# Stress-strain and stability analysis of tailing dam Toranica – Kriva Palanka

## Analyse de contrainte-tension et de stabilité du barrage de produit de queue Toranica - Kriva Palanka

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ABSTRACT

This paper deals with stress-strain and stability analysis of tailing dam Toranica – Kriva Palanka for specific stages of construction. In the technological concept of the mine for lead and zinc Toranica - Kriva Palanka (north-east of Republic of Macedonia), a tailing dam for disposal of flotation barren soil which remains after the processing of the mine material had been constructed. This tailing dam exists in the past 20 years. On the upstream side there is an embankment retention dam for diversion of river Kriva Reka into drainage tunnel. The tailing dam is on the down stream side made by fine sand and silt as products of flotation process.

The works in the mine Toranica had been stopped for some years. Stress-strain and stability analysis has been made for the existing conditions of the tailing dam and for the design conditions with upgrading of the tailing dam. The crucial parameter was defining of the need of the drainage carpet to the toe of the down stream slope of tailing dam. The calculations have been carried out by finite element method using geotechnical software package PLAXIS and by limit equilibrium method using software package GGU Stability.

RÉSUMÉ

Ce document traite l'analyse de contrainte-tension et de stabilité du barrage de produit de queue Toranica - Kriva Palanka pour les étapes spécifiques de la construction. Dans le concept technologique de la mine pour le fil et le zinc Toranica - Kriva Palanka (nord-est de la République de Macédoine), un barrage de produit de queue pour la disposition du sol stérile de flottaison qui reste après que le traitement du matériel de mine ait été construit. Ce barrage de produit de queue existe pendant les dernières 20 années. Du côté en amont, il y a un barrage en remblai pour la déviation du fleuve Kriva Reka dans le tunnel de drainage. En aval, le barrage de produit de queue est composé du sable, vase fine et des produits du processus de flottaison.

Les travaux dans la mine Toranica avaient été arrêtés pendant quelques années. L'analyse de contrainte-tension et de stabilité concerne les conditions existantes du barrage de produit de queue et les conditions de conception avec développement du barrage de produit de queue. Le paramètre crucial était la définition du besoin du tapis de drainage au point le plus bas de la pente en aval du barrage de produit de queue. Les calculs ont été effectués par la méthode d'élément fini utilisant le progiciel géotechnique PLAXIS et par la méthode d'équilibre de limite utilisant le progiciel GGU Stability.

Keywords : tailing dam, stability analysis, drainage, FEM.

## 1 INTRODUCTION

In the technological conception of the mine for lead and zinc "Toranica" - Kriva Palanka, hydro tailing dam is performed for disposal of flotation barren soil which stays after processing of the ore. The location of the hydro tailing dam is in the valley of Kriva river, on the space between the profile "Varosani" and "Cepen kamen" which is placed next to the flowing of river Toranica into Kriva River. On the upstream side is fenced with embankment retention dam for transferring of the water from Kriva River into outlet tunnel, and on the downstream side is made sandy dam from material gotten from hydro cycling of the pulp. Having in mind that the tailing material is reaching the deposition place as pulp (fluid with water, sand and mud) the space between tailing and retention dam presents landfill for sedimentation of particles. Soil particles from the mud are falling to the bottom and clean water is on the surface part of the tailing lake. The final point of the pulp (fluid) transport is hydrocyclon which serves for separation of particles bigger than 0.074 mm. So called sand (particles bigger than 0.074 mm) is forming the body of the tailing dam and mud (particles smaller than 0.074 mm) is flowing into the tailing lake in the process of sedimentation. Clean surface water from the tailing lake is overflowing in the river through collector pipe.

Geotechnical investigations have been carried out for the part of drainage carpet location. Stress-strain conditions, filtration through tailing dam and stability analysis results will be presented in the paper as well as construction details for the drainage carpet for the case of upgrading the tailing dam. Monitoring program, use of geosynthetics and environmental aspects will be presented too.

## 2 DESCRIPTION AND CHARACTERISTIC OF THE OBJECTS

Objects that are in function of exploitation of the hydro tailing dam "Toranica" - Kriva Palanka are upstream retention dam, downstream sandy dam, outlet deviation tunnel and outlet overflowing collector.

The basic purpose of the upstream retention dam is transferring of the water from Kriva River through the outlet tunnel in order not to pass through the tailing dam, mitigation of the flooding wave in order to prevent the termination of the production process and forming of artificial barrier.

For construction of the tailing dam, on the downstream side of the profile, sandy dam was made from the barren soil which is brought by semiconductor to the place for depositing. Hydro cyclone are separating the sand fractions and the tiny ones, fractions smaller then 0.074 mm are going into the accumulation and the bigger ones like wet sand are deposited into the sandy dam.



