UPDATE ON THE LITTLE SMOKY LANDSLIDE

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ABSTRACT
The Little Smoky River valley is cut into a preglacial channel infilled with very soft deposits. Valley slope instability is pervasive and very deeply seated. Highway 49 crosses the valley along an alignment that involves long sidehill traverses connected by a relatively low level bridge crossing. The south bridge abutment and land-based piers, and a significant portion of the southern valley slope exhibited movements shortly after construction in 1957. Stabilization efforts were undertaken at that time, as documented by Hayley and Thomson, 1975. Over the past 30 years more movements have occurred on both valley slopes. Numerous investigations and studies were undertaken on both valley slopes, and both slopes are being monitored at discrete instrumented locations. An InSAR study was completed to provide a widescale interpretation of the valley movements. This paper provides an overview of the salient issues and a discussion of short term and long-term mitigation options.

RÉSUMÉ
Le Little Smoky River Valley est coupé en canal preglacial infilled avec les dépôts très mous. L'instabilité de pente de vallée est dominante et très profondément assise. La Route 49 traverse la vallée le long d'un alignement qui implique de longues traversées reliées par un croisement de pont de niveau relativement bas. La butée du sud de pont et les piliers sur terre, et une partie significative de la pente méridionale de vallée ont montré des mouvements peu de temps après la construction en 1957. Des efforts de stabilisation ont été entrepris à ce moment-là, comme documenté par Hayley et Thomson, 1975. Au cours des 30 dernières années de plus mouvements se sont produits sur les deux pentes de vallée. Des investigations et les études nombreuses ont été entreprises sur les deux pentes de vallée, et les deux pentes sont surveillées aux endroits équipés discrets. Cet article fournit une vue d'ensemble des issues saillantes et une discussion d'options de réduction.

1. INTRODUCTION

Highway 49 is an important north-south transportation route in northern Alberta that completes a link between two major provincial highway trucking corridors, Highway 2 and 43. Highway 49 crosses the Little Smoky River about 48 km north of Valleyview as shown on Figure 1.

The road and bridge were completed by 1958. In response to soft soil conditions noted during construction, an additional abutment was constructed on the south bank and a short span was added. Shortly thereafter significant, widespread and deep seated movements were observed along the south valley slope, affecting the south side approach road and south abutment of the bridge structure. Additional large scale movements have also occurred along the north valley slopes, however the north abutment of the bridge appears to be unaffected by these movements. Movement rates in the order of 100 mm per year continue to the present.

The site has been extensively investigated and instrumented over the past 30 years. The depth of movement is about 40 m on the south slope and 60 m on the north slope. It was determined that gradual erosion of the toe of the valley slope by the Little Smoky River is a primary cause of the instability. Due to such issues as feasibility, practicality, cost, fisheries, navigable waters and environmental concerns an attempt to control the toe erosion and channel bed degradation has not been made.

Relatively modest improvements to the valley slope geometry and drainage measures were undertaken with limited success. Mitigation of the movements has been a prolonged and repetitive process involving structural alterations to the bridge substructure, annual patching of pavement cracks, and filling or milling of the highway at pavement settlement areas. More elaborate mitigation schemes are being considered, such as realignments that utilize the existing bridge structure, however the relatively slow rate of movement favours a maintenance strategy as determined by a cost-benefit analysis.

This paper presents a description of the site geology, a review of the site history, past site investigations and monitoring results. Recent studies, including an InSAR study are discussed in relation to current mitigation strategies and potential long-term mitigation strategies. Recommendations for future studies are also presented.

2. PHYSIOGRAPHIC/GEOLOGICALSETTING

2.1 Physiographic Setting

Thomson and Hayley, 1975 have described the general area as having gently rolling uplands with deeply entrenched river valleys. It is generally believed that rivers developed during the Tertiary period eroded very broad valleys into Tertiary

