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

IPG2023-0042

GEOHAZARD ASSESSMENT INCORPORATING LEGACY STUDIES - LESSONS LEARNED

Sherif Soliman[1], Rodney S Read[2]

[1] Advisian, Worley Group, Calgary, AB, Canada
[2] RSRead Consulting Inc., Okotoks, AB, Canada

ABSTRACT

Large-diameter transmission pipeline projects in remote locations with significant geotechnical issues in some cases take many years to develop and may involve different teams performing various studies at different project stages. In these circumstances, the evolution of understanding of pipeline route conditions can become disjointed or confused if there is a lack of continuity in project personnel, such as a change in engineering consultants, and gaps between various stages of project definition. For a project with a wealth of publicly available data and historical data from legacy studies, there are many considerations in leveraging the information in Front-End Engineering and Design (FEED)level geohazard assessment for a new project. These considerations include data reliability, scale, and currency. Considerable effort is required to build confidence in data collected and analyzed by other parties, ideally including field checks of data accuracy, but review and verification of existing data is often overlooked in scoping of projects with limited budget and schedule. The party responsible for FEED-level geohazard assessment must therefore navigate through existing information from earlier project phases with a critical eye to ensure the progression in technical definition is understood, particularly where progressive databases and Geographic Information Systems (GIS) datasets are developed, sometimes eliminating or correcting previous interpretations of geotechnical conditions such as geological fault locations and characteristics. Is the information sufficient and appropriate to the scope of work required? Are the uncertainties and limitations associated with the available information understood? Are there information gaps resulting from access or other issues? These are important questions to be asked before incorporating legacy information into geohazard assessments, especially if there are routing changes that may cross areas not previously investigated. A lack of identified geohazard features from legacy studies in a particular reroute area may indicate that the area was not previously reviewed for geohazards rather than it being free of geohazards. Once confidence in legacy data is sufficient, then limitations on how much additional interpretation is possible/defensible must be established. The use of reasonable conservatism to estimate slope stability and propose possible monitoring and mitigation options in identified geohazard areas is one approach, but must be explicitly described in associated reports to avoid creating over-confidence in results. Leveraging legacy data is easier if there is interaction between parties, or if there is continuity in the project team. This paper explores lessons learned from several large-diameter pipeline projects and provides a set of guidelines in using legacy project data in geohazard assessments.

Keywords: Geohazard assessment, legacy studies

1. INTRODUCTION

With the progression of large-diameter transmission pipeline projects through different stages leading to the FEED phase, the geohazard assessment and proposed monitoring and mitigation measures must also advance from mapping and preliminary assessment to a level that is congruent with the overall project phase. In addition, new information related to the overall project that is mostly developed during the FEED phase must be incorporated. This information may include pipeline route refinements, a detailed pipeline profile, specified pipe bends and pipe wall thickness, specific pipeline operating conditions (temperature and pressure) and pipe stress analysis results. In mountainous terrain, the construction grade profile is an additional dataset that must be considered due to its general impact on pipe profile, depth of cover, and mapped geohazards. This paper summarizes lessons learned with respect to legacy studies from several large-diameter transmission pipeline projects in North America and Australasia.

2. PROJECT LEGACY STUDIES

For major large-diameter transmission pipeline projects, particularly those located in remote greenfield settings, several campaigns of studies are common, sometimes with significant time gaps between campaigns. The result of these campaigns is typically a significant inventory of legacy reports, maps and data in various forms. For FEED studies that are intended to establish a technical basis for the Detailed Engineering phase of a project, there is an expectation from project owners that all information from legacy studies will be leveraged to the extent possible, with the idea that legacy information can obviate the need for new studies.

With this perspective in mind, there are many aspects of legacy studies to consider when attempting to compile and reuse or repurpose legacy information. Thorough review of project legacy studies that will be used to advance the geohazard assessment and develop a detailed monitoring strategy and mitigation measures is an essential first step. This step is especially critical in the case where legacy studies have been completed by other parties that are not involved in the FEED phase. The following must be considered when reviewing legacy studies from earlier project phases:

- Currency - Ensure that the legacy studies used are the latest developed for the project. This is especially important when different phases of the project extend for many years with different owner teams and engineering consultants involved at different stages, completing studies for a similar scope of work. Isolating the most reliable data from a host of precursor studies that iteratively update primary datasets is often a challenge if there is not a clear version/revision history on key datasets.
- Interpreted datasets – Where legacy studies result in interpreted data products, the basis of any interpretation of these studies and the data used for the interpretation need to be fully understood. In many cases when geohazard datasets are in a spatial format (e.g., shapefiles or geodatabase files), metadata describing the background and attributes associated with geohazard features may not be available or shown in sufficient detail. Companion reports may be available to support these spatial datasets and must be reviewed to provide a complete understanding of the data. The quality and completeness of these reports is sometimes a barrier to complete understanding of the legacy datasets, particularly if key metadata are missing.
- Uncertainties and limitations – Clear communication of uncertainties and limitations of legacy datasets is often lacking or absent in documentation from legacy studies. Where these aspects of the legacy datasets are understood, this should be acknowledged in any products generated using the legacy data along with the nature of the legacy work scope associated with these studies. What data were used in these studies as input to interpretations? Were these studies completed based on desktop work? Are there any updated datasets that should be considered? What field verification checks were completed, if any?
- Sufficiency – Once the pedigree and currency of legacy study information is understood, an evaluation of the overall sufficiency and appropriateness of the information for FEED studies must be completed relative to the required scope of work at the current project stage. This step may identify data gaps that require attention during the FEED phase or the subsequent Detailed Engineering phase.

By way of an example, for a proposed natural gas pipeline in a southern hemisphere tropical setting in a region of significant seismic activity and active tectonism, studies aimed at identifying and characterizing the seismic hazard potential and Holocene-active faults crossed by the pipeline were conducted over a decade along various potential pipeline route alignments. Due to the dense vegetative cover and limited access to parts of the project route, identification of potential Holocene-active faults relied heavily of interpretation of remote sensing data from Light Detection and Ranging (LiDAR), with limited ground-truthing possible. Earlier studies were conducted by one specialist consulting group that completed a probabilistic seismic hazard assessment (PSHA) and fault identification campaign using regional maps and LiDAR data. Interpreted fault characteristics, including orientation, style of faulting (Figure 1), predicted fault displacement based on regression equations from Wells and Coppersmith [1] and others, and anticipated Holocene activity were based on information available at the time.

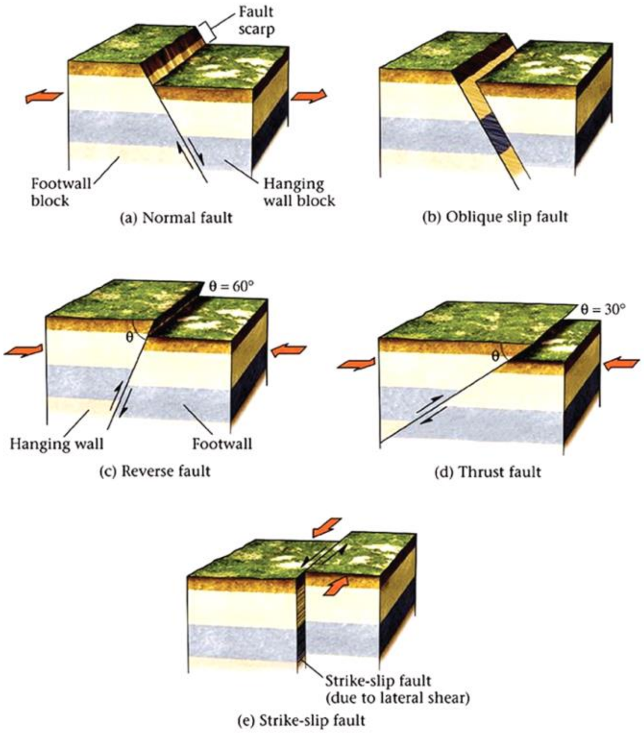

FIGURE 1: STYLES OF FAULTING CONSIDERED DURING LEGACY STUDIES [2]

As the project evolved to a pre-FEED phase, a different specialty consultant was engaged to build on this earlier work, accounting for some significant changes in the pipeline route. Some faults deemed to be confirmed Holocene active at pipeline crossing locations based on evidence from the early field reconnaissance were reinterpreted as possibly Holocene active due to a reinterpretation of the earlier field evidence. Likewise, characteristics of the faults and fault rupture displacement estimates changed significantly, with little explanation in the supporting reports. In addition, new faults were identified from newer, improved LiDAR as part of a desktop study campaign and a subsequent field verification campaign, and some previously identified faults were removed from the fault inventory without explanation.

