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ANALYSIS AND RELATIONSHIP OF SAFETY COEFFICIENT (Fs) AND CRITICAL FACTOR OF INFLUENCE THE STRESS REDUCTION (SRF) IN THE CASE OF EXTERNAL WASTE DUMP OF THE EAST WASTE DUMP - PROFILE III-III OPEN PIT "GACKO" GACKO[***]

Abstract

Analyzing the slope stability of work levels, final slopes and slope system was carried out in the area of the open pit "Gacko" according to the criteria required by the law of the Republic Srpska. This paper presents a comparative analysis of slope stability with three numerical methods by Bishop, Yanbu and Morgenstern-Price in various pore pressures $r_u=0$, $r_u=0.2$ $r_u=0.4$ and critical factor of influence the stress reduction at the same pore pressures that were already mentioned.

*The analyses of slope stability were carried out with the existing and newly obtained data. The software packages **SLIDE v6.0** and **PHASE² v8.0** of company **ROCSCIENCE** were used for calculation methods. The expected result is approximately the same value for the safety coefficient (Fs) and critical factor of influence the stress reduction (SRF) only at that point of analysis.*

***Keywords:** stress conditions, stability coefficient, pore pressure*

INTRODUCTION

Analyzing the slope stability of work levels, final slopes and slope system was carried out in the area of the open pit "Gacko" according to the criteria required by the law of the Republic Srpska. This paper presents a comparative analysis of slope stability with three numerical methods.

The analyses of slope stability were carried out with the existing and newly obtained data. The software packages **SLIDE v6.0** and **PHASE² v8.0** of company **ROCSCIENCE** were used for calculation methods. Calculation of stability was carried out by the programs **SLIDE v6.0** and **PHASE² v8.0** in the conditions of boundary equilibrium according to the criteria that are nowadays used in the world:

- Bishop,
- Janbu,
- Morgenstern-Price,
- as well as using the critical factor of influence the stress reduction (SRF).

The basic characteristics of the programs **SLIDE v6.0** and **PHASE² v8.0** are:

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[***] *This paper is the result of the Project No. TR 33021 "Research and Monitoring the Changes of the Stress Strain State in the Rock Mass "In-Situ" around the Underground Rooms with Development of Models with Special Reference to the Tunnel of the Krivelj River and Pit Bor", funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia*

SLIDE v6.0 is a program used to analyze the stability of soil and rock masses. This program provides a user - friendly range of analyses, including design, which supports the given analysis, groundwater analysis using the finite element analysis and probability analysis. CAD, which is based on a graphical interface, provides a wide range of interpretations through modeling and data to enable fast and accurate analysss. Files can be transferred to the program **PHASE^2** for slope stability using the finite element method.

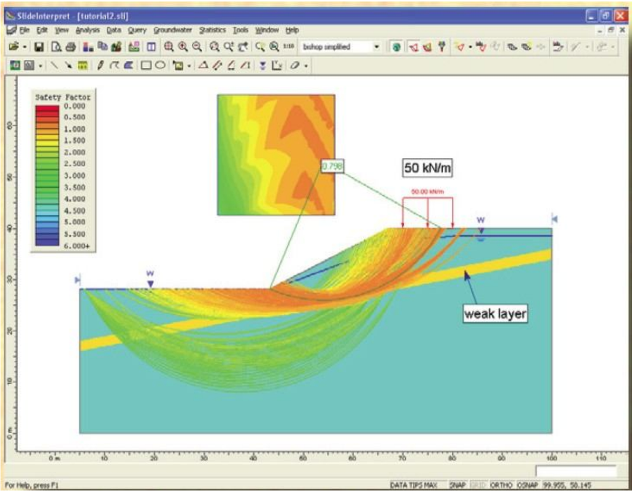

Figure 1 *An example of solving problems using the program SLIDE*

PHASE^2 v8.0 is a powerful 2D program of work based on the analysis of stress using the finite element method for both underground and surface mining of rock or soil. It can be used for a wide range of engineering projects, including the construction of tunnels, slope stability using the finite element, groundwater analysis, network modeling, analysis of probability and beyond. This program can quickly create and analyze a complex condition of models in several phases.

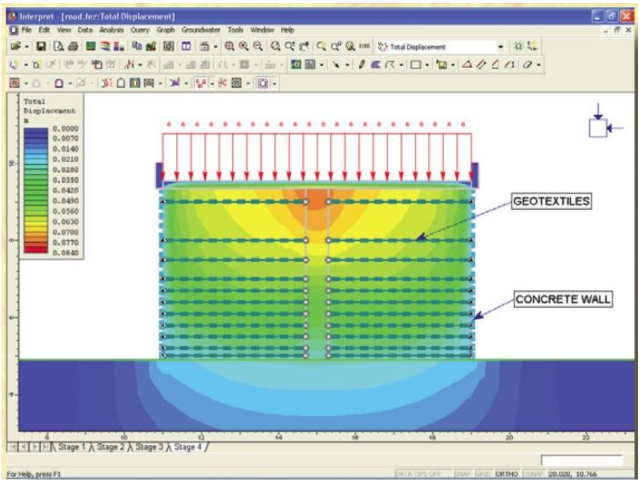

Figure 2 *An example of solving problems using the program PHASE2*

COURSE OF TESTING AND ANALYSIS OF STABILITY DATA

All geomechanical results obtained in some previously realized measurements were used as input data for programs **SLIDE v6.0** and **PHASE^2 v8.0**.

Slope stabilities are analyzed using the numerical methods by Bishop, Janbu and Morgenstern-Price while the stress-strain analysis of profiles, considering the geotechnical properties of the environment, was performed by Mohr-Columb's criterion of fracture and plastic behavior of the rock mass after fracture.

Calculation of safety factor is derived for different values of pore pressure, and the steps in the stability analysis were:

$r_u = 0.0$; $r_u = 0.2$ and $r_u = 0.4$.

The analysis of slope stability has taken into account a spreading of waves caused by the earthquake, in the most unfavorable direction, i.e. perpendicular to the forehead slope, and the adopted coefficient of seismicity which is Ks = 0.05.

Figure 3 *View of the slope on the external waste dump - East waste dump*

View of geological profile, used for analysis of safety coefficient (Fs) and coefficient of critical stress state (SRF), is shown in Figure 4.

