Application of a Landslide Risk Management System to the Saskatchewan Highway Network

Allen J. Kelly, Clifton Associates Ltd., Regina, Saskatchewan, Canada
A. Wayne Clifton, Clifton Associates Ltd., Regina, Saskatchewan, Canada
P. Jorge Antunes, Saskatchewan Highways & Transportation, Regina Saskatchewan, Canada
Allan Widger, Saskatchewan Highways & Transportation, Regina Saskatchewan, Canada

ABSTRACT
The interaction of natural forces with the highway system often results in hazards to the motorist or to the physical assets of the transportation system. Saskatchewan Highways and Transportation (SHT) required a hazard risk management system to prioritize sites for monitoring and remediation and provide recommended response levels based upon risk level. The hazards can be divided into geotechnical and landslide categories. In 2003, SHT took the first step in hazard management by implementing a landslide risk management system based upon the Alberta Transportation model.
Risk in the landslide model was evaluated by defining the likelihood of landslide occurrence or probability factor (PF) and consequences of a landslide or consequent factor (CF). The resultant of the two factors provided a numerical assessment of risk which could be ranked and categorized for response levels and management approach.
SHT identified 46 sites in the provincial road network for risk assessment. An expert panel met to assign PF and CF for each site. The sites were assigned a response level of urgent, priority, routine or inactive based upon the risk level. A management approach for inspection, monitoring and investigation was provided for each site based upon the response level.
An overview of the risk management system and its application to landslides near Shaunavon (C.S. 37-02) and Prince Albert (C.S. 302-02), Saskatchewan are provided. Details of the subsequent slope stability investigations and analysis are included.

RÉSUMÉ
L'interaction de forces naturelles avec le réseau de route a pour résultat souvent des dangers à l'automobiliste ou aux biens physiques du système de transport. Le Ministère des Routes et Transports de la Saskatchewan (MRTS) a exigé un système de gestion de risque de danger pour hiérarchiser des sites pour contrôler et le redressement et fournit les niveaux de réponse recommandés basés sur le niveau de risque. Les dangers peuvent être divisés en les catégories géotechniques et les catégories de glissment. Dans 2003, MRTS a pris la première étape dans la gestion de danger en appliquant un système de gestion de risque du glissment de terrain a basé sur le modèle du Le Ministère des Transports de la Alberta.
Risquer dans le modèle du glissment de terrain a été évalué en définissant la probabilité d'événement de glissment ou le facteur de probabilité (PF) et les conséquences d'un glissement de terrain ou d'un facteur consécutif (CF). Le résultant des deux facteurs a fourni une évaluation numérique de risque qui pourrait être classé pour les niveaux de réponse et l'approche de gestion.
SHT a identifié 46 sites dans le réseau de route provincial pour l'évaluation de risque. Un panneau expert a rencontré pour assigner PF et CF pour chaque site. Les sites ont été assignés un niveau de réponse d'urgent, la priorité, la routine ou inactif basé sur le niveau de risque. Une approche de gestion pour l'inspection, le measure sur le terrain et l'investigation a été pourvu à chaque site basé sur le niveau de réponse.
Un aperçu général du système de gestion de risque et son application aux glissements près de Shaunavon (C. 37-02) et Prince Albert (C. 302-02), Saskatchewan est fourni. Les détails des investigations de stabilité des talus subséquent et d'analyse sont inclus.

1. INTRODUCTION

Saskatchewan Highways and Transportation (SHT) have investigated landslides and their impact upon the transportation network since the 1960's. Early investigations centred around bridge site selection programs on the North Saskatchewan River. The first designed monitoring program was implemented in conjunction with remedial works at the newly opened North Battleford Bridge in 1967. Since that time, the number of unstable sites investigated and monitored has progressively increased. The technical capabilities of investigating and monitoring landslides has increased accordingly; however, the methodologies for assessing the level of hazards and investment strategies has not evolved at the same pace.

2. GEOHAZARD CLASSIFICATION

The interaction of natural forces with the highway system often results in hazards to the motorist or to the physical assets of the transportation system. Hazards can be subdivided into geotechnical hazards and landslide hazards.

