Landslides and Engineered Slopes: Protecting Society through Improved Understanding – Eberhardt et al. (eds)

Challenges in planning highway improvements in landslide terrain

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ABSTRACT: Alberta Transportation (AT) is responsible for providing a safe, innovative, and sustainable provincial transportation system in Alberta. This responsibility includes the planning, design, construction, and maintenance of public roadways. Economic and expansion pressures place demands on the roadway network capacity. In order to facilitate a rational and sustainable highway expansion program, AT undertakes numerous Functional Planning Studies (FPS) well in advance of any engineering design or construction. A FPS is a multidisciplinary project that requires input for highway planning, traffic forecasting, geometric and drainage considerations, aboriginal consultation, environmental studies, surfacing strategy considerations, and geotechnical impact. The results of these inputs are captured in the FPS, from which a long term work plan can be rationally formulated. Numerous geohazard sites, mostly landslides, impact existing public roadways, associated infrastructure and surrounding environs. These geohazard sites can play a crucial role in determining the outcome of a FPS. To manage the risks posed by such geohazard sites, AT has implemented the Geohazard Risk Management Program (GRMP) to identify, investigate, instrument, monitor and, if required, repair such sites. The FPS includes a geotechnical review of the impact of known GRMP sites. The completion of these reviews requires a practical understanding of highway geometric considerations, construction methodology and the geohazard mechanisms that affect the existing or proposed alignments. Two FPS case histories are provided which illustrate the impact of large landslide geohazards on the outcome of planning studies. Conclusions related to findings from these FPS in relation to the geotechnical input required and influence on future highway works are also provided.

1 INTRODUCTION

1.1 *General*

Alberta Transportation (AT) is responsible for providing a safe, innovative, and sustainable provincial transportation system. This responsibility includes the planning, design, construction, and maintenance of 31,300 km of public roadways. Growing economic activity, socio-political pressures, increased traffic and changing standards require network improvements from AT. These network improvements need to be carefully planned and projected many years in advance of critical needs. Planning for highway improvement work in Alberta typically involves the completion of a Functional Planning Study (FPS).

1.2 *FPS overview*

FPS assignments involve input from specialists related to planning, geometrics, traffic forecasts, environmental sciences, land purchase agents, aboriginal consultation, archaeological and historical resources assessments, drainage and stormwater management, and geotechnical engineering. These assignments are necessarily multi-disciplinary as the design service life of a highway corridor represents a long term and complex infrastructure investment made by AT on behalf of the existing and future tax payers of the province of Alberta. Network expansion can consist of grade widening, improvements to vertical and horizontal sight distances, adding additional lanes, intersection and access control, passing lanes, over-dimension truck staging or pull-out areas, new roads, and twinning of existing roadways.

One element of the FPS process which appears to have been absent is a discussion of the design life of a highway corridor. The reason for this omission is believed to be that AT has not had to address large scale relocations of existing highways to date, except for municipal centre bypass situations. This speaks to the robust stability of the public highway system in Alberta. In retrospect, established transportation corridors in Alberta have had design lifes of at least 100 to 200 years. Railways were often constructed prior to the local roadway network and appear to be an even longer term investment as a transportation corridor. The relative youth of the transportation network in western Canada limits this line of discussion for the subject sites to be discussed later in this paper. Looking to more established areas in the world, some of the transportation corridors selected by the Romans in Europe are still in use to this day, which represent a transportation corridor service life that extends up to thousands of years.

An important part of the FPS process is public consultation. This dialogue ensures a transparent and open process where the public is both informed on the nature of the proposed highway improvements and where AT can receive public opinion and additional information on the economic, societal, and often political impact of the proposed highway improvements.

The purpose of a geotechnical assessment conducted in support of an FPS is not to prepare a final design, but rather to conduct a high level overview of the geotechnical conditions that could impact the proposed development. As such, subsurface investigations are not necessary in all cases. A FPS should therefore include a high level review by a senior civil/geotechnical engineer experienced with highway design, construction and maintenance, especially where geohazards are concerned. Experience with geohazard engineering and risk management are necessary parts of conducting high quality geotechnical assessments for FPS in landslide terrain.

1.3 *Overview of geohazard risk management program*

Planning highway improvements in landslide terrain requires consideration of the impacts of known geohazards on the existing highway and assessing how they might affect proposed improvements or realignment of the highway. The presence of geohazards can profoundly impact the outcome of a FPS.

