# Grierson Hill Slide and Stabilization Strategies for Developments in the Area

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ABSTRACT

The Grierson Hill Slide occurred along the North Saskatchewan River north valley slope in 1901 and has been active for more than 100 years. The landslide has been investigated during the Grierson Hill Road construction in the 1950s, the Shaw Conference Centre development in the 1970s, and most recently for the Valley Line LRT portal and valley structures. Slope movements have been monitored using a ground survey monitoring system that was established in the early 1980s, and more recently with slope inclinometers located within the landslide area. Recent developments in the Grierson Hill area include the Edmonton Valley Line LRT tunnel and portal on the east flank of the landslide and several small recreational buildings within the landslide. These developments require careful consideration of the slope stability and potential future slope movements that could impact the structure performance. This paper updates the history of the Grierson Hill Slide monitoring and provides an overview on the slope stabilization measures that have been used for the developments in the landslide area.

RÉSUMÉ

Le glissement de terrain de la côte Grierson s’est amorcé initialement le long de la rive nord de la vallée du fleuve Saskatchewan Nord en 1901 et demeure actif depuis plus de 100 ans. Des fouilles géotechniques extensives ont été entreprises lors de années 1950 sur le site lors de la construction de la route Grierson Hill et pendant les années 1970 pour le développement de la salle de conférence Shaw. Le mouvement des talus a été initialement suivis par un système d’arpentage au sol installé pendant les années 1980 et plus récemment au moyen d’inclinomètres installés dans la zone active du glissement. Récemment, un tunnel, ainsi qu’un portail, ont été aménages sur le flanc Est du glissement de terrain lors de la construction de la nouvelle ligne Edmonton Valley du réseau de train léger municipale ainsi que plusieurs petits bâtiments récréatifs dans la zone centrale du glissement de la côte Grierson. Ces développements nécessitent un examen plus approfondi de la stabilité des talus et des mouvements potentiels qui pourront avoir un impact néfaste sur la performance des structures aménagées. Ceci nécessitera l’implantation de moyens de stabilisation de talus importants afin d’atténuer l’impact du mouvement occasionné par les glissements de terrains. Cet article présente une mise à jour de l’historique du glissement de terrain de la côte Grierson et donne un aperçu des moyens de stabilisation de talus utilisés pour les développements plus récentes dans la zone du glissement de terrain.

## 1 INTRODUCTION

The Grierson Hill Slide is located on the north slope of the North Saskatchewan River valley in downtown Edmonton. The slide is bounded by Grierson Hill Road to the north and the North Saskatchewan River to the south and extends from the Shaw Conference Center on the west side to the former Cloverdale Footbridge on the east side. The slide first occurred in 1901, extending about 500 m along the river bank with a slope height of 55 m above the river bed and an average slope angle of about 11 degrees, and covered an area of approximately 10 hectares.

The Grierson Hill Slide still remains active after more than a century. Since the initial slope failure, the Grierson Hill slope crest has retrogressed 30 m to 40 m and the riverbank has moved out more than 100 m into the river channel from its 1883 pre-slide location (Figure 1).

The Grierson Hill Slide has been extensively studied during the Grierson Hill Road construction in the 1950s and for the Shaw Conference Centre development in the 1970s (EBA and Morgenstern 1979). During that time remediation measures, including installation of dewatering wells and drainage tunnels, and construction of toe berms, were implemented and reduced the rate of the slide movements.

Recent developments in the Grierson Hill area include the Edmonton Valley Line LRT tunnel and portal structures on the east flank of the slide and the Louise McKinney Park facilities in the main slide area. Expansion of the Shaw Conference Centre within the slide area has also been considered. These developments have required a comprehensive review of the geological and hydrogeological environments of the Grierson Hill Slide and historic records of ground movement monitoring in order to evaluate the suitability of the site and develop practical slope stabilization designs.

This paper provides an overview of the geology and failure mechanisms of the Grierson Hill Slide, updates the history of the slope movement monitoring, and presents some of the stabilization measures that have been successfully implemented for previous and recent developments in the Grierson Hill area.

