METHODOLOGY AND RESULTS FROM INVESTIGATION OF GROUNDWATER CONDITION ON THE N.E PART OF COAL MINE "SUVODOL" – R. MACEDONIA

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ABSTRACT

It is a well known fact that rational, efficient and safe designing of engineering activities in coal mines is not possible without knowing in detail the groundwater conditions. It is specially emphasized in cases of complex hydrogeological conditions in the environment.

This paper is an example of investigating a very complex groundwater conditions stated in N.E part of the coal mine "Suvodol". The methodology, results and experience obtained by the authors of this paper are shown. The investigations have been made in conditions of great heterogenity of the states and conditions of the environment. These investigations are made to enable designing mining activities, considering some specifics, as are active landslide, earth dam and artificial lake near the site where the investigations took place. Models of the groundwater movement of three separated aquifer zones (two under pressure), are shown as well as models of the values of artesians pressure. The correlation between coefficient of filtration obtained by investigation in field and by empirical methods are shown, too. Thus the fact that it is essentially to define this parameter on the field is emphasized.

At the end, the matrix of interaction between the parameters of groundwater condition, geological and geotechnical factors is shown.

This paper underlines the importance of correctly set and carried out investigations of the groundwater conditions, as well as the need of appreciation of the principle of equal grade and whole grade of investigation for the whole zone of interaction between the natural environment and the engineering activities.

INTRODUCTION

The surface coal mine "Suvodol" is placed in the S.W part of the Republic of Macedonia. The coal layer and the unproductive layers have been made in lake conditions during upper pliocene. Mainly, there are layers at the bottom of the coal (layers of silty sands), productive series of coal and coal like clay and layers on the upper part of coal of volcanic material (so called trepel).

During 1995 large landslide appeared and it is active even today. It's volume is about 25 million cubic meters and depth of the sliding mass in some places is deeper than 50 m.

The appearance of the landslide caused some difficulties in the normal work of the exploitation systems and is a potential danger for the earth dam and the artificial lake which is about 250 m from the main scarp of the landslide.

In order to adopt the technics and technology of the excavation to the newly created conditions, the authors of this paper investigated the N.E part of the mine. The reason these investigations were made was to create conditions for real definition of the physical model of the terrain which will serve as a base for all the analyses of the stability, conditions for protection from the groundwaters, excavation conditions and so on.

The position of the investigation site in relation to the landslide (the actual excavation) and the dam is shown on Fig. 1.

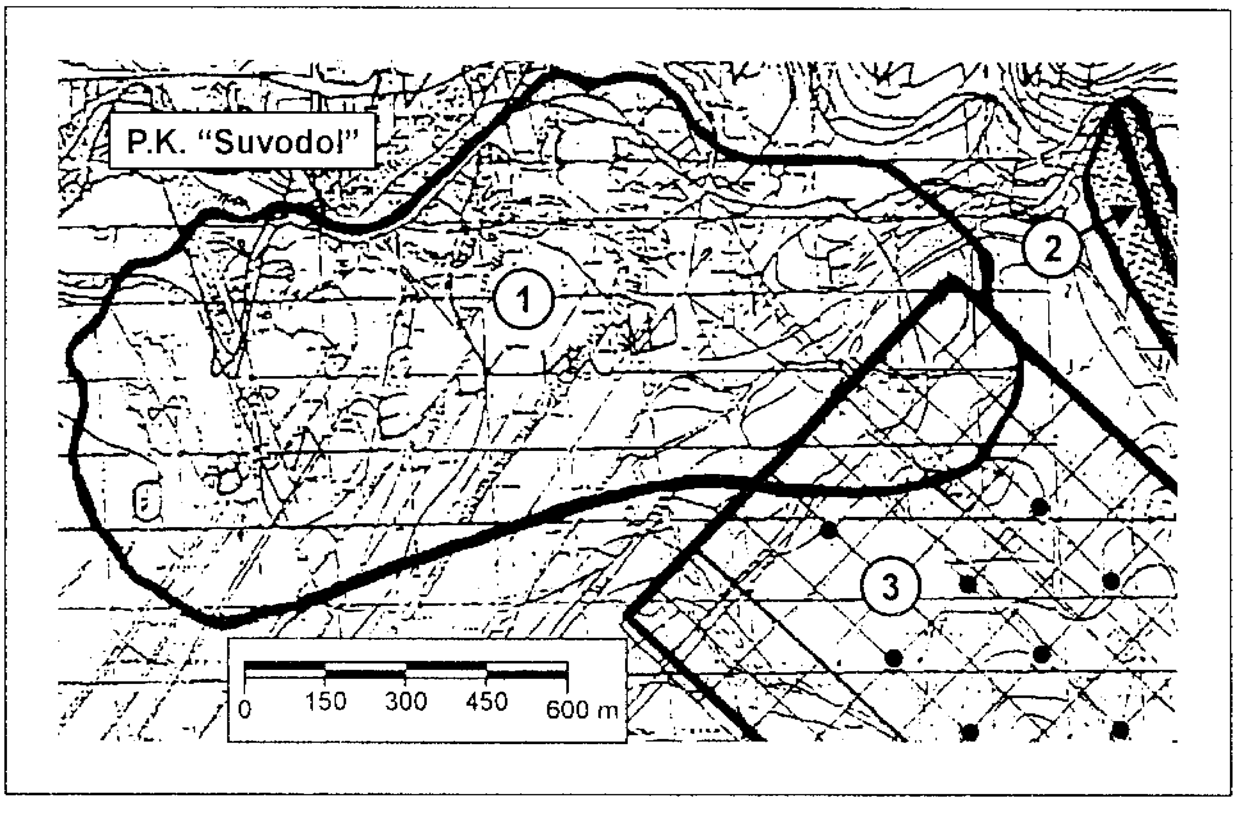

Figure 1. Position of the investigation area in relation to the landslide and the dam: 1 – active landslide; 2 – earth dam; 3 – investigation area.

All the activities were based upon previously made Project-program [2]. According to the stages of performance these activities could be considered as multy purpose investigations during exploitation.

METHODOLOGY

These investigations has been complex in the sense of solving the entire geological, geotechnical and hydrogeological situation on the terrain. This paper presents only the part dealing with the groundwater conditions, while the other results are shown in appropriate Report [3] and on symposium [6]. The area of the landslide is additionally investigated, but it is not a subject of this paper [4].

