ANALIZA RJEŠENJA KOSINE USJEKA PRIMJENOM METODA ARMIRANOG TLA, ČAVLANJA I IZRADE POTPORNOG ZIDA

ANALYSIS SOLUTION OF CUT USING METHODS OF REINFORCED WALL, SOIL NAILING AND MAKING RETAINING WALL

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REZIME

U radu su opisane analize rješenja kosine usjekna na autocesti. Primijenjene su tri metode izrade potporne konstrukcije, a to su armirano tlo HDPE geomrežama, čavlanje i potporni zid u dužini 20 m. Visina konstrukcije iznosi 10 m. Pri proračunu za izradu armiranog tla I čavlanja primijenjeni su AASHTO standardi, a potporni zid je proračunat u skladu sa EN 1997-I normama. Sve metode su implementirane u software-ski paket Plaxis koji je korišten za istraživanje. Na osnovu provedenih analiza izvršen je izbor rješenja kao najpovoljnijeg.

Professional paper

SUMMARY

The paper describes analyses solution of cut in the highway. There have been used three methods of making construction: reinforced wall with HDPE geogrids, soil nailing and retaining wall 20 meters long. AASHTO standards have been used for checking stability of reinforced wall and soil nailing, while retaining wall is based on EN 1997-I standards. All of these methods are implemented in software package Plaxis which is used for exploration. The best solution is chosen by these analyses.

1. UVOD

Analizom je potrebno utvrditi rješenje za dati problem. Kosina usjeka na autocesti je heterogeno tlo koje se sastoji od 3 sloja, a geotehničke sredine imaju sljedeće karakteristike:

1. INTRODUCTION

This analysis has to give a solution for a slope insurance. A slope cut, which is on highway, is a heterogeneous soil and it is made of three layers, so in geotechnical way they have these characteristics:

Tabela 1. *Karakteristike geotehničkih sredina*
Table 1. *Characteristics of geotechnical parts*

Parametar - Parameter	**Pokrivač Blanket**	**Raslabljen substrat Strengthened substrate**	**Substrat lapor Substrate lactose**
visina - height [m]	3,0	4,5	3,65
specifična zapreminska težina [kN/m^3] specific volume weight [kN/m^3]	18,0	19,0	21,0
kohezija - cohesion [kPa]	10,0	17,0	60,0
ugao unutrašnjeg trenja [^{o}] angle of inner friction	23	26	30
Referentni Young-ov modul [kPa] Reference Young's Module [kPa]	12 000	25 000	80 000
Poisson-ov koeficijent [-] Poisson coefficient [-]	0,3	0,3	0,3

Rješenje je moguće izvesti u tri slučaja, kao potporna konstrukcija od armiranog tla, čavlanjem ili izradom jednostavnog potpornog zida.

Solution is possible to make in three ways: with methods of reinforced wall, soil nailing or by making a simple retaining wall.

2. PRORAČUN POTPORNE KONSTRUKCIJE

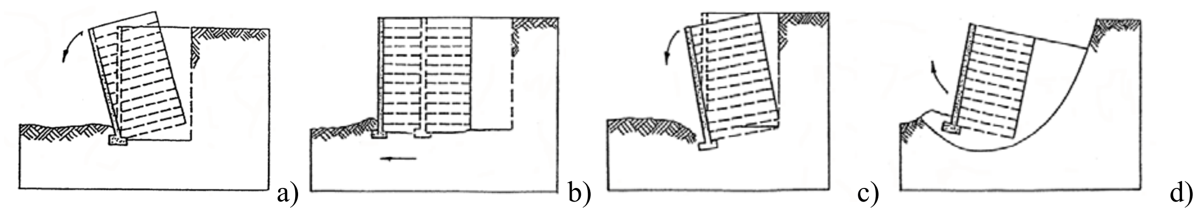
2.1. Proračun potpornih konstrukcija od armiranog tla

Kod zidova armiranog tla potrebno je provjeriti vanjsku i unutrašnju stabilnost.
Vanjska stabilnost uključuje dokaze otpornosti na:
a) prevrtanje,
b) klizanje,
c) slom temeljnog tla,
d) globalnu stabilnost, koja armiranu zonu zida tretira kao kvazi-homogeni kruti blok.