There are approximately 350 known active geohazard sites that impact Alberta highways. These geohazards are mostly related to landslides, but erosion, frost heave, swelling soil, rock fall and other geohazards are also considered. To manage the risks posed by such geohazard sites, AT implemented the Geohazard Risk Management Program (GRMP) in 1999 to identify, investigate, instrument, monitor and, if required, repair such sites.

The GRMP is managed over several regions by geotechnical consultants who are experienced in the slope stability aspects of geotechnical engineering and are familiar with the practical and operational challenges faced by AT in maintaining the highway system. The GRMP provides the support and rational for the development of annual work plans to address the sites with the highest risk level. Budget limitations dictate that only a dozen or so geohazard sites are mitigated each year. The repaired sites are replaced with new ones at a disconcerting rate. GRMP sites are typically investigated shortly after they have been observed to affect the highway; so there is usually detailed geotechnical information available on such sites available for use in an FPS. It is important to note that the GRMP was established to manage geohazard sites affecting the current configuration of the highway system and the findings of the various investigations and assessments completed to date are retrospective in nature in that they may not be immediately applicable to potential modifications or relocation options considered in a FPS.

1.4 *Basis for discussion*

AT has commissioned a number of FPS on Highways 49 and 2 between Valleyview and the Town of Peace River, in northwest Alberta. The area of these proposed highway improvements is shown in Figure 1. Typical objectives for these studies included developing the following:

- Ultimate and initial stage plans for the future upgrading of the highway to a twinned freeway (free flow) facility.
- Future interchange locations along the highway.
- Detailed functional plans that will show the appropriate staging and identify the right-of-way requirements.
- Basic right-of-way requests and address access management requirements.

The focus of this paper will be the impacts of geohazards on upgrading a highway to a freeway (free flow) facility.

2 REGIONAL GEOGRAPHIC AND GEOLOGIC SETTING

The general project area between Valleyview and Peace River, Alberta is located within the Interior Plains of Canada region and is within the drainage catchment of the Peace River known as the Peace River Lowlands physiographic zone (Davies et al., 2005). The study area is located within the Western Canada Sedimentary Basin with bedrock varying from sandstone to high plastic clay shale. The topography is generally flat to gently rolling prairie upland with deeply incised river valleys

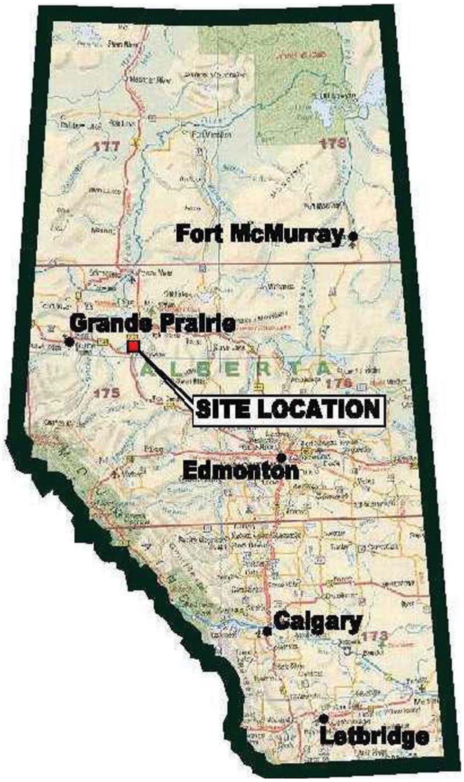

Figure 1. Site location plan.

that connect to Peace River. Many tributaries in the Peace Region are confined within pre-glacial valleys that have been in-filled with lacustrine, alluvial, till and colluvial materials. The presence of weak soil and bedrock and poor drainage in the valley slopes results in widespread and relatively large incidences of valley slope instability.

Published engineering assessments of the landslide mechanisms in this area are described by Froese et al. (2008), Mollard (1997), Skirrow et al. (2005), and Thompson & Hayley (1975) in the context of the interaction of landslides with the highway system.

3 STUDY SITES

3.1 *General*

A number of FPS have been completed for the proposed twinning Hwy 49 and Hwy 2 between the towns of Valleyview and Peace River. Two of these FPS have focused on lengths of highway that include two high profile landsliding sites, listed as follows from south to north:

- Hwy 49:12 crossing of Little Smoky Valley; and
- Hwy 2:60 crossing of Heart River valley slope near Town of Peace River (East Peace Hill).