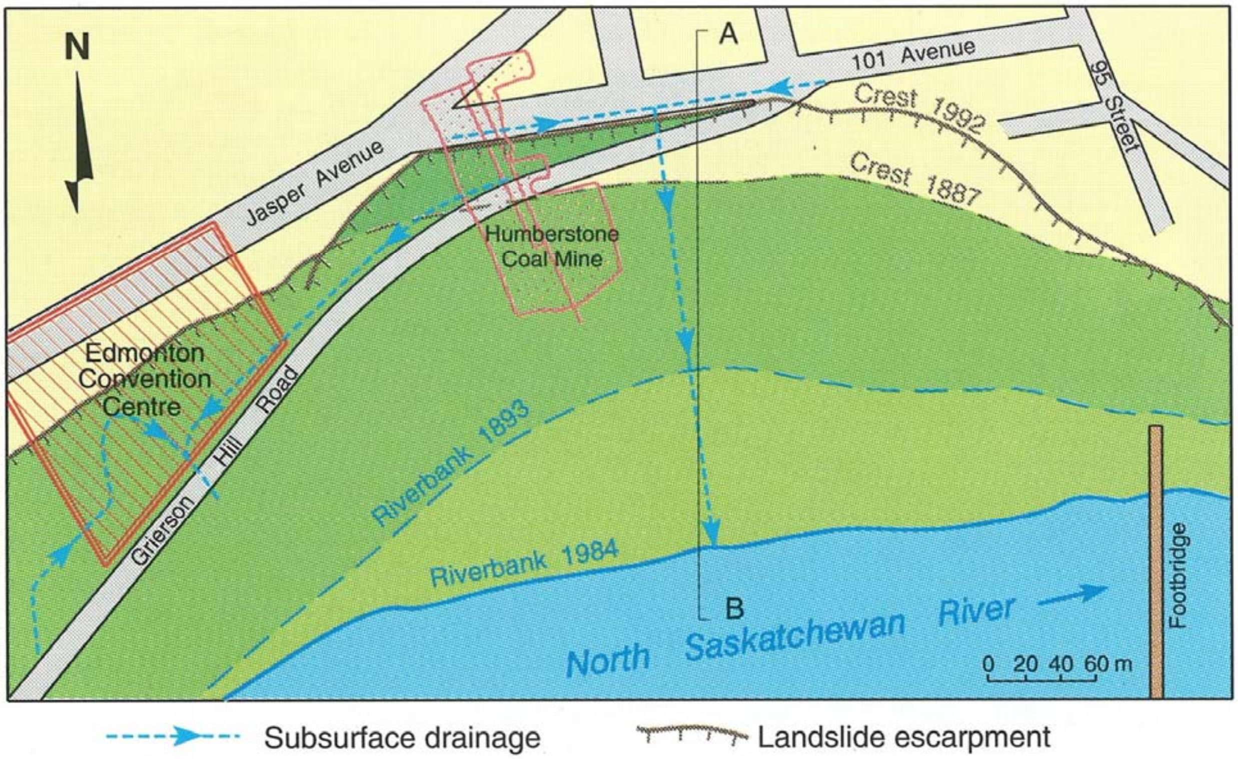



Figure 1. Site plan of the Grierson Hill Slide showing change of slide toe and crest (from Godfrey 1993)

## 2 GEOLOGY AND FAILURE MECHANISMS OF THE GRIERSON HILL SLIDE

The geological setting of the Grierson Hill slope has been well established from extensive geotechnical investigations for the previously noted developments in the area. The generalized stratigraphy consists of about 7 m of glaciolacustrine sediments overlying glacial clay till, and Empress Formation sands (also referred to as Saskatchewan Sands and Gravels) overlying bedrock at a depth of about 17 m below Jasper Avenue (Figure 2).

The bedrock consists of Upper Cretaceous interbedded clay shale, sandstone, and siltstone of the Horseshoe Canyon Formation. Coal seams and bentonite layers of variable thickness are common throughout the bedrock.

The upper bedrock has been disturbed by various geological processes including valley erosion, glacial action, river down-cutting, and most recently by coal mining activity in the late 1800s that has weakened the bedrock in the backscarp area of the valley slopes. These processes have generated weakened zones within the upper bedrock units and have contributed to the past river valley slope instability.