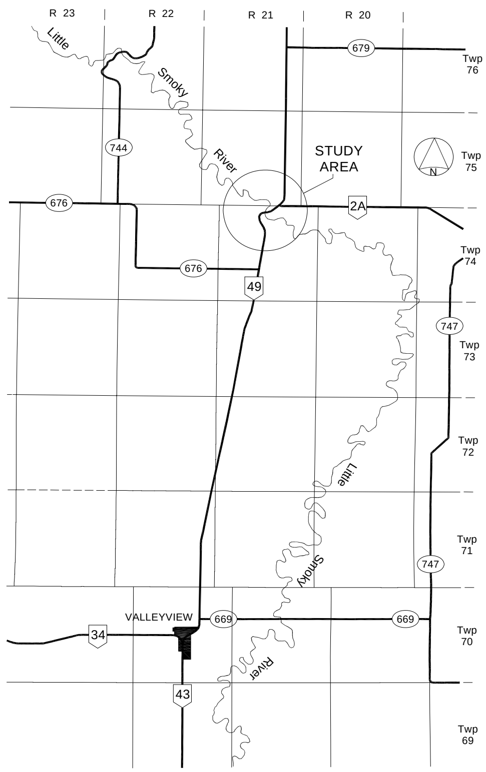

Fig. 1. Site Location Map

and Upper Cretaceous bedrock materials. Glacial advances from the northwest during the Pleistocene period deposited materials during advance and retreat sequences. Pre-existing river valleys were infilled with glacial sediments and were typically mantled with lacustrine and glacio-lacustrine deposits. The development of postglacial drainage patterns in the area has in many cases re-established past drainage patterns, and cut through the buried valley infill materials, establishing relatively steep sided valley slopes which are often slide prone.

The Little Smoky River is a tributary of the Peace River. Peace River tributary valleys are typically deeply incised, broad and V shaped, with minor to negligible terrace and floodplain development. Present day watercourses actively downcut, and to a degree sidecut, into the poorly consolidated buried valley deposits, exposing bedrock materials at river level (Lu et al, 1998). As river erosion occurs, valley slopes are undermined and prone to mass wasting. The Little Smoky River valley is typical of this process, and landslide activity is pervasive along both valley slopes. This activity can be classified as active, dormant or inactive, and is characterised by the presence of tilted benches, sag ponds, subdued and eroded crack patterns.

The overall relief in the upland or prairie region is characterised by flat to gently rolling cropland or grasslands, with the Little Smoky valley providing regional drainage.

2.2 Geology

The valley walls on either side of the river are gently sloping and undulating and have been formed by large, deep-seated, slowly moving landslides. Previous reports of the geology of the site indicate that in this area the Little Smoky River occupies a broad pre-glacial valley eroded into the bedrock. During glaciations the pre-glacial valley was infilled with till produced by up to three separate glacier advances, which are thicker than 50 m in some areas. Inter-till sand layers were deposited between the till units in some places.

The glacial deposits overlie Puskwaskau Formation grey marine shale and interbedded non-marine bentonitic shales and sandstones of the Upper Cretaceous Wapiti Formation. These bedrock strata are among the weakest and notoriously slide-prone in Western Canada (Hayley, 1968). Following deglaciation and continuing to present day, the glacial deposits that infilled the pre-glacial valleys continued to be downcut, undermined, and oversteepened. Very large scale landslide movements are deep seated, often sliding along the bedrock contact or on glacio-lacustrine deposits that occasionally overlie the bedrock. Glacio-lacustrine clay deposits, likely deposited in proglacial lakes between glacial advances, were encountered at several borehole locations along the south valley slope, however the strata was discontinuous. Upper level abandoned river terraces and cut-off meanders can be found in several areas where the valley slopes have not been affected by landsliding.

3.SITE DESCRIPTION

The study area encompasses the valley walls of the Little Smoky River adjacent to the Highway 49:10 crossing as shown on Figure 2.

3.1 Valley

The most obvious and pervasive feature of the Little Smoky River valley is the presence of large-scale landslide features that extend from the river level up to the prairie upland. These landslides are present along the outside bend of the river, which presents toe erosion as the main trigger to the slope movements. Signs of slope movement are obvious on both sides of the valley.

Large blocks movement is evident, with major blocks in the order of 50 m wide. Major scarps are several metres in height, and are generally overgrown eroded and diffuse, which is a reflection of the relatively slow rate of slope movement. Numerous minor scarps can be traced. Sag ponds are present, common and well established. Pistol butt trees, drunken forests, upturned and bent trees are common in localized areas, representative of minor slides that are relatively shallow and discrete. At the subject site the average valley slope angle is about 7 degrees on the north side and about 9 degrees on the south side.

