Geohazards Issues for the Enbridge Northern Gateway Project

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Executive Summary

The Enbridge Northern Gateway Project includes over 1000 km of pipeline running through rugged and remote mountainous terrain in Alberta and British Columbia, Canada, as well as a coastal marine terminal in Kitimat British Columbia. This terrain is particularly susceptible to landslides, debris flows, rockfalls, and lateral spreading that displace the ground and induce serious damage to pipeline systems. The potential for seismic activity further increases the risks to this project. Detailed assessments and analyses are required to ensure that the planned pipeline and terminal facilities can be designed and operated to mitigate risks associated with the geohazards in the area. Specific areas that should be addressed are summarized below.

- To fully evaluate the risks posed to the pipeline by geohazards, detailed maps at 1:25,000 scale are required that delineate the spatial distribution of various geohazards, including landslides, debris flows, avalanches, erosion, etc. The maps should show the geohazards within the 1-km study corridor, as well as those within 5-km of the pipeline route.

- Details regarding the identification and specific mitigation strategies for landslides are required. When re-routing is not possible, information is needed regarding exactly what design modifications will be incorporated to ensure pipeline integrity. Displacement-based design (as described in the PRCI Guidelines by Honegger and Nyman 2004) should be used to evaluate the large displacement capacity of the pipeline system in these areas.

- A detailed, automated landslide monitoring system should be proposed for areas where the pipeline crosses potential landslides. This system should include a deformation measurement system, daily inspection of deformation measurements, the specification of critical deformation thresholds, and a response plan.

- A schedule for in-line inspection of the pipeline should be developed, particularly for areas of landslide potential.

- The seismic design requirements must be explicitly specified. The design requirements provided in CSA Z662-07 **do not** include the effects of earthquake loads, slope movements, or earthquake-induced earth movements. Yet these loads are expected to occur along the pipeline.

- The return period for the design earthquake ground motions has not been specified. The appropriate levels of shaking for seismic design cannot be determined without the owner and engineer deciding upon an appropriate return period. Current building codes are based on a return period of 2,475 years. Design acceleration response spectra should then be estimated across the pipeline route. The potential for a magnitude 9.0 earthquake on the offshore subduction zone needs to be considered and its impact on the design ground motions demonstrated.

- The potential for earthquake-induced landslides along and adjacent to the pipeline route has not been adequately assessed. A comprehensive assessment should be performed using topographic data, geologic data, shear strength data, and ground shaking information.

- A response plan should be developed for inspection of the pipeline system after an earthquake. The sizes of different seismic events and their distance from the pipeline should be considered in developing the events that initiate an inspection.

- The potential for liquefaction, lateral spreading, and the cyclic failure of sensitive marine clays must be more thoroughly evaluated. As noted for landslide hazards, the details of the mitigation strategies to be used should be provided.

- The seismic design of the Kitimat terminal site requires additional details. The design ground motion must be specified and the influence of the local soil conditions on the ground motions must be evaluated. The marine clay overlying bedrock at the site is particularly prone to ground motion amplification. Additionally, the potential for earthquake-induced rock falls, rock slope failures, and lateral spreading of the marine clays at the Kitimat terminal must be assessed.

1.0 Introduction

The Enbridge Northern Gateway Project includes over 1000 km of pipeline running through rugged and remote mountainous terrain. This pipeline initiates near Edmonton, Alberta and will terminate at the planned Kitimat Terminal in Kitimat, British Columbia. This terminal will include storage tanks, a marine terminal, as well as other facilities.

Permanent ground displacement (PGD) represents one of the most significant geohazards associated with pipeline systems (Nyman et al. 2008). These displacements may be caused by landslides, faults, or liquefaction. While the Northern Gateway Project Application includes discussion of the potential for landslides and liquefaction along the pipeline route, the mitigation strategies have not been adequately described. Further, the potential for seismic instability has not been adequately evaluated in the application, nor have the seismic design considerations the Kitimat Terminal been appropriately described.

This report discusses various issues related to risks from geohazards that need to be considered during the application process such that an informed decision can be made about the future of this project.