The main idea of the methodology applied was these investigation to include evenly and wholly the space in which it is expected mutual influence of the engineering activities and the natural environment.

The following procedures has been applied: detail mapping of the wider area, investigation drilling (18 investigation boreholes), building in of piezometers (8 group piezometers), investigations of the chemical composition of groundwaters, field investigation of filtration coefficient, as well as laboratory analyses of physical and mechanical properties [3].

While interpreting the results, former investigation boreholes, builded piezometers for dam surveying and so on were used (in order to make the investigations step by step).

Taking into consideration the fact that the groundwater has the greatest influence on the stability of the terrain (which is specially emphasized as a problem in this case because of the existence of landslide near by), the greatest attention was paid to the groundwater conditions. This was made also having in mind the fact that for this part of the mine there were relatively little data for its hydrogeological characteristics.

The most important data were obtained by building in of so called group piezometers. For each group piezometer special borehole was made which is the safest way to isolate every aquifer zone. As an example, the scheme of builded triple piezometer with a detail of the geological condition is given on Fig. 2.

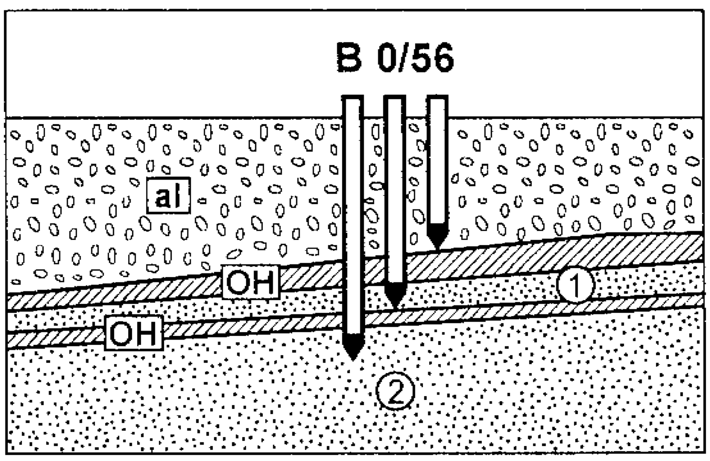

Figure 2. Scheme of triple piezometer of borehole B 0/56: al – aluvial sediments; OH – coal-like clay; 1 – interstratified aquifer zone; 2 – aquifer zone at the bottom of clay.

Great attention was paid to the defining of the contact of gneiss-pliocene sediments as a zone important for the interaction of the engineering activities and the natural environment from the aspect of stability and hydraulic link between aquifer zones from pliocene with the gneiss metamorphic complex.

In order to get the coefficient of permeability K, the method of *Le Franc* was applied. Considering the small quantity of aquifer zones, constant head phase and falling head phase was used. Coefficient of permeability of the surrounding metamorphic rocks (gneiss) is find by graph-analytical method of *Vangham*, 1972. For defining of the ground water chemical composition, appropriate chemical analyses has been made. The data about groundwater quantities were take from the existing wells in the body of the land slide.

RESULTS

It was concluded that the whole investigation area has great lithological heterogeneity which is the reason why there is great heterogeneity of hydrogeological characteristics. A detail of the geological structure with a description of the hydrogeological function of the layers is given on Fig. 3.

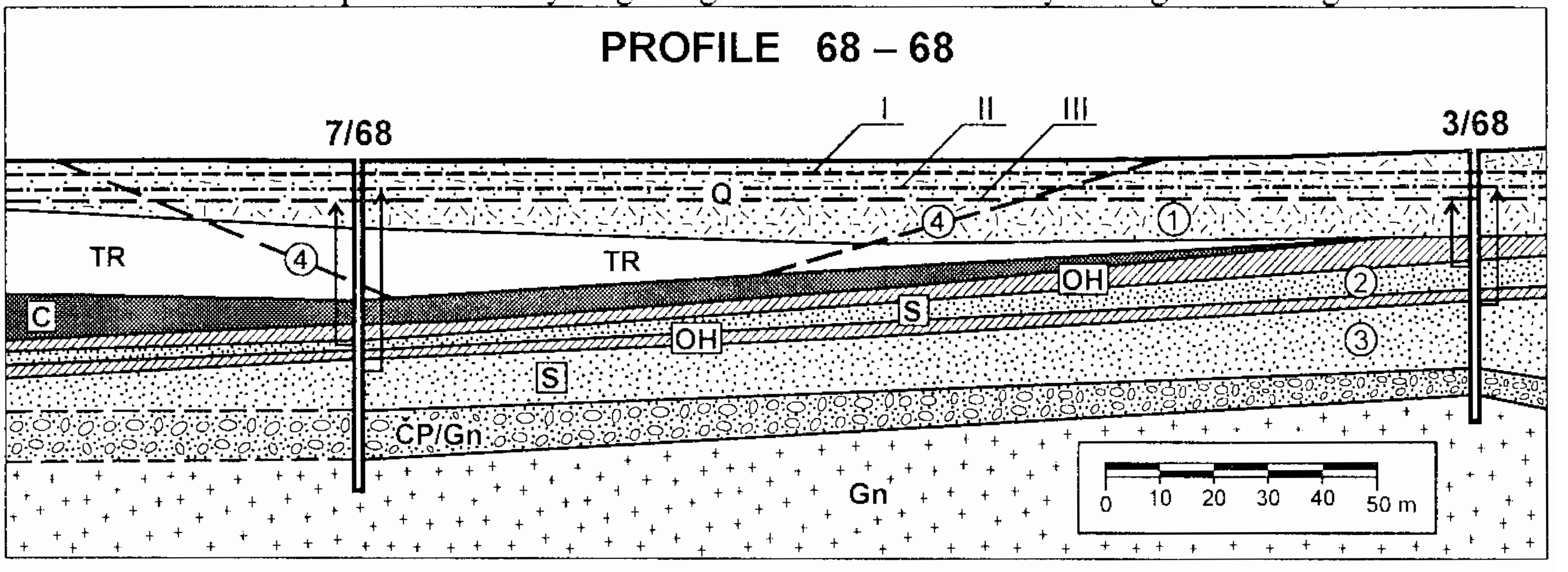

Figure 3. Detail of geological composition of the investigation area: 1 – Aquifer zone with free water level; 2 – Interstratified aquifer zone under pressure; 3 – Aquifer zone at the bottom of the coal layer; 4 – Designed cut; Q – Quarterian silty sand layer; TR – Trepel (aquifuge); C – coal; OH – coal-like clay (aquifuge); 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.

