Efficient real-time stability monitoring of mine walls

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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 now has 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 article.

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 centimetres of total displacement and typically characterised 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 [1 – 4].

**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 characterised 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 km² 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 article 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 (Fig. 1).

Çöllolar Mine case study
Çöllolar Mine is a large coal mine, located in the Kahramanmaras district in Southern Turkey, to the North of the towns of Elbistan and Afsin and operated by Park Teknik (Fig. 2).

The box cut of mine is 2.3 km long 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. 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 more than 99% availability for around the clock active and background monitoring of the pit walls.

Geological and geotechnical background

According to Yörükoğlu [6] the Elbistan
Fig. 5: Planimetric view of Çollılar 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.

The geological map and stratigraphic sequence are shown in Fig. 4. Gyttja is the most important geological formation which is composed of gastropod fossils, plant residues and humus content. Gyttja seam dips 5 – 10° towards SE with an average thickness of about 40 – 50 m. It is interbedded in the main coal seam as a very thin layer. Above the main coal seam, gyttja starts with gyttja with coal, gyttja with humus, gyttja clayey and calcaceous gyttja. Gyttja formations disappear 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 realised in 57 different wells (main well and groundwater monitoring wells). According to the test results, there are eight main aquifers, from top to bottom [8]:

- Gravel
- Clay
- Gyttja
- Gyttja with coal
- Calcareous gyttja with coal
- Coal
- Green clay
- Limestone

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

Geotechnical backround

The geotechnical model of the mine area was revised after the Alpine Orogenic Phase. The base of the region is a permo-carboniferous 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 Fig. 4.

<table>
<thead>
<tr>
<th>Material</th>
<th>Unit weight (kN/m³)</th>
<th>Cohesion c (kPa)</th>
<th>Internal friction angle ψ (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loam</td>
<td>17.6</td>
<td>31</td>
<td>21</td>
</tr>
<tr>
<td>Blue clay</td>
<td>18.1</td>
<td>33</td>
<td>23</td>
</tr>
<tr>
<td>Black clay *</td>
<td>19.2</td>
<td>6</td>
<td>26</td>
</tr>
<tr>
<td>Gyttja</td>
<td>15.4</td>
<td>23</td>
<td>32</td>
</tr>
<tr>
<td>Gyttja coal</td>
<td>13.1</td>
<td>27</td>
<td>34</td>
</tr>
<tr>
<td>Calcareous gyttja coal</td>
<td>15.0</td>
<td>24</td>
<td>32</td>
</tr>
<tr>
<td>Lignite</td>
<td>12.4</td>
<td>36</td>
<td>28</td>
</tr>
<tr>
<td>Clay (interburden) *</td>
<td>15.9</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>Bottom clay</td>
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<td>39</td>
<td>29</td>
</tr>
<tr>
<td>Landslide material **</td>
<td>14.0</td>
<td>5</td>
<td>20</td>
</tr>
</tbody>
</table>

* The layers black clay and clay (interburden are the possible sliding surface in the geological model. For these layers, the residual shear strength has been used).

** Up to now, no soil-physical lab examinations have been carried out for the landslide material. Therefore, theoretical assumptions have to implied for the first calculations stability.

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Table 1: Geotechnical parameters.

The basin takes its name from the nearest Elbistan city. The Elbistan basin covers an area of 900 km² with a mean elevation of 1,200 m a.s.l. The Afşin Elbistan Lingite Field bed formed during the rise of Toros Mountains after
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 samples were sent to the soil mechanics laboratory of the METU. In 2011, 362 undisturbed samples using Shelby tubes were taken at seven different locations and they were tested by the METU Soil Mechanic Lab. The geotechnical parameters derived from this test campaign are listed in Table 1.

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. Fig. 5 shows the planimetric view of the pit with the locations of IBIS-M radar and total stations.

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

- Low accuracy of measurements (e.g. a tolerance of ±2 cm at 1,000 m measurements distance).
- Measurements affected by weather conditions (snowy, foggy days affect 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 customisable 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. 6).

During the monitoring period June 2011 – January 2012 IBIS-M was able to pick up several moving areas highlighted in Fig. 7.

From radar data it is possible to observe a general stability of the pit with a few areas of localised movement. The most active areas have been Area 3, Area 4 and Area 6. Area 3 and Area 4 show a similar behaviour (Fig. 8): after an acceleration characterised by an important movement during June-July, the movement tends to slow down until January 2012 when the total cumulative displacement is about 1 m.

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

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: 50 m and bench angle close 90°).
- 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 localised movements occurred and none of them led to large mass-movements as occurred in February 2011.

In October 2011 small movements were detected by IBIS-M in the landslide area of February 2011, where 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, due to the radar data, the rescue operations were stopped and some small tension cracks were subsequently observed in the field. The operations started again once the radar data showed a deceleration of the movements in that area.

**Final remarks**
Slope monitoring radar today represents 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.

Çöllölar coal mine in Turkey has used IBIS-M as part of its pit monitoring system since 2011. IBIS-M has guaranteed over 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 maximising production potential and increase safety standards.

**References**


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