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For creating the first accumulation, initial dam with height of 12 m with crest on the embankment on peak elevation 945.00 m asl was created. The volume of the retention dam is approximately 11.150 $m^3$ with material from the river alluvium of Kriva River with removing of bigger blocks and installation in layers with mechanical compacting. Central clay core has been constructed to provide impermeability of retention dam.

Figure 1. Downstream sandy dam

The transferring of the water from Kriva Reka was made through outlet deviation tunnel, which was placed on the left side of the valley of Kriva Reka.

Because the space of the tailing dam is constructed for depositing only of the hard phase of the pulp, separated and clear water from the tailing dam as well as the atmospheric water is transferring through the outlet collector. The outlet collector is with circle cross section with diameter of 800 mm, performed by reinforced concrete.

## 3 SITE AND LABORATORY INVESTIGATIONS

Site and laboratory investigation works are performed for providing geomechanical parameters for the strain-stress and stability analyses of the tailing dam "Toranica".

Six investigation wells with depth of 0.70 - 1.20 m are performed and it is concluded that up to the depth of 1.00 m on the middle of the tailing dam, on the place where previously the river bed of Kriva River was placed, appears a layer of silt gravel (alluvium), while on the hill sides silt gravel (diluvium) is appearing.

A number of samples were taken for the necessary laboratory testing in order to define geomechanical parameters.

## 4 METHODS OF ANALYZE

Taking in consideration the geomechanical parameters obtained by geomechanical investigations and laboratory tests, are adopted representative geomechanical parameters enclosed in the Table no. 1

Table no. 1

| | cohesion C [kPa] | Angle of internal rubbing φ [°] | Volume weight | | Modulus of compressibility | Coefficient of filtration |
|---|---|---|---|---|---|---|
| | | | γ [kN/m³] | γsat [kN/m³] | E (Mpa) | K(m/den) |
| Flotation mud | 0.00 | 15.00 | 14.10 | 15.40 | 2.70 | 0.012 |
| Sandy dam | 0.00 | 28.00 | 17.30 | 18.10 | 4.50 | 0.060 |
| Aluvium in river bed | 0.00 | 38.00 | 21.40 | / | 44.43 | 0.0864 |
| Decayed rock | 0.00 | 38.00 | 23.00 | / | 230000 | 0.250 |

For the most critical profile, with the adopted geomechanical parameters stress-strain analysis with the finite element method (FEM) and stability analysis with limit equilibrium method were carried out.

Finite element method analysis have been carried out by software package PLAXIS including stress-strain and filtration analysis.

For computer analysis of slope stability of the sandy dam software package GGU-Stability was used in accordance with the German standard DIN 4084.

## 5 ANALYZE OF RESULTS

### 5.1 *Stress-strain analyze with finite element method*

Stress-strain analysis of the hydro tailing dam in the mine Toranica, with finite element method with the software Plaxis was made for 2 characteristic cases: without drainage and with drainage.

With analyze of the condition for normal operation of the tailing dam without drainage, it was concluded that the filtration line is on the downstream too of the dam, which could cause potential instability and the factors of safety for certain sliding surfaces drops to the value of 1.0.

The analyze made for the designed conditions without drainage, presents that if the tailing dam works with full capacity, the water level inside will form a filtration line for stationary regime of work in the embankment sandy dam (appearance of water near the downstream too–Figure 2). Conducted filtration flows and piezometric line will appear at the slope which could cause washing of the tiny material from the slope close to the too of the embankment with local instability which can cause disturbing of the global stability of the sandy dam on longer period of time (Figure 4).

Two cases were analyzed for the condition of the hydro tailing dam with drainage in the middle lowest part (the part of the former river bed of Kriva reka). First case is during normal work of the tailing dam and the second case is if the collector is not in function, which will rise of the level up to the peak elevation 987.5 m asl. In both cases the drainage is in function, it decreases the piezometric line under the slope of the sandy dam for a distance that will disable the capillar raising and freezing of the water (Figure 3). The factors of safety of the global stability is higher than 1.5.

