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# COMPARATIVE ANALYSIS OF THE STABILITY OF A FLOTATION TAILINGS DAM BEFORE AND AFTER REHABILITATION

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## Abstract

*The stability of flotation tailings dams represents one of the most important factors in the safe management of mining waste. This paper presents a comparative analysis of the stability of a flotation tailings dam before and after rehabilitation, with the aim of assessing the effectiveness of the applied rehabilitation measures. The analysis was performed using the limit equilibrium method, considering characteristic cross-sections and the corresponding geotechnical parameters. By comparing the results obtained for the pre- and post-rehabilitation conditions, changes in the factor of safety were assessed and the influence of the rehabilitation measures on the overall stability of the structure was determined. The results indicate that the applied measures significantly increase the factor of safety and contribute to an improvement in the overall stability of the dam. The obtained results confirm the importance of detailed geotechnical analysis in the design and rehabilitation of flotation tailings dams and may serve as a basis for improving geotechnical risk management.*

***Keywords:*** *flotation tailings facility, stability, design, dam stability, risk management, monitoring*

## 1. INTRODUCTION

The stability of flotation tailings dams represents one of the fundamental safety criteria for these structures, considering their specific geotechnical conditions, changes in the stress–strain state during operation, and the influence of water within the dam body and its foundation. Changes in water levels, the development of pore water pressures, the properties of the construction materials, as well as seismic loading can significantly affect slope stability and the overall behaviour of the dam [1,5].

The stability assessment of flotation tailings facilities is most commonly based on the analysis of potential slip surfaces and the determination of the factor of safety for different design conditions. Particular importance is given to the analysis of dynamic, i.e., seismic conditions, since earthquake loading may lead to a reduction in the available shear strength and the development of unfavourable stability conditions. When the analysis of the existing condition indicates unsatisfactory factor-of-safety values,

appropriate rehabilitation measures must be defined to increase the resistance of the structure to sliding [2].

One of the solutions for improving slope stability is the application of geosynthetic materials, namely geogrids and geocomposites, which form an additional reinforcement system within the structure. Their effect is reflected in increasing the resistance along the potential slip surface and achieving a more favourable distribution of forces within the slope zone [3,7,8]. The effectiveness of such a solution should be verified through an appropriate stability analysis before and after rehabilitation. The aim of this paper is to present a comparative analysis of the stability of a flotation tailings dam before and after the rehabilitation of critical sections. The analysis was performed for characteristic dam cross-sections, with particular consideration given to sections exhibiting unfavourable factors of safety under dynamic design conditions. Rehabilitation was carried out using geocomposite materials and geogrids installed at a vertical spacing of 2.5 m. The effectiveness of the applied rehabilitation solution was assessed by comparing the obtained factors of safety for static and dynamic design conditions before and after rehabilitation.

## 2. DESCRIPTION OF THE ANALYZED STRUCTURE AND METHODOLOGY

The analysis included the Valja Fundata flotation tailings facility, with the subject of consideration being the dam corresponding to the relevant cross-section, i.e., the analysed transverse dam profile. The dam crest is located at an elevation of 545 m a.s.l. The dam geometry is defined by an outer slope inclination of 1:3, while the inclination of the inner slope, facing the tailings impoundment, is 1:2. This geometry represents the basis for the stability analysis and assessment of the dam behaviour under existing conditions.

The stability analysis was performed using the Rocscience Slide software package, applying the Janbu method for determining the factor of safety of potential slip surfaces. The calculations included conditions relevant to the assessment of dam slope stability, with particular attention given to the influence of water within the dam body and the seepage regime [1,4].

The calculation results indicated that satisfactory stability conditions were not achieved in certain sections of the analysed slope. The significance of these results is particularly reflected in their correlation with the actual field conditions. Namely, seepage water, i.e., the emergence of water through the dam body and slope, was observed precisely in the sections where the analysis indicated potential instability. The presence of water has an additional adverse effect on the stress state within the material, increases pore water pressures, and may lead to a reduction in effective stresses and, consequently, in the available shear strength [5,6].

Effects of surface erosion caused by wind action were also observed on the outer dam slope. The erosion processes resulted in localized degradation of the surface slope layer and may represent an additional adverse factor with regard to the long-term stability of the structure. The observed correspondence between the numerical analysis results and the characteristic field conditions highlights the importance of geotechnical calculations as a basis for identifying critical zones and defining appropriate rehabilitation and protection measures.

In this way, the analysis methodology is not limited solely to determining the factor of safety, but also enables the correlation of calculation results with the actual condition of the structure. This is of particular importance when assessing the stability of existing tailings facilities and planning measures for their safe continued operation.

