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STABILITY STUDIES OF THE EASTERN SLOPES OF AFŞİN-ELBİSTAN, KIŞLAKÖY OPEN-PIT LIGNITE MINE (KAHRAMAMMARAŞ, SE TURKEY), USING THE 'FINITE ELEMENTS' AND 'LIMIT EQUILIBRIUM' METHODS

İbrahim AKBULUT[a], İlker ÇAM[a], Tahsin AKSOY[a], Tolga ÖLMEZ[a], Dinçer ÇAĞLAN[b], Ahmet ONAK[a], Süreyya SEZER[a], Nuray YURTSEVEN[a], Selma SÜLÜKÇÜ[a], Mustafa ÇEVİK[c] and Veysel ÇALIŞKAN[d]

[a] *General Directorate of Mineral Research and Exploration, Ankara*
[b] *Demir Export A.Ş., 06440, Ankara*
[c] *Çevre ve Şehircilik Bakanlığı, Adıyaman İl Müdürlüğü, Adıyaman*
[d] *Adıyaman İl Özel İdaresi, Adıyaman*

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ABSTRACT

In open pit mining from the safety point of view it is very important that physical and mechanical characteristics of the dug-out materials are carefully studied, and geological and geotechnical characteristics should also be considered in planning bench slopes of the dug-out materials. The purpose of this study is to work out the stable slope geometry of the eastern permanent slopes in the Kışlaköy open pit lignite mine of the Afşin-Elbistan Linyit İşletmesi. In the Kışlaköy open pit mine, 35 geotechnical drillings totalling 3393.20 m were made for the geotechnical studies and to work out slope sizing. A total of 250 vertical electrical drillings (DES) were also made to study tectonic features and lithological changes which do not have surface expressions. All these data have been used in this study. Design analyses showed that black coloured clay bands with high plasticity present in between lignite horizon is the most important unit controlling slope stability. Slope stability analyses have in general been conducted using the 'finite elements' and the 'limit equilibrium' method to suit block sliding model and to suit different groundwater conditions. In the analyses for the stresses affecting the slices; central part of the slice has been taken as a base and the 'finite elements' stability studies have been conducted then the findings have been compared. According to this it is understood that if stresses affecting the slices are conducted by the 'finite elements' method then calculated factor of safety on the bench base would be more from 1% to 7%, and in the slope angles it would be more from 1% to 23%.

1. Introduction

Kışlaköy open pit operation is situated within the limits of Afşin-Elbistan town in Kahramanmaraş South Eastern Turkey (Figure 1). Studies indicated that lignite reserves in the Kışlaköy section is 578 million tons and in the Afşin-Elbistan province it is total of 3.4 billion tons (Yörükoğlu, 1991). In his study Yörükoğlu (1991) reported that the lignite quality in the original base is; sub thermal value1170 Kcal/Kg, moisture 55%, ash 17%, combustible material 28%, total S, volatile material 18.69%, C 17.1%, H_2 1.52%.

Among the workers who carried out studies in and around the study area; Özbek and Güçlüer (1977) who carried out hydro geological studies in the Maraş-Elbistan-Çöllolar section; Gürsoy et al, (1981) carried out reserve estimation studies for the part in

* *Corresponding author : ibrahim.akbulut@mta.gov.tr*

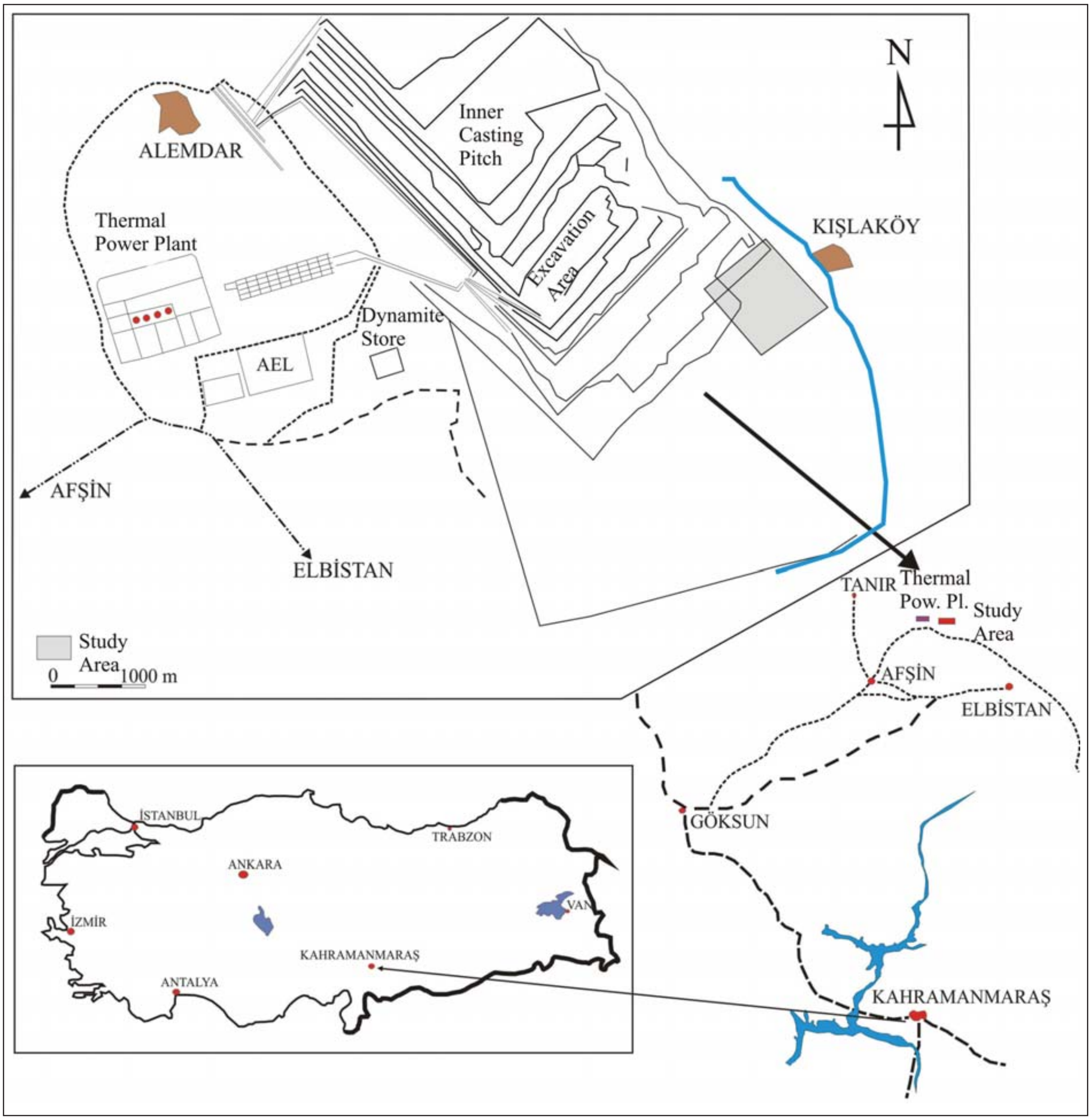


Figure 1- Location map of the study area.