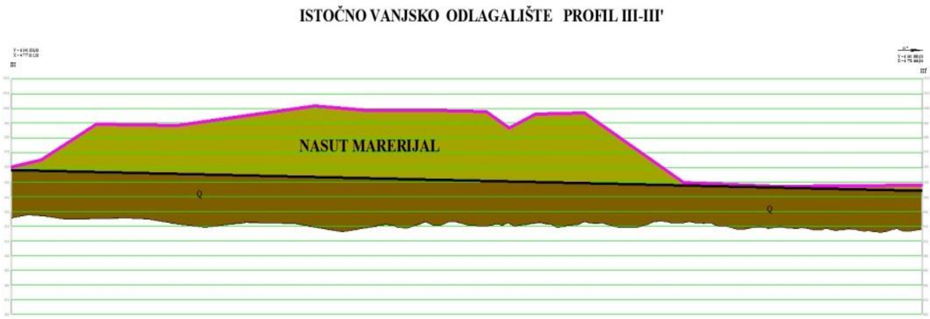

Figure 4 *Geological profile on which the stability analysis was carried out*

The adopted values of physica - mechanical parameters for analyzing the stability of operation and final slopes are:

Material	Bulk density in natural state γ [kN/m^3]	Cohesion C [kPa]	Angle of internal friction φ
Quaternary (Q)	18.30	29	13
Disposed material	15.3	22.7	36.2

Based on the engineering-geological profile of the III-III ' external waste dump - East waste dump, the stability analysis was carried out according to the said method and obtained the following safety coefficients:

Profile	Numerical methods	Safety coefficient F_s		
		Pore pressure coefficient		
		r_u = 0.0	r_u = 0.2	r_u = 0.4
III – III`	Bishop	1.493	1.185	0.886
	Janbu	1.304	1.008	0.787
	Morgenstern-Price	1.441	1.136	0.842

Graphically presented stability analysis by numerical methods, Bishop, Yanbu and Morgenstern - Price and changes of pore pressure (r_u) are given in Figures from Figure 5 to Figure 13.

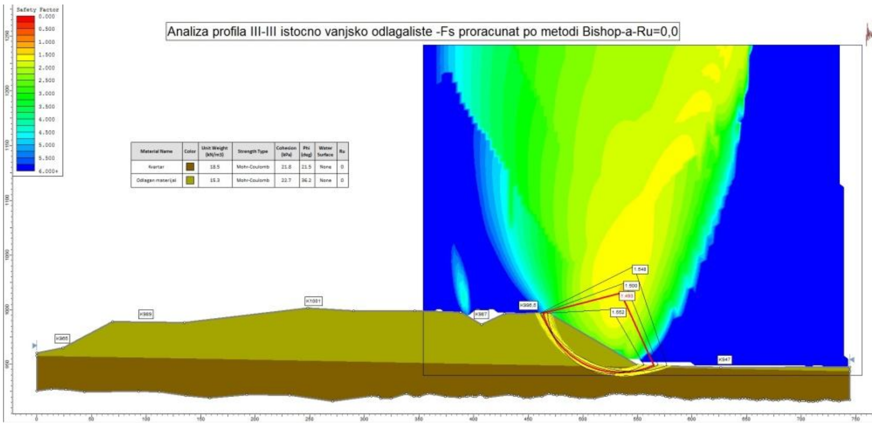

Figure 5 *Analysis of slope stability by numerical method Bishop at pore pressure r_u=0.0, Fs=1.493*

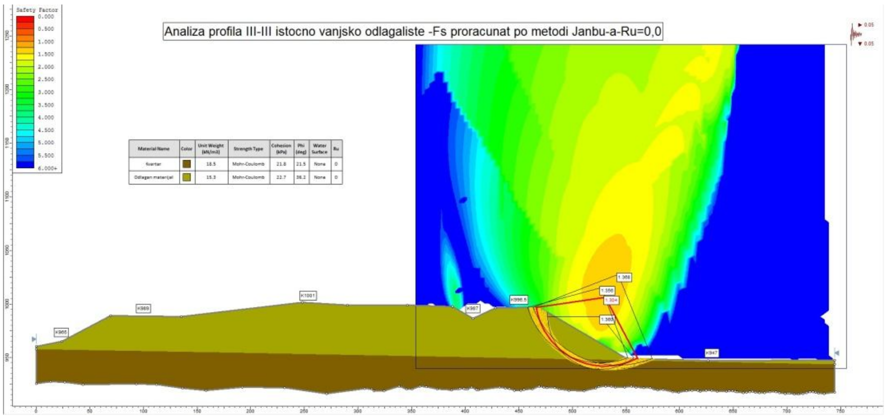

Figure 6 *Analysis of slope stability by numerical method Janbu at pore pressure r_u=0.0, Fs=1.304*

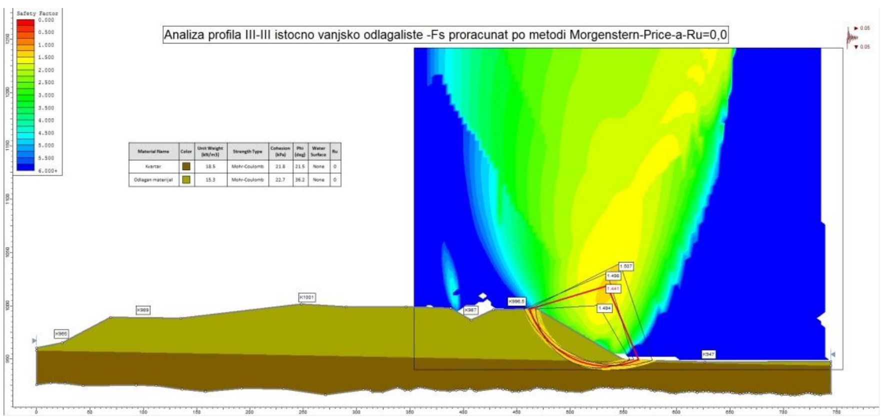

Figure 7 *Analysis of slope stability by numerical method Morgenstern-Price at pore pressure r_u=0.0, Fs=1.441*

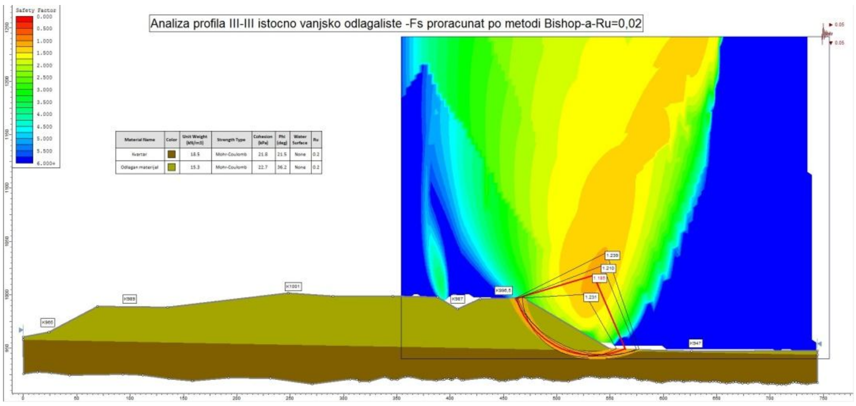

Figure 8 *Analysis of slope stability by numerical method Bishop at pore pressure* $r_u=0.2$, *Fs=1.185*

