PIPELINE INTEGRITY RISK ASSESSMENT AND MANAGEMENT

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Abstract: The significance of the risk associated with pipeline rupture caused or partially caused by landslides and other geohazards is becoming increasingly recognized by the pipeline industry. Landslides that affect the integrity of a pipeline are relatively rare events, but typically have a larger consequence than other hazard types (i.e. corrosion, stress corrosion cracking) commonly associated with pipelines. Strain build up in pipelines due to landslide activity can be caused either by a fast event, such as a debris flow, or by slow, continual movements, such as creep. The ultimate goal in pipeline risk assessment and management is understanding the risks involved and the ability to react to a failure prior to rupture. A successful way of completing this goal is to properly identify sites that may represent a geohazard, to visually inspect these sites and to create a cycle of site assessment and management practices based on the site inspections to deal with the risk presented. The cyclic assessment should be dynamic, therefore, always representing and determining the current risk conditions. For the case of slow moving landslides, a review can be scheduled such that mitigation occurs before pipeline rupture. These geohazard risk assessments should feed into an overall pipeline integrity management system allowing for the assessment of all risks to the pipeline.

INTRODUCTION

Landslides have long been recognised to represent a risk to integrity by pipeline companies, normally lumped into the category of “ground movement” (EUB 1998) with other processes such as settlement and river erosion. As damage done to pipelines by landslides is relatively rare (EUB 1998), the pipeline industry’s focus has been on dealing with integrity problems that occur more frequently. As discussed in the following section, recent statistical analyzes (Porter et al. 2004) of the costs of various integrity problems reveals that although landslides are rare, they cost pipeline companies more than any hazard, other than 3rd Party Damage.

Pipeline integrity is now largely managed within a risk assessment framework. In many cases, landslide movement has been left out of this risk assessment formulation (Cicansky and Yuen 1998) or treated separately (Muhlbauer 1996) from the other hazard types. Recent work (Ferris et al. 2003, Porter et al. 2006) has shown that a rational risk assessment approach can be developed for landslides (and other geohazards) on a consistent basis with other integrity hazards, such as corrosion. The main difference between landslide hazards and other hazards is that they occur at distinct locations whereas corrosion or stress corrosion cracking is more widespread.

The rate of movement for landslides can range from m/sec to mm/year (Cruden and Varnes 1996). The risks presented to a pipeline by fast moving landslides are different than those from slow moving landslides. For rapid earth movements, the main risk is simply their occurrence or re-occurrence, since once initiated management of the hazard is very difficult. For rapid landslides, the management practice largely consists of recognizing the locations where they can occur and to protect the pipeline from the expected effects (by such methods as deep burial, deflection berms or re-routing) so that the pipeline will not be affected. The risk presented by slow moving landslides is related to the slow build up of strain within the pipeline walls leading to wrinkles and ruptures. If the rate of movement is very low, the management practice has been, in many cases, to monitor the movement and act once the strain in the pipeline has built up to unacceptable levels. The mitigation action in these cases typically is to expose the pipeline and relieve the built-up strain. The focus in the remainder of this paper is on a system of risk management for slow moving landslides, although many of the same concepts apply to faster moving landslides and other geohazards.

PIPELINE INCIDENCE

The relative significance of the risk that natural hazards represent to a pipeline has often been underestimated by the pipeline industry in the past but is becoming increasingly recognized. Geohazards do not represent a large percentage of all pipeline incidents; however, they are a major cause of pipeline rupture as shown in Figure 1 (Porter et al. 2004). Typically, pipeline ruptures are associated with large consequences, both environmentally and economically, and therefore represent larger average costs. Landslide related pipeline failures have been found to cause more property damage in the United States, since 1984, than corrosion, and are only exceeded by costs associated with third party damage (Figure 2).