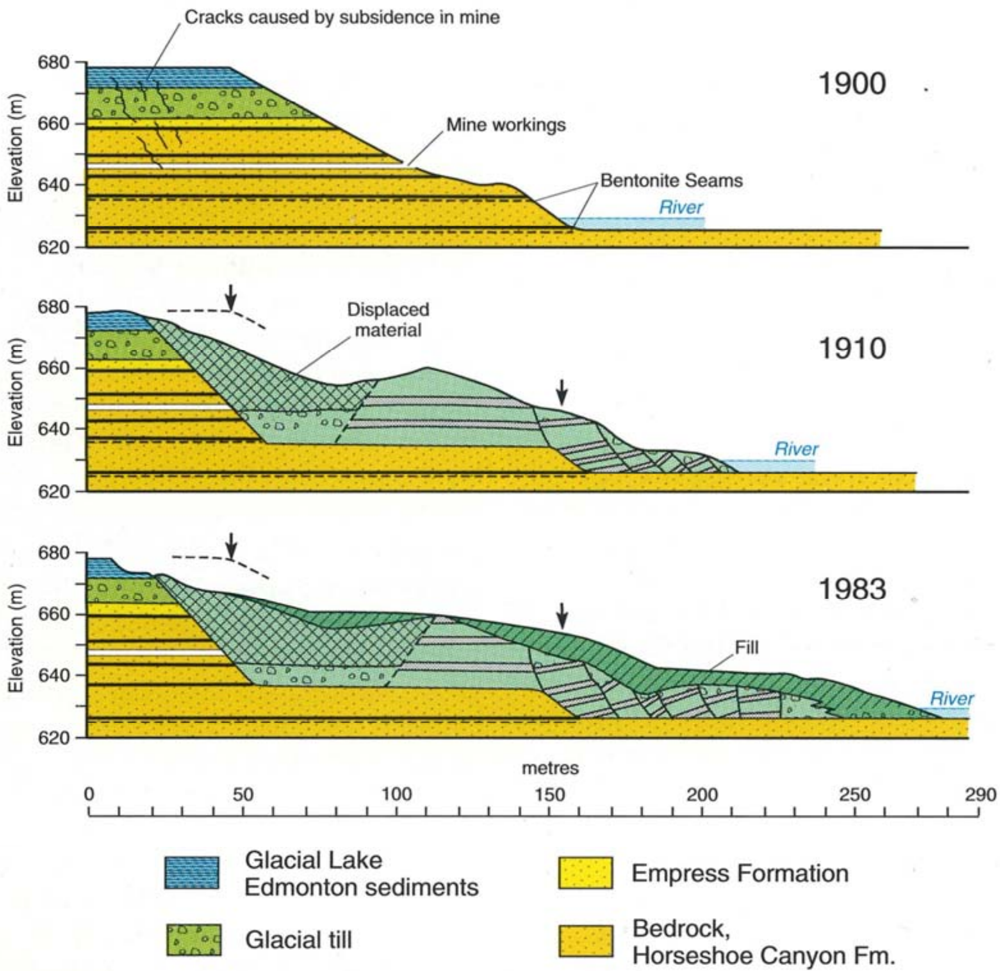
The bentonite seams in the bedrock represent flat-lying weak layers along which sliding can occur when these seams daylight in the valley slopes and within open excavations. The Grierson Hill Slide was a result of translational sliding along one of these weak bentonitic seams, at a depth of about 45 to 55 m (approximate shear plane elevation 620 m) below the top of bank.

The Grierson Hill Slide occurred in 1901 and was attributed to a combination of toe erosion along the North Saskatchewan River, strength loss in the overburden soils and bedrock due to coal mining activities in the river valley, the presence of the weak bentonite seams in the bedrock, and elevated groundwater levels following a period of prolonged precipitation.

The findings from the geotechnical investigations and slope movement monitoring indicated that the Grierson Hill Slide was a deep-seated translational slope failure (Martin et al. 1998). The slide moved southwards into the North Saskatchewan River along planar near-horizontal shear surfaces that developed along distinct bentonite seams within the bedrock. The initial slide eventually broke up into two separate slides of smaller scale, designated as the Upper Slide and Lower Slide, which have moved independently, at different rates along two distinct slip surfaces, as illustrated in Figure 3.

Since the initial failure in 1901, the Grierson Hill Slide area has been modified by extensive dumping and backfilling, mainly in the upper portions of the slopes. Between 1911 and 1940, the graben feature created by the landslide was used as a municipal landfill by the City of Edmonton. Between 1950 and 1961, nearly 50,000 $m^3$ of clay fill was placed in the graben area during the construction of the Grierson Hill Road.

Fills up to 25 m thick have been encountered in several test holes drilled in 1980 within the landslide graben area. The deeper fills consist of clay mixed with landfill materials. The upper fill generally comprises compacted inorganic clay that was placed during construction of the Grierson Hill Road in 1950s.




Note: Elevation is based on the Edmonton City Datum and 13.1 m should be subtracted to obtain geodetic elevation.

Figure 2. Stratigraphic sequence of the Grierson Hill Slide and changes of the slope configuration from 1900 to 1983 (modified from Godfrey 1993)

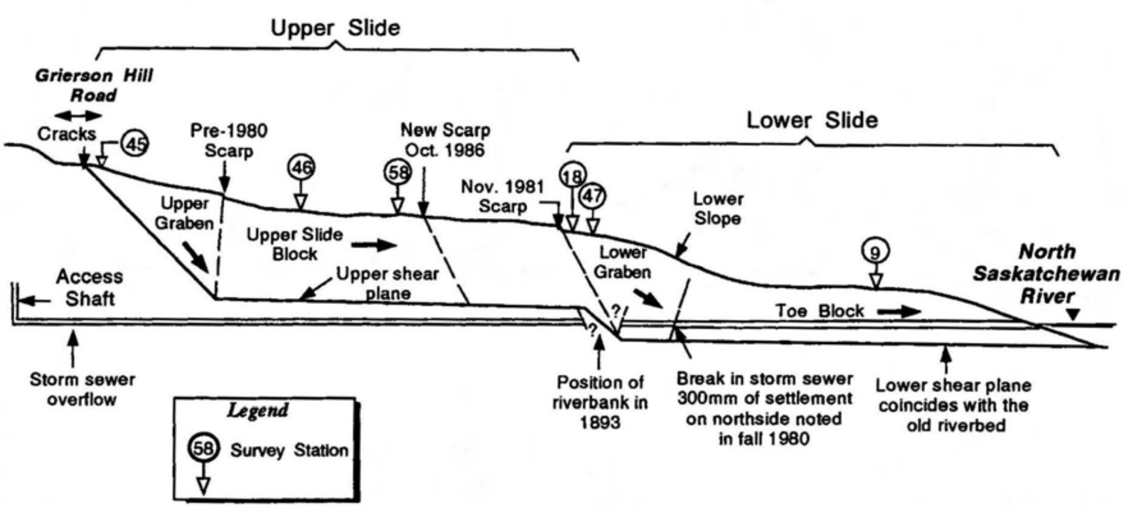



Figure 3. Schematic diagram of the Grierson Hill Slide failure mechanisms (from Martin et al. 1998)

As illustrated in Figures 2 and 3, placement of a large amount of the fill in the graben area promoted instability of the slide and pushed out the Lower Slide debris further into the North Saskatchewan River.

