Efficient real time stability monitoring of mine walls: the Çöllolar Mine case study

P. Farina, N. Coli
IDS, Ingegneria dei Sistemi SpA, Pisa, Italy

R.Yön , G. Eken, H. Ketizmen
Ciner Group, Turkey

ABSTRACT Slope monitoring radar has emerged in the last ten years as a leading edge tool for monitoring movements in open pit mines, thanks to the ability to rapidly measure wall movements with millimetric accuracy over wide areas in any weather conditions. IBIS-M is an innovative interferometric radar able to provide high spatial resolution, long working distances and fast acquisition time. The first IBIS-M unit deployed in Turkey was installed in 2011 at the large lignite open pit Çöllolar Mine operated by Park Teknik. The geotechnical staff has now 24/7 real time monitoring of the slope stability with a wide coverage on the pit walls with the capability to detect the onset of wall movements far before the occurrence of failure, thus increasing the safety standards and productivity of the mine. The IBIS-M monitoring experience at Çöllolar mine is presented in this paper.

1 INTRODUCTION

In surface mining industry a comprehensive slope monitoring program, aimed at managing potential large-scale instabilities and able to detect at the same time local scale movements, should represent an integral part of every effective slope management system. Among all the parameters to be considered and included in an effective slope monitoring program displacements, either surface or sub-surface components, play a crucial role. In fact, in open pit mines large failures are usually preceded by small scale slope movements, sometimes limited to few centimeters of total displacement and typically characterized by temporal evolutions ranging from several hours to several weeks.

The capability of providing advanced notice over the whole slope of impending instability conditions, through the accurate and timely measurement of precursor to slope collapses clearly represents an outstanding benefit for the staff of the pit involved in the geotechnical risk management.

The use of slope monitoring radars in open pit mines is today a standard practice for active monitoring of the pit walls. Radar units are effectively used to get a better understanding of the spatial distribution of slope movements and for the provision of alerts in the event of progressive movements that can potentially lead to slope failure, thus aimed at assessing the safety of workers and increase the mine productivity.

Radar technology presents the advantages of high accuracy of the measurements, long-range capabilities, limited impact of atmospheric artifacts on the measurement performances, and possibility to simultaneously acquire the response over a large number of points without the need to install artificial reflectors on the slope.

Slope monitoring radars are based on the radar interferometry, a well-known technology originally developed for satellite applications in order to retrieve ground displacements related to natural hazards

(Rosen et al. 2000, Antonello et al., 2004; Corsini et al., 2006; Bozzano et al., 2008)

2 SAR SLOPE MONITORING RADAR TECHNOLOGY

The first type of slope monitoring radar introduced into the mining market was based on parabolic dish-antenna radars (Real Aperture Radar – RAR), exploiting a fine radar beam that illuminates the target over a series of footprints.

In recent years, slope monitoring radar for mining applications has experienced significant improvement thanks to the introduction of a different interferometric radar technology, such as Ground-based Synthetic Aperture Radar (SAR), able to overcome some of the limitations of dish-antenna technology, by providing higher spatial resolution, longer working distances and faster acquisition time.

A SAR system is characterized by a limited number of moving parts, being composed by a radar sensor with a couple of small horn antennas that illuminate the monitored area while sliding along a long linear scanner. Thanks to this movement, SAR performs a full resolution scan of the observed area in a short time compared to RAR for the same area coverage (e.g. less than 3 minutes to cover an area of a 6-8 km^2 at 2 km operating distance). Fast scan time means reduced impact of atmosphere on radar data and higher sensitivity to the onset of potential failure thanks to the higher sampling rate.

In this paper monitoring results obtained by using IBIS-M SAR slope monitoring radar are presented.

The high spatial resolution of IBIS-M is an important added value for open-pit applications, since it means higher sensitivity to slope movements and capability to detect smaller areas of failure, especially for sub-bench or bench-scale failures. The typical resolution cell of IBIS-M is be of 0.5 m x 4.3 m at 1 km monitoring distance, thus allowing the detection of a $4m^2$ rock boulder even at more than 1 km scan range (Fig. 1).

