The stability analysis of the civil engineering from Oltenia mining area

Victor Arad, Susana Arad, Oana Bărăiac and Ladislau Radermacher

Abstract — The incidents produced in the mining area, Oltenia, the subsidence and damage caused to buildings and roads located in this area, involved a survey on surface stability in this area. The land affected and occupied by mining, waste dumps, buildings represents over 9500 hectares. Because of the excavation nearby areas, the biodiversity is destroyed, the groundwater regime is changed, a natural geochemical transformation of soil elements is taken place and intense erosion processes and landslides are manifested. The paper analyzes the stability of the foundation soil and of the embankments of terrestrial communications routes (DJ 675A and DC 29) which were affected by the exploitation of lignite in the area. Slope sliding phenomenon is being analysed through methods of edge state analysis using continuum or FEA approaches.

***Keywords*—**analysis, embankments, geomechanics characteristics, landslides, slopes, stability

I. INTRODUCTION

TODAY, surface mining is in continuous development world wide, both as production per unit operation, as the number of companies raising production of raw materials extracted from quarries than the total production of the same useful minerals.

In Oltenia region, Romania, the lignite extraction activity takes place in 18 open pits. Depending on the location of mining exploitation, large areas of arable land, pastures, orchards and forests were taken out of agriculture, forestry and other utilities circuit. The land affected and occupied by mining, waste dumps, buildings represents over 9500 hectares. The operating activities affected 17,000 hectares, of which 2,000 hectares were given back to economic use. In the area, oil industry is represented by 100 wells, with a production of 1 million m^3/month oil and methane gas and 2 million m^3/month, oil. Transportation installations and auto transportation in open pits are affecting the stability of the foundation soil and of the embankment terrestrial communication routes.

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It was established that most of the landslides occur after periods of heavy rainfall and dry periods, when rainfall increases the amount of water infiltrated into the ground and basement rocks which causes decreased resistance.

The main characteristics of surface mining are:
- the possibility of applying efficient methods of operation;
- the possibility of achieving a complex and complete mechanization of production methods with the use of appropriate equipment with high productivity,
- the possibility of judicious planning and organizing work.

The choice of operating methods that are to be applied to a deposit must be made on rational criteria; of efficiency to ensure high production and labor productivity; of minimum loss of useful minerals and of optimal labor security conditions.

Depending on the operating method applied, depend the following elements: technical-economic indicators obtained in quarrie, the mechanical equipment from technological flux, quarrie dimensions, number of levels and geometric elements of levels and quarrie.

Depending on the way of transport of waste in tailings dumps, exploitation methods are classified as [1]:
- exploitation methods with direct deposit waste in tailings dumps:
- exploitation methods with transshipment of waste material in dumps:
- exploitation methods based on transportation of waste rock in dumps:
- combined exploitation methods.

Oltenia lignite deposits located at shallow and various relief conditions of the area are exploited by open pits. The pit depth is between 40 and 110 m in floodplain areas and up to 180 m in hilly areas, the stripping ratio is between 2.5 and 8 m^3 tailings/tone of lignite extracted [2].

The open pits are equipped with continuous process technologies, with a maximum total projected production capacity of 40 million tons/year.

At first, the open pits were equipped with technologies in discontinuous process and after 1960 year, they switched to pits in continuous process. Nowadays, technological complexes composed of excavators with rotor and different types of cups: SRS-470 SRS-1300, SchRS-1400 and SRS-2000 are being used in the open pits from Oltenia.

The tailings resulted from the opening works was transported and stored in external dumps. In floodplain areas, dumps were located close to the final slope of the open pit and they were built vertically, multistage, the maximum height of deposition in levels was 15 m.

Depending on the characteristics of the dumped material, the external waste dumps have a generally slope angle between 6 and 9 degree.

Because of the excavation nearby areas, the biodiversity is destroyed, the groundwater regime is changed, a natural geochemical transformation of soil elements is taken place and intense erosion processes and landslides are manifested.