The most important characteristics for the main kinds of sediments is the high plasticity of coal like clay (as a prerequisite for swelling), discontinuity of the trepel (as a condition leading to sliding alongside discontinuities) and the high value of the coefficient of inhomogenity C_u according to *Allen Hazen* (as a prerequisite for the appearance of underground erosion). The characteristic granulometric curves are given on Fig. 4 and the plasticity chart of clay is given on Fig. 5.

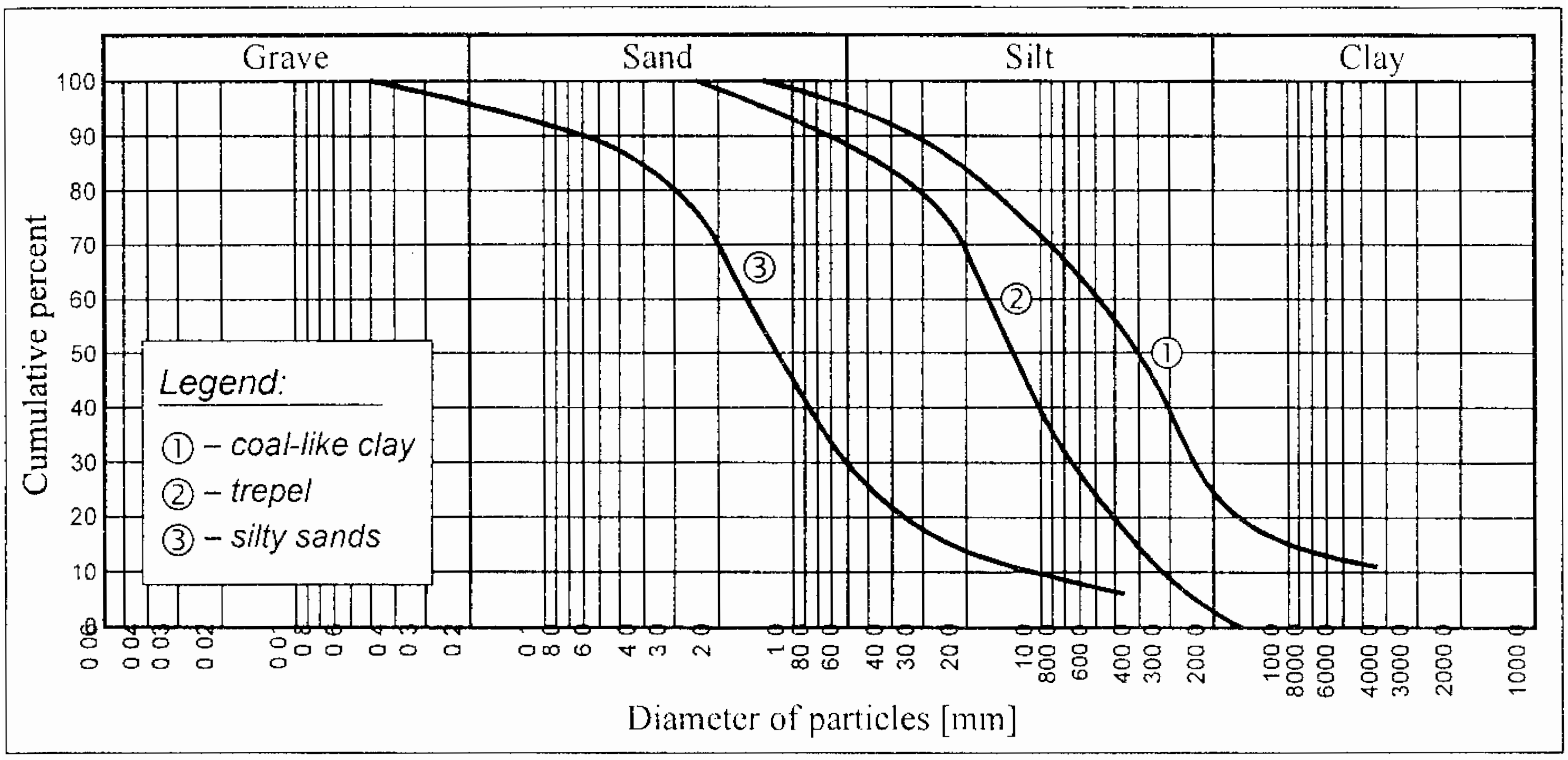

Figure 4. Typical granulometric curves of the most characteristic sediments.