# 3 GROUND MOVEMENT MONITORING IN THE GRIERSON HILL SLIDE

## 3.1 Ground Surface Survey Monitoring

Survey monitoring of the Grierson Hill Slide has been carried out since the early 1950s during the initial attempts to construct the Grierson Hill Road. Over the past several decades, the slide movements have been monitored periodically by the City of Edmonton to gain a better understanding of the slide dynamics.

The results of the ground surface survey programs undertaken between 1950 and 1996 were reported by Martin et al. (1998). Figure 4 shows the locations of the survey stations and associated movement vectors based on the survey data in 2016. Table 1 provides a summary of the recorded ground movement from 1901 to 2016.

It is evident that the Grierson Hill Slide has exhibited ongoing slope movement throughout its history and that small changes in site conditions, such as changes in groundwater table, loading and unloading of the slopes, and toe erosion, have significantly influenced the rates of slope movement.

The sensitivity of the Grierson Hill Slide to slight alteration of site conditions is highlighted in the following episodes:

- Horizontal movement rates up to 2 m per year were recorded from 1950 to 1952 due to fill placement during the Grierson Hill Road embankment construction;
- Movement rates decreased to 350 to 500 mm per year from 1956 to 1960, after extensive drainage measures including vertical wells and drainage tunnels were installed;
- Movement rates of the Lower Slide approached almost 3 m per year as a result of the toe erosion following the severe flood in July 1986;
- Horizontal movement rates at the central portion of the slide reduced dramatically to the range from 5 to 25 mm per year after construction of a 280 m long by 60 m wide berm on the lower slope and placement of a 4 m wide berm of concrete rubble along the toe of the Lower Slide between 1987 and 1991.

## 3.2 Ground Movement Monitoring with Slope Inclinometers

Over the last several decades, geotechnical instruments including slope inclinometers and piezometers have been installed and monitored. Most of the inclinometers installed within the active slide area prior to 2000 have been sheared off due to the large slope movements. Slope inclinometers installed recently and still functional to date are shown in Figure 4.

Slope monitoring over the last 15 years has indicated relatively small on-going movements along the deep-seated pre-sheared sliding surface, indicating that the deep-seated movements are relatively dormant at present. However, noticeable surficial slope movements have been detected within the overburden soils from several slope inclinometers. The monitoring results are consistent with the findings of the ground survey of the Grierson Hill slope, which have shown that most noticeable slope movements have taken place throughout the central part of the Grierson Hill Slide with lesser movements on the east and west flanks of the lower slopes.

# 4 STABILIZATION MEASURES FOR THE DEVELOPMENTS IN THE GRIERSON HILL SLIDE AREA

## 4.1 Grierson Hill Slide Stabilization – Drainage Measures from 1950 to 1963

Grierson Hill Road was constructed between 1950 and 1963 and involved placing approximately 50,000 $m^3$ of fill to raise the grade in the landslide graben area. This fill placement resulted in a substantial increase in the rate of slope movements; up to 2 m per year was measured between 1950 and 1952, and 1.5 to 2.5 m were recorded between June and August 1960.

Geotechnical investigation carried out by R.M. Hardy and Associates in 1953 concluded that the observed ground movements were caused by the surcharge of the road embankment over soft fill materials which were squeezed outwards over the top of the more stable colluvium. Blockage of the natural drainage from the backscarp coal seams by the fill placement and colluvium deposited on the slope was considered as a major contributing factor in destabilizing the soft fill materials.

Based on these observations, dewatering of the slide was considered as the most favorable stabilization solution. Nineteen dewatering wells were installed in 1953 and pumped between the fall 1953 and December 1955. A system of drainage tunnels was constructed between 1957 and 1963 to drain seepage from the coal seams and previous coal mine workings.

The dewatering measures implemented in the Grierson Hill Slide between 1953 and 1963 were considered effective in reducing slide movements. Pumping water from the wells between 1953 and 1955 decreased the movement rate to about 1 m per year, or 50 percent of the previous rate before dewatering. Movement rates measured between 1956 and 1960 decreased to 350 to 500 mm per year after the east drainage tunnel was constructed in 1957 (Martin et al. 1998).

Construction of the roadway embankment was completed in 1961 and the road was paved in 1963. Ground surface monitoring carried out from 1961 to 1969 indicated small ongoing slope movements.

