APPLICATION OF THREE-DIMENSIONAL VISUALIZATION TECHNIQUES AND DECISION MAKING USED IN THE DETECTION OF MOVEMENTS OF THE GROUND AND UNDERGROUND PIPELINES IN UNSTABLE AREAS

Robson da Cunha Santos[a], Marcelo Silva[b], Gerson Gomes Cunha[c]

[a] Fluminense Federal Institute, Campus Macaé, Engineering and Automation Control
164 km Amaral Peixoto Road, Brazil and Estácio de Sá University, General Alfredo Bruno Gomes Martins Highway, s/n - Braga - Cabo Frio / RJ, Brazil
[b] Estácio de Sá University, General Alfredo Bruno Gomes Martins Highway, s/n - Braga - Cabo Frio / RJ, Brazil
[c] Federal University of Rio de Janeiro, Alberto Luiz Coimbra Institute Graduate Engineering and Research, Civil Engineering Program/COPPE/UFRJ

[a]profbsonso@yahoo.com.br, [b]msc.marcelosilva@gmail.com, [c]gerson@lamce.ufrj.br mail

ABSTRACT
Techniques for three-dimensional visualization and simulation of construction are applied in regions where companies install pipes for oil and gas. These regions can present aspects of geological and geotechnical risks, which can compromise the structural integrity of the pipes, by movement of the solids and interaction between soil and pipe. A system capable of evaluate these regions was created based on digitalized data of aerial photographs, coordinates of control instruments and on ground topography. The system consists of a three-dimensional environment (3D) using technics on virtual reality (VR) developed to support the analysis of existing problems. The system is completely geo-referenced, which permits definig adequate solutions for the projects as well as avoiding problems for some specific areas. In addition, the system permits interaction with specialists, enabling them to indicate directly on the 3D images, the risk aspects for further evaluation *in situ* and for taking adequate decisions.

Keywords: three-dimensional, visualization and simulation, virtual reality, unstable areas

1. INTRODUCTION
New studies on pipelines demonstrated that Brazil has about 22000 km of pipelines underground, and many of these areas are considered at risk (Monitor Mercantil 2010). Many of these pipelines cross regions with distinct geologic features, presenting several unstable areas as the region of Serra do Mar. In these regions the pipelines are submitted to additional loadings imposed by ground movements.

Structural integrity of the ducts should be in perfect condition installed in these areas. It becomes necessary to survey and map all areas unstable and stud the soil mass movements. Creep movements usually involve extensive areas and present slow speed. In general they are difficult to detect through visual inspection.

Figure 1: Brazilian Pipeline Map (Calhambequi 2013)

New studies have been implemented to improve operational safety pipeline, new technologies are being developed to detect unstable areas and estimate their effect on the pipelines. A complete set of visualization and numerical simulation software platform is available and it is being used to build a three-dimensional model of all the geotechnical risky areas in Serra do Mar. The installation and operation of a pilot monitoring system, including piezometers and inclinometers on the slope and strain gauges on the pipeline, at three different pipelines crossing Serra do Mar, with data acquisition in real time is also being undertaken.

Techniques for three-dimensional visualization of areas around the pipeline have demonstrated to be a great tool to detect geologic and geotechnical risky features. It allows a detailed analysis of the adjacent slopes, being useful to guide the implementation of monitoring systems and stabilization works.

2. REGION EVALUATED
The region studied and analyzed consists of a mountainous range Brazilian relief that extends for about

1500 km along the east / south coast, ranging from the state of Rio de Janeiro to the north of the state of Santa Catarina known as Serra do Mar. The saw is characterized by the presence of thick deposits talus colluvium. Due to its formation process, these deposits are very heterogeneous, presenting all kinds of grain sizes. It is located in a region of high precipitation what in association with the geologic and geotechnical features creates a potential condition for the occurrence of creep and soil sliding movement.