SHT routinely deals with a variety of geotechnical hazards during the operation of the highway system. Erosion, settlement and soil-structure interaction phenomena are examples of geotechnical hazards. Landslide hazards include the mass movement of soil downslope in sufficient volume that it modifies, or may modify the lines and grades of the roadway and may potentially impact motorist safety or operation of the highway. Landslide hazards involve natural and engineered slopes.

SHT was interested in moving towards a comprehensive risk-based system for prioritizing and managing geotechnical and landslide hazards on the Saskatchewan highway transportation network. Partial implementation of this system began in 2003 with the development of a landslide management system. This paper discusses the implementation of the landslide management system.

3. LANDSLIDE MANAGEMENT SYSTEM

3.1 Introduction

Modern landslide management practices require the ability to:

1) Assess the degree of hazard that may be associated with unstable sites;

2) Evaluate the need for ongoing monitoring and inspection;

3) Provide for early warning or emergency response where public safety concerns warrant; and,

4) Establish priorities for investment of resources.

The methodology for landslide management incorporates a risk-based approach, mandating expenditures and efforts in proportion to the level of hazard and potential consequences of failure.

3.2 System Selection

Other agencies are addressing the natural hazard management issue. Well documented, peer reviewed descriptive system suitable for application to Saskatchewan conditions are readily available to support the development of a landslide management system. The Alberta Transportation Landslide Management System was used as an initial template since it was currently in use and could be readily modified for a Saskatchewan application.

3.3 Assessment of Risk

The basis of evaluating risk by Alberta Transportation is defined by:

Risk=Probability Factor (PF) x Consequence Factor (CF)

The PF reflects the likelihood of a landslide occurrence as assessed by a qualified geotechnical engineer. A modified 20 point PF scale from Alberta Transportation was used. The main modification was the differentiation of slope instability between natural and engineered slopes. The distinguishing feature between instability in a natural and engineered slope is based on the shear plane. In a natural landslide, the shear plane existed in the subsurface before the engineered construction took place. In an engineered slope, the landslide occurred on constructed slopes in terrain previously assessed to be stable. Table 1 shows the PF factor criteria.

The CF is the consequence of the landslide on transportation infrastructure or driver safety. The ten point Alberta CF was adopted with only minor modifications. Table 2 shows the CF criteria.

3.4 Ranking of Risk Levels

An expert panel familiar with the 46 sites monitored by SHT met to assign PF and CF for each site. PF and CF were assigned independently by each panel member and the mean Risk Level calculated on the basis of these ratings. The resulting range of risk varied from 1.0 to 160.0 for the 46 sites. The risk values were grouped into six ranges and plotted in Figure 1.

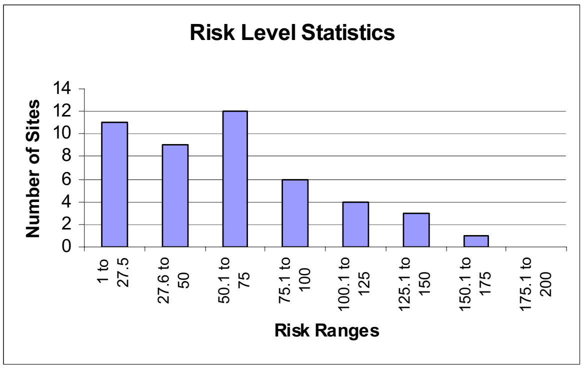

Figure 1: Summary of risk level assessment

3.5 Response Levels

Response levels of urgent, priority, routine and inactive were created based upon the risk level. The level of response varies according to the calculated Risk Level for each site. The distribution of sites in the various response levels is indicated in Figure 2. The Risk Level, number of sites, response level and corresponding management approach is included in Table 3.