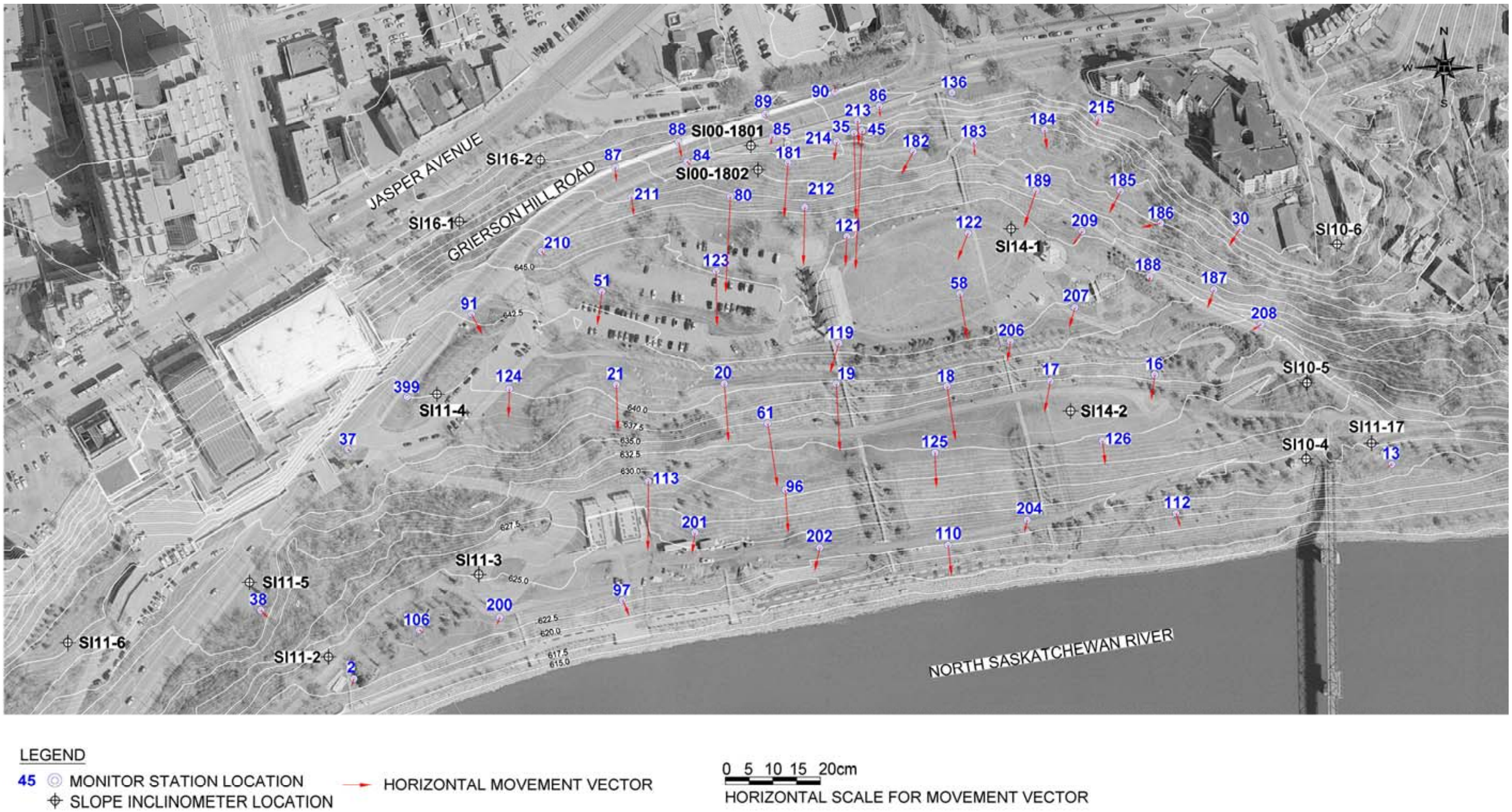



Figure 4. Site Plan showing locations of slope inclinometers, ground surface survey stations, as well as movement vectors based on survey data from 2001 to 2016

Table 1. Summary of Ground Movement Monitoring in the Grierson Hill Slide Area (Surface Survey from 1901 to 2016)

