# Complex engineering geological conditions for civil construction in the Rhodope Mountain (Bulgaria)

## Des conditions complexes de géologie de l'ingénieur pour le bâtiment dans la montagne de Rhodope (Bulgarie)

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ABSTRACT

The explored terrain falls within the central parts of the Rila-Rhodope engineering-geological region which has undergone continuous tectonic evolution. The big fault structures manifested in the region were reflected both on relief modeling and on the engineering geological properties of rocks and soils. The studied site is situated on a steep valley slope, inclined to the east and with an average altitude of 1540 m. The terrain is built of deluvial Quaternary deposits situated on pre-Cambrian gneisses and marbles. The geotechnical exploration carried out has proved that site conditions are complex and require special attention when selecting the foundation pattern. The rock substrate is covered by Quaternary deposits of variable thickness, reaching 20.00 m at some places. The conditions are further complicated by the existing zone of vertical karst forms, filled with soft clay of low strength and deformation parameters. The karstified marbles create the prerequisite of significant water inflow in the construction excavation. Unconventional foundation scheme has been accepted due to the predicted irregular subsidence of the Quaternary soils and the expected high water inflow from the karst massif. In the terrains built of old metamorphic complexes weak and karst zones of considerable thickness are encountered, which are the product of tectonic and weathering processes. Various methods of geotechnical explorations, which will guarantee the detailed elucidation of the geological circumstances, have to be applied in order to establish such zones. This will ensure the correct choice of the foundation pattern.

RÉSUMÉ

Le terrain étudié se trouve dans la partie centrale de la région de géologie de l'ingénieur de Rilo-Rhodope qui a été soumise à une longue évolution tectonique. Les grandes failles manifestées dans la région ont mis son empreinte dans le relief et dans les qualités géotechniques des roches et des sols. Le palier étudié est situé sur un versant abrupt avec une pente à l'Est et une altitude moyenne de 1540 m. Le terrain est composé de sols déluviales de Quaternaire qui couvrent des gneiss et des marbres de Précambrien. L'étude géotechnique a mis en évidence que les conditions du palier sont complexes. Cela exige une attention spéciale lors de choix de mode de fondation. Le socle rocheux est couvert des sédiments de Quaternaire dont l'épaisseur varie jusqu'au 20 mètres. Les conditions se compliquent d'une zone verticale karstique dont les formes sont remplies d'argile molle avec de faibles qualités de résistance et de déformation. Les marbres karstiques ont créé des conditions d'un considérable afflux d'eau dans la fouille de construction. A cause des affaissements irréguliers des sols de Quaternaire et en attendant de grande quantité d'eau, une vision spéciale pour la fondation est adoptée.Pour les terrains vieux métamorphiques existent des zones faibles et karstiques d'une considérable épaisseur, des zones d'une origine tectonique ou des processus d'altération. La reconnaissance de telles zones exige de différentes méthodes de prospection géotechnique pour une étude détaillée des conditions géologiques. Tout cela apporterait à un vrai choix pour la fondation.

Keywords: engineering geological survey, electrotomography, karstified marbles, soft clay parameters

## 1 INTRODUCTION

The tectonic structure in Bulgaria is characterized by great diversity resulting from intensive folding and faulting tectonic processes. Due to these circumstances both plain terrains and high rising mountains are encountered on a relatively not big area. The tectonics predetermines not only the relief of the country but to a great extent also the state and properties of the rocks and soils. The studied region is situated in South Bulgaria (Fig. 1), in the central part of the Rhodope Mt. According to the engineering geological zoning (Kamenov and Iliev, 1963) it is a part of the Western high-mountain engineering geological district of the Rila-Rhodope region. The area had been subjected to continuous epirogenic rising and as a result its high-mountain relief was formed (Dabovski et al., 2002). The manifested large fault structures in the area were reflected on both the relief and the engineering geological features of the rocks. The rocks in the fault zones are strongly crushed and changed and possess very low physico-mechanical parameters. At the surface they are also further processed by the erosion processes. The engineering geological investigation was carried out on a terrain with an area of about 6 decares, intended for a hotel complex construction. The performed survey included engineering geological mapping, drilling of exploration boreholes, laboratory investigations of soil and rock samples for determining the physico-mechanical parameters of the strata, elucidation of the hydrogeological conditions as well as geophysical studies using the continuous electrical profiling (electrotomography) method. In geomorphological respect the terrain represents a narrow valley with steep slopes and an average altitude of 1540 m. The inclination of the western slope is 30 – $40^0$, and of the eastern – about 25 – $35^0$. Erosion gullies



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are formed in the southeast and southwest end of the site. The southern part of the site is covered by very thick embankments.

