Landslide phenomenon that affected the integrity of the OCP DDV at abscissa KP 318+419; analysis and solution.

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ABSTRACT

The site subject of the following analysis is located in the sector of Pedro Vicente Maldonado province of Pichincha within the Ecuadorian territory at the abscissa known as KP 318+419. During 2005, as a result of heavy rains, small landslides occurred on the slope adjacent to the easement strip of the OCP DDV where there is an old landslide that was beginning to reactivate. OCP as part of the maintenance started to build surface drainage works to reduce the degree of vulnerability of the infrastructure installed there. The reactivation of this landslide was repeated in the following years; thus, in February 2018 and April 2021, landslides again occurred in the lower part of the slope and affected OCP Ecuador S.A.'s easement strip. The site where the landslide occurred is a gully with a height of 11m and a length of 48m occupying an area of 528m^2.The soils the site corresponds to tuffs in the superficial part, clays in the middle part and weathered siltstones at the foot of the slid slope. In order to minimize the risk of the event, several geological-geotechnical studies were carried out to characterize the geotechnical part and obtain a technical-economic solution that stabilizes the slope, protects the infrastructure installed there and is environmentally friendly.

Key words: Pipeline; Landslide phenomenon; Vulnerability; Stabilization; Probability of failure, factor of safety.

1. INTRODUCTION

Landslide phenomena affected a large part of the route of the OCP Ecuador S.A. Heavy Crude Oil Pipeline, which crosses three regions (Coast, Andean Highlands and Amazon), with geology, geomorphology and the presence of diverse and adverse climatic conditions where various natural phenomena occur (erosion, landslides, lahars, reptations, mud and debris flows, etc.). OCP Ecuador S.A as part of its Management System performs periodic geotechnical monitoring in order to detect all those areas potentially affected by landslides, vegetation cover problems and any other problem that could jeopardize the integrity of the pipeline, the safety of people or property adjacent to its area of influence; all of this is to comply with the provisions established in the Environmental Management plan for the operation stage of the Heavy Crude Oil Pipeline and the legal provisions and international standards governing all oil transportation operations.

2. METHODOLOGY

The methodology used for geotechnical management consist mainly of the following monitoring techniques:

- Visual monitoring of the DDV easement strip and its area of influence, by means of constant patrolling with trained technical personnel.
- Monitoring by photogrammetry (drones, lidar, etc).
- Survey of geological-geotechnical surface field information to characterize the landslide with existing preliminary topographic information.
- Topographic survey of the site to scale1:400.
- Realization of three geophysical investigation profiles using the seismic refraction method.
- Execution of two SPT boreholes along the landslide with unaltered samples to obtain the geomechanical properties of the soil (cohesion, friction angle, density; etc).
- Calculation of the PoF (probability of failure of the landslide).
- Geotechnical stabilization works design.
- Construction of stabilization alternative.
- Monitoring of implemented solutions and evaluation of their degrees of effectiveness.

All these techniques were used to design the final solution to the active slip that was affecting the OCP ROW at KP 318+419.

3. RESULTS AND DISCUSSION

The heavy crude oil pipeline (OCP Ecuador S. A) at the abscissa KP 318+419 crosses a low to moderate hilly area and is surrounded by moderate slopes with grassland vegetation within the right of way and secondary forest in the right bank outside the easement strip. The site where the landslide occurred is a gully that was filled with soil from the cutting of slopes during the construction of the ROW, this phenomenon of mass removal generated corresponds to a crescent-shaped rotational landslide, the escarpment formed by the landslide had a height of 11m and a length of 48m, the distance to the axis of the OCP was 8.0m (see figure 1); the slope has a slope of 40 degrees. (OCP ECUADOR S.A, 2021).

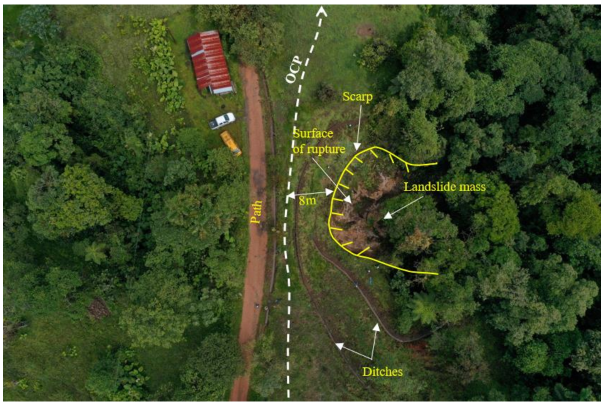

FIGURE 1. Slide location.