2. CALCULATION OF SUPPORT CONSTRUCTION

2.1. Calculation of support constructions with reinforced wall

Reinforced walls have to satisfy analyses of internal and external stability. External stability includes proves capacity of:
a) overturning (eccentricity)
b) sliding
c) bearing capacity
d) deep seated stability (rotatonial; global stability), which reinforced zone of walls threates as quasi – homogenous stiff block



Slika 1. Principi gubitka stabilnosti zida uslijed gubitka nosivosti na: a) prevrtanje, b) klizanje, c) slom temeljnog tla, d) globalni slom [4]

Figure 1. Principles of wall failure due to loss capacity of: a) overtuning, b) sliding, c)bearing capacity, d) global stability [4]

Svi proračuni trebaju zadovoljiti minimalne faktore sigurnosti koji su predstavljeni u Tabeli 2:

All of the calculations need to satisfy minimal factors of stability for external stability that are presented in Table 2:

Tabela 2. Zahtjevi minimalnih faktora sigurnosti vanjske stabilnosti potporne konstrukcije od armiranog tla [4]
Table 2. Required minimum factors of safety for external stability of reinforced wall [4]

Vanjska stabilnost - External Stability	
Klizanje - Sliding	F.S. ≥ 1.5 (MSEW); 1.3 (RSS)
Ekscentričnost u bazi - Eccentricity e, at Base	≤ L/6 in soil L/4 in rock
Kapacitet ležaja - Bearing Capacity	F.S. ≥ 2.5
Globalna stabilnost - Deep Seated Stability	F.S. ≥ 1.3
Stabilnost spoja - Compound Stability	F.S. ≥ 1.3
Seizmička stabilnost - Seismic Stability	F.S. ≥ 75% of static F.S. (All failure modes)

Unutrašnja stabilnost podrazumijeva provjeru napona u zatežućim elementima, tj. mogućnost čupanja ili prekida zatežućih elemenata. “Unutarnja stabilnost “aktivne” zone zida koja je od “pasivne” zone razgraničena linijom koja povezuje lokacije maksimalnih vlačnih sila u svakoj razini armature.

Internal stability includes checking stresses in tensiled elements that means pullout resistance of tensiled elements. “Internal stability of “active” zone of wall that is divided from passive through line that connects locations of maximum values of tensile strength on every level of reinforcement.

Položaj maksimalne vlačne sile uzduž armature utvrđen je eksperimentalnim istraživanjem velikog broja zidova stvarne veličine i razlikuje se za različite krutosti armature (Elias i dr., 1997).” [7]
Kao geosintetičko ojačanje pri proračunu i analizi izabrana je, kao najčešće korištena, HDPE mreža maksimalne nosivosti 250 kN/m’ i ukupne dužine 6,5m. Izabrana mreža ispunjava sve zahtjeve nosivosti i kao takva predstavlja idealan izbor za ojačanje konstrukcije.

2.2. Proračun potporne konstrukcije čavlanjem

Prilikom proračuna zidova ojačanih čavlima potrebno je ispitati vanjsku I unutrašnju stabilnost te stabilnost podloge (primarna I sekundarna obloga). Potrebne analize za dokaz nosivosti provedene su u ovoj analizi pri izradi rješenja zaštite kosine čavlanjem tla te su zadovoljeni minimalni uslovi faktora sigurnosti (Tabela 3).

The position of maximum value of tensile strength in reinforcement is set by many experimental exploring many real sized walls and it is different for every type rigidity of reinforcements (Elias and others, 1997).” [7]
In calculations and analysis, as a geosynthetic reinforcement it has been chosen, as mostly used, HDPE geogrid with maximum strength of 250 kN/m’ and in total length of 6,5 m. This chosen grid satisfies every requests of capacity and so it presents ideal choice for reinforced construction.