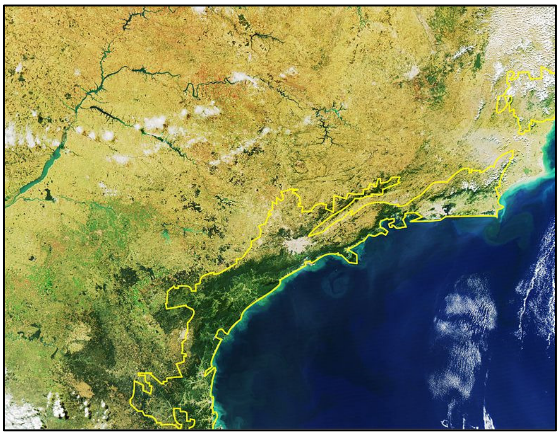

Figure 2: Satellite Image of the Serra do Mar (GoogleEarth 2013)

The best definition for the Creep can be a slow and continuous soil mass movement most of the times with no clear limits. It is caused by the action of the gravity, being activated or increased by variation of temperature and pore pressure in the soil mass. Depending on the season, the speed of soil movements can increase or decrease. It can even cease during the drought period.

Sometimes these types of movements can be noticed on the surface by the change in the verticality of trees, fences or other structures, being observed through visual inspections. When movements are very slow these evidences can escape to the eyes. In these cases it is necessary to use other ways to detect and follow the evolution of the process like the installation of field monitoring.

Figure 3: Change of Verticality of Trees

3. DATA ENTRY

The 3D visualization system of geological features of risk depends on various information and input data so that they can do analysis and make some decisions. The main input data are: the aerial photographs, contour lines to generate digital terrain model (DTM), the coordinates of the pipeline sections and coordinates the instruments.

3.1. Aerial photography

Aerial photography is considered to be the basic tool for mapping and the reconnaissance of terrain. Since the discovery of photography and its application in mapping until today, their contribution has been remarkable in the context of Cartography (Hohl 1990).

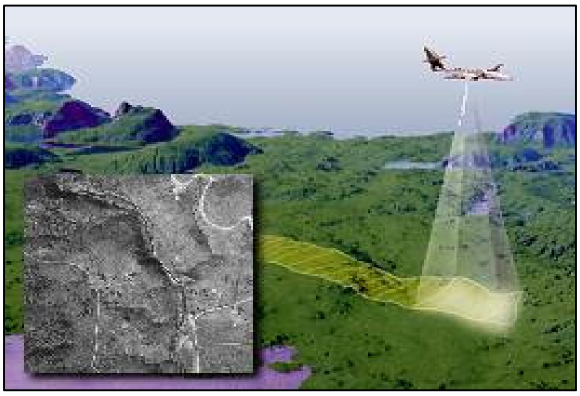

Figure 4: Model of Capture Aerial photography (Esteio Engenharia2013)

Aerial photography was solidified as an essential element for mapping with the creation of science called Aerophotogrametry and its further evolution happened in the period of the World Wars with its constant use for military purposes. With the end of periods of conflict and the discovery of new processes, equipment and materials, aerial photography has become an invaluable product for the planner, researcher and entrepreneur, besides being the raw material for the work of the cartographer (Plewe 1997).

It is, in technical terms, an aerial photograph such as that obtained by strictly air chamber (calibrated focal length, lens distortion parameters and known frame size) mounted with the optical axis of the camera in a near vertical aircraft properly prepared and approved to receive this system. The set of operations required to obtain these photos or set of pictures that superimposed and represent the area flown. This area is called the coverage aero photogrammetric. Aerial photographs are usually obtained in a sequential and overlapping longitudinal and lateral imaging allowing the entire region of interest is covered (Andrade, 1999).

3.2. Level Contours

As result of longitudinal superposition between two consecutive aerial photographs stereoscopic images were obtained. These images are placed on devices restorative semi-analytical and analytical and a basis for the model definition. These images are projected on an optical system so as to form a three dimensional model in the eyepiece (Hohl 1990).

The stereoscopic model should be oriented so as to reproduce all the characteristics of the terrain, without presenting deformations and dislocations. The orientation must also assign to the stereoscopic model, the coordinate system used for mapping, that is, it is the placement of the scale model and appropriate coordinates. The coordinates of these points are coming from aerial triangulation (Wolfgram 1993). By means of a suitable system, all of the recorded points are transmitted to equipment that composes the original cartographic. The stereoscopic mark should always be kept in contact with the surface of the feature in order to maintain the correct coordinate. For each point registers values of the X, Y and Z represent the spatial location.

The catchment of altimetry is performed with the mark stereoscopic always with a certain altitude, where the operator must search of the terrain visualized the points that have this same altitude, thus materializing the lines of constant altitude or contours, which in practice we call level contours .

