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**ASSESSMENT OF COAL MINING SUBSIDENCE DAMAGE IN SOMA-TURKEY COALFIELD
USING FEM MODELLING**

**OCENA SZKÓD GÓRNICZYCH ZWIĄZANYCH Z OSIADANIEM GRUNTU W ZAGŁĘBIU
WĘGLOWYM SOMA W TURCJI, Z WYKORZYSTANIEM METODY
ELEMENTÓW SKOŃCZONYCH**

Soma has mine subsidence problems associated with production. Therefore, property and infrastructure damage will be related with coal-mine subsidence in Soma. In this study, depending on the underground coal mine production method, damage of subsidence on energy line was determined in Soma-Turkey coalfield. Subsidence may still occur in these areas. Therefore, determining subsidence is very important. Finite element methods (FEM) and field measurements were used for determining the parameters of mechanisms. The software, Phase², used for the numerical modeling was developed by Rockscience Inc. The results obtained from modeling have been found to be compatible with previous studies and have been compared with actual field observation.

Keywords: Mining subsidence; Coal Mining; Finite element methods (FEM)

W Somie wystąpiły szkody górnicze związane z osiadaniem gruntu. Dlatego też uszkodzenia własności i infrastruktury badane będą w związku z osiadaniem gruntu. W artykule określono wielkość uszkodzeń linii energetycznej w zagłębiu węglowym Soma (Turcja) w zależności od zastosowanej metody wybierania. Ponieważ nadal ma miejsce osiadanie gruntu, ważne jest określenie jego zasięgu. Wykorzystano metody elementów skończonych raz pomiary terenowe dla określenia mechanizmu osiadania. Oprogramowanie Phase², wykorzystywane w modelowaniu numerycznym, opracowane zostało przez firmę Rockscience Inc. Następnie wyniki modelowania, zgodne z wynikami wcześniejszych badań, porównane zostały z wynikami pomiarów w terenie.

Słowa kluczowe: osiadanie gruntu, górnictwo węglowe, metoda elementów skończonych

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1. Introduction

Turkey has large coal reserves about 9 Gt (Turkish Lignite Authority, 2008). Coal may be distributed throughout the country. The better quality coal reserves seem to be concentrated in western Turkey especially Soma region. Except for a few Jurassic formations, most Turkish coal was formed in two different geological ages. The Pennsylvanian (Westphalian) coal is bituminous and Tertiary coal is brown (lignite and subbituminous) coal (Figure 1). Soma coal field consists of lignite and subbituminous coal. In this region, coal mining has been practiced since early twentieth century. Two extraction methods, underground and open pit are applied in some coal fields. Underground mining methods are mostly non-mechanized longwall. Depending on the underground mining method, significant subsidence problems have occurred. Underground mining areas are close to Soma city. Therefore, subsidence effects are very dangerous. Many researchers are focused on hazard and monitoring of subsidence using different techniques (Aksoy et al., 2004; Kim et al., 2006, 2009; Zahiri et al, 2006; Luo & Cheng, 2009; Lee et al., 2010; Lee & Oh, 2011; Demirel et al., 2011).

To determine the subsidence effects, parameters of surface movement play an important role. These parameters are subsidence, tilt, horizontal displacement, curvature and strain. These parameters can be calculated using classical theory and numerical method. The classic theory of mining subsidence engineering has been unable to give a good result under the condition of complicated structure, for example, mining in faulted rock masses, sharply inclined layers, and closed folds. In recent years, with the development of the computer, the finite element method (FEM) of rock mechanics has been used to estimate mining subsidence. Generally speaking, the result of the FEM application is far from the best use for mining subsidence (Manchao & Zhida, 1991).