2.2. Calculation support construction of soil nail walls

By calculation of soil nail walls there is some stabilitiy that need to be checked and it includes external and internal stability so as the stability of support (permanent and temporaty facing). All of these analyses has been checked in this paper and all of the minimum factors of safety are achieved (Table 3).

***Tabela 3.** Minimalni preporučeni faktori sigurnosti za dimenzioniranje čavlanog tla [5]*
***Table 3.** Minimum recommended factors of safety for soil nail walls*

Failure mode	Resisting component	Symbol	Minimum Recommended Factors of Safety		
			Static Loads		Seismic Loads (Temporaty and Permanent Structures)
			Temporary Structure	Permanent Structure	
External Stability	Global Stability (long term)	FS_G	1,35	1,5	1,1
	Global Stability (excavation)	FS_G	1,2 - 1,3		NA
	Sliding	FS_{SL}	1,3	1,5	1,1
	Bearing Capacity	FS_H	2,5	3,0	2,3
Internal Stability	Pullout Resistance	FS_P	2,0		1,5
	Nail Bar Tensile Strength	FS_T	1,8		1,35
Facing Strength	Facing Flexure	FS_{FF}	1,35	1,5	1,1
	Facing Punching Shear	FS_{FP}	1,35	1,5	1,1
	H.-Stud Tensile (A307 Bolt)	FS_{HT}	1,8	2,0	1,5
	H.-Stud Tensile (A325 Bolt)	FS_{HT}	1,5	1,7	1,3

2.3. Proračun potpornih zidova

Dokaz stabilnosti potpornih zidova se odnosi na statički proračun kojima dokazujemo da su naponi u karakterističnim presjecima na tlo ispod temelja u dopuštenim granicama, te da je zid stabilan na klizanje I prevrtanje.

2.3. Callculation of retaining wall

A proof of stability for retaining walls is based on static calculation what serves for proving that the stresses in characteristic sections on soil under base are in allowed limits and that a wall has capacity on sliding and overtuning.

Proračun se vodi iterativno. Prvo se pretpostave dimenzije, provjere naponi I nakon toga se izvrši potrebna korekcija dužina. Sve analize za dokaz sigurnosti potpornih zidova provedene su u ovom radu te su ispunjeni minimalni zahtjevi faktora sigurnosti.

3. REZULTATI I ANALIZA

Primjenom software-a Plaxis 8.6 provedeni su proračuni rješenja zaštite kosine zasjeka: armirano tlo, čavlanje i potporni zid. Dobijene su različite vrijednosti vertikalnih, horizontalnih pomijeranja, efektivnih napona i sl. pa je izabrano najpovoljnije odnosno najsigurnije rješenje.

3.1. Globalna sigurnost

Globalna stabilnost kao jedan od osnovnih uslova nije zadovoljen kod proračuna čavlanog tla. Armirano tlo i betonski potporni zid ispunili su uslov globalne stabilnosti gdje je faktor stabilnosti FS≥1,3.

3.2. Pomijeranja

Slika 2. prikazuje totalna pomijeranja proračunatih rješenja zaštite kosine. Na Slici 2.a su totalna pomijeranja tla iza lica zida armiranog tla ($38,86*10^{-3}$ m), na Slici 2.b totalna pomijeranja tla iza obloge čavlanog tla ($248,78*10^{-3}$ m) a Slika 2.c prikazuje totalna pomijeranja tla iz betonskog potpornog zida ($75,78*10^{-3}$ m).

Na Slici 3. su predstavljena horizontalna pomijeranja tla sa maksimalnim vrijednostima na vrhu: Slika 3.a - armirano tlo ($23,34*10^{-3}$ m), Slika 3.b - čavlano tlo ($222,54*10^{-3}$ m) i Slika 3.c - betonski potporni zid ($21,71*10^{-3}$ m).