2.0 Applicable Standards for the Design of Pipelines

The proposed pipeline crosses very rugged terrain that must be designed appropriately for all potential hazards. Various standards and guidelines have been developed that address pertinent issues related to these hazards, but most of these are not discussed in the Enbridge Application. Relevant standards and guidelines are discussed below.

2.1 General Standards and Guidelines for Pipelines

The Enbridge Application states that the primary standard is CSA Z662-07 Oil and Gas Pipelines Systems. Clause 4 of CSA Z662-07 deals with the design requirements for pipeline systems. As stated in Clause 4.2.4, **the stress design requirements in the standard <u>do not</u> include the effects of inertial earthquake loads, slope movements, fault movements, earthquake-induced earth movements, frost heave, as well as other loading sources**. Nonetheless, the standard states that "the designer shall determine whether supplemental design criteria are necessary for such loadings and whether additional strength or protection against damage modes, or both, should be provided." No further guidance regarding seismic design or ground movements is provided in Clause 4 of CSA Z662-07.

Clause 11 of CSA Z662-07 addresses requirements specific to offshore pipelines and Clause 11.6.6 provides guidance regarding the seismic design loads for offshore pipelines. While Clause 11.6.6 does not officially apply to onshore pipelines, the information in this section provides guidance that can be used for onshore facilities. Specifically, Clause 11.6.6.2 states that loads due to earthquake-induced stress waves, permanent ground displacements, and fault movements be considered. Additionally, Clause 11.6.6.3 indicates that the potential for earthquake-induced rock slides, slope failures, and liquefaction be considered.

An important seismic design guideline that should be followed is ***PRCI-L51927 Guidelines for the Seismic Design and Assessment of Natural Gas and Liquid Hydrocarbon Pipelines*** (Honegger and Nyman 2004). This document provides more specific guidance regarding the procedures used to evaluate the effects of seismic loads and permanent displacements on pipelines. Another important seismic guideline that should be followed is ***ISO 23469 Bases for design of structures – Seismic actions for designing geotechnical works***. This standard describes the specific seismic issues that need to be addressed during the design of geotechnical works, including the design of buried pipelines (Section H.5), and describes relevant methods of analysis for use in design.

2.2 Standards for Seismic Design Ground Motions

Critical information required for seismic design is the design ground motion. The ground motion is typically specified in terms of an acceleration-response spectrum, and this ground motion is used to evaluate the direct effects of shaking on the pipeline (i.e., induced stresses and strains) and the indirect effects of shaking (i.e., the potential for shaking to induce geohazards such as liquefaction or slope failures that damage the pipeline). Often, these indirect effects are more damaging that the direct effects of shaking.

Design ground motions at a site are generally specified via a probabilistic seismic hazard analysis (PSHA), which considers all potential earthquake sources in the area, the rate of occurrence of earthquakes of different sizes on these sources, and the range of ground motions possible given each earthquake size and its distance from the site. The PSHA provides a hazard curve, which plots the return periods of different levels of ground motion. The key issue for design is the return period that will be used to specify the design ground motion. While the standards and guidelines identified above provide important information regarding the seismic design of pipelines systems, they do not recommend a return period for design.

The Enbridge Application does not specify the return period of the ground motion level that will be used for seismic design. **The return period for the design ground motions must be specified such that the seismic loading for the pipeline and terminal facility can be determined.** Current building codes in Canada and the U.S. are based on ground motions with a return period of 2,475 years, which represents a motion with a 2% probability of exceedance in 50 years. The geotechnical report provided in Volume 3, Appendix E-1 provides some initial estimates of seismic ground motion levels across the pipeline route based on a return period of 2,475 years, but it is clear from this Appendix that Enbridge has not decided upon an appropriate return period.

Volume 3, Appendix E-1 provides estimates of the peak ground acceleration (PGA) along the pipeline route for a return period of 2,475 years and soft rock conditions (Site Class B). The reported values of PGA in Appendix E-1 represent moderate to low levels of shaking (0.12 g to 0.05 g). The moderate levels of shaking occur along the western segments of the pipeline, while the lower levels occur further to the east. Detailed engineering will require a more complete description of the ground motions, including an acceleration response spectrum, additional ground motion parameters (such as peak ground velocity and ground motion duration), and possibly complete acceleration-time series. The influence of the local soil conditions on the design ground motions must be taken into account. In general, soil will increase the levels of shaking, which leads to larger seismic demands. These design ground motions must be considered explicitly in the seismic design of the pipeline and terminal facility, and they must be used to assess the potential for geohazards along the pipeline route.