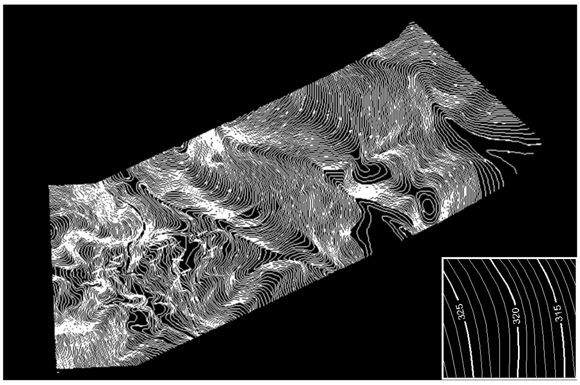

Figure 5: Model of Level Contours

3.3. Coordinates of the Pipeline

The coordinates of the pipeline are of extremely importance for the system feature to detect risks with possible problems, because from these coordinates you can define whether they suffered great effort by the soil shifted relative to its initial position (construction), or there is some kind of curvature or kneading.

A device is passed over the soil instead likely to find the pipeline. The detection and location of coordinates of the pipeline comprise a location horizontally and vertically to the soil level.

Another procedure aggregate with this type of equipment is to define locations in the pipeline where the coating is damaged. This particular feature allows you to find possible sources of deterioration and rupture of the pipeline being in a preventative maintenance and replacing most elusive and costly methods such as excavation.

In the next figure, the line can be identified in red as the coordinates of the pipeline stretch that have been raised level contours.

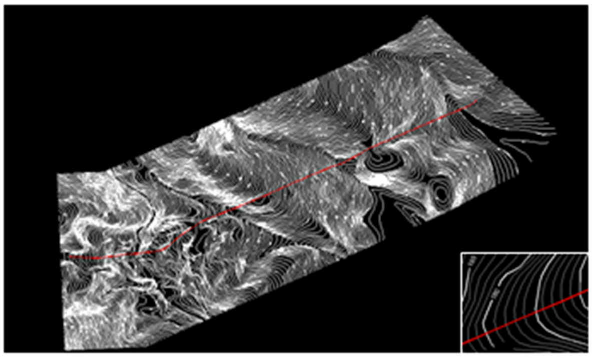

Figure 6: Example of Coordinates of the Pipeline

4. VISUALIZATION AND SIMULATION

In possession of all the data, the system takes care of processing and preparing them for your visualization and decision making on the part of the engineers responsible.

The evaluation of geologic and geotechnical features in the pipeline route is carried out through local inspections and using the three-dimensional visualization model developed from aerial photographs and topography data processing.

As advancing technology allows capturing, storing and processing a large amount of information, the features visualized in flat paper, can be brought to life in 3D forms. The 3D model is built using level contours, Triangular Irregular Network (TIN) and orthophotos.

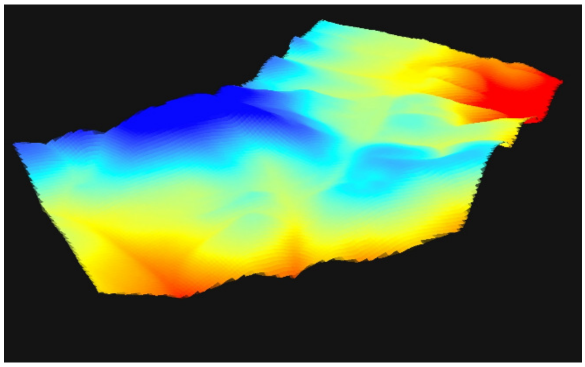

Figure 7: Data Elevation Model (DEM)

Engineers and experts can analyze the geomorphology around the pipeline and it is possible to use two kinds of surface models: Rasters and TIN. Rasters represent a surface as a regular grid of locations with sampled or interpolated values. TINs represent a surface as a set of irregularly located points linked to form a network of triangles with elevation values. Rasters are largely used in USGS (U.S. Geological Survey) in Data Elevation Model (DEM) maps covering the world in arc of 30 seconds. TIN models are not so common and tend to be more expensive to build and process. They are typically used for high precision modeling of smaller areas, such as in geotechnical application

The use of aerial photographs along with TIN model facilitates the visualization instead of using the DEM. The visualization is done in stretches 1 km long and 400 meters wide.

To start this project, criterions data are got by aerial photo. After an image rectification, contour level curves are got in scale of 1:1000, allowing the visualization of curves of 1 meter high.

