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Geomechanical model of the unstable part of the geological environment of the southern slope at the Gacko coal mine

Boško Vuković

Department of Geology, Faculty of Mining/University of Banja Luka, Bosnia and Herzegovina

Abstract: On locality of south-west and west border of neogene coal basin in which there is SP Gracanica Gacko, was determined tectonic disturbance of the crack type terrain. Sliding of the material and water penetration from the Musnica river into the surface pit have happened on 19.03.2013. During the sliding of the terrain there was a fracture of the Musnica river bed and water penetration into the pit. In the goal of analysis of geotechnical and hydro geological characteristics of the disturbed locality and causes which have led to sliding of the terrain and water penetration into the pit,in october 2013. , geological researches have been executed. On south and south west slope of the field B, investigatory drilling and the reconnaissance of the terrain have been done, all in the goal of gathering the greater number of data for the analysis of the enineering-geological building of the terrain. By doing of geological research works, in the zone of sliding and in immediate zone of water penetration into the surface pit Gracanica, classification of the terrain by the degree of stability has been executed. Classification of the terrain by stability with the analysis of the accomplished results represent issues which the work deals with. Also, in the work will be given the review on new conceptional solution of the further exploitation of the coal, on which in certain measure impacted the sliding of the masses and creation of artificial accumulation, caused by penetration of the Musnica river with the Gracanica into the surface pit.

Keywords: coal basin, surface pit,sliding, cracks,water,roof zone.

I. Introduction

For this area, 2010 was the year with the most abundant precipitation of over 3000 l/m^2. In the dry period (June–September 2011), the appearance of a system of radial cracks was registered, at the contact of Neogene and Cretaceous sediments, with the direction of extension across the river Mušnica, through the embankments to the north side, parallel to the final contours of the mine. Along the entire route of the crack, with a gap of mm to cm dimensions, a tectonic disturbance of the terrain was observed, which is manifested by peripheral (contact) subsidence of the Neogene series.

At the beginning of December 2011, on the southern slope of field "B" of the "Gračanica" surface mine, due to the increase in precipitation in the area between technological profiles PP-22 to PP-23, there was a greater deformation of the mentioned site, which was manifested by breaking off and gravitational movement of large blocks within the overburden of the main coal seam. It was estimated that the volume of the activated blocks, that is, the volume of the unstable area, is about 150,000 m^3.

Deformations on the surface of the terrain several hundreds of meters in length resulted from the engineering-geological state of the area, due to the disruption of the natural state by continuous surface excavations and the additional impact of a sudden rise in the level of underground water in the limestone hinterland. By excavating the Neogene sediments, the Neogene support with limestone sediments was removed, while the safety factor was reduced by changing the voltage state.

In the course of 2012, the sliding of the Neogene on the limestone base continues, which is manifested by the appearance of cracks in the vicinity of the Mušnica river bed. The fissure activity with gaping cracks up to 1 m, on the left and right side of the embankment, intensifies in the period January-March 2013, when the Gračanica and Mušnica rivers penetrate into the surface mine.

II. Geological Characteristics of the Terrain

The geological (research) area is made up of Quaternary, Neogene and Cretaceous sediments. The Quaternary covers the surface of the terrain, with an average thickness of about 2.50 m. It is represented by different sediments of alluvial origin. Neogene sediments are found in the basement of the Quaternary. The Neogene basement consists of Cretaceous limestones ${}^{1}K^{3}_{2}$.

1. Geological structure of the terrain

The part of the "Gacko" coal deposit where the open pit "Gračanica" was opened as a whole represents one large asymmetric syncline, with the axis of extension NW-SE, which is closer to the southwest edge of the basin. Earlier research established that the less developed southwest wing of the syncline was deformed by gravity faults approximately parallel to the basin rim [1].

The creation of engineering-geological profiles revealed the possibility of fault tectonics, which is reflected in gravity faults approximately parallel to the perimeter of the mine. Between these two profiles, the terrain includes two faults with SW-NE direction. Also from the direction of Srnević you can see a fault with the direction of extension NW-SE[2]. During mapping, cracks were measured that were caused by deformations on the surface of the ground behind the final contour of the mine. These cracks can be traced over a length of 30 to over 350 m. Their exposure is approximately parallel to the contact of Neogene and Cretaceous sediments and the final contour of the pit. In the area of their appearance, there are vertical elevations and descents of the terrain.