Vertikalna pomijeranja tla su prikazana na Slici 4: Slika 4.a – armirano tlo ($33,71x10^{-3}$ m), Slika 4.b – čavlano tlo ($161,67x10^{-3}$ m) i Slika 4.c – betonski potporni zid ($75,78x10^{-3}$ m).

The process of calculation is iterative. First of all dimensions are assumed, the stresses are checked and after that the correction of dimensions are implemented. All of the analyses for proof of safety for retaining wall have been done and the requirements of minimum factor of safety are satisfied.

3. RESULTS AND ANALYSIS

For the calculations of slope insurance, which includes: reinforced wall, soil nailing and retaining wall, there has been used a software called Plaxis 8.6. There are different results and values for vertical, horizontal displacements, effective stresses and based on that the safest solution is chosen.

3.1. Global safety

As the one of the main requirement, the global stability is not reached for soil nail wall. Reinforced wall and concrete retatining wall have reached the requirement of global stability where FS ≥ 1,3.

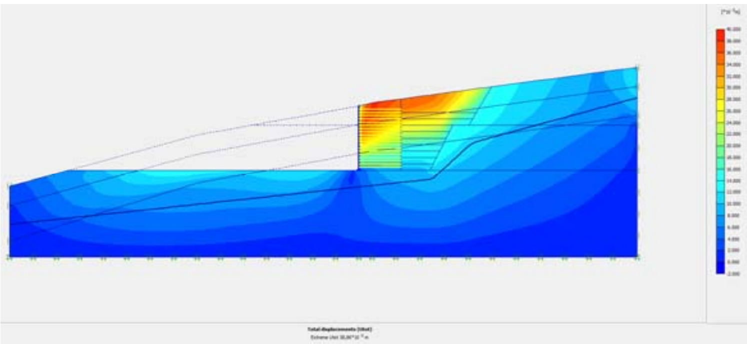
3.2. Displacements

In Figure 2. are shown total displacements for all solutions. Figure 2.a shows total displacements of soil behind the face of reinforced wall ($38,86*10^{-3}$ m), Figure 2.b shows total displacements of soil behind facing of soil nail wall ($248,78*10^{-3}$ m) and Figure 2.c shows total displacements of soil behind concrete retaining wall ($75,78*10^{-3}$ m).

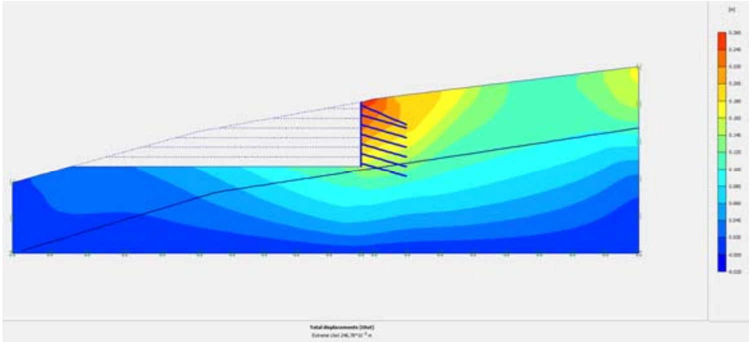
In Figure 3. are shown horizontal displacements of soil with maximal values on the top. Figure 3.a – reinforced wall ($23,34x10^{-3}$ m), Figure 3.b – soil nail wall ($222,54x10^{-3}$ m) i Figure 3.c – concrete retaining wall ($21,71x10^{-3}$ m).

Vertical displacements of soil are shown in Figure 4: Figure 4.a – reinforced wall ($33,71x10^{-3}$ m), Figure 4.b – soil nail wall ($161,67x10^{-3}$ m) i Figure 4.c – concrete retaining wall ($75,78x10^{-3}$ m).