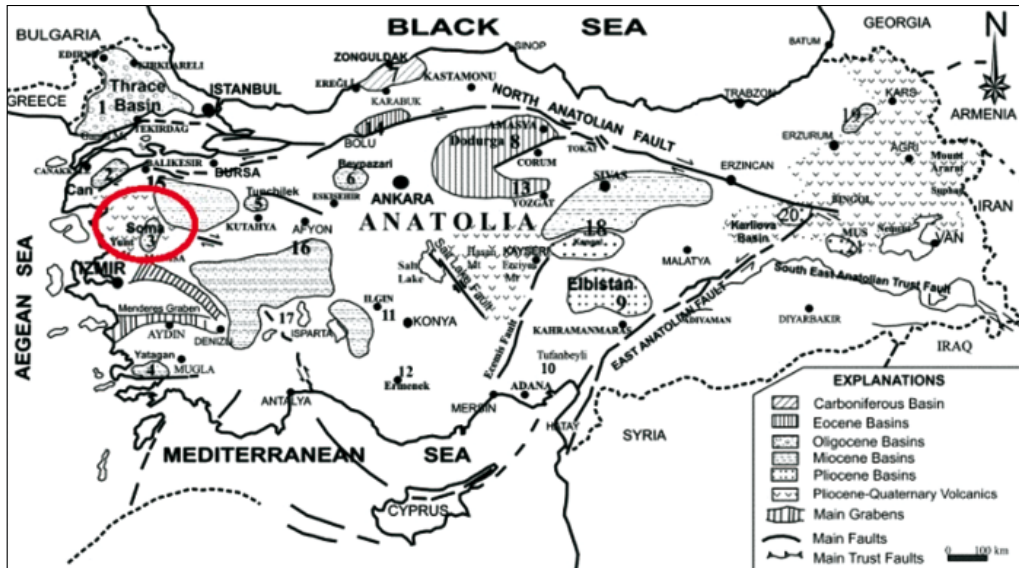


Fig. 1. Location of major coal basins and important geologic features of Turkey (Turkish Lignite Authority, 2008)

The method has been widely used by many researchers. McKinnon (2001) described a technique to calibrate boundary tractions for numerical models using stress measurements. The technique was demonstrated using a numerical model of a hypothetical mine in a mountainous region. Hart (2003) presented several applications of numerical analysis to evaluate the influence of different factors, such as topology, excavation, loading history and geologic structure, on the state of stress in rock. A reviewed published paper (Jing, 2003) was focused on the techniques, advances, problems and likely future developments in numerical modeling for rock mechanics. Yasitli and Unver (2005) presented 3D modeling of the top-coal-caving mechanism by using the finite difference code at the longwall panel of the Omerler Underground Mine located at Tuncbilek (Turkey). Aksoy et al (2006) studied on numerical modeling concerned with single and double drifts in trona field in Turkey. Islam et al. (2009) used numerical analyses to evaluate stress redistribution, strata failure, and water inflow enhancements in Barapukuria coal mine.

In this study, damage of subsidence on energy line was determined in Soma coalfield. Three coal mines have been extracted with underground mining methods in the study area. Ten pylons on energy line are above of the extraction area. Some pylons are close to border of coal mines. According to Turkish mining law, twenty meters from the border to do the extraction is prohibited. However, some of them were damaged. The purpose of this study is to determine what causes the damage to that mine. We used finite element methods to determine these damages.

Study Area

The stratigraphic section of Soma (Fig. 2-3) coalfield shows the relationships between the coal seams, enclosing sediments, and volcanics. Marl, clay, and carbonate rocks are the most abundant and most commonly associated sediments. The coal seam partings are few and mostly composed of clay and pyrite. The most commonly associated rocks are marls and clays. The associated lamellibranch shell fragments, milolid fossils found in the cited locations tend to be mostly lacustrine in origin (Ketin, 1983; Toprak, 1984, 1996).

Depth of the coal production is about 190 m. Coal seam ranges in thicknesses from 15 to 25 m, with an average extractable thickness of about 18 m. A manual vertical double-slice-caving longwall mining method is employed for the main production at the mine. In this method, the face area is maintained at about 2 m. high using hydraulic steel props and wooden posts. The coal is extracted from the face by drilling and blasting and the additional lignite thickness above the supports is recovered by caving behind the face (Fig. 4).