Finally, information is required regarding the earthquake source characterizations used in the PSHA. It appears that the earthquake source characterization is taken from published sources, and that detailed source characterization for sources close to the pipeline has not been performed. Additionally, the characterization of the maximum magnitude for the offshore subduction zone should be specified. The technical literature generally considers a maximum magnitude of around 8.0 for this segment of the fault, although magnitudes 9.0 have occurred to the south (1700 Cascadia event) and to the north (1964 Great Alaska earthquake) along this plate boundary. In light of the magnitude 9.0 Tohoku earthquake in Japan in March 2011, which occurred along a subduction zone which was believed to be incapable of producing a magnitude 9.0, significant attention should be given to the maximum magnitude along this section of the fault.

3.0 Geohazards along the Pipeline Route

Permanent ground deformations (PGD) from faults, landslides, liquefaction, or karst terrain are the most significant geohazards impacting the pipeline. Landslides and liquefaction are the most likely source of PGD along the proposed pipelines route.

3.1 Landslide Hazards

In mountainous terrain, landslides are the main triggers of pipeline ruptures (Nyman et al. 2008). Landslides can generate movements on the order of centimeters to meters (Figure 1), which induce lateral and/or axial strains within the pipeline, depending on the orientation of the pipeline with respect to the landslide. Landslides may be triggered or aggravated by various factors, such as excessive rainfall, snow melt, or earthquake shaking. Excessive rainfall and snow melt trigger landslides by increasing the pore water pressures and soil moisture within the slope materials, which reduces the strength of the soil and leads to deformation and failure. Earthquake shaking triggers landslides by increasing the driving forces on the slope, which leads to deformation and failure.

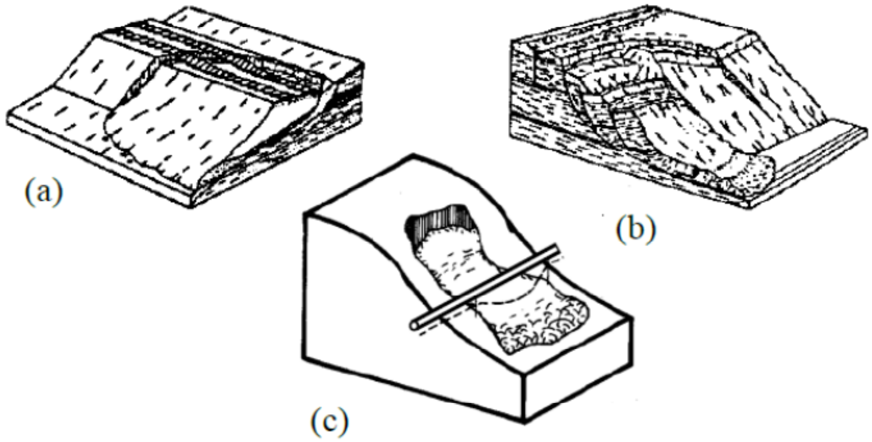

Figure 1. Landslide movements (from Nyman et al. 2008).

It is difficult to predict the movements of landslides based on known values of rainfall or snow melt. However, landslide movements in natural ground generally occur on slopes that show features of having moved in the past. These pre-existing landslides, whether currently moving or not, are considered the most likely locations where future landslides will occur under non-seismic conditions. Earthquake-induced landslides do not necessarily occur on pre-existing landslides and their evaluation is discussed in a subsequent section.

The most secure mitigation strategy against landslides is avoidance during the routing stage. Avoidance requires accurate identification of pre-existing landslides (both active and potentially active) along the proposed pipeline route, as well as accurate identification of locations where landslides may initiate in the future. Table B-1 in Volume 3, Appendix E-1 presents a detailed description of the geology and geotechnical conditions along the entire pipeline route, including the locations of potential landslide hazards. The landslide hazards were identified based on observations of previous slide movements. It appears that landslide identification has only focused on the 1-km study corridor. **However, landslide materials can travel significant distances (i.e. several kilometers), such that landslide hazards within 5-km of each side of the study corridor should be assessed (Geertsema and Clague 2011).** A risk assessment was performed by Enbridge based on their observations and the results summarized in a risk matrix (Figure 4.1 in Volume 3, Appendix E-1). This risk matrix indicates that landslides are a significant risk to the project and require mitigation.

