Catastrophic piping failure of Saskatchewan Provincial Highway No. 16: A geohazard case study

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ABSTRACT
Saskatchewan Ministry of Highways and Infrastructure (SMHI) experienced a catastrophic failure on Provincial Highway (PH) No. 16 near the town of Langham on 21 August 2007. At this location, the westbound lanes of PH No. 16 cross a steep incised gully that drains into the North Saskatchewan River. The failure occurred following a severe rain event at a site that is locally known as the Gully Fill. During investigation of the sideslope failures, planning was being undertaken to safeguard the Gully Fill embankment from the impounded water that was immediately South of the highway. While Engineers were on site, a large vertical sinkhole developed in the South sideslope of PH No. 16, adjacent to the travelled lanes. Engineers immediately closed the highway to traffic, narrowly averting injuries to the travelling public. Traffic was re-routed to the existing Eastbound lanes of PH No. 16 as two way traffic. Over the next few hours, additional sinkholes and intense deformation of the highway surface occurred. This paper documents the site conditions that led to failure as well as the design and remediation efforts that allowed the highway to be completely rebuilt in 3 months restoring four-lane functionality to the area. A discussion of the risk assessment and risk management techniques used throughout all phases of the project is also presented.

RÉSUMÉ
Le 21 août, 2007 il y a eu un échec catastrophique sur l'autoroute provinciale No. 16 près du village de Langham en Saskatchewan. Au site de l'échec l'autoroute croise un ravin apique, incisé qui se découle dans la Rivière Saskatchewan Nord. L'échec s'est passé suite à un évènement de pluie au lieu appelé Gully Fill. Durant l'investigation des ruptures de l'escarpement, une stratégie a été élaborée afin de protéger le talus du ravin du réservoir d'eau directement au sud de l'autoroute. Un grand effondrement vertical s'est développé dans la pente sud de l'autoroute tout près des voies vers l'ouest pendant que les ingénieures étaient au site. Les ingénieures ont immédiatement barré l'accès à l'autoroute pour assurer la sécurité du public. Le trafique de la voie vers l'ouest fut rediriger aux voies vers l'est qui a put permettre le trafique bidirectionnel. Plusieurs autres effondrements et grandes déformations se sont développés sur l'autoroute quelques heures suivant le premier effondrement. Ce compte-rendu inclus l'analyse des conditions du lieu qui ont mené à l'échec ainsi que la conception et les mesures de redressement qui ont été exécuté pour rétablir le service à quatre voies de l'autoroute en trois mois. Le compte rendu discute aussi les techniques d'évaluation du risque et de gestion du risque qui ont été appliqué à toutes les phases du projet.

1. INTRODUCTION

Saskatchewan Ministry of Highways and Infrastructure (SMHI) experienced a catastrophic failure on Provincial Highway (PH) No. 16 near the town of Langham on 21 August 2007. The failure area is located at the top of south bank of the North Saskatchewan River valley and along the westbound lanes of PH No. 16 (Figure 1). The Gully Fill area is located at approximately kilometre 34.72 on Control Section 16-23. At this location, the westbound lanes of PH No. 16 cross a steep incised gully that drains into the North Saskatchewan River. The highway embankment height at this location is in excess of 15 m. Movement at the nearby Historic Site Lookout located at kilometre 33.6 of this same control section has also been a concern over the past twenty years. The Canadian National (CN) Railway embankment is located immediately north of the Westbound lanes of PH No. 16 along this entire stretch of highway.

2. BACKGROUND

This site has been the subject of several reports detailing numerous soil problems. These problems have included multiple separate side-slope failures as well as severe settlement of the highway embankment and piping failures.

In addition, numerous concerns have been raised about the overall North Saskatchewan River valley wall stability in this area as it relates to both the highway embankment as well as the CN Railway embankment. The valley wall instability is triggered by erosion of the North Saskatchewan River along a curved portion of the river immediately north of this site. The weak clay shale foundations and increased water table present at this site also contribute to the instability of the valley wall.