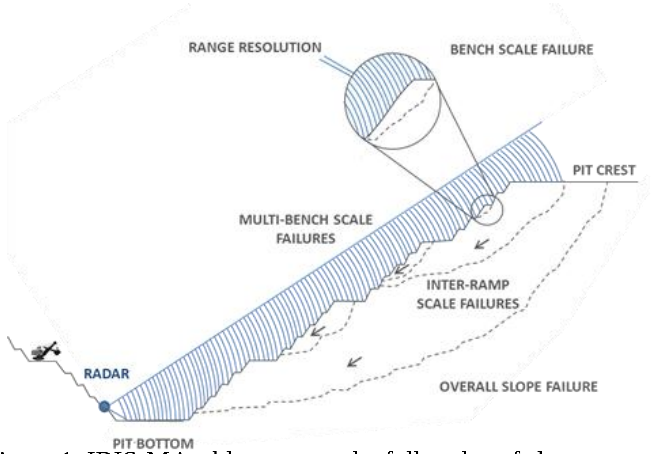


Figure 1. IBIS-M is able to cover the full scales of slope instability from sub-bench to overall slope failure. In blue the radar coverage and the range-resolution cells. (modified from Read &Stacey, 2009).

3 ÇÖLLOLAR MINE CASE STUDY

Çollölar Mine is a large coal mine, located in the Kahramanmaraş district in Southern Turkey, to the North pof the towns of Elbistan and Afşin and operated by Park Teknik (Fig. 2).

Figure 2. Location of the Çollölar Open Cast Mine

The box cut of mine is 2.3 km long and and 1.5 km wide (Fig. 3). The elevation of the mine is approximately 1.180 m a.s.l.

In February 2011 two catastrophic mass movements occurred at the mine site. As a consequence of these events, the overall slope angle in the Application Mine project was decreased from 16° with an overall stripping ratio of 2.28:1 to the current 14-15° with stripping ratio 3.614:1.

Figure 3. Aereal view of Çollölar Box Cut

Moreover, in order to increase the safety levels of the mine and reduce production downtimes, the geotechnical department of the mine installed an IBIS-M slope monitoring radar, which has been successfully operating for two years, guaranteeing 99% availability for around the clock active and background monitoring of the pit walls.

3.1 Geological and geotechnical background

3.1.1 Geological Backround

According to Yörükoğlu (1991) the Elbistan basin takes its name from the nearest Elbistan city. The Elbistan basin covers an area of 900 km^2 with a mean elevation of 1.200 m a.s.l. Afşin Elbistan Lingite Field bed formed during the rise of Toros Mountains after Alpine Orogenic Phase. The base of the region is a Permo-Carbonifierious old limestone.

Neogen lithologies are given, from bottom to top:

- Limestone Formation (possible confine aquifer)
- Bottom Clay: Greenish, bluish-plastic clay and marls of lignite bottom,
- Lignite zone with transitive layers of coal and gyttja
- Gyttja
- Greenish, blue, plastic clay, loam and marls of lignite top

The Geological map and stratigraphic sequence are shown in Figure 4.

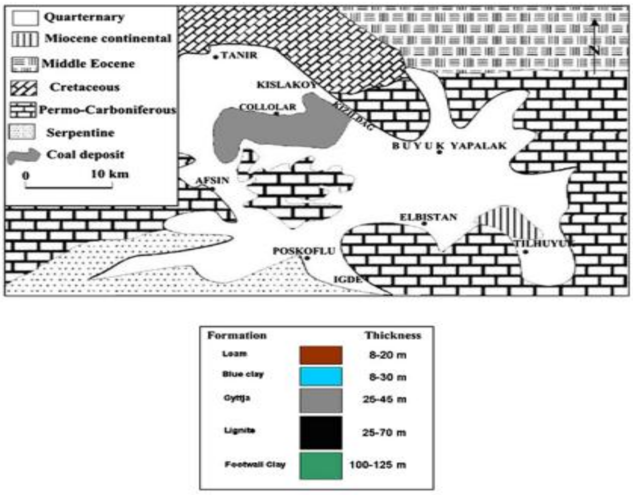


Figure 4. Çöllolar Coal Field Formation and thickness. Apdated from Ural and Yüksel (2004)

Gyttja is the most important geological formation which is composed of gastropod fossils, plant residues and humus content. Gyttja seam dips 5-10º towards SE with an average thickness of about is 40-50m.

It is interbedded in the main coal seam as a very thin layer. Above the main coal seam, gttja starts with Gyttja with coal, Gyttja with humus, Gyttja Clayey and Calcaceours Gyttja. Gyttja formations disappears toward the north and north east.