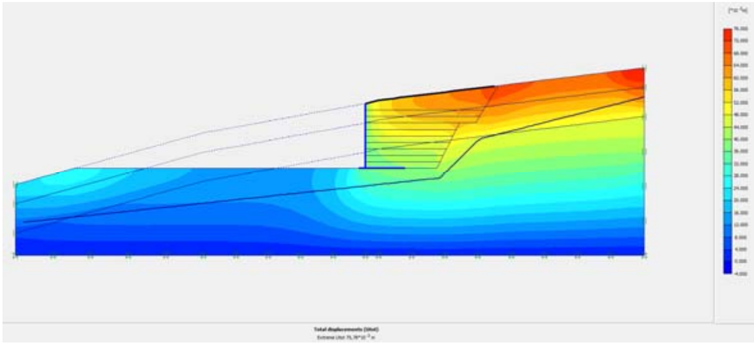
a)



b)

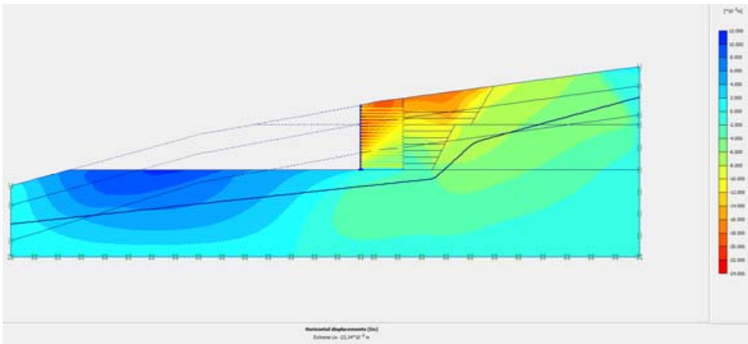


c)



Slika 2. *Totalna pomijeranja tla iza lica zida*
Figure 2. *Total displacements of soil behind the wall face*

a)



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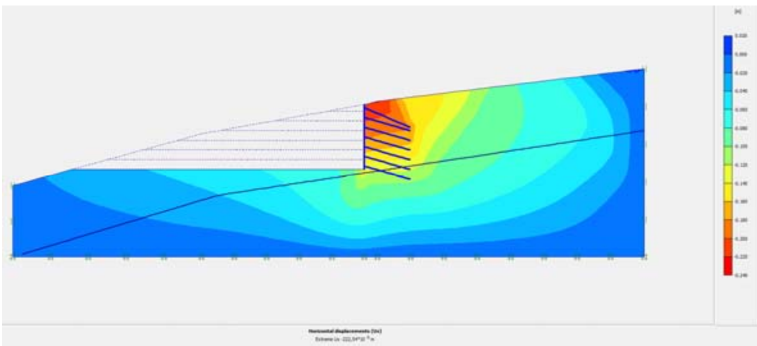
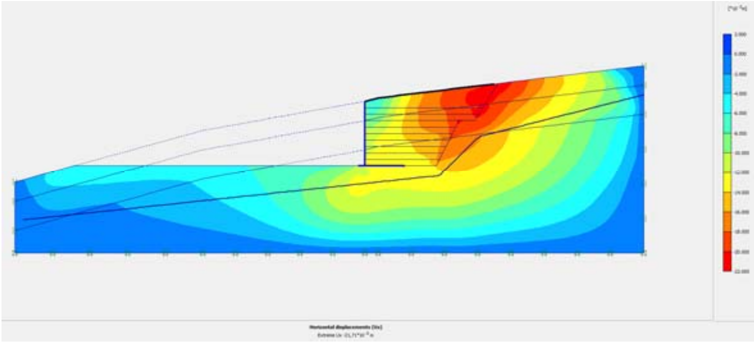
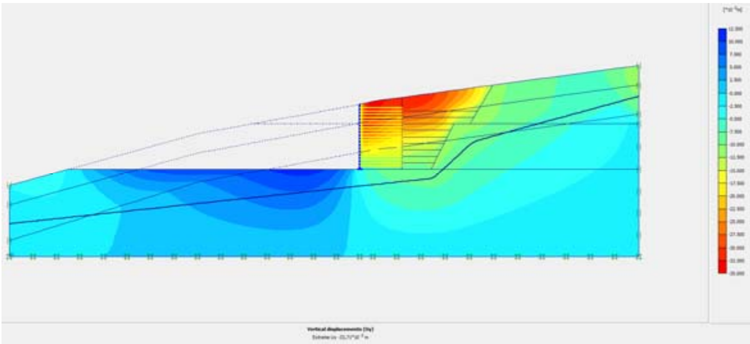


c)



