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SOIL EROSION PROCESSES IN THE VÎLSAN RIVER WATERSHED AND MITIGATION MEASURES

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Abstract This article is intended to highlight the results of a research carried out on erosion processes in the Vâlsan River watershed in Arges County, Romania. The evolution of the relief fragmentation density in accordance with the general evolution of the hydrographic network, the relief energy as a result of the erosion action on the lithological support, the registered specific soil losses ($t \cdot ha^{-1} \cdot yr^{-1}$), that are influenced by the slope of the land (%) , the volume of liquid runoff (m^3), the volumes of alluvium on the river basin (m^3), all of these are the most important parameters that give a true picture of the land degradation and soil loss in the studied river basin. In order to stop the evolution of the gully erosion process there are proposed and designed some hydrotechnical works consisting in gabions, both as check-dams on the gully erosion formations as well as gabion walls for protection of the riverbanks.

Keywords: gabions, geomorphological parameters, gully erosion, land slope, soil erosion

1. Introduction

The degradation of agricultural land is caused by soil erosion and landslides, causes that are increasingly present and that produced inseminated damage to agriculture at the national and international level.

These phenomena affect the agricultural lands within the small hydrographic basins, where gully erosion in particular (ravines) in combination with land displacements, causes soil losses of the order of thousands of tons per hectare. In Romania, the "Dictionary of geomorphology" defines the ravine as "the form of relief with ditch aspects, which originates on inclined surfaces, formed by friable rocks, following concentrated runoff". At the national level, the total erosion is 126 million tons/year, and the alluvial effluent is 44.6 million tons/year, which represents 35% from the total erosion. Regarding the participation of the forms of erosion to the total erosion rate, 84.5% comes from the agricultural land fund (106.8 million t/year), out of which gully erosion participates with 29.8 million t/year. The total land area annually lost due to gully erosion in Romania is estimated at 2,300 ha, and gullies and torrents contribute 29% of the total erosion, that is 37 million solid materials eroded annually [8]. Out of these, 18.5 million tons end up in rivers in the form of alluvium, representing 37% of alluvium transported annually. In this national erosion context, as a case-study an agricultural land affected by the gully erosion process in Vâlsan River watershed in Arges was analysed. As a soil erosion control measure it was proposed to use gabions for which the stability of gabion walls was calculated both based on formulas by Spanish model [5] and by using the Geo5 software [3]. The major consideration in the design of gabion structures is the expected velocity at the gabion face. The gabion must be designed to withstand the force of the water in the stream. Since gabion mattresses are much shallower and more subject to movement than gabion baskets, care should be taken to design the mattresses such that they can withstand the forces applied to them by the water. However, mattresses have been used in application where very high velocities are present and have performed well [2].

2. Materials and methods

According to the statistics listed above, due to the presence of a major frequency of ravines in small river basins, it was analyzed as a case study, a slope agricultural land on the Solea river basin, one of the 35 river basins that make up the watershed of the Vâlsan river (Figure 1,2,3).

The calculation model and the proposed solution in this case is suitable for all 35 river basins due to the common geotechnical structure, through the presence of marls, sandy clay, and sand marls. This taken into account the average specific erosion of 43.16 $t \cdot ha^{-1}$ versus 43.7 $t \cdot ha^{-1}$ specific to the studied basin [10].

Based on the geotechnical drilling in the area, it was found that the soil up to a depth of 4.3 m is represented by sandy clay and silty clay and up to a depth of 10 m gray silty clay is present.

For the soil stabilization, the supporting walls from the gabions proposed for filling the ravines have the advantage that local low-cost material (stone) can be used in their construction. The gabions are easy to install and can follow different terrain shapes (curves or right angles) [10].The life span is almost limitless, and their constructions doesn´t require qualified personnel. The gabions also have a drainage role due to the capacity of capturing and discharging water from infiltrations. As seen in the field images, the dimensions of the ravines are following depths between 1-3 m, width between 1-5 m and the lengths vary throughout the land reaching up to 10 m. The slope of the land of 28%, according to the average of the region of 25% [1] may determine possible landslides. The basin area of the Vâlsan river is 235,855 km^2, and the density of relief fragmentation where the lithological substratum is represented by clays, marls, sands, the value reaches 9 km/km^2 [6]. The relief energy, which represents the result of the action of erosion on the lithological support, has values between 601-700 m [10].

