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STRUCTURE OF THE GEOHAZARDS FOR MONITORING AND MANAGING SYSTEM OF RIGHTS-OF-WAY OF OIL AND GAS PIPELINE TRANSPORT SYSTEMS

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ABSTRACT

This article describes the development of a system designed to enable comprehensive, preventive, and forward-looking management of geohazards and risks related to landslides caused by rain and earthquakes along the rights of way for oil and gas pipeline transport systems. This system is referred to as the Geohazard Monitoring and Management System (GMMS).

The GMMS is composed of a geographic information system GIS and an early warning system EWS. The GIS contains data on geohazards assessed for rights of way, allowing users to directly access this information within a geographic framework. This supports monitoring and managing hazard conditions in a preventative way. The EWS continuously monitors rainfall and earthquakes, which are potential triggers for landslides, and compares these data to thresholds established by predictive rain and seismic-landslide models designed for the study area. When thresholds are exceeded, the system issues alerts for areas at risk of landslides based on the magnitude of detected rainfall or seismic events. EWS users receive notifications of active landslide alerts to facilitate prompt operational responses.

This document outlines the overall structure of the GMMS, describes the scope and key details of the GIS module, provides an overview of the EWS module's components, and explains the methodologies used to develop the rain and earthquake landslide predictive models that support the EWS.

Keywords: Geohazard, Management, Monitoring, Early Warning, Geographic Information, Rain Slip, Earthquake Slip.

NOMENCLATURE

CHIRPS: Climate Hazards Group InfraRed Precipitation with Station data.
DTM: Digital Terrain Model.
EWS: Early Warning System.
Fpga: Peak Ground Acceleration Amplification Factor.
GIS: Geographic Information System.
GMMS: Geohazard Monitoring and Management System.
PGA: Peak Ground Acceleration.
MMHTZ: Threatens Mass Movement Hazard Zoning.
ROW: Right of Way.
SF: Safety Factor
SRZ: Seismic Response Zoning.

1. INTRODUCTION

The Oil and Gas pipeline transportation systems are extensive networks with rights-of-way that are exposed to various geological hazards such as mass movements, earthquakes, floods, scour and torrential floods, among others. In order to carry out a comprehensive management of the risks associated with these geological hazards, particularly geotechnical ones, it is necessary to have detailed knowledge of the geohazard conditions to which the rights of way are exposed.

Given the need to carry out a comprehensive, preventive and prospective management of geohazards and risks associated with landslides induced by rains and earthquakes, the GMMS Geohazard Monitoring and Management System was developed, which operates as a Geographic Information System articulated with an Early Warning System.

The geographic information system (GIS) consolidates information on infrastructure, seismic response zoning studies, rainfall, regional and detailed mass movements hazard, among others. The early warning system (EWS) for landslides due to rain or earthquakes includes predictive monitoring, alert communication and operational response.

With the GMMS, the hazard conditions due to mass movements of the rights-of-way calculated in the studies (for various scenarios) and the current conditions estimated by the Early Warning System are visualized, i.e. under the given conditions of rain and earthquake. In this way, it will be possible to support the comprehensive management of the risk associated with geohazards, for example, by making plans to improve the conditions of the rights of way in the places where studies indicate the greatest hazard (preventive management) and prioritizing inspections and actions to control or prevent landslides are required after extreme rainfall events or earthquakes.

2. GMMS GENERAL STRUCTURE

The general structure of the GMMS of the rights of way of the Oil and Gas pipeline transport system has two main components, the first is the GIS Geographic Information System that centralizes for consultation the information of the infrastructure and geohazards of the rights of way and the second component is the EWS Early Warning System of landslides triggered by rains and earthquakes.

The GIS contains databases of relevant information on the operator to carry out its geohazard management such as base cartography, infrastructure, geohazard zoning, geohazard scenarios, critical sites, interventions carried out, in general all the georeferenced information that allows preventive management of geohazards that affect rights of way.

The scope of the GIS is to consult information, it does not intend to replace specialized programs (ArcGis or QGis), the purpose is to give online access to all types of users who need to know the information in a geographical consultation environment.