The mitigation strategies for landslides for the pipeline are discussed in Table 3-2 of Volume 3. The strategies include re-routing to avoid landslides (where possible) and stability enhancements where re-routing is not possible. Figure 4.2 in Volume 3, Appendix E-1 presents a risk matrix after application of the mitigation strategies. This risk matrix indicates that the risk mitigation strategies significantly reduce the landslide risk to the pipeline. However, the mitigation strategies are not described in enough detail for one to have confidence that the risks will be significantly reduced.

Mitigation of landslide hazards via stability enhancements requires a significant investment in site investigation and monitoring (Nyman et al. 2008). As noted above, the level of detail provided in the Enbridge Application does not allow one to assess whether the stability enhancements will be able to adequately reduce the landslide risk. Issues that must be considered are the mechanics of the landslide, the subsurface conditions, current and past movements, and the rate of displacement (e.g., creeping movements that develop slowly over time versus rapid movements in which > 1m of displacement occurs over a short time period). The 2004 PDCR Guidelines, as well as Nyman et al. (2008), recommend **that pipeline sections in landslide prone areas be designed with large displacement capacity and that pipe selection, welding specifications, and weld inspection account for high-strain service.** It is not clear that these issues have been considered in the pipeline selection.

Related to the landslide mitigation is the monitoring of existing landslides. Monitoring is critical to provide an early warning of landslide movements (Reid et al. 2008). Monitoring includes an array of surface and subsurface field sensors that measure soil moisture, pore pressures within the soil, ground movements, and vibrations. For remote locations, these sensors need to be rugged and have low power consumption such that they do not need to be replaced very often, and the data must be automatically acquired and transmitted to personnel who can view, process, and interpret the collected data (Figure 2). Reid et al. (2008) provides details regarding the landslide monitoring systems used by the U.S. Geological Survey and their experiences using such systems at various landslide sites.

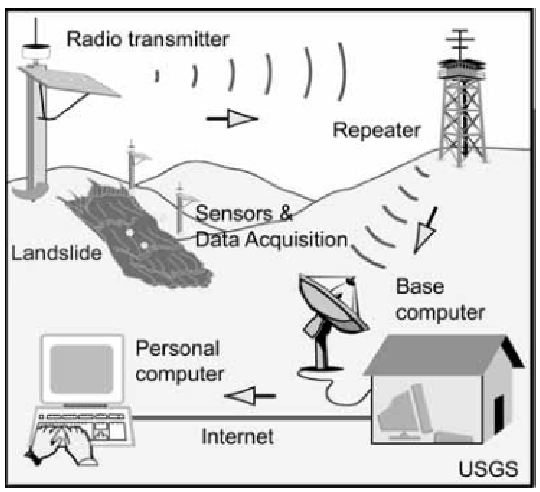

Figure 2. Example of near-real-time landslide monitoring system (from Reid et al. 2008).

The Enbridge Application mentions that monitoring will be performed, but no details regarding the type of monitoring are provided. Because of the remote location of the pipeline and the need to identify damaging movements early, it is critical that **landslide monitoring includes near-real-time measurement of deformations, soil moisture, pore water pressure, etc., and that this information is electronically logged in the field and automatically transmitted to the Enbridge Edmonton Control Centre**. A staff person with appropriate experience or training should be responsible for viewing the data each day, thresholds of deformation should be identified that require inquiry, and a response plan should be developed that outlines the procedures to be followed when the displacement thresholds are exceeded. Finally, in-line inspection of pipeline should be performed at a regular basis to identify movements of the pipeline (Honegger et al. 2009). These inspections should be compared with a baseline inspection performed after construction. The Enbridge Application indicates that in-line inspections will be performed, but no timeline is provided.

