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INNOVACIÓN EN LA GESTIÓN DEL RIESGO GEOTÉCNICO QUE INTEGRA DIFERENTES COMPONENTES PARA LA GESTION ADECUADA DE LA GEOAMENAZA EN LA INFRAESTRUCTURA DE TRANSPORTE DE GAS NATURAL.

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ABSTRACT

Promioriente is a natural gas transportation company. Its transportation system, the Gibraltar–Bucaramanga Pipeline, crosses the eastern Colombian mountain range from the Gibraltar field to Bucaramanga and then to Barrancabermeja. Of its 335 km route, 144 km of the Gibraltar–Bucaramanga pipeline pass through high and mid-mountain areas, where colluvial deposits and the region’s climatic conditions result in high susceptibility to mass movement phenomena. This factor has led the organization to continuously evolve its strategies and techniques for monitoring geotechnical risk. These techniques range from the implementation of common methods such as topographic monitoring, photogrammetry, and optical satellite imagery to the advancement toward satellite monitoring with synthetic aperture radar, the implementation of weather stations, and a machine learning model to infer the probability of mass movement events. All of this has become an early warning system to mitigate the impacts derived from geotechnical risk, shifting from a reactive to a preventive approach.

Keywords: Natural gas transportation, mass movement, risk mitigation, monitoring

1. INTRODUCTION

The route of the Gibraltar–Bucaramanga Gas Pipeline faces significant geotechnical challenges due to the topographic, climatic, and geological conditions of the regions it crosses. The Gibraltar–Bucaramanga section passes through areas highly susceptible to mass movement phenomena, which poses a constant risk to the integrity of the pipeline and the continuity of the service.

2. UBICACIÓN



In this section of the route, abrupt slope changes, combined with climatic and geomorphological characteristics, give the layout unique features.



2.1 Geotechnical risk

The previously mentioned geotechnical susceptibility condition was known due to various anomalies identified along the right-of-way since the Gibraltar–Bucaramanga pipeline began operations. However, it was not known to what measurable extent this susceptibility could affect us. For this

reason, the AVR project was launched to identify the threat, vulnerability, and risk to which the transportation system was exposed, categorizing the threat into three levels: High, Medium, and Low.



With the identification of the threat level in the transportation system, more robust topographic and photogrammetric monitoring plans began to be implemented, with an established frequency and a geotechnical control works plan to mitigate the identified threat rating and risk.

At this point, geospatial data began to gain relevance, along with all the information on variables such as:

- Geology
- Slope
- Land cover
- Distance to geological faults
- Precipitation
- Seismicity
- Geological units

These were used as sources for the creation of an infrastructure dataset which, along with a review of the state of the art on available technologies for geotechnical risk monitoring and the implementation of machine learning models, laid the foundation for the Early Warning project. This initiative aims to maintain surveillance of geotechnical risk and mitigate the impacts that mass movement phenomena and flash floods could have on transportation infrastructure.

In the review of the state of the art of available technologies, among others, the implementation of L-band synthetic aperture radar (SAR) imagery and SAR interferometry (InSAR) was identified to detect deformations along the right-of-way with sub-meter accuracy.

At the same time, the installation of meteorological stations was being carried out in areas with the highest susceptibility to geotechnical risk, to monitor in real time one of the main triggers of mass movement phenomena and flash floods.

Data from proprietary meteorological stations, along with historical data from public sources dating back to the 1970s, were subjected to descriptive statistical analysis. This led to the establishment of sectorized precipitation threshold limits to guide action plans.

These actions range from increasing the frequency of monitoring routines at identified critical sites to site visits by

geotechnical specialists for specific studies that enable the design of appropriate protection or geotechnical control works.

3. RESULTS AND DISCUSSION

I. Consolidation of a multicomponent monitoring system

A five-component early warning system was successfully implemented:

- Technological surveillance.
- Meteorological stations
- Machine learning model
 - Geotechnical sensors
 - Real-time monitoring platform

This approach enabled a shift from reactive to preventive geotechnical risk management, improving the ability to anticipate mass movement events.

II. Results of the predictive model

The machine learning model, fed with meteorological, topographic, and geological data, has generated alerts with a high correlation to actual events. For example, rainfall increases exceeding 200 mm were identified in critical areas such as Gibraltar–La Virgen, which triggered preventive action plans.

III. Impact of Weather Stations

The installed weather stations (Gibraltar, La Virgen, Chitagá, Labateca, and Cristales) have enabled effective monitoring coverage along the gas pipeline corridor, providing real-time data on precipitation, humidity, and temperature. This data has been instrumental in feeding the predictive model and validating alerts. The monitoring framework continues to be reinforced through the deployment of additional weather stations in areas identified as highly susceptible.

IV. Integration of SAR/InSAR Technology

The integration of radar satellite imagery (SAR/InSAR) will enable the detection of sub-metric deformations, even under cloudy or low-visibility conditions. This technology has strengthened monitoring capabilities in areas that are difficult to access due to topographic constraints as well as physical security concerns.

The results demonstrate that the integration of advanced technologies and data analytics significantly enhances geotechnical risk management in linear infrastructure. However, several challenges have been identified, including:

- The need to keep models updated with recent data.
- Dependence on connectivity for real-time data transmission.
- Long-term operational sustainability of the system.
- The importance of continuous improvement in machine learning models, including testing alternative algorithms, developing zone-specific models based on

varying susceptibility levels, and exploring the use of neural networks.

4. CONCLUSION

I. Transformation of the Risk Management Approach

The early warning project has enabled Promioriente to evolve from a reactive to a preventive approach in geotechnical risk management, through the integration of advanced technologies, continuous monitoring, and data analytics.

II. Effective Technological Integration

The implementation of weather stations, geotechnical sensors, satellite imagery (SAR/InSAR), and machine learning models has proven to be an effective strategy for anticipating mass movement events and triggering timely action plans.

III. Strengthening Predictive Capability

The developed machine learning model has successfully inferred high-susceptibility zones, powered by meteorological, geospatial, and topographic data. This has enabled the generation of alerts with sufficient lead time to mitigate impacts on infrastructure.

IV. Strategic Value of Technology Surveillance

Understanding available technologies and reviewing the state of the art have been essential for selecting appropriate technologies for each segment of the gas pipeline, optimizing resources and improving monitoring system coverage.

V. System Scalability and Sustainability

The early warning system is designed to be scalable and adaptable to other segments of the organization's transport

infrastructure, and even to other types of linear infrastructure. Its sustainability will depend on continuous data updates, sensor maintenance, and effective knowledge management.

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