Slika 3. *Horizontalna pomijeranja tla iza lica zida*
Figure 3*. Horizontal displacements of soil behind the wall face*

a)



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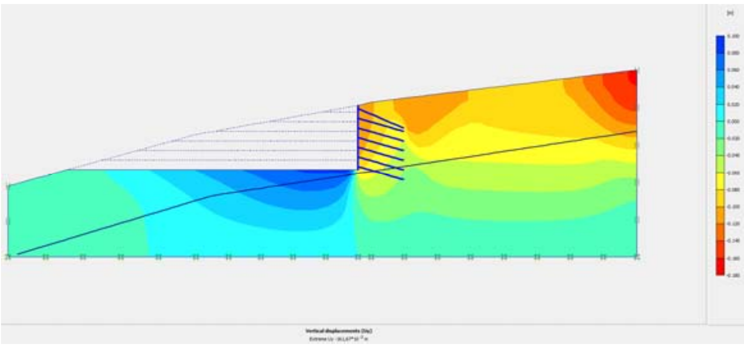
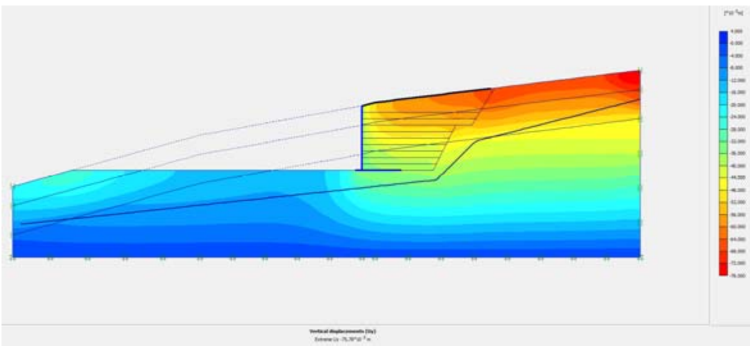


c)



Slika 4. *Vertikalna pomijeranja tla iza lica zida*
Figure 4*. Vertical displacements of soil behind the wall face*

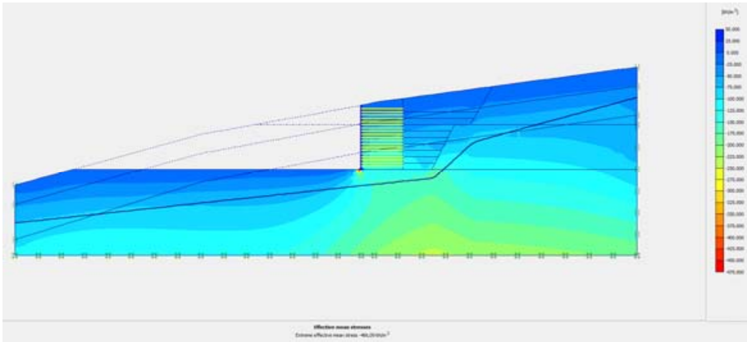
3.3. Efektivni naponi

Maksimalne vrijednosti efektivnih napona tla locirane na dnu (temeljnoj stopi) zida prikazane su na Slici 5: Slika 5.a – armirano tlo (466,09 kN/m^2), Slika 5.b – čavlano tlo (220,19 kN/m^2) i Slika 5.c - betonski potporni zid (237,64 kN/m^2).