The operating activities affected 17,000 hectares, of which 2,000 hectares were given back to agricultural or forest circuit, and the rest will be arranged and returned to other economic utilities. A percentage of 80% of the affected areas are agricultural land and 20% are former forests. The current ratio of land occupied by the 18 open pits in Oltenia Basin is 31 ha per million tons of extracted lignite.

Both cast mining and surface constructions and facilities related to mining premises, often require significant changes in the studied area by deviating water courses or execution of special hydro-technical works. And so, in Oltenia Basin it was necessary the deviation of the courses of rivers: Jiu, Tismana, Jales, Motru, Olteţ, Gilort, Amaradia and of their smaller tributaries, in lengths between 5 and 40 km, as well as the execution of some retention and attenuation dams, with the whole complex auxiliary works required.

Besides the positive effects, the deviations of watercourses causes a number of changes in the hydrographic regime of the river, which leads to a series of instability phenomena such as subsidence, discharge, landslides, erosion and crashes [1]-[3].

II. Factors that influence the geodynamic phenomena

Establishing the causes of geodynamic phenomena, such as landslides and land subsidence is difficult, because of the nature and variety of influencing factors, but it is possible through a comprehensive analysis of these factors.

These factors can be grouped into geological and hydro-geological factors, natural mechanics and geomechanics, hydro-meteorological and climatic, anthropogenic, seismic and biotic factors [4]-[5].

Geological factor refers to the geological structure of the region, to the presence of stratification surfaces, or of least resistance, faults, fissures, cracks or weakly structured plans concordant with slopes inclination, nature of the rocks and the presence of deluvial slope.

The geological structure of the region is totally unfavorable to ensure the slope stability.

The presence of argilous-marly rocks alternation and argilous-dust with formations or intercalations of sandy or sandy-argilous, with concordant inclinations as the slopes and the existence of the anticline and syncline flanks of the Amaradiei Hills. More specifically, on the alignment Seciuri-Poiana Seciuri we distinguish structural elements that influenced and still influence the production of morphological and functional changes through landslides or land subsidence.

Contact surfaces between sandy and clayish (argilous) formations are the areas most predisposed for producing landslides, especially in the increasing moisture or water saturation of sandy or dusty rocks, when colloidal clays tend to liquefaction [6]-[7].

Hydrogeological factor is represented by the presence of aquifers formations in the structure of the massive rock from Amaradiei Hills and Bustuchin-Poiana Seciuri area [2]-[3].

These aquifer formations as aquifer horizons or lenses contribute to the saturation of surrounding rocks, to the manifestation of piezometric [8] and hydrodynamic pressure and to the formation of aquifer currents (streams), of whose power lines are leading to the entrainment of fine particles from the weakly cohesive mass rocks, with formation of goals and funnels suffusion which are affecting the surface, I refer to subsidence and sliding phenomena.

Natural mechanical factors refer to the morpho-dynamic surface phenomena, which depend on the nature and strength characteristics of rocks.

Erosion phenomena of permanent water streams or of torrents formed because of the heavy rainfall represents the cause of landslides triggering, by changing the state of efforts from the massive rocks, as a result of entrainment of the rocks from the slopes base of Amaradia River and its tributaries [6].

Geomechanical factor refers to the nature and strength characteristics of rocks. From this point of view, Amaradia Hills and Seciuri-Bustuchin area have in their composition clayey (argilous) rocks and sand, in a stratiform structure, wrinkled and affected by faults, which by their nature and mineralogical-petrographical characteristics are soft rocks, with a increased sensitivity to water, passing from a high consistency state to a plastic one or even a flowing condition, as a result of liquefaction phenomena. As a consequence, this kind of rocks represent an unstable ground in any situation, especially for the structure of Amaradia Hills, considering the stress state modification related to static and dynamic strains.

