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DECISION-MAKING AND MITIGATION ACTIONS, INCLUDING DEADMAN ANCHORS AND FLEXIBLE PIPES FOR PIPELINE ADJACENT TO ROAD INFRASTRUCTURE - A CASE STUDY

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ABSTRACT

In the implementation of CENIT's Geohazards Management Strategy, the influence that existing road infrastructure has recently had on activation of instability processes that interact with infrastructure of pipeline transport systems has been identified.

This recent fact derives from expansion process that Colombian road network has had during last two decades, and by the fact that both infrastructures, the road, and the pipeline transport systems, compete for the available corridors, as a product of the geomorphological conditions of the Colombian territory, which restricts the location of pipelines rights-of-way (ROW).

This case study will analyze an event in which, after ten years of executing a road expansion project, processes of instability were activated in this infrastructure that interacted with the ROW pipeline and threatened its integrity.

Due to this event, there was a pipeline ROW because of a process of retrogressive instability in the cutting slope of the road. The decision-making process will be presented with a combination of corrective and preventive approaches and will expose challenges associated with the strategy of monitoring and implementing mitigation actions, including deadman anchors and flexible pipe. This allowed to define the timely intervention due to the evolution of the condition.

Keywords: Geohazards, Deadman Anchors, Flexible Pipe.

1. INTRODUCTION

Colombian geomorphological conditions generate restrictions on availability of corridors to locate linear infrastructure networks (i.e., roads, railways, pipelines).

In areas such as the one analyzed in this article, these infrastructure networks competed for the available space in a narrow and deep valley with very steep slopes, in an environment under the influence of a high density of geological faults.

For example, to date approximately 6000 consolidated interference conditions have been registered with the hydrocarbon transport infrastructure and the road infrastructure in Colombia is composed of 206,102 km of existing roads distributed throughout the territory in primary, secondary, and tertiary networks. For this case study, a road (with a daily transit of around 2000 cargo vehicles) through which the main foreign trade port of Colombia is connected, with an approximate mobilization of 5 million tons of cargo in 2022[1] will be considered.

With the development of the road concession projects called Fourth and Fifth Generation (4G and 5G) that involved the construction of 8,000 kilometers of road corridors, CENIT has advanced the management of short-term risks during the constructive development of the corridors, however, recent geotechnical phenomena that took place indirectly and directly due to the development of cutting slopes and embankments implemented for the development of road corridors.

The purpose of this paper is to emphasize the relevance of decision-making processes that involve innovative and timely procedures to mitigate geohazards and the importance of third-party relationship strategies along time considering the stabilization works in road infrastructure developed in pipeline interference zones regarding a new long-term insurance scenario in which the effects of the consolidation of areas in which the interaction of road and rail corridors and the routes of hydrocarbon infrastructure must be harmonized must be evaluated.

Regarding this case study, in September 2022 there was a landslide on the cutting slope of road that destabilized pipeline right of way. Because of high slope and geological-geotechnical conditions there was retrogression of the movement scarp until leaving exposed and hanging approximately 80 meters from the pipeline. The landslide is estimated to have a width and a length of about 80 meters, and in its displacement disrupted road traffic from and to main foreign trade port of Colombia. Figure 1 shows an overview of the event in September 2022 and in a dashed black line, the approximate alignment of the pipeline is observed.

To improve understanding of this study case, geological aspects will be presented initially in a general way, to later deepen on condition evolution presented and in decision-making process including execution of mitigation activities. Finally, some considerations and conclusions related with geohazards in third-party interaction will be presented.

FIGURE 1. LANDSLIDE OVERVIEW – SEP 2022

2. GEOLOGY

According with [2] and [3] the spills of diabases undoubtedly constitute the most imposing phenomenon during the geosyncline phase of the "Andes West". In the region, the “Grupo Diabásico” extends continuously from the western limits of the city of Cali, westward past the Western Cordillera, to the line formed by the Dagua River and its southern tributary, the Jordan River. There, the “Grupo Diabásico” is separated by means of a major fault from the "Dagua Group", mostly sedimentary. Further west the same “Grupo Diabásico” appears again, apparently resting normally on the "Dagua Group". For tectonic reasons this succession can be repeated.