The drainage system consisted of three coronation ditches built in natural soil that drain to the lower parts of the hillside where there is a small creek.

3.1 Geophysical Survey Results

In the KP 318+400 sector, three seismic lines were executed, two of 55.00 meters and one of 80.00 meters in length, whose location by coordinates is show in Figure 2.

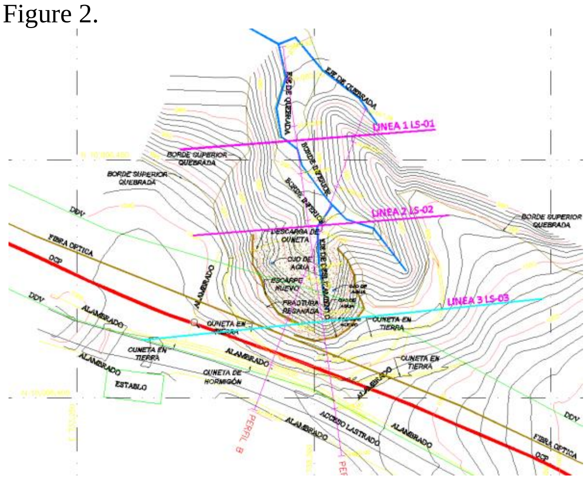

FIGURE 2. Location of the lines of geophysical research.

3.1.1 Interpretation of the Lithology According to the Seismic Refraction Lines and their Velocities

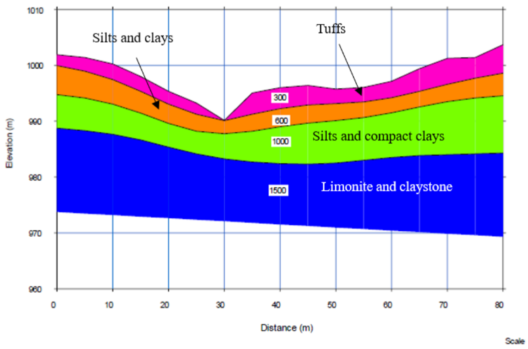

FIGURE 3. Interpretation of the geophysical line LS-03

As can be seen, the materials that make up the geological environment are very similar, the distribution in layers is due to the different degree of compaction, moisture content, etc. (OCP Ecuador S.A, 2021)

3.2 Results by SPT Drilling

The lithology of the site corresponds to a sequence of dark brown tuffs with an average height of 4.0m, its SUCS classification corresponds to clayey silt and sandy silt soils, slightly humid, under this stratum there is a layer of very compact light gray clays, and at the base of the landslide the presence of a layer of weathered yellowish-white siltstones of very compact consistency was observed. The subsurface water runoff is observed through these two layers of material, and they constitute the fault plane of the landslide (see figure 2 and figure 3). (OCP Ecuador S.A, 2021)

