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# "ENGINEERING FOR THE PALLIATIVE RECONNECTION OF OCLC PIPELINE AT PK 133+000, IN THE SECTOR OF LA CHINA, NORTE DE SANTANDER

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## ABSTRACT

*Within the particular context of the Cortinas area, located in Toledo, department of Norte de Santander, Colombia, there is a sector that is characterized by frequently presenting mass removal movements that constitute a latent geotechnical threat to residents, homes and buildings; among them, that of the hydrocarbon transportation systems, which have been affected to the point of failure, the last of this nature being the one that occurred in August 2021.*

*Since then and until today, the companies that own the pipelines have implemented strategies that must solve both the technical and socio-environmental-economic complexity, typical of the region; this in order to achieve, the immediate provisional recovery and in the long term, the normalization of it.*

*In accordance with the above, Cenit, owner of the Caño Limón Coveñas pipeline, decided to locate the pipeline on the surface of the current Right of Way, for which it was necessary to specify both the engineering design and the layout of the pipeline, the construction procedure and its protection; In addition, a monitoring system was proposed whose results should be analyzed in the coming times. The details of these activities constitute the content of this paper.*

*Keywords: Geotechnical risk, reconnection, accumulated geotechnical deterioration, palliative, monitoring, flexibility, bioengineering, carbon footprint.*

## NOMENCLATURE

DGA: Accumulated Geotechnical Deterioration.
SAR: System to monitor surface deformations using the SBAS advanced differential interferometry technique.
PHD: Horizontal Directional Drilling.
"Palliative": optimized partial mitigation, Colloquial term adopted by the project.

## 1. INTRODUCTION

The Cortinas area is located in the municipality of Toledo, Norte de Santander, it constitutes one of the scenarios where the special behavior of the Colombian geography can be verified, given its special geological, geomorphological and geotechnical conditions. The zone is characterized by extensive and deep unconsolidated hillside deposits with evidence of multiple ancient landslides that involve the rock massifs which are of sedimentary origin with intercalations of hard rocks with laminated soft rocks, with a high level of weathering, high fracturing, folded, with marked out-of-phase dip and groundwater currents with very considerable flows.

In the Cortinas area, there is a sector that, along four kilometers, is delimited between the escarpments that reach a height of six hundred meters, and the foot of its slopes that finally adjoin the left bank of the La China ravine, with an average height of 484 m.s.n.m. This sector, which faces the urban center of Samoré and the reserve areas of the Uwa indigenous community, both located on the right bank of the same ravine, is characterized by presenting, differentially but periodically (approximately every 20 years), movements of mass removal, landslides, which have constituted a permanently latent geotechnical threat for the inhabitants, the houses and existing constructions; such as homes, power towers, a primary road, as well as the infrastructure for hydrocarbons, one for gas and another that transports oil owned by Cenit. Historically, geotechnical events materialized in landslides have been known where the aforementioned hydrocarbon pipelines have been affected, generating deformation, sometimes even breaking with the immediate consequence of the suspension of the corresponding flow and environmental contamination. The last event of this nature occurred in August 2021 and the previous one in 1988.

**Figure 1. General aerial photo of the landslide La China PK 133+000.**

**Source: The author.**

From then until today, the companies that own the pipelines, each one for its part, depending on the magnitude of its impact and its organizational policies, have been developing their respective strategies for immediate recovery and normalization with projection long-term. Such strategies, in addition to resolving the technical problems, must include, as part of the solution alternatives studied, the complexity derived from both the social condition that prevails in the area, as well as those of the neighborhood with the property owners and the environmental requirements. current.

Particularly, once the event occurred, Cenit implemented a "by pass" with six lines of flexible tubing that it arranged on the projection of the Right of Way in order to provisionally re-establish the operation of the pipeline; Subsequently, after different specialized studies in which different scenarios such as variants, PHD and different response alternatives to the situation were evaluated, it decided that the most favorable immediate option consisted of letting the pipeline remain in the original Right of Way arranged in surface resting on some skids in such a way that before the potential movement of the ground it would not be affected by its thrusts as it would have happened if it had been buried as it is done regularly.

In order to make the chosen option a reality, it is necessary to specify both the engineering design that contemplates the definition of curves and alignment of the pipe, as well as the lay-out technique, the constructive mechanics and the construction of complementary protection elements such as supports. , skids, dikes to control the impacts of rockfalls, wells, and works to control water and recover vegetation cover, since containment works to stabilize permanently are practically unfeasible technically and with unreasonable costs that force us to live with the problem of instability and establish a monitoring plan for slow movements and an early warning system for possible sudden movements and blocking systems.

