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ORIGINAL PAPER

INVESTIGATION OF GROUNDWATER LEVEL CHANGE AND ITS IMPACT ON SLOPE STABILITY IN THE SECTOR-E OF AFŞIN-ELBISTAN OPEN-PIT LIGNITE MINE IN TURKEY

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ABSTRACT

The objective of this study was to examine the stability of the bench and overall slope angles that would result from the open pit mining of 1.5 billion tonnes of lignite in Sector-E of the Afşin-Elbistan lignite basin. Eleven geological sections have been developed so far for the stability investigation of the final slopes in the eastern and southern portions of Sector-E. In these studies, slope stability evaluations were carried out with the assistance of the Slide2 software. The Spencer method, which is a type of limit equilibrium method, was employed in these analyses.
Different analyses were conducted in the studies on bench slope angle and overall slope angle in accordance with the circular and non-circular slip models that occurred and/or were anticipated to occur in the region. The range of overall slope angles with acceptable coefficients of safety (SF ≥ 1.5) and reliability index (RI ≈ 3) for east slopes was 8.94° to 13.30°, and for south slopes was 6.33° to 13.49°, as determined by the slope stability analyses conducted at various groundwater levels. In addition, the relationships between the groundwater level and the overall slope angles were presented for each section.

1. INTRODUCTION

Slope stability issues may arise if the slope angles are increased to decrease the quantity of stripping in open-pit mining. Slope stability is influenced by many factors including excavation technique, drilling-blasting conditions, rock or soil unit shear strength parameters, geological structure (faults, fractures, bedding planes, joints, and discontinuity properties), rock mass/material properties, pit depth and stress state, groundwater conditions, climatic characterization, and activity.

The pore water levels in the units of slope layers go up because of groundwater, which is one of the things we talked about above. Numerous studies have been conducted on slope stability (Tutluoğlu et al., 2010; Ozdogan and Deliormanli, 2019; Koca and Koca, 2020; Scalise et al., 2021), and the careful planning necessary to acquire an adequate safety factor in these studies is vital.

On this subject, Tang et al. (2020) indicated that the suspended water region raises pore pressure and has significant effects on slope stability. Putra et al. (2017) noted the matric suction influences to the shear strength parameters. As the matric suction increase significantly, the cohesion and internal friction angle further increase. As the result, the safety factor also decreases. Guangzhu et al. (2012) found that when the water table is less than half the height of the slope, the slopes remain stable and are unaffected by seismic loads and deformations, and that when the water table approaches the earth, seismic loads caused by earthquakes may affect the slope's dynamic strength and diminish its stability.

Up to date, many researchers have developed numerous methods for the solutions of slope stability problems as a function of soil and/or rock parameters. Many field studies and experimental works have been carried out by various programmes. Empirical methodologies (Romana, 1985; Laubscher, 1990; Haines and Terbrugge, 1991; Hoek and Brown, 1997; Wyllie and Mah, 2004; Bar and Barton, 2016), limit equilibrium analysis methods (Fellenius, Janbu, Bishop, Morgenstern-Price, Spencer, etc.), and numerical analysis methods (Zienkiewicz et al., 1975; Griffiths and Lane, 1999; Lorig and Varona, 2001; Yetkin and Şimşir, 2020) are commonly used in these studies for the analysis of slope stability problems. For slope stability studies including empirical, limit equilibrium, and numerical analytical approaches, accurate estimation of groundwater level is crucial. The safety factor is affected by changes in water level, according to Sazzad et al. (2016). Consequently, raising the overall slope angle and lowering the cost of water drainage may be achieved by setting the groundwater level (GWL) at an acceptable height.

In this study evaluated analyses of slope stability at various groundwater levels, taking into account the safety factor and the overall slope angle. The factor of

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safety and GWL relationships were developed for the final overall slopes of east and south parts of the open pit mine.

2. MATERIAL AND METHODOLOGY

2.1. STUDIED AREA AND GEOLOGY

The currently uncommenced working region, known as Sector-E, spans over 400 square kilometres and constitutes almost 10 % of the Afşin-Elbistan lignite basin.

The Sector-E is located in the Kahramanmaraş province, 20 km from the Afşin county town and 15 km from the Elbistan county town. The Sector-E is linked to Sector Kışlaköy in the north, Sector Çöllolar in the northwest, Hurman river in the southwest of the study area (Fig. 1). The investigations undertaken to assess the resource of Sector-E revealed that the apparent coal reserve was calculated to be 1.5 billion tons. The average lower calorific value was found to be 1143 Kcal/kg, with a stripping ratio of 3.68 m^3/ton and coal seam thicknesses of 60 m (Besbelli et al., 2009).

The Afşin-Elbistan lignite basin is a tectonic subsidence basin that was formed between the mountains during the uplift of the Taurus mountains at the conclusion of the Alpine orogeny.

