable. On this section, deluvial-proluvial structures are registered which are isolated in smaller river zones (Figure 3).

On the section from Prokuplje to Plocnik (km: 23.5-39.4), the alluvial plane of the Toplica River is mostly covered with spacious flood cones formed of smaller torrential flows which gravitate from surrounding terrain to the Toplica River. It is formed of sands and gravel with smaller content of sandy clays and clayey sands, but with occasional local occurrences of muddy zones. These muddy zones indicate early stage of alluvial environment formation, and they are unfavourable from engineering geological aspect. Potential instabilities are only present in the zone of unregulated river banks (Figure 4).

Table 1. Engineering geological zones with extracted geological units

Section	Length (km)	Represented geological units
Nis - Prokuplje	0-17.2	Alluvial, proluvial and river-terraced plateaus (*al, pr,* t_1, t_2) Quaternary and Neogene hilly terrains (*dl-pr, el-dl, Pl, M-Pl*)
Bypass Prokuplje	17.2-23.5	Alluvial and river-terraced plateaus (*al,* t_1) Crystalline schist complex (G_s, G_a, G_m, *M, Q*)
Prokuplje - Plocnik	23.5-39.4	Alluvial, proluvial and river-terraced plateaus (*al, al-pr, pr,* t_1, t_2) Quaternary and Neogene hilly terrains (*dl-pr, dl, Pl, M-Pl, M*) Cretaceous flysch complex (*pr, K*)

Neogene hilly terrains (*Pl, M-Pl, M*) are usually covered with Quaternary sediments (*dl-pr, el-dl, pr*). They are located along the periphery of the upper and lower Toplica valley. They are intersected with stream and river valleys that have deposited proluvial sediments on both valley sides of the Toplica River. Based on age and lithological composition, terrain is divided in two parts: a younger Neogene complex downstream from the city of Prokuplje (km: 0-17.2) and an older Neogene complex upstream from Prokuplje (km: 23.5-39.4). They are separated by crystalline metamorphic complex of Prokuplje vicinity.

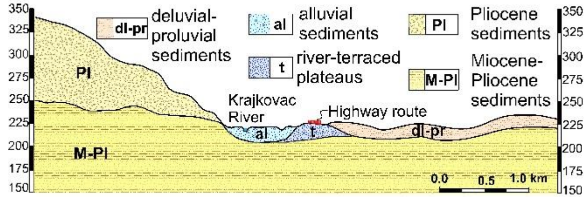

Figure 3. Characteristic engineering geological cross-section of alluvial plain terrain (km:0-5.5)

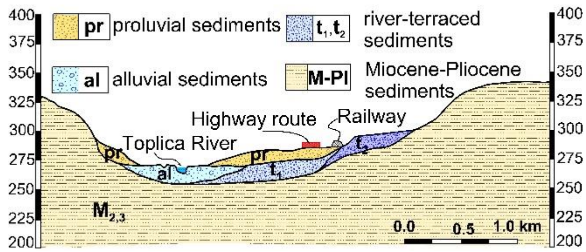

Figure 4. Characteristic engineering geological cross-section of alluvial plain terrain (km: 23.5-39.4)

The younger Neogene complex corresponds to the upper Miocene and lower Pliocene. Two horizons are determined: lower - in which fine grained sediments dominate (clays, silt with fine grained sands, coal clays etc.) and upper - built mainly of sands with rare sandy clay layers and gravel lenses. On one part of the highway route (on „Debelo Brdo“ slopes, zone from 9.0-12.0 km), unstable terrains were determined, whose relief forms are characteristic for suspended landslides (Figure 5). Pliocene coarse grained complex is saturated, and larger number of active wells is registered in the zone of outlet portal of the tunnel „Bozurna“, so the permanent influence of groundwater on the tunnel is expected (it is confirmed by observations in piezometers).

Older Neogene complex has a large distribution in central and eastern part of Toplica basin (Figure 4). It has very heterogeneous lithological composition, characterized by fine grained clayey-silty sediments (thin layered marls, claystones and sandy claystones with characteristic horizontal lamination), and rarely conglomerates and breccias.

