Chapter 2

Geohazards at Surface Coal Mines Caused by Mining Activities

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Additional information is available at the end of the chapter

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Abstract

This chapter presents a methodology of geohazard analyses caused by mining activities at coal mine "Suvodol" near the town Bitola in the Republic of Macedonia. The problems discussed here are connected with landslide with enormous dimensions. The process of sliding happened in several phases, with initial signs of sliding in 1993. The moment of global instability happened on October 27, 1995. Until now, several phases of reactivation are known. Its volume is about 30,000,000 m^3. As a result of mass movements, about 8,000,000 tons of coal is concentrated (blocked) at the toe of the landslide. Upper of the main scarp, spaced about 250 m, the earth-fill dam with a length of about 1000 m exists. The groundwater artesian effects are also present. At the toe of the landslide, the coal is partially involved in a process of self-burning, and it produces environmental unfriendly gases. All these aspects show a very specific combination of natural and man-made hazards that control the stability of the excavation and environment. The specific approach used to define risk scenarios for is then shown briefly. The suggested methodology can serve as an example for possible use in some other problems in coal mines.

Keywords: coal mine, coal self-burning, geohazards, groundwater, landslide, environment, risk, stability

1. Introduction

It is well-known that efficient designing of engineering activities and safe exploitation in coal mines is not possible without knowing in detail set of geological, geotechnical, and groundwater conditions. The main principle is that technology of excavation should always be carefully adapted to the properties of the natural environment and surroundings. This is of special importance having in mind that during the excavation process, there are possibilities for development of important induced geohazard. The induced geohazards can be connected with changes of groundwater conditions, stability of the excavation zone, possible settlements because of dewatering, possible development of coal self-burning process, influence on the surrounding structures, air and groundwater pollution, etc.

This statement is especially emphasized in cases when the exploitation is close to other infrastructure and engineering structures, as a case for coal mine “Suvodol” placed on southwest (SW) part of the Republic of Macedonia (**Figure 1**).

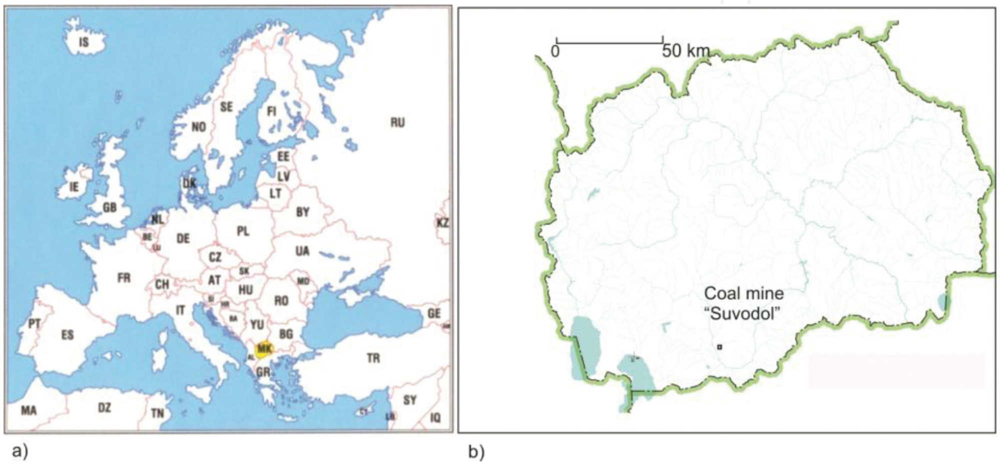


Figure 1. (a) Key map illustrating position of R. Macedonia in Europe; (b) position of coal mine “Suvodol”.

The coal mine is a main source for thermal electricity plants with coal production of about 6,500,000 tons per year. More precisely, the analyzed problem in this chapter is related to the northeast (NE) part of the mine, where during longer time large landslide appeared and caused lots of difficulties in the normal work of the exploitation systems [1]. It is also a potential danger for the upstream earth dam, which is spaced about 250 m from the main scarp of the landslide.

To overcome this problem, the authors were involved in several phases of landslide investigations and design phases. The investigations were complex and with large quantity, in order to prepare data for physical and analytical modelling [2, 3]. Later, the data are used as a base for stability and dewatering analyses, protection from surface and groundwater, excavation conditions and so on. The methods are presented within the wider context of an approach to integrate all the relevant information in a similar way as it is given in rock engineering design and construction. Namely, the methodology of developing the so-called rock engineering systems (RES) is firstly introduced in [4]. Here, we will present the used approach in developing geotechnical engineering systems (GES). The entire concept providing overall coherency in approaching engineering problems at coal mines, where the need to study the interactions has always been present.

The key question here is to have correctly carried out investigations of the groundwater and stability conditions at the zone of interaction between the natural environment and the engineering activities, estimations of risks, etc.

A framework for this concept has earlier been given in [3], while the methodology and results are explained in references [2, 3, 5–8].

2. Geological, hydrogeological, and geotechnical conditions of the analyzed area

The coal mass and the unproductive layers at coal mine "Suvodol" have been formed with a process of sedimentation in lake conditions during upper Pliocene. The geological composition is presented with the so-called bottom-coal series with layers of silty sands, productive series of coal and coal-like clay, and layers on the upper part of coal of volcanic material (the so-called trepel). The area of mine is investigated, with very detail and using complex investigation methods in a several phases before opening of the mine, but also during the phase of exploitation. These investigations have been made in the sense of solving the entire geological, geotechnical, and hydrogeological situation on the terrain. For instance, mapping of the wider area, investigation drillings, installing of group piezometers, investigations of the chemical composition of groundwater's, field investigation of filtration coefficient, as well as laboratory analyses of physical and mechanical properties are applied.

To illustrate geological and hydrogeological conditions, some results are presented in **Figures 2** and **3**.