As a monitoring system, different instruments were proposed, such as vibrating rope inclinometers, extensometers, piezometers and topographic reference markers; this in order to understand the behavior of the land and act, as far as possible, with preventive criteria. As well as establishing a relationship of the rains that have generated landslides, to determine a possible damage threshold, cross it with the saturation levels of the stability models and with SAR analysis to monitor surface deformations using the SBAS advanced differential interferometry technique.

The details of the activities carried out to ensure the final disposition of the pipeline, the recommended protections and the proposed monitoring plan constitute the content of this document.

## 1.1. PURPOSE AND LIMITATIONS

The objectives of this report are:

• Establish the stability of the slope through the analysis of the available reference information and the geotechnical exploration carried out.

• Define the route of the new alignment of the oil pipeline in a "palliative" way according to the geotechnical, mechanical and structural designs made, on the existing ROW according to the client's indications.

• Develop recommendations for the construction of stabilization works for the recovery and protection of the ROW, the slope of the landslide, as well as a monitoring plan.

Based on the field information and respective analysis, the stability conditions of the slopes are defined taking into account the old and current topography, the geological, geomorphological and geotechnical aspects that allow stability analyzes to be carried out and to recommend palliative and mitigation works. slope and protection adjusted to current conditions.

This document does not contemplate the definition of a definitive solution nor does it allow establishing how long its durability may be, since it does not take into account sudden landslides of great magnitude but, on the contrary, small displacements (between 1 and two meters) of the ground in the ROW area. Nor does it contemplate a detailed monitoring design, but it does consider a general monitoring plan.

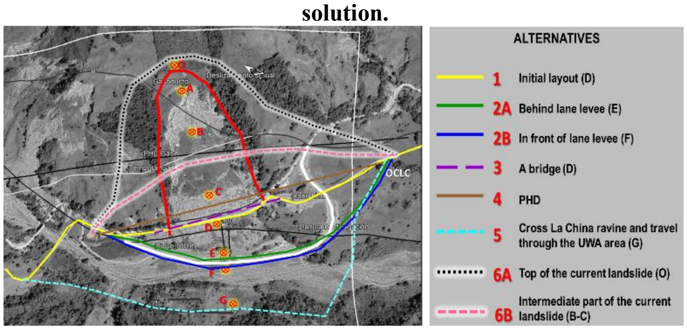
## 1.2. ANALYSIS OF VARIANT ALTERNATIVES

Prior to the definition of the "palliative" solution proposal, different options for possible definitive solutions were analysed. However, once the pros and cons were analyzed in technical, environmental, social, economic and constructive terms, it was determined that there is no efficient technical solution and that it would represent reasonable costs based on feasible, conditional feasible and non-feasible solutions. The analyzed solutions are listed and illustrated below:

**Alternative 1:** Maintain the initial layout on the moved material. 1A on supports on the surface and 1B with a hole, buried on the surface.
**Alternative 2A:** Immediately behind the vehicular lane levee.
**Alternative 2B:** Immediately in front of the vehicular lane levee.
**Alternative 3:** A bridge.
**Alternative 4:** PHD.
**Alternative 5:** Cross the La China ravine and travel through the UWA area.
**Alternative 6A:** Top of the current landslide.
**Alternative 6B:** Intermediate part of the current landslide.

Finally, alternative 1 was chosen, passing the pipeline through the initial layout, on the unstable mass, under two options: The first is to leave it on the surface using supports and skids, the second is to bury it eighty (80) centimeters, but within a ARMCO-type semicircular metal sleeve, the latter under environmental and social limitations. The other alternatives were discarded due to issues of environmental licensing, bad experiences with the stream, magnitude of the required works, physical security and communities.