The Upper Permian Çayderesi formation and the Upper Cretaceous Karaböğürtlen formation are part of the Bodrum nappe, including the Middle Triassicto-Middle Cretaceous Köseyahya nappe and the Upper Cretaceous Kemaliye formation. The basement units are overlain by the Ahmetçik formation, which dates back to the Neogene period (Bedi et al., 2009). The cross-section view containing the lithologies of the study area is shown in Figure 2. Turquoise-colored clays are present at the study area's base. As they form the base of the lignite horizons, they are also known as bottom clay (base clay). Lignite horizon concordantly overlies the bottom clay. As it is transitional with grey gyttja units, the lignite horizon has numerous gyttja alternations. The gyttja unit concordantly overlies the lignite horizons. The unit has brownish-dark grey clay levels. Beige gyttja concordantly overlies grey gyttja. It has light brown-beige-coloured silty clays with abundant Gastropods. The limestones are characterized by their light gray-gray color, abundant fossils, high hardness, medium-thick beddings, and sharply rounded fractured surfaces. The Quaternary Loam sequence discordantly overlies the limestones and has extensive coverage in the study area (Akbulut et al., 2014).

The bucket wheel excavator (BWE) + belt method is used in the Afşin-Elbistan Sector Kışlaköy, which is close to Sector-E. The excavator + truck method is used in the Sector Çöllolar. The BWE+belt method will be used for stripping and coal extraction in Sector-E. The bench height is scheduled to be 20-30 m and its width is 60 m, based on observations and experiences in Sector Kışlaköy and BWE size. Therefore, in the slope stability studies, the bench height and bench width were set at a minimum of 25 m and 60 m, respectively.

2.2. PREPARATION OF SECTIONS

Eleven geological sections were produced for the stability analyses on the final slopes of the east and south parts of Sector-E (Fig. 1). A total of 104 geotechnical drill holes (GD) conducted by the General Directorate of Mineral Exploration and Research (MTA) (Akbulut et al., 2015) were used in the development of these sections. The input parameters for slope stability assessments of Sector-E were derived from the data of unit weight, cohesiveness, and internal friction angle of lithological units obtained from the publications of Akbulut et al. (2015) included in Table 1 and Table 2.

The Slide2 program used the obtained data to perform slope stability analyses for each section. The most important reason for using this program is that it provides the critical sliding surface that can cause failure, especially in open pit mining on rock and soil slopes.

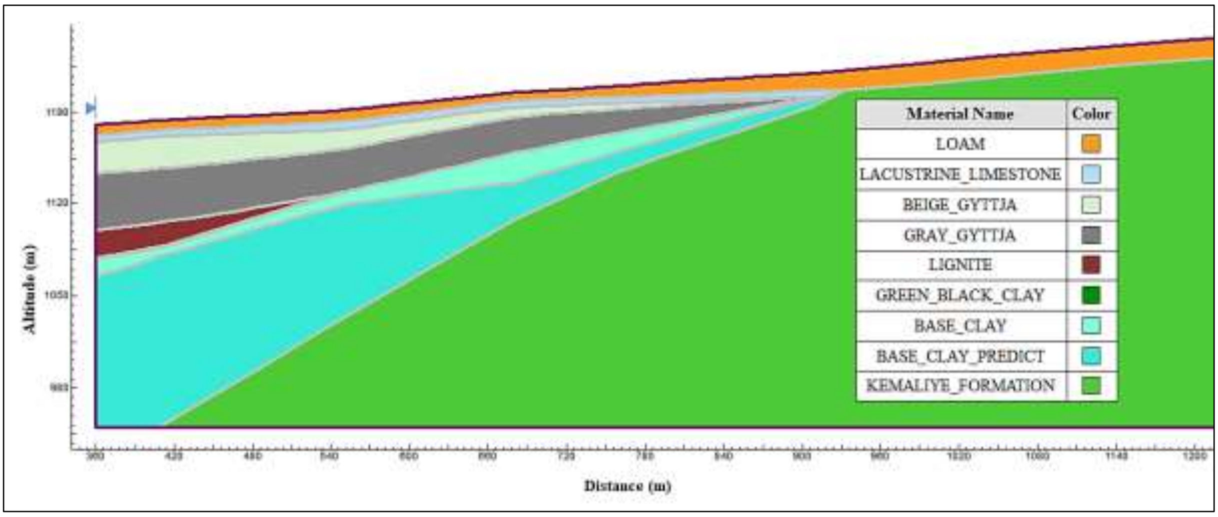

Fig. 2 Modelling of the cross-sectional structure that includes the lithologies.