One particular fault was deemed a hypothetical feature based on an interpretation of regional tectonics, and some local features evident along the pipeline route. This hypothetical fault was to be crossed by the pipeline route at a major watercourse, with limited routing alternatives to avoid intersecting this fault feature at the crossing. Predicted fault rupture displacement from regression equations [1] suggested that this feature, were it to rupture, could result in damage to the pipeline, necessitating a special crossing design and crossing methodology.

During FEED review by a third consultant of legacy studies of this hypothetical fault, no compelling evidence of its existence was found in the legacy study documentation and geophysical datasets, but eliminating it from consideration was not possible as the FEED consultant did not have firsthand knowledge of the previous studies and interpretation resulting from these studies, or the uncertainty of the findings. The issue was resolved by the owner temporarily re-engaging the pre-FEED consultant to provide additional details on the hypothetical feature, and a professional opinion on the degree of confidence in its existence. This process led to the elimination of the feature from further consideration as the evidence for its existence was not compelling. The final compilation of faults and anticipated earthquake moment magnitude for the project FEED study required considerable effort to reconcile all legacy data and eliminate outdated interpretations. Uncertainties in the resulting inventory of faults and fault attributes were communicated in a FEED study report, with a recommendation that the results should be reviewed and verified by the general construction contractor during Detailed Engineering.

3. POTENTIAL DATA GAPS

An important lesson learned is that data gaps may exist in legacy studies from earlier project phases for different reasons including the following:

- Legacy studies were completed along an earlier route alignment that does not match the preferred FEED route alignment.
- Availability of new datasets for FEED led to a new proposed route alignment during the current project phase that is outside the corridor used in the legacy studies, but these new datasets were not incorporated into the pre-FEED geohazard assessment.
- Lack of data from some locations to complete a specific legacy study within a pre-FEED project phase that closed prior to gathering the required data.
- A legacy study was completed along the pipeline route resulting in what appears to be a possible data gap, but no geohazards were identified in this area in the pre-FEED study.

Differentiating between these various possibilities may require considerable effort depending on the quality and completeness of legacy reports and associated products. Maps showing no geohazards in a particular area should be checked to ensure that the original mapping area did in fact cover the area of interest. Impediments to complete mapping of some areas, such as lack of access or landing sites, and the quality of LiDAR, should be accounted for in assessing the quality of the interpretation of geohazard features.

An unfortunately common issue on pipeline projects is confusion caused by uncertainty in chainage conventions in datasets linked to route chainage (e.g., kilometre post, KP). Some route datasets may be referenced by KP but lack the associated route revision information to convert these KP locations to Universal Transverse Mercator (UTM) coordinates. Significant reroutes should always be referenced by route revision in any 1D take-offs of data to avoid misinterpretation of location. Even minor reroutes can result in lengthening or shortening of the pipeline route, resulting in potential mislocation of geohazard features if chainage is used as the primary reference convention.

For legacy studies, route revisions may be tracked in some documents, but not consistently reported in all deliverables. For example, if a construction execution plan incorporates a set or realignments not considered in the geohazard assessment, the compilation of project information may result in data misalignment, and errors in interpretation or reporting of required mitigation locations. A key lesson learned is to ensure consistent documentation of route revision along with KP in linearly referenced datasets, and to maintain strict revision/version control on all datasets, particularly if these are incorporated into a geodatabase viewing/analysis platform.

4. CURRENT PROJECT PHASE STUDIES

As the overall project design progresses through the FEED phase, newly developed design datasets need to be incorporated into the geohazard assessment and specified mitigations. Similar to the discussion of route version/revision control in the previous section, ongoing reconciliation of project data in FEED phase studies must be undertaken to retain correct spatial alignment of data. Examples of datasets that could potentially influence the geohazard assessment and the selection of suitable mitigation measures are discussed below.

4.1 Construction Grade Plan

The construction grade plan dictates the footprint of the pipeline right-of-way (RoW), the height of cut and fill slopes, the depth of grading, and requirements for stockpiles, among other details. Although the grade plan may appear to be a construction execution scope, it actually has great influence and impact on assessing and mitigating existing geohazards, and potentially introduces new geohazards, referred to as “construction-induced geohazards”. The grade plan also affects the amount of pipe bending and depth of cover along the pipeline route.