Hydro-meteorological and climatic factors are related to the presence and intensity of rainfall and freeze-thaw phenomena and temperature variations.

It was established that most landslides occur after periods of heavy rainfall, which cause decreased rocks resistance, increased volumetric weight, manifestation of water pressure from pores and of hydrodynamic pressure, with an unfavorable influence upon the stability of slopes or embankments of earth engineering constructions.

In addition to this process, we can mention the phenomena of freeze-thaw, temperature variations and especially drought, when additional ways of water penetration may occur on the path fissures and cracks, which subsequently may become detached or sliding surfaces of the rock mass as a result of water infiltration.

The history of landslides from Subcarpathian area of Oltenia and Muntenia and especially those of Amarada Hills, where is included Bustuchin-Seciuri or Roşia de Amaradia area, show that strong correlation between hydro-meteorological and climatic factors and instability phenomena.

Anthropogenic factor represents the changes that occur in rock structure, land morphology or tensions from rock massive and geological formations, as a result of human activities [9].

Related to the DC 29 road the following activities can be emphasized:

- Lignite extraction activities;
- Oil and gas extraction activities in the area contribute to the changing of solid-liquid-gas triphasic report from the structure of deep rocks;
- Seismic activity applied for prospecting and exploring the area to determine the favorable structures for accumulation of hydrocarbons.

Prospecting activities, exploration and exploitation of hydrocarbons that are taking place in the area represents other causes of instability phenomena. Seismic prospecting activity through the explosions produced in boreholes, which have a destructive action upon geological structures, besides fracture of rocks it is causing shaking or vibration that can lead to short-term side effects such as landslides and long-term processes as local subsidence and local changes of groundwater level.

By extracting hydrocarbons in the area a process of subsidence or gradual and progressive descent of the crust and the earth surface due to components loss from the rock structure, e.g the liquid and gas components takes place. The geostatic and geodynamic stress produce some destructive phenomena upon land surface as: diving, collapses or landslides [10].

The presence of these destructive phenomena is highlighted in all Bustuchin villages, whether they are located in the contact area between hills and valleys or just the hills: Cionti, Motorgi, Nămete, Poienița, Seciuri.

The seismic factor can not be considered because the area has a low seismicity and there were not seen manifestations of sliding phenomena and land subsidence. Instead, we can say that the seismicity induced by the explosions with a character research of hydrocarbons structures and also the vibrations of the heavy transport practiced by the providing services units for the economic units in the area, could have an influence upon geostructural imbalances.

Biotic factor refers to the presence of arborescent vegetation on slopes or to their base, which on one hand lashed the rocks and eliminates erosion and on the other hand, provides water exchange in nature. Analyzing the DC29 road I can say that the default of plantation in the last 20 years of the slopes, in combination with a pronounced aging of vegetation orchards and vineyards in the area, in addition to deforestation of some slopes, have led to increased erosion, implicitly to the increasing amount of water infiltrated into the soil and to the cumulative effect of producing static imbalances.

It was found most of the landslides occur after periods of heavy rainfall and dry periods, when rainfall increases the amount of water infiltrated into the ground and basement rocks which causes decreased resistance, increased volumetric weight, showing pore water pressure and hydrodynamic pressure, all unfavorable influence on the stability of slopes or embankments.

III. Embankment and Slope Stability Analysis

During the last years have appeared several alternative approaches related to stability analysis of slopes/embankments in addition to traditional principles. It was introduced so-called principle of partial factor and the probabilistic approach. However, hasn't yet been found a solution regarding the sufficient degree of the complex shape of the slip surface and the calculation of safety factor.

In order to determine the correct natural slope/embankment stability analysis at a large scale it is necessary to establish a complex geotechnical model with data carefully processed.

Landslides are geodynamic phenomena that change the landscape, with a generally slow and regular character, which re-establish the natural balance of slopes and embankments. Depending on their location, when it occurs in an unexpected way, landslides can cause significant loss of human lives and property damage.