Table 1: Probability Factors

PF	Natural Slope	Engineered Slopes
1	Geologically Stable. **Very low probability** of landslide occurrence.	F > 1.5 on basis of effective stress analysis with calibrated data and model*. Historically stable. **Very low probability** of landslide.
3	Inactive, apparently stable slope. **Low probability** of landslide occurrence or remobilization.	1.5 > F > 1.3 on basis of effective stress analysis with calibrated data and model. Historically stable. **Low probability** of landslide.
5	Inactive landslide with **moderate probability** of remobilization. Moderate uncertainty level; or, active slope with very slow constant rate of movement; or, indeterminate movement pattern.	1.3 > F > 1.2 on basis of effective stress analysis with calibrated data and model. Minor signs of visible movement. **Moderate probability** of landslide
7	Inactive landslide with **high probability** of remobilization, or additional hazards present. Uncertainty level high. Perceptible movement rate with defined zones of movement.	1.2 > F > 1.1. on basis of effective stress analysis with calibrated data and model. Perceptible signs of movement, or additional hazards present. **High probability** of landslide.
9	Active landslide with **moderate, steady or decreasing rate of movement** in defined shear zone.	F < 1.1 on basis of effective stress analysis with calibrated data and model. **Obvious signs of ongoing slow to moderate movement.**
11	Active landslide with **moderate, increasing rate of movement**.	Active landslide with **moderate, increasing rate of movement**.
13	Active landslide with **high rate of movement at steady or increasing rate**.	Active landslide with **high rate of movement at steady or increasing rate.**
15	Active landslide with **high rate of movement with additional hazards****.	Active landslide with **high rate of movement with additional hazards.**
20	**Catastrophic landslide** is occurring.	**Catastrophic landslide** is occurring.

Notes:

*** If the described conditions for slope analysis are unknown or not met, increase the PF by one category, e.g. if quality of data used in analysis is not known, increase PF from 1 to 3. F = Factor of Safety.**

**** Additional hazards are factors which can greatly increase the rate of movement, e.g. eroding toe, groundwater, etc.**

Table 2: Consequence Factors (CF)

CF	Typical Consequences
1	Shallow cut slopes where slide may spill into ditches or fills where slide does not impact pavement to driver safety, maintenance issue.
2	Moderate fills and cuts, not including bridge approach fill or headslopes, loss of portion of the roadway or slide onto road possible, small volume. Shallow fills where private land, water bodies or structures may be impacted. Slides affecting use of roadways and safety of motorists, but not requiring closure of the roadway. Potential rock fall hazard sites.
4	Fills and cuts associated with bridges, intersectional treatments, culverts and other structures, high fills, deep cuts, historic rock fall hazard areas. Sites where partial closure of the road or significant detours would be a direct and avoidable result of a slide occurrence.
6	Sites where closure of the road would be a direct and unavoidable result of a slide occurrence.
10	Sites where the safety of public and significant loss of infrastructure facilities (such as a bridge abutment) or privately owned structures will occur if a slide occurs. Sites where rapid mobilization of a large-scale slide is possible.

Table 3: Recommended Response Levels and Management Approach for Landslide Sites

Risk Level	Number of Sites	Response Level	Management Approach
> 125	4	Urgent	Inspect at least once per year. Monitor instrumentation at least twice per year in the spring and fall. Investigate and evaluate mitigation measures.
75 to 125	10	Priority	Inspect once per year. Monitor instrumentation at least once per year.
27.5 to 75	21	Routine	Inspect every 3 years. Monitor instrumentation at least every 3 years with an increased frequency for selected sites as required
< 27.5	11	Inactive	No set instrumentation monitoring or inspection schedule. Monitored and inspected as required in response to maintenance requests

4. APPLICATION OF THE LANDSLIDE RISK MANAGEMENT SYSTEM – CASE STUDIES

4.1 Introduction

Two landslide case studies are presented to show the application of the landslide risk management system. The landslide at the Frenchman River Valley, approximately 35 km south of Shaunavon in southwest Saskatchewan, was the reactivation of a previously unknown landslide while the landslide at Prince Albert, Saskatchewan was a known landslide which was rated as routine with a risk level of 54. The risk level at the Prince Albert landslide was re-assessed after the landslide became more active.

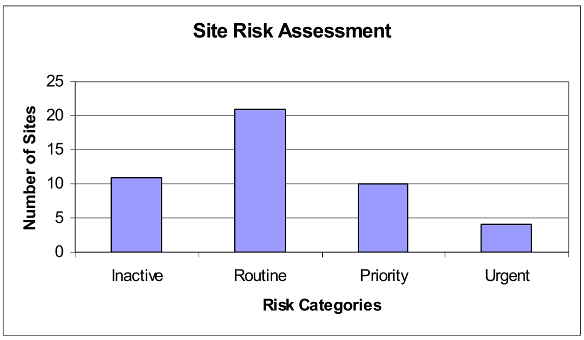

Figure 2: Summary of response levels

4.2 Frenchman River Valley Landslide

In the fall of 2003, a landslide was reactivated during realignment of Highway 37 (Control Section 37-02) on the south wall of the Frenchman River Valley, Figure 3. A large fill section was placed immediately west of the existing road, resulting in a head scarp which dropped 150 m of the existing highway by 100 mm over a period of a few days.