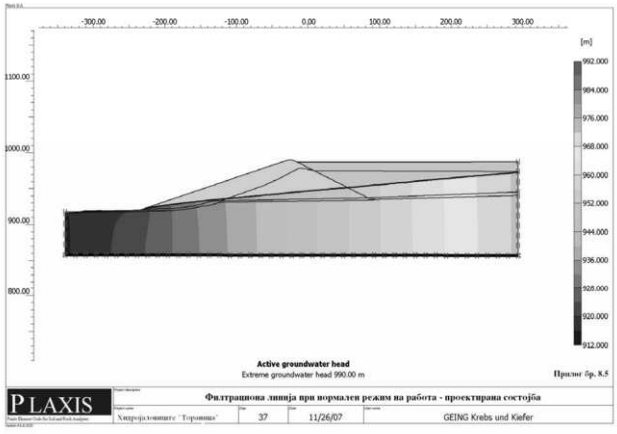


Figure 2. Filtration line during normal regime of work without drainage

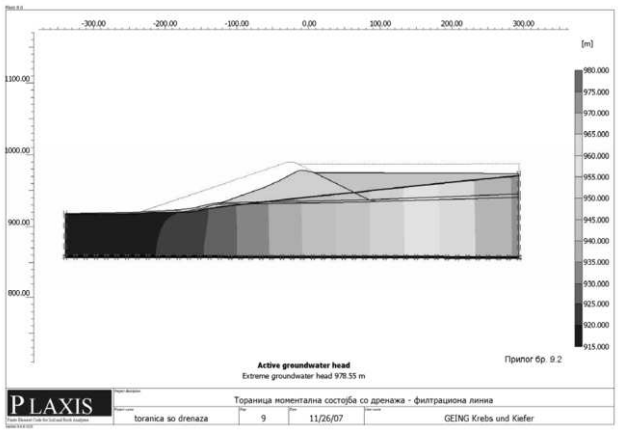


Figure 3. Filtration line during normal regime of work with drainage

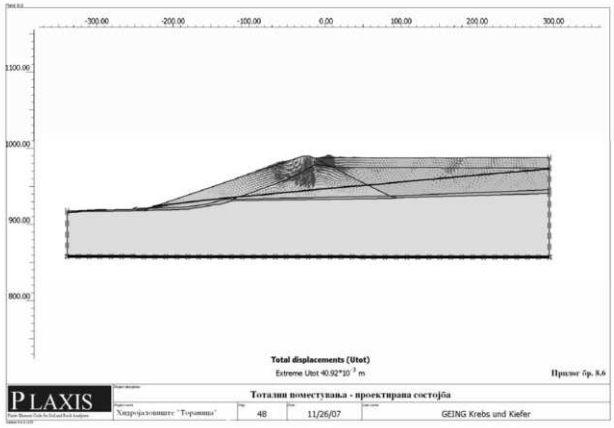


Figure 4. Total displacements - designed condition without drainage

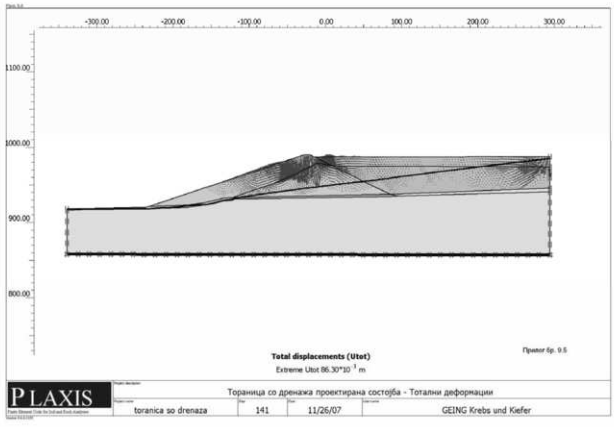


Figure 5. Total displacements - designed condition with drainage

The analyze made for the level of the water up to the peak elevation 987.5 m asl without drainage (case of termination of the collector work or appearance of upstream flooding wave) shows that the filtration line is appearing on the downstream slope of sandy dam (Figure 6), which could cause some instability problems as mentioned before for the case without drainage.

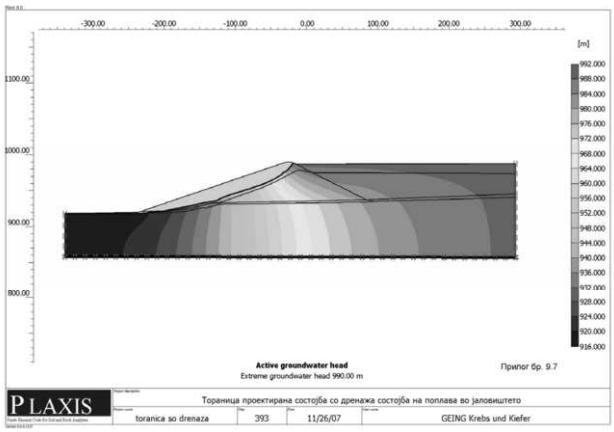


Figure 6. Designed condition with drainage for flooding of the tailing dam

## 5.2 *Slope stability analysis by limit equilibrium method*

The slope stability analysis of the sandy dam with the limit equilibrium method was carried out with the computer program GGU - Stability, with circle sliding surfaces with Bishop method. The slope stability analysis was consisted of determining of the global and local stability of the highest profile of the sandy dam for most unfavorable case of ground water (piezometric line).

