IPG 2023
INTERNATIONAL PIPELINE GEOTECHNICAL CONFERENCE
November 23rd - 24th. Bogotá D.C. - Colombia
Under the auspices of: arpel
Organize: C-IPG ACIEM
6TH INTERNATIONAL PIPELINE GEOTECHNICAL CONFERENCE IPG 2023

IPG2023-0046

PREDICTIVE MANAGEMENT IN PIPELINE-TO-LANDSLIDE INTERACTION – A CASE STUDY

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ABSTRACT

This paper will present a study case in which, based on the implementation of Cenit's Geohazard Risk Management Strategy, preventive action was taken in the face of occurrence of a successive instability process, in a colluvial mass, in an adjacent area to the right-of-way of a Cenit´s pipeline transport system.

This process of instability began in October 2022, because of excessive rainfall in the sector of interest that triggered a rock fall and a landslide. This instability process is located approximately 200 m upslope of the Right of Way (DDV). The early identification of the event, as well as its potential evolution, made it possible to establish a follow-up and monitoring plan that would allow the definition of thresholds to activate mitigation actions.

Due to landslide evolution, confirmed through following and monitoring, was possible to identify an imminent threat to the pipeline integrity, and a provisional avoidance alternative was activated. This alternative consisted in a flexible pipe variant, which was implemented in December 2022. At the same time, an engineering analyses was beginning to evaluate possible solution alternatives, as well as the detailed designs and implementation of the definitive actions for the mitigation of risk condition.

The stages of the decision-making process will be described, and the results obtained in each of them, from the early identification of the instability process. Definition and implementation of the follow-up and monitoring plan, and definition of palliative and provisional mitigation action will be illustrated too. This includes an innovative temporary solution with flexible pipe that would allow its relocation depending on landslide evolution.

Keywords: Geohazard Management, case study, Right of Way (RoW), Flexible pipe.

1. INTRODUCTION

Cenit has a Geohazard Management Strategy based on a continuous improvement process such as the PDCA cycle (see **Figure 1**).

FIGURE 1. CENIT'S GEOHAZARD MANAGEMENT PROCESS MAP. SOURCE: OWN

The implementation of this strategy, which has one base group of processes (RoW knowledge) and three functional groups (Strategy sustainment), and its permanent update, has made it possible to obtain benefits such as:

- Identify in a timely manner instability processes that affect or may affect the RoW and the pipeline, allowing to define and implement the necessary follow-up, monitoring, and mitigation actions.
- Sustained reduction the frequency of spills associated with Geohazards over the last 12 years, reaching U.S. and European International frequencies (see **Figure 2**).

Below is a description of one of the cases that illustrates the application of this strategy that is being carried out in Cenit.

2. CASE STUDY DESCRIPTION

A case study of the implementation of the Geohazard management strategy at Cenit is described below.

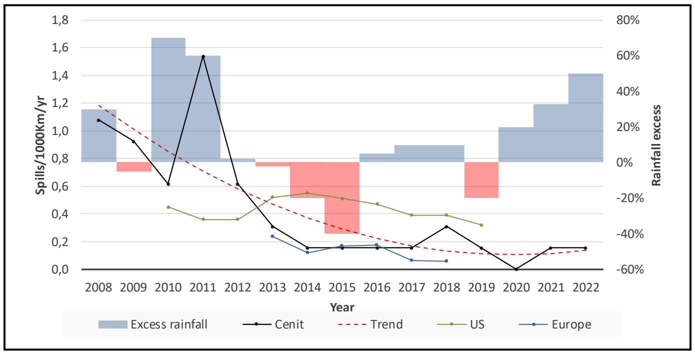

FIGURE 2. SPILLS ASSOCIATED WITH GEOHAZARDS IN CENIT´S TRANSPORT INFRASTRUCTURE.

2.1 Geological context

The study case site is located on the western foothills of the Eastern Mountain Range of the Colombian Andes Mountain, where Cretaceous rock of "Formación Umir" (gray to black carbonaceous shales with sandstone intercalations) are overlapping by Tertiary rocks of "Formación Lizama" (mottled shales with gray sandstone intercalations and some thin coal layers). On surface, there are Quaternary deposit like colluviums. (León, 1991) y (SGC, 2001). See **Figure 3**.