Hydrogeology of the Elbistan basin is very complex. To re-evaluate and verify the hydrogeological parameters, special pumping tests were realized in 57 different wells (main well and groundwater monitoring wells). According to the test results, there are 8 main aquifers, from top to bottom (MBEG, 2012):

- Gravel
- Clay
- Gyttja
- Gyttja with Coal
- Calcareous Gytta with Coal
- Coal
- Green Clay
- Limestone

Gyttja, Gyttja with Coal and Calcareous Gytta with Coal are very crucial aquifers for the basin. Water content of the gyttja series are very high, On the contrary, permeability of gyttja series is very low and water trapped locally in the pockets of gyttja behaves as a pressurized aquifer. The limestone acts as a confined aquifer and contains pressurized water.

3.1.2 Geotechnical Backround

The geotechnical model of the mine area was revised after the two catastrophic mass movements occurred in February 2011. In 2007 five geotechnical boreholes were drilled and 57 undisturbed samples using Shelby tubes were taken. Undisturbed sample were sent to soil mechanics laboratory of the METU. In 2011, 362 undisturbed samples using Shelby tubes were taken at 7 different locations and they were tested by METU Soil Mechanic Lab. The geotechnical parameters derived from this test campaign are listed in Table 1.

Material	Unit weight (kN/m³)	Cohesion c (kPa)	Internalfriction Angle ψ (deg)
Loam	17.6	31	21
Blue clay	18.1	33	23
Black clay *	19.2	6	26
Gyttja	15.4	23	32
Gyttja Coal	13.1	27	34
Calcareous Gyttja Coal	15.0	24	32
Lignite	12.4	36	28
Clay (interburden)*	15.9	9	12
Bottom clay	18.2	39	29
Landslide Material **	14.0	5	20

*the layers black clay and clay (interburden are the possible sliding surface in the geological model. For these layers. The resiudal shear strength has been used.
** Up to now. no soil-physical lab examinations have been carried out fort he landslide material. Therefore. theoretical assumptions have to implied for the first calculations stability.

Table 1. Principal geotechnical parameters.

3.2 Analysis of radar data

Shortly after the two mass movements of February 2011, a slope monitoring network was implemented to detect possible further slope movements.

The current mine monitoring system consists of two robotic total stations and one IBIS-M unit.

Total stations involve two reference locations and nine prisms.

Figure 2 shows the planimetric view of the pit with the locations of IBIS-M radar and total stations.

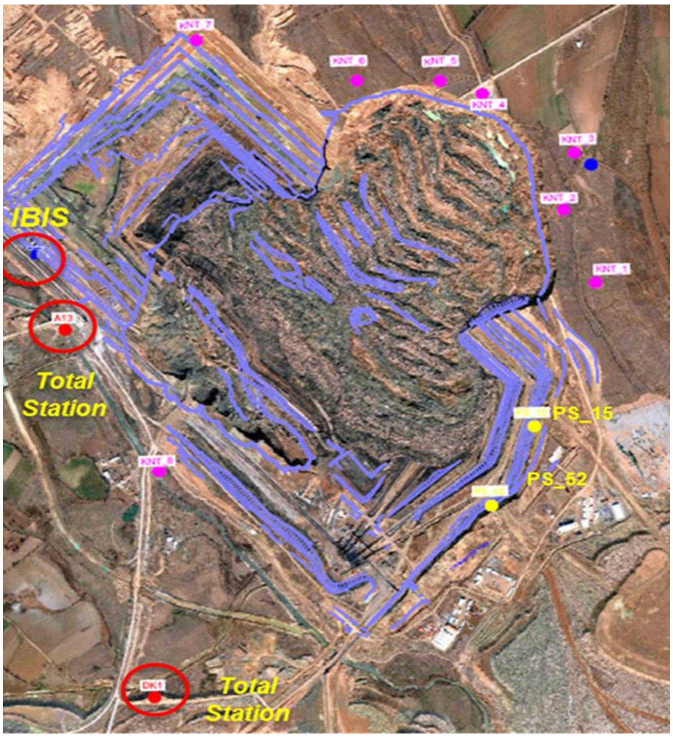


Figure 2. Planimetric view of Çollölar mine. IBIS-M wide coverage makes it possible to cover the entire area of interest from a permanent installation on the opposite side of the pit.