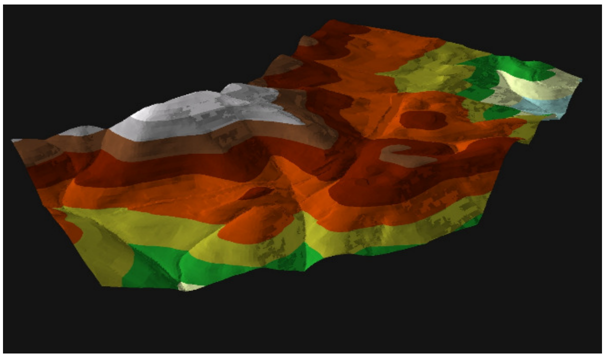

Figure 8: Triangular Irregular Network (TIN)

Figure 9: Aerial Photographs Applied the Model TIN

After that, the geomorphologic features can be recognized by specialists and pointed in the image, creating interpretative maps.

All data are preserved in their original state. The transformations are made inside the program. All data are referenced before used in visualization.

The data furnished are aerial photos and cad maps using datum SAD-69. Visualizing a three dimension data gives the observer new perspectives. A 3D view of terrain can provide insights that would be not apparently clear for an observer in the field or looking at a planimetric map.

With this model specialists can observe existing problems without visiting the place, and then perceiving incoming accidents. Therefore the 3D model increases sight inspection.

Besides that, 3D the model is connected to internet, easing the manipulation of the technicians involved in risk analysis. It is possible to show more data by hyperlinks inserted in the model. Field instruments, for instance, can be inserted in the model with original UTM coordinates and the model can access their data.

The next figures demonstrated the utilization of the internet for visualization of features without the need to visit the place of risk.

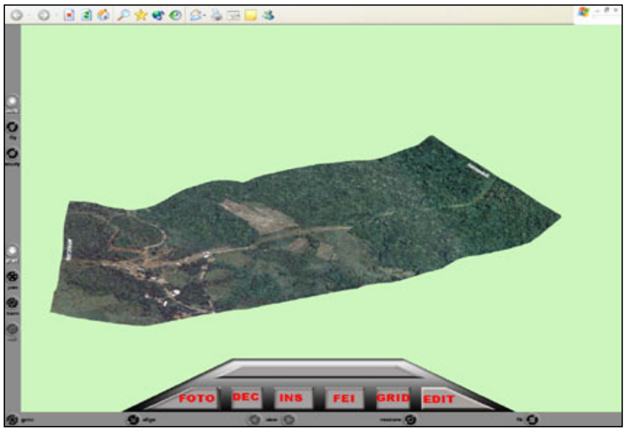

Figure 10: Overall Image of the 3D Model Aerial

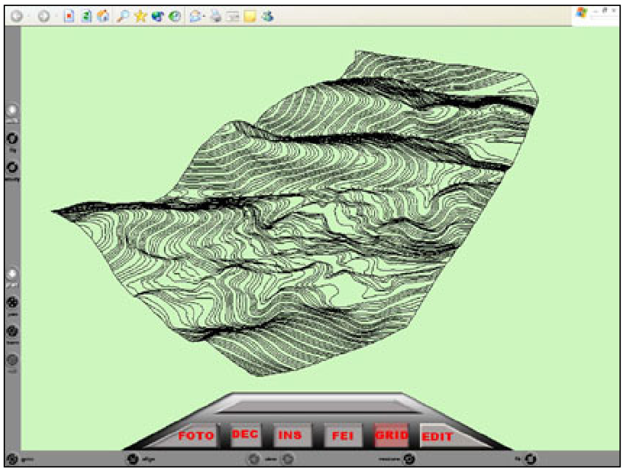

Figure 11: The 3D Visualization of Level Contours

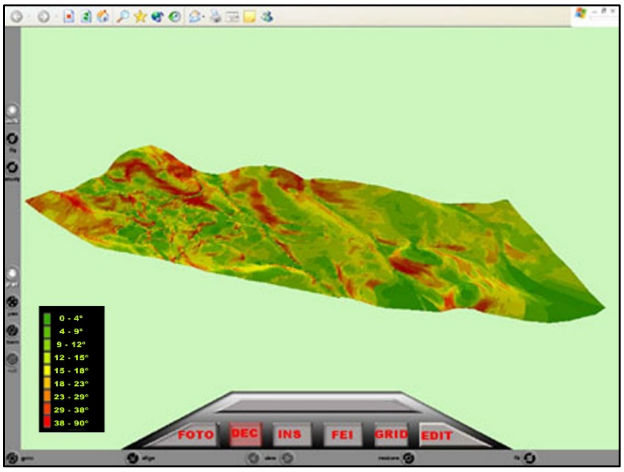

Figure 12: Visualization of 3D Declivity

5. PIPELINE AND SOIL MASS MONITORING

It is very important to monitor areas affected by soil movements. Knowing that soil-pipeline interaction is extremely complex the implementation of an extensive monitoring program including not only the slope but also the pipeline becomes mandatory.