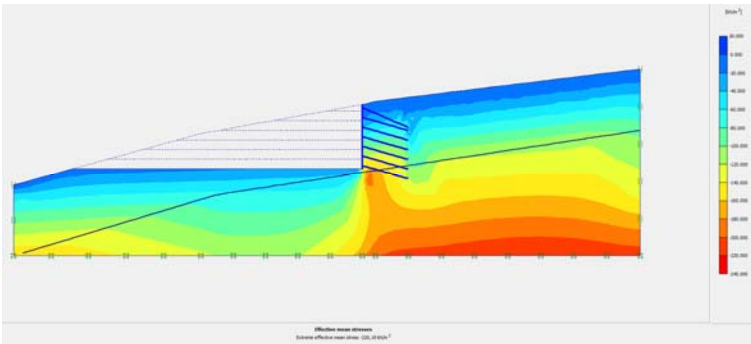
3.3. Effective stresses

Maximal values of effective stresses in soil located on the bottom (base foot) of wall as shown in Figure 5: Figure 5.a – reinforced wall (466,09 kN/m^2), Figure 5.b – soil nail wall (220,19 kN/m^2) i Figure 5.c – concrete retaining wall (237,64 kN/m^2).

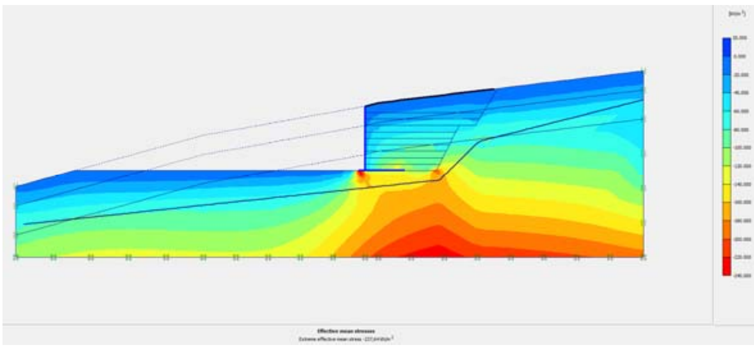
a)



b)



c)



Slika 5. *Efektivni naponi*

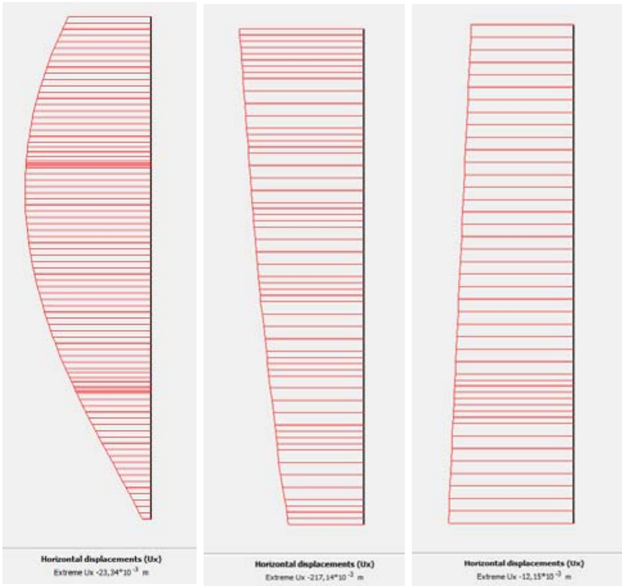
Figure 5. *Effective stresses*

3.4. Horizontalna pomijeranja lica zida

Horizontalna pomijeranja lica zida prikazana su na Slici 6.: Slika 6.a – armirano tlo (-23,34x10^{-3} m), Slika 6.b - čavlano tlo (-217,14x10^{-3} m) i Slika 6.c – betonski potporni zid (-12,15x10^{-3} m).