Methods

Theory of mining subsidence

Amount, effects, and timing of subsidence differ depending on the mining technique. The amount of subsidence is never as much as the mining height, and most subsidence occurs within days to several weeks after an area is undermined by longwall or high-extraction retreat methods, depending on the actual rate of mining. As the longwall mining process creates a large opening underground, it changes the equilibrium of nearby rock materials. The void at the mine level does not work its way slowly upward through progressive collapse up through the overburden. The monitoring of the overburden above longwalls shows that, overall, the entire overburden

		Formation	Thickness (m.)		EXPLANATION	
Quaternary	Holocene				Alluvium	
	Pleistocene				Nodular Limestone	
						Young Coaly level
						Sandstone-Gravel
NEOGENE	Pliocene	Deniş Formation			Erosion	
					Tuff-Aglomera	
			200-300		Cherty Limestone	
			300-500		Tuff - Marl series	
			7-8		Upper Coal Layer	
			120-150		Clay- sand series	
					Erosion	
	Miocene	Soma Formation	10		Limestone	
			6-10		Middle coal series	
			50-60		Limestone series	
			100		Marl series	
			15-22		Lower coal series	
			50-200		Coaly claystone	
					Sandstone Conglomerate	
Basement Formation					Paleozoic - Mesozoic Limestone	

Fig. 2. General Stratigraphic Section for Soma Coal Basin (Ketin, 1983)

from the mine level to the ground surface moves downward nearly as one mass with some bending and flexing as bedding planes slide past each other. The bedrock layers that slide past each other form thin beams that partially crack from the bending taking place. These tension cracks do not typically progress through the entire rock beam but terminate at about the center of each beam (Fig. 5). Because these cracks are discontinuous, they do not form a path for groundwater to flow from the ground surface down to the mine level. Longwall and high-extraction retreat mining cause vertical and horizontal surface movements. The ground drops vertically and moves horizontally toward the center of the trough (Bauer, 2006), which may affect surface structures

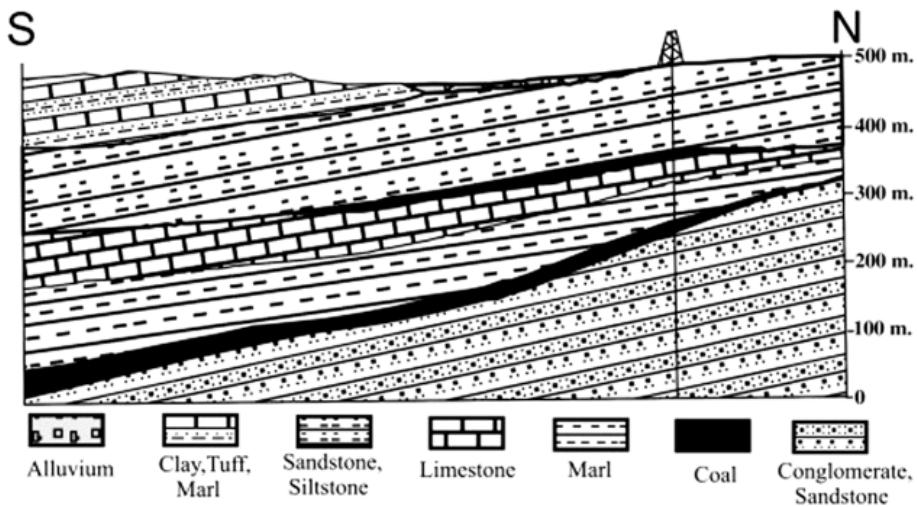


Fig. 3. An S–N Directional Geologic Section of Soma Coal Basin and the Southward Inclination of the Coal Seam (Gürsoy, 1989)