**Figure 2 Variant alternatives analyzed prior to the "Palliative" solution.**



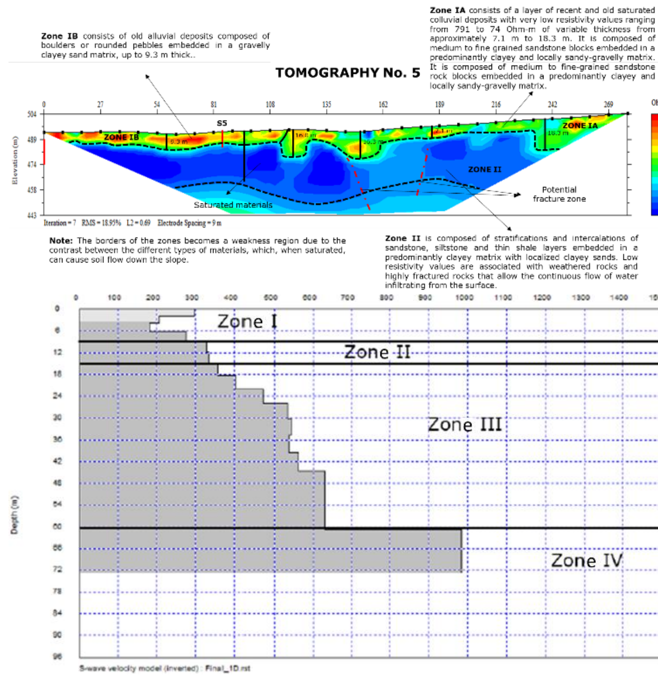

**Source: Google Earth with modifications by the author.**

## 2. ANALYSIS OF THE SLOPE

### 2.1. Exploration Campaign

As part of the investigation, three boreholes were carried out at a depth of fifty meters and two at a depth of ten meters with SPT tests and with sampling, apex on the slopes for laboratory tests, five seismic refraction lines and MASW-2D and 1D, five electrical tomographies. The different exploration methods resulted in the geological-geotechnical profile where he described a hillside deposit between 10.0 and 18.0 meters thick, below this residual soils and intercalation rocks of hard, highly fractured sandstones with very soft claystones up to 60 years of age were identified. meters, finally and up to 100 meters explored, a harder rock was identified with less fracturing compared to the previous mantle. It is presumed that this condition is maintained in depth given the structural nature of the region. Concentrated zones of fracturing and a change in stiffness were identified starting at 60 meters, consistent with the sandstone rock with apparent without intercalations.

**Figure 3 Example of the results of the geophysical tests for the characterization of the landslide.**



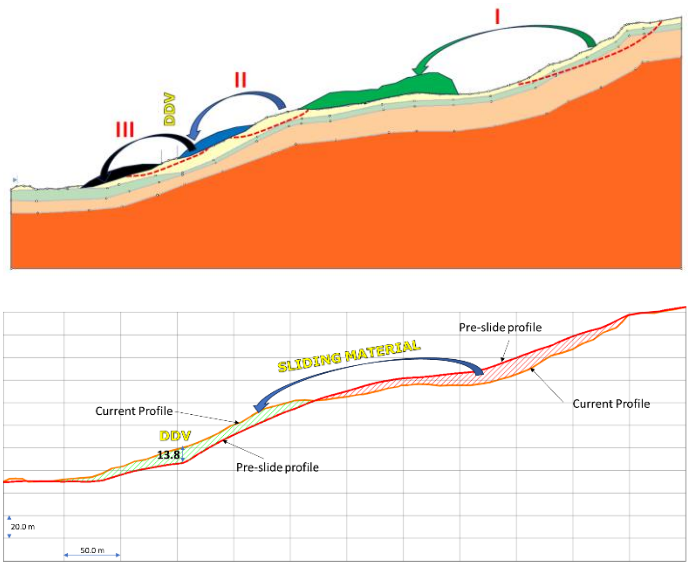

**Source: The author.**

### 2.2. Failure mechanism

Given the high degree of fracturing and weathering of the rock mantle up to a level of 60 meters, a limit equilibrium model was considered for practical purposes under the caveat that the most correct thing to do is to carry out a discrete element or finite element model that allows including the discontinuities, however, these were not part of the scope of this investigation. The stability models were carried out under earthquake scenarios and in static conditions under different degrees of saturation since given the rainfall regime, any of these is feasible and the failure condition is given by a very complex variable to define, such as the accumulated geotechnical deterioration DGA (J Jiménez 2013), this being the change in resistance conditions every time a period of rain and drought occurs, which justifies why under critical rain scenarios certain sites do not fail and if on some occasion it failed with a much smaller event.
The results of the modeling showed that, in the event of intermediate rainfall, the slopes failed in the upper zone of the main escarpment of the landslide, as well as the edge of the intermediate terrace generated by the moved and adjoining mass. with the pipeline ROW. The DDV zone is described as more stable in the face of a large-magnitude fault unless large-

magnitude masses from the upper part of the landslide fell on it. The failure mechanism of the ROW area is related to displacements, this being the consideration that made it viable to build a "palliative" work and under the concept of maintenance focused on monitoring and gradually reducing the risk, while investigating in depth. a safer solution. The reconstruction of the given failure mechanism was carried out by means of a back calculation and the comparison between the topographic surfaces before and after the landslide.