3.4. Horizontal displacements of wall face

Horizontal displacements of wall face are shown in Figure 6.: Figure 6.a – reinforced wall (-23,34x10^{-3} m), Figure 6.b – soil nail wall (-217,14x10^{-3} m) i Figure 6.c – concrete retaining wall (-12,15x10^{-3} m).



a) b) c)

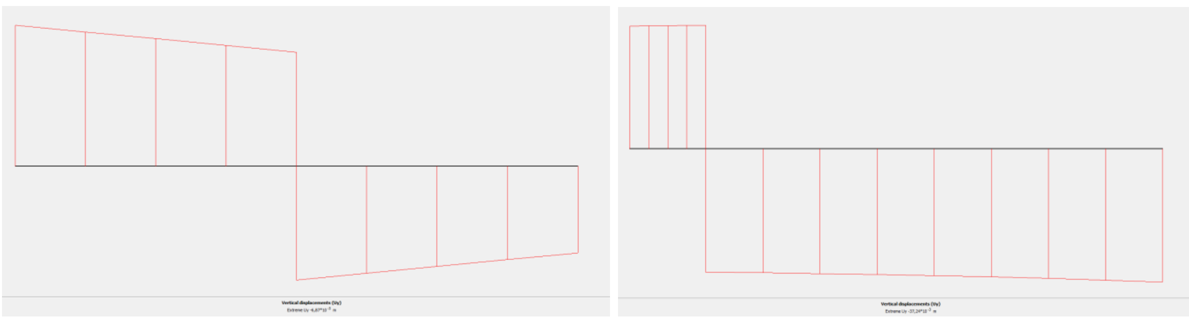
Slika 6. *Horizontalna pomijeranja lica zida*
Figure 6. *Horizontal displacements of wall face*

3.5. Vertikalna pomijeranja stope (armirano tlo i čavlanje)

Kao maksimalna vertikalna pomijeranja stope potpornog zida od armiranog tla i betonskog potpornog zida očitane su vrijednosti i prikazane na Slici 7.: Slika 7.a – armirano tlo ($-6,87*10^{-3}$ m) i Slika 7.b – betonski potporni zid ($-37,24*10^{-3}$ m).

3.5. Vertical displacements of foot (reinforced and soil nail wall)

As maximal vertical displacements on foot of support construction with reinforced and concrete retaining wall there are values presented in Figure 7.: Figure 7.a – reinforced wall ($-6,87*10^{-3}$ m) i Figure 7.b – concrete retaining wall ($-37,24*10^{-3}$ m).



a) b)

Slika 7. *Vertikalna pomijeranja stope*
***Figure** 7. Vertical displacements of foot*

4. ZAKLJUČAK

Na osnovu odrađenih proračuna i analize globalne sigurnosti, za rješenje zaštite ove kosine izabrana je metoda armiranog tla.
Metoda čavlanja tla u programu Plaxis nije zadovoljila faktor sigurnosti FS≥1,3 te je zbog toga kao potencijalno rješenje odbacujemo.

4. CONCLUSION

Based on calculated results and analasys of global stability, as a best solution for a slope insurance a method of reinforced wall is chosen.
A method of soil nailing has not satisfied factors of safety in software Plaxis (FS≥1,3), and for that it is rejected as a potential solution, ž

Potporni zid je zadovoljio faktor globalne sigurnosti međutim pokazuje velika totalna i vertikalna pomijeranja tla iza lica zida kao i vertikalna pomijeranja stope.
Prednosti armiranog tla u odnosu na betonski potporni zid je prvenstveno veći faktor sigurnosti. Potporna konstrukcija je visne 10 m za koju se uglavnom ne izvode betonski potporni zidovi koji su masivni.
Izrada potporne konstrukcije od armiranog tla predstavlja bržu i jeftiniju varijantu koja je pri tome tehnički izvodiva i za visine veće od 25 m, stoga je u ovom slučaju biramo kao rješenje problema.

Retaining wall has satisfied a minimum factor of global safety, but it has great total and vertical displacements of soil behind the wall face so as vertical displacements of foot base.
The adventages of reinforced wall in regards to concrete retaining wall are firstly of all the greater factor of safety. A support construction is 10 m height and for these constructions concrete retaining walls are not used as a massive ones.
Support construction with reinforced wall presents faster and cheaper method which is technically used for heights and above 25 m, so in this case it is chosen as a solution of a problem.

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