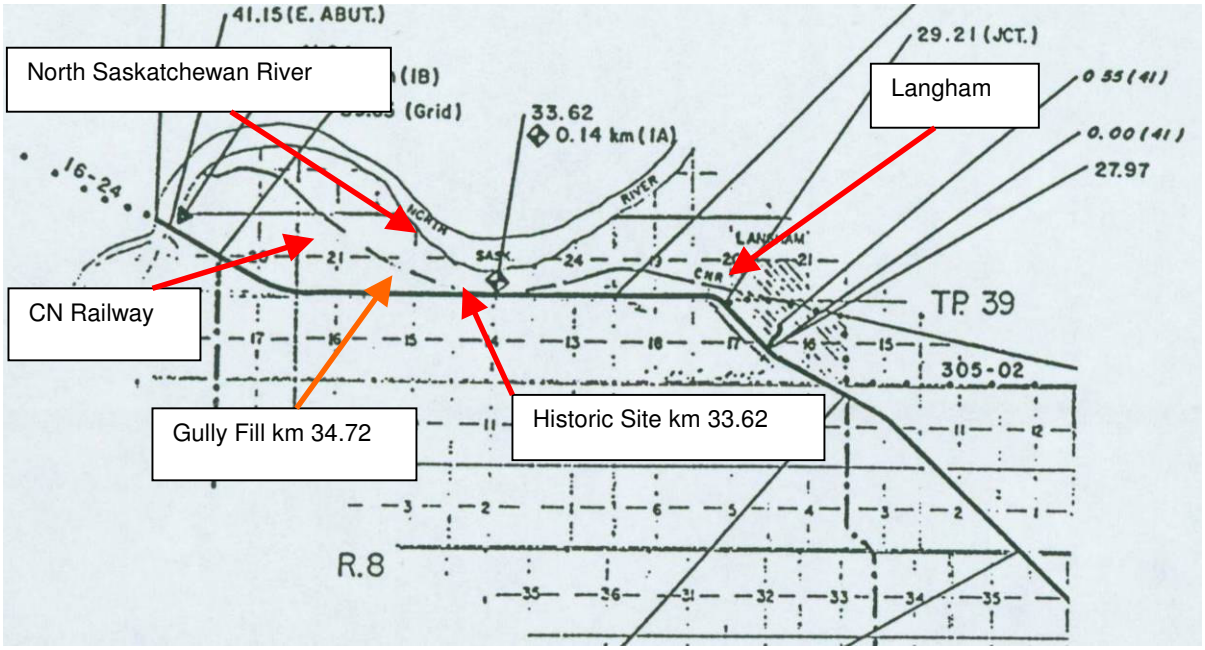

Figure 1: CS Map of Highway 16 west of Langham

Slope movement problems have been reported at the Gully Fill, since its most recent reconstruction in 1967. The original alignment of this highway predates the 1940's based on a review of historic aerial photos at the site. Modifications to the original embankment at this location included the removal of earth fill from the area immediately North of the current westbound lanes. This was due to slope movement in the railway embankment as a direct result of being loaded from the south side by a joint highway/railway embankment. As a result, the embankment on the north side of the present westbound lanes and south side of the railway was removed. All work was completed by the spring of 1968.

Surface drainage from a large area to the south accumulates in the median between the eastbound and westbound lanes at the Gully Fill. Here the runoff water enters a 900 mm diameter and approximately 160 m long culvert through the fill. This culvert daylights on the north embankment of the CN Railway. Local drainage from the ditch between the highway and the railway is funnelled to the gully, where it accumulates in a catch basin and drains vertically (4.5 m) into the through grade culvert near its mid-point.

In 1993, major slope failures west of the Historic Lookout from approximately km 34.0 to 34.5 on the north embankment resulted in major repairs. Substantial excavation effort was required to repair the slopes and restore stability to the site. The repair was successful and removed a potential stability threat from the railway. In an investigation of the culvert at the Gully Fill in December 1993, the outlet end of the culvert was completely frozen and water was accumulating upslope. The condition of the culvert was not clearly assessed due to problems with accessing the culvert at the base of this 15 m high embankment. There is a possibility that the through grade culvert may have already been compromised at this time.