**Figure 4 Probable failure scenarios and failure mechanism of the landslide.**

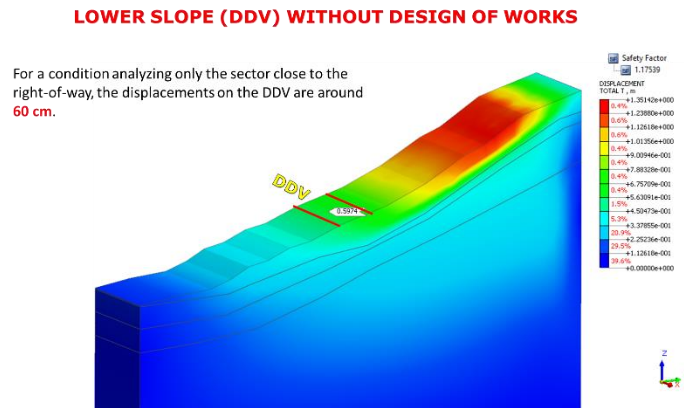



**Source: The author.**

## 2.3. Deformation analysis

Hillside deformation models were made using a finite element program without considering discontinuities, however resistance parameter values were assigned using expert criteria, analysis of laboratory results and calibrated by back-calculation. In terms of deformations in zones I and II, it generates values greater than 17 meters and stops the calculation, which infers sudden failure, in the lower part of the slope which corresponds to the DDV of the pipeline, yielded values less than one meter, which served as a key to define the objective work.

**Figure 5 Typical model of OCLC landslide and DDV deformations.**




**Source: The author.**

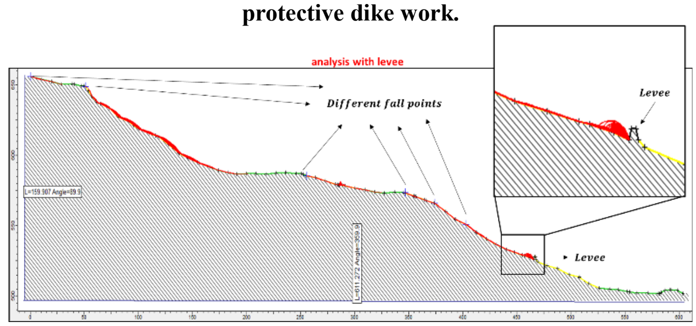
A longitudinal model was also carried out to determine the thrust forces of the calculated displacements, as well as those that would be supported by the semicircular casing of alternative 1B.

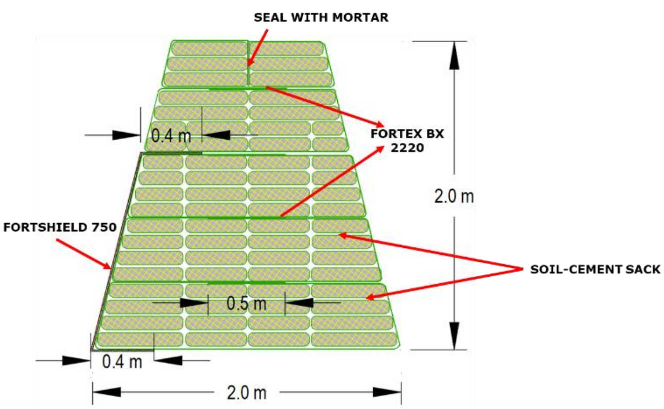
## 2.4. Rockfall analysis

For the alternative of installing the pipeline on the surface, it was necessary to analyze the risk of possible rock falls that could impact the pipeline, affect it and even break it, given that the material moved has a large number of rock blocks and evidence of rocks was identified. of large size close to the area of the provisional flexible pipe.

The results of the models defined the possible trajectories and the maximum height in the line immediately above the position of the pipe, which yielded a value of 1.5 meters in order to define the size of the protection structure, which consists of a soil dam reinforced with high modulus polyester geotextiles with bags of soil cement and protected with a casing covering the rock impact zone with a Fortshield-type geotextile.

**Figure 6 Typical model of rock falls, evidence of falls, and OCLC protective dike work.**




Source: The author.