The rain and earthquake landslide EWS comprises modules that perform predictive monitoring, alert communication and operational response. Predictive monitoring includes the seeing of rainfall and earthquakes, landslide models triggered by rain and earthquake, and checking and alert definition modules that compare in real time the rain and earthquake measurements with the thresholds established by ROW sections to define the alert levels as a traffic light of the possibility of landslides. Green: Routine monitoring, Yellow: Weekly monitoring, Red: Urgent inspection. The communication of alerts is governed by a communications protocol and a module that issues the alerts automatically, finally the operational response is based on pre-established plans and their application.

With the GMMS, operators will be able to visualize the geohazard conditions of the rights of way evaluated in the previous studies and know the state of stability of the slopes by the early warning system under the current conditions of rain and earthquake. In this way, it will be possible to support the comprehensive management of risk associated with geohazards, for example, by making plans to improve the conditions of the rights of way in the places where studies indicate the greatest hazard (preventive management) and prioritizing after extreme rainfall events or earthquakes the areas where inspections need to be carried out to control or prevent damage to the infrastructure.

3. GEOGRAPHIC INFORMATION SYSTEM

The GIS consolidates and has the information that has been collected and processed over several years for the study of geohazards in rights-of-way, which is summarized below by theme.

Infrastructure

It includes the geographical coverage of the operator's entire infrastructure such as pipelines, rights of way, accesses, camps, stations, etc. This information must be validated and updated periodically for changes when realignments or variants are made.

The implementation case comprises 170 km of ROW.

Thematic mapping

It includes all available geographical coverage of cartographic base, geology, geotechnics, hydraulics and hydrology, seismicity, properties, land cover, protected areas, social and environmental aspects.

Digital Terrain Model

The high-resolution and updated Digital Terrain Model DTM is essential to evaluate the geohazards that affect the corridors where the rights-of-way go, having the DTM of the hallway with over widths allows to evaluate the geohazards that can affect the ROW, coverage calculated from the DTM as slopes is also included, curvatures, appearance, topographic index, among others.

For the implementation case, Lidar surveys were carried out on a one-kilometer-wide hallway with a resolution of 1 m and that for the purposes of studies and models was optimized to a resolution of 2.5 m.

Seismic Response Zoning

The SRZ Seismic Response Zoning, also known as Seismic Microzoning, is one of the geohazard studies that allows the determination of seismic demands for right-of-way stability analyses.

For the implementation case, there is a raster SRZ, which presents the spatial distribution of the seismic coefficients of PGA amplification (Fpga) that quantifies the effect of the amplification or deamplification of the acceleration in rock, due to the passage of the ground motion through the stratigraphy and surface topography of the terrain, to obtain the peak acceleration of the ground motion on the surface (PGAsur). The continuously spatialized results are an input for mass movements hazard zoning, for seismic risk analysis of the ROW and for the earthquake landslide early warning system.

Additionally, for the purposes of design and construction of stability works in the rights of way, there is a seismic response zoning grouped by each geological unit, where the seismic coefficients of each zone are defined from the geostatistics of the Fpga and PGAsur values.

Mass Movements Hazard Zoning

The Mass Movements Hazard Zoning MMHZ is another of the geohazard studies that allows estimating the stability of the slopes of the geotechnical hallway where the rights of way are located.

The MMHZ was developed by two methodologies, the first consisted of applying statistical methods of evidence weights to zone the susceptibility of the terrain to landslides and combined with weights weighted with the triggers, a relative hazard zoning by mass movements was reached.

The second methodology applied is analytical, calculating the stability of the terrain by the Newmark method (infinite slope) that allows obtaining the safety factor of the slopes for three earthquake scenarios and three soil saturation scenarios, resulting in a total of 9 combined stability analysis scenarios.

Mass Movement Inventory

The mass movements inventory is relevant input for the system. Identifying locations where instability has occurred is necessary for effective monitoring and management. Additionally, inventories serve as a key resource for hazard zoning studies related to mass movements and for creating predictive rainfall models.