In mountainous terrain, pipeline construction on transverse slopes results in cut slopes and generally fill slopes, except where the transverse slope is too steep to support fill construction. Cut slopes may increase the susceptibility of existing landslide features to instability if the cut slope alters the geometry of the pre-existing landslide toe, debuttressing the feature. The cut slope itself may also represent a new geohazard location if it is oversteepened beyond a stable angle, or if the cut slope face becomes a new source zone for rock fall, for example.

Similarly, fill slopes may create conditions prone to erosion or instability if surface water is not controlled, or if the underlying natural slope material creates an unstable interface between the fill material and the native soil. In tropical settings with extreme precipitation and very high erosion rates, placement of fill material on transverse slopes must be considered carefully to avoid creating significant construction-induced hazards.

Figure 2 is a vertical section perpendicular to the pipeline alignment showing the original ground surface in green and the proposed grade surface in red. In this case, the cut slope removes a large portion of the original slope and an existing landslide, reducing the potential impact from future landslides at this location. The toe of the fill slope is well-constrained by the topography, providing a stable base for the fill construction.

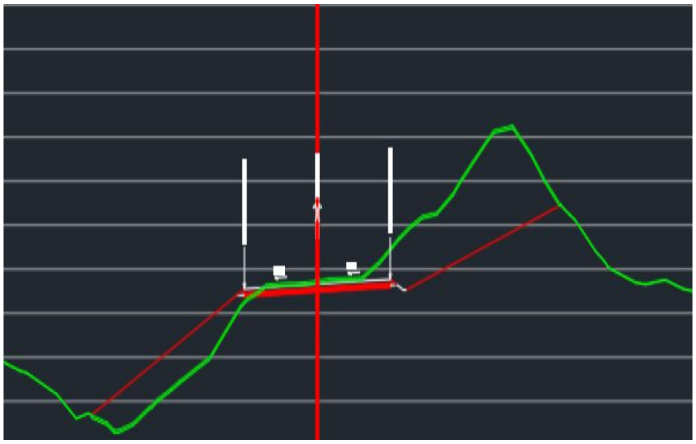

FIGURE 2: CONSTRUCTION GRADE PLAN IMPACT ON EXISTING GEOHAZARD (LANDSLIDE)

Figure 3 is a plan view of a portion of a pipeline RoW that is close to an existing landslide (hatched green area). Cut areas are shown in solid red and fill areas are shown in solid green. In this case, a significant fill area overlaps with the head of the existing landslide, reducing stability and potentially overloading the head of the landslide. This configuration was flagged for modification to avoid the interaction between the fill and the existing landslide.

Longitudinal slopes are also affected by the construction grade plan. Reduction in the natural slope angle by over-excavating the upper part of a marginally-stable slope is a means of increasing factor of safety against sliding. Conversely, over-excavation of the lower part of a slope may increase likelihood of instability. The construction grade plan must therefore be vetted in conjunction with geohazard assessment results, and vice versa. Lack of communication and cooperation between the construction execution team and the geotechnical/geohazard assessment team can lead to an unnecessary increase in geohazard susceptibility and associated mitigation requirements. An important lesson learned is that close collaboration between construction and geotechnical engineering teams throughout the FEED phase is beneficial to the project, and reduces cost and risk exposure from geohazards.