between Harman and Sinekli Villages, they reported that the age of the lake sediments in that part was Pliocene-Pleistocene; Ergüder et al. (2000) carried out geophysics studies in the eastern end slopes of the Kışlaköy open pit and found out the attitudes (strike and dip) of the faults in the area; Koçak et al. (2001) conducted reserve estimation studies and reported that known reserves were 4.3 billion tons, economically mineable reserves were 3.8 billion tons. Koçak et al. (1985), Ural and Yüksel (2000), Akbulut et al. (2007, 2008) also conducted slope stability work in the area.

In the Kışlaköy mine sustainability of lignite production mostly depends upon the stability of the permanent slopes. Because of this, within the scope of this geotechnical study, a total of 35 drillings amounting to 3393.20 m have been conducted. To establish geomechanical parameters disturbed/ undisturbed samples from every lithological unit have been collected.

All of the data gathered from laboratory tests have been evaluated together and have been subjected to finite elements and limit equilibrium methods for stability analyses and results of both methods have been compared.

2. Geology

In the study area Pliocene-Pleistocene lake sediments, Quaternary units consisting stream material and slope debris are present (Figure 2a).

At the base of the study area turquoise coloured clays are present. As they form the base of the lignite horizons they are also known as bottom clay. These greenish blue coloured (turquoise coloured) bottom clays have carbonate concretions and display less-medium plasticity and have thin-medium beddings (Figure 2b).

Lignite horizon concordantly overlies the basement clay. The unit is black-light brown coloured, has medium hardness and medium-thin beddings. There are 1-80 cm thick, black coloured clay levels, rich in bitumen with high plasticity and green coloured clay levels in places with medium-high plasticity and with fine size pebbles. As it is transitional with gray Gidya unit the lignite horizon has numerous Gidya alternations. Gürsoy et al., (1981) gave Pliocene-Pleistocene age to the lignite's. The Gidya unit concordantly overlies the lignite horizons. The unit has brownish gray-dark gray clay levels. It is very soft with medium-thick beddings. Beige Gidya concordantly overlies gray Gidya. It has light brown-beige coloured silty clays with abundant

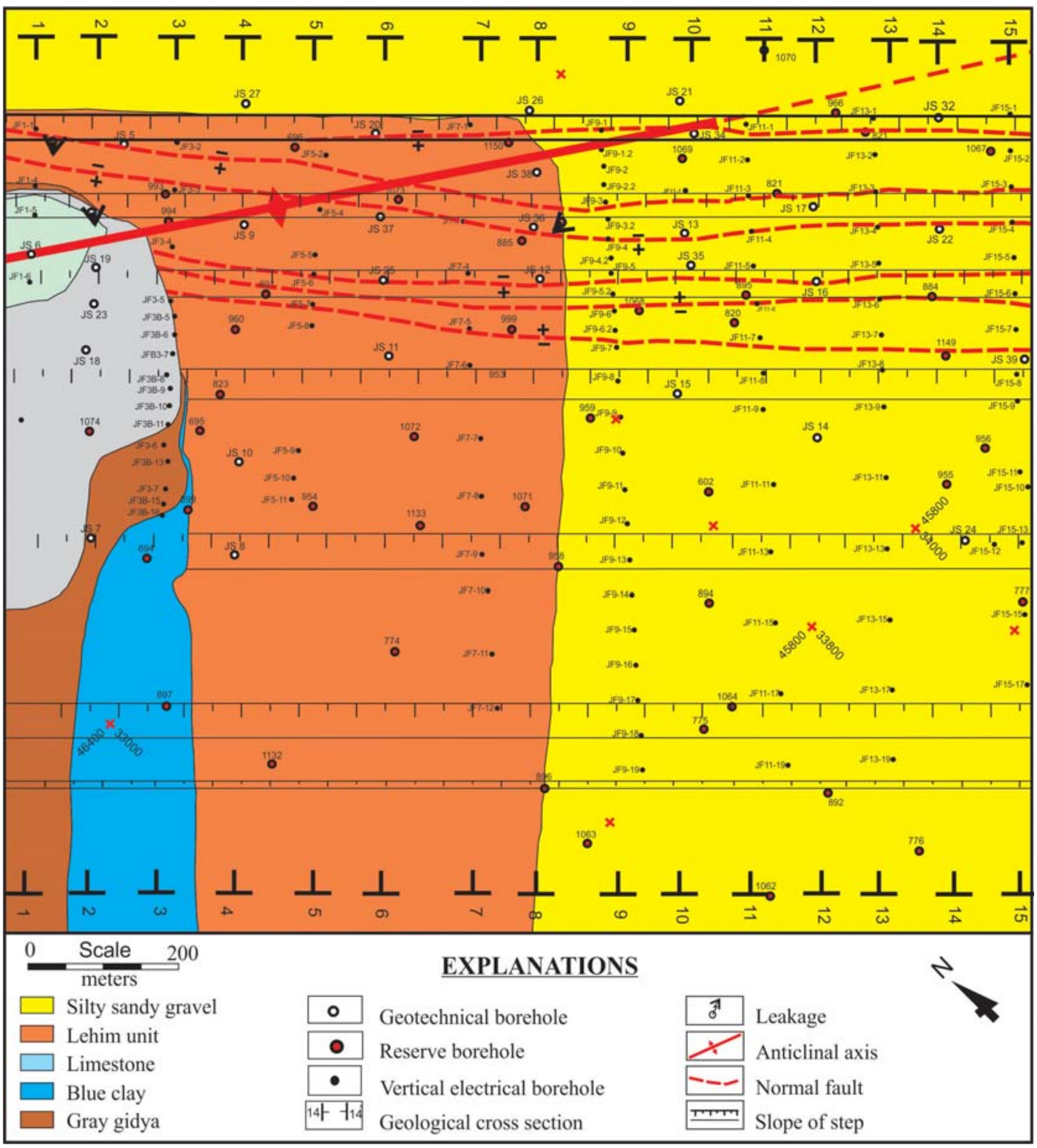


Figure 2- a. Geological and engineering geological map of the study area.