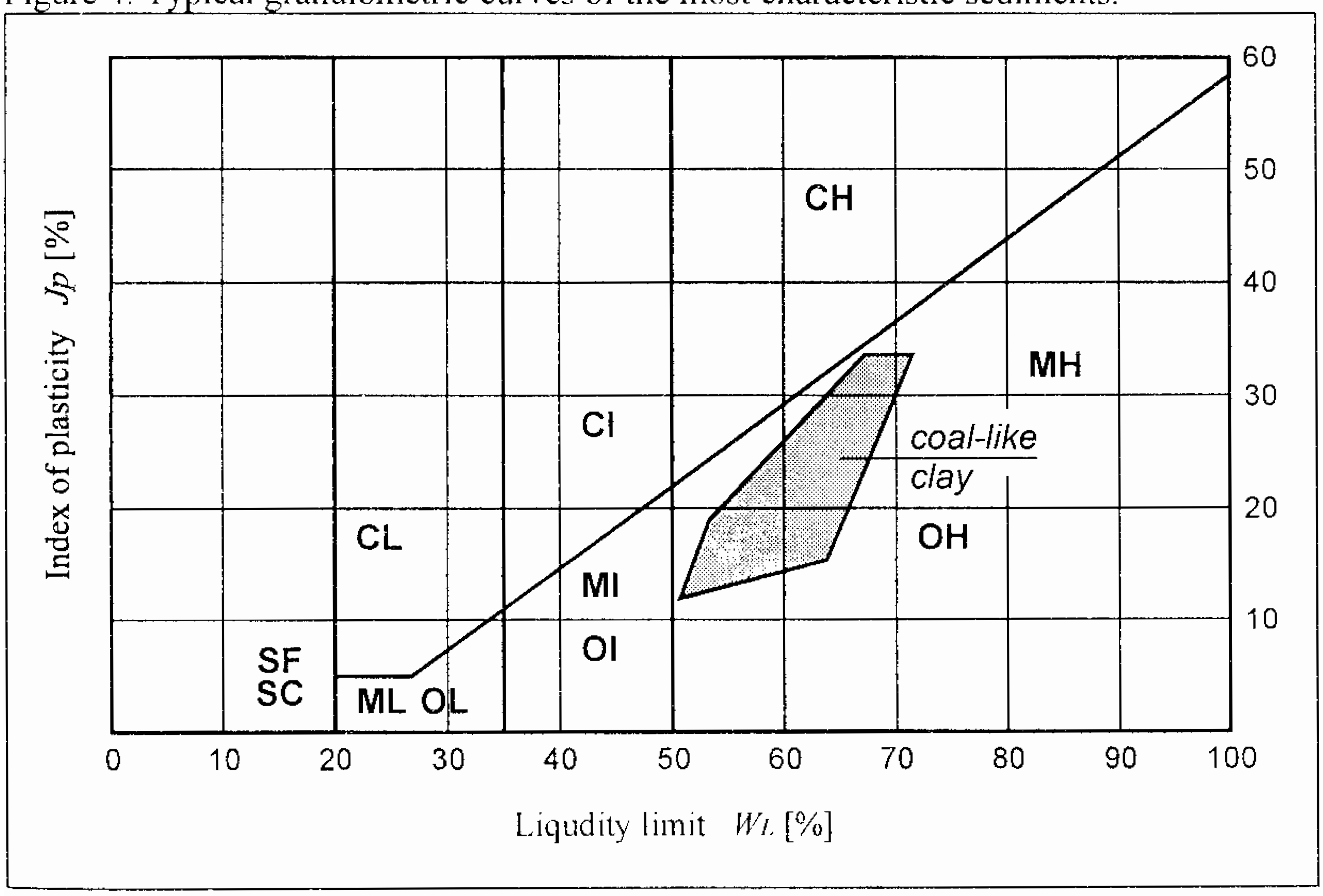

Figure 5. Plasticity chart for coal-like clay.

By the help of newly builded group piezometers and the existing piezometers, the presence of three physically separated aquifer zones are found. Fig. 6 shows a model of ground water movement for the aquifer zone with free water level. It could be seen that this aquifer is situated only on one part of the investigation site. This figure also shows the location of the existing rock masses in the investigated area.

Fig. 7 shows a model of groundwater movement for so called interstratified aquifer zone under pressure, placed between two layers of coal-like clay. This aquifer zone is situated also on a part of the investigated area.

Fig. 8 gives a model of groundwater movement for the aquifer zone at the bottom of the coal layer which can be find in the whole mine "Suvodol" and wider. For the aquifer zones under artesian conditions very high values of pressures are find.

The models are obtained by linear interpolation of data got from piezometers and boreholes.

Each zone has special characteristics and has adequate influence on the terrain stability. The role of the land slide and excavated part of the mine could also be seen and it works as huge natural drain zone. It was found that the zone of recharge of this aquifers are gneisses, which are highly jointed. Fig. 9a shows a correlation of values of the coefficient of permeability obtained by constant head phase (K_c) and by falling head phase (K_f) of investigation by *Le Franc* method. It could be noticed that there are very good corelation of values (correlation coefficient $r = 0{,}93$). For comparison, Fig. 9b shows the correlation of coefficient of permeability K_c obtained by field investigation and empirical formula according USBR ($r = 0{,}23$). It is obvious that the parameters are badly correlated which proves that direct use of empirical formula for such cases is not recommendable.