2. Engineering-geological structure and properties of isolated environments

Based on the collected data of the engineering-geological mapping of the terrain and the core of exploration wells in the exploration area, seven engineering-geological environments were distinguished [3].

2.1. Quaternary clays

They cover the Neogene sediments in layers of different thicknesses (the determined thickness in the boreholes during these investigations is 1.00-3.00 m). They are represented by yellow-brown, brown to dark plastic clays.

2.2. Marly limestones, marls and argillaceous marls (^{8}Ng).

They are represented by yellow, gray-yellow, gray, alternating, yellow-gray marls. They are often clayey, sometimes sandy. These sediments were drilled in four drilled wells in the conducted phase of the research and have the widest distribution within the analyzed profiles. They cracked a lot with frequent crushed zones.

2.3. Banded marls and gray calcareous marls with congeries (^{7}Ng)

They are represented by brown banded marls with coal, as well as gray calcareous marls with characteristic shell fossils.

2.4. Main coal seam (^{6}Ng)

The basic feature of this environment is the stratification of the main coal layer with interlayers and layers of marl, carbonaceous clays, carbonaceous marls, clayey marls. The coal is mostly dark, brown to black in color. During mapping, vertical and subvertical cracks with traces of movement were observed in the coal. Coal clays are found as interlayers in the main coal seam. The colors are dark to black, rarely with pieces of coal.

2.5. Marls and tuffitic marls (^{5}Ng)

They represent the basement of the main coal layer.

2.6. Podine clays with carbonate concretions (^{1}Ng)

The oldest package of Neogene sediments was determined in all exploration wells. They are mainly green and gray-green clays with carbonate concretions, fragments and particles of limestone. They are rarely sandy and with traces of coal. When mapping the core, frequent occurrences of slip marks (striae) were observed in them.

2.7. Cretaceous limestones ($^{1}K^{3}_{2}$)

They represent the immediate basement of the neogene complex. Sediments are bank-like, massive, yellow-white, white, gray to light gray in color.

3. Hydrogeological properties

The primary porosity of Neogene sediments (marls, clays, coal) is not significant for the circulation and accumulation of groundwater. Their secondary porosity, caused by tectonic damage, means that certain parts of these sediments in the terrain represent a coarser porous environment and are priority routes of communication of surface and underground water.

The wider area of the researched terrain is built by:

- Rock masses of intergranular porosity;
- Rock masses of fissure and fissure-caverous porosity;
- Hydrogeological complexes.

Based on the structural type of porosity, different types can be distinguished:

- Compact type released - developed within alluvial deposits;
- Released fissure type - developed in the northeastern rim of the Gatački basin within massive to well-layered dolomites;
- Fissure-karst type released – developed within the limestone of the flysch complex around the perimeter and in the immediate floor of the Neogene sediments, i.e. within the Neogene sediments [4-6]N.

III. Penetration of the Mushnica River into the Gacko Coal Mine

On March 8, 2013, during the second shift, workers of the drainage service noticed the most intensive work of cracks on Srđević road. Mine technicians went to the scene, informed the public security service (police) and closed the road to the village of Srđeviće. In addition, residents of the villages of Srđevići and Medanići were informed that the road was closed.