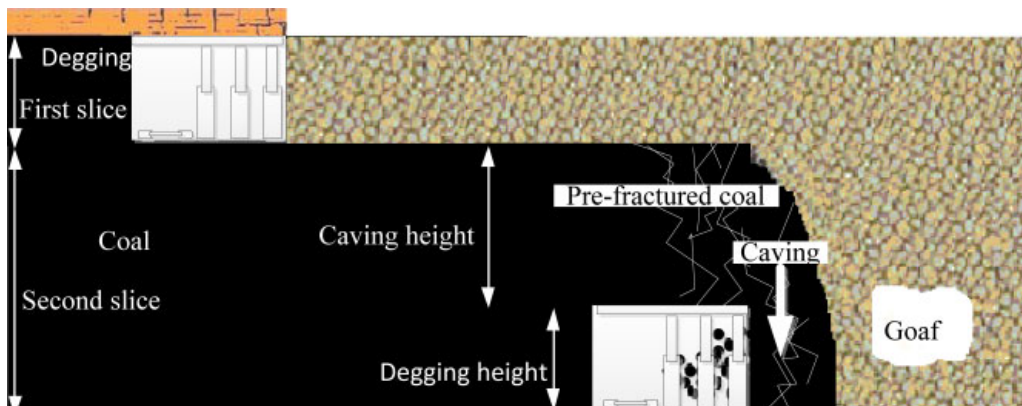


Fig. 4. Underground Mining Method in Soma Coalfield

or other features. The effects of subsidence from longwall mining are uniform and anticipated (Fig. 5). The surface over the center of the panel drops approximately 1.2 to 1.8 meters. Maximum subsidence occurs over the center of the mined-out panel and tapers off toward the edges of the panel, forming a gentle trough. Less subsidence occurs over the entryways. The areas of surface subsidence beyond the edges of the panel are defined by a point where zero vertical subsidence occurs. This area is defined by an angle called the angle of draw (Fig. 5), which varies according to differences in local geology, seam depth, and panel width. The distance from the panel edge to zero subsidence may be 0.35 to 0.45 times the depth to the mine. This point or location is not

necessarily related to damage since the amount of tension large enough to affect various structures is located just within the edge of the panel to nearly over the edge of the underground panel.

The extraction width of the panel in relation to the depth of mining generally determines the shape of the final subsided area at the ground surface (Fig. 5):

- The subcritical panel extraction width is narrow. It causes less than maximum possible subsidence at the ground surface.
- The critical panel extraction width is slightly wider. Only its center point reaches the maximum possible subsidence. The critical width of a panel is generally considered to be at least 1.5 times the depth to the coal seam, if maximum subsidence is to occur at a point at the center of the panel.
- The supercritical panel extraction width is wider than the critical width. It causes a flat area of maximum subsidence in the center of the surface trough. Although the lateral area of maximum subsidence increases, the angle of draw does not increase

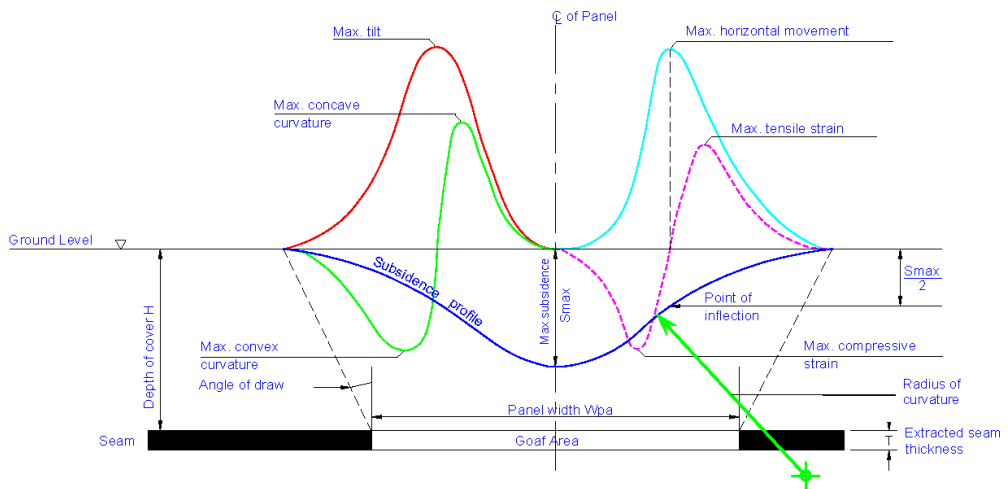


Fig. 5. Subsidence Parameter Profiles above a Single Longwall Panel (Introduction to Longwall Mining and Subsidence Mine Subsidence, 2007)

Finite Element Modeling

In mining there have been many prediction methods for determining the subsidence. The base methods for determining the subsidence are the profile function method, empirical functions, and influence function methods. On the other hand finite element method can be used for determining the subsidence. In brief, the main procedures of FEM consist of the following:

- Compute the stiffness matrix for each element based upon the assumed displacement function, the element configurations in the model, and the stress–strain relationship
- Form the stiffness matrix of the total model by summing appropriate submatrices of element stiffness.
- Solve force-displacement equations for nodal displacements, from which compute the strains and stresses.

