Slope stabilization efforts along Highway 744:04, Judah Hill Road, Peace River, Alberta

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ABSTRACT
Highway 744:04, known locally as Judah Hill Road, is a 2.5 km section of highway that ascends 220 m in elevation from the town of Peace River, Alberta to the valley uplands. The road traverses along the southwest facing side-hill of a ridge separating the Heart River and Peace River valleys. The general stratigraphy encountered is comprised of a complex layering of glaciolacustrine silts and clays, glacial clay till, outwash sands and gravels, pre-glacial gravels, and clay shale bedrock. Alberta Transportation has identified, instrumented, monitored, and remediated 14 slides grouped into seven areas along this stretch of highway since the road was paved in 1984. Due to the complex geological conditions, challenging failure conditions, and roadway constraints repair designs have varied widely. These efforts have included the use of realignments, timber pile retaining walls, anchored cast-in-place concrete retaining walls, mixed lime and gravel columns, geotextiles, surface drainage diversions, horizontal and pumping drains, earthworks, and the use of lightweight fill (tire chips and sawdust). Temporary measures have included the use of Bailey type bridges to span failed areas. These efforts are discussed herein with discussions regarding the varying results of each method. Special emphasis is placed on recent slide activity.

RÉSUMÉ
Le 744:04 de route, connu localement en tant que Judah Hill Road, est une section de 2.5 kilomètres de la route qui monte 220 m dans l'altitude de la ville du Peace River, Alberta jusqu'au dessus de vallée. La route traverse le long du colline latérale de revêtement de sud-ouest d'une arête séparant les vallées de Peace River et de Heart River. La stratigraphie générale produite est composée d'une mise en couches complexe des vases et les argiles glacio-lacustres, l'argile glaciaire jusqu'à, les graviers d'outwash des sables et, les graviers préglaciaires, et la roche en place de schiste d'argile. Le transport d'Alberta a identifié, équipé, surveillé, et fixe 14 glissières groupées dans sept secteurs le long de ce bout droit de route depuis que la route a été pavée en 1984. En raison des conditions géologiques complexes, des états provocants d'échec, et des contraintes de chaussée, conceptions de réparation ont varié considérablement. Ces efforts ont inclus l'utilisation des réalignements, murs de soutènement de pile de bois de construction, ont ancré les murs en béton moulés sur place de soutènement, les colonnes mélangées de chaux et de gravier, les géotextiles, les déviations extérieures de drainage, les drains horizontaux et de la pompe, les terrassements, et l'utilisation de la suffisance légère (les morceaux et la sciure de pneu). Les mesures provisoires ont inclus l'utilisation du type ponts de Bailey d'enjamber des secteurs échoués. Ces efforts sont discutés ci-dessus avec des discussions concernant les résultats variables de chaque méthode. La considération particulière est placée sur l'activité récente de glissière.

1 INTRODUCTION

The town of Peace River is located in northwest Alberta (Figure 1), approximately 400 km northwest of Edmonton, AB. The town is connected to its outlier communities and farms by two primary and three secondary highways, including Highway 744. The highway provides an access route to Peace River from the south, and links farmers and communities located west of Heart River and east of Peace River to each other and to the town. Overall, the roadway has a traffic count of approximately 360 to 440 vehicles per day.

Since being paved in 1984, geotechnical issues have persisted along on the northern portion of this roadway, at control section 744:04. Along this stretch of highway, landslides and geotechnical issues are prevalent and invariably involve loss of one and occasionally both traffic lanes. In addition to the loss of infrastructure the consequences of these geohazards result in detours of up to 50 km.

To date, over 14 slides (grouped into 7 geographical sections) have been identified and remediated along this stretch of roadway extending along the side-hill. Due to the varying topographical and failure conditions at each site, various remedial measures have been attempted by Alberta Transportation along this 2.5 km stretch of road. These efforts are discussed herein.