3.2 Specific Terrain Stability Issues along the Pipeline Route

The pipeline route crosses rugged mountainous terrain that has a history of stability issues, including landslides, debris flows, and erosion. Schwab (2011) provides a thorough and detailed description of the geologic and fluvial processes that are occurring along the pipeline route and pose risks to the project. The findings from this report are summarized below.

The pipeline route is most susceptible to terrain stability as it approaches and crosses the Coastal Ranges towards Kitimat. The three main physiographic regions in this area are the Nechako Plateau, the Hazelton Mountains, and the Kitimat Ranges. The Nechako Plateau is characterized by gently rolling hills and extends approximately from Burns Lake (KP~930) to the Morice River Valley (KP~1045). The Hazelton Mountains extend from Gosnell Creek (KP~1045) to Nimbus Mountain (KP~1080), and include rugged peaks and rounded lower elevation mountains. The Kitimat Ranges extend from Nimbus Mountain (KP~1080) to the end of the pipeline route (KP~1170), and include steep peaks/narrow valleys as well as the alluvial valley of the Kitimat Trough.

In the Nechako Plateau, evidence of significant erosion events is present in various creeks, such as the Tchesinkut Creek that experienced an erosion event in the early 1980s that transported approximately 250,000 m^3 of sediment. Evidence of landslides is present along the ridges of volcanic rocks that extend from Houston to Francois Lake, with the most striking evidence along the ridges above Parrott Creek within the general pipeline corridor (near KP 990). West of KP 1000 and the Houston Pump Station, the pipeline corridor crosses Owen Creek and associated glaciolacustrine sediments. This area has experienced surface erosion and stability problems, including stability problems along the Morice Owen Forest Service Road, and the pipeline corridor crosses a large historic earth flow feature.

Figure 3. Evidence of landslides in ridges above Parrott Creek (Schwab 2011)

In the <u>Hazelton Mountains</u>, the pipeline corridor crosses the Gosnell Creek Valley and Clore Canyon to Nimbus Mountain. A series of fluvial fans extend into the Gosnell Creek Valley and cross the pipeline corridor. These fans are very active, with over 80 debris flood events being documented over the last 50 years. This activity has caused problems for the Crystal Forest Service Road, which parallels the pipeline corridor. There are significant stability issues through the Clore Canyon, with fractured and weather bedrock present as well as sackungen (Figure 4). The pipeline corridor includes a tunnel to bypass these problems, but the depth of the instability must be investigated with respect to the proposed tunnel alignment and portal locations.

Figure 4. Google Earth image of sackungen feature along the Clore River Canyon (Schwab 2011)

In the <u>Kitimat Ranges</u>, the pipeline corridor includes a tunnel through Nimbus Mountain and then traverses the Upper Kitimat Valley and Kitimat Trough. The Upper Kitimat Valley contains the Upper Kitimat River, and the valley is flanked by steep mountain slopes with various creeks that drain to the Kitimat River. These creeks, including Hoult Creek and Hunter Creek, experience frequent debris flows that cause both erosion and avulsion along the valley. For example, 13 flood events have been documented at Hunter Creek since 1950, with significant channel shifting in 1987 and 1992 (Figure 5). These events are relatively commonplace along the Upper Kitimat Valley and have caused considerable problems for the Kitimat Mainline Forest Access Road. The Kitimat Trough that extends south from approximately KP 1125 consists of alluvial and glaciomarine sediments that may post significant problems for the pipeline. In particular, the Trough contains sensitive glaciomarine clays that are very susceptible to instability and large runout distances. Since the 1950s, several landslides have occurred in these glaciomarine clays at various locations within the Kitimat Trough and evidence of ancient landslides is present along the pipeline corridor. The segment of the pipeline most at risk to movement of glaciomarine clays is the area around the Wedeene River, where thick layers of clay are present and evidence of previous instability is present.

It is clear that there are significant geohazards along the pipeline corridor. To fully understand the extent of these hazards and to evaluate Enbridge's claim that they have avoided them effectively, **it is critical that 1:25,000 scale maps be developed of the identified hazards along a 10-km wide swath centered along the pipeline corridor (i.e., 5-km on each side of the pipeline route).** Some of this information is included in Appendix B of Volume 3,

Appendix E-1 of Enbridge's submittal, but it is not shown in graphical form such that the spatial extent relative to the pipeline corridor can be evaluated. Additionally, the information in Appendix B focuses on the pipeline corridor itself rather than the larger 10-km wide study area.