Fig.1 - Sheet erosion in Vâlsan River watershed

Fig.2 - Gully erosion Vâlsan River watershed

Fig.3 - Sheet and gully

Table 1

Şolea watershed morphometric parameters

Parameter name	Value	Unit of measure
The surface of the river basin	670	Ha
Maximum precipitation in 24 hours with 10% calculation return period	72.5	mm
Weighted average slope of valleys in the hydrographic basin	0.10	%
Volume of liquid leakage	276	m^3
Coefficient of transportability of alluvium	0.30	m^3
The total volume of alluvium in the watershed (Wta)	22,427	m^3
The specific volume of alluvium on the hydrographic basin (m3 , ha-1) with 10% insurance	33.7	m^3 x ha^{-1}

Fig.4 - Studied Area – Braduleţ, Argeş

The studied land is located in Bradulet commune, Arges County (Figure 4), on the watershed Şolea with morphometric parameters presents in the Table no.1, and has an area of 6,500 m^2, it is 130 m long and 50 m wide. According to the altitudes of the land, the maximum level is 803 m, and the minimum level is 765 m (the difference in altitude is 37 m). The altitude of the land was calculated using the Altimeter application.

3. Results and discussion

For the calculation of the gabion walls needed to stabilize the ravines, the following general data were used, and the stability factor was calculated for 1 m length of the gabion wallwith a height (H) of 1.5 m in Figure 5 and H of 1 m in Figure 6.

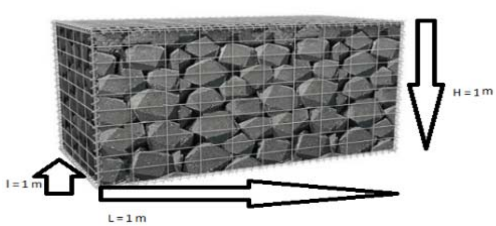


Fig.5 - Gabion basckets' with H=1m

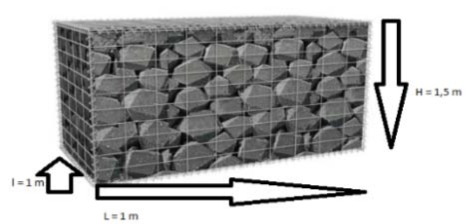


Fig.6 - Gabion basckets' with H=1,5m

The dimensioning model of gabions is inspired by the calculations belonging to the Spanish engineers. Below are presented the necessary dimensioning parameters (Table 2), the dimensions of the ravines and of the gabion´s walls (Table3, Table 4) as well as the formulas used in the Table 5.

Table 2

General parameters for sizing gab

Parameter name	Symbol and value
The slope of the limiting terrain	α=28°
Inclination of the inner face of the wall	β= -5°
The angle of internal friction	Φ=32°
The apparent soil density	D_a = 1900 kg/m^3
The apparent density of the filling	D_u = 2300 km/m^3
Soil pressure	P_b = 25.000 kg/m^2
Overload	q=0

Table 3

Dimensions gully no.1 and Gabion Wall

	H (m)	L (m)	l (m)	B gabion base (m)
Dimensions of gully no. 1	2,5	10	3	
Gabion Wall Dimensions	2,5	10		3

Fig.7 - Gully no. 1

Table 4

Dimensions of gully 2 and Gabion Wall

	H (m)	L (m)	l (m)	B gabion base (m)
Dimensions of gully no. 2	3	8	3	
Gabion Wall Dimensions	3,0	8		3