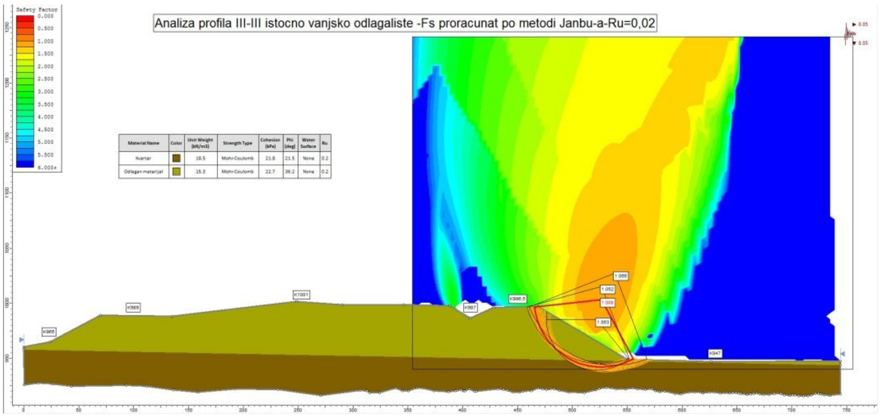

Figure 9 *Analysis of slope stability by numerical method Janbu at pore pressure* $r_u=0.2$, *Fs=1.008*

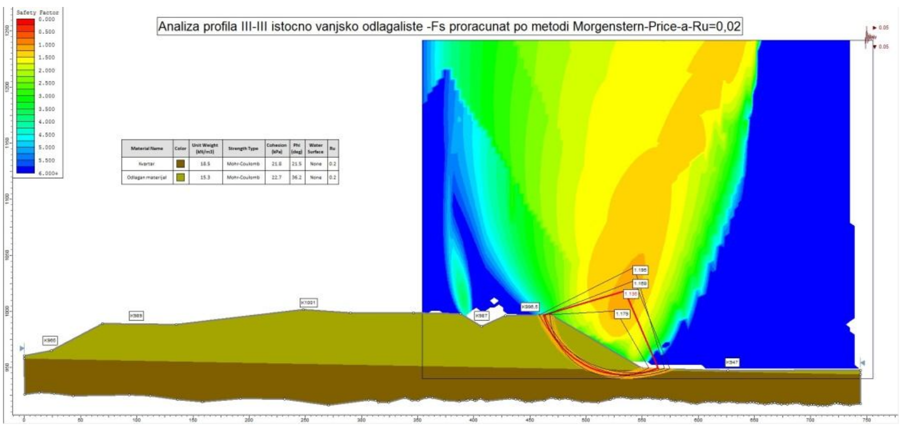

Figure 10 *Analysis of slope stability by numerical method Morgenstern-Price at pore pressure* $r_u=0.2$, *Fs=1.136*

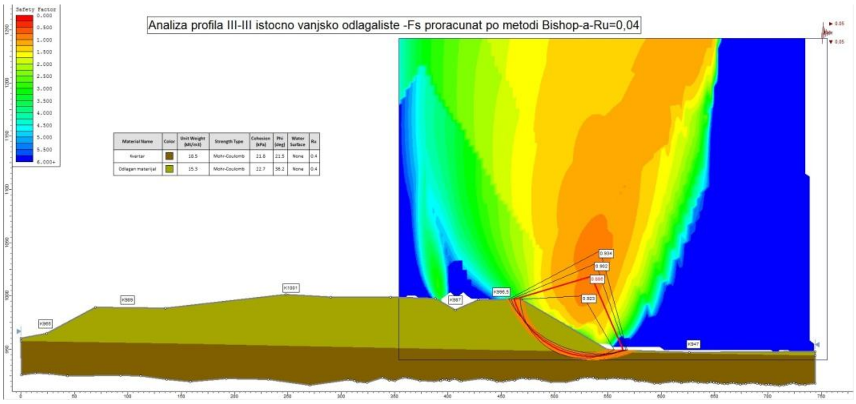

Figure 11 *Analysis of slope stability by numerical method Bishop at pore pressure r_u=0.4, Fs=0.886*

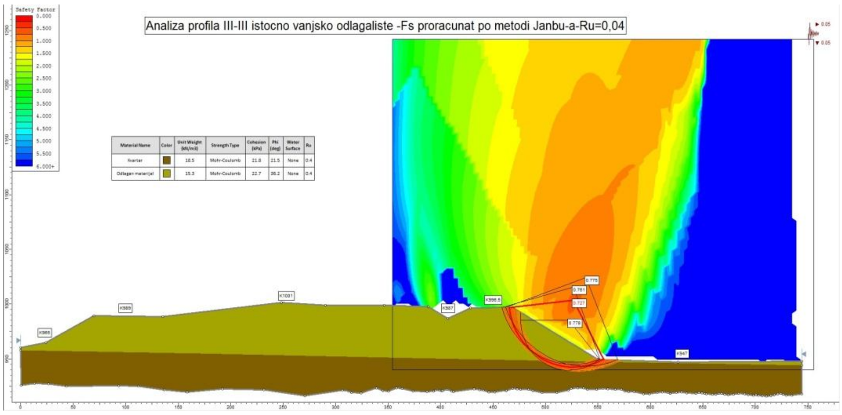

Figure 12 *Analysis of slope stability by numerical method Janbu at pore pressure r_u=0.4, Fs=1.787*

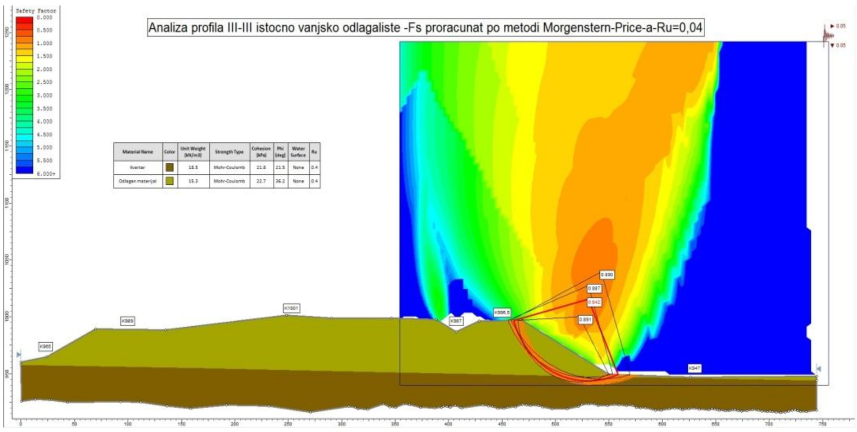

Figure 13 *Analysis of slope stability by numerical method Morgenstern-Price at pore pressure r_u=0.4, Fs=1.842*

Based on the engineering-geological profile of the III-III ' external waste dump - East waste dump, the stability analysis was carried out according to a mathematical model of finite element method with change of pore pressure (r_u) and the following coefficients critical stress state (SRF) were obtained:

Profile	Coefficient of critical stress state (SRF)		
	Coefficient of pore pressure		
	$r_u = 0.0$	$r_u = 0.2$	$r_u = 0.4$
III – III`	1.39	1.10	0.78

Graphically presented stability analyses over the coefficients of critical stress state (SRF) with a change in pore pressure (r_u) are given in Figures from Figure 14 to Figure16.