| **Period** | **Location** | **Rate of Movement (mm/year)** | **Remarks** |
|---|---|---|---|
| 1901 - 1910 | Crest of the slope | 4,000 | Based on survey records from 1901 to 1910 |
| | Toe of the Slide | 4,500 – 5,500 | |
| 1950 - 1952 | Central portion of the Slide | 2,000 | Construction of the Grierson Hill Road; Slide was moving as a single unit (uniform movement) |
| 1953 - 1955 | Central portion of the Slide | 1,000 | Dewatering from wells installed on the west of the slide; Uniform movement |
| 1956 - 1960 | Central portion of the Slide | 350 - 500 | Dewatering from drainage tunnels installed on the west of the slide; Uniform movement |
| Jun. – Aug. 1960 | Central portion of the Slide | - | 1.5 to 2.5 m displacement because of fill placement in the landslide graben in 1959 and 1960 |
| 1961 - 1980 | Central portion of the Slide | small | 200 – 500 mm from 1961 to 1969; cracking and settling were noted on the Grierson Hill Road outside lane |
| 1980 - 1984 | Grierson Hill Road | 260 | Upper Slide and Lower Slide were moving at different rates; Bimodal shear surface; Lower Slide was less stable |
| | Upper Slide | 150 | |
| | Crest of Lower Slide | 540 | |
| | Toe of Lower Slide | 480 | |
| Jul. – Oct. 1986 | Grierson Hill Road | 250 | Significant river bank erosion caused by the flood in July 1986; Lower Slide was less stable |
| | Upper Slide | 130 | |
| | Crest of Lower Slide | 2,800 | |
| | Toe of Lower Slide | 2,900 | |
| Jul. 1986 – Jul. 1987 | Grierson Hill Road | 270 | Significant river bank erosion caused by the flood in July 1986; Lower Slide was less stable |
| | Upper Slide | 130 | |
| | Crest of Lower Slide | 1,850 | |
| Nov. 1987 – May 1992 | Grierson Hill Road | 60 | Slope stabilization with construction of a toe berm (completed in October 1987) |
| | Upper Slide | 16 | |
| | Crest of Lower Slide | 26 | |
| | Toe of Lower Slide | 20 | |
| Nov. 1993 – Apr. 1996 | Grierson Hill Road | 12 | Average rate of movement in the central portion of the slide was about 10 mm per year |
| | Crest of Lower Slide | 9 | |
| Apr. 2001 – Apr. 2016 | Upper Slide | 17 | Greater movements observed in the Upper Slide indicated creep movements of upper slope into the landslide graben |
| | Crest of Lower Slide | 7 | |
| | Toe of Lower Slide | 4 | |
| Apr. 2001 – Apr. 2016 | East lower slope | 1 - 4 | Slope area south of 101 Avenue and east of 95A Street |
| Apr. 2001 – Apr. 2016 | West lower slope | 1 - 2 | Slope area south of the Grierson Hill Road and West of 97 Street |

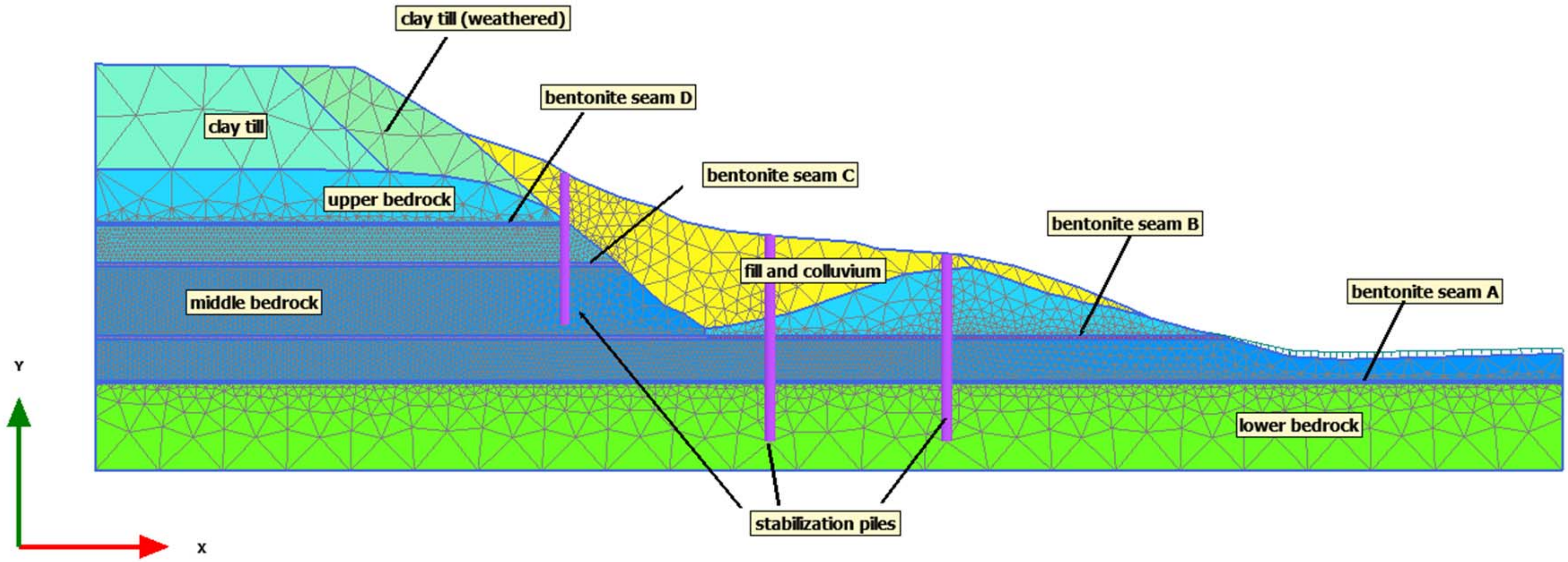



Figure 5 Conceptual design of slope stabilization piles for the Edmonton Valley Line LRT in the Grierson Hill Slide Area

## 4.2 Grierson Hill Slide Stabilization – Toe Berms from 1987 to 1991

The North Saskatchewan River experienced a 1:50 year flood in July 1986 which resulted in erosion of up to about 6 m of the riverbank along the toe of the Lower Slide. The loss of toe support was followed by a significant increase in the rate of movement and the total movement of the Lower Slide was about 1.8 m between July 1986 and July 1987, with the maximum movement rate measured at the crest of the slide up to 2.8 m per year.