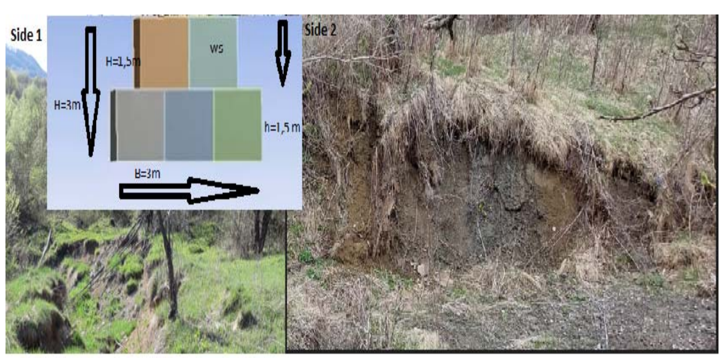


Fig.8 - Gully no. 2

Table 5

Formulas for calculating the dimensions of gabion walls

Parameter name	Symbol and value
Active soil pressure	$Pa = ½*D_a*H^2*k_a$
Active pressure coefficient	$K_a= Tan^2(45 – Φ/2)$
The moment of overturning	$M_o = Pa* H/3$
The weight of the gabion box	$G = D_u * V * 0,8$ (kg/m)
The total weight of the blocks	Gt= G*n (n= no gabion box) (Kg/m)
Coefficient for the material from which the box is made	0,8
Vertical weight	$ws = (L*l*h) * D_a$ (kg/m)
Horizontal distance to the center of gravity	dq (m)
The moment of resistance	$M_r = G_t * dq_t+ ws*dq1$ (kg/m/m)
The overturning safety factor	$SF = M_r /M_o$
Safety factor when sliding	SFr = (Gt+ws) * tanΦ / Pa
Coefficient for the elasticity factor	$X = M_r – M_o / N$ $N = G_t + ws$
Eccentricity limit	e= B/2 – X < B/6
Maximum pressure on the foundation	$p = G_t /B *(1+6e/B)$ $p≤P_b$

Table 6

Gully no.1 wall dimensioning calculation (result)

Gully no.1	Pa	Ka	G_t Kg/m	Ws Kg/m	M_o Kg/m/m	M_r Kg/m/m	SF>2	SFr>1,5	X	e B/2-X<B/6	$p≤P_b$ kg/m^2
	1781	0,30	11960	950	1781	20552,5	11,54	7,2	1,45	1,5-1,45=0,05<0,5	43867< 25000

Table 7

Gully no. 2 wall dimensioning calculation (result)

Gully no.2	Pa	Ka	Gt Kg/m	Ws Kg/m	Mo Kg/m/m	Mr Kg/m/m	SF>2	SFr>1,5	X	e B/2-X<B/6	p≤Pb kg/m2
	2565	0,30	13800	1425	2565	24619	9,6	3,7	1,4	1,5-1,4=0,1<0,5	5520< 25000

The calculations were performed by the author of this article according to the calculation guidelines regarding the stability of the gabions based on the geotechnical parameters of the soil and field measurements (the calculations are not reproduced). It is found from the calculations in the Tables 6 and 7 that the eccentricity limit (e) is met, as well as the condition that the maximum pressure on the foundation (p) is less than or equal to the admissible soil pressure (Pb). To stabilize the entire land, it is proposed to build a gabion wall located at the base of the slope in Figure 9 on a length of 30 m, with a height of 3 m. The sizing calculation were made using the Geo5 software, generating the stability factors.

Fig.9 - Gabion wall proposal

The parameters of the earth used in the calculation of the land´s stability is presented to Figure 10 and the slope stability verification in Geo5 is presented to Figure 12.