The GIS consolidates the inventory of mass movements of the study area with relevant attributes of mass movements such as type of event, affected area, date of the event, mitigation works executed, qualification of the current hazard condition of the site, etc.

For the case study, information was collected from 414 events of various types, mostly rotational landslides, with which the analysis of weights of evidence of the MMHZ was performed.

For the rain-slide model, it is necessary to have the date of occurrence of the landslides to associate the series of rains preceding the event, in this case the inventory consolidated 204 mass movements with the date of occurrence.

A very relevant aspect is the location of mass movements, which must be reviewed and validated with various sources of information such as satellite images, aerial photographs and maps of mass movements hazard.

Historical rainfall records

The system has the coverage of the rainfall stations that operate in the rights of way and surroundings, this coverage is associated with the historical database of daily rainfall for consultation. Additionally, the GIS includes the results of the rainfall analyses of the CHIRPS portal of the study area, such as maps of average monthly rainfall and average annual rainfall for see.

The information from the rainfall stations and the monthly and annual rainfall maps are available for consultation by users who need to carry out detailed analyses of specific sites, as well as to see the rainfall projections for each month.

Optionally, the system can be linked to a weather forecast channel to centralize the information in a single query portal.

Analysis Unit

The coverage analysis unit is polygon type, it is defined to spatially represent sectors of homogeneous characteristics of the right-of-way, where each polygon consolidates information used in the EWS of input such as safety factors, rainfall thresholds and critical accelerations; and calculated information such as accumulated rainfall and accelerations due to an earthquake. This coverage is then the key that associates the characterization of the stability variables with the triggers, showing spatially in the GIS module the dynamic results of the EWS alert states.

In the case of implementation, after several tests, a 100 m wide right-of-way sectorization was defined (50 m on each side of the pipeline axis) and divided into sections of 50 m in length and on the right and left shoulder of the ROW, leaving polygons of approximately 50 m by 50 m on each side of the pipeline axis. The results obtained with this division manage to summarize well the hazard conditions by differentiating the shoulder from the right of way, this division being then the one used as the unit of analysis of the system.

4. EARLY WARNING SYSTEM

The developed Early Warning System is an effective tool to quickly assess the impact of geohazards associated with rainfall and earthquakes on the stability of the land of the rights of way. This system has a predictive monitoring module that establishes the alert levels, which are communicated in a timely manner to the personnel in charge of the infrastructure to advance the operational response in accordance with the actions defined by the corresponding alert level.

The predictive monitoring module calculates and issues three levels of landslide alert by comparing in real time the rainfall and earthquake measurements with the thresholds (critical rain or critical acceleration) established for the unit of analysis.

The alert levels given by the system are "Green or stable" which suggests routine monitoring, "Yellow or potentially unstable" which recommends inspection of the right of way at least once a week and level "Red or high probability of landslide" which indicates that urgent inspection of the identified sector of the right of way must be carried out.

The following section outlines the methodological elements and procedures used in developing the rain-slip and seismic-slip modules.

The scope of the EWS is to establish alert levels for possible landslides generated by precipitation or seismic movements, applicable to the entire right-of-way at a local scale. The methods used do not evaluate the hydrodynamic behavior of the slopes considering factors such as rainfall, infiltration and saturation. The use of coupled hydrodynamic models is recommended for the monitoring and analysis of critical sites, provided that detailed information on the properties of the materials and triggers is available, obtained through specific instrumentation. The instrumented critical site can be integrated into the GMMS as an add-on module.

Rain Slip Model

Studies on rainfall thresholds that cause landslides are scarce in Latin America; efforts have been made mainly in urban areas with significant slopes or in road projects (Aristizábal et al. (2022), Ramos et al. (2015), Hidalgo et al. (2014)).

In general, the methodologies aim to estimate the level of precipitation that has caused landslides, using two parameters: one related to the accumulation of rain in a given period and the other to the intensity of the precipitation in the last days or on the day of the event. The most common thresholds are the ratio of accumulated precipitation over 15 or 30 days to the day's precipitation (downpour).