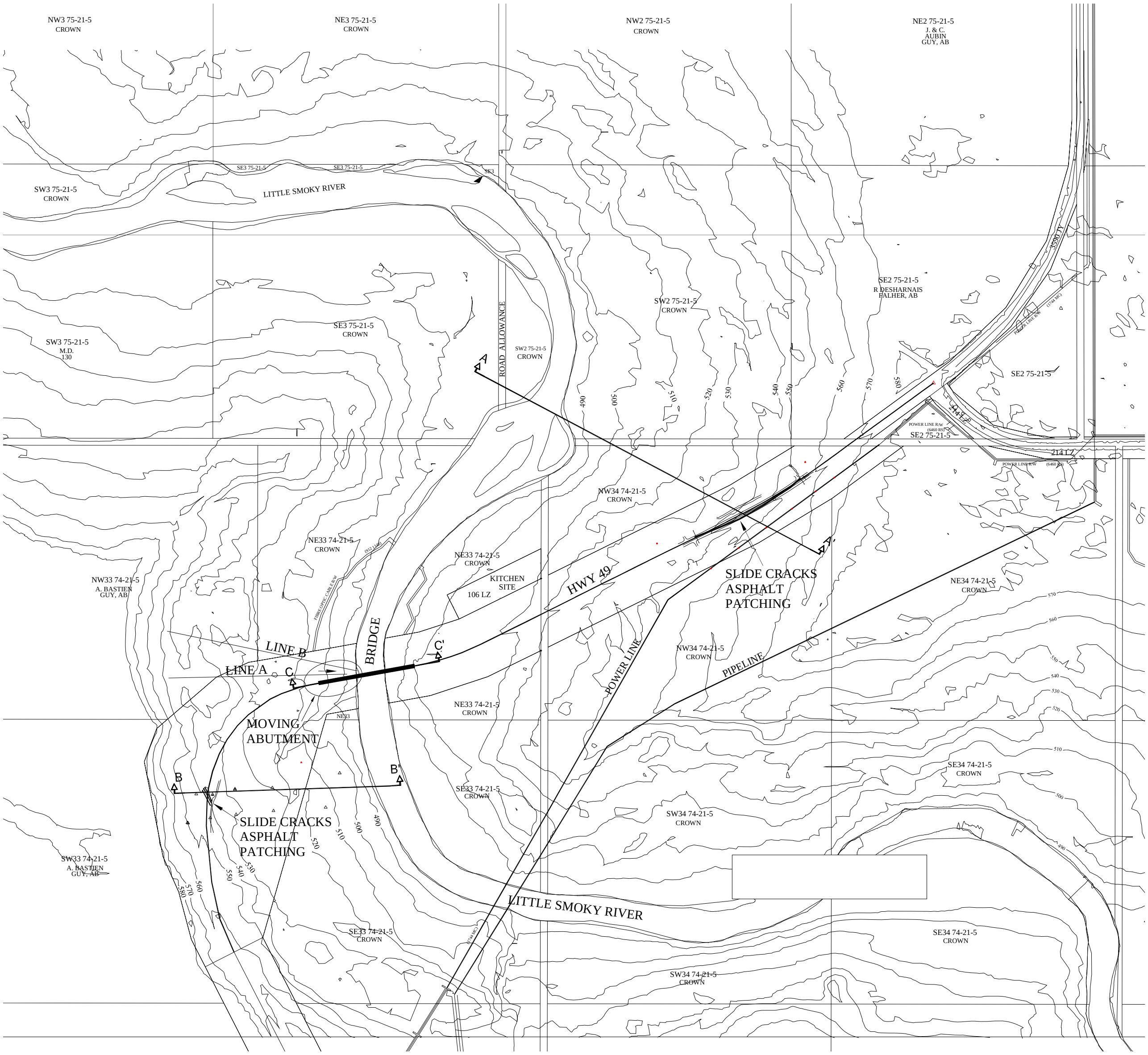

Fig. 2. Site Contour Plan

3.2 Little Smoky River

The Little Smoky River valley is about 120 m deep and has a top of valley width of 2400 m. The river is about 70 m wide at the bridge locations. The flow rate typically peaks in May and June. The maximum daily discharge varied from 200 to 1800 cu.m/s between 1970 and 1996, with the peak of 1800 cu.m/s occurring in June, 1996. This discharge exceeded the 1:100 year design flood event of 1710 cu.m/s. A scour profile taken shortly after the flood showed channel bed degradation of 0.7 to 1.2 m across the entire river channel; lateral bed migration was not recorded (Hydroconsult EN3 Services, 1997)

3.3 Bridge and Highway

Highway 49 crosses the Little Smoky River in NE Sec 33 Twp 74 Rge 21 W5M, about 48 km north of Valleyview, Alberta (Figure 1). The bridge and approach roads were built during the period of 1956 to 1958.

The bridge is 271 m long and consists of a 6 span structure with the longest span being 62 m. The three bridge abutments are founded on driven steel H-piles with average pile depths of 13 m. The four pier foundations are supported on driven timber piles with average pile depths of 2.4 m for the river based piers and 6.4 m for the land based piers. The piles terminate in stiff clay or clay shale bedrock. Bridge maintenance and rehabilitation records indicate extensive problems related to squeezing of expansion joints and extensions to abutments.