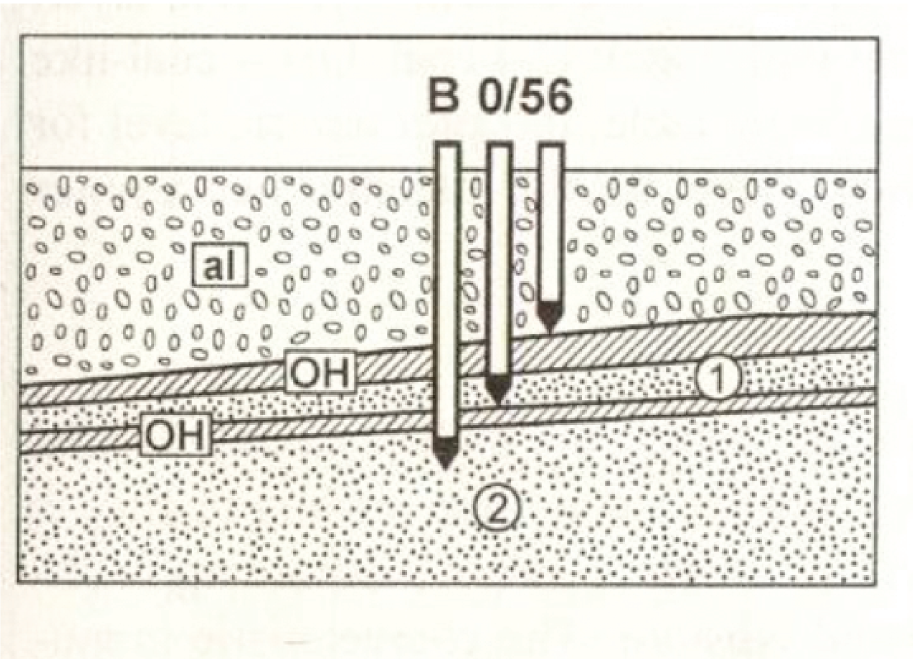


Figure 2. Schematic of installation of triple piezometer in a borehole B 0/56: al – alluvial sediments; OH – coal-like clay; 1 – interstratified aquifer zone; 2 – aquifer zone at the bottom of clay.

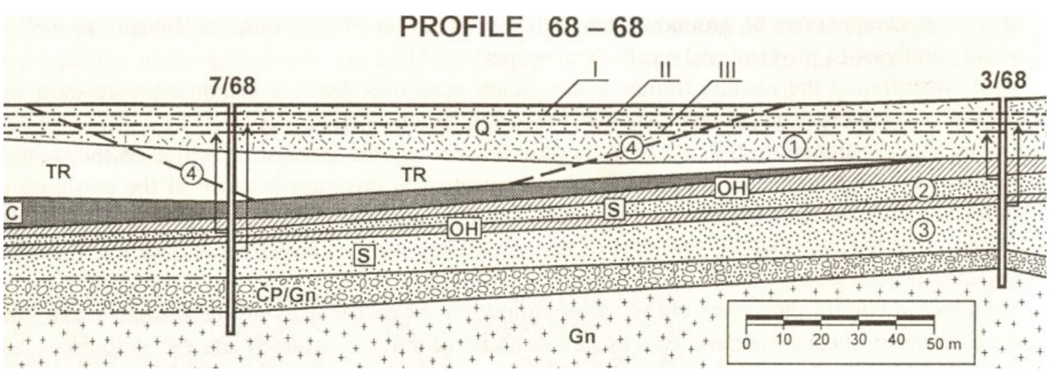


Figure 3. Detail of geological and hydrogeological composition at one zone of coal mine "Suvodol": 1 – Aquifer zone with phreatic line; 2 – Interstratified aquifer zone under pressure; 3 – Aquifer zone at the bottom of the coal layer; 4 – Designed cut; Q – Quarterian silty sand layer; TR – trepel (aquiclude); C – coal; OH – coal-like clay (aquiclude); S – silty sands (aquifer); Gn – gneiss; I – free water table; II – piezometric level for the aquifer zone at the bottom of the coal layer; III – piezometric level for the interstratified aquifer zone under pressure.

Some of the zones at the coal mine are with high lithological heterogeneity, which is the reason why there is heterogeneity of hydrogeological and geotechnical characteristics. By the help of installed piezometers, the presence of several physically separated aquifer zones is shown in **Figure 4**.