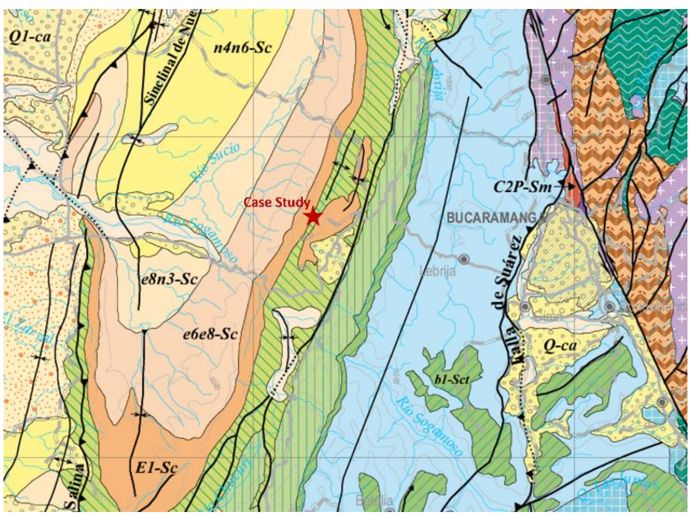

FIGURE 3. GEOLOGY OF STUDY CASE ZONE (SGC, 2023)

This site is in a complex and dynamic tectonic region by interaction of Nazca, Caribe, and South America tectonic plates. Due to this dynamic, intense fractured rock are present, as well as anticlinal and syncline structures limited by reverse and thrust faults.

2.2 Rainfall

CENIT has a rainfall network to monitoring its RoW's, through which an excess rainfall in case study area was identified. This was one of the reasons why frequent visual inspections were carried out in the area. **Figure 4** illustrate previous months rainfall conditions compared with its climatology, for the study case area.

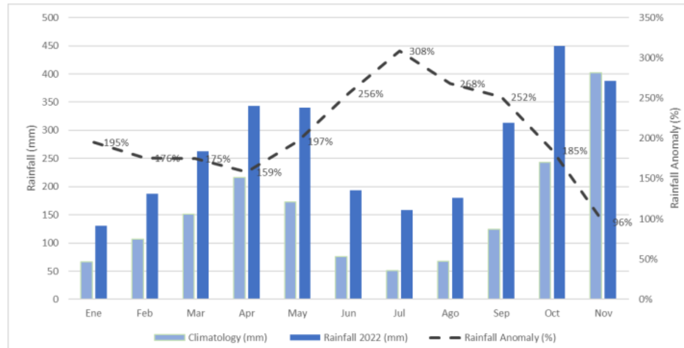

FIGURE 4. STUDY CASE AREA´S RAINFALL ANOMALY CHART.

2.3 Early Identification

In October 2022, through RoW Patrol the rock fall from a scarp, and their accumulation at the toe of the slope were identified, 200 m upslope from RoW, on a Colluvium deposit (see **Figure 5** and **Figure 6**).

FIGURE 5. OCT. 2022. ROCK FALL LOCATED UPSLOPE OF THE ROW.

Because of this condition, a monitoring plan was established to visit it at last two times per month. In November 2022, one month later, a toe bulge was identified (see **Figure 7**), and during the following two (2) weeks, the instability process evolution was denoted by the following aspects:

- A second toe bulge located downslope from the previous one (see **Figure 7**).
- Rise of the road's drainage ditch due to lateral load (see **Figure 8**).

FIGURE 6. ROCK FALL AT THE TOE OF MAIN SCARP.

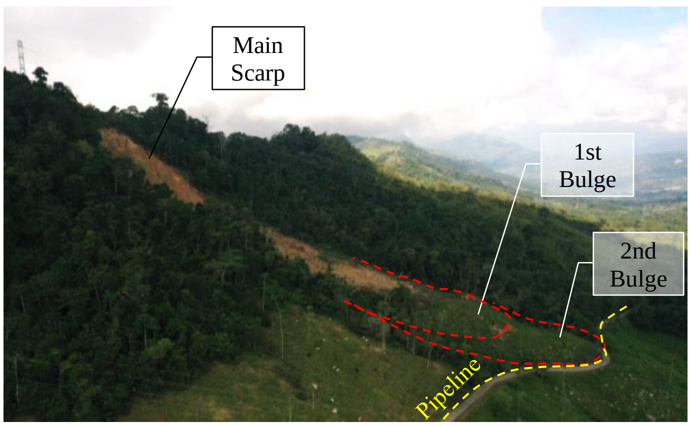

FIGURE 7. DEC. 2022. TOE BULGES IDENTIFIED

FIGURE 8. RISE OF THE ROAD'S DRAINAGE.

Given the characteristics observed in the landslide evolution, and by its activity (SGC, 2017), a successive landslide was identified such as the one illustrated in **Figure 9**. This condition represents an imminent interaction between landslide and pipeline, considering the shallow depth at which the pipeline was located (of about 2 m) compared with failure surface inferred.