Bridge deck expansion joints were reconstructed in 1964, 1977, 1982, 1992 and 1998. Repairs or extensions to the south side abutments were completed in 1965, 1971, 1980, 1982, and 1998. Extensions to the south side pier were done in 1966, 1968, 1983, and 1998.

Road use data from 2003 shows an Average Annual Daily Traffic (AADT) count of 1450 and total Equivalent Single Axle Loads (ESAL's) of 224. The access down the valley slope to the bridge is a standard 12.5 m two lane paved highway with climbing lanes on both sides of the valley where the grade is steepest. The maximum highway grade is 7%, while the average grade is about 5%. The north and south highway approaches traverse across rather than down the valley slopes, which helped to reduce initial construction costs and kept the grades to reasonable limits. This design is typical of most valley crossings in the Peace River area of Alberta however it also serves to expose long stretches of the highway to valley slope movements.

Significant surficial drainage improvements were undertaken on the south valley slope in the 1960's, with the intent of draining sag ponds and controlling the flow of surface waters. Minor drainage work and road realignments were completed on both slopes in 1972 during grade widening to accommodate the passing lanes.

The large-scale valley slope movements intersect the highway at numerous locations, resulting in well defined, slowly opening cracks. These cracks are typically patched once (south side) or twice (north side) yearly. Several metres of asphalt patching have been placed over the past 47 years. Approximately 200 tonnes of asphalt patch is placed annually. Annual maintenance costs for the roadway are about $50,000 to $100,000.

4. INVESTIGATIONS AND STUDIES

4.1 Information Review

This portion of Highway 49 was at one time Highway 43, and prior to that it was Highway 34. These designation changes, and institutional changes in record keeping, have made it difficult to find and retrieve archived data and maintenance information. Fortunately much of the older data was captured and summarized in previous studies.

The Little Smoky River valley crossing on Highway 49 is referenced in no less than 4 technical journals and academic publications, and is the subject of a dozen engineering reports and a functional planning study. The main referenced papers, reports and files are listed in Section 9.

Hardy et al, 1962, presented the first published reference to the Little Smoky landslide. The site was the subject of two academic studies (Rennie, 1966 and Hayley, 1968). Thomson and Hayley, 1975, presented a comprehensive review of the site conditions in their paper. Serious maintenance and safety concerns prompted the 1998 Functional Planning Study (UMA, 1998) in which several potential realignment options were reviewed and a geotechnical assessment and detailed aerial photograph interpretation (Mollard, 1997) were completed. The study described areas of high, moderate and low risk of landslide activity, and essentially concluded that within a 10 km reach upstream and downstream of the existing crossing it would be unlikely to find stable ground.

Alberta Infrastructure and Transportation employs a geotechnical risk management program that categorizes landslide and other geohazard sites, for which annual engineering assessments and an instrumentation monitoring program is undertaken (Thurber Engineering, 2000). The annual assessment reports are presented on the department's website:

http://www.trans.gov.ab.ca/Content/doctype372/production/SH03.htm

Most recently an engineering assessment (Thurber Engineering, 2002) on the north valley slope and an InSAR study (AMEC Earth & Environmental, 2004) were completed. The former study provided encouraging realignment options that utilized a stable ridge between zones of slope movement. The latter study was partially successful in defining zones of movement and is described in greater detail later in this paper.

The exact number of exploratory boreholes, slope indicators, standpipe and pneumatic piezometers installed at the site over the past several decades is not known. Slope indicator numbering stopped at 35, after which perhaps twenty or more slope indicators were installed, most recently in 2001. The 'life span' of the slope indicators was typically 3 years or less. Due to the escalating costs of replacing slope indicators, in relation to the value of the information gained from the instruments, alternative means of gathering slope movement information are being explored.

4.2 Sliding Mechanism

Both valley slopes are examples of large scale, deep-seated retrogressive translational landslides. The north valley slope has a somewhat more rugged and disjointed appearance then the south side, which may be partially due to the surface grading and drainage improvements undertaken on the south valley slope, which might mask irregularities.

There are two adjoining slide zones on the south side of the river, one on either side of the bridge. Borehole logs along a profile through the east slide zone indicate a till covered shale surface with discontinuous clay strata interbedded between the till and shale (refer to Figure 4). The shale surface is approximately concave, dipping from a high point at about elevation 525 m and bottoming out at about elevation 485 m at about river level. The upper part of the valley is relatively steep, indicative of the thick upland till strata that is outside of the influence of the bedrock slide plane.