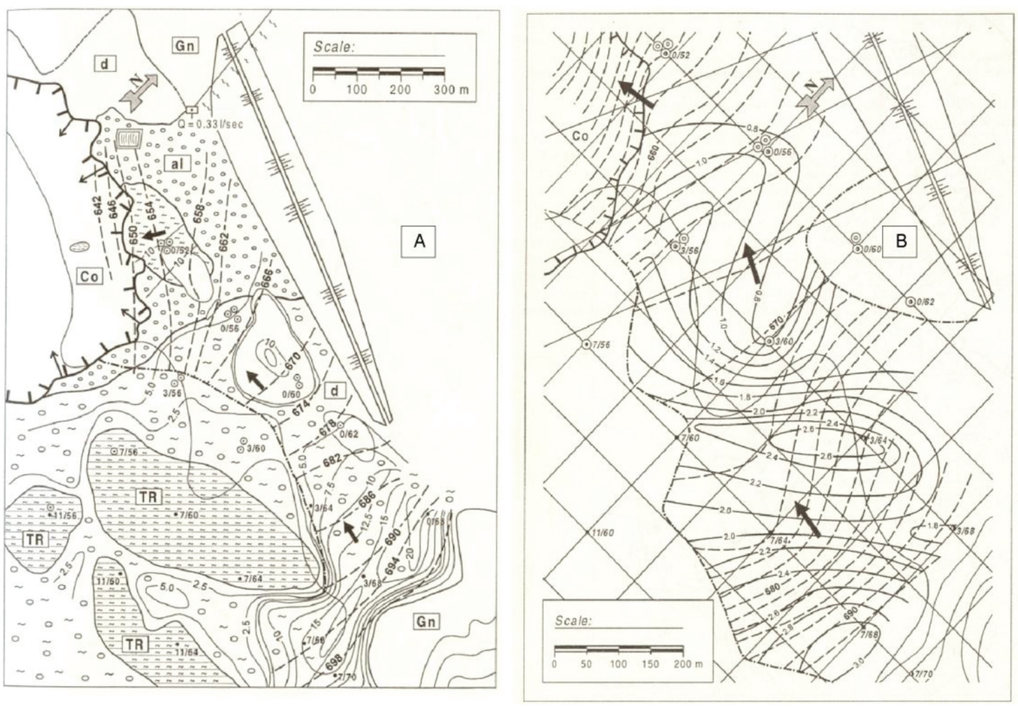


Figure 4. (**A**) Engineering geological map of the NE part of coal mine: ➡ – groundwater flow paths for the aquifer zones; --- 670 --- contour lines of groundwater level; al – alluvial sediments; dl – deluvial sediments; TR – trepel; Gn – gneiss; (**B**) Model of the groundwater movement for the interstratified aquifer zone under pressure at the NE part of the coal mine: ------- 2 -------- the contour line of equal artesian pressure (in bars); Co-colluvial material (active landslide) [5].

Figure 4A presents a model of groundwater movement for the aquifer zone with free-water level. **Figure 4B** presents the model of groundwater flow for the so-called interstratified aquifer zone under pressure, placed between two layers of coal-like clay. The aquifer zone under artesian conditions exist also bellow main coal layer with high values of pressures, affecting stability of the area.

Chemical composition of groundwater is also very important, because it influenced the installed equipment (pumps) for dewatering (**Table 1**).

Content of ions in mg/l	pH	Ca^{2+}	Mg^{2+}	Fe^{2+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	Free CO^2	Rest
Aquifer zone with free water table	6.8	20.1	12.5	0.4	158	194	701.5	–	15.5
Interstratified aquifer zone under pressure	6.5	216	21.8	2.6	184	256	760.5	70	6.8
Aquifer zone at the bottom of the coal layer	5.7	140	24.3	4.8	19	43.6	549.3	111	1.3

Table 1. Typical chemical composition of the aquifer zones.

It can be noticed that there are aggressive groundwater components with the presence of gas (CO_2, Radon, and others), which is important from ecological aspect and working conditions at the mine.

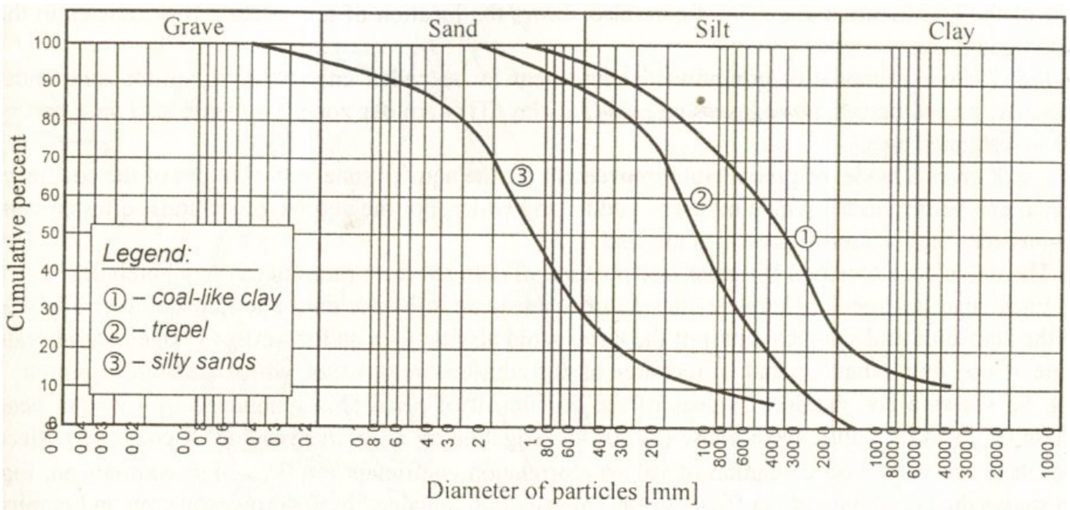
3. Brief overview of landslide elements

The complex geological and hydrogeological elements, combined with excavation for coal production, were a reason for occurrence of large landslide on the NE part of the mine. The initial phase of activation was at the end of 1995, but several large reactivation phases were also present in 1997 and 1998. Some smaller movements were also present in parts of the landslide continuously till present days. In order to illustrate the scale of the event, the main elements of the landslide are given in **Table 2**.

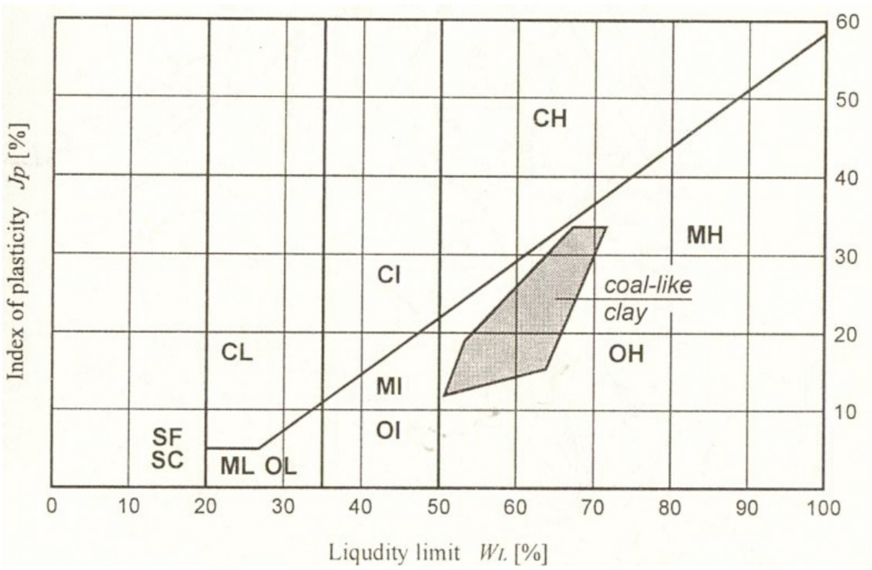
Landslide element	Value
Length (m)	About 1700
Width (m)	Min. 650–Max. 880
Area (m^2)	About 1,050,000
Volume (m^3)	About 30,000,000
Depth to sliding zone (m)	Min. 14–Max. 55

Table 2. Main landslide elements.