2 GEOLOGICAL SETTING

The Peace River area has a complex geological setting as a result of processes associated with the last glacial event (late Wisconsin) and Holocene erosion. The following is a brief summary of these processes as presented in 1:100,000 scale maps of Paulen et al. (2004a, b) and discussed by Davies et al. (2005) and Morgan et al. (2008).

Figure 1. Map of Alberta showing the location of Peace River.

Investigations by Paulen et al. (2004a, b) indicate that during the advance of the Laurentide Ice Sheet, ice dams resulted in the formation of proglacial lakes that deposited glaciolacustrine sediments coarsening upward into sands and gravels as the ice margin advanced. As deglaciation began at approximately 11,000 years BP, localized ice surges occurred, and ice damming resulted in the formation of Glacial Lake Peace which lasted long enough to deposit over 20 m of silt and clay. As Glacial Lake Peace drained, the Peace River immediately began down-cutting through the Quaternary sediments. Today, at the project location, the Peace River has incised through approximately 180 m of Quaternary sediments and 30 m into underlying bedrock.

Throughout the Peace River area, the low strength deposits of Glacial Lake Peace silt, clay and sand of varying thicknesses have experienced extensive landsliding during river down-cutting that has continued on until present. This landsliding has resulted in thick accumulations of colluvium along the valley walls. In addition to slope stability issues occurring in the Quaternary deposits, failures within the underlying shale bedrock has also contributed to the area morphology.

The Alberta Geological Survey (AGS) conducted a drilling program within the town of Peace River in December 2008 as part of a municipal landslide hazard study (Morgan et al., 2009). The program included a drill site at the top of Judah Hill near the Lookout Slides location (Figure 2). Two boreholes were advanced at the drill site using sonic and mud rotary techniques. The sonic drilling was used to obtain continuous core samples within the Quaternary sediments overlying the bedrock while the mud rotary hole was advanced through the sediments and into the Cretaceous bedrock below to facilitate the collection of down-hole geophysical logs.

The drilling indicated a sediment depth of approximately 165 m overlying the Shaftesbury Formation Cretaceous marine shale. Generally speaking, the sediment consists of approximately 20 m of rhythmically bedded silts, clays and sands making up the Glacial Lake Peace deposits overlying a diamicton (silt tills and debris flow sequences) approximately 60 m thick. This diamicton is underlain by 75 m of rhythmically bedded silts, clays and sands which contain a package of sands 25 m thick. The mud rotary drilling indicated a 10 m sequence of sand, silt and gravel overlying the shale at 165 m below ground surface.

Detailed examination of the sonic core samples revealed horizontal to low angle slickensides within the rhythmically bedded silts and clays both above and below the diamicton. These weak shear zones within the interbedded silts and clays, particularly the units below the diamicton, are suspect for a number of slides within the Peace River area. In addition, a few high angle slickensides were noted in the diamicton near the contact with the overlying clays and sands.

3 SLIDE LOCATIONS

Figure 2 shows LiDAR imaging of Highway 744:04 with the 7 slide group locations superimposed over top, and Figure 3 shows an oblique photograph of the road. The LiDAR image clearly indicates that the topography along the east valley wall of the Peace River valley is a remnant of landslide activity, as are all Heart River valley slopes. Judah Hill Road can be seen to intersect many old slide features along its descent into the town of Peace River. Table 1 outlines the geotechnical history of each slide area over the life of the roadway.

4 REMEDIAL MEASURES

Alberta Transportation's geotechnical engineers use an observational approach framework within their risk management of landslide hazards affecting roadways. Within this approach, they identify, assess and monitor problem areas, and prioritize which hazards will be fixed as available budget and level of risk dictate. Each of the seven distinct areas along Judah Hill Road has been scrutinized using this method, complete with yearly field observations and instrumentation monitoring (slope inclinometers and piezometers). Where a remedial measure has been required along the road, the following options have been pursued.