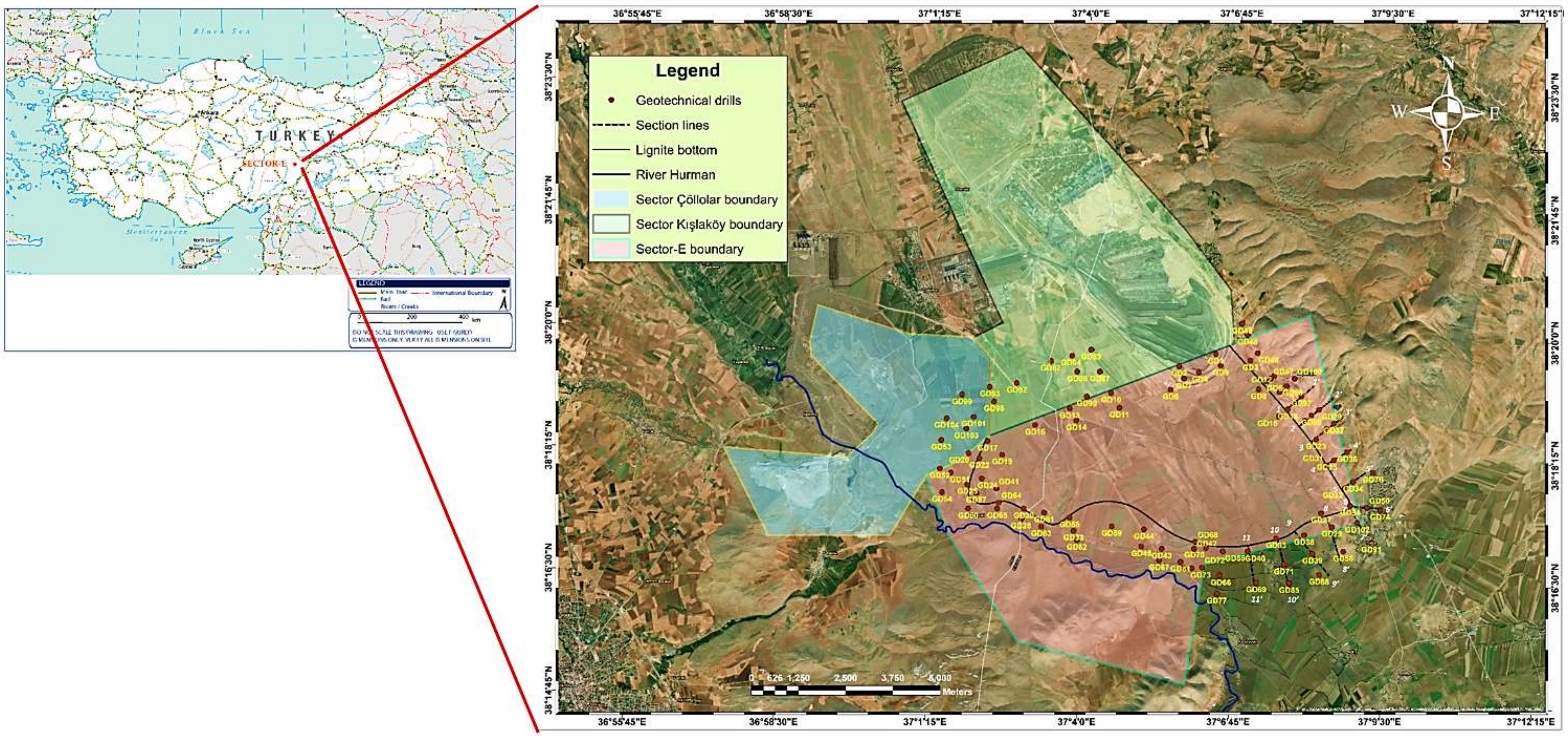

Fig. 1 Location and boundary of studied area.

Table 1 The parameters of limit equilibrium analysis (east part).

Units of formation	East part		
	γ_s (Unit weight, kN/m^3) (Min, Max)	c (Cohesion, kN/m^2, Min, Max)	ϕ (Phi, angle, Min, Max)
Loam	18.73±0.65 (17.85, 20.10)	24.70±17.58 (3.70, 52.85)	27.63±5.51(21.50, 36.70)
Beige gyttja	17.26±1.13 (14.81, 18.44)	28.55±15.93 (6.44, 45.92)	33.44±2.59 (29.81, 37.00)
Gray gyttja	15.50±1.24 (11.77, 16.87)	36.18±6.95 (25.99, 43.83)	33.82±2.54 (29.10, 36.00)
Lignite	11.57±0.70 (10.49, 13.24)	53.74 ±68.74 (2.54, 171.70)	30.84±6.57 (23.30, 39.30)
Green-black clay	15.79±1.41 (13.34, 17.95)	38.63±21.97(7.35, 78.22)	13.74±3.79 (8.60, 17.60)
Base clay	18.44±0.42 (17.55, 19.12)	36.05±14.57 (14.64, 50.58)	23.84±3.38(19.90, 28.70)
Kemaliye formation	19.42±(17.46, 20.69, 0.90)	46.37± 31.96 (4.87, 87.84)	22.40±3.49(17.60, 26.70)

Table 2 The parameters of limit equilibrium analysis (south part).