GEO5 is a powerful software suitable for solving geotechnical problems based on traditional analytical methods and Finite Element Method (FEM). Individual programs verify a specific structure, which keeps them intuitive and easy to use. Individual programs have the same user interface and communicate with each other, while each program verifies definite structure type. The basic geotechnical approaches implemented in the GEO5 software are applicable all over the world, although most countries adopt their own standards and conventions. GEO5 offers a unique way of applying standards which significantly simplifies the work of the designer and at the same time allows to verify the structure with all the required approaches.

GEO5 allows setting of standards and analysis methods centralize for all GEO5 programs. The program allows to perform the structure verification according to five methodologies: Verification according to safety factor (ASD), limit states, EN 1997, LRFD and Chinese standards. The verification methodology based on the "Safety factor" is historically the oldest and most widely used approach for structure safety verification. The principal advantage is its simplicity and lucidity. In general, the safety is proved using the safety factor:

$$FS = \frac{X_{pas}}{X_{act}} > FS_{req}$$

Where, FS is computed factor of safety, X_{pas} is a variable resisting the failure (resisting force, strength, capacity), X_{act} is a variable the causing failure (sliding force, stress) and FS_{req} is the required factor of safety. When performing the analysis using the "Safety factor", neither the load nor the soil parameters are reduced by any of the design coefficients [4].

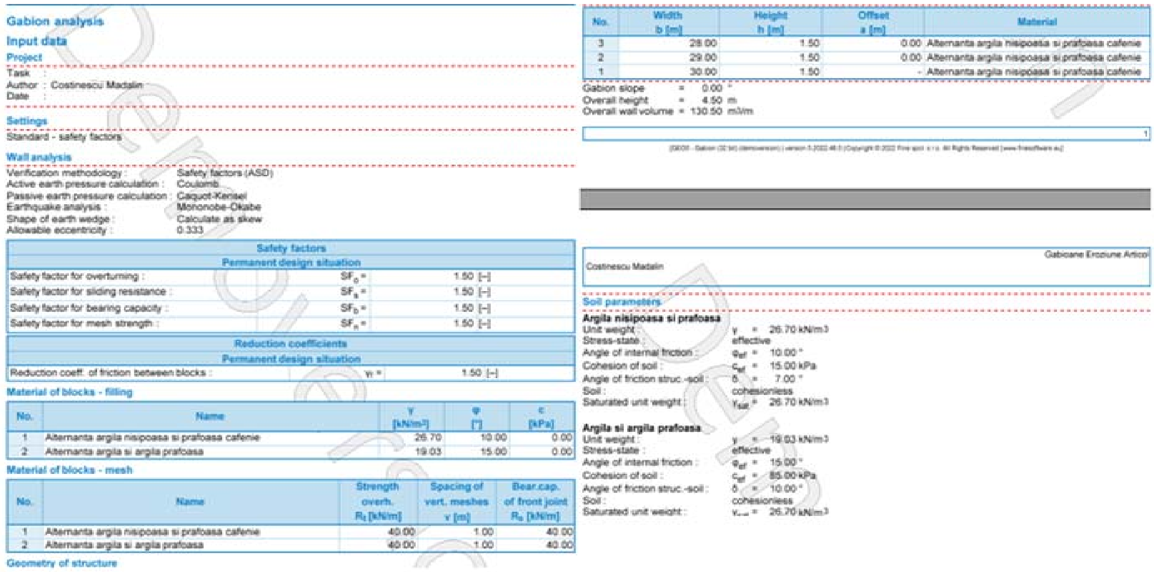
In the capture from Figure 10 and Figure 12 is highlighted the result of the stability calculation for the gabion´s wall designed in GEO5. The result includes the confirmation regarding the stability of the land on the slope with a stability factor of 1.81, value above the stability limit of 1.50. In order to calculate the stability, the soil parameters for the soil layers resulting from the geotechnical study of the area were entered into the GEO5 platform. The main soil layer such as sandy clay and dusty clay are angle of internal friction of 10.00°, cohesion of soil of 15 kPa, angle of friction structure-soil of 7.00° and saturated unit weight of 26.70 Kn/m^3.