Since Young's modulus and Poisson's ratio vary from element to element, it is necessary to determine the stress-strain transformation matrix:

$$[D]_i = \frac{E}{(1+\gamma_i)(1-2\gamma_i)} \begin{bmatrix} 1 & \gamma_i/(1-\gamma_i) & 0 \\ \gamma_i/(1-\gamma_i) & 1 & 0 \\ 0 & 0 & \frac{(1-2\gamma_i)}{2(1-\gamma_i)} \end{bmatrix} \quad (1)$$

where; i refers to the i^{th} element and E and γ_i are Young's modulus and Poisson's ratio, respectively. Computation of $[D]_i$ for each element is an additional procedure, but compares with the analysis of an ordinary problem in plane elasticity. Once Young's modulus and the Poisson's ratio are assigned and $[D]_i$ is formed for each element, the stress analysis follows the pattern for a conventional finite element method (Su et al., 1969).

In our study case phase² (Rockscience Inc.) was used for determining the subsidence that occurs under electric pylons. Phase² is a 2-dimensional elasto-plastic finite element program used to calculate stresses and displacements around underground openings, and can be used to solve a wide range of mining, geotechnical and civil engineering problems.

The Phase² model for this problem is a graded mesh 75 segments (discretizations) around the circular opening 3 noded triangle finite elements were used for analysis.

Experimental

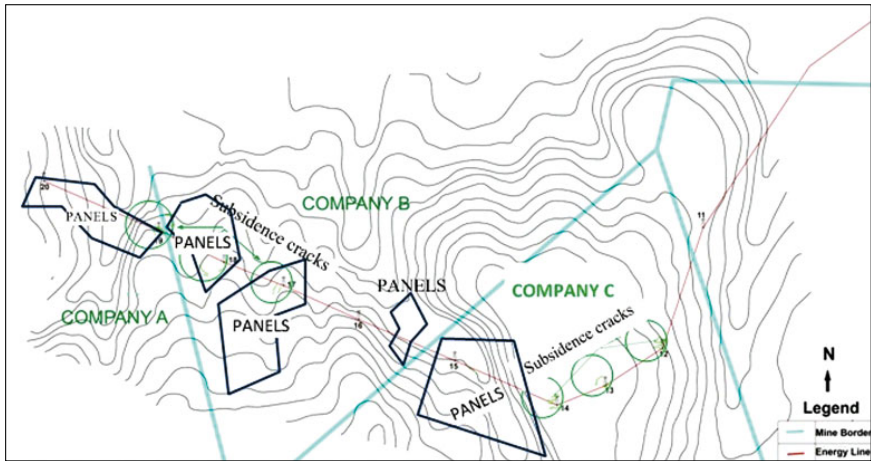
Field Study

In field study, we observed surface subsidence cracks especially around of the pylons and determined damaged pylons. Large-scale subsidence cracks were observed as 1-3 m opening widths and 2-14 m total displacement on the surface. Energy line including pylons, coal mine borders and coal seam contours are shown on the map (Fig. 6). An example image of damaged pylon is given Figure 7. All observation results are tabulated in Table 1.

TABLE 1

All observation results of field study

Pylon Number	Damaged case	Subsidence Cracks
11	-	-
12	√	√
13	√	√
14	√	√
15	-	√
16	-	√
17	√	√
18	√	√
19	√	√
20	-	-



a)



b)

Fig. 6. General preview of study field

According to the observation results, pylons, No.11-12 were not damaged. Pylons, 15-16 were not damaged; however subsidence cracks were observed around them. Other pylons were both damaged and subsidence cracks were observed. In this study we focused on pylons, 15, 18 and 19, as these pylons were close to the mine border.

Laboratory Study

In order to use the Finite element model of the subsidence, mechanical properties of rock formations above the coal seam were determined. For this purpose the rock samples were collected based on the formations given in Figure 3. These samples were carried out rock mechanics tests, which are density, unconfined compressive strength (UCS), elastic modulus. Grain density



Fig. 7. Preview of subsidence effects on Pylons (No: 18-19)

was measured with a He-pycnometer (Micromeritics, The AccuPyc II 1340). UCS tests were performed using hydraulic press (ELE, 300 tons capacity). The samples were loaded in axial strain control at a rate of 50kg/sec. To determinate of elastic modulus were performed during UCS testing, and consists of measuring and recording the axial/lateral deformation history of the sample in addition to its load history. Both are measured in accordance with the procedures given in ASTM D7012–10, with the length to diameter ratio of 2 by using NX-size core samples. Geological Strength Index (GSI) suggested by Sonmez ve Ulusay (2002) was determined using field measurement and observation.