The slide plane appears to conform to the concave shale surface. It is not known if the slide daylights at river level, or continues below river bed level to daylight in a scoured bedrock surface, or the river thalweg proper. The length, width and depth of the slide are about 500 m, 1600 m, and 20 m respectively, producing a Lr/Dr of about 25. The maximum depth of sliding is about 34 m however deeper movements may be present nearer to the centreline of the slide mass. Back analysis of the west slide zone by Hayley, 1968, using a block dislocation model, predicts a residual friction angle of 11 degrees for the shale, which is consistent with local experience. A more current stability analysis is being contemplated, to account for new borehole information and analytical techniques.

At Cross-section B-B', the south valley slope creeps at a rate of about 10 to 30 mm per year while west of the bridge the creep rate is about 50 to 100 mm per year. Intuitively a correlation between slope movement and river erosion or prolonged rainfall should exist, however the Functional Planning Study could not find such a correlation, albeit only a limited data set was available. The south slope is considered meta-stable, with a FOS just above unity. Rapid movement of the slope is unlikely due to the massive size of the slide and stress release provided by the ongoing creep movement

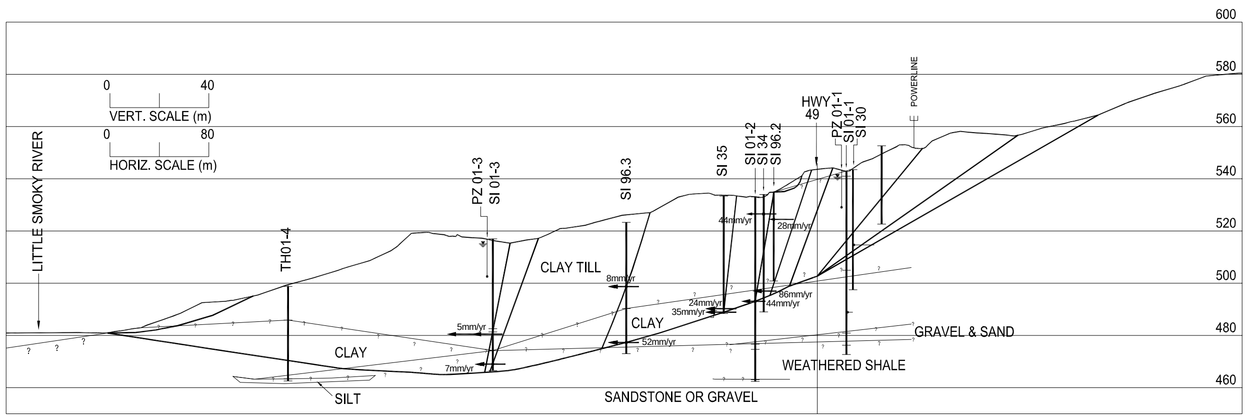

Fig. 3. Stratigraphic Cross-section A-A' through north slide

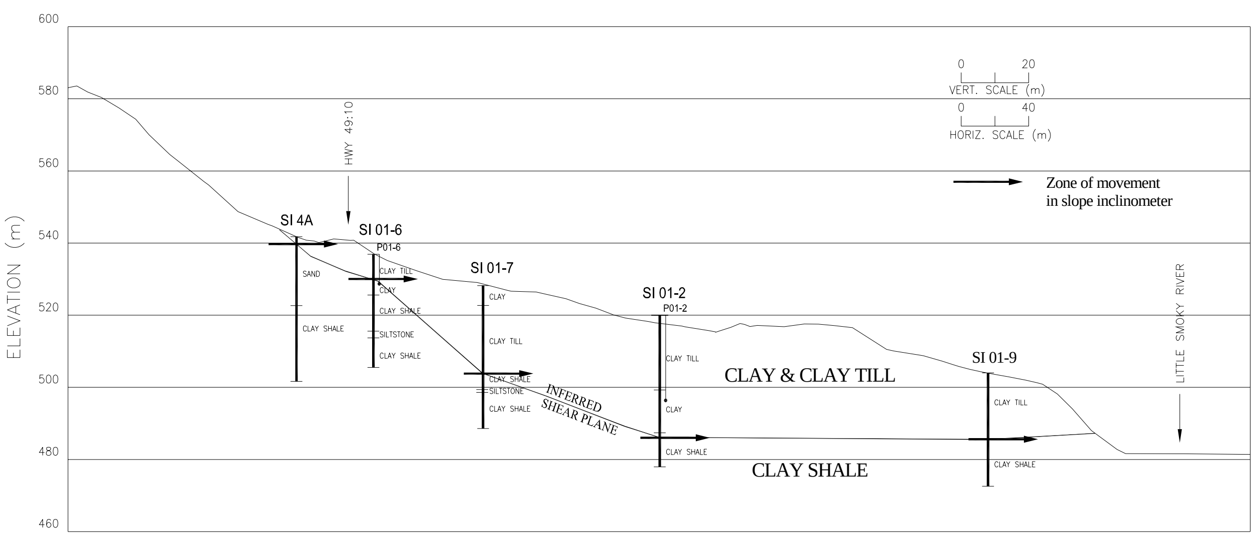

Fig.4. Stratigraphic Cross-section B-B' through south slide

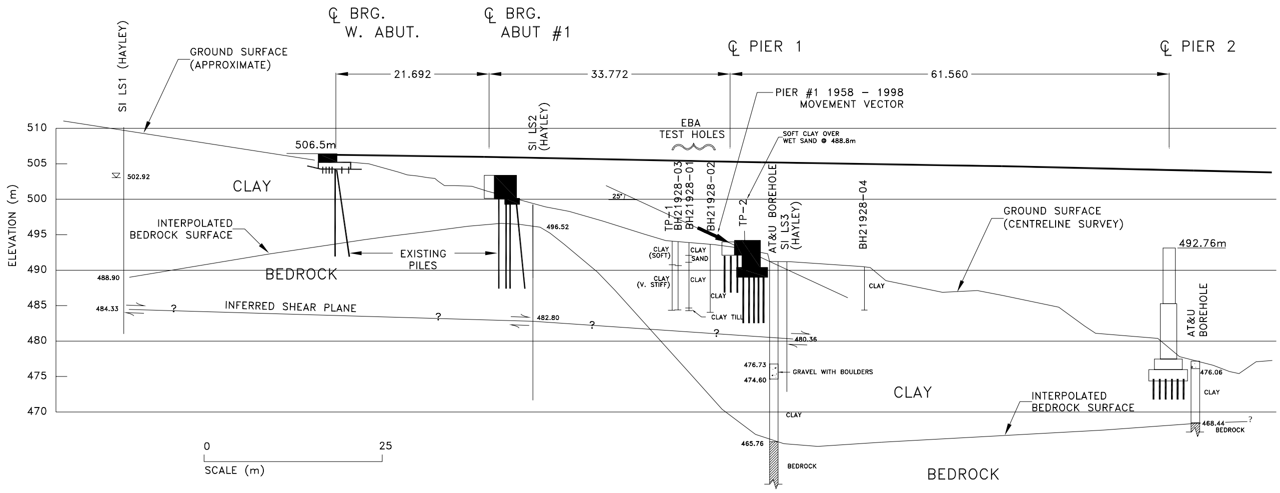

Fig.5. Stratigraphic Cross-section C-C' through south bridge abutment

