Open-Pit "Filijala" Northwest Slope Stabilization
In Order to Reduce Damage Risk and Environmental Protection

Sanacija Severozapadne Kosine PK „Filijala“ u cilju
Smjena Oštećenja i Zaštite Okoline

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Abstract: The development of the marl exploitation in the open pit "Filijala" caused the instability appearance in northwest final slope area. The location of this part of the mine in relation to surrounding objects demanded stabilization of the slope in order to prevent further spread of damage. For these purposes, a detailed analysis of the current state of slope stability were carried out, which used as a basis for determining appropriate stabilization measures for the slope.

Key words: slope stability, stabilization, risk

1. INTRODUCTION

The cement marl deposit near Beočin is known as the "Filijala" since 1838. Exploitation of marl, as raw materials for cement production in cement factory is being done since way back in 1860. Marl deposit "Filijala" is divided into three exploitation area "Severno polje", "Medu polje" and "Južno polje". This deposit is located in the zone of village called Beočin selo from which it is about 1 km away and in the vicinity of the cement factory Lafarge BFC, from which it is about 2.5 km away "by air" and about 4 km away by asphalt road. From the Beočin it is located about 1.5 km away (Figure 1). The "Filijala" marl deposit covers the area of 792,563 m².

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Today, the exploitation process at open pit "Filijala" is carried out by the continuous technology, using bucket wheel excavator, which requires excavation front layout as long as possible without significant changes in route directions, in order to minimize the belt conveyor transfer. Due to deposit conditions, especially for the quality of marl, the continuous technology can not be applied exclusively, but the discontinuous exploitation technology is also used. Discontinuous technology is designed for excavating parts of deposits that can not be excavated by the bucket wheel excavator, as well as the simultaneous mining with both technologies to homogenize excavated marl quality.

2. SLOPE INSTABILITY APPEARANCE

![Figure 1 - The geographical position of marl deposits "Filijala"](image1.png)

![Figure 2 - Direction (—) of appearance of northwestern final slope instability](image2.png)

![Figure 3 - Marl complex deformations - movements at floor of the open pit (elevation 120)](image3.png)
Instability of the northwestern slope was observed with progress of work on the excavation of marl in the open pit "Filijala". In the field these changes are manifested in deformations - marl complex movements at the bottom of the open-pit at a level of 120 m in this zone, Figures 2 and 3. Open pit mine in this area has come to its exploitation boundaries in the plan, while it was scheduled in the vertical to reach the altitude 80 m.

In the specified area of the open pit a geological heritage was recorded, with the best development of Pannonian period (Figure 4). For the above reasons, the Institute for Nature Conservation of Serbia passed a decision in which the northwestern part of deposit "Filijala" in mining area "Severno polje" with area of 24,720 m² in was excluded.

This paper aims to present a procedure for stabilization of the unstable northwest slope of the open pit by taking into account the position of the excluded part of the deposit (geological heritage) and the proximity of the village. Stabilization of unstable slopes is carried out in order to reduce the risk of spreading the damage (deformation) and thus protect the nearby and wider area of the open pit "Filijala" and provide continuation of exploitation process.

3. RESEARCH FOR SLOPE STABILIZATION

The analysis of existing technical documentation for "Filijala" marl deposit determined that on the basis of available geomechnical data it is not possible to verify stability of the northern part of the open pit (Figure 6). For these reasons, additional research was conducted in order to determine detailed geological structure of this part of the deposit, and to supplement the necessary geotechnical data of the characteristical lithological units. This research covers the drilling of five exploration boreholes, which are shown in Table 1, detailed geological and geomechanical mapping of core drilling was carried out, hydrogeological testing, sampling and geomechanical laboratory testing (Gojković and Čebašek, 2007a).
4. SLOPE STABILITY ANALYSIS

In order to carry out the stabilization of northwest slope of the open pit, stability analysis of the current situation of the final slope in this area was performed. Based on this analysis the danger of appearance an spreading of slope instability was pointed out. After that, the impact of proposed measures for stabilization by constructing counterweight embankment in the lower part of the final slopes was analysed. Detailed calculations and slope stability analysis of the final slope in the northwestern area of the open pit "Filijala" were carried out on three geological-technological sections labeled as A - A', B - B' and C - C', and the position of these sections is shown in Figure 7.

Sections that were analyzed consisting of marl complex, alluvial-polluvial complex and loess deposits, Figures 8, 9 and 10. There are three faults in each section, in a slope toe, at the slope head and the third is located behind the top of slope and below the incline called "Oštra glavica". The geometry of the slope of individual sections is shown in Table 2 Taking into account the geological structure and the geometry of the slope stability for further calculations the finite element method was adopted (www.rocscience.com, 2001-2004; www.rocscience.com, 2005).