Using a monitoring system it is possible to calibrate and to validate the established soil-pipeline interaction model. The analysis of instrumentation results allows a technical decision about the right moment to intervene on a pipeline. So pipeline operational safety can be guaranteed.

The complexity of the phenomena should always be considered. An extensive program of monitoring is usually recommended. It is necessary to evaluate the causes and consequences of soil movements. Nowadays, in several critical areas, the soil mass is monitored with inclinometers and piezometers. The frequency of readings varies from case to case. In general, they are taken each three months. Sometimes it becomes necessary to increase this frequency during the rain season.

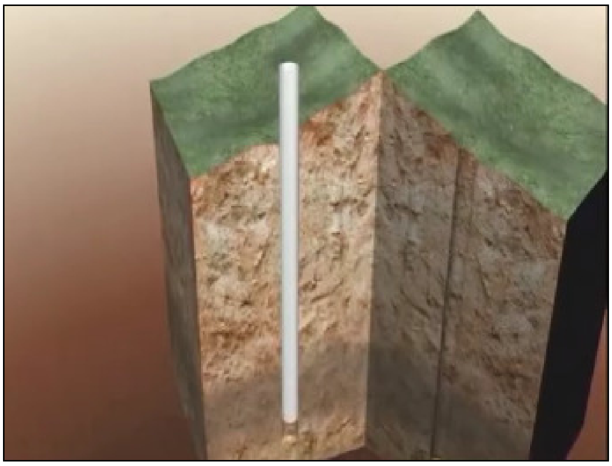

Figure 13: Model of Piezometers

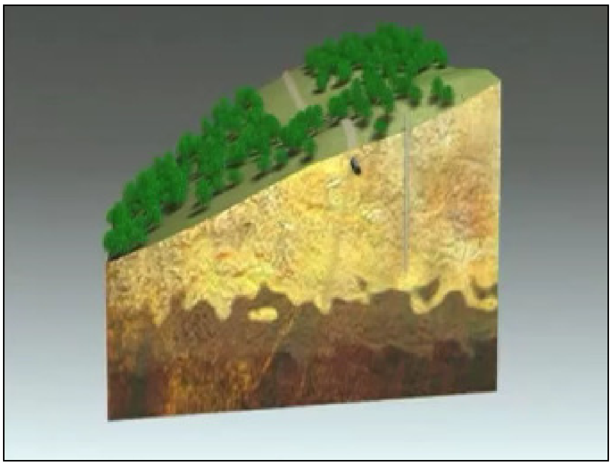

Figure 14: Model of Inclinometer - Initial State

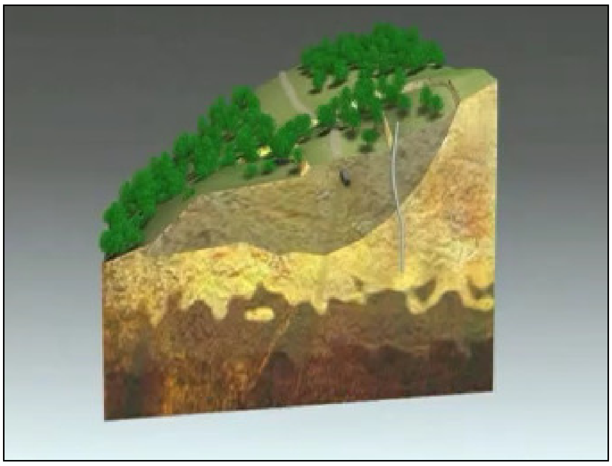

Figure 15: Model of Inclinometer – Final State

Slope monitoring, however, is valuable to understand the process of soil mass movements that did not allow an evaluation of stresses transmitted to the pipeline. On this purpose it was necessary to install strain gauges on the pipeline surface. Another detected problem is that the period between readings, many times can not correspond to the necessity of each point.