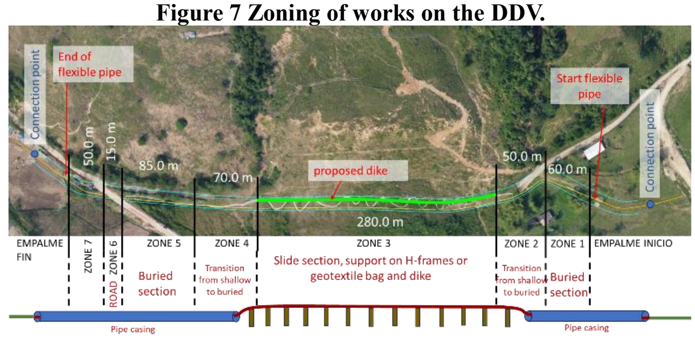
## 2.5. Geometric design.

The geometric design arose after several attempts to trace it in plan and profile, with the purpose of finding a balance between length, control of excavation heights to affect the stability of the landslide as little as possible, costs, fewer longitudinal and vertical curves, execution times to put the pipeline into operation very quickly, availability of materials and easy access, ease of construction, flexibility in the face of hillside movements, less environmental impact, among others, and given the construction difficulty given the property limits, irregular topography and restricted spaces.

For the geometric design, a zoning was defined, which mainly includes the landslide zone (movement), the transition zone at the ends of the landslide to give it freedom of movement, the zones without movement, but with land restriction, and the splicing zones. and preventive closing valves.

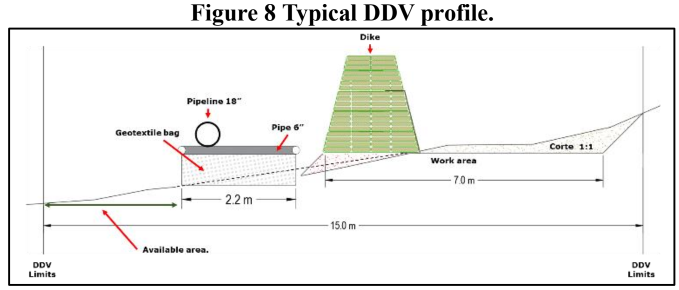
For geotechnical construction activities, it was recommended to use a bowtie-type backhoe, a Bocat and a Benitín-type compactor or similar.

**Figure 7 Zoning of works on the DDV.**




Source: The author.

**Figure 8 Typical DDV profile.**




Source: The author.

Behind the dam, a ditch is recommended to collect the water in this entire sector and it will be arranged by means of transversal downpipes at the low points, crossing the dam using a 36" Novafort-type pipe sufficient to give continuity to the section of the ditch and to continue going down to deliver to the ground through a delivery structure.

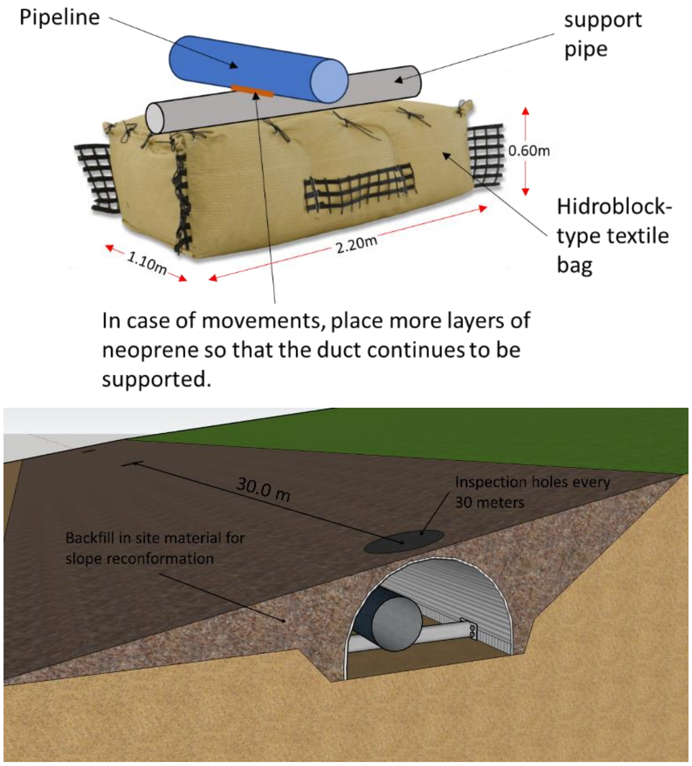
## 2.6. Support and insulation system

Given the condition of avoiding buried pipes as much as possible (alternative 1A), surface supports were proposed given the difficulty of burying "H" frame type supports due to the presence of multiple rocks and large size on the surface. The support system consisted of 2.2mx1.1mx 0.6m high Hidroblock-type textile bags filled with soil cement, separated every 4.0 meters, which support a circular metal pipe skid partially lined in neoprene to protect the duct.