Results and Discussion

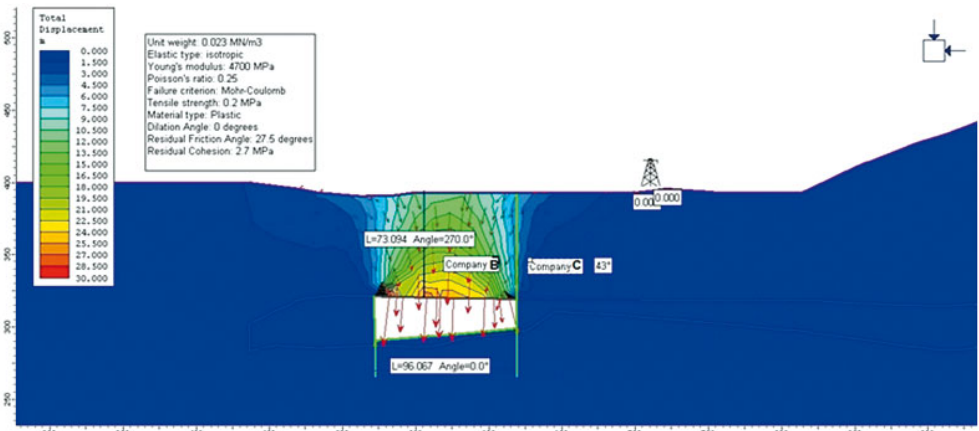
Finite element method is utilized in order to determine the subsidence effects and parameters. This method was applied using Phase2 (Rockscience Inc.) software. Rock mechanics tests given Table II were applied to the samples. The obtained data used in modeling are given in Table 2. These data were used as input data in Phase² software. FEM results are shown in Figures through 9-11.

In this study, depending on the dip of the coal seam, angle of draw was determined using FEM analysis between 32 and 68 degrees. Draw angle of Soma region was reported as an average of 50 degrees in the previous studies (Aksoy et al., 2004; Yenice, 1999; Onargan et al., 2009). These results conformed to subsidence cracks observed during field study. According to the FEM analysis results, total displacement range is between 3-13.5 m. These results also were quite similar to that observed in the field.

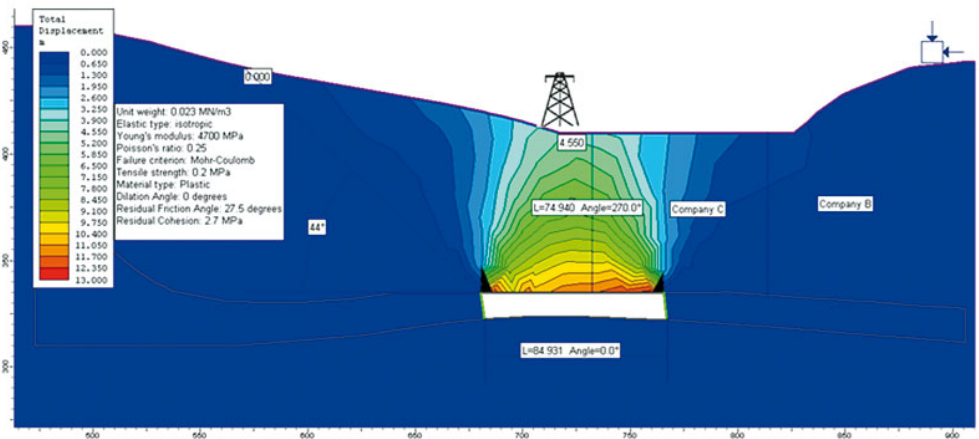
TABLE 2

Input data for FEM Modeling

Samples	Density	Uniaxial Comp. Strength (UCS)	Young's Modulus	Poisson's Ratio	Geological Strength Index (GSI)
	Average Value (gr/cm ³)	Average Value (MPa)	Average Value (MPa)	Average Value (ratio)	(index)
Tuff	1.8	8	6700	0.18	23
Sandstone-Siltstone	2.1	0.35	890	0.4	5
Marl	2.4	70	13415	0.25	69
Limestone	2.5	85	19300	0.2	74