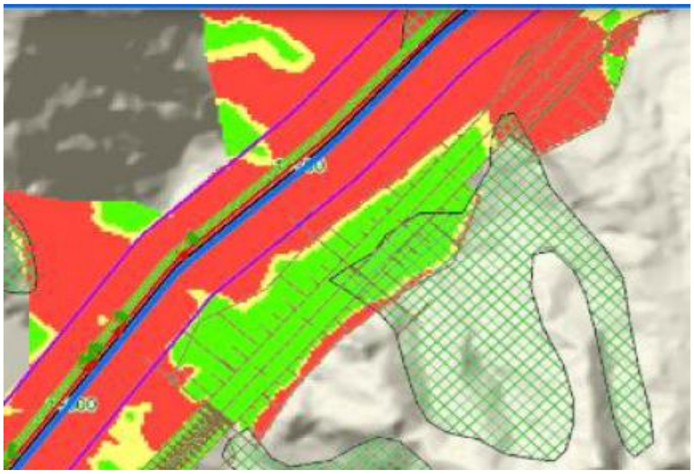

FIGURE 3: CONSTRUCTION GRADE PLAN INTRODUCING A POTENTIAL GEOHAZARD

4.2 Pipeline Strain Capacity

Legacy studies of geohazards are often generic in their framing, typically qualitative in nature, and seldom consider the interaction of the pipeline and the geohazard directly through a vulnerability assessment. One could argue that this is appropriate given the lack of specificity about pipeline design details in early project phases. A significant step change in geohazard assessment at the FEED phase is to incorporate vulnerability in the quantification of geohazard severity in relation to pipeline integrity.

Once results from legacy studies of geohazards have been thoroughly vetted and a geohazard inventory has been created, it is necessary to revisit the identified geohazard locations in light of the construction execution plan and grade profile, along with the proposed pipe profile. In this way, originally qualitative ranking of geohazard features can be recast in quantitative terms that reflect the FEED level pipeline design.

Quantifying of geohazards along pipeline route alignment is achieved by delineating credible geohazards along the pipeline route and estimating likelihood (or annual probability) of geohazard occurrence and vulnerability of the pipeline system to a geohazard occurrence at an identified location.

Annual probability of a specific geohazard occurrence accounts for the degree of certainty that a geohazard occurrence at a specific location is feasible or infeasible in addition to the frequency of occurrence of the geohazard representing the number of events per year (i.e., an annualized basis) based on an estimated recurrence interval of geohazard triggers (e.g., rainfall, seismicity) or progressive development of a critical state (e.g., progressive toe erosion, episodic movement).

Vulnerability comprises several components: a temporal component that accounts for rate of development of the geohazard, a spatial component that accounts for the proximity of the pipeline to the zone of influence of the geohazard and pipe strain or stress capacity in relation to ground displacement. Pipe strain or stress capacity can be determined through numerical modelling of soil-pipe interaction cases that represent the various credible geohazards (landslides, gully erosion, subsidence, fault displacement, etc.) to establish critical displacement thresholds related to the selected limit state, which can be compared to estimates of expected displacement based on empirical relations and deterministic analysis incorporating available data to support engineering judgment.

The product of these two terms (probability of occurrence and vulnerability) is referred to as pipeline susceptibility. For a risk context of pipeline loss of containment, susceptibility is an estimate of the annual probability of failure (PoF) due to a geohazard occurrence at a site within a pipeline segment.

Susceptibility targets for a project can be established using a reliability-based approach such as CSA Z662-19 Annex O [3, 4] or other means. Where applicable, the steps in such a reliability-based approach involve establishing a working level pipeline susceptibility target (expressed as events/year per site) for any site potentially subject to geohazards, estimating the unmitigated pipeline susceptibility due to geohazards at each site, selecting mitigation options to reduce the unmitigated pipeline susceptibility to a level at or below the working level susceptibility target, applying a sliding evaluation window to estimate the contribution of the mitigated geohazards within the sliding window to PoF from all threat categories expressed as events/km·year, then comparing results to relevant reliability-based allowable PoF thresholds (e.g., Equations O.3 and O.5 in CSA Z662-19 Annex O) to determine if the estimated geohazard PoF distribution exceeds the threshold. If the geohazard PoF profile does not exceed the threshold, the identified geohazards are considered adequately mitigated (controlled). If there are excursions in the geohazard PoF profile that exceed the defined allowable PoF threshold, then additional mitigation may be warranted at specific locations to achieve As Low As Reasonably Practicable (ALARP) post-mitigation conditions.

Screening for identified geohazards considering pipe strain capacity must be completed to identify geohazards that could have impact on pipe integrity and distinguish them from others that may be construction safety concerns. At the FEED stage of a project the delineation of credible geohazards that could affect pipeline integrity along the project route will use screening criteria developed from pipe-soil interaction analysis for the specific pipeline properties. The criteria will differ depending on the geohazard type and characteristics. The specific screening criteria used in a given project must be documented so any updates can be considered in the Detailed Engineering phase of the project. Examples of criteria that can be used in a parametric pipe-soil interaction analysis include different values of pipe wall thicknesses, operating conditions and length of pipe exposed to different possible scenarios of ground displacement on slopes in relation to the pipeline alignment/profile. In addition, considerations of the product in the pipe will have impact on pipe material (e.g., sour versus non-sour service) and the need to adopt strain-based design and accordingly the strain capacity of the pipe under specific loading conditions.