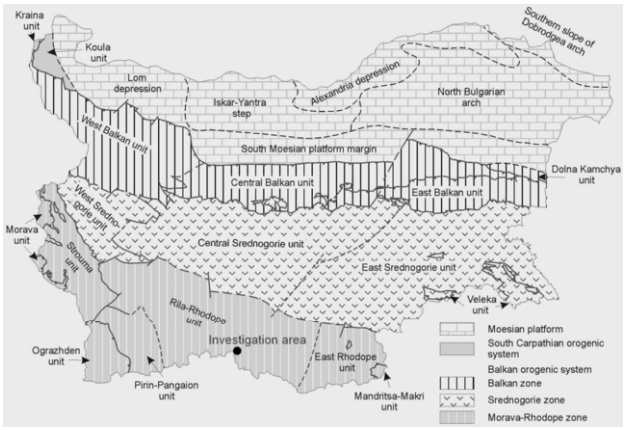


Fig. 1 . Situation of the studied terrain

## 2 GEOLOGICAL-TECTONIC STRUCTURE

The studied region is built of rocks and soils with Archaic, Proterozoic and Neozoic age (Sarov 2007a, 2007b) .

The Archaic rocks are represented by migmatized biotitic orthogneisses (index 6 in the geological map) (Fig. 2). They occupy a small area to the west of the Pamporovo resort and are situated on top of biotitic and amphibole biotitic migmatized orthogneisses or are enmeshed with them in lateral direction.

The Proterozoic is represented by the rocks of the Madan and Asenitsa lithotectonic units. The Madan lithotectonic unit is represented by migmatized biotitic and amphibole biotitic gneisses (index 5 in the geological map). Biotitic gneiss-schists are often encountered among them, forming inhomogeneous rapidly wedging strips.

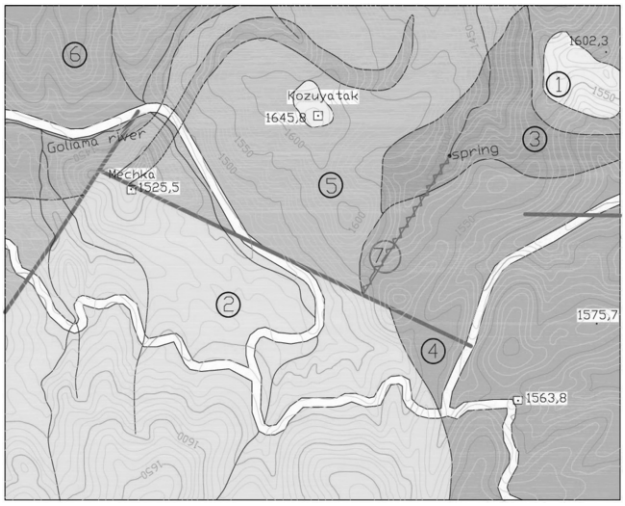


Fig. 2. Geological-tectonic map of the region
1 – breccia conglomerates, conglomerates and sandstones; 2 – sandstones, conglomerates, gravelites, aleurites and coal lenses; 3 – calco-schists, mica and chlorite-epidote schists; 4 – marbles; 5 – biotitic and amphibole biotitic gneisses; 6 – migmatized biotitic orthogneisses; 7 – situation of the studied site and established weak zone

The marbles are the most widespread rocks of the Asenitsa lithotectonic unit in the region (index 4 in the geological map). They are white to gray-white, with massive or striped texture, very often fine-grained. They build thick layers. Single calco-schist levels are established among the marbles.