## 3. RESULTS OF THE ANALYSIS AND OBSERVED DAMAGE MECHANISMS

The results of the stability analysis performed for the dam at the Valja Fundata flotation tailings facility showed that slope stability is not uniform along the entire analysed profile. In certain sections of the slope, the calculations identified zones with less favourable stability conditions, i.e., potential slip surfaces indicating the possibility of localized instability. The obtained results indicate that, when assessing the stability of an existing tailings facility, the slope geometry alone cannot be considered; it is also necessary to take into account the condition of the materials, the presence of water, and the processes occurring on the slope surface.

The presence of water within the dam body and on the dam slopes represents a particularly significant factor. In the sections where reduced stability was identified by numerical analysis, seepage water was also observed in the field. The emergence of water through the dam body and on its slope represents an unfavourable indicator of the condition of the structure, as it may result from the development of seepage paths through the embankment. An increase in water content and pore water pressures leads to a reduction in effective stresses within the material, thereby reducing the available shear strength and, consequently, the factor of safety of the slope [1,5].

A correlation was also observed between the occurrence of seepage water and localized zones of reduced stability, confirming the importance of properly assessing hydrogeological and seepage conditions when evaluating existing tailings facilities. The presence of water does not necessarily cause sliding directly; however, prolonged seepage may lead to changes in the physical and mechanical properties of the materials, internal erosion of the embankment, and the gradual development of unfavourable zones within the dam body.

In addition to the influence of water, pronounced effects of surface erosion caused by wind action were observed on the outer slope. Erosion resulted in localized displacement and degradation of the surface slope material, thereby altering the original geometry and surface protection of the embankment. Although this is primarily a surface process, its long-term action may contribute to the progressive deterioration of the slope condition, particularly in zones already weakened by the presence of water or unfavourable stability conditions.

The results of the analysis and field observations indicate the interaction of several adverse factors, including slope geometry, water seepage, reduction in effective stresses, and surface erosion. Their simultaneous action may lead to the progressive development of damage and a reduction in the safety of the structure. Therefore, for existing flotation tailings facilities, stability assessment should not be based exclusively on numerical calculation results; these results should also be compared with findings from visual inspections and field condition monitoring.

In the specific case considered, the correspondence between the zones where the analysis indicated unfavourable stability conditions and the zones where seepage water was observed represents a significant indicator of the actual behaviour of the structure.

At the same time, the presence of erosion processes indicates the need to implement appropriate rehabilitation and slope protection measures, with the aim of preventing further deterioration and ensuring the long-term stability of the dam.

### 3.1. Rehabilitation Measures and Their Effect on Stability

Based on the results of the stability analysis and the field observations, the rehabilitation measures were focused on improving the stability of critical sections of the slopes and limiting the adverse effects of water and surface erosion. Following the implementation of the rehabilitation measures, a new stability analysis was performed for the same profiles, while the same calculation criteria and the Janbu method implemented in the Slide software were retained [7,8], in order to ensure comparability of the results obtained before and after rehabilitation (Table 1).

**Table 1.** *Comparative analysis of the dam at the Valja Fundata flotation tailings facility before and after rehabilitation*

| Profile | Static FoS – Before | Static FoS – After | Dynamic FoS – Before | Dynamic FoS – After |
|---|---|---|---|---|
| **1–1'** | 1,679 | **1,783** | 1,133 | **1,100** |
| **2–2'** | 1,694 | 1,694 | 1,188 | 1,188 |
| **3–3'** | 1,511 | **1,556** | 0,851 | **1,125** |
| **4–4'** | 1,351 | 1,351 | 0,797 | **1,008** |
| **4A–4A'** | 1,249 | **1,563** | 0,839 | **1,201** |
| **5–5'** | 1,482 | 1,482 | 0,964 | **1,097** |
| **6–6'** | 1,925 | 1,925 | 1,079 | 1,079 |
| **6A–6A'** | 1,629 | 1,629 | 1,024 | 1,024 |
| **6B–6B'** | 1,555 | 1,555 | 1,002 | 1,002 |
| **ŠP 2–2'** | 1,964 | 1,964 | 1,382 | 1,382 |

The results show that the greatest improvement was achieved under dynamic conditions, particularly for Profiles 3–3', 4–4', and 4A–4A'. For Profile 3–3', the factor of safety increased from 0.851 to 1.125, while for Profile 4–4' it increased from 0.797 to 1.008. The most pronounced improvement was recorded for Profile 4A–4A', where the dynamic factor of safety increased from 0.839 to 1.201, corresponding to an increase of approximately 43%.

Under static conditions, an increase in the factor of safety was also observed for certain profiles. The greatest change was achieved for Profile 4A–4A', where the factor of safety increased from 1.249 to 1.563, corresponding to an increase of approximately 25%. For Profiles 2–2', 4–4', 5–5', 6–6', 6A–6A', 6B–6B', and SP 2–2', the factor-of-safety values remained unchanged, indicating that the rehabilitation measures did not have a significant effect on the stability of these cross-sections, i.e., no substantial modification of the analysed geometry or conditions was required in these sections.