Units of formation	South part		
	γ_s (Unit weight, kN/m^3) (Min, Max)	c (Cohesion, kN/m^2, Min, Max)	ϕ (Phi, angle, Min, Max)
Loam	19.22±2.09(17.26, 26.38)	22.18±12.51(7.14, 41.47)	26.68±9.18 (13.90, 38.60)
Blue-green clay	18.63±0.67 (17.46, 20.01)	60.18±23.06 (41.40, 98.71)	19.84±7.74 (10.40, 28.50)
Beige gyttja	16.77±1.02 (11.87, 16.67)	87.88±32.02 (52.26, 139.39)	30.08±1.45 (28.50, 31.60)
Gray gyttja	14.71±1.02 (11.87, 16.67)	19.92±12.35(6.58, 42.78)	34.37± 2.07(32.10, 37.30)
Lignite	11.38±1.38 (6.77, 15.40)	61.48±28.08 (1.47, 97.75)	30.23±2.05 (27.60, 33.70)
Green-black clay	17.65±1.65 (13.44, 19.61)	29.19±14.27(14.75, 54.78)	15.27±3.50 (10.20, 19.00)
Base clay	19.91±1.68 (16.18, 24.03)	36.06±28.64 (10.58, 78.71)	23.32±4.38 (17.70, 27.20)

Table 3 Bench slope angles and factors of safety.

Lithology	Bench height (m)	Bench slope angle degree)		Bench factor of safety			
				(Circular type)	(Block type)	(Circular type)	(Block type)
		East benches	South benches	East benches		South benches	
Loam	25	21	21	1.380	1.378	1.644	1.637
Blue-green clay	25	-	21	-	-	1.485	1.483
Beige gyttja	25	43	58	1.398	1.392	1.451	1.453
Gray gyttja	25	44	35	1.439	1.417	1.447	1.429
Lignite	25	51	61	1.384	1.406	1.52	1.375
Base clay	25	24	-	1.336	1.328	-	-
Kemaliye Formation	25	26	-	1.639	1.633	-	-

3. METHOD OF ANALYSIS

Slope stability investigations in the Afşin-Elbistan lignite basin have used circular and block type slip models (Ural and Yuksel, 2004; Tutluoğlu et al., 2010; Akbulut et al., 2014; Akbulut et al., 2015). The Spencer (1967) method was used in this study of slope stability. This is one of the limit equilibrium methods that can figure out slip masses based on slices. Additionally, this approach is capable of simulating irregular failure surfaces and relies on both force and moment equations. The Spencer method is used in many studies (Flores and Karzulovic, 2001; Lupo and Mandziak, 2001; Valdivia and Lorig, 2001; Das and Sobhan, 2010) in the literature. This investigation used the Slide2 program (Rocscience, 2018), which is based on the limit equilibrium analysis method and integrates the Spencer method. Slide2, a two-dimensional program that is based on the limit equilibrium method, has demonstrated its effectiveness in the analysis of soil and rock slopes, fills, dams, and retaining walls. The program Slide2 is capable of analysing circular, block, and composite slide models using ten different methods, including Ordinary/Fellenius, Bishop simplified, Janbu simplified, Janbu corrected, Spencer, Lowe-Karafiath, GLE (General Limit Equilibrium)/Morgenstern-Price, Corps of Engineers #1, Corps of Engineers #2, as well as Sarma. This program also lets you evaluate reliability and seismicity using statistical and seismic data gathered from the field.

3.1. DETERMINATION OF BENCH SLOPE ANGLES

The bench slope angles of all units on the east and south slopes of Sector-E were determined as part of the investigation (Şengün, 2021). The Slide2 program was executed by utilising the minimum, maximum, and average values of the slope analysis parameters (unit weight, internal friction angle, and cohesion) for each unit in question, as well as the minimum (0.5 m below the bottom of the bench) and maximum (fully saturated) values of the bench's water level. Subsequently, slope stability calculations were conducted, using the suggested bench height of 25 meters and a minimum safety factor of 1.3. The evaluations conducted utilising the average unit weight, cohesion, internal friction angle, minimum and maximum groundwater levels have identified slope angles that provide a factor of safety over 1.3. These slope angles are shown in Table 3.

3.2. DETERMINATION OF OVERALL SLOPE ANGLES

The analysis began by examining the boundary sections where the bench was positioned at the end of the site, with a height of 25 m and a minimum width of 60 m from the coal base, taking into account the bench angles matching with the lithological units detailed in Table 4 and the geometrical conditions of the site. Given the significant water issues in the research region, we calculated the average and maximum groundwater levels for each section based on the height and the width of the benches.