Robotic total stations, although one of the most diffuse monitoring tool for surface movements, present some limitations:

- Low accuracy of measurements (e.g. a tolerance of ±2cm at 1.000m measurements distance)
- Measurements affected by weather conditions (snowy, foggy days effects the measurements precision.)
- Not possible to measure movements in real-time necessary for critical monitoring.

These limitations are overcome by slope monitoring radar, which ensures sub-millimetric accuracy, operability under all weather conditions and real-time active monitoring with customizable alarming capabilities.

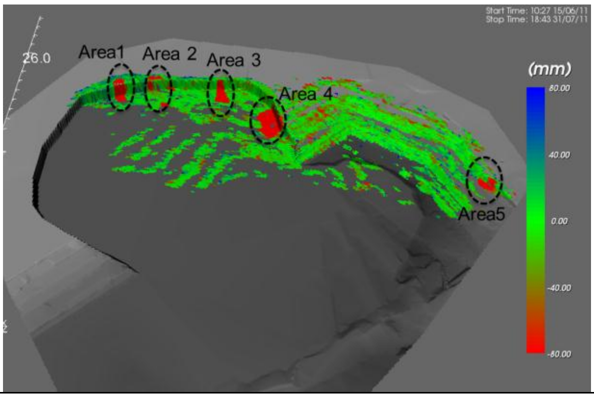
The broad area coverage makes it possible to monitor the pit wall from a semi-permanent installation on the opposite side of the pit, at a working distance of about 2 km (Fig. 3).

Figure 3. IBIS-M installation at Çollölar.

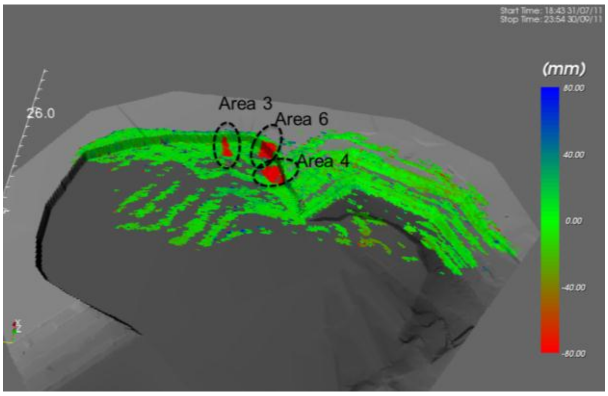
During the monitoring period June 2011-January 2012 IBIS-M was able to pick up several moving areas highlighted in Figure 5.

From radar data it is possible to observe a general stability of the pit with a few areas of localized movement. The most active areas have been Area 3, Area 4 and Area 6.