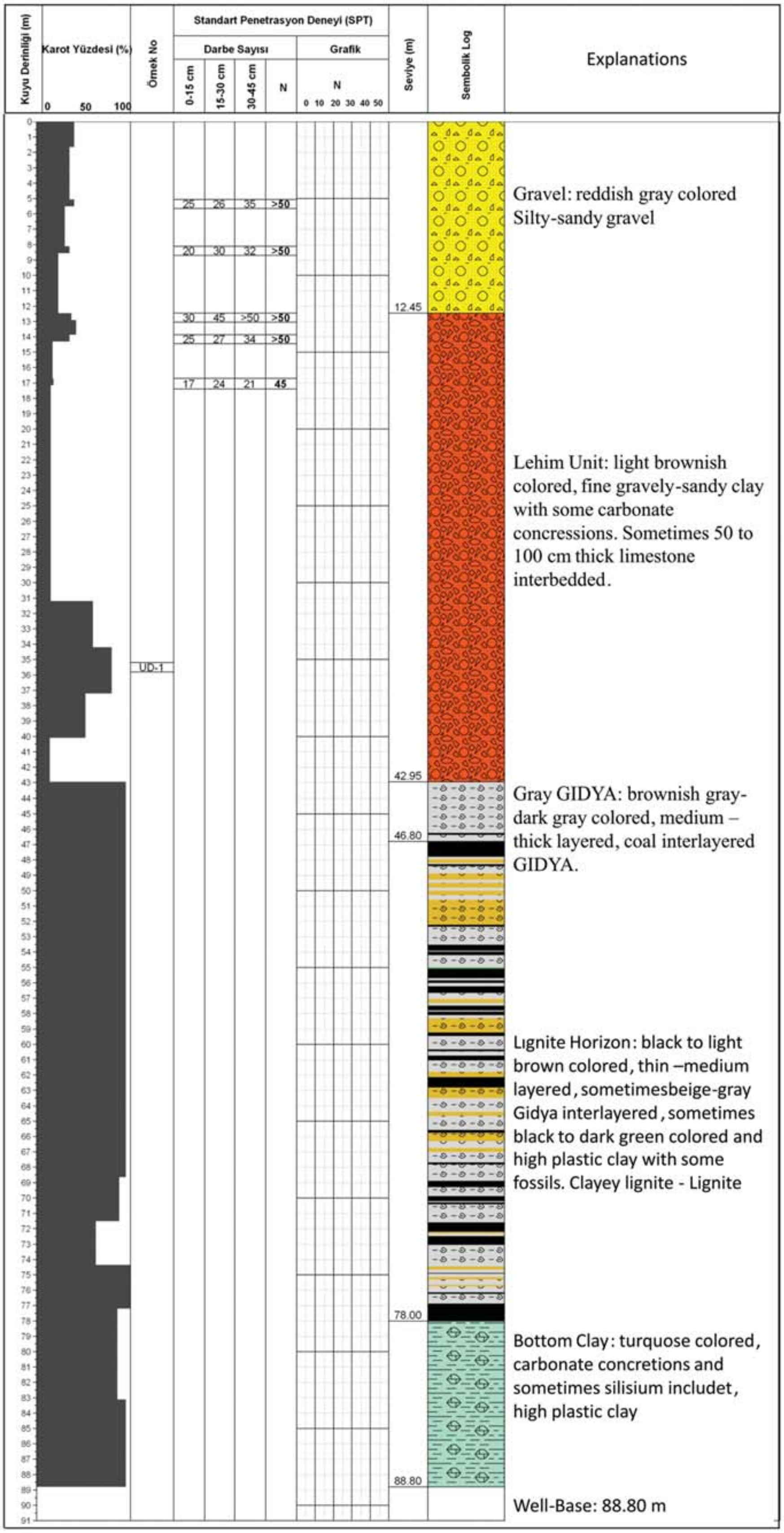


Figure 2- b. Geological and engineering geological map of the study area.

Gastropods. The units represents lake environment and has limestones at the top (Gürsoy et ., 1981). Limestones are light gray-gray coloured, have abundant fossils, hard-very hard, with medium-thick beddings, broken surfaces have sharp corners. Quaternary Lehim sequence discordantly overlies the limestones and have extensive coverage in the study area.

Geophysics studies revealed the attitudes of the faults which had no surface expressions. These faults run NW-SE direction, developed along the eastern slopes at the edge of the basin.

3. Geotechnical Study

Geotechnical studies have been carried out in two stages. In the first stage; geotechnical drillings, geophysical studies and samplings have been carried out. In the second stage; laboratory test results of the collected samples have been evaluated.

To be able to establish lateral and vertical extensions of the units present in the study area General Directorate of Mineral Research and Exploration (MTA) carried out total of 35 geotechnical drillings amounting 3393.20 metres (Akbulut et al., 2008).

In all of the drillings depths of ground water levels have been controlled. In the unexcavated parts the ground water level was 4.00 m; in the excavated parts it was 30 m; in the parts where drillings intercepted the basement rocks, it was 61.50 m It is possible that 61.50 m static ground water level is the water level of the karstic parts.

Within the scope of the geophysics study a total of 250 vertical electrical drillings (VED) have been conducted and results have been evaluated. Data obtained from these VED's have been compared with the results of the mechanical drillings and attempts have been directed to identify all possible tectonic features.

To establish geo-mechanical parameters to be used for designing permanent slopes; a square specimen cutter 10 cm x 10 cm x 3 cm dimensions was used and 4 sets of undisturbed samples from the fresh face of the units and 4 disturbed samples for the index studies have been collected. By using thin edge tubes (shelby) 31 undisturbed samples from the drillings have also been collected.

In the laboratories on the ground type samples in accordance with ASTM (1994) abd BSI 1377 (1990) strength and index tests have been conducted.

4. Geotecnical Evaluations

Within the scope of geotechnical evaluations first of all engineering classifications of the lithological units have been made. In the engineering classifications 'unified soil classification' (ASTM D-2487 1994)) have been used to evaluate grain size distribution analysis and Atterberg limits. According to this; sandy parts of the Lehim Sequence is in the SM-SP group, whereas silty parts in the MH group, and the whole section is in the CH group. They all are classified as clays with "high plasticity".

Gray Gidya is represented with MH group and bottom clay with CH-CL-MH group soils. Depending upon the result of liquid limit test, black clays have been classified as OH-MH group soils.