Despite the vast expanse, the “Grupo Diabásico” hardly allows itself to be studied in detail, both because of deep weathering, which turned the surface into a thick layer of "red earth", and because of the dense texture of the rock, which only allows microscopic examination. In this layer of "red earth" are often observed diabase blocks, not yet decomposed. Undoubtedly, the material has been partially redeposited by landslides, etc.

In a few places siliceous shale or lydite intercalations are observed between the diabase rock. These interpositions, sometimes fossiliferous, prove that these are submarine spills of diabases. In general, these sedimentary intercalations are very thin, from which it can be deduced that the main volcanic activity took place in a relatively short time.

From these characteristics, it was possible to deduce that there was a high probability of retrogression of the instability process, given the potential for the residual soil to have a great thickness and the presence of relict structures (inherited discontinuities), which impacted decision-making regarding the immediate mitigation actions and temporary solution that will be described in section 3 and section 4, respectively.

From Geology of “Valle del Cauca” [4] and Geology of Map 279 Dagua [5], the landslide was developed is on Cretaceous rocks of the Volcanic Formation (Kv), this formation formerly known as “Grupo Diabásico” (Nelson [2]; Barrero [3]) has as its type locality the main road between Cali and Dagua. It is composed of diabases, basaltic lavas and lava pads, also including dolerite silos. Available chemical analyses indicate that these are low potassium tholeiitic basalts (Barrero [3]; Millward et al., [6] y [7]). Some common traits associated with major fault zones are breach and quartz and epidote veins. Low-grade metamorphic mineral associations of burial have been reported by Barrero [3] and Rodriguez [8].

The most prominent structural feature within Cretaceous rocks is the presence of a complex regional system of interconnected faults of approximate NE-SW orientation (see Figure 2). Faults are both normal and inverse and the complex faulting pattern suggests that large-scale horizontal movements played an important, if not dominant, role in the tectonic evolution of the range

The course of the stratification of the fold and cleavage axes is normally parallel to the direction of the range, although individual blocks bounded by faults may be parallel or subparallel to the limiting faults. It can be thought that local variations are mainly due to the presence of intrusions or the rotation of differential horizontal movements along limiting faults, and it is possible to observe in direction changes of streams and in geomorphological features as shown in Figure 3.

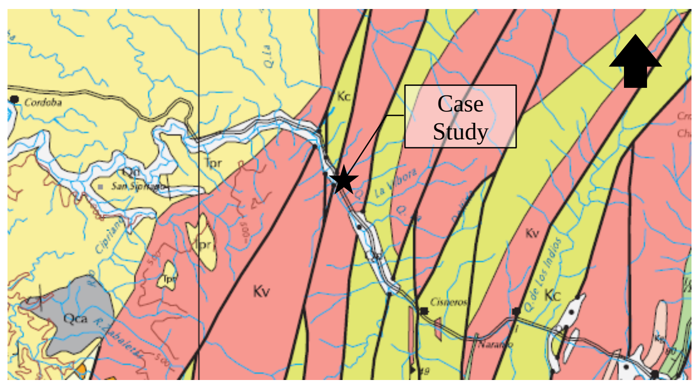

FIGURE 2. GEOLOGY OF VALLE DEL CAUCA [4]

FIGURE 3. INFERRED FAULT ALIGNMENT – MARCH 2018

From the complex of both normal and inverse regional faults and their satellite faults it can be inferred as a hypothesis that rocks are highly fractured. These fractures, in addition to helping the infiltration of water and rock weathering generating lateritic soils of "red soils", allowed the decision-making process to not consider a long-term solution that included horizontal directional drilling (HDD) as a construction technique, because there was a high probability that it would not be successful.

3. LANDSLIDE EVOLUTION

When road expansion activities were carried out, more than 10 years ago, the road operator stabilized its cutting slopes through anchored system. This stabilization was necessary, due to a landslide that occurred when executing the slope cuts, and after completion, the main scarp was 22 m from the alignment of the pipeline, as shown in Figure 4.