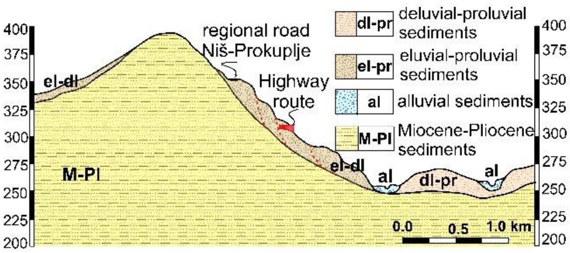

Figure 5. Characteristic engineering geological cross-section of Neogene hilly terrain (km: 9.0-12.0)

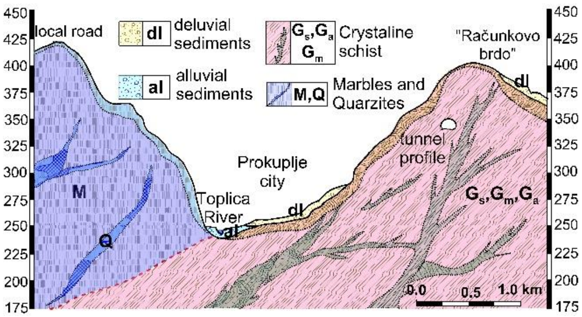

Figure 6. Characteristic engineering geological cross-section of the crystalline schist complex

The central part of the highway route is built of crystalline schist complex (*Gs, Ga, Gm, M, Q, ρ*) of different quality with variable height of weathering zone (Figure 6). In the structure of this metamorphic complex, fine grained gneisses dominate, with presence of amphibole and micaschist gneisses, with appearances of marbles and quartzites in the form of wires. Amphibolites do not represent a permanent horizon, but appear in the form of lenses with max thickness of 10 m. Products of physical-chemical decomposition of this complex have different thicknesses, ranging from 0.5 m to over 5.0 m. More solid gneisses and amphibolite have thinner weathering zone and build up morphologically more prominent parts of the terrain. Planar erosion with sporadic linear erosion is present on steep slopes, and products of these processes are deposited at the bottom of the slopes and on the flat parts of the terrain.

3. GEOTECHNICAL ZONING OF THE TERRAIN

3.1. Zoning of the terrain according to engineering geological limitations

Zoning is performed based on natural conditions that are currently present in the terrain, taking into account engineering geological and hydrological characteristics, morphology of the terrain and basic meteorological conditions. During the formation of engineering geological limitation map, zoning of the terrain was performed into: A-terrains with minimal limitations, B-terrains with minor limitations and C-terrains with larger limitations (Figure 7).

A - terrains with minimal limitations are favourable and stable in natural conditions. These terrains include crystalline schist complex, clastic carbonate sediments with eluvial-deluvial zone thickness of up to 2 m and flattened ridge and slopes with inclination up to 10^0. Also, lake sediments are included with eluvial and deluvial structures, river-terraced plateaus and spacious torrential areas, distant from the influence of river and stream flow.

B - terrains with minor limitations are terrains with conditionally favourable engineering geological characteristics (conditionally stable on slopes). These terrains include crystalline schist complex and clastic carbonate rocks with eluvial-deluvial weathering zone of thickness over 2 m on slopes with inclination $>10^0$, lake sediments with eluvium and deluvium >2 m on slopes with inclination $> 5^0$ and alluvial and spacious or smaller torrential areas with occasional active influence of torrential flows. Within this zone, smaller marsh parts of the terrain are extracted that are determined in alluvium of the Toplica River.

C - terrains with larger limitations have unfavourable engineering geological characteristics, potentially unstable to unstable on slopes and in the case of larger cuts. These terrains include crystalline schist complex and clastic carbonate sediments with eluvium and deluvium thickness of over 2 m, on slopes with inclination $>15^0$, stream valleys with constant torrential activity, alluvial-proluvial plateaus with active torrential flows with high river banks.