For the movement transition zone and even the landslide under alternative 1B (minimally buried), the installation of an ARMCO-type semicircular casing or sump joined at the base with circular metal tubes spaced every 6.0 meters was proposed to give it rigidity, support and free movement to the pipeline.

The total length of the replacement for the normal reconnection of the pipeline was approximately 700 meters and approximately 10 vertical bends were required.

**Figure 9 Schematics of support and isolation system to allow free movement of the ground.**




**Source: The author.**

## 2.7. Mitigation works

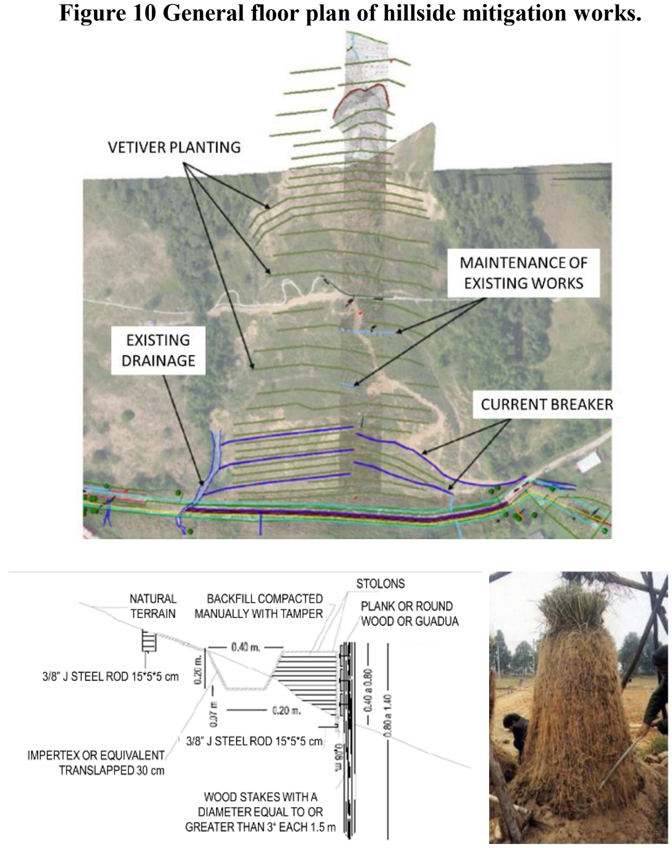
Both the "mitigation" works and the mitigation works on the slope were defined under a bioengineering approach with the purpose of reducing the carbon footprint as much as possible and making a contribution to the environment and the greenhouse effect and pollution.

As a complement, trying to maintain the stability of the slope, mitigation works are proposed, consisting of an account, current breakers, revegetation and planting of vetiver at different strategic points on the slope.

For the lower slope, that is, where the ROW is located, as a complement to the works described above, it is proposed to plant rows of Vetiver grass that allow erosion control, protecting the slopes against weathering and surface runoff. This species can develop even up to 2800 m.s.n.m. and due to the rigidity of their stems, they function as a natural water sink, helping to control runoff flows. In addition, the resistance to cutting of the roots of Vetiver grass is considered very high compared to other species, this helps in a certain way to the surface stability of the soil since the roots act as a natural reinforcement of the soil, increasing its mechanical properties.

As part of additional mitigation, cleaning of the blocks at the back of the dam must be carried out periodically, so that it is not subjected to overloads that affect its integrity or that the accumulation of unwanted elements fills the gap over time. height of the dam and it cannot continue fulfilling its function of protecting the oil pipeline.

**Figure 10 General floor plan of hillside mitigation works.**




**Source: The author.**

## 2.8. Monitoring

As the proposed solutions are palliative, because the slope is very susceptible and there is a high uncertainty regarding its behavior in the future, a fairly rigorous and complete monitoring plan is recommended, consisting of inclinometers, cairns for topographic control (6), piezometers (3) (recommended for vibrating wire and pore pressure measurement) and extensometers (3). Preferably automated with remote sensors that warn of increased ground deformations during extreme rainfall, as well as increased ground saturation levels.