The methodologies apply various data analysis techniques, from statistics to probabilistic models, all under the assumption that rain is the trigger and do not take into account the previous stability of the terrain, the latter being a significant limitation of these methods, since the thresholds are general for large areas without differentiating the sectors susceptible to landslides.

Taking into account the revised methodologies, the first objective of the rain-slide model is to identify the capacity of the land to accumulate rain without suffering landslides in terms of how much accumulated rainfall has been statistically triggered by landslides in the study area, which is known as the critical rainfall threshold (capacity). The second objective is to characterize the spatial and temporal behavior of the rainfall in the study area in order to spatialize the rainfall recorded in the rainfall stations, so that it is possible to know in real time how much rain has fallen along the rights-of-way (demand). With these objectives in mind, the procedures for determining rainfall thresholds by areas susceptible to landslides and for spatializing rainfall presented below were developed.

Critical Rain Thresholds

The critical rainfall thresholds and their spatial distribution were defined by the procedure shown in the **Figure 1**, the combination of statistical analyses to define the thresholds that are then validated with analytical analyses stands out from the procedure, obtaining a zoning of critical rainfall thresholds.

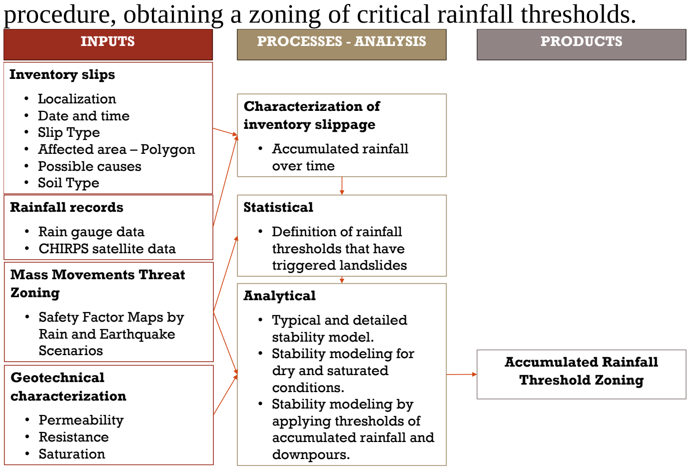

Figure 1. Procedure for obtaining rainfall thresholds that trigger landslides

To define the critical rainfall thresholds, a statistical procedure like that proposed by Aristizábal et al. (2022) was applied, which consists of calculating the histogram of accumulated landslide frequencies versus the accumulated rainfall for 3, 15, 30 and 60 days from the rainfall series of each landslide. Based on this histogram, the limit between the green and yellow alert threshold is established at 10% of the accumulated frequency, that is, there is a 10% probability of landslides occurring when the accumulated rain is below the yellow alert threshold. The limit between the yellow alert threshold and red alert is defined for 50% of the accumulated frequency, that is, there is a probability between 10% and 50% probability that landslides will occur when the accumulated rain is in the yellow alert range and a probability greater than 50% when it is equal to or greater than the red alert threshold. The **Figure 2** It shows this analysis and the alert levels in the graph of the accumulation series.