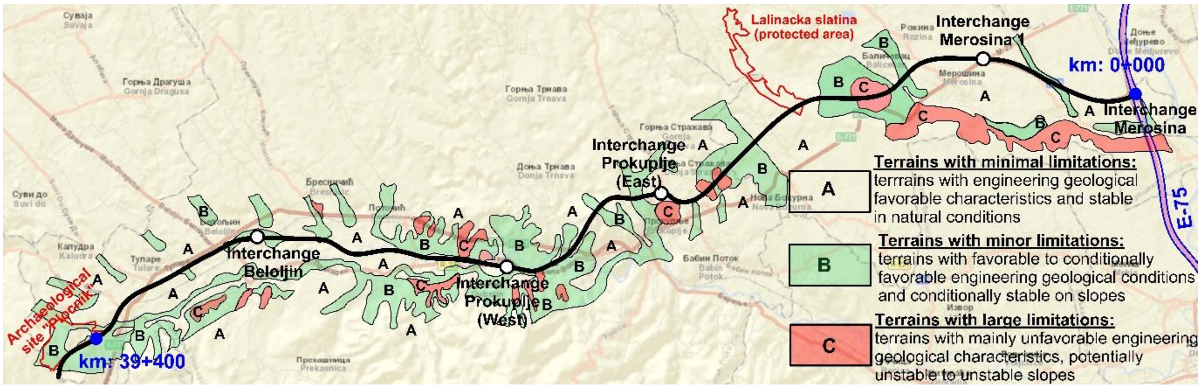

Figure 7. Map of engineering geological limitations along the highway route

3.2. Zoning of the terrain according to geotechnical conditions for construction

Geotechnical conditions are very complex, because the highway passes through numerous cuts, and entire route is built on the embankment in alluvium of the Toplica River. In relation to the total route length, about 20 % (7.8 km), is on the terrains with characteristic morphology, so appropriate structures were designed (33 bridges, 8 overpasses, 5 interchanges, 6 ramps and 6 tunnels). Zoning of the highway route in relation to the geotechnical conditions for construction was performed based on numerous factors that are generally divided into three categories (Hsai-Yang and John, 2014):

- „factors of the past“ i.e. basic geological structure of the terrain (lithostratigraphic and lithogenetic characteristics, age of rock masses, genesis) and basic hydrogeological characteristics (permeability, aquifer characteristics),
- „factors of the present“ i.e. relief (characteristic shapes, longitudinal and transverse inclinations), modern geological processes and occurrences (sliding, surface decomposition, erosion), hydrogeological conditions (groundwater level, flooding), coverage of the terrain, climatic conditions,
- „factors of the future“ that are related to the geotechnical complexity of planned highway structure construction (excavations, cuts, embankments, drainage etc.).

The influence of the mentioned factors over time is schematically presented in Figure 8. Three categories are defined: A-„favourable“, B-„conditionally favourable“ and C-„unfavourable“ terrains (Rakic et al. 2018).

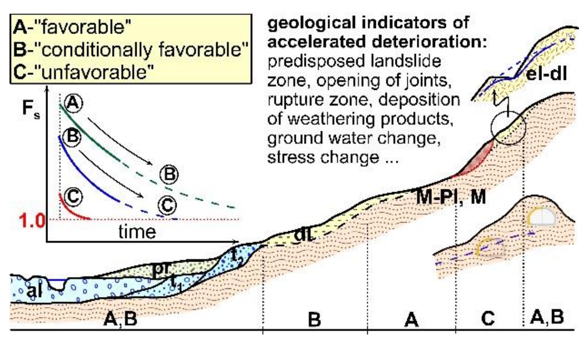

Figure 8. General model of terrain zoning based on geotechnical conditions

Category A includes terrains that are stable in natural conditions. Maximal groundwater level is at a depth greater than 2 m in these terrains. In solid rock masses is not expected rock fall or erosion as well as shallow sliding on unsecured slopes over 2 m in height. Heterogeneity in terms of lithological composition, weathering degree of rocks as well as variable physical-mechanical properties, does not have significant impact on conditions of construction.

Category B includes terrains that can be conditionally stable in inadequate performing of construction works (high slopes, portals and approach cuttings of tunnels). These are terrains in which maximal groundwater level is 2 m, landslides can be activated and smaller rock falls (weathering, erosion and shallow sliding on unsecured slopes over 2 m in height), slopes endangered by erosion of different intensity, occasional activity of torrential flows, fluvial erosion with undermining of river banks, periodic flooding of the terrain. Certain significance will also have heterogeneity in terms of lithological composition, weathering degree and primary alternation of rock mass as well as variable physical-mechanical properties. In these terrains, temporary reduction of safety factor can be caused by short-term and temporarily events.

Category C includes terrains that are potentially unstable to unstable on slopes, terrains in which active and suspended landslides are registered (possibility of causing new landslides on conditionally stable slopes due to inadequate earthworks), constant activity of torrential flows and torrential flooding, wetland terrains, muddy saturated soils. The great importance on construction conditions has the heterogeneity in terms of lithological composition, weathering degree and variable physical-mechanical properties.