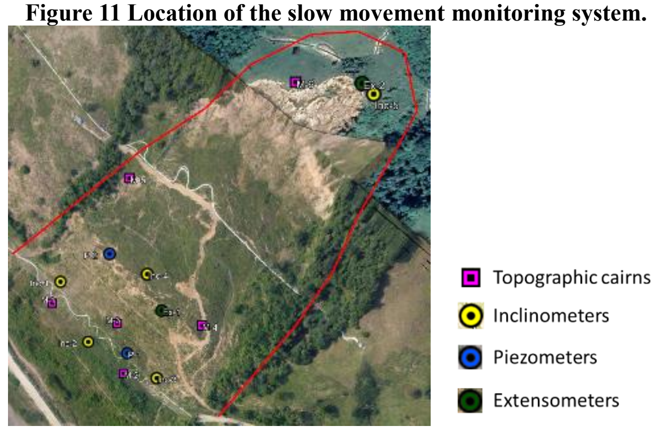
**Table 1. Alert criteria for inclinometers.**

| THREAT STATUS | EVIDENCE OF THE STATE | ACTIONS TO EXECUTE |
|---|---|---|
| **NORMAL** | The cumulative displacement curves are within the accuracy ranges of the reading torpedo. The speed of the measured movements enters the field of extremely slow movements, that is, of the order of 0.04 mm/day or less. | Continue monitoring to ensure stable behavior over time. |
| **ALERT** | Accumulated displacement curves begin to move out of reading accuracy ranges or begin to define breaks even within the reading accuracy range. The speed of the measured movements enters the field of very slow movements, that is, of the order of 0.04mm/day to 4.3mm/day. | Continue monitoring increasing the frequency between weekly and biweekly to establish incremental behavior of the evidence over time. Carry out follow-up visits at least weekly to identify the possible appearance of more telling field evidence. |
| **ALARM** | The accumulated displacement curves have gone out of the reading precision ranges with or without defined reading breaks and present incremental trends over time (incremental is understood as a continuous behavior in which the increase in displacements persists). The speed of the measured movements enters the field of slow movements, that is, of the order of more than 4.3 mm/day. | Increase reading frequency (weekly minimum). Carry out follow-up visits at least once a week to evaluate the evolution of the evidence of field. Organize an extraordinary committee among the related actors and inform the competent authorities. |

**Source: The author.**

If it is not possible to install automated sensors, it is recommended to carry out the complete monitoring every 3 months and in the winter times every month, to obtain a complete and updated vision of the geotechnical conditions over time. This will allow trends to be identified and corrective actions taken in a timely manner.

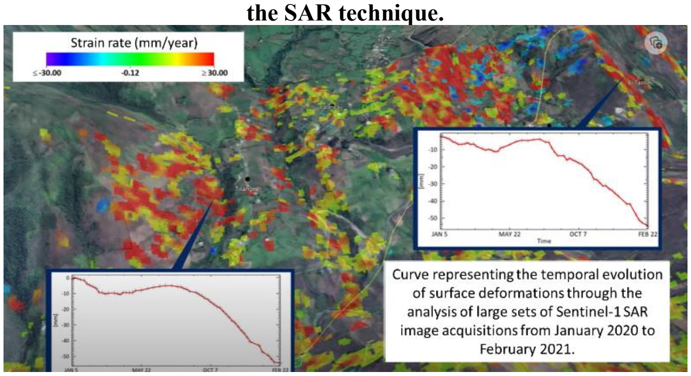
**Figure 11 Location of the slow movement monitoring system.**




**Source: The author.**

The previous proposal includes a monitoring system for low deformations and slow movements. For sudden movements, the importance of establishing remote systems is considered, with alerts based on the considerable increase in pore pressure considered in the stability models that give rise to failure. In the same way, a cause and effect analysis can be carried out where possible damage thresholds are established based on the maximum daily, accumulated and even permanent rainfall data, as hydrological instrumentation has already been implemented, in the study area and the surrounding area. that these records are available in such a way that when they occur, the pump block contingency plan is activated. Additionally, it is proposed to measure the DGA from direct sampling or cutting directly in the field and in-depth geophysics and SPT tests after each season of extreme rain. Finally, a SAR measurement system can be implemented to monitor surface deformations using the SBAS advanced differential interferometry technique, as has been implemented elsewhere. Early warning is a great uncertainty worldwide which is the reason for multiple investigations and today there is nothing concrete or it may not even be possible to determine precisely.