4.1 Surface Water Management and Subsurface Drainage

Attention to detail and respect of the surface and groundwater conditions continues to play a vital role in stabilization activities along Judah Hill Road. In almost all

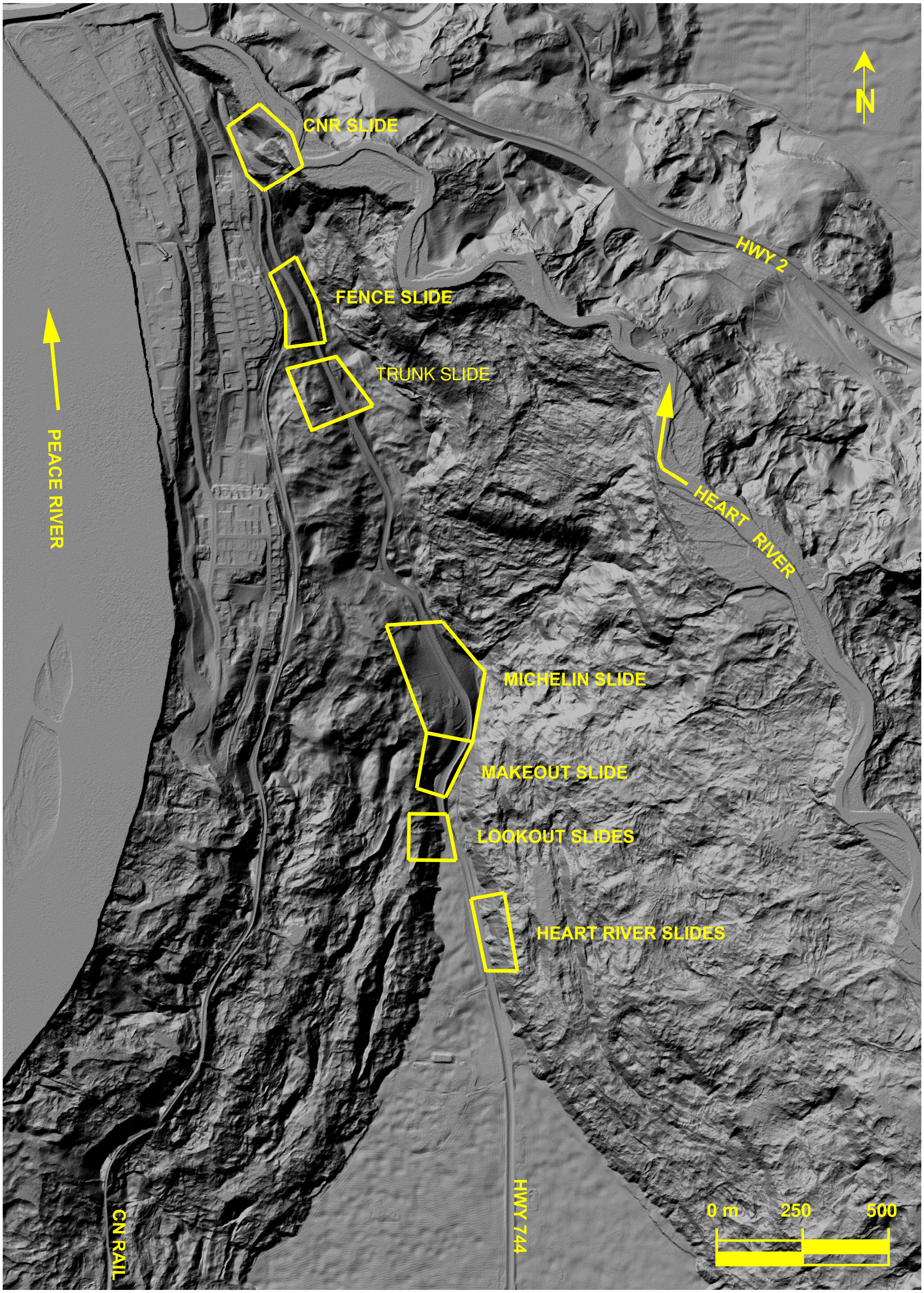

Figure 2. LiDAR image of Hwy 744:04 showing locations of slide areas (courtesy of the Alberta Geological Survey).