Slopes and embankments, being simultaneously or successively under the influence of several causes which tend to modify the existing balance of forces in massive, they eventually fail, and thus it is forming a landslide, creating for a certain period a new state of equilibrium for that slope or embankment [8].

The slope sliding phenomenon is being analysed through methods of edge state analysis using continuum or FEA approaches [9]-[11]-[12]-[13]. Common Classical methods of analysis are divided as:

- Infinite slope analysis;
- Mass Methods (Culmann's method; Fellenius − Taylor method);
- Methods of Slices (Bishop's simplified method, Ordinary method of slices).

The measure of the instability degree is measured by a safety factor Fs, which represents the ratio between the moment of ultimate resisting forces M_R and the moment of driving forces M_D:

$$Fs = M_R / M_D \tag{1}$$

For $F_S = 1$, the slope is in a critical condition. Conventionally, the safety factor Fs is introduced, defined as the relation between available shear strength and shear strength existing along a specific sliding surface [14].

Tangential stress τ on the sliding surface of a strip is given by Coulomb's law:

$$\tau = c + \sigma . tg\varphi \tag{2}$$

Which: σ is normal stress on the sliding surface and c is cohesion.

Slope sliding phenomena usually takes place when the local or general balance is destroyed, between the forces that are the requesting the embankments and internal forces of resistance, which opposes sliding, under the action of internal or external, natural or artificial factors.

Study of sliding phenomena or study of their possible evolution can manage and finalize for various purposes such as: preventive analysis of slope stability for checking the predisposition to slip and to express an assessment regarding the anthropogenic use of the area; analyzing a slip phenomena for a kinematics interpretation, individualization of causes and proposal of appropriate interventions to avoid future dangers of slipping or anthropic surfaces recovery; analyzing a landslide for the assessment of performance of some human works in the area; analyzing slides from non anthropic areas, in order to gather data to improve the possibility of producing the phenomenon; the estimation predisposition to imbalance of some human works that tend to change the causes that predispose to sliding or that interact directly with the equilibrium conditions of the embankments [15].

Before proceeding to the study methodology of sliding phenomena, we should note that in the initial phase of the study it is extremely important to perform a bibliographical consult, such as: geological, geo-morphological, hydro geological, geological applied and geotechnical, as well as basic and topic geological cartography consultation.

The objectives presented are pursued in successive phases of work, which have the aim to reconstruct the geological conditions and recent geo-morphological evolution, and then to proceed with the reconstitution of the embankment and sliding geometry through direct and indirect methods of Geophysical type, the determination of physical and mechanical properties of rocks, the formulation of interpretative models, the checking of stability on analytical and / or geomorphology bases. Finally, we reach to the individualization of typology and to the designing of possible works of rehabilitation to the disturbed equilibrium.

IV. CASE STUDY ON THE DC 29 ROAD

Landslides can occur after cylindrical-circular sliding surfaces or after surfaces assimilated to a plan. Composite surfaces can be found in individual cases, when geological conditions influence the shape of the sliding surface.

For embankments stability analysis it was used the GeoTecB software, specialized in geotechnics, a product of the Italian company Interstudio. GeoTecB analyzes the natural and artificial slope stability, with any kind of geometry, both under static and seismic conditions, as well as in natural or saturated state.

The first step in using GeoTecB is introducing the geometric and geotechnical elements that characterize the embankment followed by the definition of sliding surfaces. The program automatically calculates the stability coefficients, using for this purpose the Fellenius, Jambu and Bishop methods. Ultimately, it is determined the critical sliding surface, which it corresponds the minimum value of the stability coefficient.

GeoTecB analyzes the slope stability and natural slopes with complex geometry, homogeneous or heterogeneous, taking into account the hydrostatic level, both under static and seismic shocks conditions.

For stability analysis, the program uses Fellenius, Janbu and Bishop methods.