The second soil layer which has in composition sandy and sandy clay with the angle of internal friction of 15.00°, the cohesion of the soil is of 85 kPa, the angle of the friction structure-soil is of 10.00° and the saturated unit weight of 26.70 Kn/m^3.The calculation of local stability of the land in the slope studied was carried out using the GEO5 program. The calculation methods used are:

"Sarma" method – method based on limit equilibrium, in which the volume of soil located above the potential sliding surface is divided into blocks. By applying the criterion of satisfying the balance conditions of moments and forces, information is obtained regarding the balance of each individual block and finally the balance of the massif analyzed.

Method „Bishop” - method based on the boundary balance, in which the rupture occurs after a single, cylindrical, ceding surface. The shear strength along the breaking surface corresponds to the same deformations and accordingly to the same degree of shear strength mobilization.

Based on geotechnical data, the stability analysis was performed with the calculation hypothesis in which the land is naturally without an overload. The stability analysis was carried out in accordance with the provisions of Eurocode 7 – SR EN 1997-1, taking into account this calculation approach.



Gabion analysis

Input data

Project

Task :
Author : Costinescu Madalin
Date :

Settings

Standard - safety factors

Wall analysis

Verification methodology : Safety factors (ASD)
Active earth pressure calculation : Coulomb
Passive earth pressure calculation : Caquot-Kerisel
Earthquake analysis : Mononobe-Okabe
Shape of earth wedge : Calculate as skew
Allowable eccentricity : 0.333

Safety factors		
Permanent design situation		
Safety factor for overturning :	SF_o =	1.50 [–]
Safety factor for sliding resistance :	SF_s =	1.50 [–]
Safety factor for bearing capacity :	SF_b =	1.50 [–]
Safety factor for mesh strength :	SF_n =	1.50 [–]

Reduction coefficients		
Permanent design situation		
Reduction coeff. of friction between blocks :	γ_t =	1.50 [–]

Material of blocks - filling

No.	Name	γ [kN/m³]	φ [°]	c [kPa]
1	Alternanta argila nisipoasa si prafoasa cafenie	26.70	10.00	0.00
2	Alternanta argila si argila prafoasa	19.03	15.00	0.00

Material of blocks - mesh

No.	Name	Strength overh. R_t [kN/m]	Spacing of vert. meshes v [m]	Bear.cap. of front joint R_s [kN/m]
1	Alternanta argila nisipoasa si prafoasa cafenie	40.00	1.00	40.00
2	Alternanta argila si argila prafoasa	40.00	1.00	40.00

Geometry of structure

No.	Width b [m]	Height h [m]	Offset a [m]	Material
3	28.00	1.50	0.00	Alternanta argila nisipoasa si prafoasa cafenie
2	29.00	1.50	0.00	Alternanta argila nisipoasa si prafoasa cafenie
1	30.00	1.50	-	Alternanta argila nisipoasa si prafoasa cafenie

Gabion slope = 0.00 °
Overall height = 4.50 m
Overall wall volume = 130.50 m3/m

1

Costinescu Madalin
Gabioane Eroziune Artico

Soil parameters

Argila nisipoasa si prafoasa
Unit weight : γ = 26.70 kN/m3
Stress-state : effective
Angle of internal friction : φ_{ef} = 10.00 °
Cohesion of soil : c_{ef} = 15.00 kPa
Angle of friction struc.-soil : δ = 7.00 °
Soil : cohesionless
Saturated unit weight : γ_{sat} = 26.70 kN/m3

Argila si argila prafoasa
Unit weight : γ = 19.03 kN/m3
Stress-state : effective
Angle of internal friction : φ_{ef} = 15.00 °
Cohesion of soil : c_{ef} = 85.00 kPa
Angle of friction struc.-soil : δ = 10.00 °
Soil : cohesionless
Saturated unit weight : γ_{sat} = 26.70 kN/m3

Fig. 10 - Parameters of soil used in Geo5

Calculation approaches are expressed symbolically by combining sets of partial coefficients for actions and effects of actions (A), for material properties (M) and for resistances (R). In the stability analysis of the slopes (generally the sloping soils masses), the following calculation approaches are used:

Approach 1:

In this approach, the partial coefficients are applied to the source, that is, on the representative values of the actions and on the characteristic values of the parameters of the shear resistance of the land. There are two groups of partial coefficients:

Group 1: A1 “+” M1 “+” R1:

This grouping aims to achieve safety against unfavorable deviations by reference to the characteristic values of actions or effect of actions, while the calculation values of land properties are equal to the characteristic values.