Table 1. Timeline of remedial measures at slide sites along Judah Hill Road (Hwy 744:04).

Location	Year	Remedial Measure
CNR Slide	1984	Identification of slide issues
	1984	Timber piles installed and road realigned
	1986	Toe berm constructed
	1987	Horizontal drains installed
	1988	Concrete pile wall installed, concrete ditch liner above wall placed
	1989	Pumps installed into belled pile holes backfilled with clean gravel, tiebacks for piles installed, area around belled piles and at front of wall backfilled with lightweight fill (sawdust)
	2006	River scour removes lower third of toe berm
Fence Slide	1988	Identification of slide issues
	1988	Gravel and lime "stone" columns installed, asphalt curb placed on downhill side of road, drains established in uphill side of road, approximately 70 m long fence installed on uphill side of road
	1992	Granular fill used to rebuild subsidence around columns
	1998	Seepage interceptor ditch and french drains installed on uphill side
	2004	Stone columns protruding through road (up to 25 mm) as a result of ongoing subsidence of roadway
	2005	Slope failure encompassing downslope lane of road
	2005	Slide mass around columns excavated and replaced with geogrid reinforced fill
Trunk Slide	1999	Big 'O' interceptor drain installed in uphill ditch
	2004	Sand and gravel ditch armour placed to reduce retrogression of erosion scar near road
	2005	Drain pulling apart at joints
	2009	Ongoing monitoring
Makeout Slide	2001	Identification of slide issues
	2001	Construction of berm to divert water from slide, corrugated steel pipe installed to move water from upstream ditch to downstream
	2005	Major slide encompassing road, temporary Bailey bridge resting on driven piles used to maintain traffic, road and utility pipeline realigned into backslope, slope above road flattened, toe berm with geogrid reinforcement constructed
	2008	Ongoing skin failures / settlement features of regraded slope
Michelin Slide (north)	1997	Road realigned and anchored pile retaining wall installed
	1999	Ongoing movement below wall
Michelin Slide (south)	1986	Identification of slide issues
	1988	Gravel and lime "stone" columns installed
	1996	Uphill ditch cleaned out and re-established
	1997	Road realigned (see north Michelin Slide)
	1998	Failures repaired with berm and shear key along with shredded tires as lightweight fill
	2009	Ongoing shallow failures, not affecting roadway
Lookout Slides	1997	Identification of slide issues
	2009	Ongoing monitoring
Heart River Slides	1997	Identification of several slide issues
	1998	Slide closest to the road excavated and rebuilt with granular fill, drains installed
	2009	Ongoing monitoring