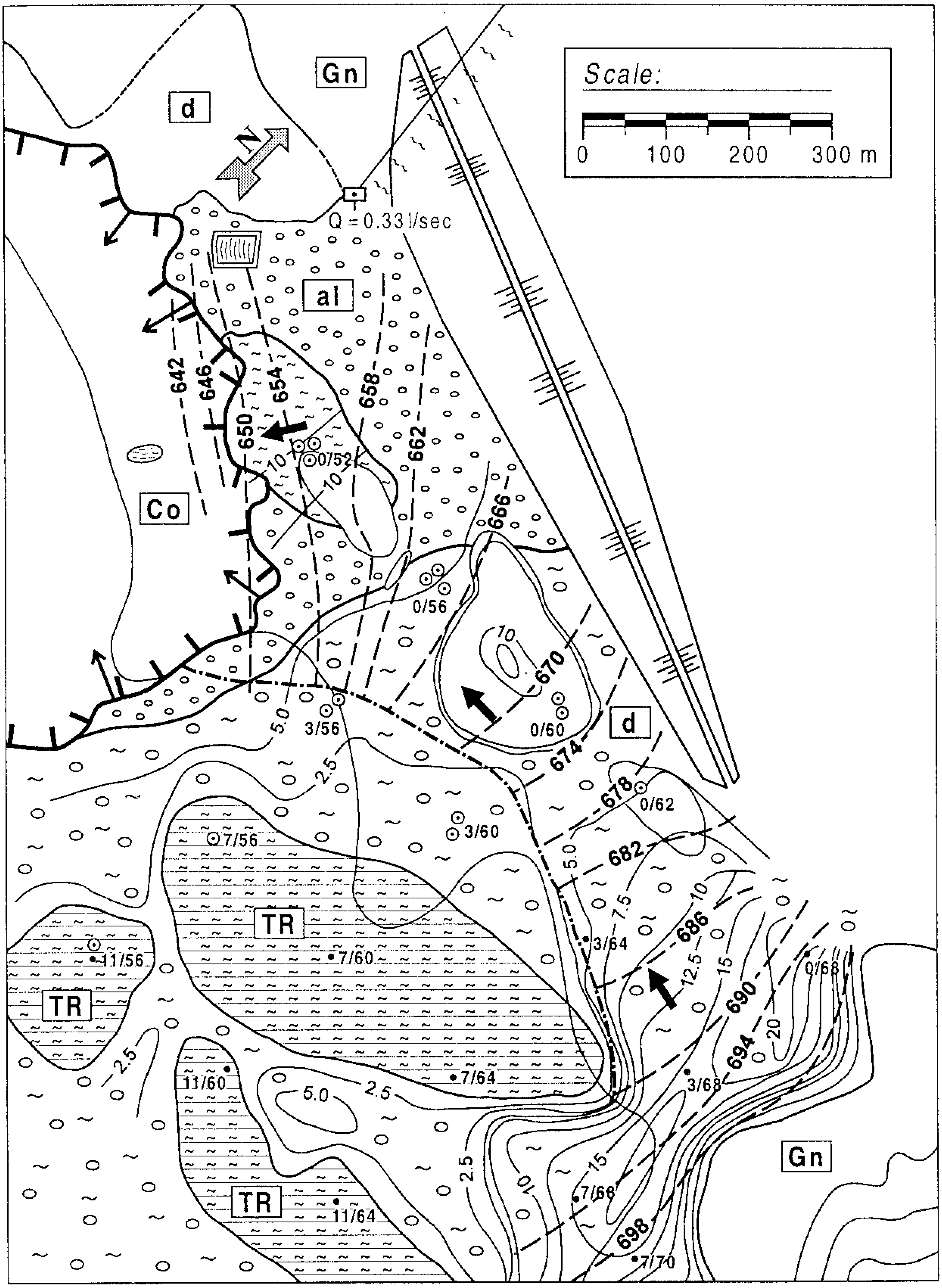

Figure 6. Engineering geological map of the investigated area: ➔ – direction of the groundwater movement; — — 670 — — – hydro-izohipse; al – aluvial sediments; dl – deluvial sediments; TR – trepel; Gn – gneiss; Co – coluvial material (active landslide).

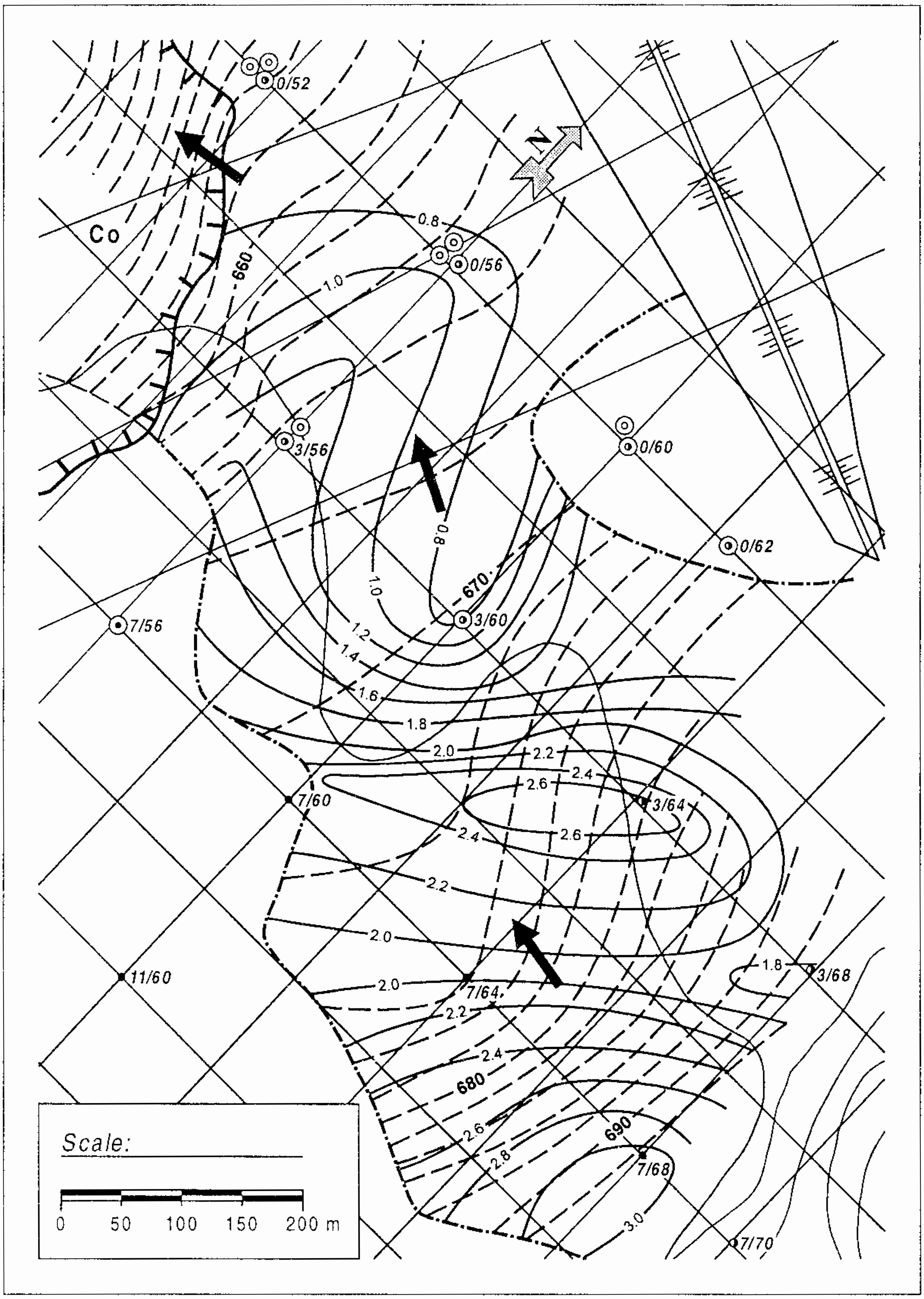

Figure 7. Model of the groundwater movement for the interstratified aquifer zone under pressure: ➔ – direction of the groundwater movement; — — 670 — — – hidroisopiesas; — — 2 — — – isoline of equal artesian pressures (in bars); Co – coluvial material (active landslide).