As shown in Figure 3, probabilistic analyses were performed to quantify the probability of failure (PF), reliability index (RI-normal, RI-lognormal), and factor of safety (FS-deterministic, FS-mean). The deterministic safety factor, is the safety factor calculated for the global minimum slip surface, from the regular (non-probabilistic) slope stability analysis. The mean safety factor is the average safety factor derived from probabilistic modelling. It is the mean safety factor, derived from all safety factors computed for the global minimum slip surface. The probability of failure may be stated as the ratio of the number of analyses with a safety factor below 1 to the total number of samples (Rocscience, 2018). It is determined as follows:

$$PF = \frac{numfailed}{numsamples} \times 100 \qquad (1)$$

The reliability index (β) is a measure of the number of standard deviations (σ_{FS}) that separate the critical safety factor (= 1) from the mean safety factor (μ_{FS}). The safety factor results can be assumed to have a normal or lognormal (LN) distribution in order to calculate the reliability index (Rocscience, 2018). It is determined as follows:

$$\beta = \frac{\mu_{FS}-1}{\sigma_{FS}} \quad (2)$$

$$\beta_{LN} = \frac{ln\left[\frac{\mu}{\sqrt{1+V^2}}\right]}{\sqrt{\ln(1+V^2}} \quad (3)$$

A reliability index of at least 3 is often advised by professionals to guarantee a safe slope design. The lognormal distribution is considered to be the most suitable approach for fitting the safety factors. Compute the reliability index by using Equation 3, where μ represents the mean safety factor and V represents the coefficient of variation of the safety factor (σ / μ), (Rocscience, 2018).

The stability of slopes with an initial geometry of 25 m bench height and 60 m bench width was assessed without dewatering. In these assessments, the groundwater level was determined based on the precise location of the property. After doing these assessments, it was concluded that no bench would withstand instability without dewatering.The reliability index was approximately 3 and the probability of failure was 0 %, as indicated by the statistical evaluation.

Under the conditions of the minimum cohesion, minimum internal friction angle, and maximum groundwater level, the sensitivity assessments were conducted until the safety factor reached a minimum value of 1. The average water table set are located 0.5 metres below the base of the first bench, while the remaining benches are placed at specific depths (40, 30, 20, 10 metres). The maximum water table extends through the bottom of each bench. The Slide2 program automatically determines the minimum groundwater level based on the average and maximum groundwater level locations on the designated area.

The critical groundwater level was established at 40 m in this study due to the fact that dewatering studies conducted in other sectors of the region indicated that the groundwater level could decrease to a maximum of 40 m. Bench widths were increased and groundwater levels were decreased until the target safety factor (SF >= 1.5) was maintained. Various conditions were thus tested. In order to determine the overall slope angle for the east and south sections, we conducted slope stability analyses that took into account the groundwater level, the safety factor, and the reliability index.

4. EVALUATION OF ANALYSIS RESULTS

Initially, we conducted bench slope stability analyses for each layer. The slope angles of the east and south slopes were calculated with a safety factor of at least 1.3 and a slope height of 25 m for each layer. The bench slope angles for the lithological units on the east and south slopes are as follows: 21˚ in the loam unit, 43˚ in the beige gyttja unit, 44˚ in the grey gyttja unit, 51˚ in the lignite unit, 24˚ in the base clay unit, 26˚ in the Kemaliye formation, 21˚ in the South loam unit and the blue-green clay unit, 58˚ in the beige gyttja unit, 35˚ in the grey gyttja unit, and 61˚ in the lignite unit.

Analysis of slope stability was conducted to ascertain the overall slope angle for each section (6 sections for the east and 5 sections for the south) of the east and south slopes.

In section 1-1', the safety factor and reliability index values were achieved when the groundwater level was at least 30 m, considering the limiting site constraints of a maximum bench height of 25 m and a minimum bench width of 60 m. In this situation, the measured overall slope angle for section 1-1' was determined to be 13.29° (Fig. 3). The safety factor was 1.273 when the normalised GWL reached its maximum value, as indicated by the sensitivity analysis results in the same section (Fig. 4). We assessed the changes in overall slope angles at water tables of 20 and 10 meters. The overall slope angles for this section were determined to be 11.69° and 11.11°, respectively, and a correlation was established between the overall slope angle and the GWL (Fig. 5). Significant increases in the overall slope angle were detected when the distance between the water table and the base of the slope decreased.

The slope geometries that are the result of the same analyses of slope stability that were conducted for all sections are illustrated in Table 4.

Examinations of the suggested bench geometries indicated that the widths of the benches ranged from 60 to 125 m and extended as the distance between the groundwater level and the base of the slope decreased.

Furthermore, the overall slope angles with a factor of safety FS ≥ 1.5 and a reliability index RI ≈ 3 were found to be 8.94 to 13.30 on the east slopes and 6.33 to 13.49 on the south slopes, according to the analysis of slope stability for different groundwater levels. These investigations resulted in the establishment of correlations between the GWL and the overall slope angle, as well as between the safety factor and the normalised GWL of each section, as illustrated in Table 5. Table 5 also demonstrates that the safety factor and the normalised GWL have a highly correlated coefficient ($R^2 > 0.99$) and that the overall slope angle and the GWL have a strong correlation.

5. CONCLUSIONS AND RECOMMENDATIONS

The stripping ratio is widely recognised as critical to the economic viability of open pit mining. The stripping ratio is primarily dependent on the overall slope angle. Consequently, it is crucial to design both the final and working slopes in a manner that allows for the safe and economical operation of open pit mines. The Sector-E, which is an important part of the Afşin-Elbistan lignite basin, was the subject of slope stability analyses in this investigation. Initially, eleven geological sections were produced for the stability analysis of the east and south slopes of Sector-E. The Slide2 program performs a variety of

Table 4 Bench geometry and results of slope stability analysis.