**Figure 12 Example image of surface deformation monitoring using the SAR technique.**




**Source: The author.**

## 2.9. Contingency plan

As a contingency plan in the event of a possible oil spill, the installation of check-type valves is proposed, in such a way that it beats the results of the monitoring or a high intensity rain and with certain previous rains it can generate a landslide. Early warning criteria must be established through a detailed failure probability study.

## 3. CONCLUSIONS AND DISCUSSION

The studies of the scenarios regarding the behavior of the slopes, both of the upper one of the landslide and of the intermediate one and of the lower one on which the ROW is located, reflect that the terrain is susceptible to failure even if they were complemented with works robust and unreasonable in terms of costs. This concept was validated if one takes into account the experience in the recently conducted surveys, which have been very difficult to carry out to date, which is why there is a high degree of uncertainty about the potential behavior in the future, since they present Recently moved, very thick materials on a steep slope of soft rocks intercalated with harder but highly fractured materials and with groundwater currents of significant flows at high pressure.

In accordance with the above, as contemplated from the beginning, when it was recommended to "live with the problem" assuming that the cone of the landslide on which the ROW and pipeline will be located will present some movements, and that the upper slope will to generate rock falls, both with a high potential to affect the pipeline; reason for which the pipe is placed on the surface.

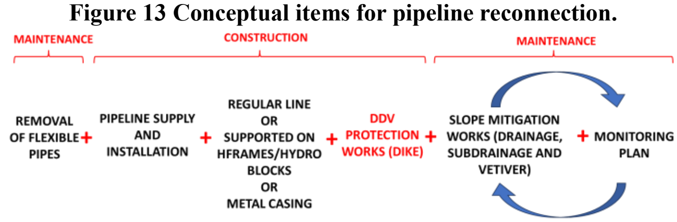
In the same way, the current high uncertainty and the level of risk that derives from it must be gradually reduced, based on the results of the monitoring plan that is carried out both to verify the effectiveness of the works and to predict the natural behavior of the environment, to ensure, as far as technically possible, the continuity of the pipeline operation from a maintenance point of view.

Regarding the analysis of deformations, it is concluded that the displacements have such important magnitudes (especially the area of the hillside above the ROW) that, under the effects of the triggering factors rain and earthquake, possibly lead to the failure of the pipeline. This being an extreme scenario that must be permanently considered, a situation that validates the monitoring plan that is implemented.

Predicting a landslide at present is not very clear and involves multiple investigations, therefore, a monitoring system for slow movements and another for sudden movements is proposed in order to reduce uncertainty and try to carry out contingency plans that reduce contamination. and accidents affectations generated by the failure of the pipelines.

The following diagram shows the conceptual items that were taken into account for the study and it is recommended that they be taken into account for the proper start-up and continuity of the operation according to who corresponds in order to reduce the risk gradually.

**Figure 13 Conceptual items for pipeline reconnection.**




**Source: The author.**

In maintenance, work must be done together and based on the results of the monitoring plan in order to update, improve or repair the corresponding mitigation works.

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## REFERENCES

Deslizamiento Chunchi Analisis SAR - YouTube (Geoespace Solutions).

Jorge E. Jiménez S.: Las tres Leyes de la Geotecnia (jorgejimenezs.blogspot.com) (J. Jiménez 2006).

Jorge E. Jiménez S.: SEMIOLOGÍA GEOTÉCNICA (jorgejimenezs.blogspot.com) (J. Jiménez 2006).

Estudios y diseños para la reconexión "paleativa" del OCLC en la zona de Troya, 2023, ED INGEOTECNIA SAS.

Asesoría geotécnica para determinar las alternativas de reconexión del OCLC en el PK 133+000 en agosto de 2021, 2023, ED INGEOTECNIA SAS.

"Ingeniería de detalle para la construcción del cruce PHD en el sector La China norte de Santander" realizado por JHS Ingeniería LTDA, 2021.

ASME B31.4 para el diseño mecánico.

Reglamento Colombiano de Construcción Sismo Resistente NSR-10

Requerimientos técnicos, estudios y diseños para mejoramiento de carreteras Invias 2011.

Cartografía geológica a escala 1:100.000 del SGC.

Especificaciones generales de construcción de carreteras Invias 2013.