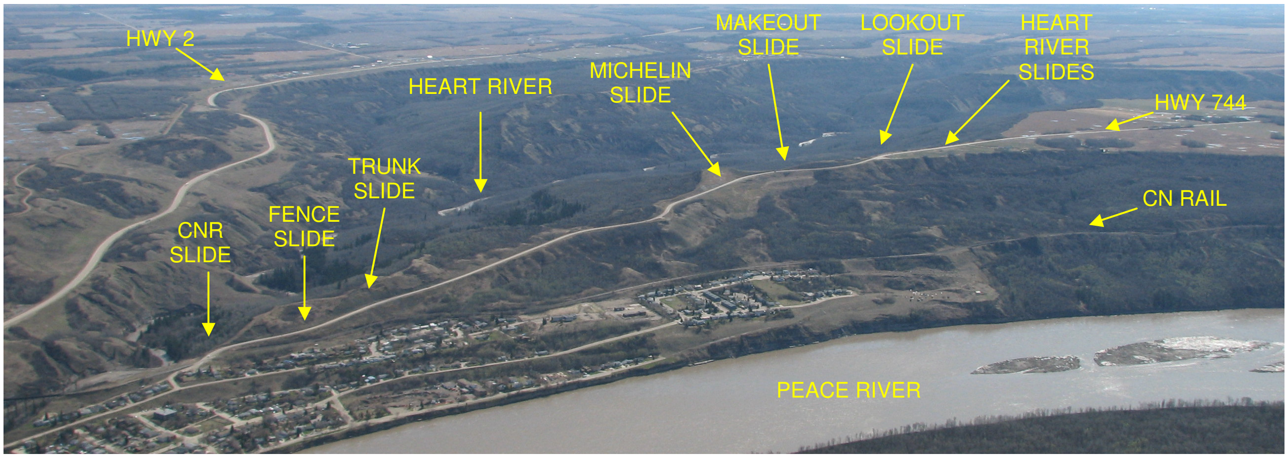

Figure 3. Photo of Judah Hill Road (Hwy 744:04) looking Southeast (courtesy of the Alberta Geological Survey).

slide scenarios, groundwater has been identified as a contributing factor as an instigator or aggravator of slides. As such, any work completed on site is evaluated from a surface water runoff management perspective. In addition, surface or groundwater management is generally employed as an initial fix along with the observation approach for lower risk / priority slides, and drainage measures are routinely applied as a first line of defence, or as part of an integral slope stability control measure during the application of other slide stabilization means.

Some examples of issues associated with surface and groundwater at Judah Hill Road, starting from the valley uplands, include the instabilities at the Heart River Slides and Lookout Slide locations. These zones consist of four instabilities each that exist within or at the edge of old slide scars. Both sites are continually aggravated by surface water diverted from the highway right-of-way. Most of the slides are currently only being monitored, as their behaviour is either not currently affecting the road or are of low priority for remediation. One of the Heart River Slides, however, did threaten the highway, and as a result, it was graded with significant drainage control measures implemented.

Along the side slope of the Peace River Valley, however, groundwater and surface water have taken a more dramatic role. Drainage measures have played a part in all of the major slide fixes that have included a more robust stabilizing method. At the Michelin Slide, Makeout Slide, and Fence Slide zones, drainage measures were implemented prior to and during the various road realignments, retaining wall installations, and shear key constructions (discussed in more detail below). These have primarily involved transferring water from the uphill ditch to the downslope side of the road without discharging the water into an unstable zone.

Where drainage conditions were identified as a cause of major erosion and potential sliding issues corrugated plastic pipes have been used to transfer water to a safer location. At the Judah Hill Trunk (Trunk Slide location) for example, a 450 mm pipe was installed to transport water from the uphill side of the road and through a gully below the road that was an active area of erosion. Although the inlet to the pipe is protected with erosion control matting and a ditch block, erosion issues still occur at the inlet locations and require minor repairs periodically. A similar trunk exists near the CNR Slide as an outlet for all of the dewatering wells at the site. Originally, horizontal drains into the slope and a concrete drainage apron at surface were employed to dewater the head-slope. When movements persisted, belled piles (filled with gravel) were drilled such that the bells interconnected with each other to provide a drainage wall. The water was pumped from the gravel filled piles and removed from the slide discharges into the nearby trunk and into the Heart River, rather than into the adjacent slopes. In both of these locations, the controlled removal of water from the site has likely reduced movement, however ongoing movements have persisted due to a variety of factors.

Control of ground and surface water has contributed to the stability in some locations. Challenges have been encountered when a change to the hydraulic regime has been employed. The best example of this is the seven instabilities that occurred after the road was realigned near Michelin Slide. On a smaller scale, numerous slides have been instigated and have propagated at drainage discharge locations, most of which have required either separate additional remedial measures or a change to the discharge location.

4.2 Grading, Geotextiles, and Lightweight Fill

In some cases surface or groundwater drainage measures were not sufficient in reducing the propagation of lower risk slides. In addition there are instances where significant and rapid movement has occurred such that the functionality of the road or safety of the public is compromised. In these cases earthworks solutions have typically been considered and employed. Several examples of earthworks solutions consisting of slide excavation and rebuilding the roadway with granular fill include one of the Heart River slides, as well as the Michelin, Makeout, Fence, Trunk, and CNR Slides.