It is particularly significant that, following rehabilitation, the dynamic factor-of-safety values for the critical profiles reached or exceeded 1.0, whereas before rehabilitation they were below this value for Profiles 3–3', 4–4', and 4A–4A' (Figure 1). This confirms the positive effect of the applied rehabilitation measures on the overall stability of the analysed sections of the dam.

**Table 2.** *Comparative results of the stability analysis before and after rehabilitation*

| Profile | Static FoS – Before | Static FoS – After | % | Dynamic FoS – Before | Dynamic FoS – After | % |
|---|---|---|---|---|---|---|
| **1–1'** | 1,679 | **1,783** | +6,2 % | 1,133 | **1,133** | **2,9 %** |
| **2–2'** | 1,694 | 1,694 | 0,0 % | 1,188 | 1,188 | 0,0 % |
| **3–3'** | 1,511 | **1,556** | +3,0 % | 0,851 | **1,125** | **+32,2 %** |
| **4–4'** | 1,351 | 1,351 | 0,0 % | 0,797 | **1,008** | **+26,5 %** |
| **4A–4A'** | 1,249 | **1,563** | **+25,1 %** | 0,839 | **1,201** | **+43,1 %** |
| **5–5'** | 1,482 | 1,482 | 0,0 % | 0,964 | **1,097** | **+13,8 %** |
| **6–6'** | 1,925 | 1,925 | 0,0 % | 1,079 | 1,079 | 0,0 % |
| **6A–6A'** | 1,629 | 1,629 | 0,0 % | 1,024 | 1,024 | 0,0 % |
| **6B–6B'** | 1,555 | 1,555 | 0,0 % | 1,002 | 1,002 | 0,0 % |
| **ŠP 2–2'** | 1,964 | 1,964 | 0,0 % | 1,382 | 1,382 | 0,0 % |

The most important conclusion from the table is that the rehabilitation measures had the greatest effect on the dynamic stability of the critical profiles. Profile 4A–4A' showed the greatest overall improvement, with an increase in the dynamic factor of safety of 43.1%.

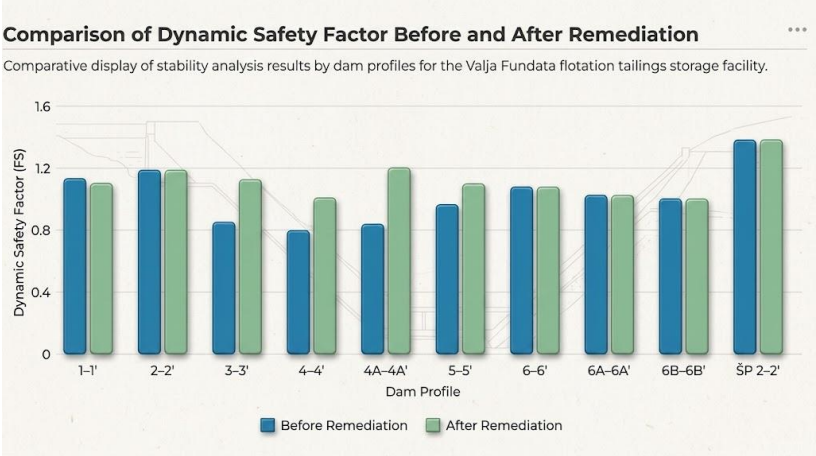



**Figure 1.** *Comparative presentation of the dynamic factor of safety for the analysed profiles before and after rehabilitation*

## CONCLUSION

The numerical stability analysis of the dam showed that the critical slip zones were predominantly formed in sections of the structure where unfavourable field conditions had been observed, primarily the occurrence of seepage water and localized erosion. The obtained results indicate a pronounced relationship between the hydrogeological conditions, the condition of the structure, and the overall stability of the dam, confirming the importance of detailed geotechnical analysis in assessing its actual condition.

The analysis of the characteristic profiles showed that the factors of safety before rehabilitation were less favourable, particularly under dynamic conditions. Following the implementation of the planned rehabilitation measures, which included the installation of

geocomposite materials and geogrids in a regular arrangement, an increase in the factor of safety was achieved for the analysed critical profiles. The most pronounced improvement was recorded precisely in the profiles that exhibited the most unfavourable conditions before rehabilitation.

The obtained results confirm the justification of the applied rehabilitation approach and indicate that the combination of geotechnical analysis, identification of critical zones, and application of appropriate geosynthetic materials can significantly contribute to increasing the stability and reliability of the structure. Of particular importance is the fact that the numerical model results correlate with the field observations, confirming the potential of numerical analyses as a reliable tool for defining and verifying rehabilitation measures.

For structures of this type, which are exposed during operation to changes in geometry, seepage conditions, and the characteristics of the incorporated materials, continuous monitoring of the structure's behaviour and periodic updating of geotechnical analyses are essential. In this way, potential zones of instability can be identified in a timely manner and appropriate measures can be undertaken to maintain the long-term safety of the dam.

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