Fellenius's method assumes that sliding occurs after cylindrical-circular surface, and the stability is analyzed by dividing sliding prism into several pieces, Fig. 1.

Starting from the equilibrium condition, the factor of safety of the slope Fs, will be calculated using the relation:

$$Fs = \frac{tg\varphi \sum N_i + c\sum l_i}{\sum \pm T_i} \tag{3}$$

where: φ - internal friction angle, Θ- slope angle, α slip angle, ΣN_i - normal component of gravity forces of slices, ΣT- reaction in tangential direction Σl_i- total length of the slip surface; c- cohesion.

The explanation of the *Fs* factor of safety calculation is shown in Figure 1.

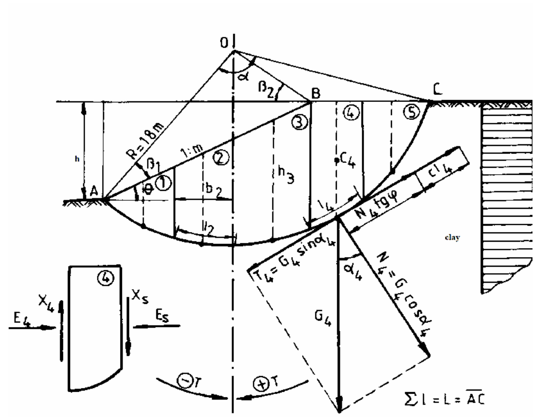

Fig. 1. Calculation of safety factor through Fellenius method

Fellenius obtained the numerical solution of the stability calculation, considering horizontal and vertical forces that occur between strips as void.

GeoTecB program calculates automatically the effective weight of strips, taking into account the actual level of hydrostatic level.

Janbu's method is a simplified version, extrapolated and for situations when the slope is composed of several layers with different mechanical and physical properties, and it is based on the calculation of shear strength effort.

The method is also based on the assumption of calculating several pieces, forces involved in sliding on a strip as those shown in Figure 2. Starting from the equilibrium condition to rotation and to horizontal and vertical translation, the safety factor is determined by the relation (4):

$$F = \frac{\sum_A^B \tau_f \Delta x (1 + tg^2\alpha)}{\sum_A^B \left\{ \Delta Q + (\gamma + z + q + \frac{\Delta P}{\Delta x} + \frac{\Delta T}{\Delta x}) \right\}} \tag{4}$$

Where tangential stress is (5):

$$\tau_f = \frac{c + \left(\gamma + z + q + \frac{\Delta P}{\Delta x} + \frac{\Delta T}{\Delta x}\right) tg\alpha}{1 + \frac{1}{F} tg\varphi \cdot tg\alpha} \tag{5}$$

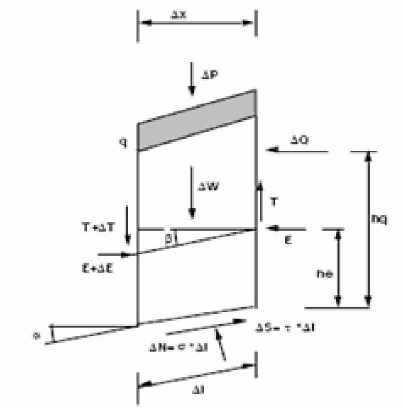

Fig. 2. Explanation of the safety factor in Janbu's method

GeoTecB software determines the stability coefficient using Fellenius's method, and then uses the calculated value as a starting point for the iterative cycle. T and ($T + \Delta T$) forces, shown in Figure 2, are not considered in the iterative cycle, they are determined subsequently. F_0 value determined from the iterative cycle is multiplied by a coefficient C_f, like in the diagram from Figure 3, where are represented the curves $F = F_0 \cdot C_f$.