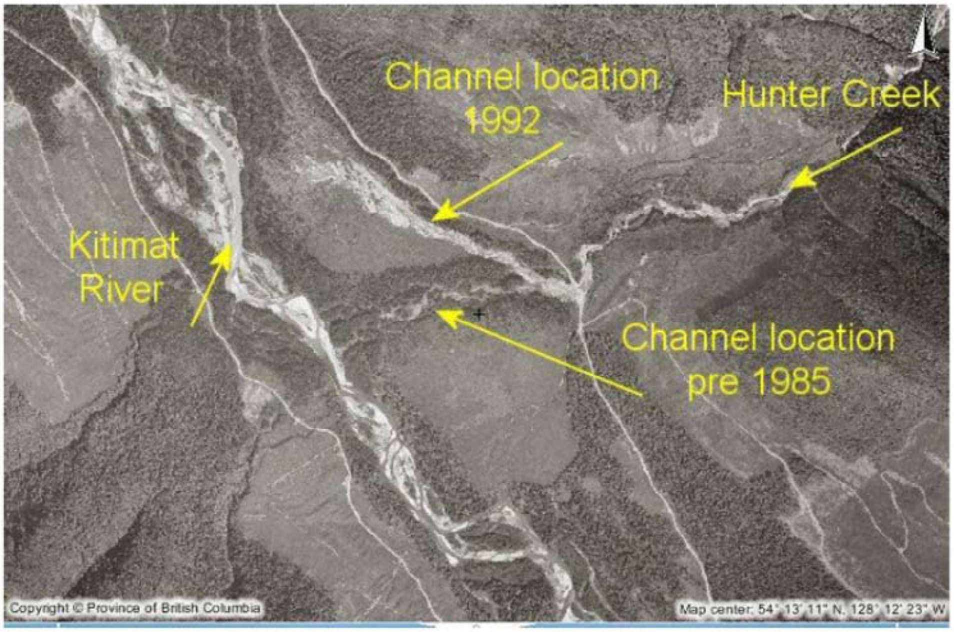

Figure 5. Hunter Creek channel avulsion in 1985 and 1992 (Schwab 2011)

3.3 Seismic Landslide Hazards

The Enbridge Application does not explicitly evaluate seismic landslide hazards, but rather it appears to assume that seismic landslides are only a concern with existing landslides. Figure 6 shows the landslides induced by the 1994 Northridge earthquake within the Oat Mountain Quadrangle of California. Also shown in this Figure are the mapped landslides from this quadrangle. It is clear that the earthquake-induced landslides occurred over an area much larger than the existing landslides. In fact, only 1% of the earthquake-induced landslides occurred in the areas mapped as previous landslides. This information points to the need to develop **a more comprehensive assessment of the seismic landslide potential along the pipeline route**. While the seismic motions along the pipeline are moderate, the consequences of an earthquake-induced landslide are very high. The seismic landslide assessment should include an integration of topographic data, geologic data, shear strength data, and ground shaking information (Jibson et al. 2000, Saygili and Rathje 2009) within a Geographic Information System for identifying areas prone to earthquake-induced landslide hazards. This assessment should include not only the 1-km proposed corridor, but also adjacent areas because earthquake-induced landslides can travel significant distances.

Related to seismic issues, a response plan should be developed in the event of an earthquake. This response plan should consider the sizes of seismic events that will initiate the need for detailed inspection and the distance between the fault rupture of the event and the pipeline. For example, a magnitude 6 event within 30 km may initiate inspection while a magnitude 9 within 300 km may initiate inspection. Note that these distances represent distances to the fault rupture plane and not epicentral distances. If distance was defined based on epicentral distances, larger distance thresholds would be required.