Considering the night conditions, the only thing that could be noticed was the work on the cracks on the asphalt road to the village of Srđeviće (in place of the existing cracks that were repaired by filling buffers). This phenomenon was mainly manifested in terms of the creation of gaping cracks and material sinking. No significant changes were observed in the part of the field between the road and the southwestern slope of the mine. Cracking was also registered in the pipeline for pumping out water and one metal "support" was bent. This was evidence of the existence of stress and displacement of the terrain. On March 9, 2013, around 7:15 a.m., water broke through the main protective embankment. In the period from 8:00 a.m. to 8:15 a.m., "bangs" were heard, probably caused by the flow of water into field "B" through the fracture zone. The sliding of material and the penetration of water from the river Mušnica into the surface mine occurred on March 9, 2013 at 8:15 a.m. The crash itself lasted about 10 seconds and was followed by a cloud of dust and fog. During the slide, the bed of the Mušnica river broke and water entered the mine. Due to the breaking of the Mušnica river bed, the Gojković stream also flooded in because the water from the Gojković stream was directed east through the Mušnica bed. Only a small amount of water flowed from the Gojković stream in the Srđević gorge. As the Gračanica river flows into the Mušnica before the place where the river bed broke, the Gračanica practically flowed into the surface mine. The sliding direction of the material was south-north, which could be seen from the material in field "B" before filling with water. The wider and narrower location of the landslide zone, the consequences caused by the landslide and the penetration of the Mušnica river (with Gračanica) and the Gojkovića stream into field "B" of PK "Gračanica" Gacko, are shown in Figures 1-4.


Pictures 1 and 2: Movement of blocks from the south side of the surface mine (zone of river penetration into the mine)

Figure 3: Launched marl blocks from the south side and the formation of an artificial accumulation in the Gacko coal mine

Figure 4: Landslide on the western side of the surface mine (Gojković stream zone)

IV. Terrain Classification According to Degree of Stability

On the southern and southwestern slope of the "B" field, exploratory drilling was carried out and terrain reconnaissance was carried out, all with the aim of collecting as much data as possible for the analysis of the engineering-geological structure of the terrain.

Based on the obtained data, both from the exploratory wells and the mapping of the terrain, it was categorized according to the degree of stability. According to the degree of stability, the tested terrain is classified into the following categories:

1. Conditionally stable terrain

In the region of the designed profile 1-1' and the executed geomechanical borehole GM-5, no significant deformations were observed on the ground, while during the determination of the extracted core from the realized borehole, several tension cracks with soft, clayey fillings and traces of sliding were observed. Northeast of the borehole, in the slope above floor 925, in the earlier period there was water seeping, which indicates that in the immediate vicinity there are channels through which water sinks during heavy rainfall and the increase in the water level of the Gojković stream. At the same time, it washes out binders in the rock massif, expands channels and springs on the slopes of the floor. In the same picture, you can see the consequences of the springing of water, where it is horizontal and vertical tearing of the block occurred. On the same floor, there are two parallel cracks of 5 cm gap, running north-south, and millimeter cracks parallel to them, which, after receiving water, increase in width in a short period of time, weaken the binder in the rock massif, causing tearing and separation of blocks.

By determining the extracted core, from the drilled well, and based on the traces of movement, both in the accompanying interlayers and in the coal seam, it can be concluded that with deeper cutting in the surface mine, this terrain changes from conditionally stable to predominantly unstable terrain.