Figure 1. Incidents by Cause and Size of Leak (after Porter et al. 2004)

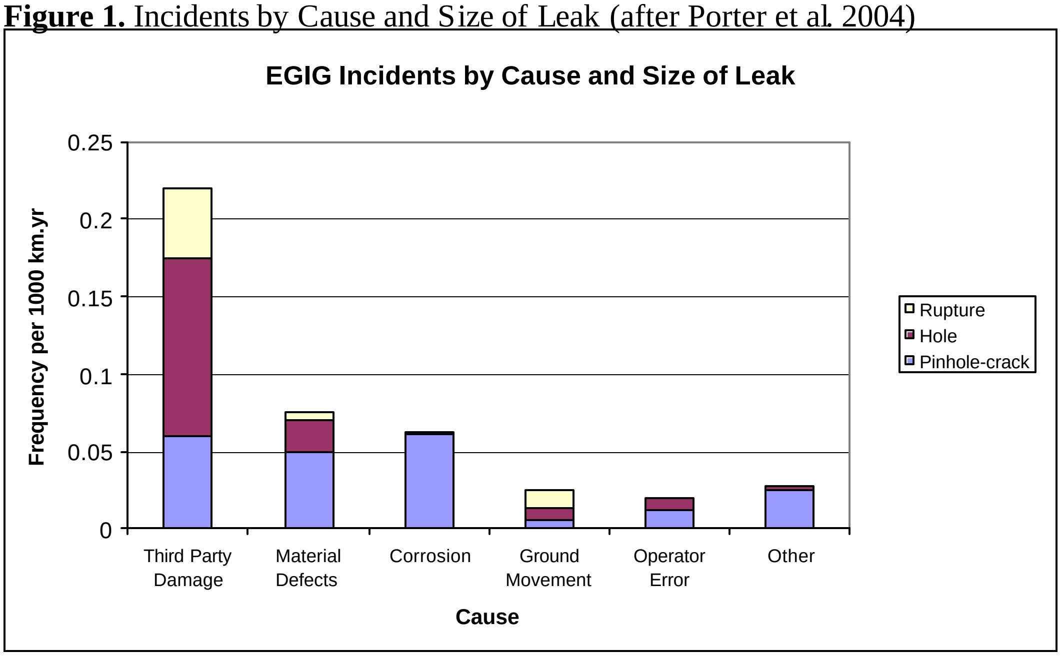
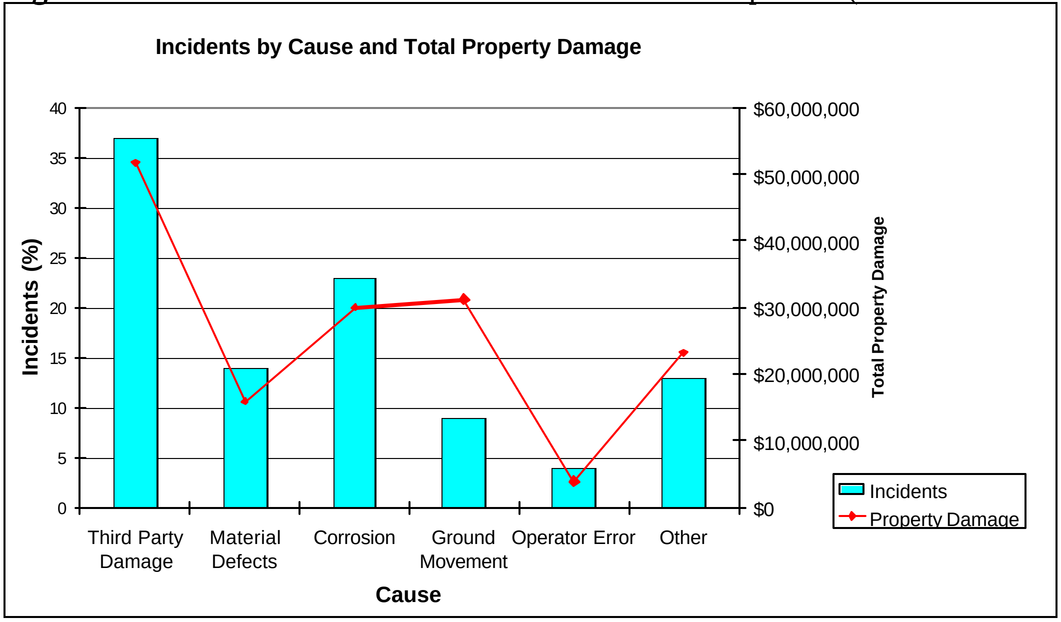