Section number (Bottom altitude, m)	GWL (m)	Bench width (m) (Bench number)											Overall slope angle (°)	Factor of safety		Bench height (m)	Realibilty index
		1	2	3	4	5	6	7	8	9	10	11		Circular	Block		
East slope 01-01′ (1078)	**30**	**60**	**60**	**60**	**60**	**60**							**13.29**	**1.504 (1.273)***	**-**	**150**	**3.734**
	20	70	70	70	70	70	70						11.69	1.512	-	161.23	3.733
	10	80	80	80	80	80	80						11.11	1.494	-	166.82	3.549
Bench angles (˚)		24	24	24	24	24	26										
East slope 02-02′ (1034)	**40**	**60**	**60**	**60**	**60**	**60**	**60**	**60**					**12.76**	**1.5 (1.250)***	**-**	**193.64**	**3.236**
	20	75	75	75	75	75	75	75					11.57	1.507	-	200	3.194
	10	85	85	85	85	85	85	85					10.89	1.515	-	202.8	3.179
Bench angles (˚)		24	24	26	26	26	26	21	21								
East slope 03-03′ (1028)	**40**	**90**	**90**	**90**	**90**	**90**	**90**						**13.3**	**1.52 (1.255)***	**-**	**181.36**	**3.604**
	30	95	95	95	95	95	95						12.85	1.497	-	183.62	3.51
	20	100	100	100	100	100	100	100					11.33	1.495	-	190.4	3.402
	10	105	105	105	105	105	105	105					9.89	1.65	-	205.23	3.824
Bench angles (˚)		51	51	44	44	43	43	21									
East slope 04-04′ (1028)	**40**	**105**	**105**	**105**	**105**	**105**	**30**						**12.67**	**1.758 (1.450)***	**1.774**	**157.45**	**5.939**
	20	120	120	120	120	120	30						11.54	1.709	1.78	158.21	5.284
	10	130	130	130	130	130	30						10.89	1.682	1.688	158.56	5.388
Bench angles (˚)		51	51	49	44	44	44	40									
East slope 05-05′ (1014))	**40**	**110**	**110**	**110**	**110**	**110**							**12**	**1.943**	**1.704 (1.000)***	**146.75**	**3.258**
	20	130	130	130	130	130							10.51	1.907	1.6	146.59	2.604
	10	160	160	160	160	160							8.98	> 2	1.644	150	2.747
Bench angles (˚)		51	51	44	44	43	43										
East slope 06-06′ (1000)	**40**	**110**	**110**	**110**	**110**	**110**	**30**						**12.12**	**> 2**	**1.695 (1.007)***	**156.6**	**3.292**
	20	135	135	135	135	135	30						10.42	1.975	1.585	157.39	2.677
	10	165	165	165	165	165	30						8.94	> 2	1.566	159.07	2.476
Bench angles (˚)		51	51	44	44	43	43	50									

Table 4 Bench geometry and results of slope stability analysis - continued.

Section Number (Bottom altitude, m)	GWL (m)	Bench width (m) (Bench number)											Overall slope angle (°)	Factor of safety		Bench height (m)	Realibilty index
		1	2	3	4	5	6	7	8	9	10	11		Circular	Block		
South slope 07-07′	**40**	**95**	**95**	**95**	**95**	**95**							**13.49**	**1.958**	**1.73 (1.018)***	**150**	**3.175**
(1000)	20	120	120	120	120	120							11.26	> 2	1.728	149.25	3.077
	10	140	140	140	140	140							9.9	> 2	1.649	148.04	2.582
Bench angles (˚)		51	44	44	43	43	43										
South slope 08-08′	**40**	**120**	**120**	**120**	**120**	**120**	**120**	**120**	**100**				**9.51**	**1.984**	**1.707 (1.136)***	**208.92**	**3.087**
(934)	20	150	150	150	150	150	150	150	100				8.33	> 2	1.572	209.63	2.502
	10	180	180	180	180	180	180	180	100				7.3	> 2	1.598	210.06	2.564
Bench angles (˚)		51	51	51	44	44	43	21	21	43							
** South slope 09-09′	**40**	**120**	**120**	**120**	**120**	**120**	**120**	**120**	**120**	**100**			**9.56**	**1.829**	**1.545 (1.024)***	**239.6**	**3.015**
(906)	20	170	170	170	170	170	170	170	170	100			7.45	1.953	1.713	238.92	3.933
	10	205	205	205	205	205	205	205	205	100			6.48	> 2	1.681	238.92	2.993
Bench angles (˚)		61	61	35	35	35	58	21	21	21	41						
** South slope 10-10′	**40**	**125**	**125**	**125**	**125**	**125**	**125**	**125**	**125**				**9.91**	**1.74**	**1.577 (1.126)***	**228.52**	**3.034**
(906)	20	180	180	180	180	180	180	180	180				7.46	> 2	1.68	228.7	3.291
	10	220	220	220	220	220	220	220	220				6.33	> 2	1.74	228.7	3.288
Bench angles (˚)		61	61	35	58	58	58	21	21	21							
** South slope	**40**	**120**	**120**	**120**	**120**	**120**	**120**	**120**	**120**				**9.95**	**1.666**	**1.601 (1.049)***	**218.19**	**3.104**
11-11′	20	170	170	170	170	170	170	170	170				7.57	1.934	1.680	218.23	3.281
(834)	10	210	210	210	210	210	210	210	210				6.34	>2	1.737	218.23	3.442
Bench angles (˚)		61	61	35	58	58	58	21	21	21							