The most important characteristics for the main kinds of sediments are the high plasticity of coal-like clay and Pliocene silts, high value of the coefficient of uniformity C_u, and low shear strength of coal-like clay and silts with high plasticity. The typical granulometric curves and the plasticity chart of clay are given in **Figure 5**.



(a)



(b)

Figure 5. (a) Typical granulometric curves of the most characteristic sediments; (b) plasticity chart for coal-like clay.

Graphical presentation of main landslide elements is presented in **Figures 6** and **7**. From **Figures 6** and **7**, it is obvious that the main lithological units are very disturbed and displaced from their original position. Fortunately, during the process of sliding, the retrogressive extension of movement stops about 250 m from the earth-fill dam and during the main phase of activation, there were not injured working stuff.

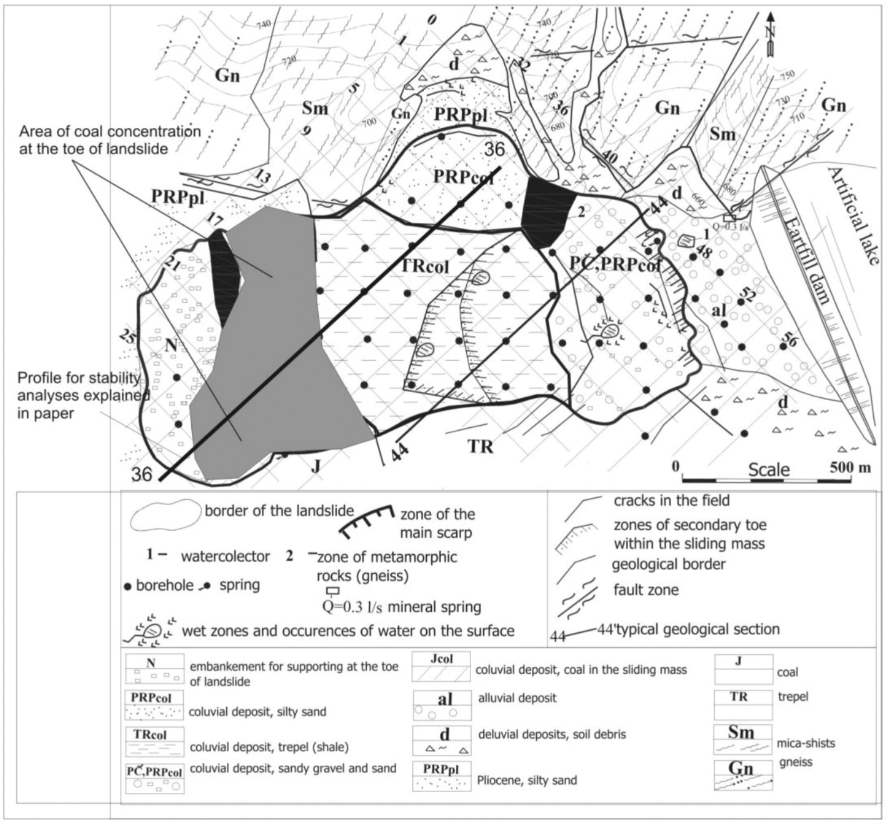


Figure 6. Simplified engineering geological map of the landslide in relation to the earth-fill dam [2].

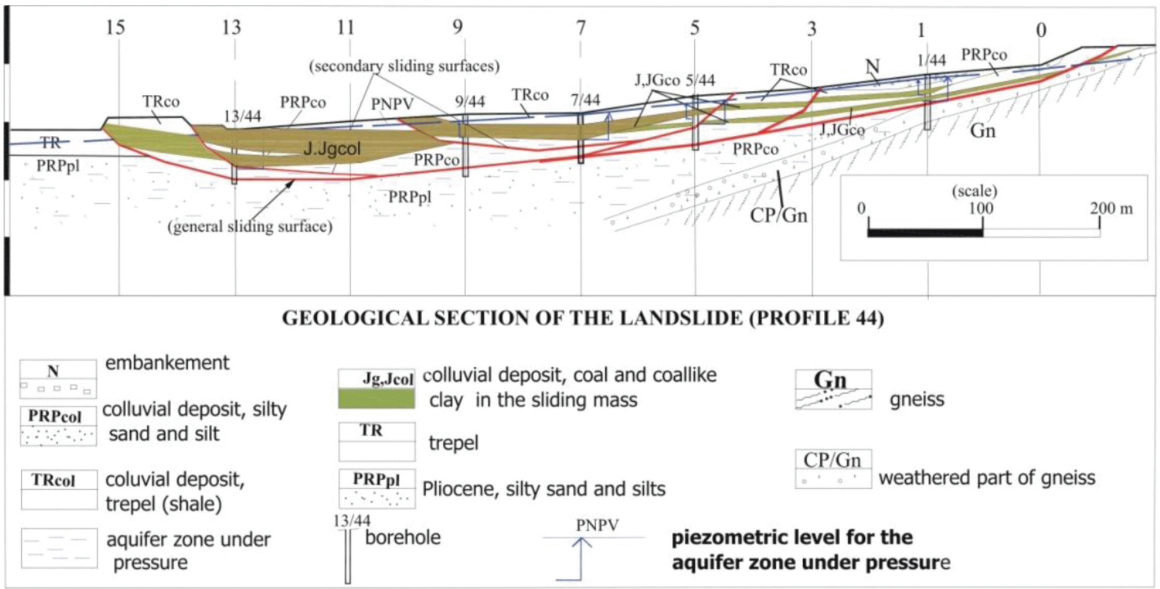


Figure 7. Presentation of geological composition of the landslide along one profile.