Because of this increase in movements, a 280 m long by 60 m wide toe berm measuring 32,000 $m^3$ of compacted clay was constructed in the summer of 1987 to buttress the Lower Slide. The thickness of the toe berm fill ranged from 1.5 to 5 m. The construction of the toe berm was effective in reducing the slope movements, and the average movement rate measured at the crest of Lower Slide between 1987 and 1992 decreased to 26 mm per year.

In 1991, a 4 m wide toe berm of concrete rubble and rip-rap was constructed along the toe of the Lower Slide to further stabilize the riverbank and protect the slide from erosion. With the successful implementation of the toe berm stabilization, the average movement rate of the Grierson Hill Slide has decreased to less than 20 mm (horizontal) per year since 1993.

## 4.3 Shaw Conference Centre – Unloading the Upper Slope and Anchored Retaining Walls for Excavation

The Shaw Conference Centre (SCC) is located immediately north of Grierson Hill Road along the backscarp of the Grierson Hill Slide. A comprehensive geotechnical investigation for the Shaw Conference Centre was undertaken between 1978 and 1979 (EBA and Morgenstern 1979).

Based on the findings of the geotechnical investigation and slope stability assessment, it was concluded that the most effective means of achieving long term stability for the SCC development involved unloading the site with approximately 20 m deep excavation of the upper slope in order to provide an adequate factor of safety (Balanko 1980).

Due to the site constraints and concerns of potential movements along the weak bentonite seams and stress relaxation in the upper slope, tangent pile walls with permanent tie-back anchors were installed to support the vertical excavation and the SCC building was isolated from the retaining walls by a gallery.

Construction of the SCC was completed between 1980 to 1983. The excavation was supported on three sides by tangent pile walls with multiple levels of prestressed anchors. The design anchor load applied on the north wall below Jasper Avenue was about 3,700 kN per linear meter wall length. The excavation was carefully monitored to ensure that ground movements remained within tolerable limits. The measurements from the slope inclinometers indicated that the movements of the tangent pile walls into the excavation ranged from 10 to 20 mm at the top of the piles. Movement of the order of 30 mm was observed along one of the bentonite seams when the excavation was completed (Chan and Morgenstern 1987).

Unloading the slope by removal of a significant amount of materials from the upper slope was considered successful in improving the overall slope stability required for the SCC development. Ground movement monitoring of the Grierson Hill Slide indicated that construction of the Shaw Conference Centre had negligible influence on the stability of the adjacent slopes. The facility has performed well to date since its opening in 1983.

## 4.4 Edmonton Valley Line LRT from Downtown to Mill Woods – Slope Stabilization Piles

The southeast expansion of the Edmonton Valley Line Light Rail Transit (LRT) traverses the north bank of the North Saskatchewan River at the eastern flank of the Grierson Hill Slide. The south portal of the LRT tunnels and the north abutment of the river crossing bridge are situated on the eastern flank of the slide. Construction of these critical structures in the slide area necessitated a detailed geotechnical assessment of the site stability and careful consideration of the potential impacts of future slope movements on the performance of the LRT facilities.

Slope stability analyses were performed to evaluate the long-term stability of the LRT works and the need for slope reinforcement measures (Wang and El-Ramly 2012). Even though discernable deep-seated movements were not detected in the short term, the stability analyses indicated that the slope had a relatively low factor of safety, in the range of 1.1 to 1.3.

Furthermore, the factor of safety of the overall valley slope could decrease with time as a result of strength reduction due to a long-term strain-softening of the soils and bedrock and other destabilizing factors, indicating a high level of geotechnical risk.

Considering the consequences of a potential slope failure, slope stabilization piles extending well below the potential sliding surfaces was considered to be the most feasible engineering solution to provide acceptable long-term slope stability.

Based on the potential failure modes identified from the slope stability analyses, multiple rows of vertical pile walls were required to improve the local and global stability of the natural slope. An upper row of piles was required near the tunnel portal to maintain positive support to the upper slopes. Additional rows of piles were required below the tunnel level on the flat portion of the riverbank to anchor the slope toe and enhance the stability of the lower slope (Figure 5).

The rows of stabilization piles were designed to improve the factor of safety of the natural slope by 30 percent. This improvement was considered essential to prevent future excessive slope movement and the degradation in shear strength of bedrock material with time due to stain-softening.