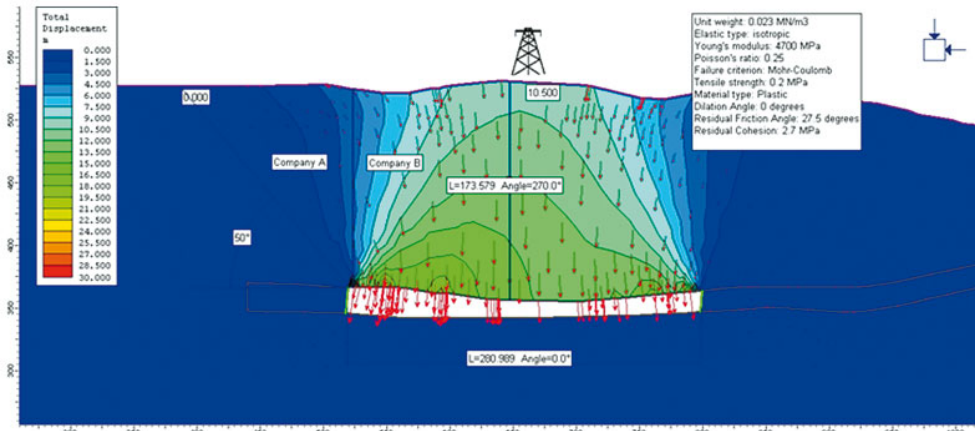


a)

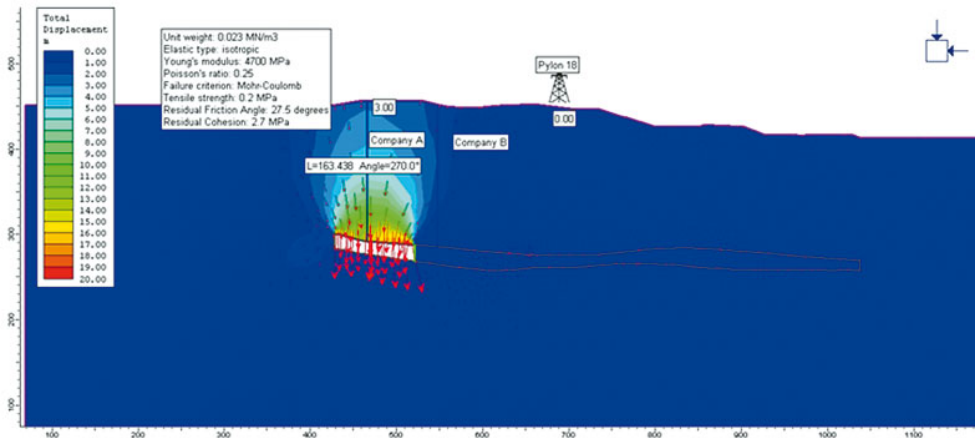


b)

Fig. 8. FEM analysis results of Pylon-15



a)



b)

Fig. 9. FEM analysis results of Pylon-18

Pylon, No:15 is above coal mine borders called “C”. However, this pylon is located close to coal mine border called “B”. During the field study, no damage on this pylon was observed (Fig. 6a). Both the pylon and near the border of the mine panel is used for FEM analysis. The results of the analysis show that there is no damage from subsidence cracks caused by extraction of the panels on the pylon (Fig. 8).

Pylon, No:18 is within the borders of coal mine called “B”. This pylon is located close to coal mine border called “A”. In the field study, we observed serious damage on the pylons (Fig. 6a, 7). There are also two panels around the pylon in “B” coal mine. According to the results obtained from FEM analysis, damage on the pylon is caused by extraction of panels in „B“ coal mine (Fig. 9).