Annual inspection reports, photographs and instrumentation data are presented on the AT website for the GRMP sites at these locations (AT, 2011). The first FPS to be completed was the East Peace Hill study in 2006/2007. The Little Smoky study was undertaken in 2010 with portions of it still underway at this time.

The geotechnical assessments of the geohazard areas included the following general tasks:

- Background review of all readily available background information;
- Air photo review;
- Review of topography developed from recent air photo data, which was plotted superimposed on air photo background, and/or review of LiDAR data;
- Discussions/interviews with AT and review of archival information prior to mobilizing to the field;
- Ground reconnaissance;
- Helicopter reconnaissance conducted with AT's regional coordinator of the GRMP;
- Discussion of findings with the rest of the FPS team; and
- Preparation of a geotechnical assessment report.

The findings of these tasks were then incorporated into the overall multi-disciplinary FPS report which was then submitted to AT.

Helicopter reconnaissance was included given the magnitude and extent of the landsliding geohazards that were known to be affecting the subject sites as it was recognized that a ground based reconnaissance alone would not be sufficient to assess field conditions for either existing large scale geohazards or potential re-alignment.

In both cases, geometrical/alignment improvement concerns were recommended to be less important than maintaining the stability of the slopes. The logic behind this recommendation is that the value of the investment in an improved highway could be reduced or more than negated by exacerbated landsliding activity.

3.2 *Little smoky river valley*

3.2.1 *Existing site conditions and highway operating issues*

The Little Smoky River valley is the site of one of the highest profile landslide sites in western Canada. Deep-seated valley-slope encompassing landslides affect both the right and left valley slopes, one abutment and pier foundation for the bridge structure and the bridge approaches within the valley. The bridge crossing has two lanes with an Annual Average Daily Traffic (AADT) of 2270 (AT 2011). There are passing lanes located on either side of the bridge on the uphill portions of the highway.

It appears that the current bridge location was selected to take advantage of a ridge on the north side of the river and the seemingly favourable topography associated with what is now known to be a landslide zone on the south bank of the river. There is a relatively sharp turn on the south abutment approach which was necessitated by the limited space on the south valley slope. Review of historical records in AT's archives revealed a large number of insurance claims related to accidents at this location. It is telling to note that the number of such documents was quite large compared to the documents relating to engineering matters.

The bridge has been retrofitted to accommodate landslide movement under the south abutment (Rebel, unknown date). The landslide movement rate is about 100 mm/year which is typical for large deep seated landslides in clay shale (Brooker & Peck 1993). AT has noticed a relationship between short term peaks in flow rates and increased river bank erosion in the Little Smoky River caused by relatively low return period (i.e., low with respect to the consequences of landslide failure) runoff events and short-term increases in the rate of landslide movement.

Despite the bridge structure and the foundations for one abutment and one pier being rehabilitated in the late 1990s, the ongoing landslide movements still require structural realignment and jacking approximately every 24 months. AT's ongoing expense to operate and maintain the bridge site is about $250,000 per year, not counting the structural rehabilitation works completed in the late 1990s that cost several million dollars. A similar operating cost is expended annually to patch and level the approach roads that both cross over active landslide scarps.

3.2.2 *Findings of geotechnical assessment portion of FPS*

At the outset of the study, AT specified that any alternate crossing proposed for the Hwy 49 crossing of the Little Smoky River valley should not cross existing landslides. To undertake the significant investment re-route the highway from its current location with its known geohazard problems to another site with similar or potentially worse problems was unacceptable to AT. A plan showing the existing alignment and the various alignments considered, including the geotechnically preferred alignment, in the FPS geotechnical assessment is presented in Figure 2 (EBA 2011). This crossing

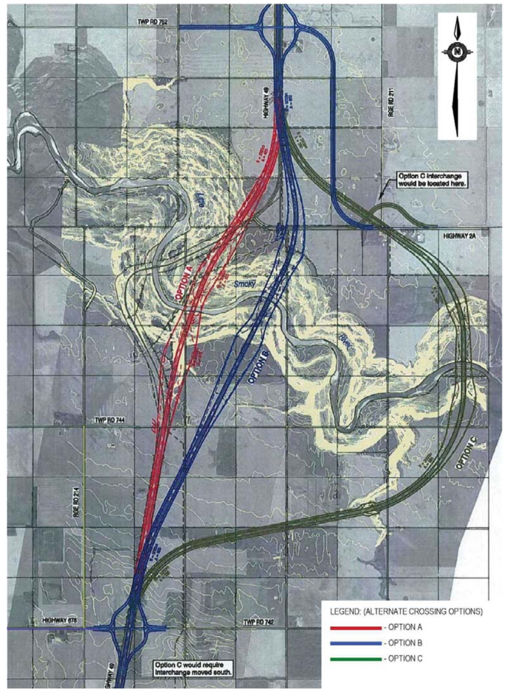

Figure 2. Re-alignment options for Hwy 49 through Little Smoky River valley.

location was first identified by J.D. Mollard and Associates Ltd. in 1997.