A risk assessment was conducted to determine the recommended management approach. The PF for the landslide was 15 because of rapid movement and additional hazards from creek toe erosion. The CF was 10 because there was a public safety issue and the possibility of significant loss of infrastructure. The resulting Risk Level was 150, which fell in the urgent response level category.

Immediate action was taken to detour traffic around the landslide and halt construction of the fill section. An airphoto assessment of the site indicated there were three landslide blocks below the existing road, Figure 3 and a block above the existing road. The existing road was in a cut section between two blocks.

A stratigraphic drilling and instrumentation program was undertaken to determine remedial options. Seven slope inclinometers were installed to depths ranging from 30 m on the lower landslide block to 55 m in the block above the existing road. Four pneumatic piezometer nests with two to three piezometers each were installed adjacent to select slope inclinometers.

Inclinometer readings indicated movement between elevations 885 m to 895 m along a bentonitic rich zone within marine shale. The rate of movement progressively increased from 0.3 mm/day in the lower block (SI6) to 0.9 mm/day in the upper block (SI3/SI203). The block above the road (SI7) did not appear to be moving. The rates of movement indicated the lower and middle blocks were moving independently from the upper block which was loaded with the road fill.

The stratigraphy, porewater pressures, laboratory testing and depth of movement were used in conjunction with a digital terrain model to conduct two and three dimensional slope stability modelling. Results of stability modelling indicated the location of the landslide toe was very sensitive to minor changes in the stability model, Figures 4 and 5. The stability modelling also showed the extent of the critical failure did not extend back into the road fill which was believed to have reactivated the landslide. The stability model confirmed the upper block was moving independently from the lower and middle blocks.