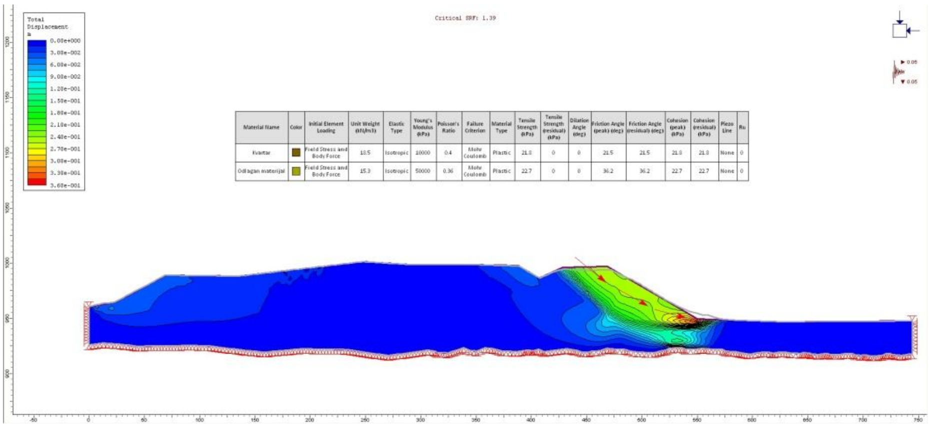

Figure 14 *Analysis of slope stability over stress conditions of material at pore pressure $r_u = 0.0$, SRF = 1.39*

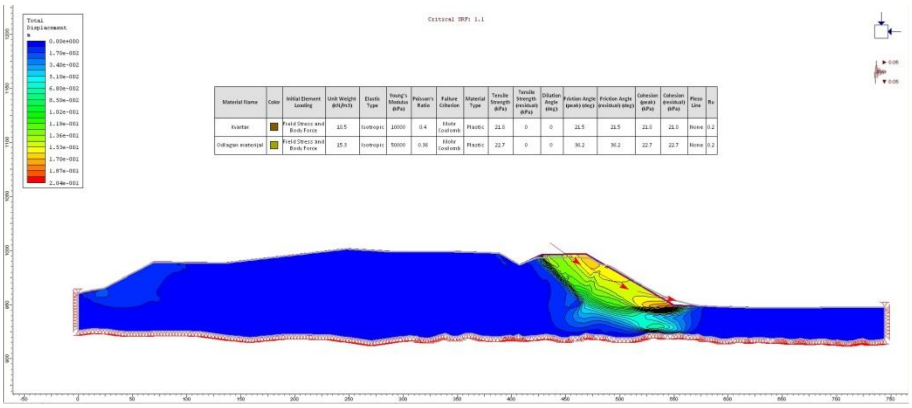

Figure 15 *Analysis of slope stability over stress conditions of material at pore pressure $r_u = 0.2$, SRF = 1.10*

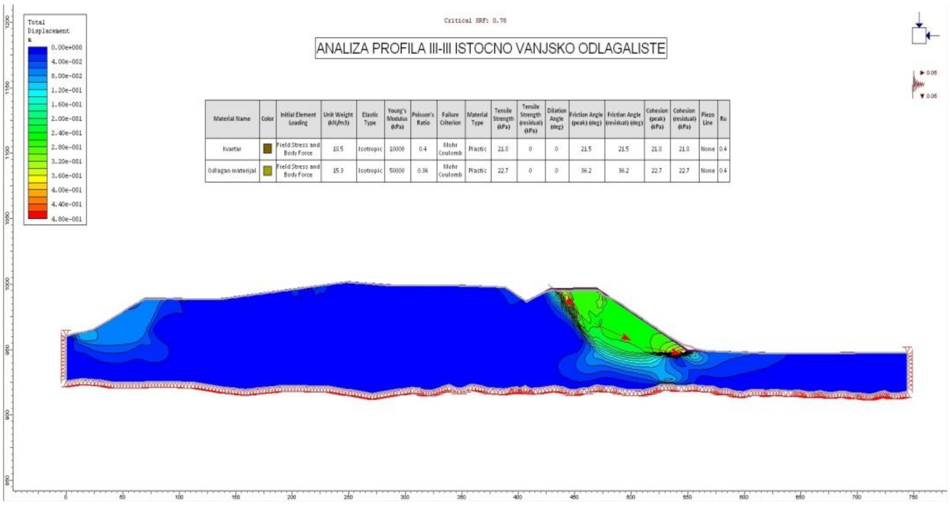

Figure 16 *Analysis of slope stability over stress conditions of material at pore pressure $r_u = 0.4$, SRF = 0.78*

CONCLUSION

Analyzing the results obtained in calculation for slope stability at pore pressures r_u=0.0; r_u = 0.2 and r_u = 0.4, using three numerical methods by Bishop, Janbu and Morgenstern-Price, as well as the finite element method for calculation the stress conditions, it can be concluded that the stability coefficient (F_s) and the coefficient of critical stress condition (SRF) only at this point of stress condition is almost identical.

It was confirmed by this analysis that in addition to the possibility of application the coefficient of critical stress condition (SRF) in checking the filed stability in relation to the stress conditions that occur within the soil, a control of stability coefficient (F_s) can be.

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Dragan Ignjatović, Lidija Đurđevac Ignjatović*,*
Milenko Ljubojev, Dragan Zlatanović***

ANALIZA I ODNOS KOEFICIJENTA SIGURNOSTI (Fs) I KRITIČNOG FAKTORA UTICAJA SMANJENJA NAPONA (SRF) NA PRIMERU VANJSKOG ODLAGALIŠTA JALOVINE, ISTOČNO ODLAGALIŠTE PROFIL III-III PK "GACKO" GACKO***

Izvod

Na području PK „Gacko" vršena je analiza stabilnosti kosina radnih etaža, završnih kosina i sistema kosina prema kriterijumima koje zahteva zakon Republike Srpske. U radu je izvršena uporedna analiza stabilnosti kosina sa tri numeričke metode, po Bishop—u, Janbu i Morgenstern-Price-u. pri različitin pornim pritiscima r_u=0, r_u=0,2 r_u=0,4 i kritičnog faktora uticaja smanjenja napona pri istim pornim pritiscima koji su već spomenuti

*Sa postojećim i novodobijenim podacima izvršene su analize stabilnosti kosina. Za proračunske metode korišćeni su paketi programa **SLIDE v6.0** i **PHASE² v8.0** firme **ROCSCIENCE.** Očekivani rezultat je, približno ista vrednost za koeficijenata sigurnost (Fs) i kritičnog faktora uticaja smanjenja napona (SRF) samo u toj tački analize*

***Ključne reči:** Naponska stanja, koeficijent stabilnosti, porni pritisak*

UVOD

Na području PK „Gacko" vršena je analiza stabilnosti kosina radnih etaža, završnih kosina i sistema kosina prema kriterijumima koje zahteva zakon Republike Srpske. U radu je izvršena uporedna analiza stabilnosti kosina sa tri numeričke metode

Sa postojećim i novodobijenim podacima izvršene su analize stabilnosti kosina. Za proračunske metode korišćeni su paketi programa **SLIDE v6.0** i **PHASE² v8.0** firme **ROCSCIENCE.**

Programom **SLIDE v6.0** i **PHASE² v8.0** proračun stabilnosti vršen je u uslovima granične ravnoteže prema kriterijumima koji se danas koriste u svetu:

- Bishop,
- Janbu,
- Morgenstern-Price,
- kao i pomoću kritičnog faktora uticaja smanjenja napona (SRF).