Figure 4 illustrates the scenario of lateral or transverse ground displacement, represented as block failure due to slope instability that will deform the pipeline. There are some uncertainties associated with the results of the parametric study and the geohazard site under consideration. These uncertainties include the exposed pipeline length used in the parametric study compared to the pipeline length exposed to soil displacement at the specific site under assessment, and pipeline operating conditions compared to the ones used in the model. Important considerations include whether the site is close to a compressor / pump station or not, actual failure depth of the landslide relative to pipe elevation to determine if the soil block will cause pipe deformation, and implications of considering only the horizontal component of the soil displacement impacting the pipe.

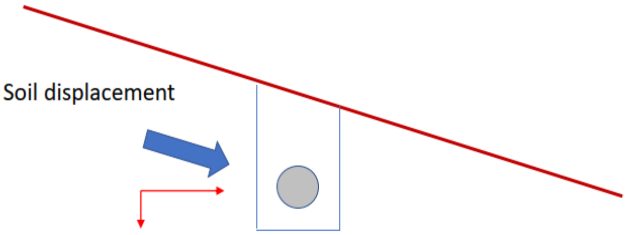

FIGURE 4: LATERAL OR TRANSVERSE SOIL MOVEMENT IN RELATION TO THE PIPELINE

Figure 5 illustrates ground displacement parallel to the pipeline, which is the case of soil movement along the ditch line and the pipeline RoW on longitudinal slopes, with soil moving along the pipeline causing additional stress and strain in the pipe. The uncertainties in this case include the assumption that soil movement is parallel to the pipe alignment and interacting directly with the pipe, also the length of the pipeline exposed to the ground displacement used in the parametric study for pipe strain capacity compared to the site under assessment.

FIGURE 5: SOIL MOVEMENET ALONG THE PIPELINE ON A LONGITUDINAL SLOPE

Figure 6 illustrates the case of subsidence or erosion gullying resulting in loss of support beneath the pipe. The uncertainties in this case include the assumption of pipe operating conditions used in the model performed in the parametric study compared to these conditions at the location of such a possible geohazard, as well as the width and depth of the area of soil loss.

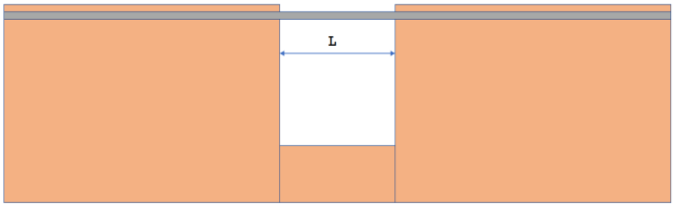

FIGURE 6: SOIL SUBSIDENCE OR GULLY EROSION INTRODUCING PIPE FREE SPAN

Parametric analysis of potential fault crossing configurations must account for the fault style (see Figure 1) and expected magnitude of fault rupture displacement. Figure 7 shows the case of a reverse/thrust fault crossing and the variables to determine for the specific crossing. Different design criteria (stress-based versus strain-based design, heavy-wall pipe, etc.) may be considered depending on the nature of the product in the pipeline, and other constraints.

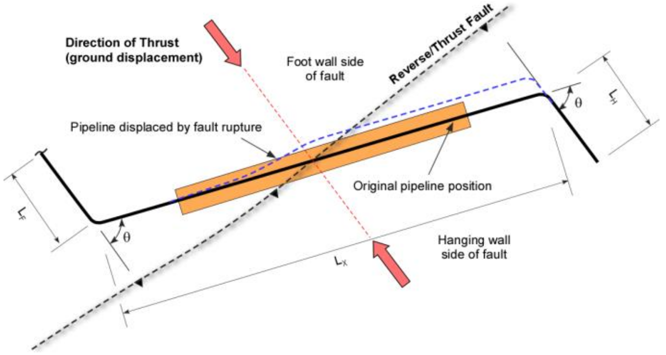

FIGURE 7: CONSIDERATIONS FOR A HOLOCENE-ACTIVE FAULT CROSSING DESIGN [6, 7]

The objective of this screening is not to achieve final design and identify specific, but to confirm, by using reasonably conservative assumptions, long-lead items such as pipe selection. Refer to Chapters 11-15 of the ASME book "Pipeline Geohazards: Planning, Design, Construction and Operations" [5] for examples of empirical relations and rationale for geohazard screening.