Results from the investigations also indicate that the sliding surfaces are very deep, usually along coal-like clay and silts with high plasticity (**Figure 7**).

To illustrate this, we present the map with relative subsidence and uprising of the field, after the phase of main activation and the map of the thickness of the landslide (**Figure 8**) [2].

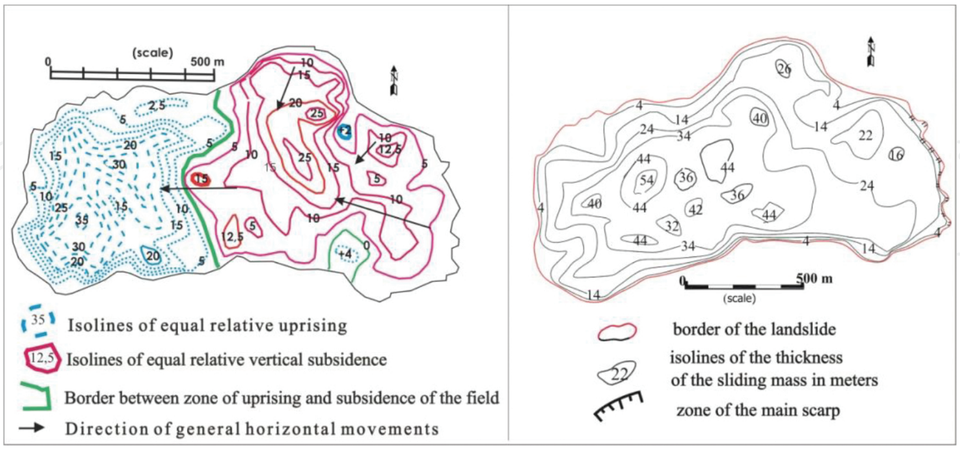


Figure 8. Isolines of relative vertical uprising and settlements in meters (left side) and isolines of landslide body thickness (right side).

It is more than obvious that the range of horizontal and vertical displacements is very large, and the thickness of the landslide body is very high. In one word, the event can be described as a "small tectonic."

A lot of secondary scarps and zone of "secondary toe" were also defined. Artesian effects are directly observed during drilling. A huge quantity of sand was transported from drilling bottom to the ground surface, because of high artesian pressures and hydraulic gradients. Analyzing all data, it can be noted that groundwater conditions have the greatest influence on the stability. The aquifer zone under artesian conditions with gases is especially important. Another important hazard and very restrictive factor was the process of self-burning, which happened because of coal's direct exposition on the fresh air.

Shortly, the problem is too complex and unique that every technical action is always connected with numerous restrictions and risks.

4. Methodology of hazard and risk analyses

Analyzing the behavior of the landslide from the time of its occurrence until present days, some facts can be underlined such as follows.

- After the main movements, the initial technical measures are applied as unloading and crack filling in critical zones, in order to minimize any further retrogressive development of sliding in the dam direction,
- The excavation of the coal was stopped at this area,

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- The toe of the landslide was supported with embankment zone (see **Figure 6**),
- The hydrostatic influences of the aquifer zones for the zone between the earth-fill dam and the main scarp was decreased with dewatering wells,
- The entire surface of the landslide was graded and drained for fast atmospheric water influences, etc.

In addition, there were several phases of smaller landslide reactivations. An important new element and very restrictive additional factor after the sliding was a process of self-burning, which happened because of coal's direct exposition on the fresh air. Thus, to minimize these effects, two main risk scenarios are analyzed (**Figures 9** and **10**).

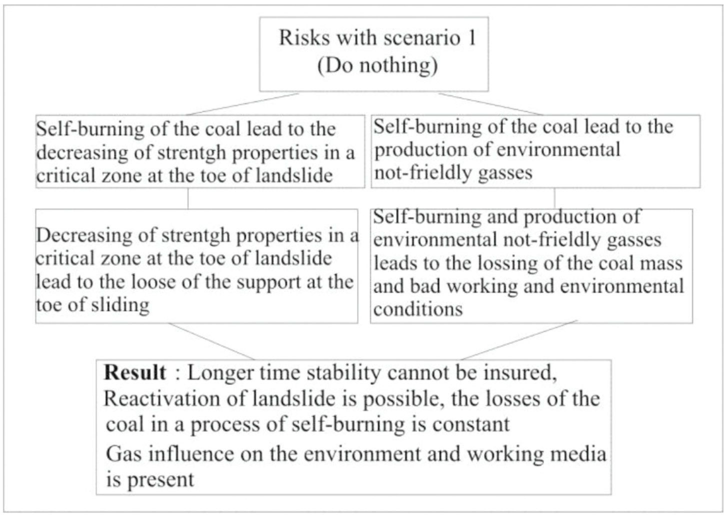

Figure 9. Presentation of main problems in Risk Scenario 1.

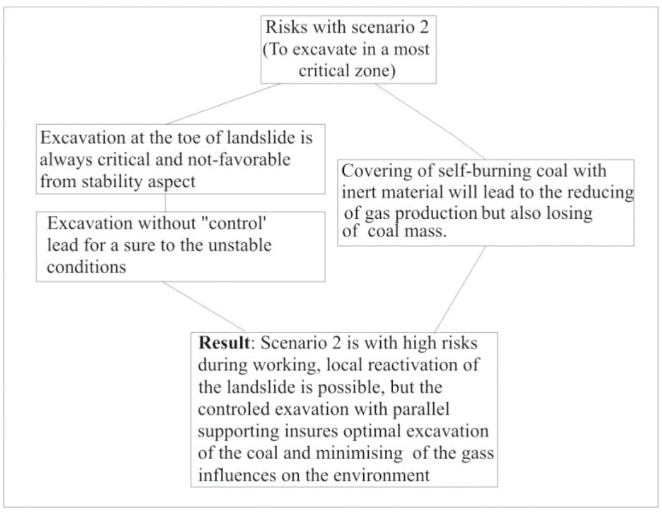

Figure 10. Presentation of main problems in Risk Scenario 1.