Group 2: A2 “+” M2 “+” R1

This grouping aims to achieve safety against unfavorable deviations in relation to the characteristic values of the soil resistance parameters and to the uncertainties in the calculation model, admitting at the same time that the permanent actions are very close to the representative values and the variable actions can deviate a little in the case of unfavorably deviasons from representative values.

The approach 3

In this approach, a single grouping of partial coefficient sets is used: (A1* or A2*) “+” M2 “+” R3. The characteristic values of the actions coming from the structure are multiplied by the partial coefficients of the set A1 to establish the calculation values. The calculation values of the actions generated by the land (geotechnical actions) are established using the partial coefficients from the M2 set for the parameters of the resistance of the land and from the A2 set for the actions.

The dynamic stability calculations (in earthquake) were made with the bishop balance limit method (considering a land acceleration value for design ag = 0.25 g (Figure 11), in two distinct situations:

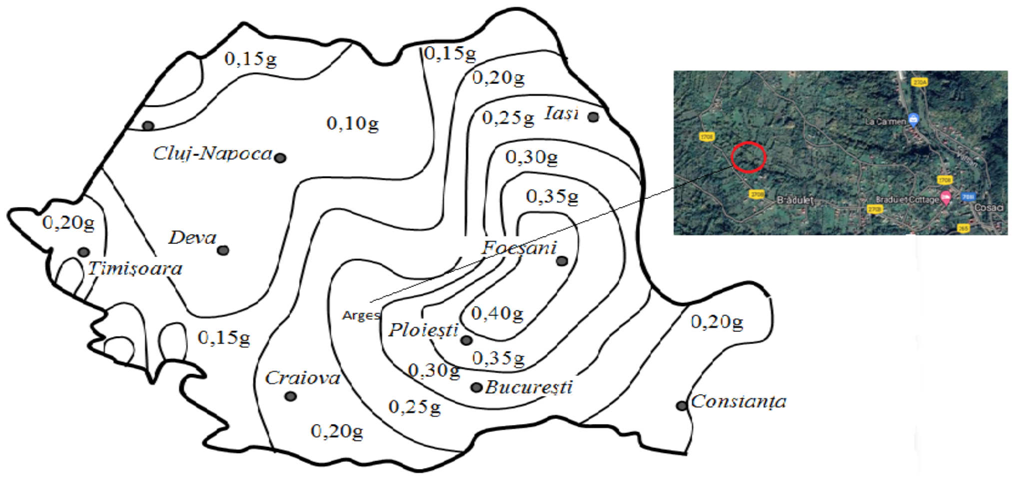


Fig.11 - Seismic zoning map according P100 – 1/2013

- according to the classical methodology, the verification is carried out based on the allowable stability factor, so that Fs min effective ≥ Fs admissible. Following the stability calculation in Geo5 Fs min effective = 1.80 ≥ Fs admissible = 1.50 (Figure 12).
- according to SR EN 1997-1, SR EN 1990/NA, SR EN 1998-1, SR EN 1998-5, and SR EN 1998- 5/NA for verification with GEO5 limit state. The partial safety coefficients for the actions or the effects of the actions in the earthquake calculation are equal to the unit, according to SR EN 1990/NA. As input data, the calculation values of the shear resistance parameters were introduced to the terrain characteristics, applying the partial coefficients specified in SR EN 1998-5/NA that are equal in value to those corresponding to the M2 set of SRS EN1997-1.