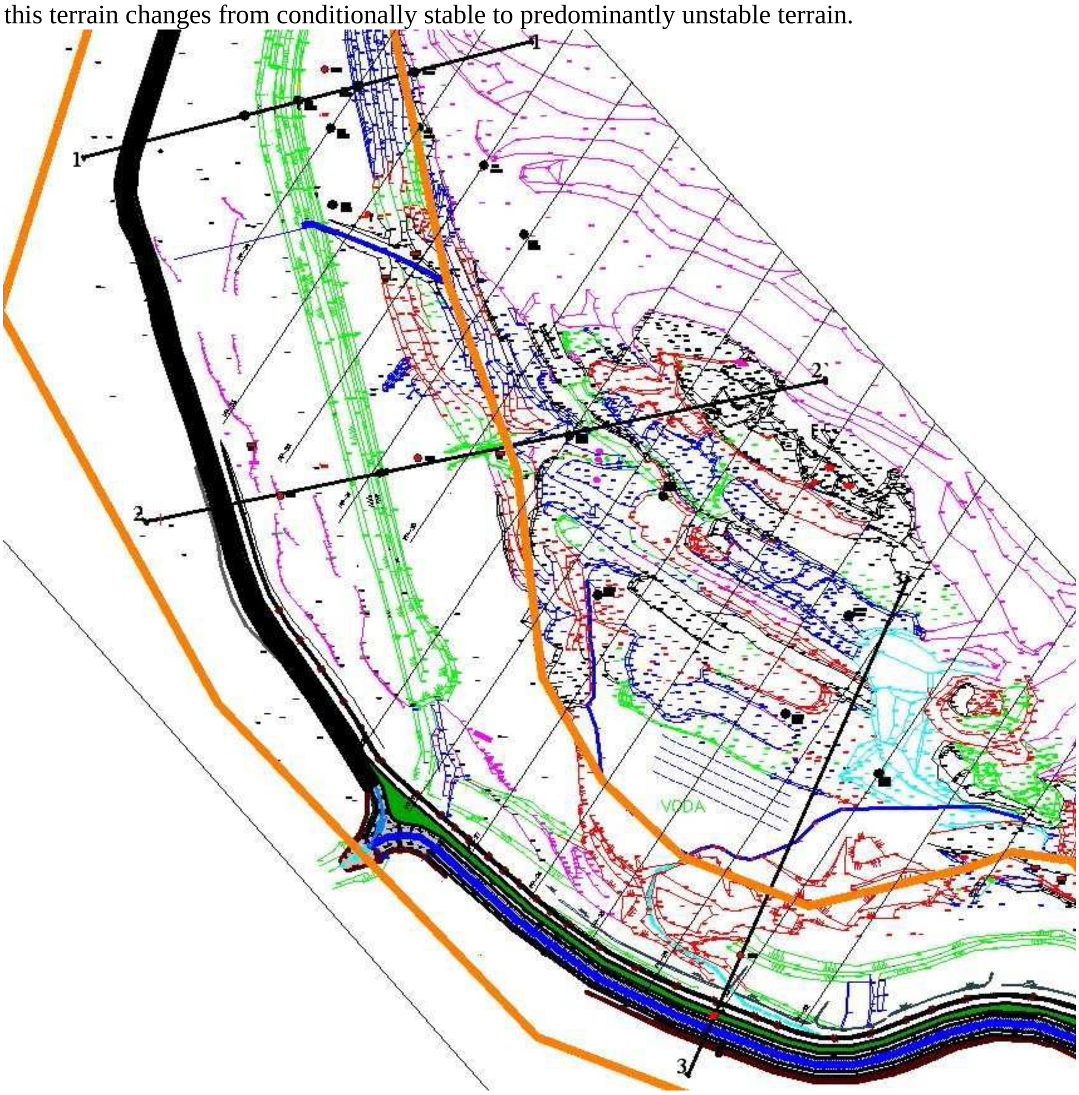

Figure 5: Situational map with analyzed profiles 1-1', 2-2' and 3-3' in the southwestern and western part of field "B"

In the area under the old bridge for Srđeviće over the Mušnica, near the border of field "A" and field "B", rare tension cracks were registered and at that moment, rare, scarce water seeps. Bearing all that in mind, this same part of the terrain becomes potentially unstable in extremely hydrologically unfavorable conditions and eventual cutting of hypsometrically lower levels. Zones of conditionally stable terrain cover an area of 0.16 km^2.

2. Unstable terrain

It includes the NW and SE part of the projected cross section 2-2'. The south-eastern border of this terrain ends about 150 m before the mouth of the Gojković stream in Mušnica. The western part of the terrain rests on Cretaceous sediments and immediately from the contact with them there are numerous discontinuities and ruptures that occur at a distance of less than 5 m. Numerous discontinuities and ruptures are present in the GM-1 exploratory well execution zone. Generally speaking, all discontinuities and ruptures have the direction of providing contact with Cretaceous sediments. Figure 6 shows the deformations on the ground in the area where the GM-1 exploratory well was executed.