In several instances, the slope angles for graded slopes, toe berms, and roadway fills have required the use of geosynthetics to remediate the slides given the steep topography of the Peace River valley side-hill (typically 15 to 45 degrees). In particular, the toe berm at Makeout Slide constructed in 2005 required layers of geogrid within the toe berm and shear key to ensure enough passive restraint to the expected driving forces. Geosynthetics, such as non-woven geotextiles have also been used in various erosion control situations, as well as with the placement of granular fill around stone columns, etc.

Where the slope grading was expected to pose a negative effect on the nearby slopes, lightweight fill has been applied. At Michelin Slide, the granular fill used consisted of lightweight tire shreds to allow for the reconstruction of the roadway embankment while minimizing the load transferred to the slope below the slide area. A similar approach was used at the CNR Slide after belled gravel drainage piles were installed where lightweight sawdust fill was used as backfill around the drains and at the front of the pile wall such that the driving forces may be reduced.

In most cases, where an earthworks remediation design has been employed, the slope is considered to be stable and the repairs are 'permanent'. As discussed, however, the steep topography on the side-hill precludes this method as a valid remedial measure in many situations, and in locations where it is viable, often additional measures such as geosynthetics or lightweight fill are required to ensure an appropriate factor of safety without loading a slide further downslope.

4.3 Retaining Structures

Retaining structures have been implemented as the repair of last resort at locations where drainage or earthwork solutions have either failed at a site or are not viable, or where the risk and consequences of a slide are judged to be high.

Retaining structures have been constructed at four locations along Judah Hill Road, the most prominent of which is at the CNR Slide. Originally, CN Rail installed timber piles when the presence of a slide was identified. The timber piles were not successful since they were not installed deep enough and were not tied-back. Since movements persisted, a bored cast-in-place pile wall was installed, which consisted of 36 piles that were 762 mm in diameter and 20 m deep. It was known at the time of installation that the pile depths would terminate above the shear zone. The piles were installed to maintain the road surface, and because deeper piles would not have been feasible. When movements continued, and when dewatering and lightweight fill solutions did not stop cracking completely, additional piles were installed and a robust tie-back system was applied. The tie-backs included conventional grouted anchors, while others were connected to concrete dead-man anchors located on the other side of the highway. Over the life of the wall, the submersible pumps installed in the gravel filled piles have stopped working and minor cracking has periodically been observed behind the wall, but no additional impacts to traffic have occurred. Recently, however, river scour at the toe of the slope has occurred in a dramatic fashion, and will require remediation to ensure the long-term viability of the wall adjacent to the highway and rail line.

A second retaining wall, consisting of 91 concrete piles (760 mm in diameter and 20 to 25 m long) anchored with 24 m long anchors (grouted for 12 m) was installed at Michelin Slide. Since a grading remedial scheme was believed to accelerate sliding further downslope, a pile wall was required at this location. This wall has been in good working condition since it was installed in 1997, although persistent movements downslope of the slide have raised concerns whether the pile will remain serviceable if a complete loss of passive confinement occurs.

Some unconventional retaining structures have been implemented at the Fence Slide and Michelin Slide locations in the form of stone columns. At the time of installation, it was believed that a complete removal of failed slide debris and reconstruction of the slope would be expensive and would result in a closure of the road for several months. As a result, stone columns were installed at both sites on the downhill side of the road as an attempt to reduce movements. Overall, 490 columns were installed between the two sites; however it is unclear how many stone columns exist at each location. The columns were 760 mm in diameter, 6.7 m deep, and on a 2 m (approx.) grid. They were installed in three rows along the down-slope (south bound) lane of the road at each location. As an added level of security, the stones installed into the columns were mixed with limestone to provide a cementitious effect in the event that groundwater movement in these zones was present.