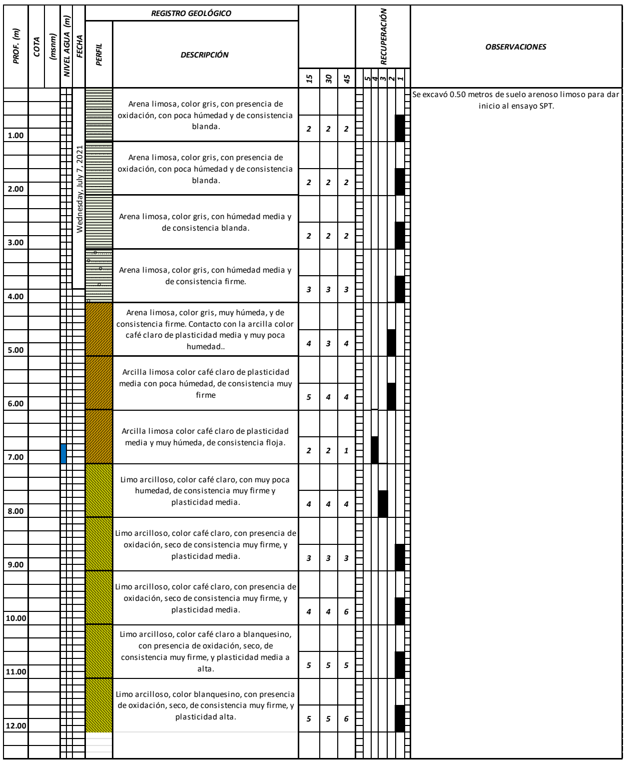

FIGURE 4. Lithological columna according to SPT -01

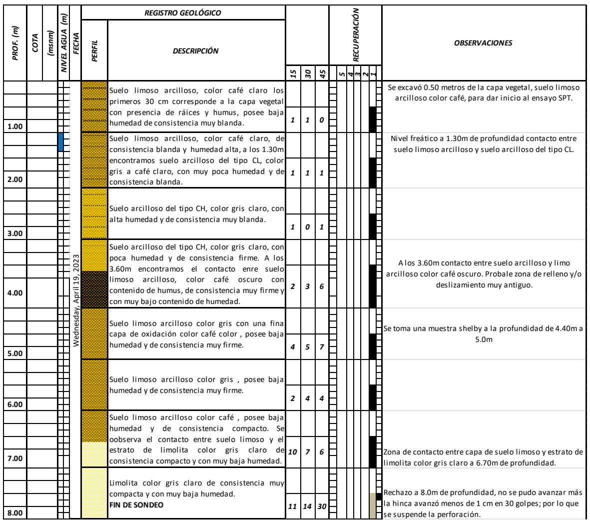

FIGURE 5. Lithological columna according to SPT -02

3.2.1 Laboratory Test

Laboratory tests consistent with the altered samples recovered during the progress of the soundings were carried out in:

Moisture content	ASTM D-2216
Granulometry by washing	ASTM D-422
Atterberg limits	ASTM D-4318
Triaxial UU	ASTM D-2850

The results obtained in these tests served to classify the soils according to the SUCS Unified System, which allowed knowing the stratigraphic sequence of the subsoil.

The tests were carried out in accordance with the current processes and standards specified by the INEN and ASTM.

Table 1. Summary of SUCS classification results.

SUCS CLASIFICATION									
ID	SAMPLE DEPTH (m)	MOISTUR CONTENT (%)	ATTERBEG LIMITS			GRAIN SIZE			SUCS
			LL	PL	PI	% GRAVEL	SAND	% FINES	
SPT-01	12.0-13.20	114.17	148	79	69	0	14	80	MH
SPT-02	2.40-3.14	115.25	121	75	46	0	20	80	MH

Table 2. Triaxial test results.

TRIAXIAL ASTM 2850						
Drill hole	Depth (m)	Gravedad Específica (gr/cm^3)	C (kPa)	Ø (°)	Ɣd KN/m3	Ɣm KN/m3
SPT-1	12.60-13.20	2.67	23.5	4.9	5.93	12.65
SPT-2	2.40-3.14	2.66	68.80	3.5	6.14	13.16

3.3 Stability Analysis

In order to analyze the conditions that the slope will present, we proceeded to develop geotechnical models taking into account the current topographic survey of the area, as well as the use of geomechanical parameters of resistance to cutting of the soils tested. The models were defined and analyzed by computer programs based on finite elements. These parameters correspond to the shear strength values of the materials, the groundwater conditions and the seismic acceleration coefficient for the pseudostatic analysis.

Condition 1. Generation off orces and deformations with the current conditions.

In this stage, the stresses and deformations are generated under the current conditions, that is, according to the parameters obtained from the undisturbed samples, a stability analysis is carried out, assuming a rise in the water table. As a result, it is obtained that the slope in static conditions was stable.

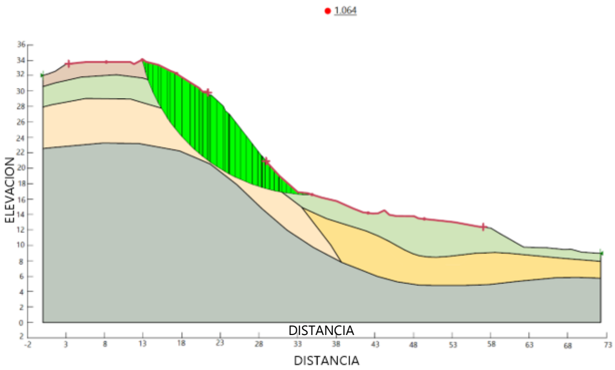

FIGURE 6. Stability analysis under static conditions.

Condition 2. Loss of mechanical properties

In this stage, a retroanalysis is carried out in the stability analysis model, where a loss of the values of the mechanical properties of the soil is considered due to the saturation of the soil structure. That is, make a model in which the problem of slope instability is presented with the objective of reproducing the approximate change pattern in pseudostatic conditions (with seismic acceleration data according to the history of earthquakes in the area of influence of the study site). As we can see in the figure, the slope is unstable with the presence of earthquakes of moderate intensity.