Figure 6: Deformations on the ground

Figure 7: Spring of water at the border of Quaternary and Ng

Some cracks in this part are continuously over 200 m long, up to 1.5 m wide and up to 2 m deep. It should be emphasized that in this part there was a gradual lowering of the terrain, that is, the subsidence of Quaternary formations, which can be seen in the mentioned picture [4]. Quaternary formations are of very low strength and are subject to erosion or washing away. During the execution of the exploratory well, in one of the cracks on the border of the Quaternary and the Neogene, a small amount of water was observed, which can be seen in Figure 7. In the immediate vicinity of the executed well GM-2, i.e. to the south of it, there are numerous cracks and subsidence terrain. 100% of the mud was lost during the entire time the mentioned borehole was being drilled, and at approximately 14 m of its depth, you can hear the seepage of water. Traces of movement in the Neogene sediments are visible on the core of the GM-1 borehole, and at the contact with the Cretaceous sediments, striae, i.e. traces of movement, are clearly visible, which indicates that the movement of sediments in this part occurred at the border with the limestones (base part) and directly above them.In case of unfavorable hydrological conditions and water penetration into the cracks, there is washing of the binder, movement and tearing of the blocks, so that the observed terrain can be moved in a short period of time, resulting in complete instability of the working slopes. In Figure 8, in one of the present cracks, the tearing of the blocks can be seen in the horizontal and vertical planes, and above the blocks, the soil in the quaternary deposits. In Figure 9, cracks and dredging on the slopes of the floors are shown[4].

Figure 8: Tearing blocks

Figure 9: Dredging on slopes

In this zone of observation by the geodetic service, rappers have been placed on the observation of impaired stability. On the basis of the comparative displacements, millimeter to centimeter oscillation of the benchmark can be seen, which indicates that the process of moving the ground is still ongoing. The zone of unstable terrain covers the largest area of observed slopes of 0.28 km^2.

3. High risk terrain

It is contoured in the domain of profile 3-3' and in the zone of geomechanical boreholes GM-3 and GM-4. The area itself covers a part of the immediate confluence of the Gojković stream with Mušnica, up to approximately the border of field "A" with field "B" and is completely located under the bed of the river Mušnica[5]. The observed terrain is covered by two faults running SW-NE and SE-NW. In this zone, water from the Mušnica River entered, forming funnel-shaped sliding surfaces and a huge amount of sediments slid into the bottom of the "B" trench. During the tour of the field, several places of water springs were found on the slopes of the floors, i.e. in the already moving rock mass, which continues to worsen the damaged area so that there is a great danger of the movement of other materials again[5]. The new cracks that appear in this belt indicate that the terrain is very unstable, so it is necessary to stop the penetration of water from Mušnica as soon as possible and to somewhat shorten the time of movement of damaged material.

During the determination of the extracted core from the GM-3 and GM-4 wells, in several places in the Neogene sediments, fault mirrors, probably sliding legs (because they are hypsometrically in the lower levels of the swollen material, pictures 10 and 11), were found, which indicates to us that in in the previous period, the movement of these masses began, and with the appearance of several unfavorable factors, there was a slide. In Figure 11, the entrainment of the higher moving masses over the unmoved terrain is clearly visible. As in the zone of unstable terrain, in this part as well, the geodetic service of the mine and thermal power plant has set several reference points along the profile lines for observing disturbed stability. In the report dated 31.07.2013. years, the elevation of the ground on some rappers was recorded. These rapiers are located on the slope of the mine, just below the mouth of the Gojković stream in Mušnica and define a distance of about 50 m.

Figure 10: Sliding feet?


Figure 11: Pulling the moving masses

During the drilling of the GM-4 exploratory well, 100% of the water used for drilling was lost, and the terrain was affected by a series of cracks, and through one of them, the water came out on the slope of the floor (elevation 933), picture no. 12.


Figure 12: Discharge of water from the sloping floor

In order to ensure an unimpeded flow of water, it is necessary to clear the Mušnica bed (downstream of the confluence with the Gojkovića stream) of vegetation and other vegetation (pictures 13 and 14). The high-risk terrain covers an area of 0.23 km^2.