Mica schists, chlorite-epidote schists and calco-schists are also established (index 3 in the geological map). These rocks are encountered as intercalations with a thickness of up to tens of meters among the marbles and are distributed to the north of the Pamporovo resort. The mica and chlorite-epidote schists alternate with thin stacks of rich in mica gray-yellow calco-schists.

The Neozoic is represented by Paleogenic and Quaternary sediments. The Paleogene is represented by the Group of the polymictic breccia-conglomerates (index 1 in the geological map) and the Group of the sandstones (index 2 in the geological map). The Group of the polymictic breccia-conglomerates is observed in small outcrops to the northwest and northeast of the Pamporovo resort. They are represented by polymictic breccia-conglomerates with sandy, sandy-clayey and seldom sandy-carbonate filler. They are irregularly intercalated by lenses, layers and thin stacks of gravelites, sandstones and limestones.

The Group of the sandstones is observed from the town of Smolyan to the Pamporovo resort. The sandstones are light gray, light yellow, rusty colored, thick-layered and massive, varigrained. Well outlined lens-like bodies of polymictic fine- and medium-gravelly conglomerates as well as inhomogeneous lenses and limestone layers, bituminized schists, coal, tuffs and breccia conglomerates are observed among the sandstones.

The Quaternary in the region is represented by deluvial formations. They are found everywhere in the slope feet or in the zones of fault disturbances. They are built of sandy-soil or clayey-soil mass with numerous angular pieces of various size. Their color is reddish or reddish-brown.

In tectonic respect this area is determined by the superposition of several structural plans, which reflect the structure formation of the pre-Cambrian mega-stage. This mega-stage is divided in two stages – the first one is related with the metamorphism of the rocks from the proto-Rhodope super-group and the second – with the development of the rocks from the Rhodope super-group.

## 3 HYDROGEOLOGICAL CONDITIONS

Marbles play the major role in the hydrogeological conditions of the region. They are strongly cracked, dislocated and karstified. The surface karst forms are widespread in the area, where they form the contemporary karst relief – hollows, blind valleys, dolines, backsets, karren, etc. There is no surface run-off in this part – the whole precipitation water sinks in the pot-holes. The groundwater is drained mainly by the Chepelarska River. Its valley is deeply incised, with steep slopes and with acute-angle profile.

The groundwater in the studied area is established at a different depth from the terrain surface. The water level in the exploration boreholes vary within the range from 5,30 m (BH-6) to 18,00 m (BH 1 and 2) from the terrain elevation. The lithological varieties represented in the investigated region predetermine the formation of a common complexly set up aquifer horizon determined by the karst forms in the marbles. The composed hydrodynamic map (Fig. 3) of the site shows that the underground filtration flow is directed to southwest-northeast and its hydraulic gradient is I = 0,346. The water exhibits slight carbonic acid aggressiveness towards concrete.

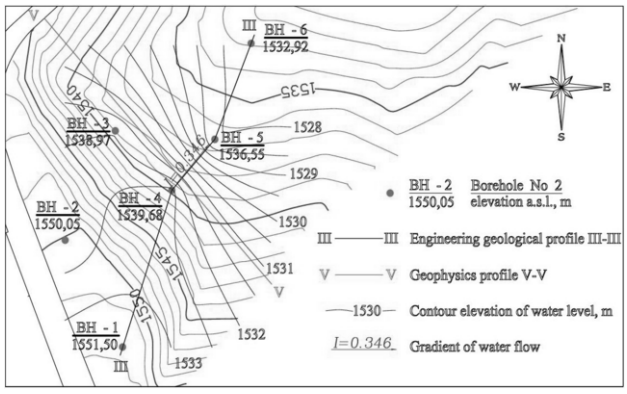


Fig. 3. Situation of the exploration boreholes and hydrodynamic map

## 4 ENGINEERING GEOLOGICAL CONDITIONS

Depending on the genesis, lithological features and physico-mechanical parameters of the varieties established in the exploration boreholes, five engineering geological layers have been distinguished (Fig. 4, Fig. 5, Table 1).