Osnovne karakteristike programa **SLIDE v6.0** i **PHASE² v8.0** su:

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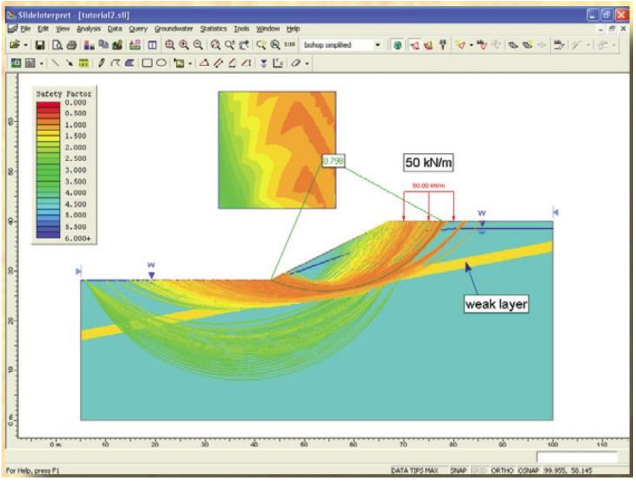
** *Inovacioni centar Mašinskog fakulteta, Beograd, e-mail: dr.dragan.zlatanovic@gmail.com*

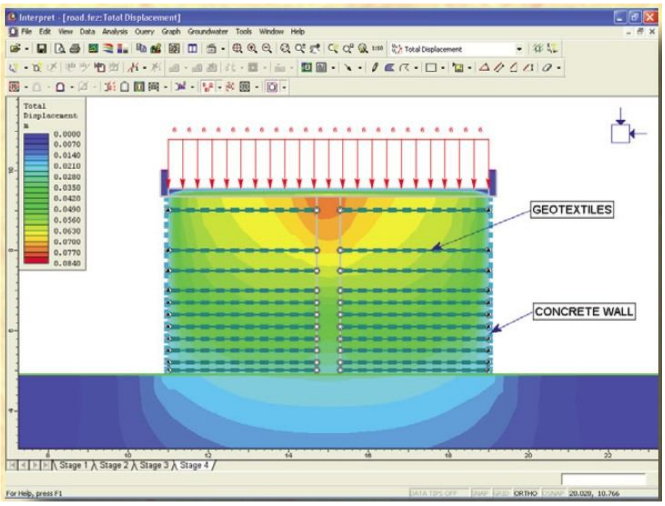
*** *Rad je proizašao iz projekta broj TR 33021 "Istraživanje i praćenje promena naponsko deformacijskog stanja u stenskom masivu „in-situ" oko podzemnih prostorija sa izradom modela sa posebnim osvrtom na tunel Kriveljske reke i Jame bor" koji je finansiran sredstvima Ministarstva za prosvetu, nauku i tehnološki razvoj Republike Srbije*

SLIDE v6.0 je program koji se koristi za analizu stabilnosti tla i stenskih masa. Ovaj program obezbeđuje razumljiv spektar analiza, uključujući i dizajn, koji podržava datu analizu, analiza podzemnih voda metodom konačnih elemenata i analiza verovatnoće CAD, koji se bazira na grafičkom interfejsu, pruža široki spektar interpretacija putem modeliranja i podataka koje omogućavaju brze i tačne analize. Fajlovi se mogu preneti u program **PHASE^2** za stabilnost kosina metodom konačnih elemenata.



Sl. 1. *Primer rešavanja problema uz pomoć programa SLIDE*

PHASE^2 v8.0 je moćan 2D program koji svoj rad bazira na analizi napona uz pomoć metode konačnih elemenata, kako za podzemna tako i za površinska otkopavanja stena ili tla. Može se koristiti za široki spektar inženjerskih projekata, uključujući konstrukcije tunela, stabilnost kosina pomoću metode konačnih elemenata, analiza podzemnih voda, mrežno modeliranje, analiza verovatnoće i šire. Sa ovim programom se može brzo kreirati i analizirati kompleksno stanje modela u više faza.



Sl. 2. *Primer rešavanja problema uz pomoć programa* ***PHASE^2***

TOK ISPITIVANJA I ANALIZA PODATAKA STABILNOSTI

Svi geomehanički rezultati koji su dobijeni u nekim ranije vršenim merenjima korišćeni su kao ulazni podaci za programe SLIDE v6.0 i PHASE^2 v8.0.

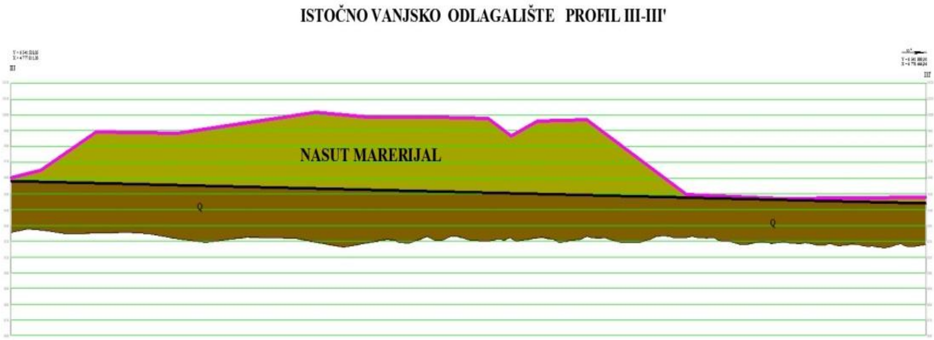
Stabilnosti kosina su analizirane uz pomoć numeričkih metoda po Bishop-u, Janbu i Morgenstern-Price-u dok je naponsko-deformaciona analiza profila, imajući u vidu geotehnička svojstva sredina, rađena po Mohr-Columb-ovom kriterijumu loma i plastičnim ponašanjem stenske mase nakon loma.

Proračun faktora sigurnosti izveden je za različite vrednosti pornog pritiska, a koraci pri analizi stabilnosti bili su: r_u = 0,0; r_u = 0,2 i r_u = 0,4.

U analizi stabilnosti kosina uzeto je u obzir prostiranje talasa, izazvanih zemljotresom, u najnepovoljnijem pravcu, tj. upravno na čelo kosine, a usvojeni koeficijent seizmičnosti koji iznosi Ks = 0,05.