The south abutment of the bridge appears to be located along the flanks of the two adjoining slide zones. At this location the subsurface soil conditions consist of clay overlying clay shale bedrock. A deeper, narrow infilled channel appears to be present along the river channel, where bedrock is encountered at about 470 m in the south half of the channel and at about 460 m in the north half. The inferred slip surface of the slide is partially located in the top of the shale and the overlying clay as shown in Figure 5. Slide movements are in a direction that is slightly skewed in an upstream direction to the centreline of the bridge with an average rate of about 125 mm/yr.

The true basal slide plane below the north valley slope remained elusive until a series of very deep slope indicators were installed in 2001 (refer to Figure 3). The boreholes, installed to 65 m depth, found the basal sliding plane mainly between elevation 465 to 485 m, approximately coincidental with that found on the south valley slope. Prior slope indicators, installed to shallower depths, intercepted intermediate back scarps of the translational block movement, giving a perception of a shallower based valley slope movement. The north valley slope movement is significantly larger in size than the south side. A broad arcuate failure mass, about 2200 m wide, 900 m long and 55 m deep exists. The highway traverses along the left flank of this very large movement. At the toe of the slide a small island exists within the Little Smoky River. The island may be a slide feature, or at the least presents an anomaly as a depositional river feature along the outside bend of the river.

The north valley slide continues to creep at a rate of 50 to 100 mm per year. A detailed back analysis of the north valley slope has also not been undertaken, although the slope is also considered to be meta-stable.

The trigger mechanisms for the slope movements is still considered to be erosion of the toe of the slope, in combination with rainfall infiltration and a sliding plane at residual.