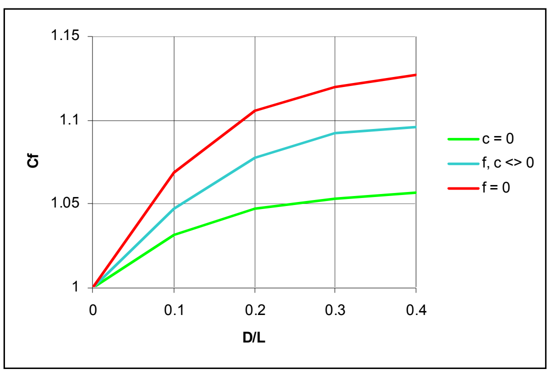

Fig. 3. Graphical determination of F_0

Bishop's method uses an iterative procedure and has a medium degree precision between Fellenius and Janbu methods. The major difference from Janbu method is that it ignores the normal forces between the strips, while, contrary to Fellenius's method, this method takes into account shear forces between the strips.

The stability analyzes were performed on cross sections 1-1, 7-7, 8-8 and 9-9, made on the situation plan of DC 29 road, shown in Figure 4 [2].

For the analysis of stability, a geotechnical study was done on the rocks in the area [16]. Laboratory tests performed on rock samples collected from the study area showed the values presented in Table 1.

The stability coefficient values for the studied sections are presented in Table 2, and are shown in Figures 5, 6, 7, 8, 9 and 10.

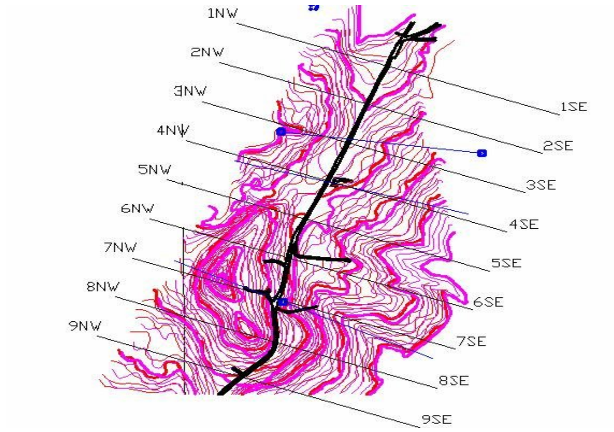

Fig. 4. Location plan of Poiana-Seciuri area along DC 29 road

Table 1. The physical-mechanical properties of rocks

Material	Volumetric density $\cdot 10^4$[N/m³]		Angle of internal friction φ[⁰]	Cohesion C [MPa]
	Natural state	Saturated state		
Topsoil	1,636	1,990	7	0,086
Sandy clay	1,780	2,010	21	0,12
Clay	1,760	1,950	11,5	0,205
Dusty clay	1,750	1,900	12	0,4
Consoli-dated sand	1,650	1,850	25	0,175

Table 2. Numerical results of stability analysis

Section	Factor of Safety		
	Fellenius	Janbu	Bishop
1 – 1 Nat.	2,42	2,70	2,50
1 – 1 Sat.	1,80	2,06	1,90
7 – 7 Nat.	1,39	1,45	1,40
7 – 7 Sat.	0,95	1,04	1,02
8 – 8 Nat.	1,30	1,34	1,30
8 – 8 Sat.	0,87	0,90	0,87
9 – 9 Nat.	1,41	1,48	1,43
9 – 9 Sat.	1,01	1,08	1,04

We can see from the results presented in the Table 2 that the slope on which is located DC 29 road is stable under natural moisture, but the stability reserve is significantly reduced during periods of precipitation. In these cases we obtained subunit values of the safety factor Fs < 1 for the sections 7-7, 8-8 in saturated state and for the section 9-9 in saturated state the safety factor ranges between 1,01 and 1,08. The value of safety factor for section 9-9 in saturated state indicates a high risk of producing landslides, a fact confirmed by reality [20].