Sl. 3. *Izgled kosine na vanjskom odlagalištu jalovine – Istočno odlagalište*

Izgled geološkog profila koji je poslužio za analizu koeficijent sigurnosti (F_s) i koeficijenta kritičnog naponskog stanja (SRF), dat je na slici 4.



Sl. 4. *Geološki profil na kome je vršena analiza stabilnosti*

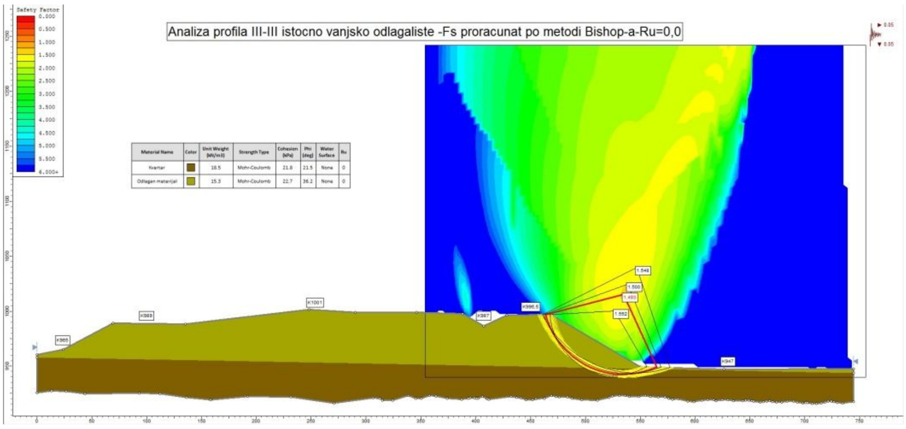
Usvojene vrednosti fizičko - mehaničkih parametara za analizu stabilnosti i radnih završnih kosina su:

Materijala	Zapreminska težina u prirodnom stanju γ [kN/m^3]	Kohezija C [kPa]	Ugao unutrašnjeg trenja φ
Kvartar (Q)	18,30	29	13
Odložen materijal	15,3	22,7	36,2

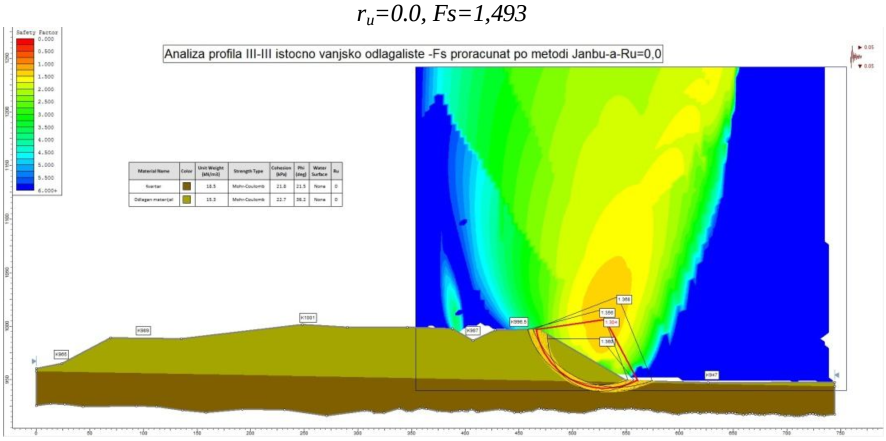
Na osnovu inženjersko-geološkog profila III - III' vanjskog *odlagališta* jalovine – Istočno odlagalište, urađena je analiza stabilnosti prema već rečenim metodama i dobijeni su sledeći koeficijenti sigurnosti:

Profil	Numeričke metode	Koeficijent sigurnosti F_s		
		Koeficijent pornog pritiska		
		$r_u = 0.0$	$r_u = 0.2$	$r_u = 0.4$
III – III`	Bishop	1,493	1,185	0,886
	Janbu	1,304	1,008	0,787
	Morgenstern-Price	1,441	1,136	0,842

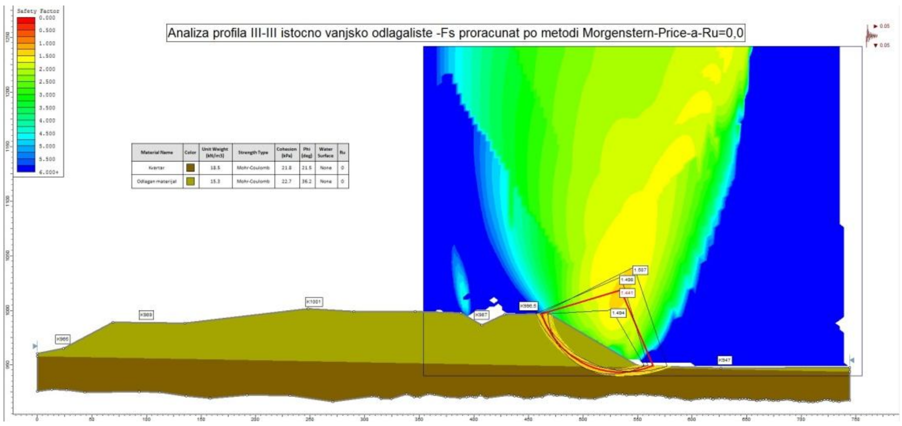
Grafički prikazane analize stabilnosti po numeričkim metodama, Bishop, Janbu i Morgenstern-Price i promeni pornog pritiska (r_u) date su na slikama od Sl. 5 do Sl. 13.



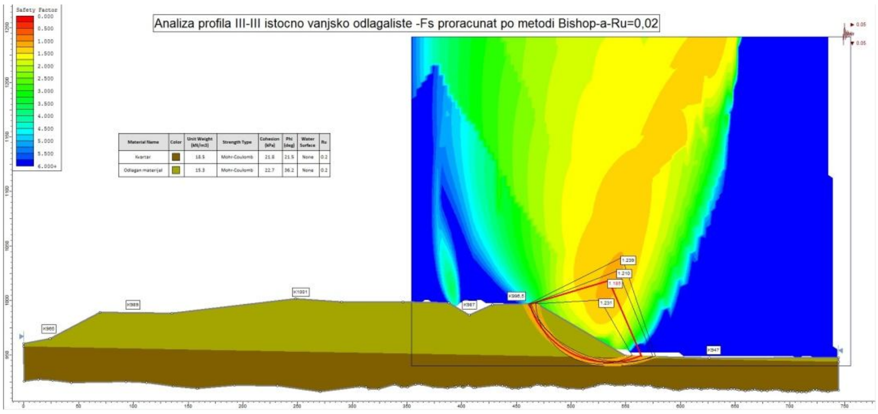
Sl. 5. *Analiza stabilnosti kosina po numeričkoj metodi Bishop pri pornom pritisku r_u=0.0, Fs=1,493*