*: Safety factors for maximum GWL.
**: Cross section of second area.
Note: Suggested GWL are in bold

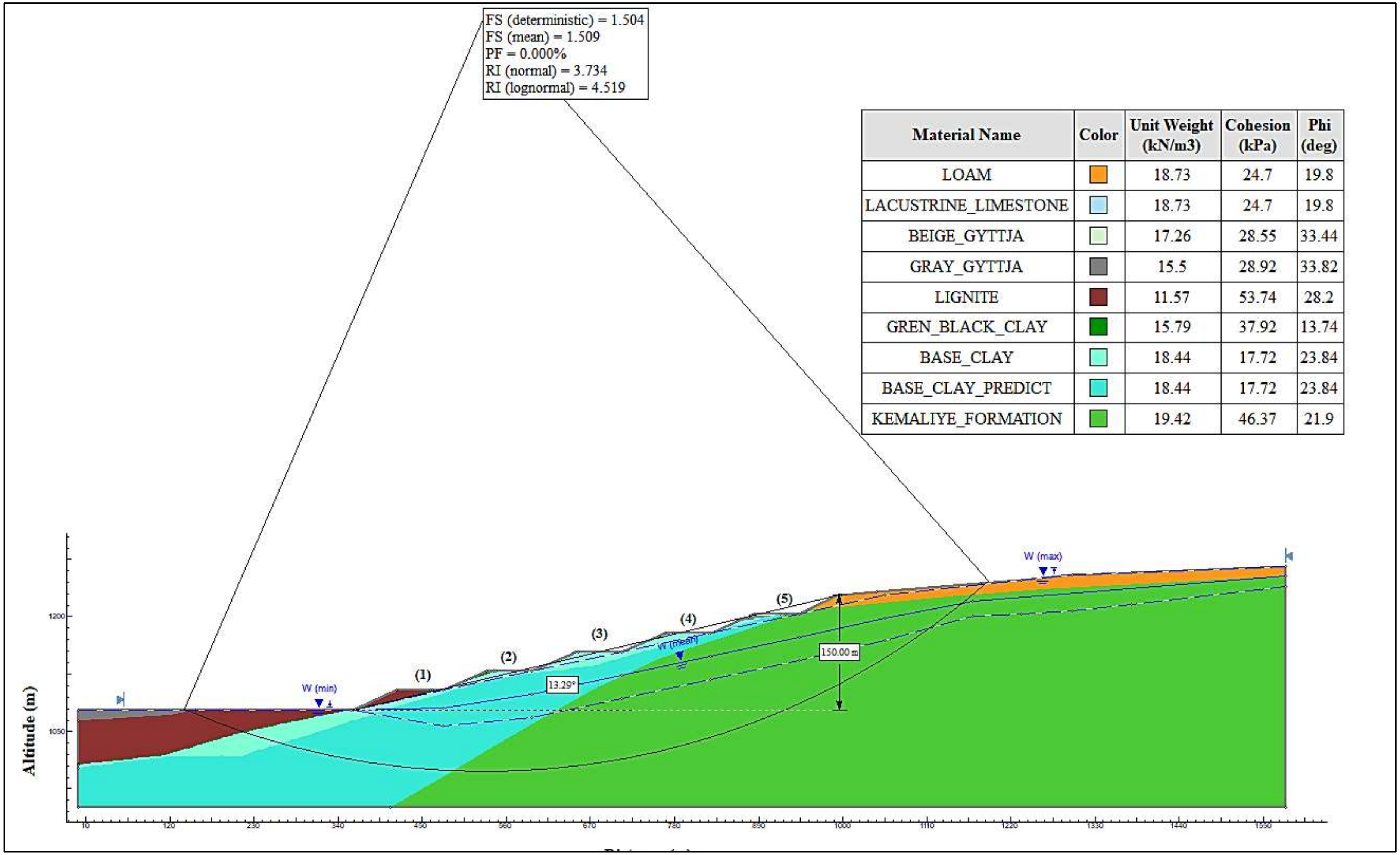

Fig. 3 The results of the slope stability analysis for sections 1-1' of the east section..