4.3 InSAR

In late 2003 a study was undertaken to map the deformations on the north and south valley slopes utilizing spaceborne satellite data (AMEC Earth & Environmental, 2004 and Vexcel Canada, 2004). Synthetic aperture radar interferometry (InSAR) is a technique that utilizes repeat-pass radar satellite data that collects imagery of the same location on the earth at different time intervals and measures phase shift in the imagery in order to assess changes in ground height. In order to have the optimal chance to collect movement data, movement must be roughly parallel or oblique to the line of site of the satellite look angle.

The aim of the study was to review available radar satellite data that covered the site since 1993 and to assess the relative mobility of the valley slope within the study area. Available data sources reviewed included the following:

- ERS-1: 1993 – 2000, 20 meter pixel horizontal resolution, 2 cm wavelength
- JERS: 1995 – 1997, 20 metre pixel horizontal resolution, 25 cm wavelength
- Radarsat-1: 2000 – present, 8 metre pixel horizontal resolution, 2 cm wavelength

For all three data sources, a list of both ascending and descending track data covering the site in the early spring or late fall was compiled. Based on further filtering of the data, completed by Vexcel Canada, the removal of topographic data, georeferencing and overlay on the available air photo base, the zones and rates of movement shown on Figure 6 are provided.

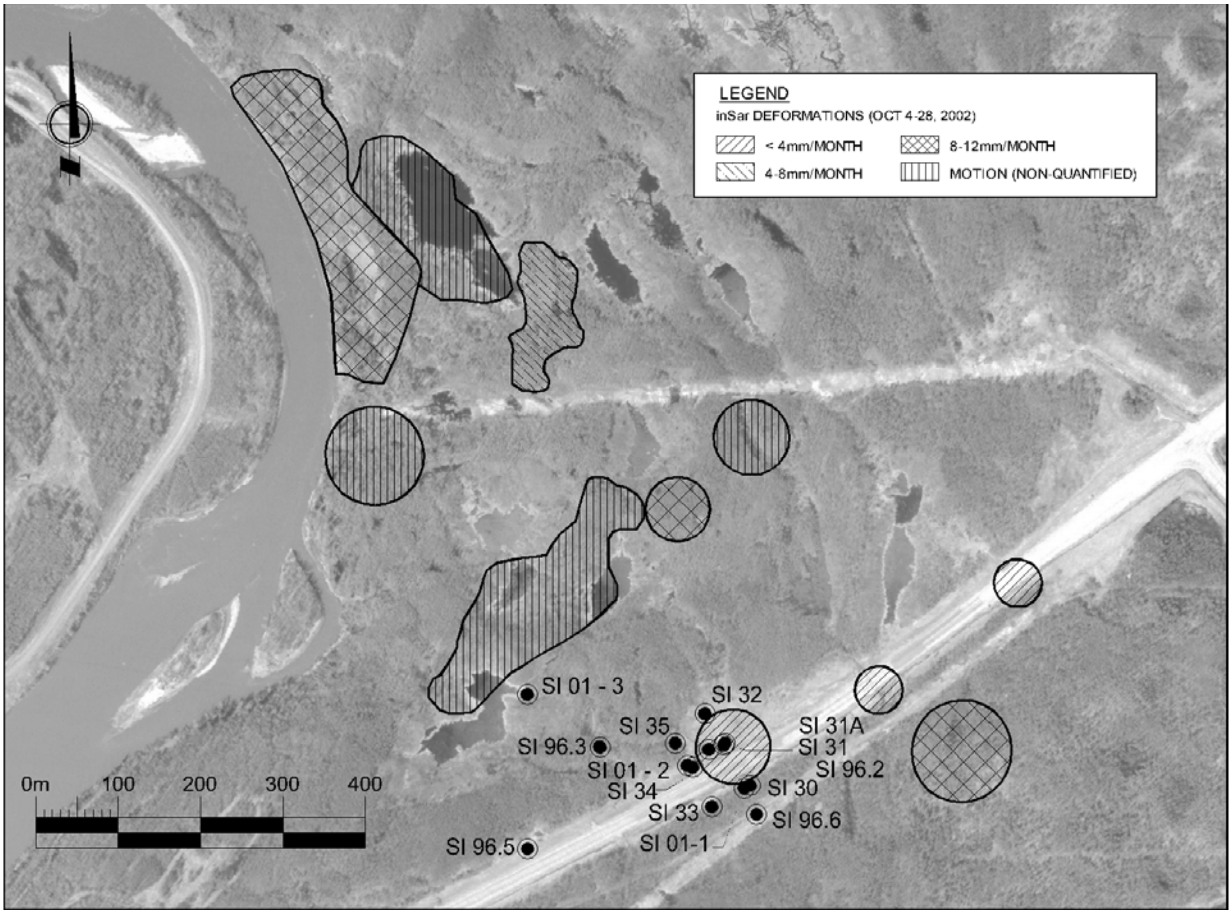

Fig. 6. Zones and rates of movement from InSAR

A zone of movement detected by the InSAR assessment was found to be centered over the embankment where the majority of the SI's are located. The range of motion detected by the InSAR was between 3.2 to 4.4 mm/month. This is comparable to average rates of movement (up to October 2001) in the SI's in this area of between 2.3 and 5.2 mm/month. The movement rates on the slope inclinometers are reasonably close to those observed in the InSAR analysis, providing further indication that the movements mapped by InSAR are realistic.