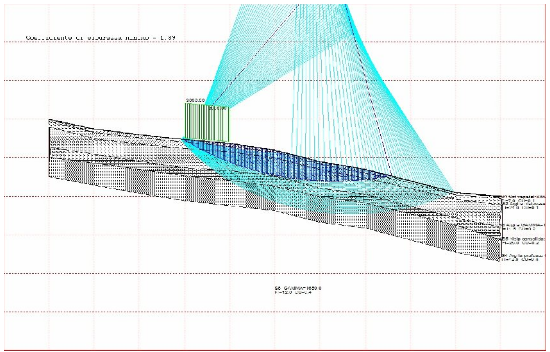

Fig. 5. Stability in natural state - Section 7–7

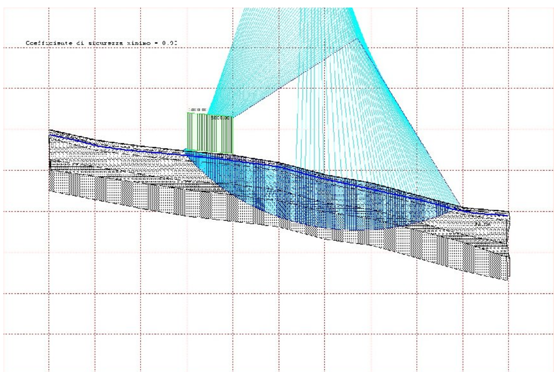

Fig. 6. Stability in saturated state – Section 7–7

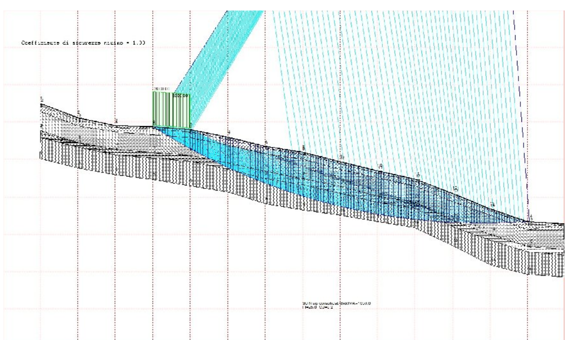

Fig. 7. Stability in natural state - Section 8–8

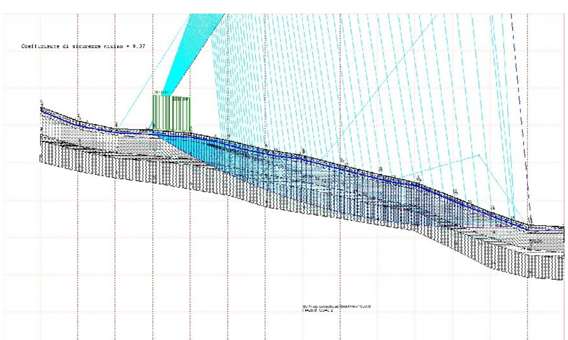

Fig. 8. Stability in saturated state – Section 8–8

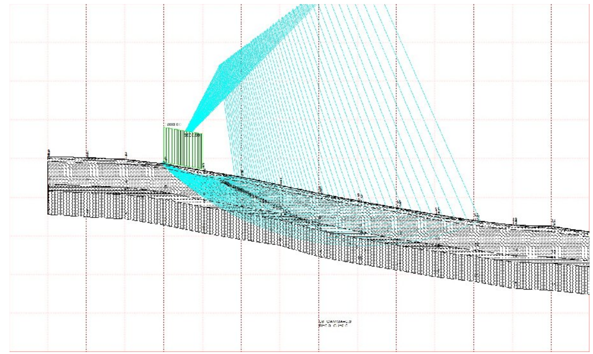

Fig. 9. Stability in natural state - Section 9–9

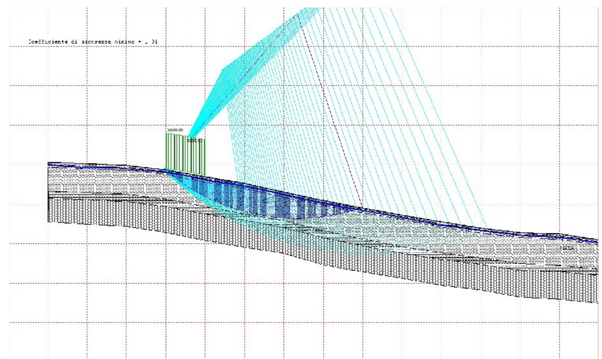

Fig. 10. Stability in saturated state – Section 9–9

It is therefore necessary works to strengthen transport infrastructure in the studied region.

V. Results and Observations

From the observations and studies carried out we show a few examples of the impact of lignite exploitation from open pit and of the spoil bank Valea Şoimului, upon the roads and buildings from the area and have presented in next figures: 11, 12, 13, 14, 15, 16 and 17 [17].

In Figures 16 – 19 are shown aspects regarding DC 29 road before and after rehabilitation.

From the geotechnical study, we conclude that the high slope of the embankment associated to geotechnical characteristics of foundation soil and water action, is the main cause of landslide occurrence that affected DC 29 road and buildings in the area [15]-[18].

Fig. 11. DJ 675C road km 17+380

Fig. 12. DJ675C road km 27+000

Fig. 13. Aspects that show how the buildings foundation was affected

Fig. 14. Aspects of the lignite exploitation impact on building in Seciuri

Fig. 15. Aspects of the lignite exploitation impact on buildings in the area

Fig. 16. Section of road affected by slip

Fig. 17. Overview of the landslide slope affecting DC 29 road

The natural slope to the left side of DC 29 road is covered by grass and, despite some local sliding surface is relatively stable. A proof of this is also the relatively good condition of collection and drainage systems of water, and a support wall built in the studied area, Figure 18 and 19.

Fig. 18. Retaining wall made of reinforced concrete

Fig. 19. Consolidation of the road in the degraded area

VI. Conclusion