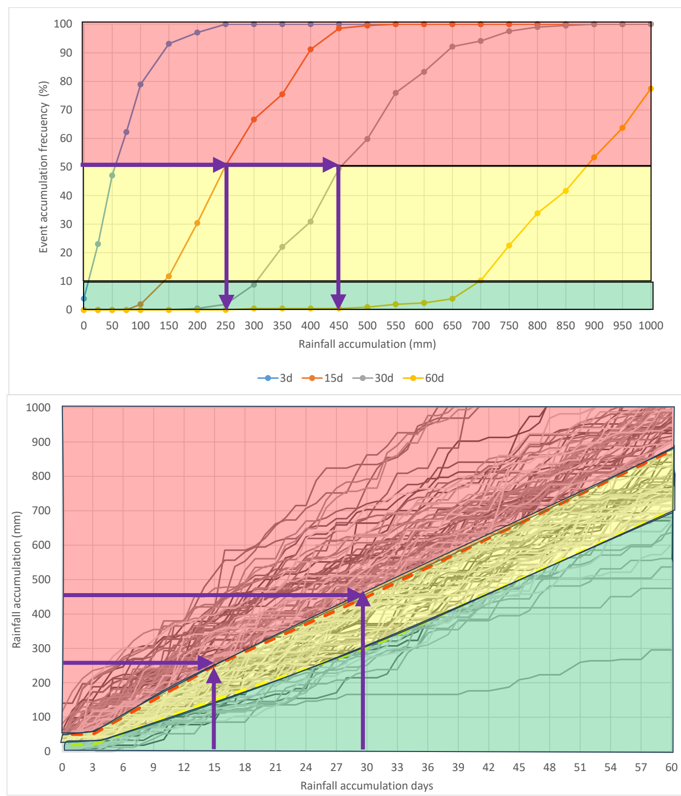

Figure 2. Yellow and red rainfall thresholds and MM rainfall accumulation series

In the upper is the histogram of frequencies for accumulated rainfall in periods of 3, 15, 30 and 60 days, which serves as a basis for defining the thresholds. For example, for 15-day accumulated rainfall, the threshold to activate the red alert corresponds to 250 mm (50% of events). At the bottom, the figure shows in gray the series of rainfall accumulations of all the events analyzed together with the thresholds calculated by the frequency histogram, where the limits of the thresholds are observed as a function of time and the amount of accumulated rainfall; in the case, there are 250 mm at 15 days of accumulated precipitation.

To spatially identify where the calculated thresholds apply, the safety factor under saturated conditions of the MMHZ was identified for each site analyzed and its relationship with the accumulated rainfall thresholds, **Figure 3** shows the results obtained where it is identified that the thresholds apply to the sectors with SF less than 1.5 (90% of events) of the MMHZ with a resolution of 2.5 m by 2.5 m. As the EWS works for the 50 m by 50 m unit of analysis, geostatistical analysis should be performed to identify the statistical metric of SF in the unit of analysis that is most suitable to correlate with rainfall thresholds. This step is important so that the EWS only issues an alert of potentially unstable sectors and is not generally to the entire area where the rain threshold is exceeded.

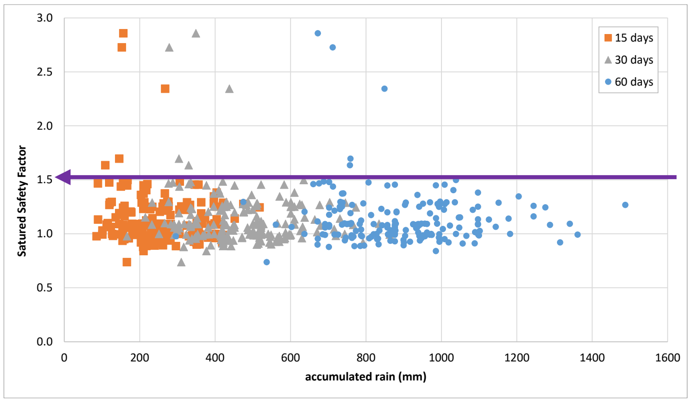

Figure 3. Safety factors of landslide sites versus detonating accumulated rain

Precipitation spatialization

Rainfall spatialization is the procedure by assign to each unit of analysis the series of accumulated rainfall based on the daily rainfall records and the hydrological studies of the rainfall recorded as shown in the **Figure 4**.

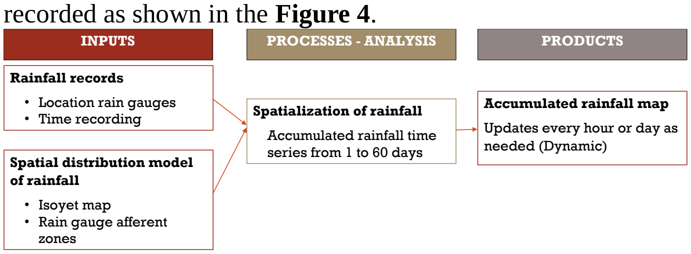

Figure 4. Procedure for obtaining the distribution of accumulated rainfall

In the case of implementation, rainfall is reported by the operator of the rainfall stations. These specific data from the stations are spatialized by homogeneous precipitation zones throughout the corridor of the rights of way according to the analysis of historical rainfall carried out, the analysis is carried out by areas of influence and spatial interpolation.