Figure 2. US DOT Incident Data for Gas Transmission Pipelines (after Porter et al. 2004)



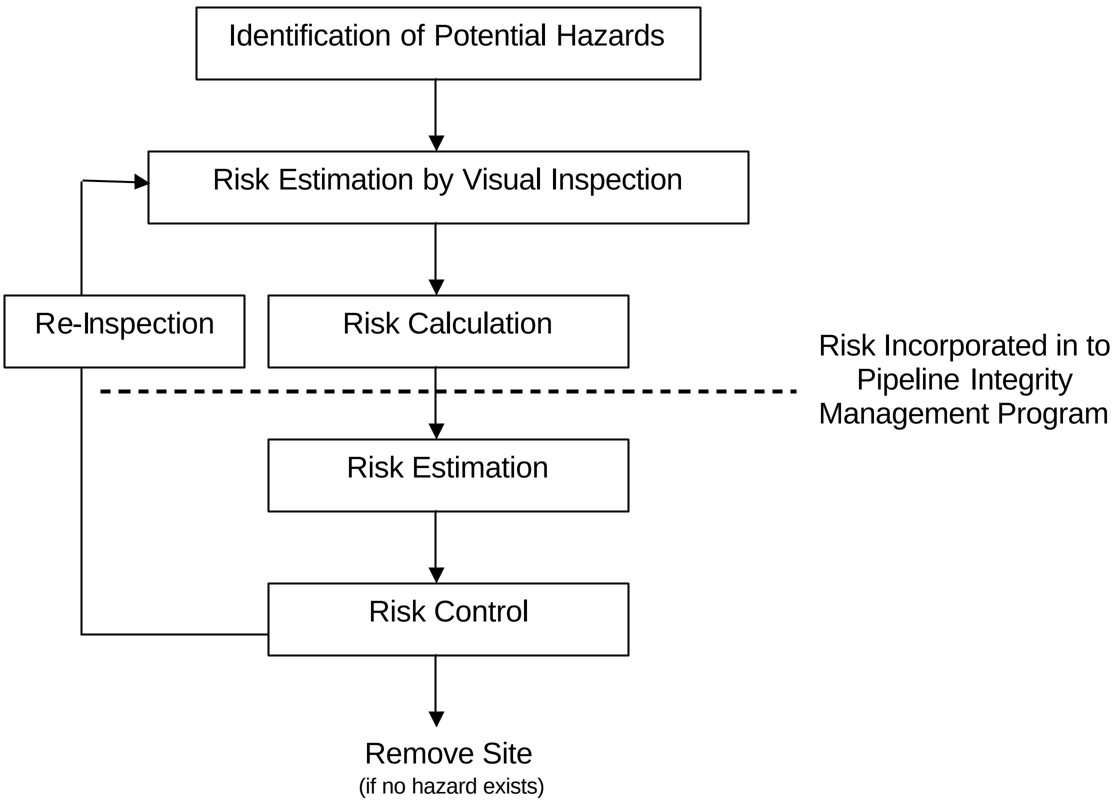
RISK MANAGEMENT FRAMEWORK

The Canadian Standards Association (CAN/CSA-Q850 1997) framework for risk management calls for a combination of risk assessment and risk control. The Association goes further with respect to oil and gas pipeline systems, specifying that risk assessment shall be a formalized process comprising risk analysis and risk evaluation (Porter et al. 2006). Once the risk has been assessed and a risk control action has been decided upon and undertaken, the CSA guidelines also call for a re-assessment to determine if the risk control had the desired effect. Therefore, a process of risk assessment which allows for the on-going review of sites and re-assessment of the current state of risk is necessary. This on-going assessment feeds back into the risk management process and leads to a re-examination of all sites in an attempt to ensure all hazardous sites are being managed in an appropriate manner.

A cyclic approach appears to be a practical framework for including geohazards into an overall risk management program (Leir 2004). Figure 3 shows this adapted risk management framework.