During the planning stage for completion of the eastbound lanes of PH No. 16 in 1996, a location study was completed. This study identified the appropriate site for the highway based on the numerous stability issues experienced in the past as well as concerns about the North Saskatchewan River valley wall stability and its impacts on the current highway (Misfeldt – 1996). Relocation of the new eastbound lanes to a point south, where stability was not a problem, was selected. The lanes were positioned with sufficient offset south to handle the future relocation of the existing westbound lanes to allow both sets of lanes to be located away from the area of instability. The decision to relocate the westbound lanes was deferred until the westbound lanes were compromised.

3. SYNOPSIS OF EVENT LEADING TO FAILURE

On 17 - 19 August 2007 a severe (1:50 year) rain event occurred (approximately 200 mm in 48 hours) in the Langham area. Water backed up behind the eastbound lanes of PH No. 16 and flowed into the gully between the eastbound and westbound lanes (Figure 2 and Figure 3). The water began to build up due to the inability for the long through grade culvert to pass the water flows. The water began to run towards the east and flow through the highway at that point. This culvert was unable to handle all of the flow and at approximately noon on 19 August 2007, the water began to overtop the highway surface of the westbound lanes approximately 150 m east of the Gully Fill. At this location, a sideslope failure occurred on

the north slope of the westbound lanes due to the overtopping event. The vertical headscarp drop at the north pavement edge was in excess of 2 m for a length of approximately 70 m (Figure 4). The location of this failure is the same location as the repairs to the embankment conducted in 1993.

During the site investigation on 21 August 2007, a major failure occurred at the Gully Fill. A large body of water accumulated south of the embankment of the westbound lanes. This area was of concern because of the historical problems at the site and the possibility that a rapid drop in the water level could initiate a "rapid draw down" failure. It was surprising to find that most of the water had disappeared overnight. This presented a concern about a possible slope failure and loss of stability. While investigating the reasons for the rapid water loss a hole appeared adjacent to the south shoulder on the west lanes. The sinkholes and deformation (Figure 5) occurred very rapidly resulting in the closure of the westbound lanes of PH No. 16 and the rerouting of traffic to the eastbound lanes at approximately 3:15 PM on 21 August 2007.

4. ANALYSIS OF OBSERVED FAILURE

Excavation and examination of the gully culvert through the embankment found that it was in poor condition (eroded with holes), contained boulders and rocks, as well as a tire with wheel rim (Figure 6). Restrictions on water flow through the embankment caused water to back-up" into the gully. This caused the overtopping of the highway to the east and created large seepage pressures around the culvert. These seepage pressures caused a form of piping around the culvert to occur. While this piping likely started some time ago (the gully was previously filled with water and had to be pumped in 2005), piping type failures can accelerate with time and the recent large rain fall event triggered the eventual failure of the embankment. During this event, a large quantity of soil was washed out of the embankment. This was evidenced by the dark colored discharge of water in the North Saskatchewan River observed and photographed from the air (Figure 7) as well as from the downstream culvert. The large cavity created by the piping undermined the highway and lead to the failure on 21 August 21 2007.

The highway in this location is also on an active landslide. A slope inclinometer (SI 124) to the east near the site of the overtopping showed movement. Another slope inclinometer (SI 125) down slope of the gully has shown considerable movement and at different depths. This SI is now inoperable. The readings from these slope inclinometers are shown in Figure 8. Two slope inclinometers installed in the gully embankment have both sheared off near the base of the embankment. Figure 9 contains a conceptual model of slope movement along the valley slope. The landslides slowly work their way up the slope (retrogress) when activated. The present westbound lanes appear to be just inside the last slide block, with only 5 mm of horizontal movement in the past 7 years. In contrast, SI 125 down slope has had over 50 mm of movement the past 6 years with multiple slip surfaces (at least 3 evident at SI 125 location).

Figure 2: Aerial view of site looking west

Figure 3: Aerial view of site looking southeast

Figure 4: Aerial view showing water overtopping highway and small slide

Figure 5: Catastrophic sinkhole failure of 'Gully Fill' Embankment

Figure 6: Photo of tire and rim in culvert

Figure 7: Photo of sediment flowing into river.