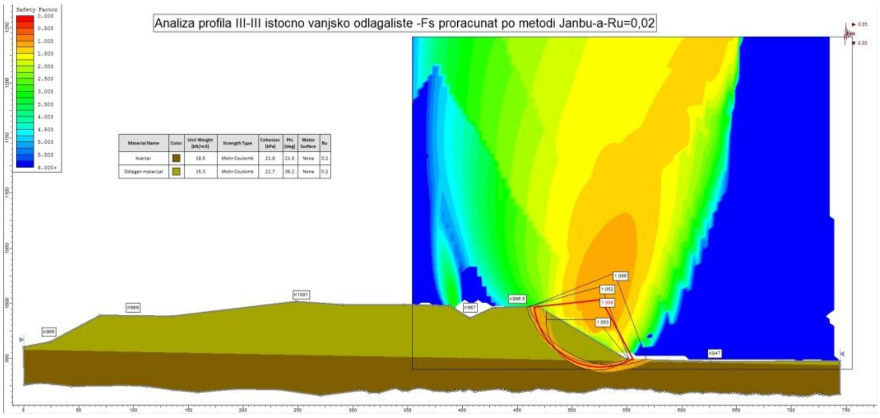
Sl. 6. *Analiza stabilnosti kosina po numeričkoj metodi Janbu pri pornom pritisku r_u=0.0, Fs=1,304*



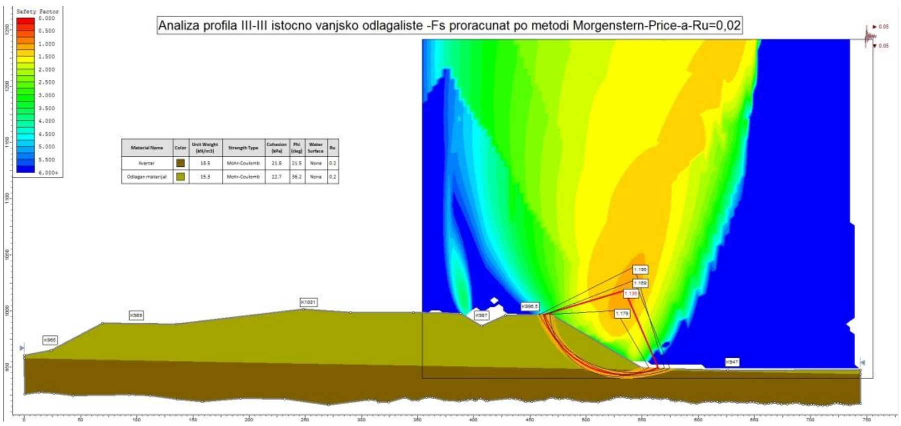
Sl. 7. *Analiza stabilnosti kosina po numeričkoj metodi Morgenstern-Price pri pornom pritisku r_u=0.0, Fs=1,441*



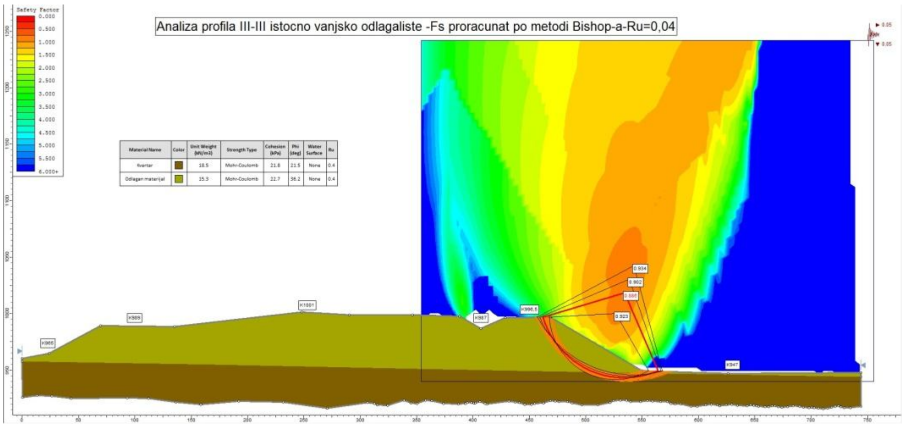
Sl. 8. *Analiza stabilnosti kosina po numeričkoj metodi Bishop pri pornom pritisku* r_u*=0.2, Fs=1,185*



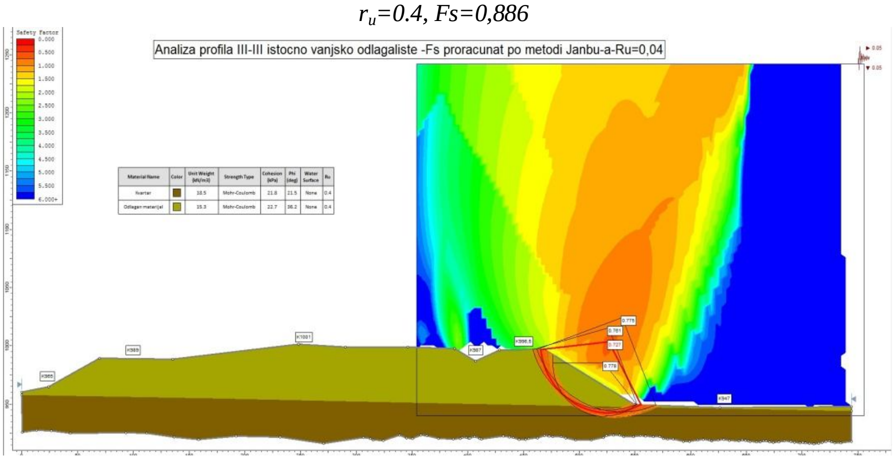
Sl. 9. *Analiza stabilnosti kosina po numeričkoj metodi Janbu pri pornom pritisku* r_u*=0.2, Fs=1,008*



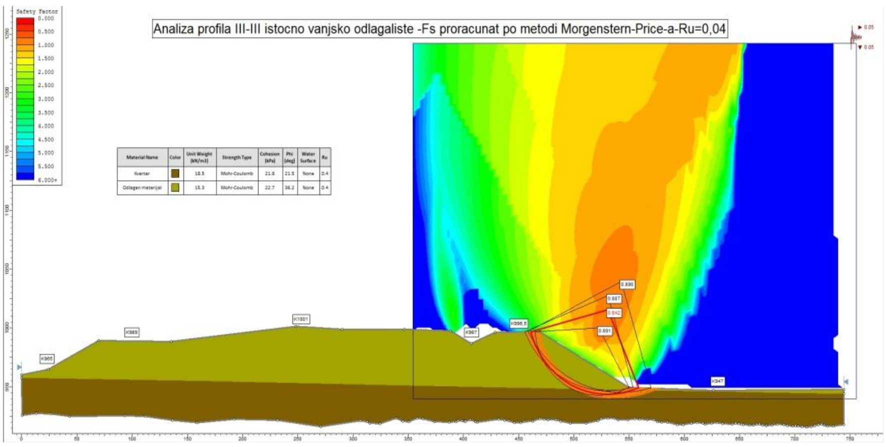
Sl. 10. *Analiza stabilnosti kosina po numeričkoj metodi Morgenstern-Price pri pornom pritisku* r_u*=0.2, Fs=1,136*