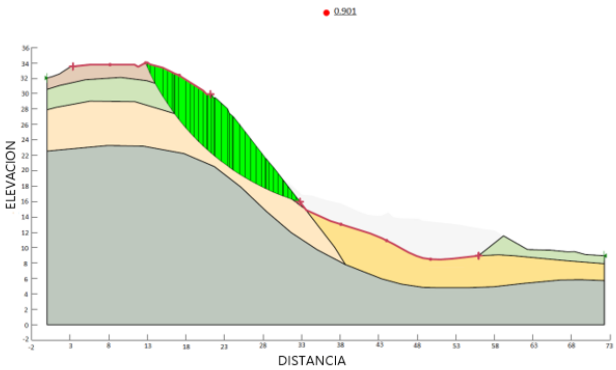

FIGURE 7. Stability analysis under pseudostatic conditions.

3.3.1 Calculation of Probability of Landslide Failure (PoF)

It corresponds to a methodology proposed by Naviq Consult Inc. (Naviq) in 2014, which provided its services for the evaluation of geological risks that constitute a hazard to the integrity of the pipeline operated by OCP S.A.
Included in this calculation are data on the static and pseudostatic factor of safety, depth of the water table, type of soil, type of vegetation, width and length of the landslide, soil permeability, depth of the pipe, depth of failure plane, area of the recharge basin, return period of rains and earthquakes, sliding speed and vulnerability of the pipeline with respect to the direction, position, shape and depth of the sliding. Figure 8 shows the calculation of the PoF before executing the mitigation works.

24/06/2021

KP 318+419
PRE MITIGACIÓN
DATOS

Ii	Fs est:		1.07				*Ii:*	*0.82*
	Fs seudo est:		0.689					
	v:		1					*1.00*
	H agua crít:	[illegible]	1.025					
	w desliz:	[illegible]	55					
	K:	[illegible]	0.036					
	i:		40°	%	83.91			
	A cuenca:	[illegible]	7917					
	$Ic = \frac{v * w * h * k * i}{A}$							
	Ic:	[illegible]	0.021510085					
		[illegible]	21.51008526					
	aH:	[illegible]	0.01					
	M:		3.7					
	Pdo retor. lluv.	año				<1	1.00	
	Pdo retor. sismo.	año	0.01	0.005	0.01118	1.652	44.87454	
	flluv:		1					
	fsismo:		0.02					
	IF	1.00000						
Fr	Veloc. Desplaz.	[illegible]	gradual				*Fr:*	*0.10*
		[illegible]	gradual					
Vi	L horiz:	[illegible]	25				*Vi:*	*0.395*
	w proyec:	[illegible]	55					
	fd:		0.5					
	fp:		0.79					
	fl:		1					
PoF	$PoF = Ii * Fi * Fr * Vi$						PoF:	3.24E-02

ANALIZADO POR:	MICHAEL GIBBONS

Probabilidad	Definición	Evento/año
Inminente	Su ocurrencia es inminente y en el muy corto plazo	$>10^{1}$
Muy probable	Ha ocurrido más de 2 veces en la empresa	$10^{1} - 10^{2}$
Probable	Ha ocurrido en la empresa	$10^{2} - 10^{4}$
Poco probable	Evento posible en la industría, pero raramente ocurre	$10^{4} - 10^{6}$
Improbable	Su ocurrencia es teóricamente posible pero no se conoce que haya ocurrido en la industría.	$<10^{6}$

FIGURE 8. Pre-mitigation PoF calculation.

3.4 Stabilization Solutions

Alternative 1
Gabion wall

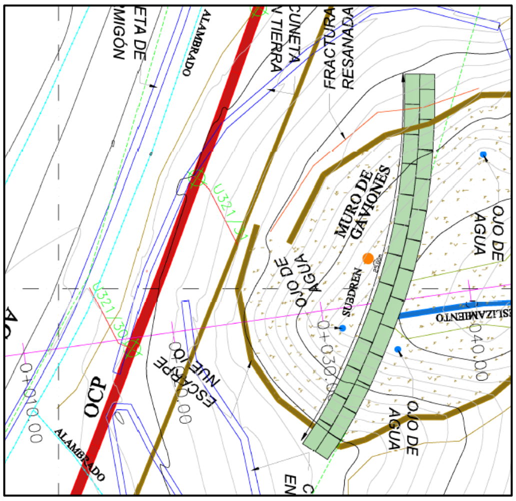

FIGURE 9. Gabion wall design.