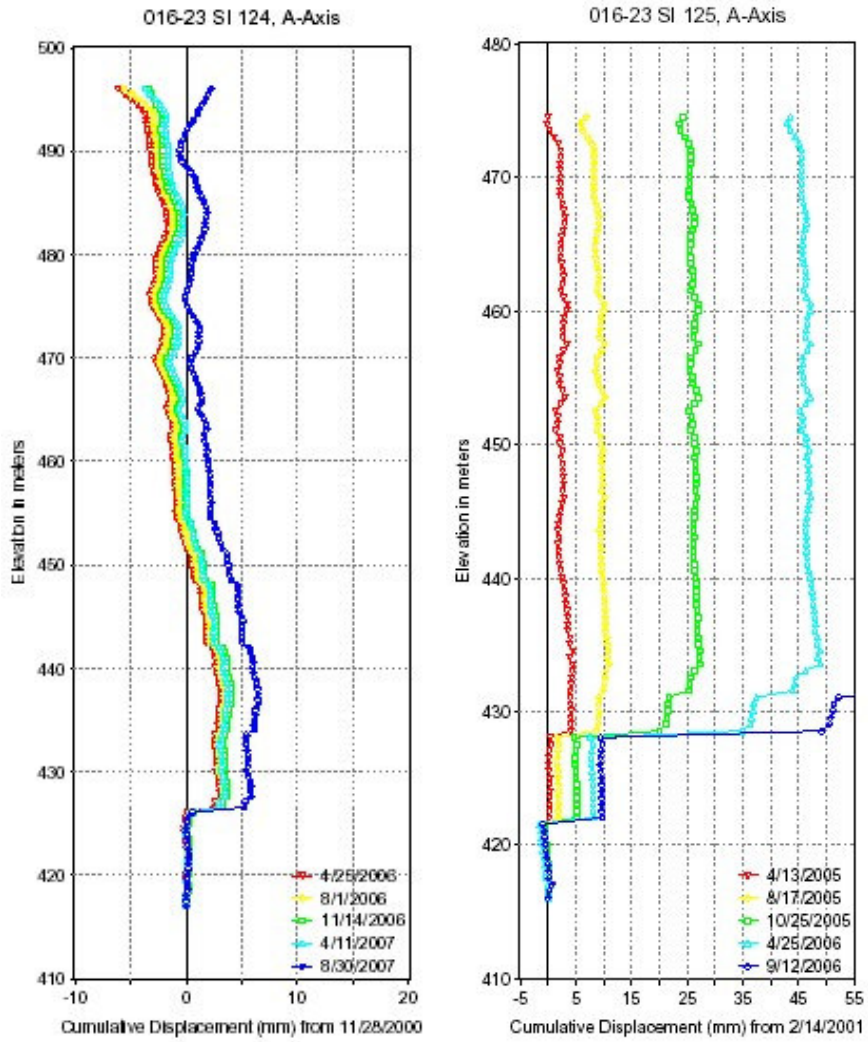

Figure 8: Slope inclinometer results.

5. RECOMMENDED ALTERNATIVES

5.1. Alternative 1: Rebuild Existing Westbound Lanes

This option was to rebuild the present westbound lanes embankment from the bottom up at both the Gully Fill and the sideslope failure location 150 m to the East. The grade would be excavated down to the existing culvert slowly in order to ensure that all failed and weakened portions of the existing embankment are identified. This would also enable an assessment of what actually caused the failure of the embankment and culvert.