Defining alert levels

The alerts are given when the accumulated rainfall at 3, 15, 30 and 60 days exceeds the yellow threshold in the first instance and then exceeds the red threshold in the second instance, the analyses show that the alerts must be given because two criteria are met, the accumulation at 15, 30 and 60 days and the criterion of detonating rain between 1 and 3 days. The alert level drops 8 days after rainfall falls below the threshold.

The results of alert levels are shown in the polygons of the analysis unit used for the early warning system.

Earthquake Slip Model

The methodologies to analyze landslides triggered by earthquakes have been developed for several years. Among the most relevant studies of stability and susceptibility to landslides on a regional scale are Wilsony & Keefer, 1983; Wieczorek et al., 1985; Wilson & Keefer, 1985; Jibson, 2000.

The method of Jibson (2000), for example, establishes an analogy between slippage (a volume of material that slides on a fault surface) and a rigid block that slides on an inclined surface. For this block, it is possible to determine a critical acceleration, which is the acceleration that induces a force greater than the resistant forces, thus initiating the movement and producing a displacement of the block (Diaz-Parra et al, 2011).

The earthquake-slip model is the other component of the early warning system, the objective of the model is on the one hand, to define the capacity of the terrain to withstand the accelerations of an earthquake without suffering landslides in terms of critical acceleration estimated from the regional model of ground stability of the MMHZ (capacity). On the other hand, characterization of the seismic activity that may affect the study area to define the most appropriate attenuation and site effects models to spatialize the maximum accelerations of the ground after the occurrence of a strong earthquake in the area of influence (demand).

Based on the critical acceleration (threshold) and the maximum acceleration of the ground on the surface, the displacements of the sliding block (infinite slope method) are estimated in each unit of analysis, then the alert levels are defined based on this displacement (Diaz-Parra et al, 2011), if it is less than 1 cm there is no alert (green). if it is between 1 cm and 5 cm it is a yellow alert and if it is greater than 5 cm it is a red alert.

With these objectives in mind, the procedures for determining acceleration thresholds by areas susceptible to landslides and for spatializing of maximum ground accelerations were developed as presented below.

Acceleration Threshold

The acceleration threshold or critical acceleration was calculated with the procedure shown in the **Figure 5**, which has the SRZ and the MMHZ as its main inputs.

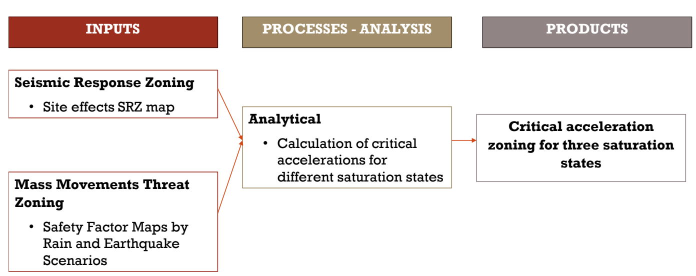

Figure 5. Procedure for obtaining critical accelerations (thresholds)

The acceleration threshold that a slope can withstand without being affected is called critical acceleration, which was proposed by Newmark, who showed that the critical acceleration of the volume of material that slides on a fault is a function of the static safety factor and the slope of that surface, as follows:

$$Ac = (SF - 1)g \; sen \; \alpha$$

Where Ac is the critical acceleration in gals, g is the acceleration of gravity (980 gal), SF is the static safety factor and α is the angle formed by the fault surface, which is assumed to be planar fault parallel to the ground surface, therefore, it is assumed to be equal to the slope of the terrain. For the implementation case, the static safety factor was evaluated in the MMHZ study for three scenarios of saturation, dry condition, partially saturated condition and saturated soil. So with the 2.5 m by 2.5 m slope raster and the 2.5 m by 2.5 m SF rasters of the scenarios, the critical acceleration maps for these same three scenarios, dry, partially saturated and saturated, are calculated with the help of the map raster calculator of the GIS tools.