4.3 Pipeline Operating Conditions

Pipeline operating conditions (operating pressure and temperature) are important factors to consider during the FEED phase of a project due to the direct influence on determining strain capacity and strain demand of a pipeline. In addition, the variations of these operating conditions along pipeline route in combination with other factors including pipe profile (bend locations), soil type, and depth of cover may introduce other hazards such as upheaval buckling. The pipe operating conditions within certain climatic setting (e.g., Arctic conditions) may also lead to consideration of frost heave and thaw settlement hazards that will require further assessment and potential mitigation. Arctic conditions may also affect pipeline crossing configurations of a specific geohazard, such as above ground fault crossing.

5. SUPPLEMENTAL INTERPRETATION

Following the review of the legacy studies and the data available from earlier project phases, in addition to any new data or design available at the FEED phase of the project, and considering the level of the uncertainty understood in the legacy studies, leveraging the overall available data and advancing the design as required in the FEED phase of the project will need to take place. A reasonable professional decision is needed to determine the level and extent of any additional interpretation, the assessment methodology, and design requirements that can be completed.

To account for uncertainty in the legacy data, and as applicable and based on project and site conditions, reasonable conservatism can be adopted in the geohazard assessment, such as assuming shallow groundwater table on slopes in the calculation of factor of safety, assuming the main faults in the legacy datasets are Holocene-active unless proven otherwise by field investigation, assuming credible worst case soil properties for the assessment of slope stability in the absence of site specific information and assuming reasonable credible pipe operating conditions in determining strain capacity.

For all project deliverables, clear statements are included about assumptions used in the assessment completed, basis of the assessment and the data used, and the necessity to complete verification studies in the Detailed Engineering phase. Also, identification of critical areas where field reviews are recommended must be outlined in project FEED deliverables.

In various projects, adopting system-wide fibre optic monitoring along the pipeline and scheduled in-line inspection surveys to detect possible permanent ground deformation locations is a reasonable approach. In addition, in the absence of detailed site-specific information at geohazard locations and the resulting uncertainty in assigning specific mitigation, a staged monitoring strategy is recommended for geohazards. This strategy involves repeated collection of LiDAR data and orthophotos at regular time intervals and following significant seismic or weather-related events to complement the pre-construction baseline LiDAR of the project corridor for change detection analysis. Other techniques such as Interferometric Synthetic Aperture Radar (InSAR) could also be deployed depending on the site conditions (e.g., slope aspect, vegetation coverage, cloud cover, etc.). This change detection analysis is intended to identify landslide locations exhibiting permanent ground deformation that could pose a potential threat to pipe integrity, and to identify locations for detailed slope monitoring using conventional instrumentation such as slope inclinometers and piezometers. The site-specific instrumentation would then be designed based on conditions at each site, the nature of movement, and the severity of the threat to pipeline integrity.

6. ASSESSMENT OF A SPECIFIC GEOHAZARD SITE

A summary of recommended steps to be followed when performing a site-specific geohazard assessment for the FEED phase of a project relying on legacy studies is as follows:

- Identify the geohazard feature and assign a unique identifier, accounting for the type of geohazard.
- Ensure the data used in the assessment is the latest developed for the project including any publicly available data and document the basis for analysis.
- Review the data to be used and clearly understand the limitations and uncertainties of the information, including whether field verification was completed.
- Collect relevant current project data during FEED such as construction grade plan, pipe strain capacity, and newly completed site investigation, if any.
- Assign the start and end KP, route revision and corresponding UTM coordinates to provide a clear reference basis for the data.
- Evaluate the degree of certainty that a geohazard occurrence at this specific location is feasible or infeasible, informed by evidence of instability and estimated factor of safety.
- Assign the frequency of occurrence of the geohazard based on an estimated recurrence interval of geohazard triggers (e.g., rainfall, seismicity) or progressive development of a critical state (e.g., progressive toe erosion, episodic movement).
- Assess the impact of the construction grade plan on the identified geohazard and its expected interaction with the pipeline.
- Estimate vulnerability components: temporal, spatial, and pipe strain or stress capacity in relation to ground displacement.
- Calculate pipeline susceptibility
- Compare the selected per site susceptibility threshold to the calculated susceptibility for this specific site to determine if any mitigation measures are required.
- If applicable, based on the susceptibility target selected for the project, apply the reliability-based approach to determine if the estimated geohazard PoF distribution exceeds the allowable PoF threshold. If the geohazard PoF profile does not exceed the threshold, the identified geohazards are considered adequately mitigated (controlled) as described in Section 4.2 of this paper.
- Summarize and document all assumptions, uncertainties and limitations of the assessment completed in various relevant project reports and records.