This approach begins with identification of potential hazard locations, remembering that there may be thousands of kilometres of pipelines within the system under review. Once the list of potentially hazardous sites is created, an estimation of the risk at each site should be undertaken by conducting a visual assessment at the site. A risk for each site is then calculated based on the information collected during the visual assessment. This risk value can then be incorporated into, or run parallel with, a pipeline company's integrity program. It can then evaluated against similar acceptability criterion as the other hazard types. Once the risk has been evaluated, an appropriate action or control can be decided upon based on the nature of the risk presented. After the risk control or mitigation has been completed, the site can then be re-evaluated in order to determine if a hazard still exists at that site. If no hazard remains the site can be removed, and if a hazard remains, a new risk level of the site is then determined. In this manner, risk reduction can be observed. This type of framework represents a preventative approach to managing hazards, instead of the typical reactive approach.

Figure 3. Natural hazard and risk management framework



IDENTIFICATION OF POTENTIAL HAZARDS

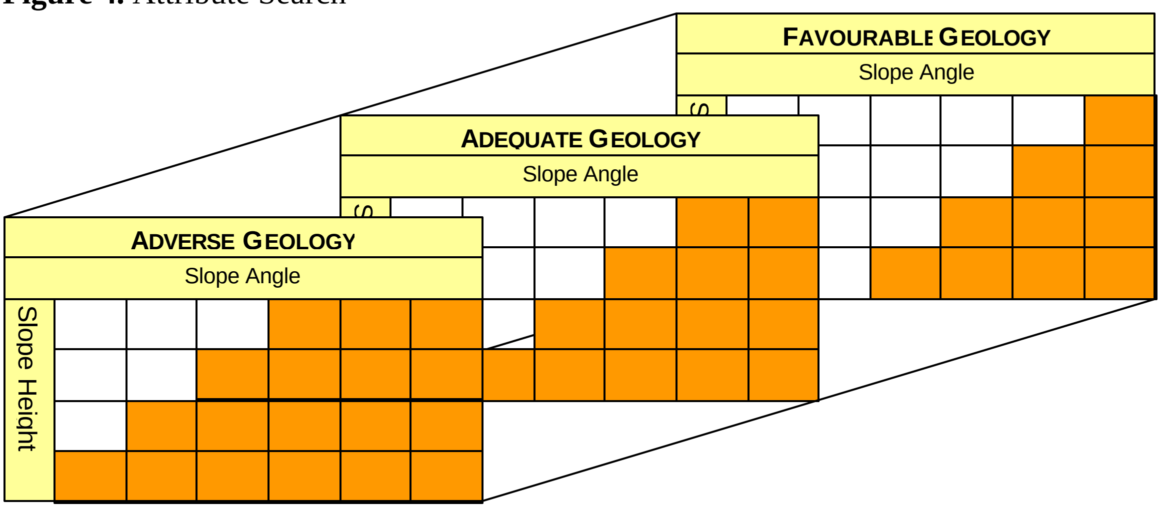
Pipelines have been installed in a variety of terrain types and the potential for landslides to occur varies with this terrain and local geologic conditions. The risk management process begins with identification of sites to be considered. Given the large areas traversed by pipeline systems, landslide potential mapping (Soeters and van Westen 1996) is too complicated. Three simpler methods typically and successfully used include; review of stereo air photographs, visual inspection from the air during normal aerial patrols and performing attribute searches based on topographic and geologic information. The methodology used to identify the potential geohazard sites is usually selected based on the type of information that is readily available.

The air photograph review and the aerial patrol are typically done in a cursory manner, looking for locations which show evidence of current, past and adjacent landslide activity. Sites are included if they are considered by the inspector to have a high potential to develop problems.

With the advance of GIS techniques, mapping information from a variety of sources can be easily combined to determine potential landslide sites. To be useful as a screening tool, the system needs to be simple and conservative given that many pipelines have great lengths. The screening tool that has been developed uses only three attributes: Slope Angle, Slope Height, and Geological Conditions. Each of these parameters is categorized and given scores based on groupings, such as slopes heights =10 m, 10 to 20 m, =20 m. The geology score dominates the results. In order to keep the system workable, the geology types were simplified into three categories: favourable, adequate and adverse. Although at first review this seems to be a simplification of complex geological processes, one must keep in mind that the purpose of this exercise is to develop quickly a list of sites requiring further evaluation. Using this system, the analyst should generally err on the conservative side.