3.2.1. Section: Nis – Prokuplje (km: 0.0-17.2)

Section of the highway Nis (south) – Prokuplje (east) from km: 0.0-17.2, is divided in two subsections (km: 0-5.5 and km: 5.5-17.2).

The first one coincides with the existing route of regional road Nis – Kursumlija, which will represent one traffic lane of new highway. It is divided into two characteristic zones: Zone I - consists of alluvial-terraced or alluvial-proluvial sediments in the surface zone, and Zone II - consists of deluvial-proluvial sediments in the surface zone (terrain base is made of Mio-Pliocene clayey-marl sediments). On this subsection, the highway is built at the level of the terrain or on embankments height of 0.5 to 1.5 m (locally, in the case of bridges approaches, embankments of higher heights are designed). The groundwater level is at depth over 5.0 m, and only in the zones of smaller streams is at depth of about 2.0 m. In geotechnical sense, most of the route is estimated as favourable-A. Conditionally favourable-B is a part of the route where the embankment of height over 3.0 m is designed, at a point where the existing embankment of regional road will be widen (Figure 9).

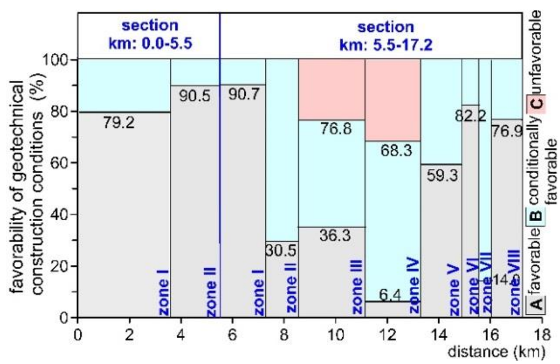

Figure 9. Terrain zoning according to geotechnical conditions for construction (km: 0.0-17.2)

The second subsection is the longest one (about 12 km), so geological structure is slightly more complex with extremely variable lithological structure. Therefore, eight characteristic zones are defined (I – VIII). The beginning of this section is related to the separation of the highway route from the existing regional road Nis – Kursumlija, while the end of the section is in the beginning zone of metamorphic complex. The groundwater level is variable, on lower level terrains is about 2.0 m, but it is usually much deeper or not determined. This subsection is the most demanding in geotechnical sense, because of great depths of cuttings in terrains that are prone to superficial and linear erosion-ravines (locally over 8 m), as well as because of construction of high embankments (over 6.0 m). Therefore most of this subsection (about 45%) is characterised as conditionally favourable-B and more than 12 % as unfavourable-C because in some chainages embankment height is over 15 m, which requires special construction methods. In some zones, conditionally favourability is caused by high groundwater level, especially in the part of the terrain built of Pliocene series with extremely high groundwater content. Locally, terrains with steeper slopes are affected by modern processes and instability occurrences (shallow sliding is determined which affected weathering zone of Neogene sediments). Within this section, construction of three tunnels is planned: „Debelo brdo“, „Slatina“ and „Bozurna“.

3.2.2. Section: bypass Prokuplje (km: 17.2-23.5)

On this section, geological structure is complex in neotectonic and structural way. It includes two different structure blocks: so called Nis - Mio-Pliocene characterized by descending and Radan – Proterozoic metamorphic complex characterized by rising along fault zone NE-SW. Therefore, zoning according to the weathering degree was performed within this section: upper weathering zone of gneiss (clayey silts), lower weathering zone of gneiss (degraded and faulted fine grained gneiss, micaschist gneiss and amphibolite gneiss) and faulted fresh fine grained gneiss, micaschist and amphibole gneiss with appearance of marble and quartzite. In the initial zone of the section, the problem may be a high groundwater level that is extremely variable along the route, and is difficult to describe in general, but has been analysed for each structure separately. In crystalline schist complex, the interaction of more compact and solid components - quartzite and marble, and softer and more degraded gneisses of different composition was analysed. Occurrences of rock falls and torrential activities of streams are possible. Within this section, three zones were defined (Figure 10). Due to the construction of larger number of bridges, and because this section is built of solid rock masses, most of the section is characterized as favourable - A (around 70%), and 27% as conditionally favourable – B. Due to the height of embankments and use of geosynthetics for their reinforcement, determined degraded zones with high groundwater level and one fault zone, small part is characterized as unfavourable – C. Within this section is also planned construction of three tunnels: „Vrsnik“, „Racunkovo brdo“ and „Plehane kuce“.