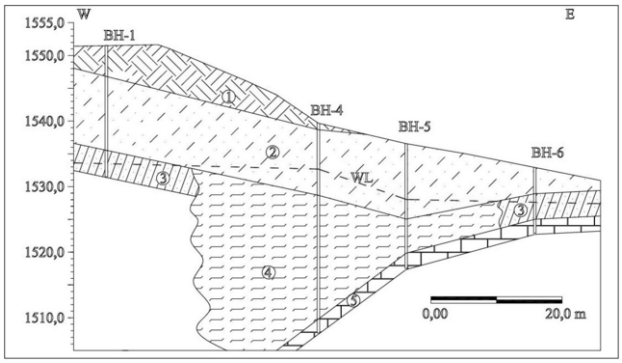


Fig. 4. Engineering geological profile
1 - embankment; 2 – sandy clay with single gravel pieces; 3 – gravelly sandy clay; 4 – weak zone of red-brown very soft sandy clay; 5 – marbles; WL - water level

Layer 1 – Embankment: it is outcropped in the west part of the studied terrain. The layer thickness in the exploration boreholes is from 1,00 to 9,00 m, and it becomes thinner in east direction. The layer is built of construction waste, gravels and sand with filler of dark brown to black silty sandy clay in soft to firm consistency.

Layer 2 – Quaternary sandy clay: it is established in all exploration boreholes. The layer is built of deluvial red-brown sandy clay in firm consistency. Its thickness is from 4,00 to 11,50 m.

Layer 3 – Quaternary gravelly sandy clay: it is embedded directly under Layer 2 and is missing only in MC NoNo 4 and 5. It is embedded at a depth from 4,00 to 20,00 m under the terrain surface. The entire thickness of Layer 3 was not passed through in the exploration boreholes BH NoNo 1 and 2. It is represented mainly by red-brown gravelly sandy clays in firm to stiff consistency.

Layer 4 – Weak zone: the layer is wedged between Layers 2 and 4 and is established only in exploration boreholes NoNo 4 and 5. It is embedded at a depth of 11,00 - 11,50 m from the terrain surface. Its depth varies from 5,2 to 18,90 m.

The approximate dimensions of the zone are width from 20 to 26 m and length from 25 to 45 m. The area of the zone amounts to about 870 $m^2$. The layer is represented by red-brown sandy clay in very soft consistency.

Layer 5 – Karstified marbles: this layer represents the bed-rock of the territory of the studied site. The inclination of the marble layers is from $15^0$ to $40^0$ to the north northeast. It is seen in neighboring outcrops that the marbles are fissured in large blocks and karstified. The rocks are strongly changed and strongly weathered along the fissure system. The layer is observed only in exploration boreholes NoNo 4, 5 and 6. It is embedded in the interval from 7,90 to 29,90 m from the terrain surface and subsides in west direction. The marbles are strongly cracked, dislocated and karstified.

Table 1. Physico-mechanical parameters of the soils

| Parameters / Layer | Bulk density g/cm$^3$ | Apparent electrical resistance Om.m | Consi-stency index Ic | Bearing capacity MPa |
|---|---|---|---|---|
| Layer 2 | 1,96 | 75 - 104 | 0,60 | 0,19 |
| Layer 3 | 2,02 | 104 – 240 | 0,70 | 0,22 |
| Layer 4 | 1,98 | < 75 | 0,11 | <0,10 |
| Layer 5 | 2,52 | 240 - 1400 | - | 0,50 |

The embankment of different soils and construction waste was not characterized because it was insufficiently compacted, with heterogeneous composition and strongly variable parameter values. This layer will be subjected to removal at the places of foundations. The relatively close mineral and grain-size composition is typical for the Quaternary cover, including layers 2, 3 and 4, and this is reflected also on the bulk density of the materials. The characteristic feature of the soil of Layer 4 is that it is with very soft consistency and has a very low load bearing capacity. During the exploration of this layer the drilling rod sank in this soil only by the load of its own weight. The marbles also exhibit variable parameters due to their cracking and weathering but as a whole they are characterized by high load bearing capacity.