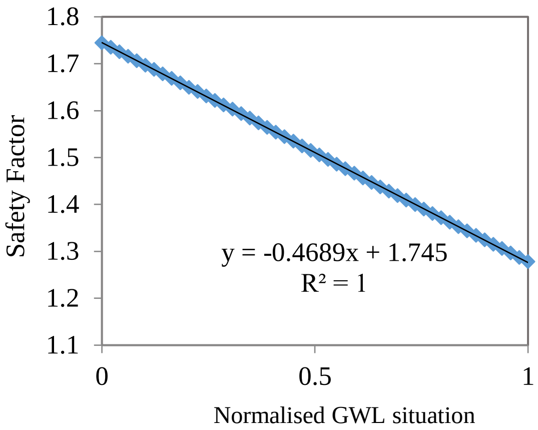

Fig. 4 The relationship between the factor of safety and the normalised GWL situation for section 1-1'.

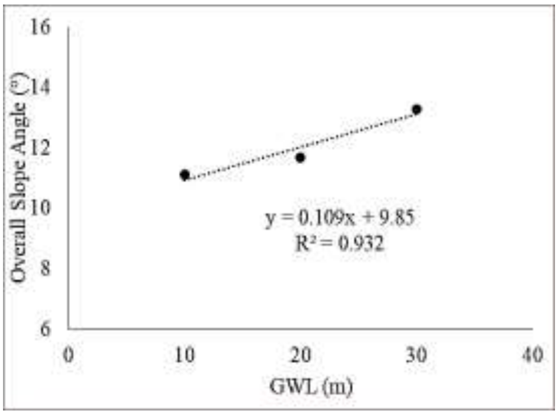

Fig. 5 The change of the overall slope angle with GWL for section 1-1'.

Table 5 Results of slope stability analysis.

Section number	Relationship between the factor of safety and the normalised GWL situation	The change of the overall slope angle with GWL
1-1'	y= -0.4689x+1.745 R^2=1.00	y= 0.1090x+9.850 R^2=0.93
2-2'	y= -0.5137x+1.764 R^2=1.00	y= 0.0619x+10.295 R^2=0.99
3-3'	y= -0.5357x+1.792 R^2=0.99	y= 0.1175x+8.905 R^2=0.96
4-4'	y= -0.6337x+2.0734 R^2=0.99	y= 0.0589x+10.325 R^2=0.99
5-5'	y= -1.0586x+2.1643 R^2=0.96	y= 0.0969x+8.325 R^2=0.96
6-6'	y= -1.1130x+2.2029 R^2=0.98	y= 0.1030x+8.09 R^2=0.98
7-7'	y= -1.1663x+2.2639 R^2=0.97	y= 0.1185x+8.785 R^2=0.99
8-8'	y= -1.0386x+2.2064 R^2=0.99	y= 0.0716x+6.710 R^2=0.98
9-9'	y= -0.9891x+2.0332 R^2=0.99	y= 0.1031x+5.425 R^2=0.99
10-10'	y= -0.8568x+1.9973 R^2=0.99	y= 0.1198x+5.105 R^2=0.99
11-11'	y= -1.0222x+2.097 R^2=0.99	y= 0.1201x+5.150 R^2=0.99

slope stability analyses using circular and block-type slide models. Bench and overall slope angles were established by setting the bench height to 25 m, the bench width to a minimum of 60 m, and the safety factor to 1.3 for the bench and at least 1.5 for the overall slope angle, all in accordance with the operating conditions. In the sensitivity assessments of each layer, the bench slope angles were determined in consideration of cohesion, internal friction angle, groundwater level, and safety factor, with a minimum safety factor of 1. The bench angles associated with the east slopes were determined as follows: 21 degrees in the loam unit, 43 degrees in the beige gyttja unit, 44 degrees in the grey gyttja unit, 51 degrees in the lignite unit, 24 degrees in the base clay unit, and 26 degrees in the Kemaliye formation. The bench angles for the south slopes were estimated as follows: The values are 21 degrees in the loam and blue-green clay units, 58 degrees in the beige gyttja unit, 35 degrees in the grey gyttja unit, and 61 degrees in the lignite unit. The stability analysis results of the recommended bench geometries demonstrated that the benches' widths varied from 60 to 125 m and increased as the distance between the groundwater level and the base of the slope decreased. An analysis of slope stability at various groundwater levels (Table 4) revealed that slope angles with a factor of safety over 1.5 and a reliability index close to 3 varied between 8.94 and

13.30 degrees for east slopes and 6.33 and 13.49 degrees for south slopes. Furthermore, for each section, relationships were established between the overall slope angle and GWL, as well as the factor of safety and normalised GWL. The safety factor and normalised GWL, as well as the overall slope angle and GWL, showed significant correlations (Table 5). Consideration of the findings from this research is advised for both the cost analysis of dewatering and stripping, as well as the planning of these activities. It is also recommend reevaluating the obtained results in light of the changing conditions in both dewatering and mining operations. Slope analyses should be repeated at regular intervals, taking into account the new values of the slope analysis input parameters (cohesion, internal friction, unit weight), which may change depending on the GWL drops due to dewatering operation.

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