Although we were able to detect the ground movement over the 24 day time period, it is not considered that the use of spatial InSAR is likely the most effective method for monitoring of slopes at the Little Smoky Crossing because the vegetation cover on site leads to decorrelation between SAR images. Froese et al, 2001 provide a more detailed discussion of the InSAR technique for detection of slope movement along with specific discussion of the Little Smoky site.

5. MITIGATION STRATEGIES

The massive extent and great depth of the slope movements and the nature of the primary trigger for slope movements combine to limit mitigation options for the site. The existing slope movements are relatively slow moving, at least in relation to the height of the valley, and are to a degree predictable and established within the past 50 years. At present the only practical and feasible mitigation options appears to be to continue to deal with the movements as a maintenance item, and to budget accordingly.

Asphalt patches and milling are typically carried out twice a year at the north slide and once a year at the south slide to maintain the highway surface in a sufficiently smooth condition. The concrete cap of the south abutments and pier of the bridge were widened in 1998, aligned in the direction of the slide movement and provided with adjustable bearing seats and pins to allow the slope to move under the bridge without causing distress to the bridge. Mitigation options such as armouring of the river bank, dewatering the slope, pile walls, and even a tunnelling option have been discussed. The only alternative mitigation option that is economically feasible is to realign the highway to take a more direct approach in and out of the valley. This would reduce the length of highway exposed to movements, and could be designed to shift onto areas of lower risk. The cost for this option, on the north side alone, is estimated at $1 to 2 million for a minor shift to the east into an intermediate risk zone and $10 to $15 million (depending on design grade) for a more significant shift with deep cuts to a low risk area along the hogs back ridge further to the east. These high costs, which do not guarantee that future problems would be eliminated, are difficult to justify on a life-cycle cost-benefit basis.

6. FUTURE STUDIES

Although mitigation options are limited, there is sufficient interest and merit in continuing to advance our understanding of the site issues. However the costs of installing very deep boreholes are prohibitive, especially with little chance of new knowledge to be gained in this direction and little chance of realignment at this time.

6.1 InSAR with Targets

A potential option under consideration for monitoring surface movements is the installation and monitoring of radar targets on the slope. This technique has been previously utilized in northwestern Alberta by TransCanada Pipelines (Froese et al, 2004) and involve the installation of phase stable targets that will return a highly coherent reflection back to the satellite allowing for monitoring of movement at these point source targets as little as 2 mm over long periods of time in heavily vegetated terrain. Conceptually this would consist of an array of surface targets installed at strategic locations on the slope where a better understanding of the overall movements is required but it is logistically and or financially prohibitive to install other means of monitoring.

6.2 Additional Drilling Investigations

The installation of slope indicators may be done, in the off chance that site conditions and the socio-political climate demand that the road be ‘fixed’. In this case a series of boreholes would be advanced along the proposed realignment routes, and additional slope indicators or other appropriate slope monitoring devices installed at offset locations. Some focused drilling and instrumentation may be installed to collect and correlate river flow rates, rainfall data and slope movement. Undisturbed sampling of the slide plane material may be done, but this is not a priority.

7. CONCLUSION

The Little Smoky River crossing on Highway 49 has presented challenges to Alberta Infrastructure and Transportation since 1957. Deep seated, pervasive and massive valley slope instabilities affect both valley walls. Accumulated movements of more than 3 metres have been mitigated through innovative bridge substructure designs, subtle realignment of the highway and periodic, often annual maintenance related activities. Stabilization of the north and south valley slope is not considered feasible, and partial avoidance of the higher zones of movement via a complete realignment of the approaches into the bridge site may be the only practical option. Costs for such realignments are prohibitive in relation to current maintenance related mitigation options.

A recent study using InSAR technology indicates that a possible realignment corridor is present that avoids the broad scale areas of movement

8. ACKNOWLEDGEMENTS

The authors wish to acknowledge and applaud the Alberta Infrastructure and Transportation staff who have diligently maintained the site despite significant and persistent ground movements, and who have supported ongoing investigations and the InSAR study.

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