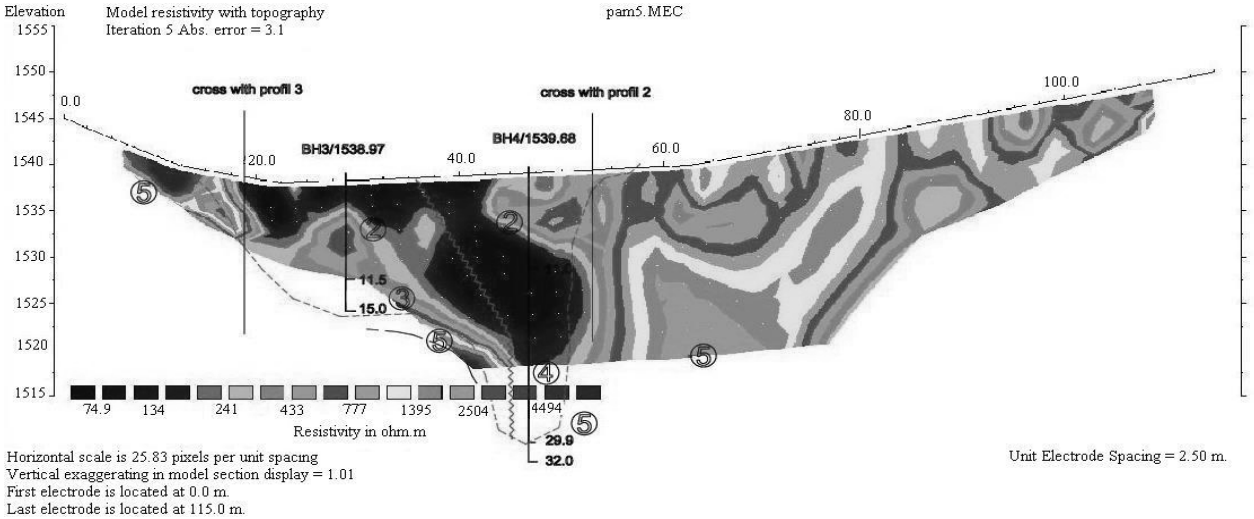


Fig. 5. Geophysical profile
2 – sandy clay; 3 – gravelly sandy clay; 4 – weak zone; 5 – marbles

Geophysical explorations were carried out for additional outlining of the weak zone using the continuous electrical profiling (electrotomography) method with the ARS 200-E device. The data obtained from the measurement were processed using the RES2DIN–ver.3-50 software yielding the automatically determined 2D model of the electrical resistance for the geological section.

## 5 CONCLUSIONS

The performed field survey and laboratory testing of soil and rock samples provide the grounds to make the following conclusions:

- The investigated terrain is situated in a valley with steep slopes, built of Proterozoic cracked and karstified marbles and Quaternary sandy clays on top of them, which partially fill up the karst caverns. The valley formation was the result of the combined impact of tectonic, karst and erosion processes. The left bank of the valley is built of marbles, covered by a thin eluvial-deluvial layer. The right bank of the valley is built of marble rock blocks with clayey filler or small block-fissured marble with clayey filler along the cracks to a depth exceeding 15-20 m from the terrain.
- An elongated karst form with a depth of 16-30 m and width of 20-26 m is developed in the central part of the valley. Its distribution is in southwest-northeast direction. It is filled with red-brown very soft sandy clays with very low physico-mechanical parameters.
- Groundwater with high flow rates is formed in the karstified marbles. There is a spring at a distance of about 500 m to the northeast of the studied site downwards the valley, which is the source of one of the left tributaries of the Chepelarska River.
- The contrasting strength and deformation properties of the rocks and soils of the soil base are taken under consideration in the foundation of the building. The situation and depth of the foundations is chosen in such a manner that the load of the building is applied via reinforced concrete piles on the marbles beneath the weak soil. The selection of the concrete for the piles takes into account the slight carbonic acid aggressiveness of the water towards concrete.
- Special attention should be paid during engineering geological investigations in carbonate terrains to the existence, size and spatial distribution of the karst forms. Very often abundant aquifer horizons with significant level and flow rate fluctuations of groundwater are formed in them. In some cases, as in the present study, the karst may be filled up with weak water saturated soils.

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