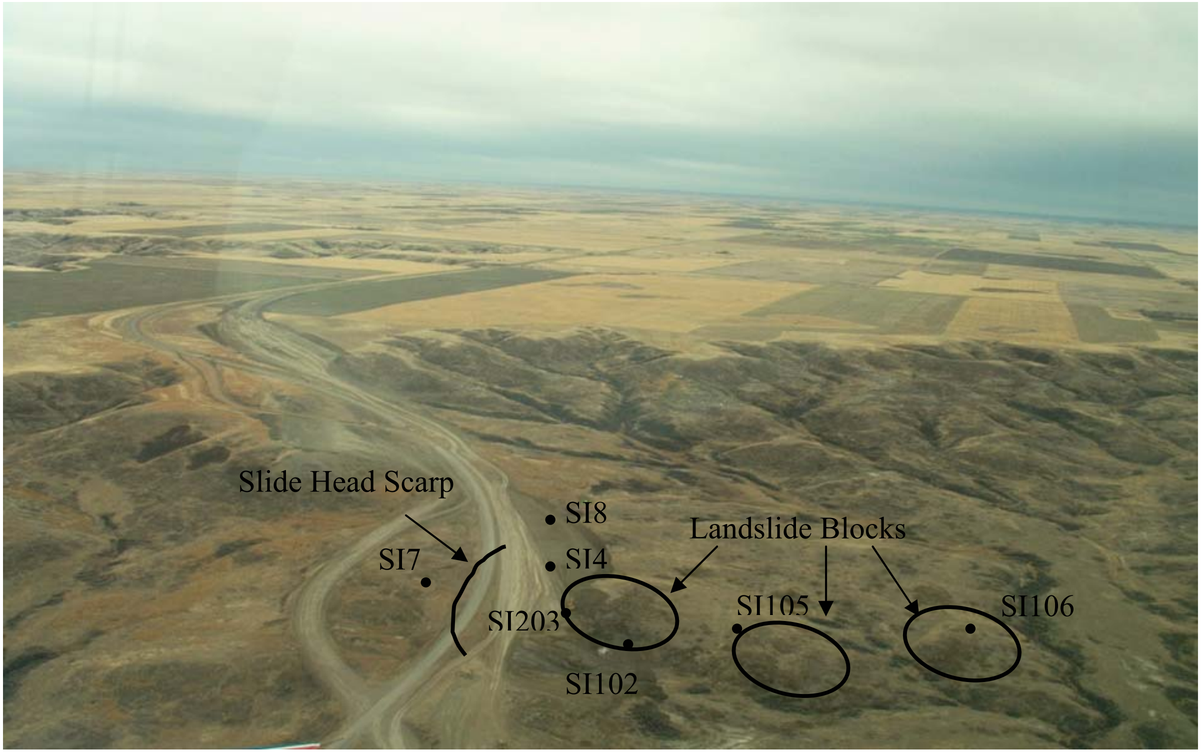

Figure 3: Approximate location of landslide and slope inclinometers at Frenchman River Valley.

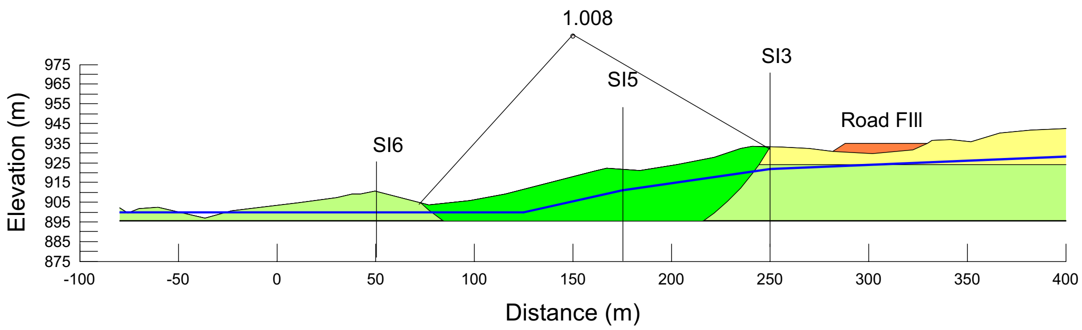

Figure 4: Slope stability of middle block.

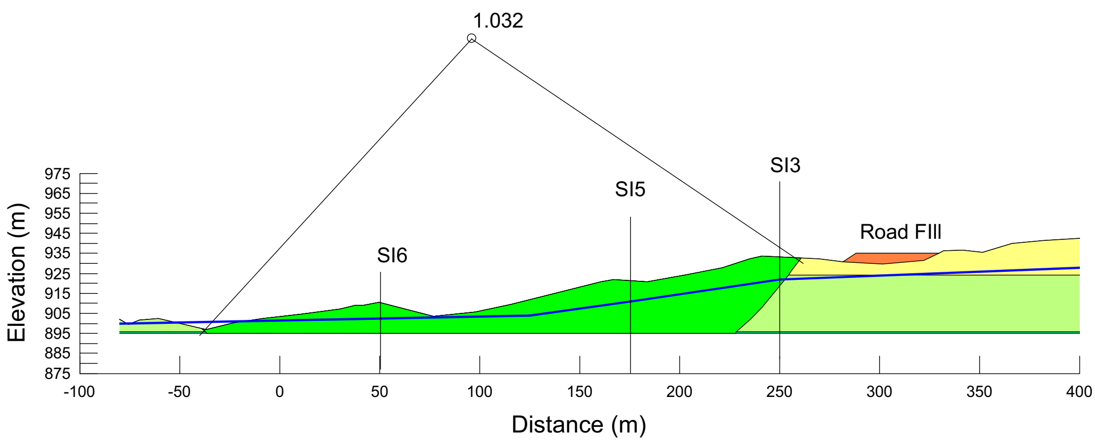

Figure 5: Slope stability of lower and middle block.

Remediation considered berming and unloading of the slope. Berming of the toe was believed to be too risky because of the sensitivity of the toe location and the possibility that berming could activate landslides further down the valley wall. The upper block appeared to be moving independently from the other blocks; therefore, the remedial focus was on the upper block. The alignment of the road through the landslide was revisited to shift the highway into further cut above the existing road and off the landslide. In addition the large fill was removed to return the lower and middle blocks to preconstruction conditions, preventing retrogression of the landslide back into the new highway alignment. Figure 6 shows movement in the upper block (SI203) dropped to minor creep after the large fill was removed between the 06 and 20 May 2004.