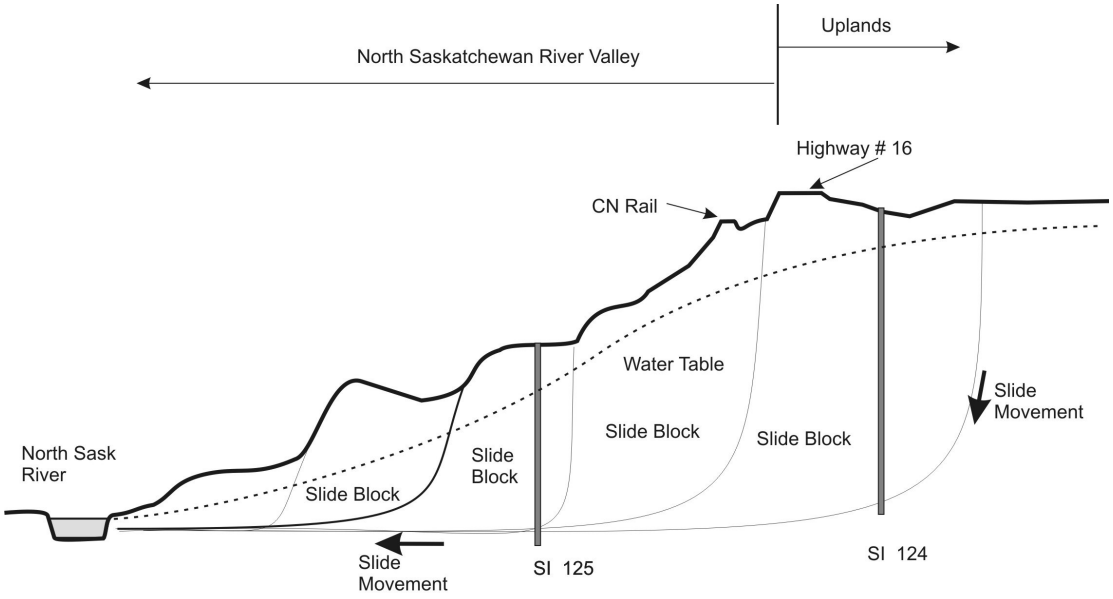

Figure 9: Conceptual slope model.

5.2. Alternative 2: Repair Existing Westbound Lanes Concurrently Building New West Bound Lanes

This option was to repair the existing westbound lanes to allow traffic to utilize the lanes during the winter and through construction of the new westbound lanes. This would include the excavation of the failed area and the restoration of the original embankment to allow traffic on the existing westbound lanes. As traffic uses the existing the westbound lanes, the new westbound lanes would be constructed to the south parallel to the existing eastbound lanes.

5.3. Alternative 3: Relocate and Build New Lanes

This option involved having westbound lanes relocated immediately North of the existing eastbound lanes. This would involve approximately 3.5 km of new construction. Relocating of the westbound lanes would locate the new lanes outside of the identified North Saskatchewan valley wall landslide area.

There were borrow locations available in the current median and the existing westbound lanes could be a potential borrow source as well. The surfacing structure would be increased to address the possible issues of wet/weak subgrade in order to shorten the construction time for the project. During construction at the Gully site, trench and toe drains would be incorporated into the design as well as instrumentation in the side slopes to monitor the future performance of the site.

5.4. Alternative 4: Repair Existing Westbound Lanes and Tender New Lanes for Completion in Fall 2008

This option was to repair the existing westbound lanes to allow traffic to utilize the lanes while a tender was issued for completion of the new lanes the following year. This would require the existing westbound lanes to be repaired and operational for an extended period of time. The new lanes would start construction during the summer of 2008 with a planned completion in the fall of 2008.

6. RISK ASSESSMENT

Geohazard and Corporate Risk Assessments were conducted on all options to assess the risks involved with the solutions at this location.

6.1. Immediate Risks

The highest immediate risk to SMHI was identified to be another rain event. This would likely cause further damage to the failed embankment. The rain event could also endanger the CN Railway down slope to the north.

Many options were proposed and discussed in regards to the attenuation or diversion of water under this scenario. With the failure of the culvert through the westbound lane embankment, it was decided that the best emergency measure was the installation of pumps. Pumps were installed to lower the water level at the gully, if a rainstorm event occurred.

6.2. Geohazard Risk Assessment

The Geohazard Risk Assessment was completed in accordance with the SMHI landslide risk management system (Kelly et al. 2004). Based on this system, a Probability Factor (PF) and Consequence Factor (CF) are determined, which are used to calculate the risk level as shown:

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

Once the Risk Level is determined, all the options can be compared.

Using the Geohazard Risk Assessment technique, Alternative 3 provided the lowest short term and long term risk. Alternative 1 had the highest short term and long term risk with a prolonged period of time until risk would begin to drop based on performance.

It was decided, based on the Geohazard and Corporate Risk Assessment techniques, that the immediate relocation of the westbound lanes (Alternative 3) provided the best solution for this catastrophic failure.

7. ACKNOWLEDGEMENTS

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