Both scenarios have possible negative influences on the environment and working conditions, but the main argument to accept Scenario 2 was the following.

- The process of self-burning leads to constant loosing of the coal mass and decreasing of the mechanical properties at the most critical toe zone from stability aspect.
- Covering of the zone of self-burning will lead to final closure of this zone.

The named arguments were a reason to apply an engineering solution, not a typical mining practice, and to accept Risk Scenario 2. Namely, it was decided that it is better to start with excavation, which will be analyzed in details with all possible negative consequences, as opposed to allow to lose a high quantity of coal in a process of self-burning, and finally to face the same situation—to have instability due to decreasing of the volume of the coal in the toe of the landslide. Shortly, the solution can be explained as a methodology of parallel excavation and supporting. In phases of decision-making, we used methodology of the so-called interaction-matrix method firstly introduced by [4]. The most important step in this methodology is to establish the objectives of the project and the analysis. The relevant problems are placed along the leading diagonal of conceptual interaction matrix. Then, all the interactions are established, and the problem structure is developed. An example of a relevant interaction scheme is in a form of Geotechnical Interaction Matrix and is presented in **Figure 11**.

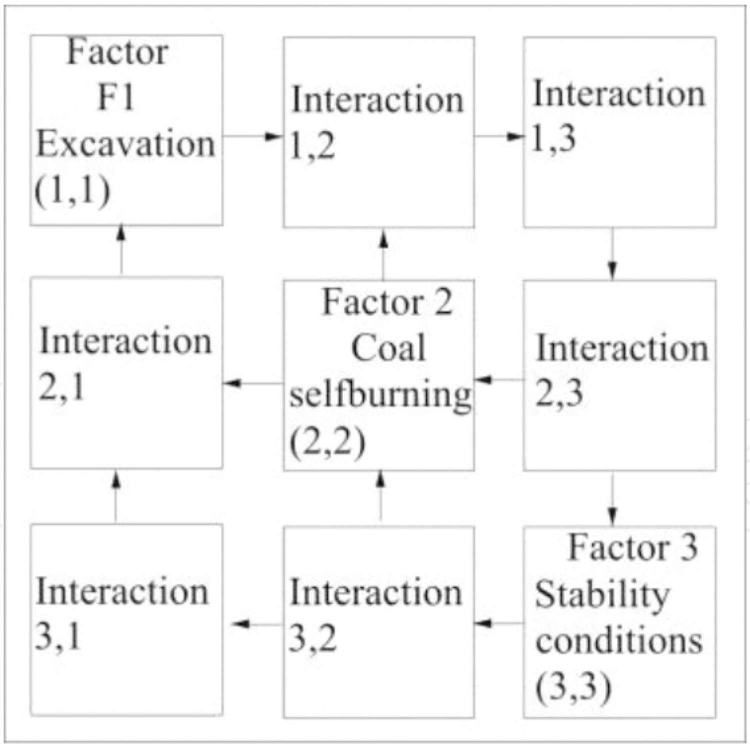

Figure 11. Conceptual matrix of interaction between tree basic factors.

F1 group of factors is related to the technology of excavation such as applied excavation and supporting method, depth of excavation, way of transportation, dewatering concept and so on. F2 group is related to the characteristics of self-burning process (area of burning, intensity, gas production, etc.). Group of factors F3 is related to the stability of the field, defined with movements of the masses and safety during the work. All possible interactions in a fist place are defined qualitatively, which is a very important step for engineering judgment and decisions. Explanations are given as follows.

- Interaction 1, 2 means that elements of the excavation can have an influence on the process of self-burning, because faster and efficient nearby excavation can stop the spreading of burning in wider areas.
- Interaction 1, 3 means that the elements of the excavation have a direct influence on the stability conditions, because correctly designed and applied technology of excavation create stable field conditions.
- Interaction 2, 3 means that the process of self-burning during longer time has an influence on the shear-strength parameters and leads to possible unstable conditions (beside other negative influences).
- Interaction 3, 2 shows that the stability of the field is the governing element, which affects possible access to zones of self-burning.
- Interaction 3, 1 means that stability of the field affects the way of excavation technology in numerous ways.
- Interaction 2, 1 means that the process of self-burning influences the excavation process, because of difficulties in access and in heavy working conditions.

It is obvious that such "simple" matrix shows several complex mutual influences between the environment and the engineering activities, and all of this shall be incorporated in design.

Based on this approach, detailed stability analyses were prepared for some representative profiles [6]. The software package SLIDE 5, product of RocScience, is used. The input parameters are defined earlier during the phases of investigations as well as with back analyses. The main properties are given in **Table 3**.

Material type	Cohesion C (KPa)	Angle of internal friction ϕ (o)	Unit weight γ (kN/m³)
Disturbed trepel	0	13	15.64
Coal-like clay	0	9–10	16.63
Silty sands	0	21	21.25
Silts with high plasticity	0	11	19.5
Crushed coal in a sliding mass	15	25	11.61
Gneiss	200	50	26

Table 3. Main physical and mechanical parameters of the materials in a sliding mass.

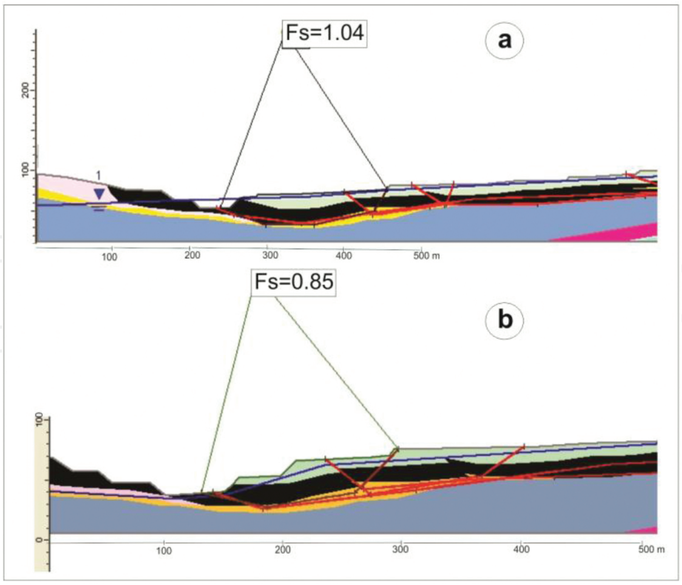

Figure 12. Typical outputs from stability analyses for initial phases of excavation; (a) before any kind of engineering activities; (b) hypothetical case without parallel support of the excavated zone.