7. DISCUSSION

Recognizing the value and pitfalls of leveraging legacy data from pre-FEED project phases into geohazard assessment during the FEED phase, the team responsible for this assessment should inventory the information available, establish a chronology related to the legacy studies, and identify outstanding questions related to the genesis and pedigree of the information to discuss with the owner. In cases where the most recent information cannot be easily distinguished, or if there are outstanding technical questions regarding the validity or certainty of legacy interpretations, it is important to highlight these issues in joint meetings with the owner to seek resolution. In some cases where the consultant who completed the legacy studies is not engaged in the FEED phase, it may be required to re-engage the original consultant on a limited basis to provide a professional opinion on the findings of legacy studies completed by that consultant. This approach avoids a third party having to assume responsibility for interpreting the findings of work by others, and in the instance where the outcome of the professional opinion is a potential impediment to successful completion of the project, a first-hand opinion is a preferred basis for decision than a second- or third-hand opinion.

Uncertainty in legacy datasets must be understood and communicated along with any additional uncertainty associated with interpretations made during the FEED phase. A prudent statement to include in all FEED deliverables is for the general construction contractor selected for Detailed Engineering to conduct verification analysis to check the results of the FEED analysis, and to refine the analysis as required through additional desktop and field studies. This helps to convey the level of precision in the analysis results and gaps or deficiencies in information that should be filled as part of Detailed Engineering.

8. CONCLUSION

An abundance of legacy studies for a project is beneficial but requires considerable effort to review and assess the quality and relevance of legacy information in relation required deliverables for the FEED phase of a pipeline project. The lessons learned documented here are intended to increase awareness of the potential challenges in incorporating legacy information into engineering deliverables.

ACKNOWLEDGMENTS

The authors wish to acknowledge Worley for support in producing this paper, and the various projects that have been undertaken from which these lessons learned have been extracted.

REFERENCES

[1] Wells, D.L. and Coppersmith, K.J. 1994. New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement: Bulletin of the Seismological Society of America, v. 84, p. 974-1002.

[2] Read, R.S., M. Rizkalla and G. O'Neil. 2019. Chapter 13 Geohazard Assessment and Management – Geohazard, Weather

and Outside Force Mechanisms. In Rizkalla, M., and R.S. Read, eds. 2019. Pipeline Geohazards: Planning, Design, Construction and Operations. American Society of Mechanical Engineers (ASME), pp. 459-579.

[3] Canadian Standards Association CAN/CSA Z662 15/16. Oil and Gas Pipeline Systems. Mississauga, Ontario

[4] Read, R.S. 2021. Pipeline Geohazard Target Susceptibility Threshold – A Reliability-Based Rationalization. Paper IPG2021-65935, Proceedings of the ASME-ARPEL 2021 International Pipeline Geotechnical Conference IPG2021, June 21-22, 2021.

[5] Rizkalla, M., and R.S. Read, eds. 2019. Pipeline Geohazards: Planning, Design, Construction and Operations. American Society of Mechanical Engineers (ASME). 800 p.

[6] PRCI. 2017. Pipeline Seismic Design and Assessment Guideline (2017 Revision). Prepared for the Pipeline Design and Materials Technical Committee of Pipeline Research Council International, Inc. by D.G. Honegger Consulting and D.J. Nyman and Associates, PR-268-134501-R01.

[7] Nyman, D.J. and G. Bouckovalas. 2019. Chapter 11: Assessment and Mitigation of Seismic Geohazards for Pipelines. In Rizkalla, M. and R.S. Read. 2019. Pipeline Geohazards: Planning, Design, Construction and Operations. American Society of Mechanical Engineers (ASME), 2019, pp 389-448.