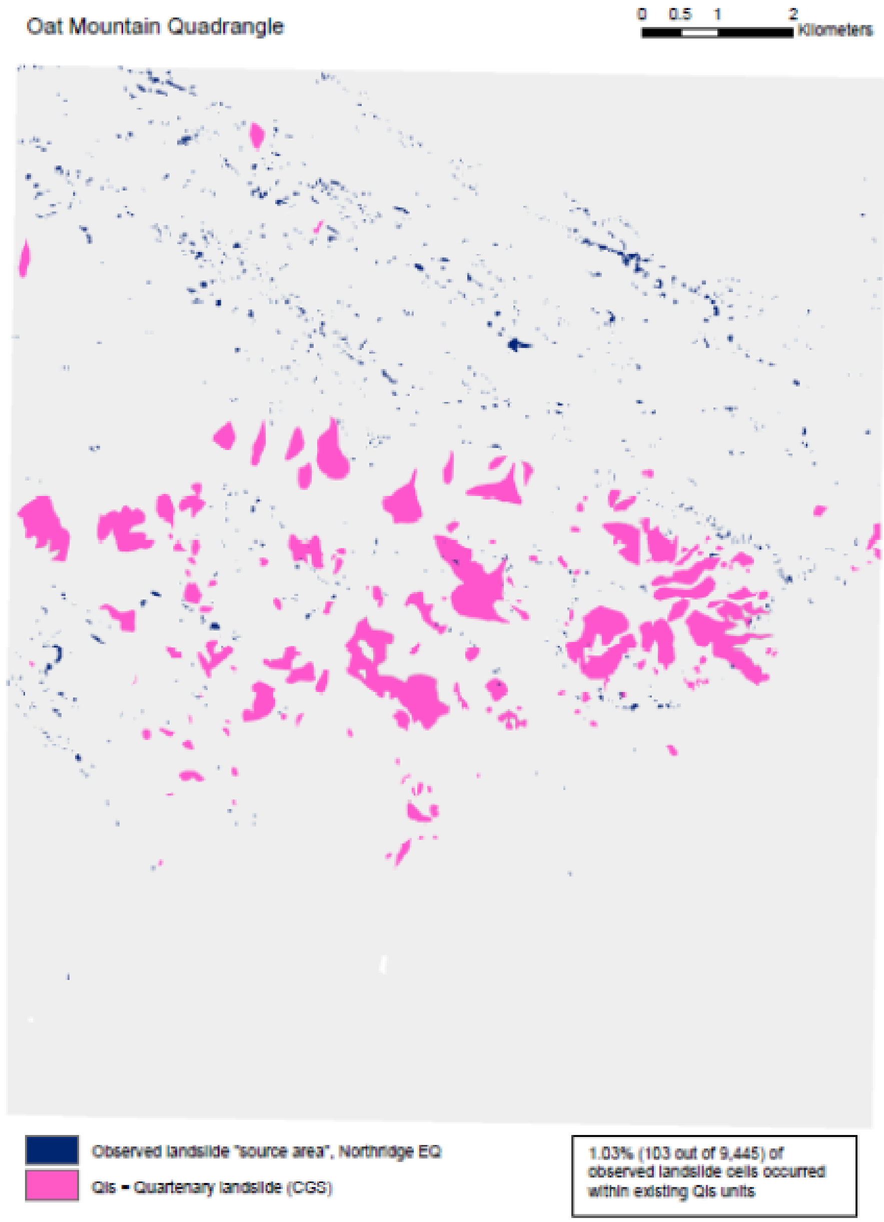

Figure 6. Observed landslides in the Oat Mountain Quadrangle of California induced by the 1994 Northridge earthquake and mapped Quaternary landslides within the Oat Mountain Quadrangle.

3.4 Liquefaction and Lateral Spreading Hazards

Liquefaction represents the significant loss of strength in predominantly granular soils (i.e., sands and gravels) that are saturated. Liquefaction is most commonly induced by dynamic loading, such as earthquake shaking. Sensitive clays may also lose significant strength due to earthquake shaking, but this phenomenon is not typically called liquefaction. The procedures used to identify liquefaction hazards are different than those used to identify cyclic failure of clays, although the consequences may be similar (e.g., lateral spreading).

Lateral spreading and flow failures are the most critical liquefaction effects that can damage pipeline systems. These failures can also occur in sensitive clays. Pipeline water crossings and pipeline sections along Quaternary alluvium close to rivers and streams are most susceptible to liquefaction. Volume 3, Appendix E-1 indentifies areas along the western segments of the pipeline route that are susceptible to liquefaction. Additionally, these sections also cross sensitive marine clays, which are susceptible to lateral spreading.