Table 8

Calculation of seismic coefficients according to SR EN 1998-5:2006

Seismic zone	a_g	k_h	k_v
Curtea de Arges - Bradulet	0.25	0.34	0.17

Where:

a_g = acceleration of the land for design = 0.25

k_h (horizontal seismic coefficient) = $S \cdot a_g/r$ in which Sag represents the maximum seismic acceleration value of the land for the various categories of stratigraphic profile. To the factor r can be assigned the value r = 2 in the case of quite flexible works (weight walls), while in all other cases it is given the value 1 (walls resistant to flexion, walls on pilots or anchors, closing walls) and k_v (vertical seismic coefficient) = 0.5 * k_h

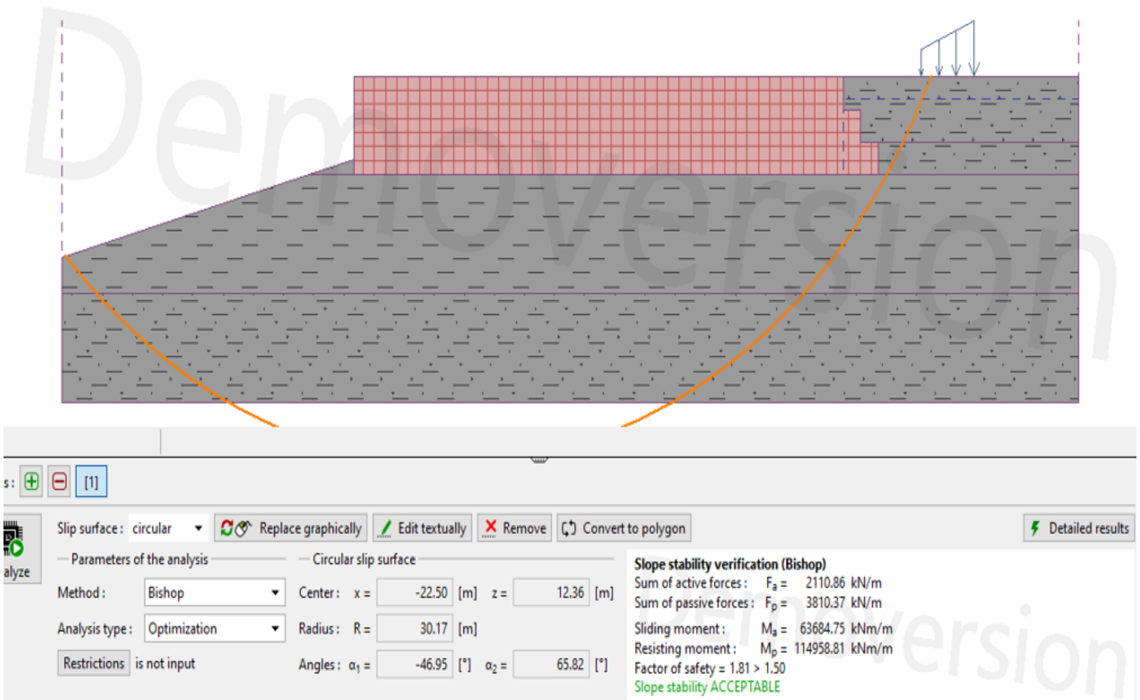


Fig. 12 - Slope stability verification

4. Conclusions

According to the previously proposed works to be implemented, the stability of the lands affected by gully erosion and landslides, can be achieved. This way the land can be stabilized and reintroduced in the economic circle of agriculture and in the same time soil losses caused by gully erosion are minimized. The present solution is based on the construction of gabion walls. The ravines will be covered with soil so that the land is levelled keeping its slope in order to be restored to the agricultural economic circuit by reusing it as pastures. Moreover, to achieave of further stability of the land, it is also proposed to plant an orchard as a source of an additional contribution from the economic point of view.

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