Different phases of excavations and scenarios are involved in calculating. For example, in **Figure 12a**, we illustrate a value of safety factor (FS = 1.04) before any kind of engineering activities. In **Figure 12b**, we illustrate a hypothetical value of safety factor. This is a case, if we have a case without parallel support of the excavated zone when the safety factor is bellow FS = 1.

In practice, this case can be explained as a state of allowable deformations in a term of slow (controlled) sliding, which is expected during initial phases of excavations.

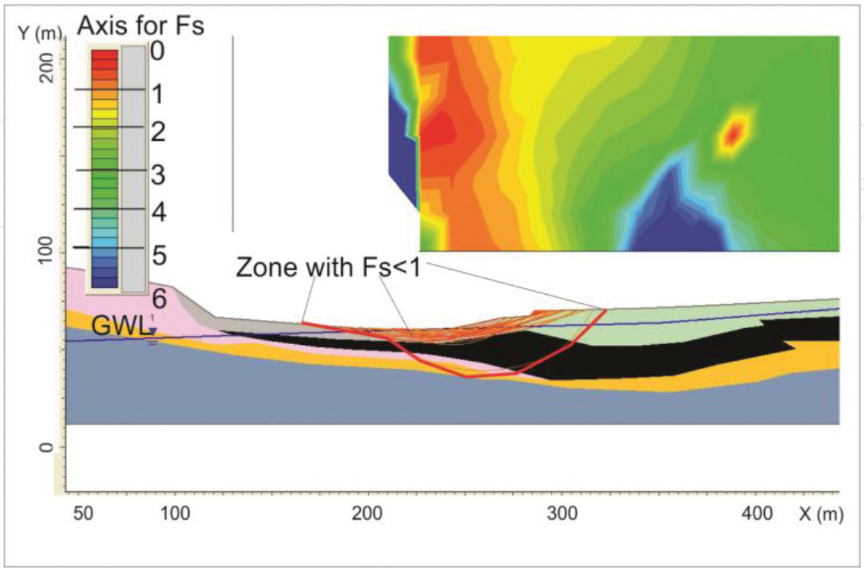

Figure 13. Simulation of stability if the process of self-burning was not stopped.

In **Figure 13**, we give an estimation of the long-term influence of the self-burning process. For the case in **Figure 13**, it was estimated that, in long-term, the upper zones of coal will be transformed into coal ash. Minor unit weight and internal friction angle are used in analyses. Results show that "new" sliding surfaces can be expected with values of safety factor smaller than 1 (unstable state).

Figure 14 explains cases of parallel excavation, support, and decreasing of artesian pressure, when the safety factor has values FS = 0.98 and FS > 1.1, respectively.

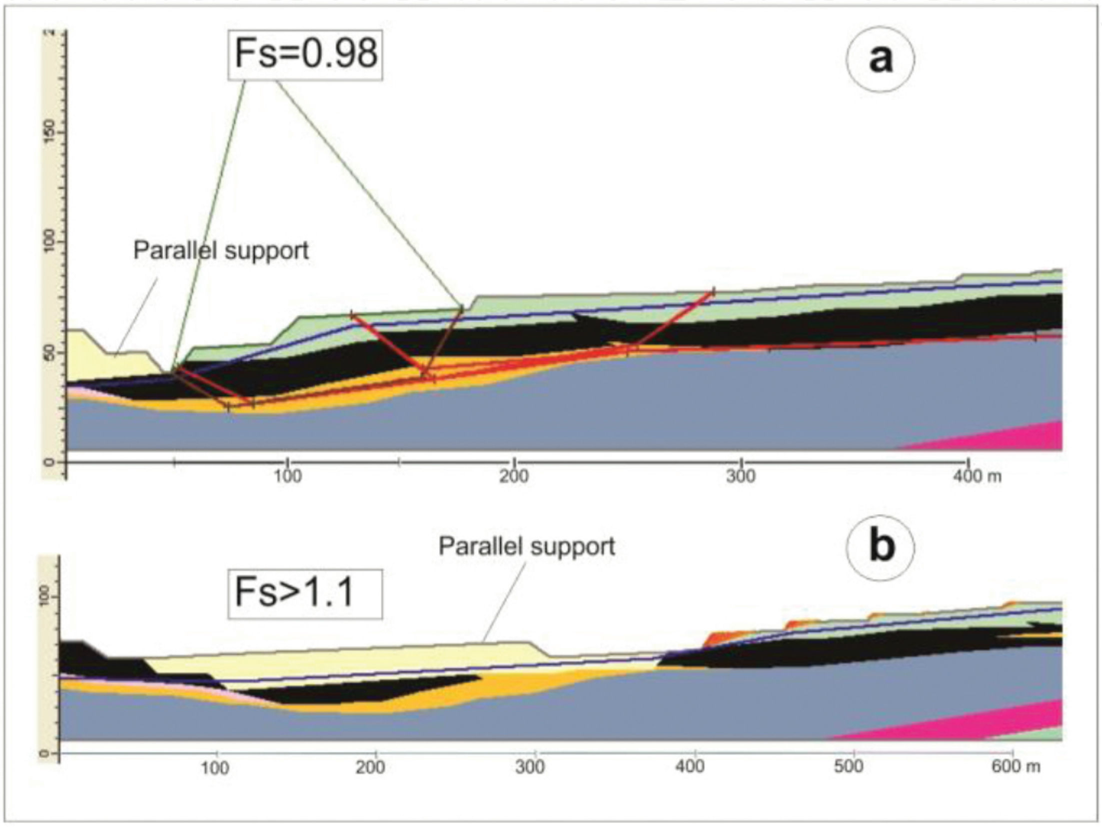

Figure 14. Analyzed cases with (a) parallel excavation and support; (b) with parallel excavation, support and decreasing of artesian pressure.