Once CENIT identified in September an instability process through its inspection plan, it began the verification of the condition that included pipeline location, as well as a drone inspection, initially identifying a scarp retrogression between 10 and 15 meters (Figure 5), that is, 10 meters away from the pipeline. This landslide reactivation includes the failure of anchored system (including lagging wall with reinforced shotcrete) built by road operator.

Between the end of September and October beginning, the crown of the landslide, begins to present cracks that represented advances in the retrogression of the landslide (Figure 6) of about 4 m each time, due to inherited discontinuities, as was possible to identified. Because pipeline was underground in the crown, the interaction with the instability process was causing lateral loads on the pipeline.

In this same period, CENIT in a Reactive Management Approach, began the construction of an attachment system to provide support to the pipe, composed by Deadman anchors, guy line and clamps which were tied to the pipeline as shown in Figure 7, as a preventive action in case of a new retrogression of the main scarp.

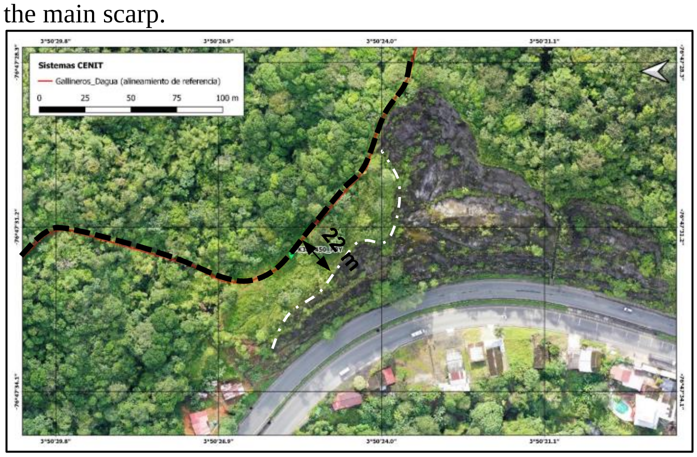

FIGURE 4. LANDSLIDE AND PIPELINE ALIGNMENT OVERVIEW – AUGUST 2019

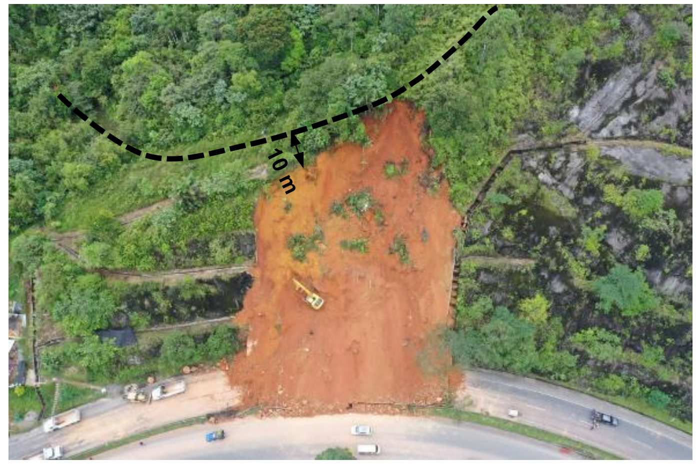

FIGURE 5. LANDSLIDE SCARP RETROGRESSION – SEP 2022

FIGURE 6. CRACKS IDENTIFICATION IN THE LANDSLIDE CROWN

FIGURE 7. ATTACHMENT SYSTEM

Days after, due to road operator could not continue with activities of landslide removal with excavator due to high risk, and there was evidence of progress in main scarp retrogression, CENIT begins pipeline stresses release where the cracks had been identified. These had to be executed manually, for the reasons stated above (Figure 8).

FIGURE 8. MANUAL EXCAVATION TO STRESSES RELIEF

At the next day landslide crown collapses exposing the pipeline, and the attachment system built begin to work structurally. Thanks to pipeline stress release activities from the previous day and to the attachment system arranged, and despite the collapse of landslide crown, pipeline integrity of the pipeline. This collapse also generated the total closure of road (Figure 9).