When the attribute values are combined, they can then be displayed in a matrix, as shown in Figure 4. A threshold value is then determined to allow for the inclusion of all potential hazard sites. All sites exceeding this score are added to the inventory to be further evaluated. This threshold should be determined by practical experience and knowledge of the terrain being evaluated. The value achieved by the attribute stacking should not be taken as a ranking, rather all sites which are represented by values above or equal to the threshold represent the potential for slope instability and should be inspected.

Figure 4. Attribute Search



One limitation of this methodology is that new values or groupings must be made for a change in terrain. For example, a system set up for mountainous terrain will severely underestimate slopes within a low relief terrain.

Risk Estimation

Once an inventory of potential hazard sites has been created, the risk posed by the landslide to the pipeline can be estimated for each site. This is best done by a visual assessment and/or interpretation of instrument readings, if available. Risk estimation, based on visual assessment, is applicable to landslide types in which changes over time can be observed (slower movements). This excludes debris flows, rock avalanches, etc., which often show no sign of failure before the event occurs. Porter et al. (2006) outlines the risk analysis for these types of events, which involves estimation of re-occurrence intervals.

During a visual assessment, observations on or near the pipeline Right-of-Way are often the only indication to instability within a slope. This visual inspection of the slope can be done either by review of recent air photographs or via site (ground) inspections. Although the visual inspection can be done by either method, combining these two methods has proved to be highly effective. The review of air photographs can reveal large scale instabilities, not obvious when on the ground and site inspections reveal details not apparent on air photographs and also show the most recent conditions. Geomorphological mapping techniques can be tailored to any specific project objectives and using the appropriate scale of photo, the air photo review can be a cost-effective way of reviewing the hazards along a pipeline (Tribe and Leir, 2004).

During the visual assessment of the site, the presence of features such as scarps, ponded water, tilted trees, etc., are noted and recorded on a field form. The observations are then used to develop an estimate of the risk presented by the site. As an example, the risk of future landslide occurrence based on existing conditions would be increasingly higher for the observations of; hummocky ground, overgrown landslide scars, tension cracks and headscarps. More observations which indicate both past and current activities results in a higher estimate of the future risk.

In terms of the risk to the pipeline, this understanding of the landslide hazard needs to extend to determining the relationship between the hazard and the location of the pipeline. Pipeline companies normally will have undertaken several different surveys to determine the location of their pipeline as well as the depth of cover above the pipeline. This type of background information can be used to help determine the risk, for example if sliding is above the pipeline, the risk of rupture is less than if the pipeline is within the mass of a deep seated landslide.

Instrumentation readings, when available and correctly located for the landslide under consideration, provide valuable and detailed information to determine the risk at a site. This level of detailed information, on the location and rate of movement (i.e. from slope indicator casings) combined with an understanding of the landslide type allows a detailed understanding of the risk to the pipeline to develop. Without this level of detail, estimates of pipeline strain are very difficult to determine. With instrument information available, it can be introduced into a soil-pipeline interaction analysis to assess pipeline strain.

Instruments are normally available only at sites which have experienced problems in the past, or if visual assessments have indicated the need for such detailed information.

Risk Calculation and Integrity Programs

Based on the visual observations made during the risk estimation, a probability of failure is estimated. A risk of pipeline rupture is then estimated for each hazard site based on these observations. Risk can be done using a variety of published techniques (Ang and Tang 1984; Fell 1994; Mulbauer 1996) and the observer should use an appropriate method. Once the risk has been calculated, it can then be included into a pipeline integrity management program operated by the pipeline company. This can be done as the risk presented by the landslide is represented by a probability of failure which is comparable to other hazard types.