At the Michelin Slide, the stone columns ultimately were not sufficient at restraining slope failures, and the roadway was realigned. The columns were not removed, and may be providing some useful restraint against failure in that location. At the Fence Slide, ongoing subsidence of the road surrounding the columns has occurred, which was originally attributed to settlement of the fill. Since the piles have periodically protruded through the road surface, granular fill and highway overlays have been added to these locations. With the ongoing settlement around the piles continuing, it was postulated that the loss of ground around the piles was due to a deep seated movement. In 2005, a failure ultimately occurred at this location resulting in the slide mass around the columns being excavated, and reconstructed with geogrid reinforced granular fill. Although it is difficult to evaluate the effectiveness of the stone columns at Michelin Slide, however the columns at Fence Slide are deemed to have worked appropriately as they delayed eventual failure, and are believed to have subdued the expression of the slide when it eventually occurred.

A final barrier present along Judah Hill is a simple wire-mesh fence installed at the Fence Slide location to reduce the likelihood and frequency of till blocks toppling from the slope onto the roadway.

4.4 Roadway Realignments

Where slide movements have persisted, and where geometry and space were available, roadway alignments have been used as a last chance remedial measure. This has occurred at the CNR, Makeout, and Michelin Slide locations. For the case of the CNR slide, the shift of the

CN rail tracks and the roadway provided room necessary for the installation of the pile wall. For the Michelin Slide site, the road realignment was required to accommodate the new remedial measures, including a pile retaining wall.

For the Makeout Slide, the roadway realignment (and associated pipeline realignment) was a necessary part of a remediation scheme for a slide that had extended beyond both lanes of the road. During the investigation, design, tendering and construction process associated with the slide repair traffic was maintained on a Bailey bridge that spanned the slope instability and was supported on pile foundations. For the realignment the upslope area was sloped back to accommodate the realignment. This combination of a off-loading from the top of the slide, and construction of a toe berm made the grading option viable. At this site the road had to be completely reconstructed so the cost premium to realign the road was not consequential. Had the realignment option not been pursued, a barrier may have been required at a significantly higher cost.

5 COSTS

The overall costs for the ongoing monitoring, roadway repairs, instrumentation, and remediation of slides along this section of roadway is difficult to determine due to the length of time the road has been in service, the numerous slide zones, and large number of measures attempted at the site. Of the records available, it was determined that:

- in 1994, it was estimated that approximately $800,000 had been spent on slide repairs at CNR Slide, Fence Slide, and Michelin Slide, and on monitoring to date;
- in 1997, approximately $2 million was allocated to the pile wall repair at Michelin Slide (and presumably to conduct other remedial measures, such as the berm and lightweight tire fill at the adjacent slide); and
- in 2005, $3.3 million was required to construct the roadway realignment, temporary Bailey Bridge, and slope grading operations applied at Makeout Slide.

In addition to the costs listed above, there have been costs associated with the reconstruction of Fence, Trunk, and Heart River slides, as well as significant intangible costs associated with the roadway including yearly monitoring trips conducted by Alberta Transportation and various consultants, instrumentation monitoring activities, roadway crack repairs, and traffic interruptions.

6 CONCLUSION

Over the last 25 years, significant money, expertise and risk management has been used to maintain the 2.5 km section of Highway 744:04 – Judah Hill Road. Several options have been employed on the seven distinct sliding areas, consisting of ongoing monitoring, slope dewatering, surface water diversions, slope grading, geosynthetics installation, use of lightweight fill, installation of barrier systems, and roadway realignments. Due to the sensitive nature of the slides and the varying topography along the road, no single option can be applied for all situations. Further, care must be taken when implementing a remedial measure to ensure that nearby slides are not being aggravated or re-activated, as has happened in several instances in the past.

Ultimately, it is Alberta Transportations wish that the slope will maintain short and long term stability, but based on the history of the roadway, periodic sliding is likely to occur in the future at known sites and at presently stable locations. As these instabilities occur, failures and successes associated with remedial measures at other locations along the road will be used to guide new designs. As new techniques or options arise, they will invariably be used where appropriate as well.

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