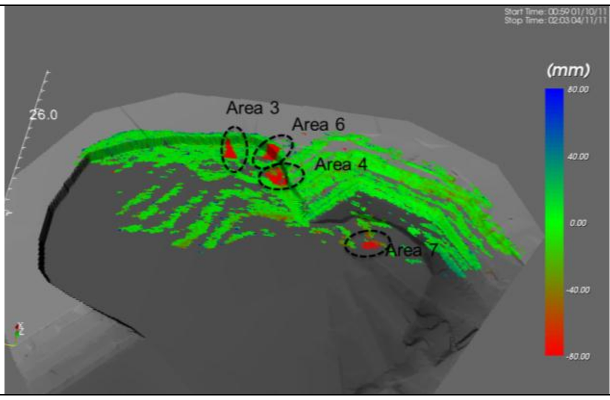
June 2011 – July 2011



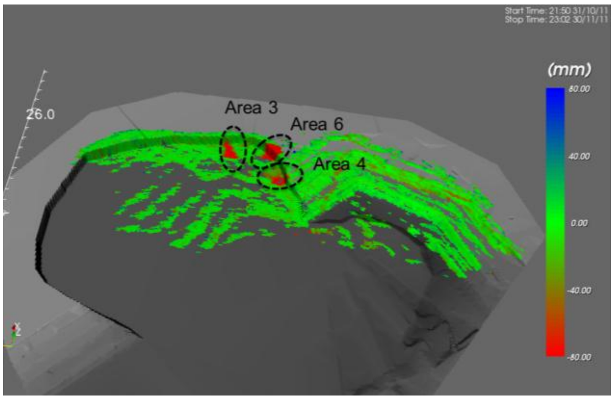
July 2011 – September 2011



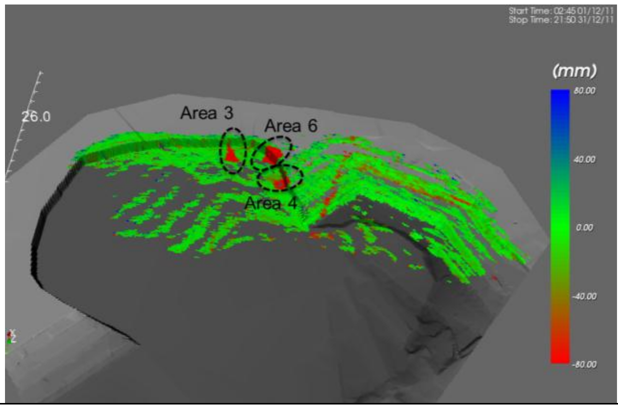
October 2011



November 2011



December 2011



January 2012

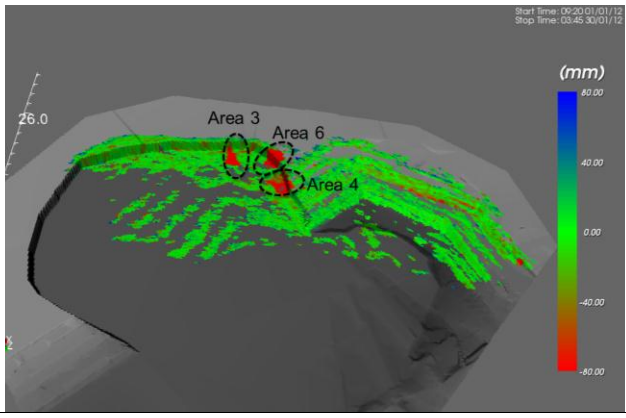


Figure 5. Monthly cumulative displacement radar maps covering the period from June 2011 to January 2012, highlighted in red the areas of movement.

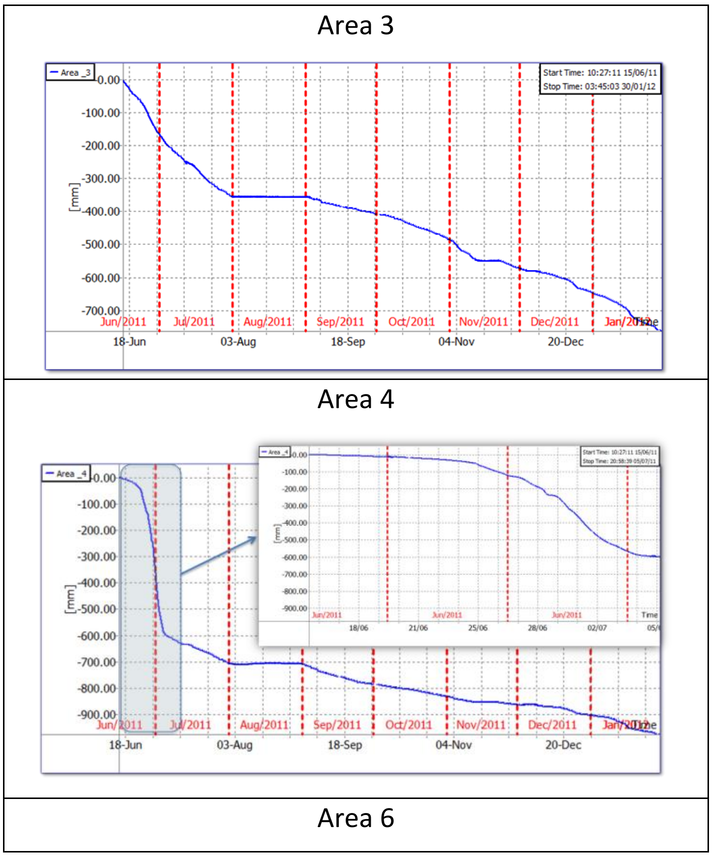
Area 3 and Area 4 show a similar behavior (Fig. 6): after an acceleration characterized by an important movement during June-July, the movement tends to slow down until January 2012 when the total cumulative displacement is about 1m.

On the contrary, Area 6 only activates in September 2011and rapidly moves with an accelerating trend until January 2012, with a total cumulative displacement that exceeds 2.4m.