Spatially the critical accelerations are assigned in the units of analysis (50 by 50 m polygon), taking the minimum values of Ac, if the value is 0 gales it is limited to a minimum value of 5 gals so that the subsequent calculation of displacements generates results and is not indeterminate.

Spatialization of maximum ground accelerations

The spatialization of the maximum accelerations of the ground is the procedure to calculate for each unit of analysis how much acceleration the earthquake produces, the process is shown in the **Figure 6**.

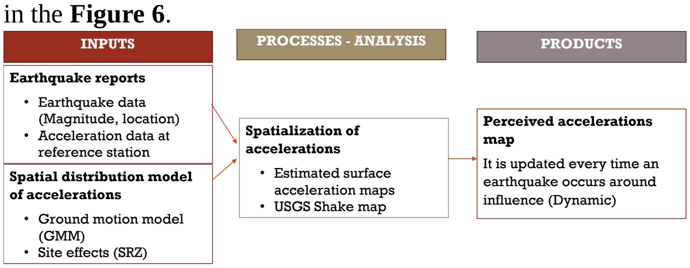

Figure 6. Procedure for obtaining maximum ground accelerations due to earthquakes (demand)

The earthquake is analyzed from the report issued by the geological or geophysical services that operate the seismological and accelerograph networks of the country, these reports contain information on the magnitude, depth and location of the event, with which the acceleration in rock is calculated for all the polygons of the analysis units with the attenuation models applicable to the region and type of seismogenic source. Then it is amplified with the average site effects amplification factor Fpga of the polygon given in the SRZ study, the result of the process is the map of maximum terrain accelerations (PGAsur) calculated for all polygons of the unit of analysis.

Earthquake slope displacements and alert levels

As mentioned, the methodologies for analyzing landslides triggered by earthquakes recommend that the displacements produced by the seismic event be calculated by analyzing the resistance of the sliding block, which can be represented in the critical acceleration value. The original proposal of Jibson 1993 and 2000 recommends an expression based on the critical acceleration and the seismic parameter Arias intensity of the detonating earthquake, however obtaining the Arias Intensity requires accelerograms that in many cases are not available as soon as the event occurs, so to facilitate the use of this methodology on a regional scale some authors have developed empirical expressions that allow obviating the integration process and to estimate the displacement based on a parameter of seismic intensity and critical acceleration (Jibson, 1993; Jibson, 2000). For the present case, the following expression is used (Yegian et al., 1991):

$$D = \left(a_{max*} N_{eq*} T^2\right) * 10^{0.2 - 10.1*\left(\frac{a_c}{a_{max}}\right) + 16.4*\left(\frac{a_c}{a_{max}}\right)^2 - 11.5*\left(\frac{a_c}{a_{max}}\right)^3}$$

Where a_{max} corresponds to the maximum ground acceleration in Gales, Ac is the critical ground acceleration in gals, Neq is the equivalent number of cycles of the actual ground earthquake as an indicator of the duration of the strong movement, and T is the dominant period of the seismic signal at the slope site.

Although the displacement evaluated in this way may not necessarily correspond to the actual displacement, it allows characterizing and comparing the behavior of the terrain during a seismic movement (Jibson, 2000).

For the purposes of the early warning system, alert levels are classified according to calculated displacements in a manner like those proposed by (Wilson et al 1985, Yegian et al 1991 and Diaz-Parra et al 2011) as follows:

- If the displacement is less than 1 cm, it is classified as stable with green color.
- If the displacement is greater than 1 cm and less than 5 cm, it is classified as potentially unstable with yellow color.
- If the displacement is greater than 5 cm, it is classified as a high probability of sliding with red color.

The alert level results will be displayed for the units of analysis used for the early warning system.