Risk Evaluation

Often linear structures, like pipelines, face many geohazards and resources are not always immediately available, therefore the sites need to be prioritised and ranked to determine which sites exceed tolerable risk levels. Risk evaluation is a structured process to differentiate levels of risk. Where risks exceed tolerable levels, management options are identified and evaluated under the task of risk control. Risk evaluation includes the values and judgements of the pipeline company in the decision process. This includes the social, environmental and economic consequences of a hazard event in order to identify a range of alternatives for managing the risks. The goal is to decide whether to accept or treat the risks and set action priorities. Generally, pipeline rupture is considered to be unacceptable and the value for the consequence is equal to one. Therefore, total risk is equal to the probability of failure. The consequence value was selected as one for this paper, varies with risk tolerance of different regulations and the company.

A corresponding inspection frequency and action due date is assigned based on the calculated risk, as per Table 1. This provides the pipeline company with guidance on when each slope should be visited for re-inspection and a proposed timeline for each action item. Thresholds are normally determined by the pipeline company, which allows the estimated probability of failure to be grouped and schedules recommendations to be set. The philosophy is to set the schedule of recommended action such that it occurs before any significant change in site conditions. At that point, the sites are then re-evaluated during the investigation and a new assessment and schedule is produced.

Table 1. Risk Classes and Proposed Inspection Frequencies

Total Risk	Risk Class	Proposed Action Priority
= 0.1	Very High	< 6 months
= 0.05	High	< 1 year
= 0.01	Moderate	< 2 years
= 0.001	Moderate	< 3 years
= 0.0005	Low	< 4 years
< 0.0005	Very Low	< 5 years

RISK CONTROL

After the risk has been estimated and evaluated, the next step is to determine what type of control measure needs to be undertaken. Risk control is the process of decision making for managing risk. This is often done through risk cost-benefit analysis techniques. The geohazard risk analyst can provide background information or normally acceptable limits as guidance to the decision maker.

Recommendations for a particular site vary widely with the nature and type of the hazard encountered and the level of knowledge about the site and hazard. The range of recommendations normally made is shown in Table 2.

Subsequent assessments review these features to determine any changes that would indicate further slope movement. As information is obtained from any of the recommended actions, except site removal, it influences the risk estimation of that site. A better estimate of risk is achieved with the inclusion of more information. For example, if the risk control is to monitor the site, then the information received from the drilling investigation (subsurface conditions) and from the instrument itself (slope movement) is input into the risk estimation equation and a new risk estimate would be produced based on this information. This new risk estimation may also lead to a new risk control measure. This risk control may be to remove the site from the database, mitigate the site, or it may help dictate a schedule for monitoring the instruments.

Table 2. Recommendations

Recommendation	Description
Mitigation	General field actions such as riprap placement, slope erosion control, slope drainage control, slope stabilization, or relocate pipeline
Monitoring	Installation of instruments to quantify the progression of a hazard.
Detailed Investigation	Site specific investigations to gather more information such as site surveys to determine depth of cover, stream morphology, pipe location, or drilling to obtain subsurface information, or time-series air photo interpretation.
Inspections – Ground	Site visits on foot to review the status of the hazard, elements, vulnerability, consequences, and provide new or revised recommendations.
Inspections – Aerial	Site visits by air to review the status of the hazard, elements, vulnerability, consequences, and provide new or revised recommendations.
Inspections – Office	An office-based assessment study such as reviewing the As-built designs, brief air photo interpretation, review of monitoring data.
Removal of Site	Once the site has been proven not to be a hazard, the site may be removed from the database. More than one inspection is required to safely make this assumption.

Risk control should not be the final action in a pipeline integrity risk management system. It is a means to gather more detailed information on the risk presented to the site. If all the information obtained can conclude that the site does not, and will not, represent a hazard to the pipeline, the site can be removed from the database. Otherwise, the site will remain in the system and be re-assessed to ensure no adverse changes occur. If they do, the calculated risk value increases and different controls will be enacted.

SUMMARY

The risk presented by a geohazard, in this case a landslide, can be managed; however, it is important to realize that this is an on-going process that must be maintained in order to be effective. The cyclic process of hazard evaluation, beginning after hazard identification, allows for the constant updating of risk presented by an individual site based on the latest visual observations made. As information is obtained from any of the recommended actions, except site removal, it influences the risk estimation of that site.

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