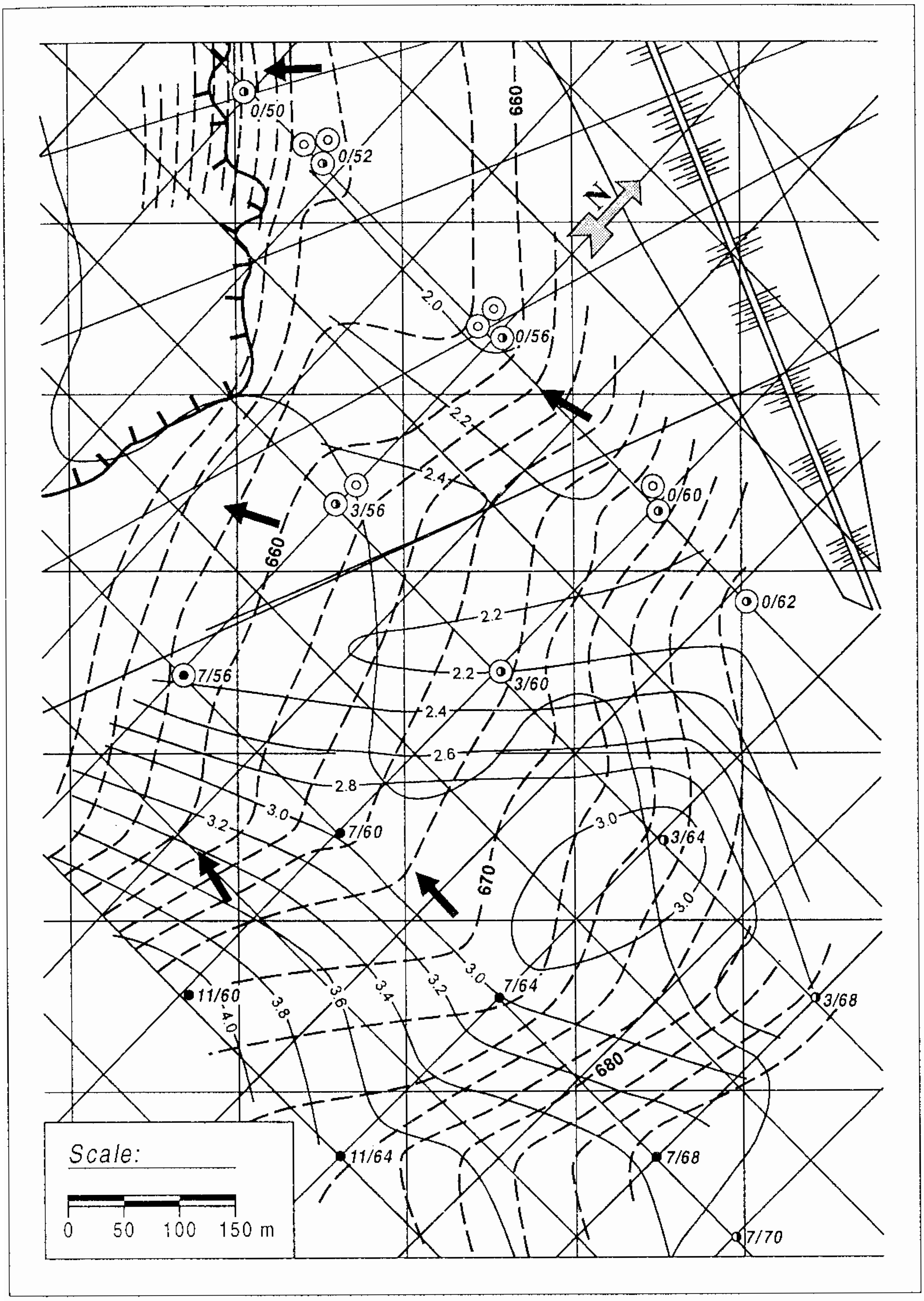

Figure 8. Model of the groundwater movement for the aquifer zone at the bottom of the coal layer: ➔ – direction of the groundwater movement; — — 670 — — – hidroisopiesas; — — 3 — — – isoline of equal artesian pressures (in bars).