The slope stability analyses indicated that the stabilization piles should be designed to withstand a total shear force of the order of 2,500 kN per linear meter along the slope. The sensitivity of the slope to the slight disturbances associated with construction work also required that any construction work on the valley slope should proceed in a cautious manner and should be assisted with an observational approach.

The final slope reinforcement design consisted of 34 cast-in-place concrete piles in four rows. The bottom two rows consisted of 15 cast in place concrete piles, 2.1 to 2.4 m diameter, and extending 30 m deep. The upper two rows consisted of 19 piles of 1.5 m diameter with pile length varying from 35 to 47 m. All the slope stabilization piles extended about 8.5 m below the deepest potential sliding surface. The slope stabilization piles were installed between July 2017 and March 2018. Construction of the LRT tunnel portal and bridge abutment on the slope commenced after the bottom two rows of stabilization piles were in place.

Extensive geotechnical instrumentation and monitoring programs were developed and implemented to monitor the construction-induced slope movements. Readings of the ShapeAccelArray (SAA) have not detected any deep-seated ground movements in the Grierson Hill Slide area to date.

### 4.5 Louise McKinney Park Buildings

In 1978, the Grierson Hill Slide area was graded and landscaped into the current Louise McKinney Park. Developments in the park to date have involved construction of several recreational facilities including the Millennium Stage, River Front Plaza and Promenade, Chinese Gardens, Trans-Canada Trail Pavilion and recent utility installations. Further developments are being planned.

These buildings are situated within the active landslide area. In addition, some of these facilities are underlain by a significant depth of poor quality miscellaneous fill containing variable soils, landfill materials, and buried organics.

It was not considered feasible or practical to stabilize large portions of the landslide where these facilities are located. On this basis, the park facilities were designed to accommodate potential long-term slope movements, in the order of 20 mm in horizontal and 5 mm in vertical per year (Tweedie and Lao 2013).

The facilities were designed to incorporate sufficient flexibility so that structural components could be jacked up or relevelled in future if required to accommodate potential long-term total and differential settlements. Raft foundations and spreading footings have been used to support the existing facilities in the Louise McKinney Park. The facilities have performed successfully to date and the ongoing slope movements in the Grierson Hill Slide area do not appear to have significant influence on the as-built structures.

## 5 CONCLUSION

Historical records and engineering studies indicate that the Grierson Hill Slide area is marginally stable. The slide is sensitive to small changes in ground conditions and construction disturbance, which must be considered in the design of developments in the area. Recent rates of slope movements following construction of the toe berm and erosion protection have decreased considerably from pre-construction measurements.

Drainage measures and toe berms were successfully implemented to stabilize the active landslide and control excessive slope movements during the Grierson Hill Road construction. Unloading the site by removing a large quantity of materials from the upper slope was carried out during the Shaw Conference Centre development to improve the overall slope stability.

For the recent Edmonton Valley Line LRT project, slope reinforcement with multiple rows of slope stabilization piles was considered the most feasible solution to improve the stability of the natural slope and prevent potential slope movement and degradation.

## ACKNOWLEDGEMENT

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## REFERENCES

Balanko, L.A. 1980. *Edmonton Convention Centre Slope Stability Solution*. Canadian Society of Civil Engineers, Edmonton Section Seminar Technical Paper No. 80-1, Edmonton, Alberta.

Chan, D.H. and Morgenstern, N.R. 1987. Analysis of progressive deformation of the Edmonton Convention Centre excavation, Canadian Geotechnical Journal, 24:430 – 440.

EBA Engineering Consultants Ltd. and Norbert R. Morgenstern Consultants Ltd. 1979. *Edmonton Convention Centre Geotechnical Evaluation*. Report submitted to the City of Edmonton.

Godfrey, J. D. 1993. *Edmonton Beneath Our Feet*. Edmonton Geological Society, Edmonton, Alberta, Canada.

Martin, R.L., Williams, D.R., Balanko, L.A. and Morgenstern, N.R. 1984. The Grierson Hill Slide, Edmonton, Alberta. *Proceedings of the 37th Canadian Geotechnical Conference,* Canadian Geotechnical Society, Toronto, Canada, Canadian Case Histories – Landslides: 125 - 133.

Martin, R.L., Lewycky, D.M. and Ruban, A.F. 1998. Long Term Movement Rates in a Large Translational Landslide. *Proceedings of the 51st Canadian Geotechnical Conference*, Canadian Geotechnical Society, Edmonton, Alberta, Canada, 1: 23-30.

Tweedie, R.W. and Lao, A. 2013. *Louise McKinney Park Riverfront Plaza Expansion*, Report submitted to the City of Edmonton, Thurber Engineering Ltd., Edmonton, Alberta.

Wang, X. and EL-Ramly, H. 2012. *Edmonton Southeast LRT Expansion Preliminary Study of the Stability of the North Valley Slope in Grierson Hill Slide Area*, Report submitted to AECOM, Thurber Engineering Ltd., Edmonton, Alberta.