Fine grained grounds have abundant organic materials. In the plasticity chart they are classified as organic silt below A-line and have 'high – excessively high' liquid limit value (IAEG Commission, 1981).

In the fine grained grounds the ratio of plasticity index to percentage (%) of clay is described as activity coefficient and this gives information on the clay minerals. In Figure 3 in the activity abacus GrayGidyashows "Medium – low activity", Lehim and Black Clay show "Medium-high-very high activity"distributions.

According to atterberg limits classification system these units have been classified as; Lehim Sequence = tight-very tight; Gray Gidya = very soft; Black Clay = hard-very hard; Bottom Clay = hard-very hard (Akbulut et al., 2008).

Undisturbed samples collected from the study area to determine geomechanical parameters to be used in design analysis of permanent slopes have been subjected to relevant tests.

Shear tests were carried out depending upon the location of the samples collected, taking designated normal stress (σ_n) values into account, in line with the standards (ASTM D-3080) under different vertical load stages, 1 x 2.5 inch diameter and/or 6 x 6 x 2 cm dimensions These tests were carried out on the materials, at least 3 times for each unit, so peak and residual shear strength parameters have been established for each unit.

Akbulut et al., (2007) carried out back analyses and found that landslides developed in the Lehim Sequence and under the control of the black plastic

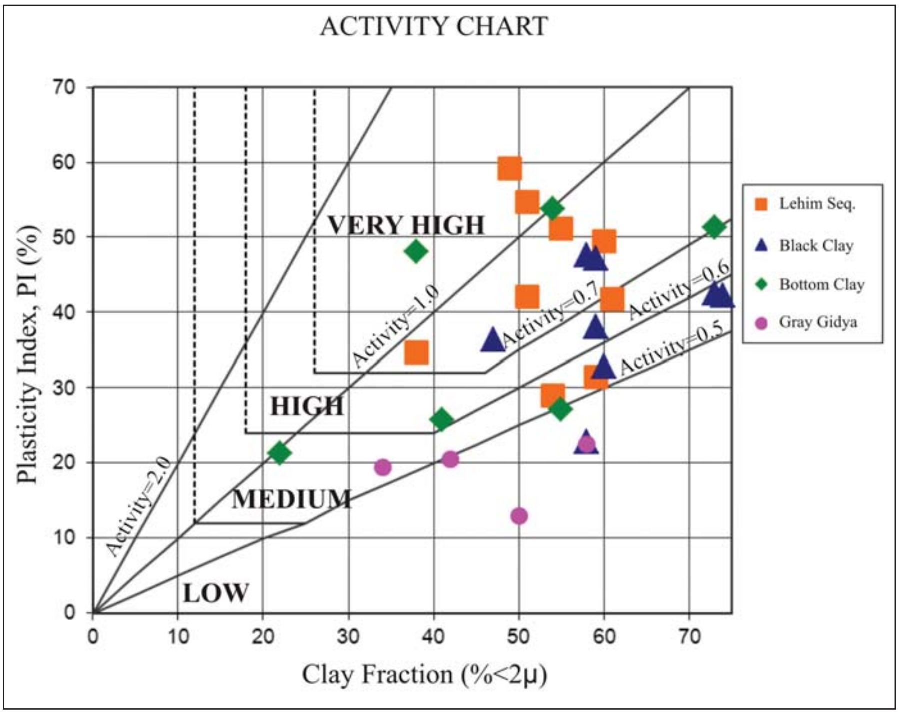


Figure 3- In the study area distribution of fine grained units on the Activity Chart.

clay in the lignite horizon, residual shear strength parameters were effective during the process of sliding. Due to these results, residual shear strength parameters, obtained from the laboratory tests have been used for the stability analyses.

In the field studies it was found that sometimes fault zones had clay fillings (gouge) and in other areas they didn't have filling (gouge) materials. Analyses have been carried out for the differing situations; "no discontinuity", and "discontinuity present" that planes (fault) having fault materials in them. Geo-mechanical parameters used for the design analyses are given in table 1.

5. Stability Design Analyses

In the final slope designs, factor of safety (FOS) value has great importance. In a simple term FOS value is defined as; ratio to resisting to sliding forces. In the stability analyses if FOS=1, then it is considered as equilibrium (balance) condition and during sliding this condition is considered valid. Because of that, in designing slopes, FOS values are preferred to be greater than 1 (FOS>1) not to have instability.

In this present study for the permanent slope designs, FOS coefficient is suggested to be FOS=1.3.

Table 1- Geo-mechanical parameters used in design analyses (Akbulut et al., 2008).

Unit	Unit volume weight (γ, kN/ m^3)	Residual internal friction angle (ϕ, °)	Residual cohesion (c, kPa)
Lehim	17,85	21,38	21,79
Limestone	20,78	26,80	51,80
Gray Gidya	15,05	34,84	10,54
Lignite	10,90	33,30	12,76
Black clay	15,90	11,20	20,82
Basement clay	17,46	25,83	14,19
Discontinuity plane	10,90	29	0,1
Fault material	12,57	9,10	43,31

On the other hand, it was suggested that in a short period of time if materials are loading at the heel of the slopes then FOS= 1.2 could be acceptable.

In the prepared design analyses, the ”General Limit Equilibrium” (GLE) (Fredlund and Krahn, 1977) method has been considered as a base. GLE takes the forces into account between slices, at the same includes momentum and force balances into calculations. For the designs GEO-SLOPE (SLOPE/W 2007) software has been used. This software provides solutions with the ”finite elements and limit equilibrium” approach. It could carry out (2D) analyses, accounts seismic forces and ground water level and provides solutions with various methods.

Permanent slope analyses have been carried out primarily for the single benchs. This analysis aims at working out safe ”slope angle and slope heights” for one bench. Depending upon the character of the ground different models has been used. If the ground is not firm and consists of loose materials then “circular sliding model” is necessary to obtain a safe result. For firm rocky mass then the “block sliding model” was used.

6. Comparison of Calculated Design Analyses Made by Using ‘Finite Elements’ and ‘Limit Equilibrium’ Methods

So far the ”Limit Equilibrium” method has been successfully used in the slope stability analyses. The ‘Finite Elements’ method has been used in all engineering problems as well as in the slope stability analyses. The most important difference between the ”Finite Elements“ and the ”Limit Equilibrium” method is that, the ”Finite Elements“ shows the stress distribution in a more realistic way and enables stability analysis to be carried out.