The advantages of the geotechnically preferred alignment include the following:

- Large deep seated and active landslides appear to be avoided (subject to further investigation in subsequent studies);
- The topography of the proposed crossing site permits the freeway geometrical design requirements to be met without the creation of high head slopes and approach fills (e.g., 20 m or more);
- On the north side of the river valley there is an eroded bend in the river that has created a terrace about 10 to 15 m above the existing river elevation. The remaining valley wall slope is located about 300 m north of the river channel, well away for the destabilizing influence of toe erosion on the outside bend of the river; and
- The south bank is on the inside bend of the river with the valley slope being one of the steepest slopes in the Little Smoky River valley which indicates favourable natural slope stability conditions.

The location of the geotechnically preferred crossing is well outside (about 8 km) of the historical Hwy 49 corridor and will result in approximately 12 km of existing highway and a major bridge structure being abandoned and approximately 15 km of new highway and a new bridge being built. AT does not lightly abandon a bridge site and an associated significant length of highway, especially one where significant operational and maintenance investment has been made over many years.

3.3 *East peace hill*

3.3.1 *Existing site conditions and highway operating issues*

The incidence of landslides along this section of highway is such that, in practical terms, the entire length of valley wall is affected by landslides experiencing various degrees of activity. The distribution of active and historical landslides on East Peace Hill is shown in Figure 3 (EBA 2007). The highway at this location is a three lane highway with 2010 AADT of 4250 (AT 2011). There is a passing lane on the southbound uphill lane from the base of East Peace Hill to the crest of the Heart River valley slope. From a traffic perspective, there are existing concerns and bottlenecks associated with the south interchange and the traffic capacity of the bridge across the Peace River. However, these areas are at the lower limits of the East Peace Hill area and landsliding concerns are relatively muted in this area compared to the rest of the slope.

The stability of the slope along the East Peace Hill appears to be influenced by the amount of rainfall that occurs over a one or two year period. There is a strong correlation of large landslides occurring after one or two year-long periods of higher than normal rainfall since construction. Based on this, the current configuration of the highway on East Peace Hill is viewed to be conditionally stable and quite sensitive to rainfall. However, in contrast to the relatively slow movements of the Little Smoky River site, the landslides at the East Peace Hill can be quite rapid, with the potential to cause loss of the highway in a short period of time. In 1984 a landslide occurred over a 200 m length of the highway that deflected the pavement surface several meters below design grade over a period of a few hours.

An important consideration is that the East Peace Hill route of Hwy 2:60 was constructed in the early 1960s to replace a former route (Pat's Creek) that was even more troublesome due to landsliding activity and geometric constraints imposed by the available topography. The only alternative route into Peace River from the south along Highway 744 (Judah Hill Road) is experiencing a greater level of landslide activity than the East Peace Hill route. As such, there is no practical alternative for re-alignment to improve the interaction between the highway and landslides.

3.3.2 *Findings of geotechnical assessment portion of FPS*

The geotechnical assessment conducted as part of the FPS questioned the need to upgrade the highway to a twinned freeway, considering that