FIGURE 9. LANDSLIDE OVERVIEW AFTER CROWN COLLAPSE

In the following days, as landslide evolved, left a pipeline section of about 80 meters long exposed and hanging at the main scarp, and a complete attachment system (composed by seven deadman anchors were built in addition to six installed as a preventive measure during the event of more than 10 years ago), was operational. On average deadman anchors were installed four meters from the main scarp, at the opposite end of the narrow ridge that was constituted (see Figure 10, Figure 11, and Figure 12).

4. TEMPORARY SOLUTION

Considering landslide evolution and pipeline condition (Figure 13) and based on understanding of Geology described in section 2, in a Preventive Management Approach, CENIT decided to prolong decision to halt pipeline operation, and with the aim of reactivating it and guaranteeing supply of fuels for the west of the country, was advance in an alternative plan, which consisted of installation of a section of flexible pipe above ground of approximately 400 meters in length, parallel and attached to the same deadman anchors.

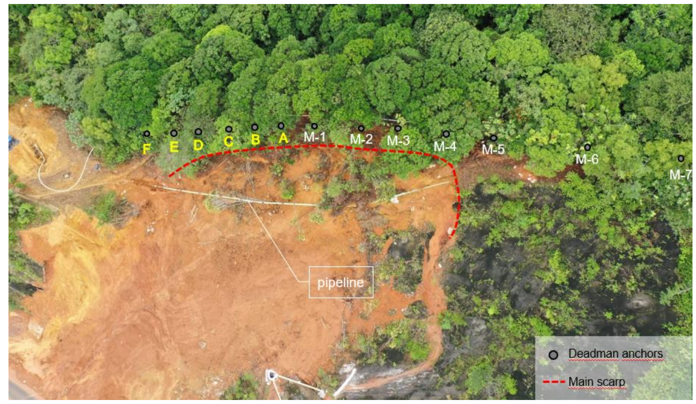

FIGURE 10. LOCATION AND DISTRIBUTION OF DEADMAN ANCHORS

FIGURE 11. PIPELINE AND ATTACHMENT SYSTEM VIEWED FROM MAIN SCARP

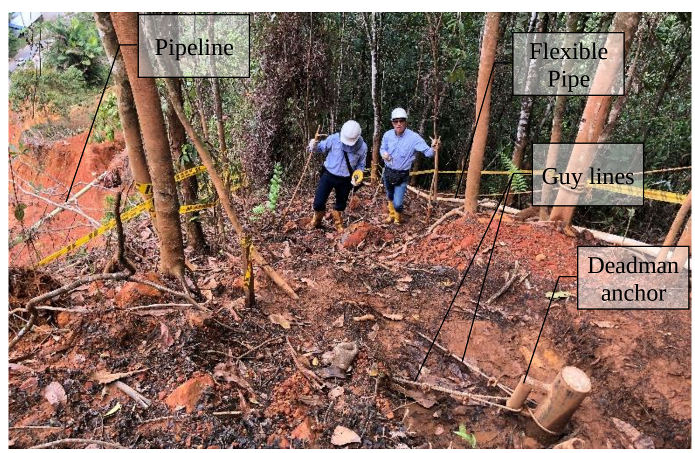

FIGURE 12. NARROW RIDGE OVERVIEW NEAR TO MAIN SCARP

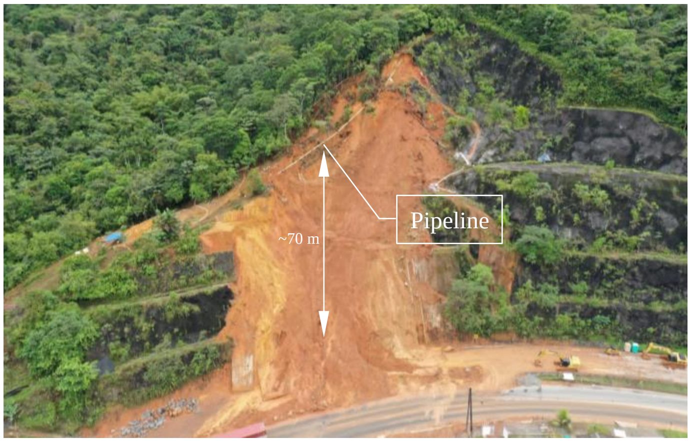

FIGURE 13. PIPELINE CONDITION AFTER LANDSLIDE RETROGRESSION

A flexible pipe is a non-metallic pipe qualified for use in water, gas, and oil at high pressures, elaborated and certified under the API RP 15S standards. It is based on non-ferrous materials, so it does not corrode. Special anti-UV white that externally coats the pipe protects it from sunlight, so, it allows above ground or buried disposition. Flexible pipe is transported by means of spools (see Figure 14). Figure 15 shown a temporary solution overview and Figure 16 and Figure 17, shown flexible pipe installed and operative.

FIGURE 14. FLEXIBLE PIPE SPOOLS

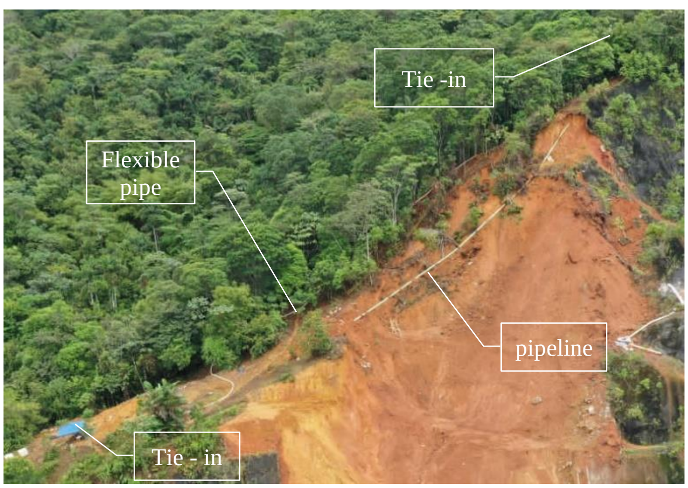

FIGURE 15. TEMPORARY SOLUTION OVERVIEW

FIGURE 16. FLEXIBLE PIPE HALFWAY UP THE SLOPE

FIGURE 17. FLEXIBLE PIPE ON NARROW RIDGE

Currently, pipeline is operating safely, without an integrity alert or landslide reactivation to date. Likewise, engineering studies of definitive mitigation alternatives have been developed, and licensing processes are being advanced. In these studies, a residual soil profile of about 35 m and an intensely fractured and weathered rock were identified.