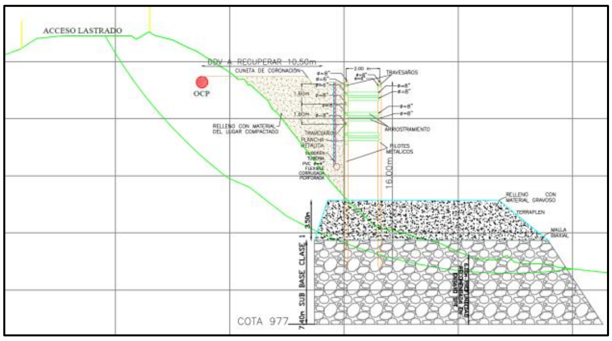

FIGURE 10. Cross section detail metal screen.

Calculation of the factor of safety

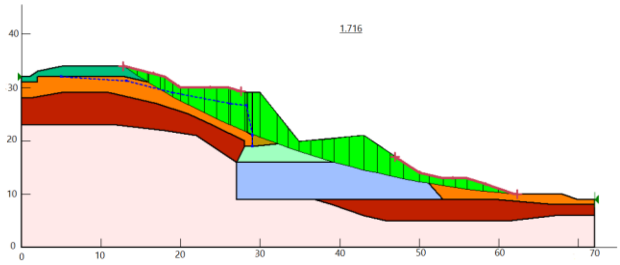

FIGURE 11. Safety factor in static conditions with the execution of the gabion wall.

Alternative 2
Mechanically stabilized soil wall

The composite stability of the mechanically stabilized soil system includes part of a combined external and internal stability analysis where it is verified that both the retained soil NOT reinforced and part of the reinforced fill interact to give an acceptable Factor of Safety. For the construction of this alternative, high-resistance polyester geotextiles, which have proven to have a great performance capacity for mechanically stabilized walls and slopes. Figure 12 presents the profile of the proposed solution. (Rodríguez, 2021). For the project, load was considered due to the traffic of the road above the reinforced slope of 12kN/m2; Additionally, a horizontal acceleration of 0.20g was considered and represented 50% of the maximum acceleration of 0.40g, which is the seismic acceleration threshold established by OCP in this sector. This decrease in top acceleration in walls and slopes corresponds to a good practice adopted for this type of structures.

During the construction of the mechanically stabilized soil wall, the foot of the slope was first reinforced using a platform by driving piles with 8-inch pipes with a shear resistance of 100KN, which were embedded at a maximum depth of 6m, which was the gust level. to piloting. A bed of ballast wrapped in non-woven geotextile and reinforced with geotensioning was placed on top of the piles, after which three platforms of reinforced earth walls wrapped in non-woven geotextile and reinforced with high-strength woven geotextile were assembled. where it gave us a safety factor of 1.49.

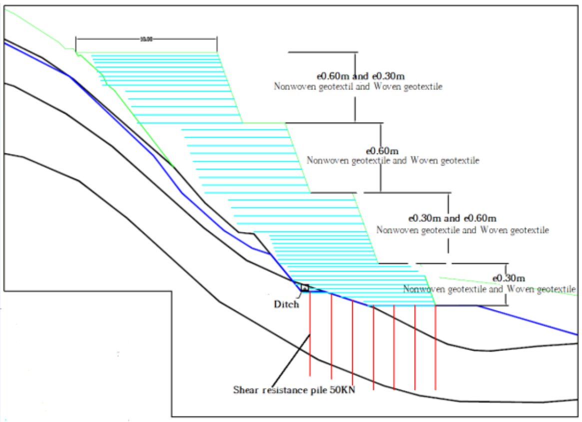

FIGURE 12. Soil wall solution for slope stabilization.

Calculation of the factory of safety

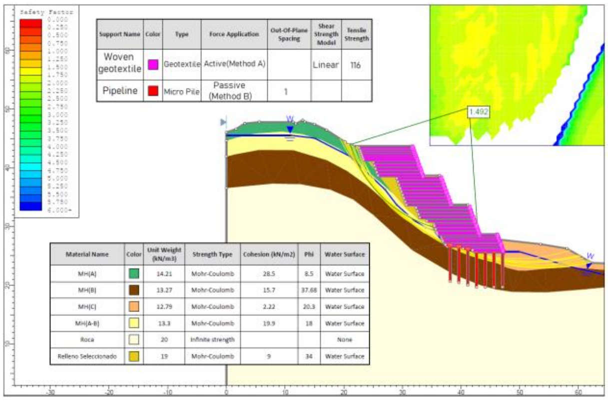

FIGURE 13. Static stabilization analysis Global Slope Mechanically Stabilized.

4. CONCLUSION

According to the geotechnical studies and slope stability analysis, the safety factor was at the equilibrium state limit. OCP Ecuador S.A, due to security regulations, it was decided to execute the alternative of the mechanically stabilized soil wall; because the safety factor was increased to 1.49 and the proposal was technically and economically viable.

5. REFERENCES

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