Table 1 - Overview of exploration boreholes in the area North slope of open pit "Filijala"

<table>
<thead>
<tr>
<th>Borehole</th>
<th>Borehole depth</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>B - 1/07</td>
<td>83.50</td>
<td>7</td>
</tr>
<tr>
<td>B - 2/07</td>
<td>110.00</td>
<td>7</td>
</tr>
<tr>
<td>B - 3/07</td>
<td>92.00</td>
<td>6</td>
</tr>
<tr>
<td>B - 4/07</td>
<td>37.00</td>
<td>5</td>
</tr>
<tr>
<td>B - 5/07</td>
<td>37.00</td>
<td>5</td>
</tr>
</tbody>
</table>

Figure 6 - North slope of open pit "Filijala" in which area additional research and slope stability analyses were conducted.
Figure 7 - North slope of open pit "Filijala" with position of geological-technological sections A - A’, B - B’ i C - C’

Figure 8 - North appearance of section A - A’

Figure 9 - North appearance of section B - B’
Parameters for further slope stability calculations were adopted according to the analysis of the results of geomechanical laboratory tests and performed statistical calculations for individual lithological units. These parameters were determined with 95% confidence, and are presented in Table 3. Values of angle of internal friction $\phi$ and cohesion $c$ for marl complex were determined using the Hoek-Brown’s failure criterion. For this purpose the software package RocLab - Rocscience Inc. 1.031 (freeware version) was used (Gojković and Čebašek, 2007b).

**Table 3 - Calculation parameters for each lithological unit determined by statistical calculations**

<table>
<thead>
<tr>
<th>Material</th>
<th>GSI</th>
<th>$m_i$</th>
<th>$D$</th>
<th>Unit weight $\gamma$ [kN/m$^3$]</th>
<th>Internal friction angle $\phi$ [$^\circ$]</th>
<th>Cohesion $c$ [kPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marl complex</td>
<td>40</td>
<td>7</td>
<td>0.7</td>
<td>18.55</td>
<td>18.51</td>
<td>63</td>
</tr>
<tr>
<td>Alluvial-prollevial complex</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>19.20</td>
<td>28</td>
<td>1.45</td>
</tr>
<tr>
<td>Loess deposits</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>20.00</td>
<td>19.35</td>
<td>12.69</td>
</tr>
<tr>
<td>Waste rock material</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>20.00</td>
<td>19.24</td>
<td>11.99</td>
</tr>
<tr>
<td>Counterweigh embankment</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>13.33</td>
<td>19.24</td>
<td>11.99</td>
</tr>
</tbody>
</table>

Stability analysis of the current state of final slopes in this part are defined safety factors which amounted to $F_s = 0.94$ (section A - A’), $F_s = 0.84$ (section B - B’) and $F_s = 0.90$ (section C - C’). The analysis of the distribution of maximum shear strain...
(Figures 11, 12 and 13) shows that the maximum concentration is in the zone immediately below the toe of slope, which is fully consistent with the deformations that were observed at the bottom of the open pit during the field observation. Based on these results it was concluded that it is necessary to carry out stabilization of the final slope in this area.

**Figure 11** - Section A - A’ slope stability analyses results with the distribution of maximum shear strain (potential slide plane)

**Figure 12** - Section B - B’ slope stability analyses results with the distribution of maximum shear strain (potential slide plane)
5. SLOPE STABILIZATION

Stabilization of this part of the final slope is only a possible by change of slope geometry. Using other measures for stabilization, such as drainage and rock bolting was not possible because in this area of the open pit there is geological heritage, and application of technological measures was not the matter of subject because it was a final slope. In this case the construction of the counterweight embankment in toe part of the slope has been applied as stabilization measure and removing earth material at the top of the slope was not possible because of the position of the zone of geological heritage, the configuration of the surrounding terrain and proximity to surrounding neighborhoods. construction of the counterweight embankment in toe part of slope prevents any new rock mass movements and provide a satisfactory safety factor $F_s \geq 1.30$. In this way the environment and the nearest point of the settlements Beocin and Beocin Selo are protected, as well as the safety and secure movement of people and machinery that work in the open pit "Filijala" are provided.