Meanwhile, monitoring continues through monthly visits by geotechnical engineers and maintenance group, to timely identify any deviation from the established parameters; in the same way that through the nearest meteorological monitoring station belonging to the network of Cenit stations, the current weather and forecast are evaluated, to take timely and anticipated decisions.

5. CONCLUSION

CENIT with a pipeline network of approximately 8500 km, presents a susceptibility to effects because of short-term interaction in interference zones with infrastructures of other economic sectors and particularly with road and railway infrastructure, which for its development make use of heavy machinery for the development of cutting and filling slopes.

However, recent geotechnical phenomena that took place indirectly and directly due to the development of cutting and filling slopes for road corridors more than a decade ago, alert CENIT to a new long-term monitoring scenario in which the effects of consolidation of these areas and evolution of stabilization works carried out in the past by third parties, must be evaluated.

Two dimensions of performance management can be observed in this case study. First, effectively executed reactive management, which includes the cycle of timely condition identification, analysis and decision-making to avoid containment loss. Second, preventive management, through implementation of a temporary solution that has allowed pipeline safe operation.

From when the landslide started to the time the temporary solution was built, it took about one month, so this case study shows an efficiently use of resources and an adequate relationship with third parties.

Identification of landslide from its initial stage has been considered a success, which favored the timely decision-making and execution of immediate mitigation actions to avoid affecting pipeline integrity (Reactive Management Approach).

Following the above, the identification of an adequate temporary solution strategy to continue system operation, so that the time out of service was minimum, has allowed to expand the range of possibilities to restore transport of hydrocarbons safely (Preventive Management Approach).

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