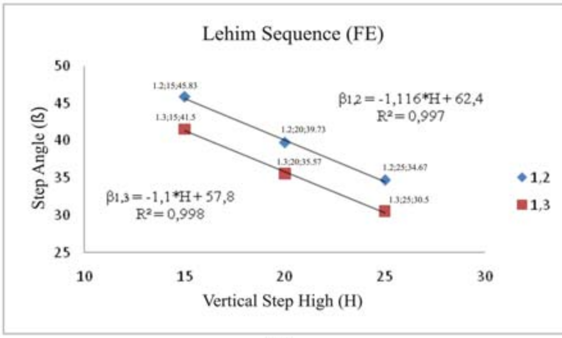
In the ‘Limit Equilibrium’ methods, when trying to establish strength equilibrium in the process of achieving results, FOS value is accounted to be the same for each slice. This causes difference between the calculated stress distributions along the sliding plane than the actual one. In the ”Finite Elements” method, an equilibrium is established for the stress and deformation conditions, so calculations would be based on more realistic stress distribution data. In the ”Limit Equilibrium” method central part of each slice is taken as a base in calculating the stresses effecting to the slices. In the ”Finite Elements” method, on the other hand, the stresses effecting base of each slice is calculated for the analyses. “Two methods” term is used to explain the stress calculations affecting the slices, all other calculations are same.

In this study above mentioned differences have been taken into account and analyses have been carried out accordingly. For the design analyses first of all to establish bench geometry, Lehim Seq., bottom clay and for the lignite, safety coefficients have been taken as FOS= 1.2 and FOS=1.3. According to these values graphics have been prepared showing “Slope height (H) – Slope angle (β)” relationship (Figures 4, 5, 6). As it is seen in the graphics, in the “Finite Elements” method, in the Lehim Seq., when F= 3, the bench with H=20 m would have β= 35.8° bench angle; in the bottom clay for a H=25 m bench, bench angle would be β= 30.5°; in the lignite horizon for a H= 25 m bench, bench angle would be β= 46.0°. In the “Limit Equilibrium” method in the Lehim Seq. for a H= 20 m bench, bench angle would be β= 33.4°; in the bottom clay, for a H= 25 m bench, bench angle would be ,= 28.8°; in the lignite horizon, for a H= 25 m bench, bench angle would be β= 45.3°. This show that on the bench base for the same safety coefficient (F=3) there is 1% to 7% difference in calculations between “Finite Elements” and “Limit Equilibrium” methods, ”Finite Elements” being higher.

Akbulut et al., (2007) studied the landslides developed in the study area and concluded that failure developed in “block sliding model”. As the failures in the lignite horizon developed in the block sliding model, analyses have been carried out to fit to this model. Taking discontinuity planes into account general slope analyses have been repeated.

In the study area to understand geology (structure), 15 cross sections right angle to the planned slopes have been prepared. In these sections geology (structure) appeared same, so stability analyses have been carried out on 7 sections.

Slope stability analyses have been carried out by applying ‘Finite elements’ and ‘Limit equilibrium’ methods to find solutions. According to F= 1.2 and F= 1.3 safety coefficients, graphics showing ?Slope height (H) – Slope angle (,)?relations. One of the analysed sections was 14-14 (Figure 2). ?General slope angle – Safety coefficient” and ?Groundwater level – General slope angle” relations graphics for 14-14 section have been prepared. In Figure 7 (a, b) discontinuity plane, in figure 8 (a, b) in the case of discontinuity plane being present are given. In Figure



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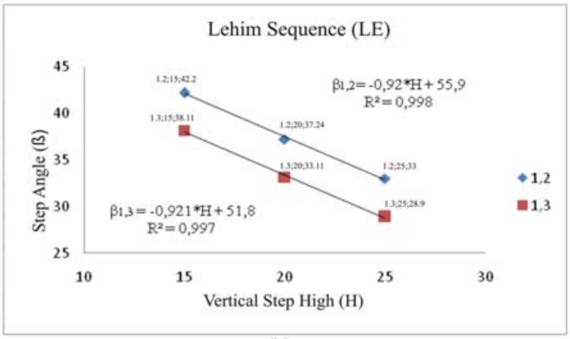
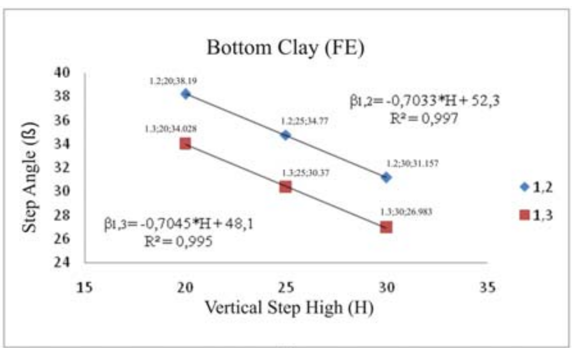


(b)

Figure 4- For the Lehim unit;



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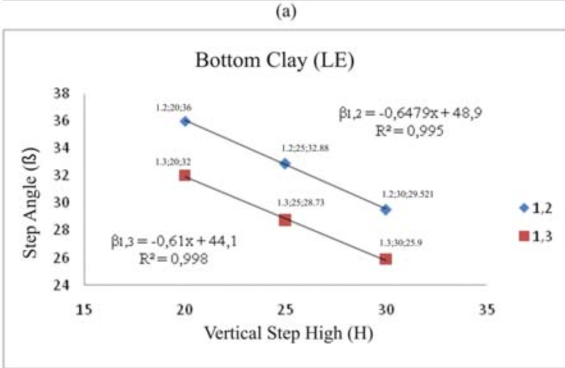
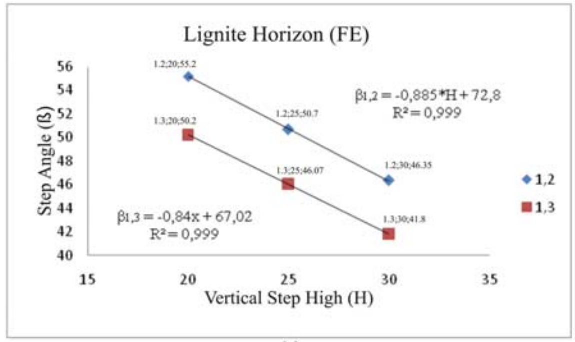


Figure 5- For Basement clay;



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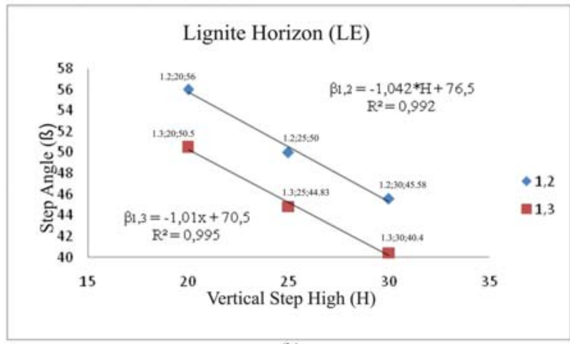

(b)

Figure 6- For lignite horizon; according to; a) 'Finite elements' (FE), b) 'Limit equilibrium' (LE) relationship between bench height (H), bench angle (β).