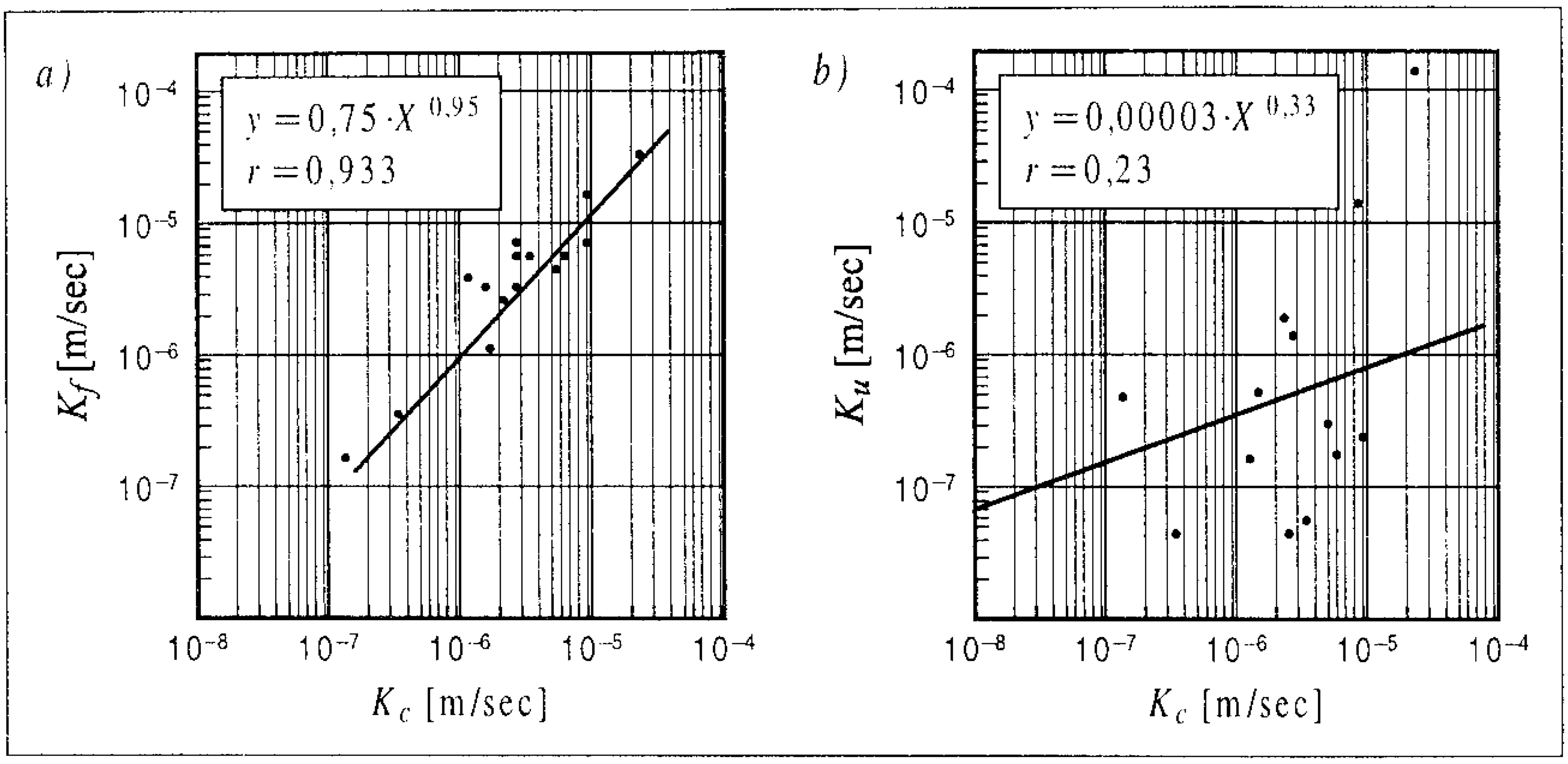

Figure 9. (a) Correlation between coefficient of permeability obtained from the constant head phase (K_c) and from falling head phase (K_f); (b) Correlation between coefficient of permeability obtained with field test (K_c) and from the empirical formula (K_u).

The following table shows the chemical contents of groundwater and it can be noticed that in each case there are aggressive groundwater with presence of gas (CO_2). This is significant from the aspect of chemical interaction with eventual builded equipment for ground water pumping. The presence of gas is important from the mechanical and ecological aspect.

Table 1. Typical chemical composition for the aquifer zones.

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	12,50	0,4	158,0	194,0	701,5	–	15,5
interstratified aquifer zone under pressure	6,5	216	21,87	2,6	184,0	256,2	760,5	70	6,83
aquifer zone at the bottom of the coal layer	5,7	140	24,30	4,8	18,0	43,6	549,3	111	1,50

APPLICATION OF THE RESULTS FOR PROGNOSIS OF INTERACTION BETWEEN THE NATURAL ENVIRONMENT AND THE ENGINEERING ACTIVITIES

The basic prerequisite for adequate prognosis of interaction of geological environment with the engineering activities is to separate each aquifer zone. If this prerequisite is not fulfilled it could not be possible to make real analyses of the stability and design the conditions for ground water protection.

What is specific in this case is the fact that there are no high values of groundwater quantities. On the other side its hydrostatic and hydrodynamic effects are very important.

All the results from the investigations, the calculations and the data of the pumping of the ground water from the near by wells show small quantity of groundwater [3]. For example, the rate between pumped groundwater in a year and the excavated mass, expressed with coefficient K_v for whole mine "Suvodol" is $K_v = 0{,}24 - 0{,}26$ (mines with the lowest degree of the coefficient K_v).

On the other side, as a result of existence of high values of piezometric pressures and uplift phenomena the authors have paid special attention to the influence of the groundwater to the stability of the terrain. Having this in mind, numerous advises have been given to the Project Designer [3]. It is considered also that as a designing solution excavation of the cut along the profile No. 7 is offered (Fig. 3).

The authors have taken part only in the stage of investigation of this project but not in the designing. That is why there is no comment on the choice of the solution.

In our opinion, a very useful way of finding out the possible mutual influence of the system natural environment – object is the so called matrix of interaction after *J. A. Hudson* [5].

Fig. 10 shows the four basic factors of interaction which form the main diagonal of the matrix. These factors are involved mutually, in 12 basic kinds of interaction.