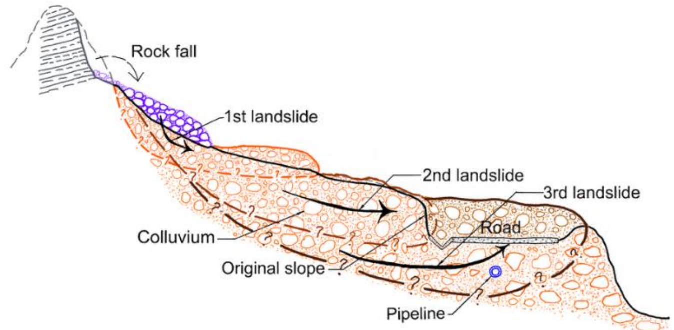

FIGURE 9. ILLUSTRATIVE DIAGRAM OF THE SUCCESSIVE LANDSLIDE IDENTIFIED.

2.4 Monitoring plan

In addition to the first monitoring plan implemented, the pipeline was detected and its location was marked on the concrete pavement slabs (see **Figure 10**), as well as specific points of interest, to identify progress in the interaction between the landslide and RoW (i.e. monitoring of the opening in concrete pavement slabs joints – see **Figure 11**).

FIGURE 10. SURFACE DETECTION AND MARKING OF PIPELINE ALIGNMENT.

FIGURE 11. MONITORING OF THE OPENING IN CONCRETE PAVEMENT SLABS JOINTS.

This monitoring plan allowed to estimate the time available for implementation of preventive mitigation measures to operation under controlled integrity conditions.

2.5 Temporary mitigation plan (flexible pipe)

Considering landslide-pipeline interaction inferred, and with the aim to continue a safe operation, the following actions were evaluated as immediate mitigation alternatives:

- Cable-stayed bridge for pipeline with metal pipe towers, anchorages, and cable-stay.
- Variant (conventional) in metal pipes, outside the area of influence of the instability process.
- Bypass in flexible pipe thorough the currently affected area and the potential one. For this, the need to carry out re-blocks according to the progress of the landslide was considered.

In an expert judge workshop, it was established that the most appropriate temporary solution for the conditions of the site was the construction of a bypass in flexible pipe.

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 12**). **Figure 13** shown a temporary solution overview, installed and operative.

FIGURE 12. FLEXIBLE PIPE SPOOLS

FIGURE 13. BYPASS IN FLEXIBLE PIPE (6").

3. RESULTS AND DISCUSSION

The implementation of Cenit's Geohazards Management strategy has made it possible to identify, in a timely manner, an instability process that would affect the integrity of one of its hydrocarbon transport systems. Likewise, this has made it possible to define follow-up and monitoring actions, as well as the analysis, definition, and implementation of temporary solutions to keep it in safe operating conditions.

Once the temporary solution was operative, the engineering studies of the site were started. At the time of writing this document, work is underway to collect information about geological and geotechnical variables, and the following options of mitigation alternatives were considered:

- Horizontal Directional Drilling (HDD). The aim is to elude the instability process below its failure surface.
- Overpass. Cable-stayed bridge for pipeline with metal pipe towers, anchorages, and cable-stay. It seeks to avoid the instability process with an above ground solution.
- Robust retaining structures and stabilization works; accompanied by works to manage and conduct surface runoff and subsurface flows.

Due to activity of the landslide and its evolution, in addition to third party activities to recover the road´s transit (see **Figure 14**), what were considered in the temporary solution decision-making process, it has been necessary to relocate the flexible pipe four times without impacts for integrity of the system.

Currently, the monitoring plan implemented (including topographical surveys, rainfall monitoring and geotechnical assessment) and the temporary solution, has allowed us a safely operation and the business continuity.

FIGURE 14. JUN 2023. TEMPORARY SOLUTION OVERVIEW.

4. CONCLUSION

CENIT has an effective Geohazards Management Strategy that has allowed it to generate a sustained reduction in the occurrence of spills associated with Geohazards. Proof of this is the study case that has been presented in this paper.

ACKNOWLEDGEMENTS

To CENIT for allowing us to participate in training events, in which knowledge management and share experiences are the key to continuous improvement.

To the Geohazard Management Contractor, who has been involved in the implementation of the Geohazard Management Strategy.

To the operation and maintenance team, since their absolute and unrestricted participation in the implementation of the strategy, especially in the monitoring, as well as in the implementation of the temporary solution, have contributed to avoiding a spill associated with this geohazard.

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