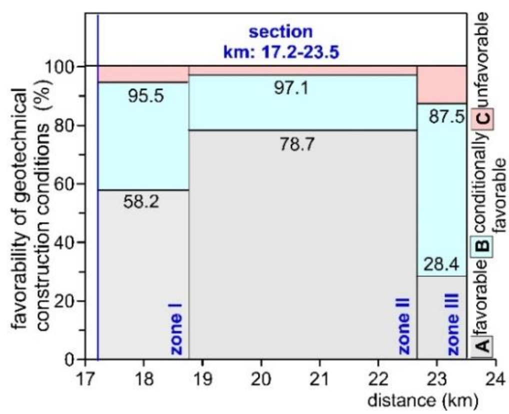

Figure10. Terrain zoning according to geotechnical conditions for construction (km: 17.2-23.5)

3.2.3. Section: Prokuplje-Plocnik (km: 23.5-39.4)

This section is divided in two subsections from km: 23.5-32.1 and from km: 32.1-39.4.

On the first subsection, base is built of Miocene Pelite-clayey sediments: marly clays, clayey marls, claystones and semi-cohesive sands with sandstone layers. It is characterized by high groundwater level (up to 2.0 m), but alluvial and river-terraced planes are beyond the influence of the Toplica River flow, so they are stable. Potential instabilities are present in the zone of unregulated river banks, which can have significance during the construction of the bridge over the Toplica River, and less significance in zone of smaller bridges over its tributaries. Three zones are defined in this subsection (Figure 11). Foundation of bridges will be carried out in gravel and embankment settlements are mostly negligible and will take place in short period of time. Coarse grained sediments dominate in surface part, with good strength and deformability characteristics, so it is characterized as favourable-A for construction (around 79%). The rest (around 19%) is characterized as conditionally favourable-B mostly due to locally presence of muddy areas at certain depths. The negligible part of the route is unfavourable-C, due to appearance of muds at the surface of the terrain.

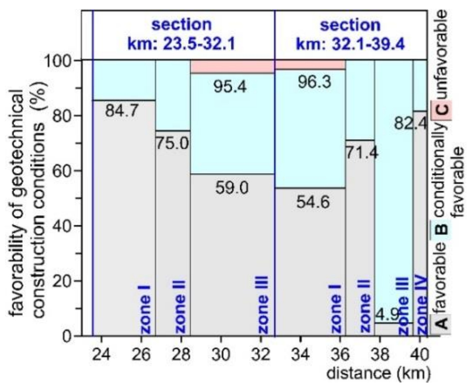

Figure11. Terrain zoning according to geotechnical conditions for construction (km: 23.5-39.4)

The second subsection is built of Miocene creation, while at the very end of the highway base is built of flysch sediment complex of Cretaceous age (K^3_2- marlstone, marl, sandstone with alevrolite layers, claystone and limestone). Proluvial (*pr*) or alluvial (*al*) sediments of the Toplica River and its tributaries are deposited over them. This subsection is divided in four zones (Figure 11). High groundwater level (up to 2.0 m) is determined in flattened parts, while it is much deeper at the very end (right valley side of the Toplica River). Most part of the route is outside of the Toplica River influence, so it is stable. Regardless of the fact that coarse grained sediments with good strength-deformability characteristics dominate in surface part, about half of the route is conditionally favourable-B because of the construction of high embankments (locally over 10 m). In the zone where smaller streams flow into the Toplica, muddy saturated zones are present which are characterized as unfavourable-C (around 2 %).

4 CONCLUSIONS

Results of performed investigation works are used for the general zoning of the terrain in the wider zone of the highway route, taking into account engineering geological, morphological and hydrogeological characteristics. Geotechnical zoning is performed according to the previously completed zoning of the terrain, based on numerous factors which are generally divided in three basic categories: „factors of the past“, „factors of the present“ and „factors of the future“. In this way, identified sections are: „favourable“-A (around 63%), „conditionally favourable“-B (around 32%) and „unfavourable“-C (around 5%) sections, that are related to the complexity of planned structure construction at the highway route (bridges, tunnels, excavations, cuts, embankments etc.).

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