Sl. 11. *Analiza stabilnosti kosina po numeričkoj metodi Bishop pri pornom pritisku r_u=0.4, Fs=0,886*



Sl. 12. *Analiza stabilnosti kosina po numeričkoj metodi Janbu pri pornom pritisku r_u=0.4, Fs=0,787*

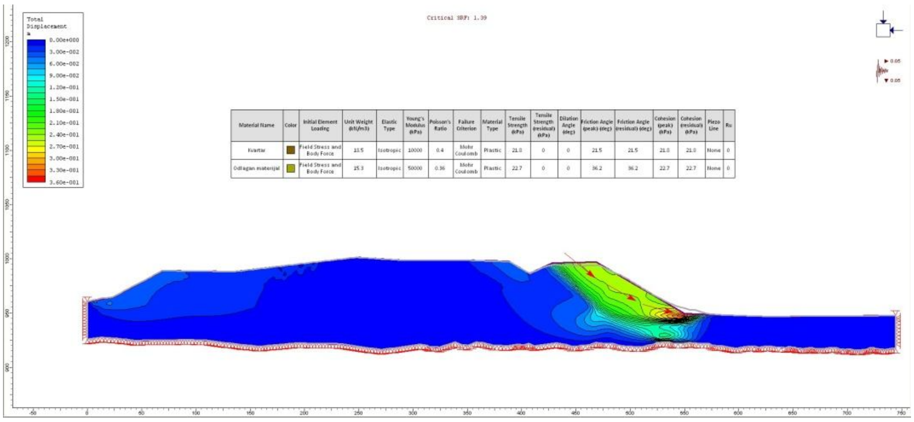


Sl. 13. *Analiza stabilnosti kosina po numeričkoj metodi Morgenstern-Price pri pornom pritisku r_u=0.4, Fs=0,842*

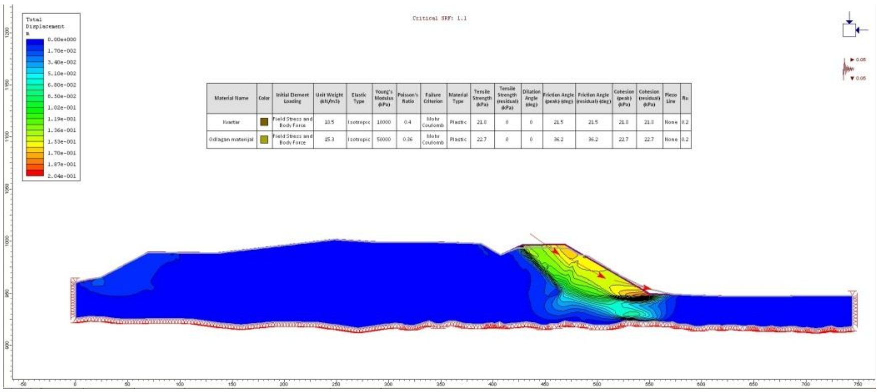
Na osnovu inženjersko-geološkog profila III - III' vanjskog *odlagališta* jalovine – Istočno odlagalište urađena je analiza stabilnosti pre*ma* matematičkom modelu *metodom konačnih elemenata sa promenom pornog pritiska* (r_u) *i* dobijeni su sledeći koeficijenti kritičnog naponskog stanja *(SRF)*:

Profil	**Koeficijent kritičnog naponskog stanja (SRF)**		
	Koeficijent pornog pritiska		
	r_u = 0.0	r_u = 0.2	r_u = 0.4
III – III`	1,39	1,10	0,78

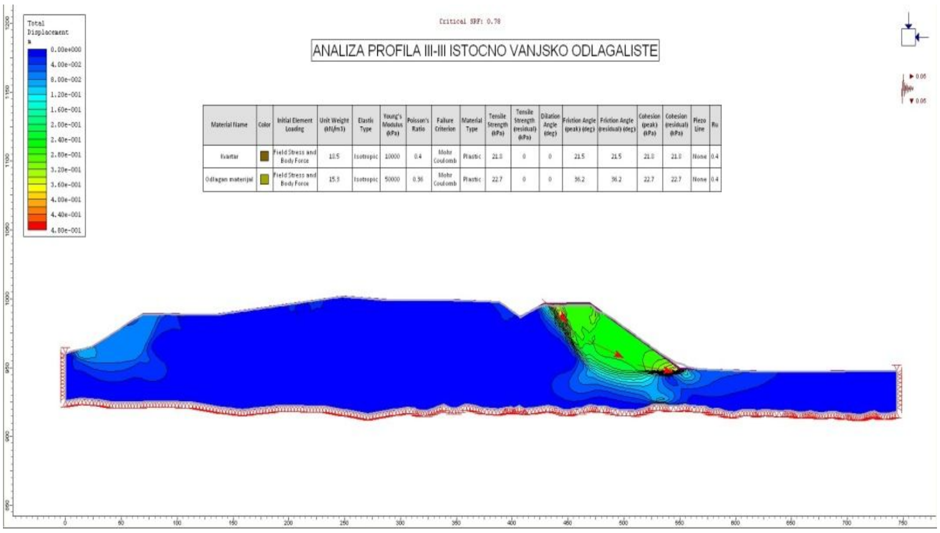
Grafički prikazane analize stabilnosti preko koeficijenta kritičnog naponskog stanja (SRF) sa promenom pornog pritiska (r_u) dati su na slikama od Sl. 14 do Sl. 16.



Sl. 14. *Analiza stabilnosti kosina preko naponskih stanja materijala pri pornom pritisku r_u=0.0, SRF=1,39*



Sl. 15. *Analiza stabilnosti kosina preko naponskih stanja materijala pri pornom pritisku r_u=0.2, SRF=1,10*



Sl. 16. *Analiza stabilnosti kosina preko naponskih stanja materijala pri pornom pritisku r_u=0.4, SRF=0,78*

ZAKLJUČAK

Analizom rezultata dobijenih pri proračunu za stabilnosti kosina pri pornim pritiscima r_u=0,0; r_u = 0,2 i r_u = 0,4, koristeći tri numeričke metode, po Bishop-u, Janbu i Morgenstern - Price-u kao i metodu konačnih elemenata za proračun naponskih stanja, može se konstatovati, da je koeficijent stabilnosti (F_s) i koeficijenta kritičnog naponskog stanja (SRF) samo u toj tački naponskog stanja skoro identičan.

Tom analizom smo potvrdili, da pored mogućnosti primene koeficijenta kritičnog naponskog stanja (SRF) u proveri stabilnosti teren u odnosu na naponska stanja koja se dešavaju unutar tla, može da bude i kontrola koeficijenta stabilnosti (F_s).

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