These movements occurred as a consequence of the following factors:

- Bench height and steep bench angle consequence of the two landslides in February 2011 (bench height: 50m and bench angle close 90º).
- Presence of low-cohesion geological formations (such us gravel, loam)
- Bad weather conditions (rainy and snowy season)

Radar data show that during the monitored period only localized movements occurred and none of them led to large mass-movements as occurred in February 2011.



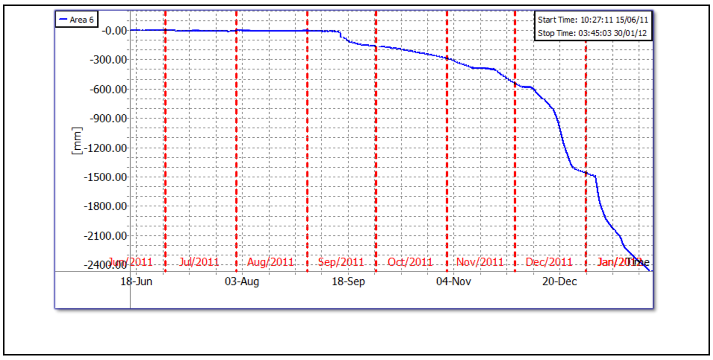


Figure 6. Displacement time series relative to Area 3, Area 4 and Area 6 over the period June 2011 – January 2012

In October 2011 small movements were detected by IBIS-M in landslide area of February 2011, were some search and rescue operations were undergoing. The use of the radar allowed the local staff to manage the risk associated to the rescue operations. In fact, according to the radar data, the rescue operations were stopped, some small tension cracks were subsequently observed in the field and the operations started again once the radar data showed a deceleration of the movements in that area..

4 FINAL REMARKS

Slope monitoring radar represents today a standard practice for real-time monitoring of slope displacements in open-pit mines. IBIS-M is based on the SAR technique that ensures the highest resolution and longest operating distance available today. By covering all the scales of slope potential instabilities, from bench scale in open-pit mines to overall slope instability, IBIS-M is the perfect tool for both active and background long-term monitoring.

Çollölar coal mine in Turkey has used IBIS-M as part of its pit monitoring system since 2011. IBIS-M has guaranteed 99% radar availability and was able to properly pick up several moving areas that showed different evolution during time. The full coverage allowed the geotechnical staff to accurately map the stability hazards and develop a production plan accordingly, thus maximizing production potential and increase safety standards.

REFERENCES

Antonello, G., Casagli, N., Farina, P., Leva, D., Nico, G., Sieber, A.J., Tarchi, D. 2004. *Ground based SAR interferometry for monitoring mass movements*. Landslides 1, pp. 21-28.

Bozzano, F., Mazzanti, P., Prestininzi, A. 2008. *A radar platform for continuous monitoring of a landslide interacting with a under-construction infrastructure*. Italian J. of Engineering Geology and Environment 2, pp. 35-50.

Corsini, A., P. Farina, G. Antonello, M. Barbieri, N. Casagli, F. Coren, L. Guerri, F. Ronchetti, P.Sterzai, and D. Tarchi. 2006. *Space-borne and ground-based SAR interferometry as tools for landslide hazard management in civil protection*. International Journal of Remote Sensing, 27, pp. 2351-2369.

Collolar Open Cast Mine Afşin-Elbistan Coal Basin, *Mine Plan for Restart of Coal Mining. (2012), MBEG*

Harris, N., Noon D., Rowley, R. 2006. *Case Study of Slope Stability Radar used in Open Cut Mine*, in Proc. of Int. Symp. on Stability of Rock Slopes in Open Pit Mining and Civil Eng., Cape Town, South Africa, 2006, pp. 335-342.

Read, J., Stacey, P. 2009. *Guidelines for Open Pit Slope Design*. CSIRO Publishing, Collingwood.

Rosen, P.A., Hensley, S., Joughin, I.R., Li F.K., Madsen, S.N., Rodriguez, E., R.M. *Goldstein 2000. Synthetic Aperture Radar Interferometry*. Proc. of the I.E.E.E. 88, pp. 333-382.

Ural, S., Y üksel, F., 2004. Geotechnical characterization of lignite-bearing horizons in the Afsin–Elbistan lignite basin, SE Turkey. Engineering Geology 75 (2), 129–146.

Yörükoğlu, M. (1991) Afşin-Elbistan Mining Project and Mining Activities at AELI Establishment of TKİ. Madencilik dergisi. Sayı 3. Pp. 13-29.