It can be concluded that for all variants, the values of safety factor that are usually not allowed in the mining practice. On the other side, the designers went into the calculated risk to excavate some quantity of the coal from one side and from the other to stop the process of self-burning. The main prerequisite to accept this risk was to apply all measures of surface dewatering and to have all time visual and geodetic observations during the work for control of possible rapid movements.

The excavation was conducted with discontinued type of equipment, which can be evacuated in a fast way if necessary. It can be noted that to date, in total, about 4,000,000 tons of coal are already excavated at this critical zone, with parallel support at the toe. As expected, minor gradual movements were observed during excavations.

5. Conclusions and recommendations

The given analyses are example, but in practice, it is sometimes necessary to deal with unusual cases that face high risks. This must be not a rule but only exceptions from rules.

All approaches in investigation and design shall completely be adapted to the characteristics of the natural environment; it is not possible to define the physical model of the terrain. Thus, we suggest the methodology of analysis presented in **Figure 15**.

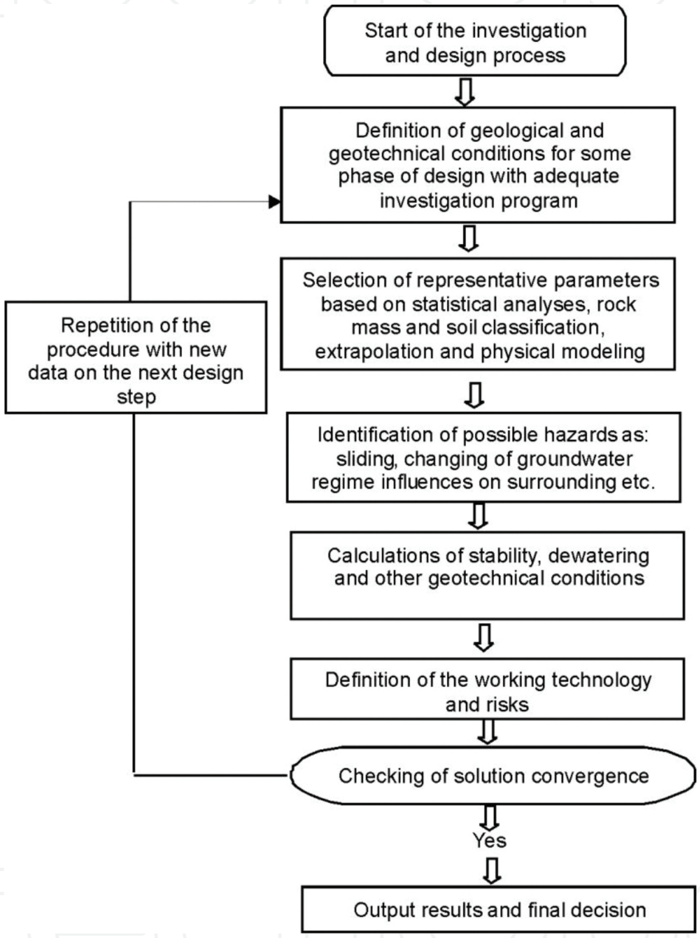

Figure 15. Suggested methodology for hazard and risk estimation at surface coal mines.

In every case, this article clearly shows that it is fundamental for successful design of each engineering activity to be acquainted in detail with the properties and conditions of the work and natural environment, possible hazards, and risk estimations.

The physical model of the terrain must be the basis for all numerical and mining analyses. We suggest using the interaction matrix method, as a useful approach in decision-making. Defined interactions are a good basis for complex analytical and numerical analyses, where the interactions can be defined with all necessary outputs (safety factors, stress-strain conditions, groundwater quantities, etc.).

Such approach can be adapted for numerous engineering problems, but it is necessary to have a team of specialists in mining, geological, and geotechnical engineering to solve such heavy engineering problems in an appropriate way.

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References

[1] Jovanovski M., Papic J., Dambov R., Pesevski I.: Stability aspects of excavation in landslide zone for a coal mine Suvodol, R. Macedonia, 3rd Balkan Mining Congress, Izmir, Turkey, 2009.

[2] Gapkovski, N., Jovanovski, M., Manasiev, J., Martinovic, A.: Report from the additional geotechnical investigations on the N.E. part of the coal mine "Suvodol" – Bitola, Faculty of Civil Engineering, Skopje, 1996.

[3] Jovanovski, M., Gapkovski, N.: Methodology and results from investigation of groundwater condition on the N.E. part of coal mine "Suvodol" – R. Macedonia, 6th International Mine water Association Congress, Bled, Slovenia, 1997.

[4] Hudson, J.A.: Comprehensive rock engineering, Pergamon Press, Oxford, England, 1993.

[5] Jovanovski, M., Donevska, K., Peshevski I.: Design of the dewatering at a coal mine Suvodol, Faculty of Civil Engineering, Skopje, 2007.

[6] Jovanovski, M., Papich, J., Peshevski I.: Design of the stability of the slopes at the coal mine "Suvodol", Faculty of Civil Engineering, Skopje, 2007.

[7] Jovanovski M., Popovska C., Donevska K., Peshevski I.: Interaction matrix method in hydrogeological analyses at coal mines, 11th International Symposium on Water Management and Hydraulic Engineering, Ohrid, R. Macedonia, September 04–09, 2009.

[8] Panovski A., Djorlev, S., Jovanovski M.: Design of an excavation in an landslide zone of the open coal mine Suvodol, RI Ruding, Skopje, 2007.