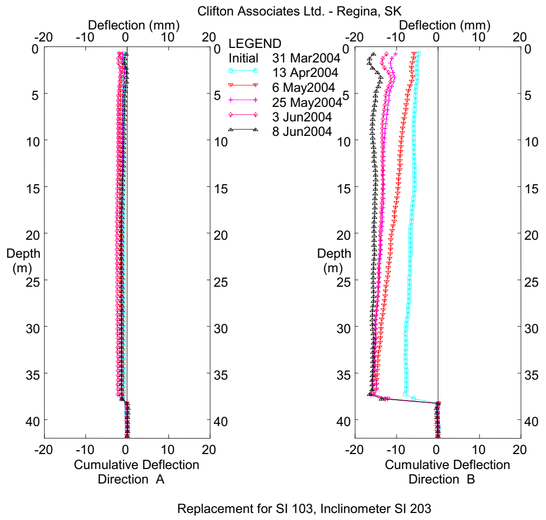

Figure 6: Movement of upper block as indicated by SI203.

4.3 Prince Albert Penitentiary Landslides

Two landslides approximately 3.5 km and 4.5 km west of the Saskatchewan Penitentiary at Prince Albert are impacting Highway 302 (Control Section 302-02), Figure 7. The highway is located adjacent the North Saskatchewan River which is actively eroding its river bank, resulting in large retrogressive failures, Figure 8. There are three distinct slump blocks between the highway and the river bank. Locally, there is groundwater discharge along the river bank in the two landslide areas which contributes to the instability of the river bank.

The first failure at 3.5 km west has affected the north shoulder, but the west bound lane is in good condition. The length of the failure at the highway right-of-way was 110 m and the vertical displacement in the sideslope of the highway embankment was 230 mm. The highway at this location is a fill section constructed over the edge of the most southerly landslide block. Erosion of the riverbank has triggered the most recent movement of the fill section.

The second failure at 4.5 km west affects a fill section constructed over a drainage channel. A fourth slump block was forming which crossed the highway into the upslope ditch. The landslide was estimated to be approximately 180 m long along the south shoulder of the highway. A dip in the highway at the west extent of the landslide was evident and signed by SHT.

A risk assessment of the first failure determined the landslide along the north shoulder did not pose an immediate danger to the highway; however, regular inspections and a slope inclinometer were recommended to monitor future movement. The landslide was assigned a PF of 15 because the landslide was active at a high rate of movement with additional hazards such as toe erosion and groundwater discharge on the river bank. A CF of 5 was assigned because a partial road closure may be a result. The risk level was 75 which is at the boundary of a routine and priority site.

A risk assessment of the second failure indicated the failure posed a greater risk to the road and public safety. A PF of 15 was assigned to the landslide for the aforementioned reasons of the first failure. A CF of 10 was used because of the risk of road closure and a public safety issue in the event of a sudden large movement. The resulting risk level was 150 which classified the landslide as urgent. Daily inspections and additional instrumentation were recommended.

A slope inclinometer was already in place along the east edge of the landslide above the third slump block; however, another slope inclinometer and a pneumatic piezometer nest were installed in the third slump block immediately below the landslide. The investigation of remedial options is ongoing.

5. CONCLUSIONS

The landslide risk management system was successfully applied to the Saskatchewan highway network. Risk assessments were used to rank 46 sites and allocate appropriate resources for monitoring and investigation.

6. REFERENCES

Alberta Transportation. Attachment 1 – Risk Level, Project Site Documentation Binder Contents. Alberta Transportation Geotechnical and Erosion Guides, Geotechnical Reference Materials.

Clifton Associates Ltd. (2003). Risk Management System for Landslide Sites in Saskatchewan. Consultants report prepared for Saskatchewan Highways & Transportation, File No. R3392, 12 September 2003.

Figure 7: Prince Albert Highway 302 landslide extents. Landslide 4.5 km from penitentiary at bottom left

Figure 8: Active erosion along North Saskatchewan River bank