In order to improve pipeline's safety, we implemented a new monitoring system including inclinometers and piezometers on the slope and strain gauges on the pipeline with data acquisition in real time. Inclinometers were used to measure the displacements of the soil and an eletric piezometer were used to assess changes in soil pore pressure. Inclinometers were used to measure soil displacements while eletric piezometers was used to evaluate variations of soil pore pressures.

6. THREE-DIMENSIONAL VISUALIZATION AND DECISION-MAKING

Decisions are made in meetings from 3D models. Risk features are traced by experts who then go to the site to ascertain the terms displayed on models. These decisions could take days and huge expenses because they would have to go to where all the engineers who attended the meeting with the 3D model. The next figure presents a detail model demonstrating the risk.

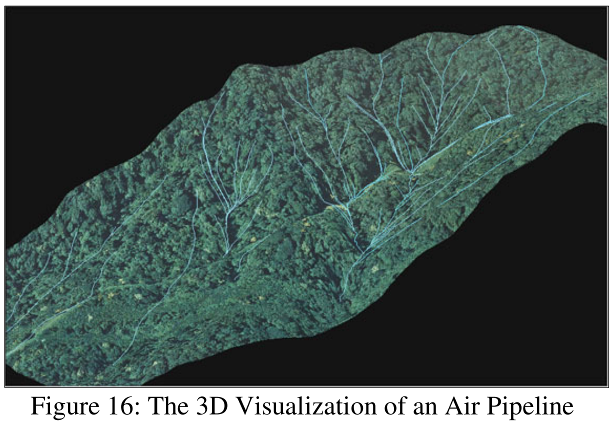

Figure 16: The 3D Visualization of an Air Pipeline

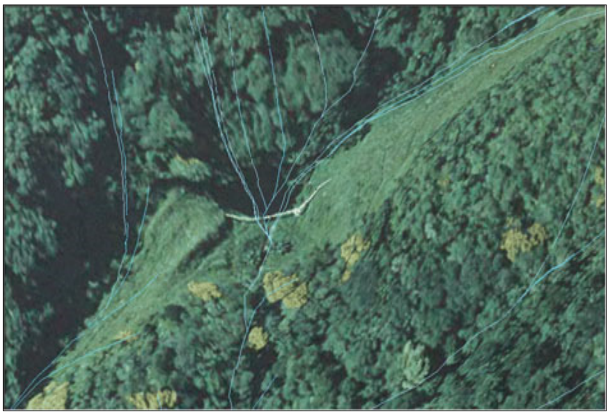

Figure 17: Detail of the Air Pipeline

With the 3D model visualization, engineers were on the scene and confirmed that the air pipeline was running a great risk, because it was a passage of water and debris coming from the mountain.

Figure 18: Picture Taken in Place

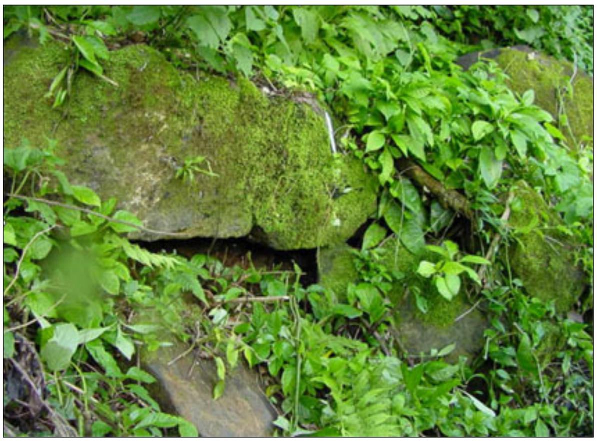

Figure 19: Visualization of Blocks of Loose Rocks

According to the photos by engineers with access to 3D models of the system we arrived at a unanimous view that the pipeline should be buried. In times of many rainfall debris could cause an oil leak at the pipe break.

Figure 20: Photo with Pipeline Being Buried

Figure21: Pipeline Buried

7. CONCLUSION

The pipeline installed in unstable areas should be considered a geotechnical work. The interaction of soil with pipeline should permanently be considered in order to ensure the structural integrity of the pipeline. In these areas, new technologies must be developed and implemented to improve safety.

The 3D visualization has a valuable role in the detection of new risk areas and decrease in oil spill accidents, preventing the pollution of nature.

The system enables environmental rehabilitation works and the pipeline system will indicate areas with preventive, corrective or mitigating. It is also used to display the results of specific inspections, routine seasonal and, when necessary, minimize the maximum accidents that impact the environment, whether they are generated by natural or anthropogenic action.

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