Constructing the counterweight embankments in toe part of the slope as stabilization measures increases the stability of the whole slope, and increases the stability of the open pit floor. Should the counterweight embankment had an impact on the stability of the slope his height has to be (Gojković et al. 2004; Maksimović 2005):

$$H_e = \left( \frac{1}{3} + \frac{1}{2} \right) \cdot H = \left( \frac{1}{3} + \frac{1}{2} \right) \cdot 53.26 \approx 17.7 \div 26.6 \text{ m}$$

where is:
- $H_e$ - embankment height in the toe part of slope [m],
- $H$ - stabilized slope height [m], $H = 53.16$ m.

In the previous part of this paper (Table 2) was indicated that the final slopes height in the northwestern part of the open pit "Filijala" is $H = 53.16$ m, and the...
required height of the counterweight embankment ranges from 17.7 m to 26.6 m. For further analysis of the possibility of slope stabilization in this area, as well for stability calculations it is assumed that the counterweight embankment height is $H_n = 20$ m, and the angle of the embankment slope is $\alpha_n = 25^\circ$. Embankment is about 110 m long and 162 m wide, and at the top it is 103 m wide and it is formed from 120 m to 140 m elevation. Groundwater level in the slope body is at elevation of 148 m. Appearance of the counterweight embankment in toe part of slope is given in Figures 14, 15 and 16.

Figure 14 - Appearance of section A - A' with applied slope stabilization measures

Figure 15 - Appearance of section B - B' with applied slope stabilization measures
Final slope stability analysis with applied stabilization measures by constructing the counterweight embankments in toe part of the slope in this part have defined the safety factors which amounted \( F_s = 1.38 \) (section A - A'), \( F_s = 1.32 \) (section B - B') and \( F_s = 1.39 \) (section C - C'). The analysis of the distribution of maximum shear strain (Figures 17, 18 and 19) shows that the maximum concentration is in the zone below the toe of embankment slope, which is fully consistent with the required minimum value of safety factor \( F_{s,\text{min}} = 1.30 \). Here it should be noted that the potential slide plane with a minimum safety factor of slopes in all analyzed sections with applied stabilization measures is located in the zone of the embankment slope. This indicates that the overall slope with applied stabilization measures safety factor is greater.
Open-pit "Filijala" northwest slope stabilization ...

Figure 18 - Section B - B' slope stability analyses results with the distribution of maximum shear strain (potential slide plane)

Figure 19 - Section C - C' slope stability analyses results with the distribution of maximum shear strain (potential slide plane)

Table 4 - Overview of slope geometry with slope stability analyses results using finite element method

<table>
<thead>
<tr>
<th>Section</th>
<th>State of slope</th>
<th>Slope height $H$ [m]</th>
<th>Slope angle $\alpha$ [$^\circ$]</th>
<th>Safety factor $F_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A - A'</td>
<td>The current state</td>
<td>51.10</td>
<td>24</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>With counterweight embankment</td>
<td>52.56</td>
<td>19</td>
<td>1.38</td>
</tr>
<tr>
<td>B - B'</td>
<td>The current state</td>
<td>53.16</td>
<td>26</td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td>With counterweight embankment</td>
<td>52.56</td>
<td>19</td>
<td>1.32</td>
</tr>
<tr>
<td>C - C'</td>
<td>The current state</td>
<td>48.30</td>
<td>23</td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td>With counterweight embankment</td>
<td>52.56</td>
<td>19</td>
<td>1.39</td>
</tr>
</tbody>
</table>
Based on these applied stabilization measures on the sections A - A', B - B' and C - C' in the northwest slope area of the open pit "Filijala" the counterweight embankment has been constructed in the toe part of slope. Construction of the embankment covered a broader area of the final slope, which has increased overall stability of the slope to the value of the safety factor ($F_s \geq 1.30$) which is issued by the law, Figure 20.

![Figure 20 - Appearance of counterweight embankment in northwestern slope area at open pit "Filijala"](image)

6. CONCLUSION

The development of the marl exploitation in the open pit "Filijala" caused the instability appearance in northwest final slope area. The stability analysis of this zone of slope showed that the value of the safety factor $F_s$ is somewhere in between $F_s = 0.84$ to $0.94$, and that it is necessary to stabilize the slope. Subject to the preceding, and taking into account the position of the slope (near the location of geological heritage) and its environment (close settlements Beočin and Beočin Selo), an analysis of the possibilities of slope stabilization by constructing the counterweight embankment in the toe part of slope was carried out. Embankment provided the complete stability of the entire slope with the values of the safety factor $F_s = 1.32$ to $1.38$. Based on the performed calculations and analysis the embankment was constructed in this area of the open pit, covering the greater part of that which is shown in the proposed stabilization measures. In this way the safety factor was further increased, reducing the risk of the spread of damage and thus protecting environment and facilities.

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REFERENCES