5. CONCLUSIONS

The Geohazard Monitoring and Management System for rights-of-way of Oil and Gas pipeline transportation systems is a tool that allows, on the one hand, to centralize the information of the regional geohazard studies carried out on the right-of-way and detailed studies of unstable sites in a geographic information system; and on the other hand, an early warning system that will monitor rainfall and seismic activity, which based on stability models, will identify the sectors where landslides may occur and issue alerts to take the respective actions

The Early Warning System will have a monitoring module and will issue landslide alerts by comparing in real time the rain and earthquake measurements with the thresholds established by ROW sections, it will be done as a traffic light of possibility of landslides that defines the alert level, the Green color being a stable condition that requires routine monitoring; Yellow, a potentially unstable situation that recommends increasing weekly monitoring of identified sites; and Red color is when there is a high probability of slippage and urgent inspection is recommended.

For the development of the rain and earthquake landslide models of the early warning system, several information inputs are required that have been developed and consolidated in recent years, this same information will be part of the geographic and documentary information system that will make up the GMMS. The seismic response zoning studies, and mass movements hazard zoning , collect and provide various inputs, in addition to updating the information on the inventory of mass movements and the historical rainfall in the study area.

In order to synthesize the results of the models and to be able to have a practical number of zones for the purpose of rapid monitoring of alerts, it is necessary to define a unit of analysis, for the case of implementation use a division of the right-of-way, taking 100 m wide (50 m on each side of the pipeline axis) and dividing it into sections of 50 m in length and per shoulder right and left of the ROW, leaving polygons of approximately 50 m by 50 m on each side of the pipeline axis.

The critical rainfall thresholds and their spatial distribution were defined by statistical analysis to define the thresholds that are then validated with analytical analyses, obtaining a zoning of critical rainfall thresholds. The results obtained are identified that the thresholds apply to the sectors with FS less than 1.5 (90% of events) of the MMHZ. For the analysis units, an average safety factor of less than 2.5 are those that have presented landslides triggered by accumulated rain, for which the thresholds calculated to these areas susceptible to landslides are zoned only, when the average safety factor of the analysis unit is greater than 2.5 the system maintains the green or stable alert level.

In the case of implementation, rainfall is reported by the operator of the rainfall stations. These specific data from the stations are spatialized by homogeneous precipitation zones throughout the corridor of the rights of way according to the analysis of historical rainfall carried out, the analysis is carried out by areas of influence and spatial interpolation.

The alerts are given when the accumulated rainfall at 3, 15, 30 and 60 days exceeds the yellow threshold in the first instance and then exceeds the red threshold in the second instance, the analyses show that the alerts must be given because two criteria are met, the accumulation at 15, 30 and 60 days and the criterion of detonating rain between 1 and 3 days. The alert level is lowered 8 days after rainfall drops below the threshold.

The earthquake thresholds are expressed in terms of critical acceleration that was calculated from the MMHZ maps for the scenarios without a dry, partially saturated and saturated earthquake. Spatially the critical accelerations are assigned to the units of analysis, according to the analyses the minimum value of the Acrit min polygon will be used, if the value is 0 gales it is limited to a minimum value of 5 gales so that the calculation of displacements generates results and is not indeterminate.

The triggering earthquake is analyzed from the report of the geological or geophysical services, taking the magnitude, depth and location of the event, the acceleration in rock is calculated for all the units of analysis with the attenuation models respective to the tectonic environment that caused it, then it is amplified with the amplification factor of site effects Fpga average of the polygon given in the SRZ study, the result of the process is the map of maximum terrain accelerations (PGAsur) calculated for all units of analysis.

With the critical acceleration (threshold) and the maximum acceleration of the ground on the surface, the displacements of the sliding block (infinite slope method) are calculated in each unit of analysis, then the alert levels are defined according to this displacement, if it is less than 1 cm there is no alert (green), if it is between 1 cm and 5 cm it is a yellow alert and if it is greater than 5 cm it is a red alert.

The considerations and methodologies applied for the GMMS are presented, which can be adapted to each specific project considering the available information and needs of the operators of the oil ang gas transportation systems.

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