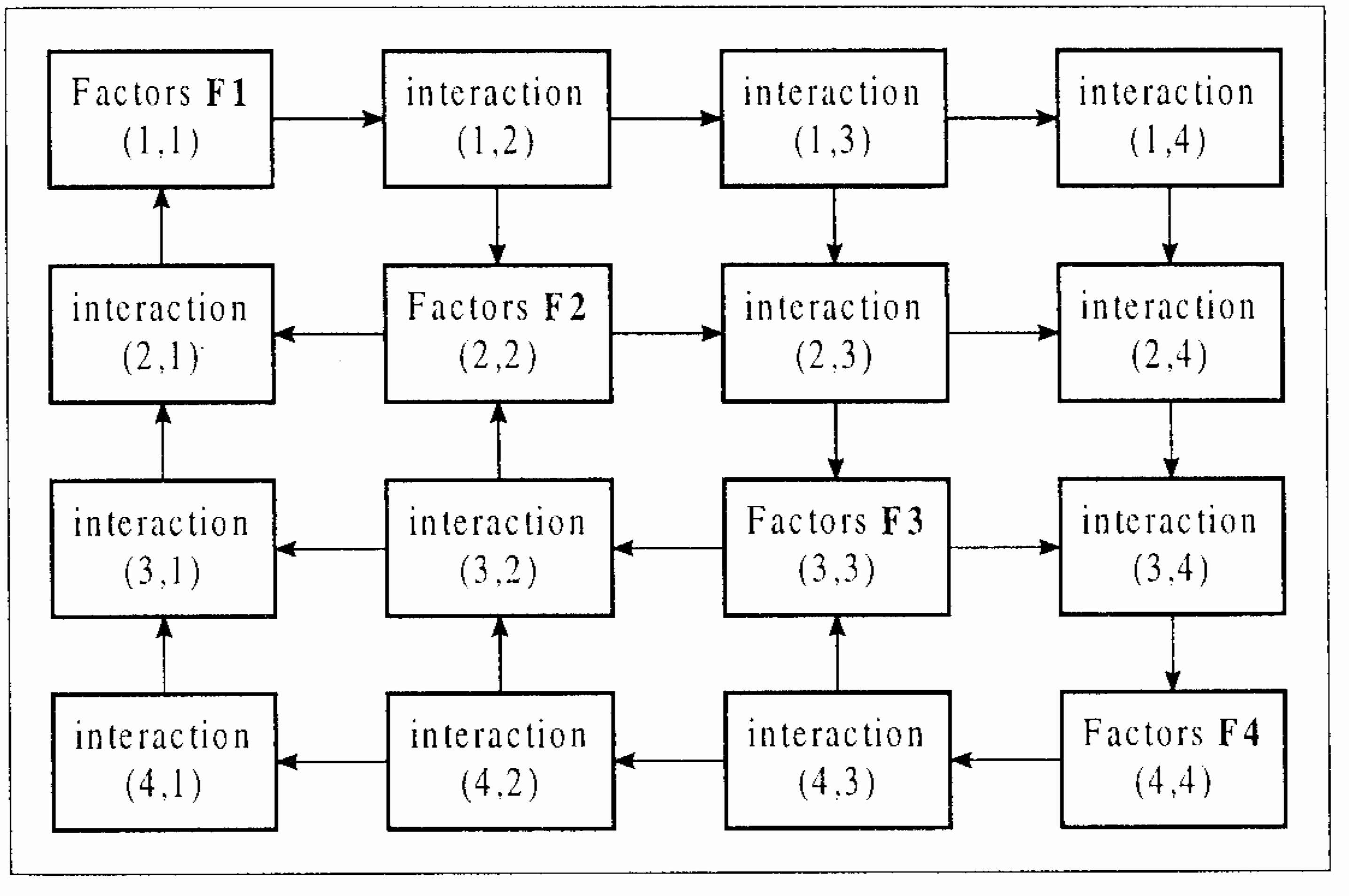

Figure 10. Matrix of interaction between 4 basic factors which have influence on the stability of the area: **F1** – Structural physical and mechanical characteristic of the sediments; **F2** – In situ stress; **F3** – Ground water condition; **F4** – Characteristics of the engineering activities.

F1 group of factors is related to the sum of properties such as: unit weight, porosity, moisture content, strength properties, discontinuities at the trepels, plasticity of clay, thickness of layers and so on. **F2** group is related to the in situ stress. **F3** group is related to the velocity of ground water movement, hydraulic gradients, hydrostatic and hydrodynamic pressures, filtration characteristics, aggressiveness of the waters and so on. At the end, group of factors **F4** is related to the characteristics of the object, such as its depth, wide, dips and heights, technology of excavation and so on.

All possible interactions of these factors have influenced the efficiency and safety of construction of the object. Qualitative expression of these basic influences is given bellow.

Interaction 1,2 – Layers thickness and their weight influence the in situ stress.

Interaction 1,3 – Changes in litological composition, effective porosity and so on influence the filtration, groundwater movement velocity and so on.

Interaction 1,4 – Physical and mechanical properties are the base for designing stable dips and highs of the slopes.

Interaction 2,1 – In situ stress influences degree of compaction of sediments, opening of the joints in trepel and so on.

Interaction 2,3 – In situ stress influences the ground water condition, pore water pressure, decreasing of the filtration in higher stressed zones and so on.

Interaction 2,4 – In situ stress determines the point up to which excavation could be made without penetration of groundwater on the floor of the cut (because of the values of hydrostatic pressures).

Interaction 3,1 – Groundwater condition influences the decreasing of the strength properties of sediments, increasing of porosity as a result of pumping and so on.

Interaction 3,2 – Groundwater condition influences the decreasing of the total stress (concept of effective stresses).

Interaction 3,4 – Artesian pressures, inflow of ground waters, chemical interaction and so on, influence the designing of safety measures for protection.

Interaction 4,1 – Excavation influences the change in natural moisture content, unit weight, decreasing of the strength properties and so on.

Interaction 4,2 – Excavation leads to the changes in situ stress , stress concentration and so on.

Interaction 4,3 – Excavation influences the groundwater condition through velocity movement change, possibility to form critical hydraulic gradients and appearance of underground erosion and so on.

It is obvious that not only a group of geological, geotechnical and hydrogeological elements influences the characteristics in the designing of the object but also the construction of the object contributes to the change of series of properties and conditions. It is possible to analyze in detail the mutual influence between each physical, mechanical, structural and other characteristics, which on the other hand lead to the increasing of dimensions of matrix of interaction.

The above aspects besides qualitatively could be encompassed quantitatively by adequate analyses, monitoring after construction, investigation during construction and so on (which overcomes the frames of this paper).

For illustration, some methods which should be applied for qualitative definition of some interactions are given below.

Prognosis of possible penetration of groundwater from the floor of the cut (interaction 3,4), which on the other hand needs designing of adequate safety measures, can be made by the following simple criteria:

$$\gamma_w \cdot H < \gamma \cdot h$$

where: γ_w – unit weight of water, γ – unit weight of coal-like clay, h – thickness of coal-like clay layer, H – artesian pressure value.

The method of *Istomina V. S.* [1] could be used for interaction 3.4 (case if the excavation goes to the sands, when there is a possibility to develop critical hydraulic gradients). Interaction 2.4 may be evaluated by the stability analyses before excavation with a safety factor **F**, while the interaction 4,2 can also be evaluated by the stability analyses in the stage of excavation. The comparison of the safety factors obtained in both cases is a quantitative indicator of these interactions. In order to define the stress- strain condition in different stages (before excavation, in the stage of excavation, after the excavation) the finite elements method could be applied.

It is obvious that even matrix of interaction of the lowest range shows several complex mutual influences between the natural environment and the engineering activities. The neglect of these complex influences in the stage of designing or construction may lead to undesired consequences.

CONCLUSION

It is fundamental for successful designing of each engineering activity to get acquainted in detail with the properties and conditions of natural environment. Among the factors of the natural environment that have the greatest influence upon the excavation conditions, protection conditions, stability of terrain and so on, the groundwater conditions are specially emphasized. When there are more separate aquifer zones, it is necessary to separate them completely. The authors recommend to apply a method of isolation by separate borehole for each part of group piezometers. It is also necessary to make all the analyses based upon the methods performed on the field. The empirical methods could lead to great errors.

Without an adequate methodological approach in investigating, an approach which will be completely adopted to the characteristics of the natural environment, it is not possible to define the physical model of the terrain. The physical model of the terrain must be the base for all mathematical models.

What is specially important is that the whole area of investigation has to be covered evenly and wholly by the investigations in the complete interaction zone of engineering activities and the natural surrounding.

At the end, the authors recommend to use separately for each object the concept of matrix of interaction about all influential factors and this will be the subject of our further analyses.

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