9 (a, b) in the case of fault plane being present 'Finite elements' and 'Limit equilibrium' methods applications in; (a) FOS coefficient – general slope angle, (b) general slope angle – groundwater level relations have been given. In Figure 10, position of slope profile and critical sliding plane is given. Collective results are given in table 2.

Under FOS = 1.3 conditions if general slope angle is not a discontinuity plane; according to the 'Finite elements' method it would be between 12.8° and 17.4°, according to the 'Limit equilibrium method it would be between 10.1° and 14.9°; on the other hand, if general slope angle is a discontinuity plane then according to the ' Finite elements' method; it would be between 11.7° and 14.0°, according to the 'Limit equilibrium' method, between 10.4° and 12.5°; if sliding surface is a fault plane, then, according to the 'Finite elements' method it would be between 11.1° and 12.2°, according to the 'Limit equilibrium' method between 10.2° and 11.9°.

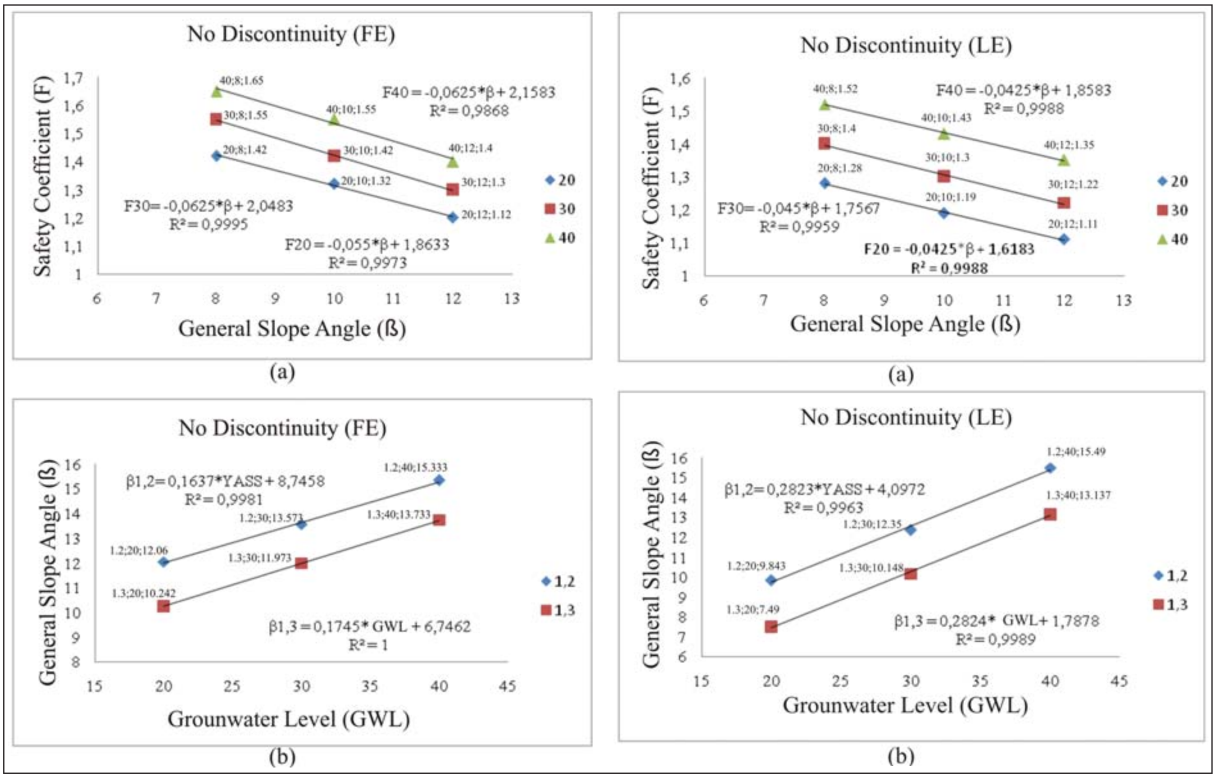

Figure 7- a) In the case of no discontinuity, according to the "Finite elements"method; b) In the case of no discontinuity, according to the "Limit equilibrium"method; a) FOS coefficient – General slope angle, b) General slope angle – Groundwater level relations.