Contact surfaces between sandy and clayish (argilous) formations are the areas most predisposed for producing landslides, especially in the increasing moisture or water saturation of sandy or dusty rocks, when colloidal clays tend to liquefaction [7]-[19].

Aquifer formations contribute to the saturation of surrounding rocks, to the manifestation of piezometric and hydrodynamic pressure and to the formation of aquifer currents (streams), of whose power lines are leading to the entrainment of fine particles from the weakly cohesive mass rocks, with formation of goals and funnels suffusion which are affecting the surface, I refer to subsidence and sliding phenomena.

By extracting hydrocarbons in the area a process of subsidence or gradual and progressive descent of the crust and the earth surface due to components loss from the rock structure, e.g the liquid and gas components takes place. The geostatic and geodynamic stress produce some destructive phenomena upon land surface as: diving, collapses or landslides.

Geotechnical study from Poiana Seciuri area shows that clay and sand are rocks susceptible to the phenomenon of sliding. From the analysis of rock stability according to its state, we found a stability coefficient ranging between 1.3 and 2.5 for natural condition, so the embankment is stable. While, for the rocks in saturated state the stability coefficient varies between 0.95 and 2.06 [20].

For section 7-7 the stability coefficient ranges between 0.95 and 1.04, for section 8-8 the stability coefficient ranges between 0.87 and 0.90 so in these sections instability phenomena of the embankment may be occurring.

As is shown in Figure 10, 11, 12, 13, 14, 15 and 16, these instability phenomena have affected roads and housing from area and preservation measures were require.

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V. Arad, S. Arad, S. Apostu, O. Baraiac, "The impact of coal mining in Jiu Valley on environment and rehabilitation of the area", *Conference Proceedings SGEM2012*, Book Series: International Multidisciplinary Scientific GeoConference-SGEM, Albena, Bulgaria, ISSN 1314-2704, Vol. 1, 877 - 884 pp, 2012.
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