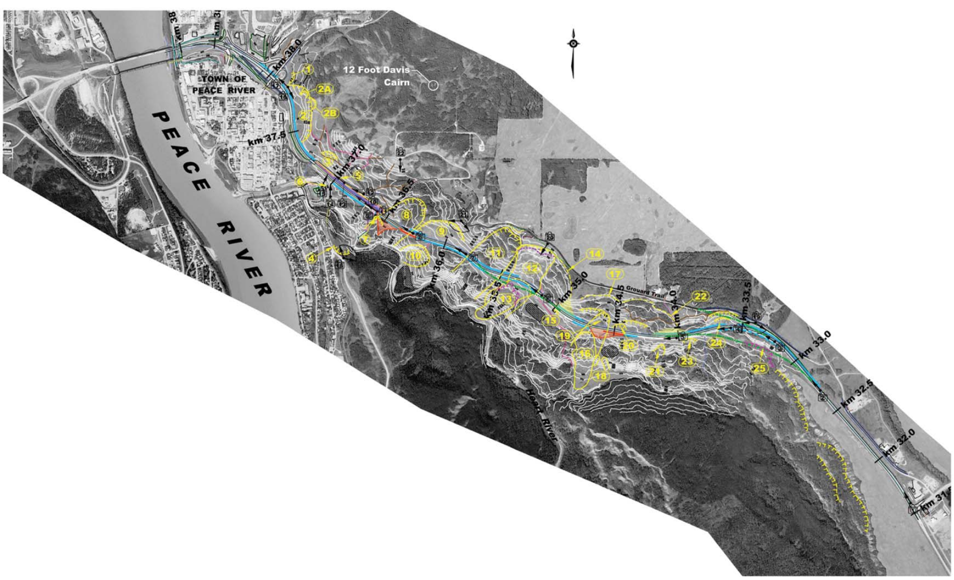

Figure 3. East Peace Hill.

there already was a passing lane in place on the southbound, uphill portion. This recommendation to reconsider the need for twinning was made recognizing that there is not another feasible alignment location should the twinning works exacerbate the existing concerns with landsliding affecting the highway.

4 DISCUSSION

The findings of an FPS are considered at both the departmental and governmental levels. The justifications for supporting various options or proposed projects vary from site to site and region to region and depend on many factors. From the perspective of the geotechnical engineering, it must be recognized that the recommendations made on the preferable route that has less risk associated with geohazards will be balanced out against long standing establish transportation corridors, trade routes, historical costs and investments, from both operational and societal perspectives.

It is AT's burden to weigh competing interests in assessing the best configuration or location for a highway improvement. A geotechnically sustainable solution, where relatively minimal maintenance associated with avoiding active landsliding zones or not proceeding with the proposed development may not be acceptable from other perspectives. As a responsible steward of public infrastructure, AT will not lightly abandon public assets which have been in service for over half a century, even those with considerable annual maintenance expense.

There is potential for a degree of inertia in engineering assessments to avoid the selection of alternate routes given AT's preference to maintain existing transportation corridors. Proposing an alternate location for a highway is cautiously approached FPS studies. Even when this inertia is overcome, geotechnical considerations on the "best" alignment to avoid geohazards may prove to be only a benchmark for comparative purposes for other less geotechnically desirable options where risk management/tolerance and significant annual budget for maintenance works is to be exercised. A proposed alignment that will have a high likelihood of long-term maintenance issues is unlikely to find support within AT. However, it is the purpose of a FPS assessment to vet all possible options to permit AT to make, as much as practically possible, an informed decision. In other cases, identifying the lack of practical alternatives and underlining the risks associated with the existing highway also allows AT to make an informed decision when assessing how a highway improvement should take place in landslide terrain.

In all cases, the geotechnical assessment re-emphasizes the need for monitoring and awareness of the risk of slope failure causing traffic flow disruption and permits this information to be communicated to both the highest levels of the department during the decision making process and also to the public during public consultation.

The rate of movement of a landslide is also a key consideration deciding if a highway improvement can be conducted on landslide terrain or if the route should be relocated. It is understand most of AT's GRMP sites have movement rates that are in the order of 10 mm/year or less which permits a more pragmatic, maintenance approach to be taken, especially when the movements can be accommodated through maintenance, design/construction or both. For cases with an elevated rate of movement, such as the Little Smoky River crossing, decisions on maintaining the existing corridor or adopting a new route are more difficult for AT to make.

The practical service life of a transportation corridor is generally quite long which means that the likelihood of the route being exposed to extreme events such as seismic events or rainfall events is elevated. However, experience has shown that the subject sites are sensitive to rainfall or run-off events that are relatively low period events when the service life of the highway corridor is considered. Overall, AT's operating practices do not include consideration of extreme events such as high return period rainfall/runoff or seismic events sized to be proportional to the likelihood of failure or consequences of failure in geohazard assessments. In the case of seismic loading, the general area of the subject sites has relatively low design ground motions for seismic events.

Additional considerations on the apparently long service life of a transportation corridor reveals some opportunities for AT to explore new perspectives on the planning of highway improvements in landslide terrain. Through these considerations and completion of FPS, AT will endeavour to select the most sustainable solution that considers not only the perspectives of geotechnical engineering and economics, but also the other important elements included in a FPS for planning highway improvements in landslide terrain.

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