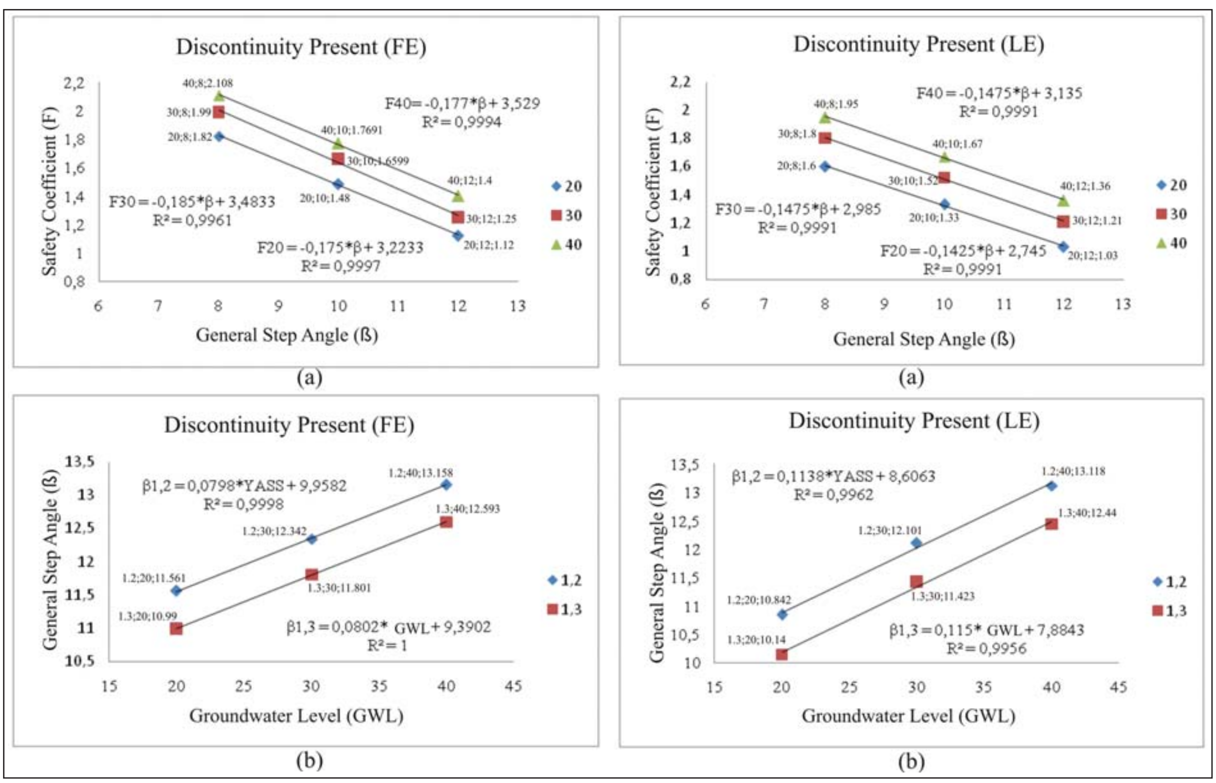

Figure 8- a) In the case of discontinuity present, according to the "Finite elements"method; b) In the case of discontinuity present, according to the "Limit equilibrium"method; a) Safety coefficient – General slope angle, b) General slope angle – Groundwater level relation.

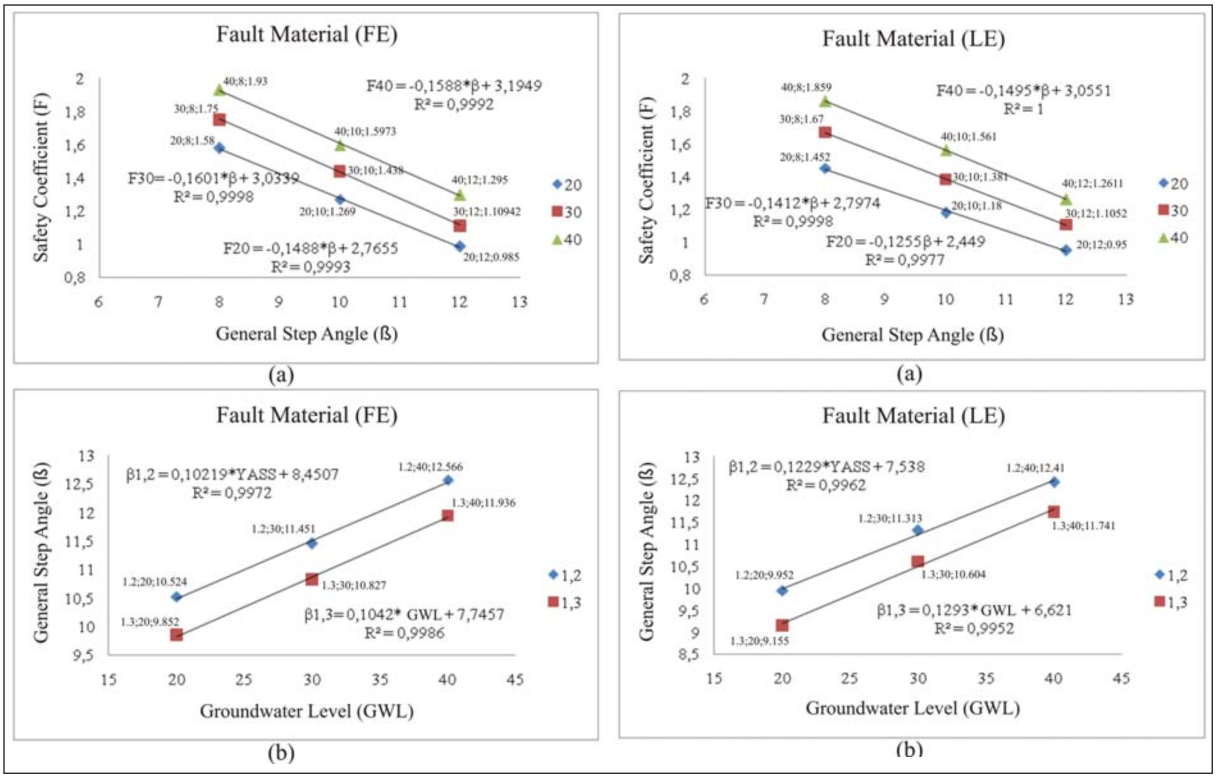

Figure 9- a. In the case of fault material present, according to the 'Finite element' method; b.In the case of fault material present, according to the 'Limit equilibrium method; a) FOS coefficient – General slope angle, b) General slope angle – Groundwater level relation.

Table 2- Collective analyses results of the representative sections from the study area (for GWL =30 m) (FE= Finite Elements, LE= Limit Equilibrium).

Section no	General slope angle (β) (°)											
	No discontinuity plane present				According to the discontinuity surface				According to the fault plane			
	FE	LE	FE	LE	FE	LE	FE	LE	FE	LE	FE	LE
	F=1,2	F=1,3	F=1,2	F=1,3	F=1,2	F=1,3	F=1,2	F=1,3	F=1,2	F=1,3	F=1,2	F=1,3
2-2'	19,0	17,4	17,4	14,9	12,6	11,7	11,3	10,4	11,7	11,2	11,4	10,5
4-4'	17,2	15,7	16,1	14,3	13,4	12,6	12,5	11,8	13,2	12,2	12,7	11,9
6-6'	19,2	17,5	15,2	13,4	14,9	14,0	13,3	12,5	13,9	13,0	12,5	11,7
8-8'	16,0	14,2	14,9	12,8	12,4	11,7	11,2	10,5	11,8	11,1	11,0	10,2
10-10'	14,0	12,8	12,8	11,4	12,3	11,7	11,3	10,7	12,1	11,5	11,4	10,7
12-12'	15,2	13,3	13,3	11,2	12,4	11,9	11,9	11,4	12,3	11,6	11,4	10,8
14-14'	13,7	12,0	12,6	10,3	12,4	11,8	12,1	11,4	11,5	10,9	11,2	10,5

In the "Finite elements"method when FOS coefficients become 7% higher, it would be 20% more in the general slope (as total slope height increases). In the open pit operations these analyses must be compared with the actual positions and particularly also with the back analyses. When slope stability matters have been solved with the "Finite elements" method, if the findings are in accord with the actual situations then keeping with the safety, using this method would be advisable.