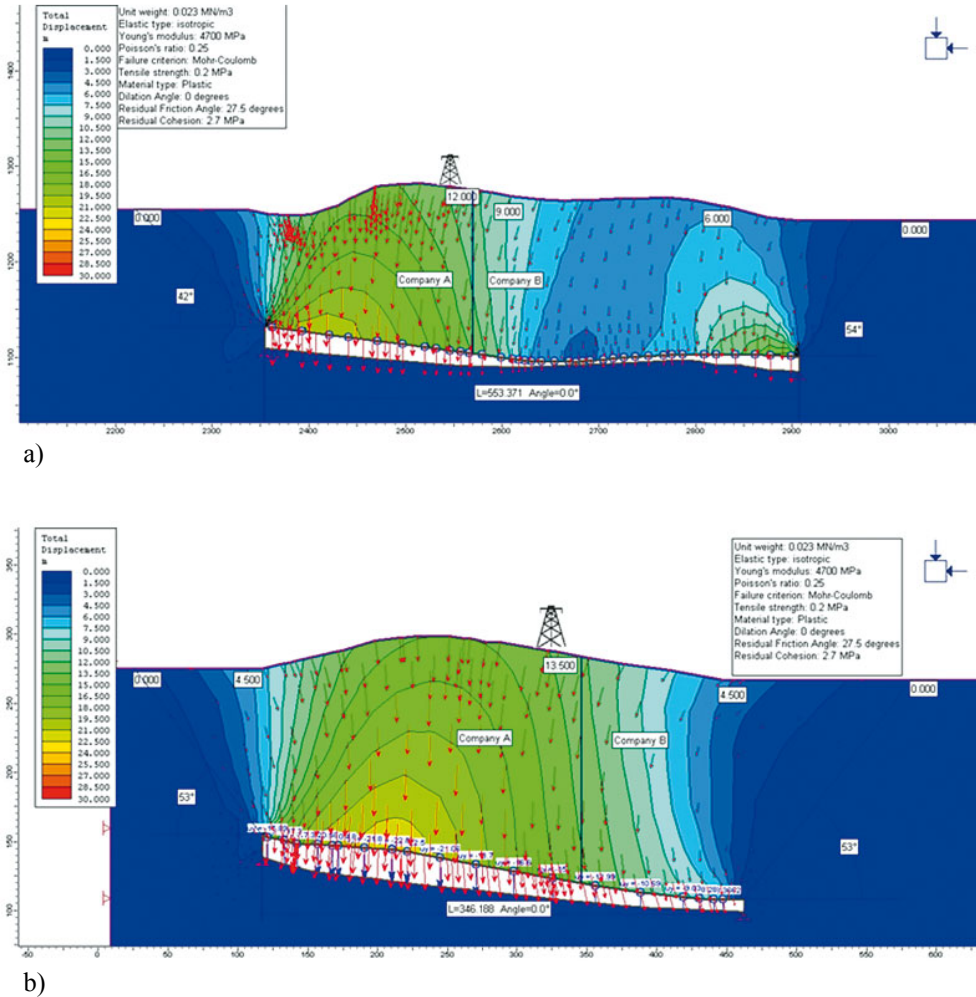


Fig. 10. FEM analysis results of Pylon-19

Pylon, No:19 is on the extraction of coal mine called “A”. This pylon is near to coal mine border called “B”. In the field study, serious damage was seen on the pylon (Fig. 6a, 7). There is a panel the nearest to both border and pylons in „A“ coal mine. There are also two panels are around the pylons in “B” coal mine. According to the results obtained from FEM analysis, damage on the pylon is caused by extraction of panels in both „A“ and “B” coal mine (Fig. 10).

In the study area, the effects of subsidence occurred by underground coal mining method and have already damaged pylons, No: 12, 13, 14, 17, 18 and 19. The stability of the pylons has also deteriorated. Therefore, Pylons, No: 15 and 16 are under great risk. Because of the stability deterioration, tension of electricity wires is increasing on the pylons every day. As a result, the part of energy line from Pylon No:11 to Pylon No:20 has not been used for a long time. The part

of energy line should be replaced. Underground mining operation is continued and also subsidence is present as well. That should be the way new energy line will be designed under surface.

Conclusions

This paper presents a study of subsidence damage on the energy line encountered at the Soma Region underground coal mine extractions in Turkey. In this study, field observations and numerical analysis were applied to determine the subsidence parameter of the field under investigation. We used Phase² (Rockscience Inc.) software for numerical analysis.

There are ten pylons above underground mining operation area. Six of them have been seriously damaged. Therefore, stability of the energy line was deteriorated. Three mines are extracted coal by underground mine operation and there are three pylons are close to mine borders. According to Turkish mining law, twenty meters from the border to do the extraction is prohibited. However, these pylons were also damaged.

In this study we determined which coal mine panels caused subsidence using FEM. Numerical analysis results obtained have been compared with actual field observation and previous studies. The subsidence profiles have been found quite similar to that observed in the field and previous studies.

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