With the slope stability analysis performed for the actual condition of the tailing dam with piezometric line adopted according to piezometers monitoring, the factor of global stability is Fs=1.54 (Figure 7), which is higher then the minimal allowed according to the regulations for this kind of slopes Fmin=1.3. It points out that the sandy dam in these conditions is stabile. It should be pointed out that during the analysis local shallow sliding surfaces are appearing on the slope of the sandy dam because of the variable inclination of the downstream slope, which could affect the global instability on long term.

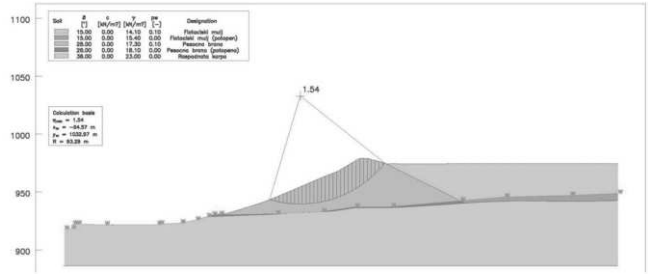


Figure 7. Global stability - present condition

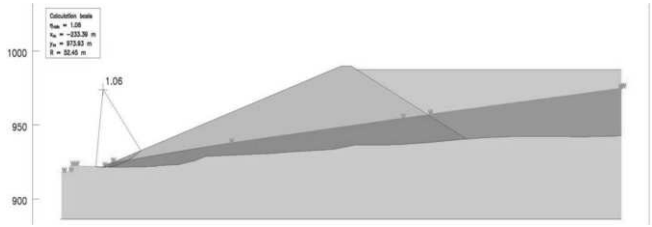


Figure 8. Designed condition without drainage

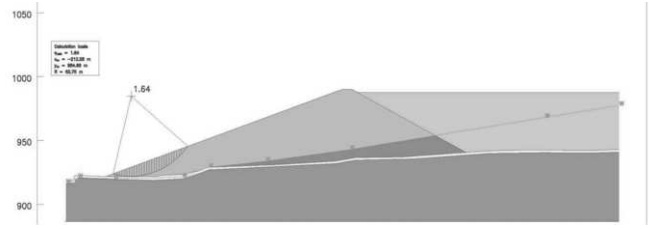


Figure 9 Designed condition with drainage

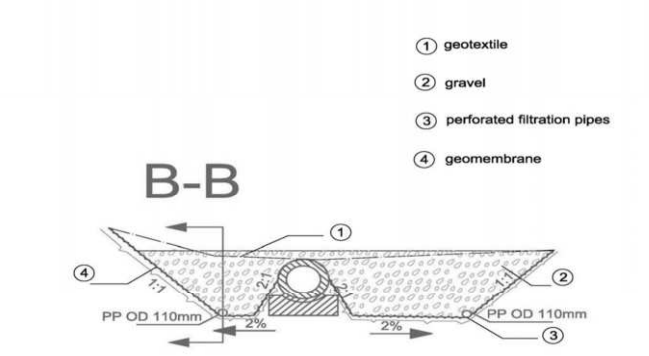


Figure 10. Detail of drainage blanket

## 6 CONCLUSIONS AND RECOMMENDATIONS

On the base of on the performed stress-strain and slope stability analysis of the sandy dam of tailing dam Toranica - Kriva Palanka, following conclusions and recommendations can be pointed out:

- ⇒ For long term and active use of the hydro tailing dam, it is strongly recommended performance of drainage blanket (Figure 10);
- ⇒ The stability of the sandy dam in conditions of active use and appearance of flooding wave or termination of the collector operation is not satisfying;
- ⇒ The results of the slope stability analysis for the designed case for the level of 990m asl without drainage show that the piezometric line is appearing on the downstream slope close to the too which could cause slope erosion and long term instability;
- ⇒ In the process of active use of the hydro tailing dam and exceeding the existing height of the sandy dam, it is strongly recommended to achieve and to respect the designed downstream slope of 1:3, as a condition for stability of the hydro tailing dam.
- ⇒ Continuous monitoring of the water level in the piezometers and in the accumulation has to be conducted;

It is recommended ABA leaching test to be conducted, as a measure for preventing possible environmental impact.

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