Figure 13: Plants downstream of the Mušnica River bed


Figure 14: Plants upstream of the Mušnica river bed

V. Overcoming the Problem of the Influence of the Landslide in the Gacko Mine

After the degradation of the terrain due to the penetration of the Mušnica river and the Gojković stream into field "B" of the "Gračanica" surface mine, there was a need for an urgent solution to the newly created problem. Due to the intrusion of enormous amounts of water from the Mušnica river into the Gračanica surface mine, an accumulation was formed in the mine, so measures were taken to remedy this situation, by building a temporary bed (temporary "bypass") of the Mušnica river in a length of 960 meters and by building a new Gojković bed. stream (permanent solution). The aim of these relocations is to:

- mine insurance against the influence of surface water,
- minimize the infiltration of surface water into the mine,
- enable staged execution of regulatory works in accordance with the stated priorities.

The first remedial measure, was to urgently prevent further inflow of water from the Mušnica river into the excavated area of the surface mine, which was done in the shortest possible time by excavating and relocating part of the Mušnica river bed (approx. 960 m long) to a stable part of the terrain and partially remediating the bottom of the Gojković bed streams in the most vulnerable places.

The second rehabilitation measure, which was carried out in the summer of 2013, is the relocation and regulation of the Gojković stream bed, as well as the definitive arrangement of the relocated part of the Mušnica river bed, which will permanently protect the surface mine from possible intrusion of water from these streams.

The third remedial measure, is to prevent further destabilization of the soil, i.e. sliding of the southern and southwestern slopes of the Gračanica Gacko surface mine, which would be carried out by "supporting the moving masses", i.e. by depositing overburden in the excavated area. It should be noted here that, before the penetration of water from the Mušnica River into field "B", this area was planned for the formation of an internal landfill and the disposal of a large part of overburden, interlayer tailings and selective tailings from field "C". However, the newly created situation has led to the fact that it is necessary to first drain the water from field "B", in order to free up the planned space for the formation of a landfill, as well as that the newly created situation requires faster disposal dynamics at the bottom of the mine, i.e. the very "subversion of the moving masses". as measures to rehabilitate this area.

Conclusion

After the degradation of the terrain due to the intrusion of the Mušnica river and the Gojković stream into field "B" of the Gračanica Gacko surface mine in March 2013, there was a need for an urgent solution to the newly created problem. The solutions were reflected in the relocation of the watercourses of the MušnicaRiver and the Gojkovića Stream, as well as the filling of field "B" and the formation of an internal landfill.The activation of the landslide on the southern side of the Gračanica surface mine contour caused the southern end contour of the mine to move towards the northern side within the open pit mine. Together with the masses from the final contour of the mine, water from the Mušnica river bed (with Gračanica) penetrated into the excavated space of the mine and filled it at an elevation of 910 m.

The process of rehabilitating the aforementioned slopes required: temporary relocation of the degraded riverbed of the Mušnica river to a safe distance from the surface mine as well as the Gojković stream with adequate protective embankments, pumping of water from the excavated area into the mine, controlled and planned collection of rainwater from the surrounding area via existing watercourses, which must be adequately carried out in the river Mušnica and Gojkovića potok, leveling of the terrain in the area of the landslide in order to close the sliding cracks, which would prevent a significant infiltration of water into the sliding body, based on the analysis of the stability of the southern and southwestern contours of the mine, determine what measures must be taken in order to stability of the same, based on the existing condition and input parameters obtained on the basis of research wells drilled in the area of the landslide, with the definition of the sliding surface, monitor the direction, speed and size of the mass displacement, via built-in reference points, by geodetic observation and measurement, so that possible mass movements.

On the southern and southwestern slope of the "B" field, exploratory drilling was carried out and terrain reconnaissance was carried out, all with the aim of collecting as much data as possible for the analysis of the engineering-geological structure of the terrain. Based on the obtained data, both from the exploratory wells and the mapping of the terrain, it was categorized according to the degree of stability. Thus, according to the degree of stability, terrains are classified into the following categories: conditionally stable terrain, unstable terrain and high-risk terrain. These data confirmed the conclusions of the engineering-geological mapping and reconnaissance of the terrain that the given geological units have undergone significant changes in terms of new cracks that appear in this belt and which indicate that the terrain is "not at rest".

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