The final routing and design must fully consider the effects of liquefaction and lateral spreading. This evaluation must incorporate field data and take into the account the design ground shaking levels (which have not been adequately described). Table C-1 of Volume 3, Appendix E-1 identifies locations along the pipeline where liquefaction is a potential risk, but the mitigation measures identified for these sites are simply to re-route or "design for liquefaction." However, there is no standard approach to design for liquefaction. The lateral spreading of marine clays is treated similarly, with the mitigation measures identified as re-route or "further investigation required." Again, it is not clear how the lateral spread hazard will be mitigated via this further investigation. Honegger et al. (2006) describes some approaches that have been to deal with pipelines that cross lateral spread zones. These approaches include deep burial and large-displacement pipeline capacity that utilize strain-based design.

4.0 Geohazards Issues at the Kitimat Terminal Site

The Kitimat terminal is located in an area with steep topography and variable subsurface conditions. Bedrock outcrops across some of the site, but other areas consist of up to 25 m of soil, including sensitive marine clays, over bedrock. The bedrock is strong, but heavily jointed.

The foundations of all structures at the site must be adequate to support the appropriate loads and achieve required performance targets. The marine clays at the site will present significant problems for the foundation systems. Not only are these clays susceptible to excessive settlements, but seismic shaking may cause lateral spreading in sloped areas and these deformations can damage a foundation system.

From a seismic perspective, the dynamic response of a soft/medium stiff clay overlying bedrock can lead to significant ground motion amplification which will impart enhanced loads on the overlying structures. This amplification must be incorporated in the design ground motions developed for the site. Thus, shear wave velocity (Vs) measurements are required for the site. Amplification for a site with shallow bedrock (depth to bedrock less than about 100 m) should be estimated via site-specific site response analysis, because most simplified methods (i.e., those based on the average Vs over the top 30 m) do not appropriately account for shallow bedrock.

The steep topography adjacent to the coast has the potential for rock falls or larger scale stability problems. These failures can occur both under static conditions and seismic conditions. These hazards must be appropriately identified, which for the seismic case requires the design ground motion levels. Mitigation strategies must be put in place.

5.0 Summary Recommendations

The following information is required before an informed decision can be made about going forward with the project.

Topic	**Required Information**
Geohazards Identification	• 1:25,000 scale maps showing the identified geohazards along a 10-km wide swath centered along the pipeline corridor.
Design Ground Motions	• Design acceleration response spectra, peak ground velocities, and ground motion durations at locations along the pipeline route and at the Kitimat Terminal site. • These motions should be generated for the expected ground conditions at each location (i.e., the appropriate shear wave velocity of the underlying materials). • These motions should be associated with an appropriate return period • The influence on the design ground motions of a magnitude 9.0 occurring along the coastal subduction zone should be demonstrated.
Pipeline design for large displacements	• Demonstrations of the ability of the proposed pipeline design to withstand 1-m of lateral movement. This can be demonstrated using strain-based design (PDCR Guidelines).
Monitoring	• A detailed, near-real-time landslide monitoring plan that includes automated data acquisition and transmission • A plan and schedule for in-line inspections of the pipeline
Seismic Landslides	• A seismic landslide map for the region adjacent to the pipeline. This region should extend 5-km on each side of the proposed 1-km corridor. • This map should be generated in a Geographic Information System using the mechanistic procedures, such as those outlined by Jibson et al. (2000) or Saygili and Rathje (2009).
Liquefaction	• A quantification of the potential for sands along the pipeline route to liquefy under the design ground motions. This assessment should be performed using field measurements of Standard Penetration Tests and/or Cone Penetration Tests. • Specific information on design alternatives for sites where liquefaction cannot be avoided by re-routing.
Marine Clays	• A quantification of the potential for marine clays along the pipeline route and at the Kitimat Terminal site to fail cyclically under the design ground motions. This assessment should be quantified using monotonic and cyclic laboratory tests on samples of clay. • Specific information on design alternatives for sites where marine clays cannot be avoided by re-routing.

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