If the "Finite elements" method has been used general slope angle would be about β=11°. The "Limit equilibrium"method is also considered for slope designs and it has less numbers of samples. Because of this, in this study with traditional "Limit equilibrium"method general slope angle was determined as β=10°.

According to these analyses results if the general slope angle was calculated with the 'Finite elements'

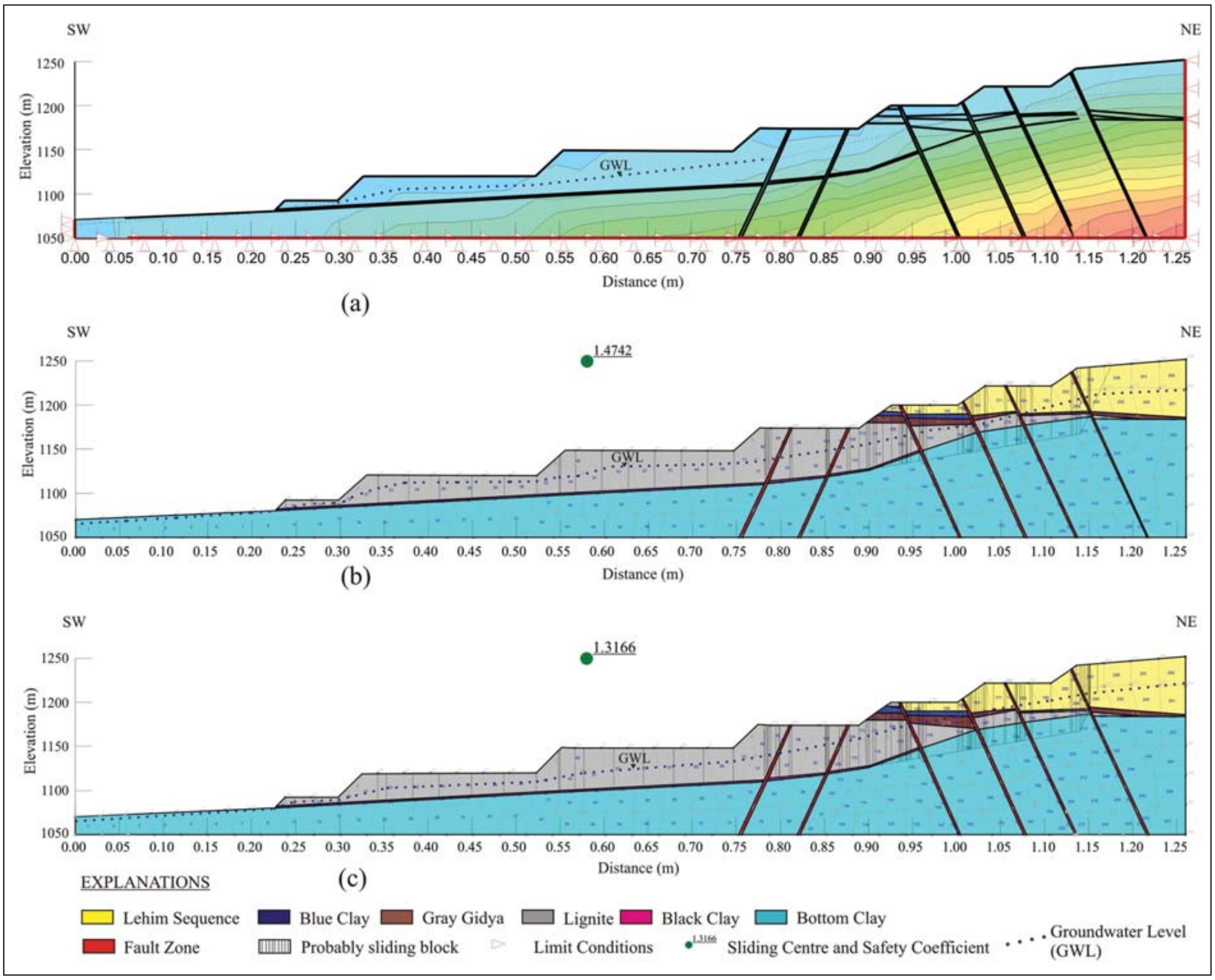

Figure 10- a) The maximum total stress distribution by using 'Finite elements' method, b) according to 'Finite elements' method; analysed slope profile and position of critical sliding plane, c) according to 'Limit equilibrium' method analysed slope profile and position of critical sliding plane.

method, FOS coefficients would be between 1% to 23% higher then if it was calculated with the 'Limit equilibrium' method.

7. Results and Suggestions

The following results have been obtained from the conducted geotechnical studies in the Kışlaköy (Afşin, Elbistan, Kahramanmaraş, South Eastern Turkey) lignite open pit mine.

According to unified soil classification, which take grain size and viscosity limits of the units together into account the Lehim Sequence has been grouped as SM-SP, MH and CH for whole section; Gray Gidya as MH, Bottom clay as CH-CL-MH and black clay as OH-MH class soils.

In the bench base analyses when FOS=1,3, in the 'Finite elements' method in the Lehim unit of a bench with H=20 m, bench angle would be β= 35.8°, in the Bedding clay, for a bench H= 25 m high, bench angle would be β= 30.5°, in the lignite horizon for a bench H= 25 m high, bench angle would be β= 46.0°. In the 'Limit equilibrium' method in the Lehim Sequence for a bench H= 20 m high, bench angle would be 33.4°, in the Bottom Clay for a bench H= 25 m high, bench angle would be β= 28.8°, in the Lignite Horizon for a bench H= 25 m high, bench angle would be β= 45.3°.

When there is a discontinuity plane, when F=1.3 is in the 'Limit equilibrium' condition according to 'Finite elements' method, general slope angle would be 11.7° - 14.0°, in the 'Limit equilibrium' method, it would be 10.4° - 12.5°.

When FOS coefficients are calculated at the bench base with the "Finite elements" method, they would be 1% to 7% higher then if they were calculated with the 'Limit equilibrium' method. In the general slopes this rate changes from 1% to 23%.

The analytical results carried out by finite element and limit equilibrium methods should be compared with actual conditions in open pets particularly by using previous analyses.

If the calculations were done by finite element methods, the slope angle would be 11°. But, according to the conventional limit equilibrium method, the slope angle is calculated as 10° and it is proposed to open with angle degree 10° for this area.

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