



Application of Air Launched Soil Nails to a Soft Soil Landslide

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ABSTRACT

The Saskatchewan Ministry of Highways and Infrastructure (SMHI) engaged MDH Engineered Solutions Corp. (MDH) to assist in the investigation of a shallow landslide in an environmentally sensitive area on Provincial Highway No. 56 north of the town Lebre, Saskatchewan. Part of this work involved the development of repair options to stabilize the roadway embankment. The landslide was on a heavily vegetated and steep embankment with a water course at the toe of the embankment. Traditional repair techniques such as slope flattening or a toe berm would be difficult to construct and would have significant local environmental impacts. In order to address these concerns, air launched soil nails (soil nails) were chosen as the best method to stabilize the slope. The soil nails could be installed from the road surface which would mitigate any environmental impacts and safety concerns. The design and installation procedures are primarily based on empirical parameters. This paper describes the landslide and air launched soil nails.

RÉSUMÉ

Le ministère des autoroutes et de l'infrastructure de Saskatchewan a engagé MDH Engineered Solutions Corp. pour collaborer sur une étude d'un glissement peu profond sur l'Autoroute Provinciale No. 56 au Nord du village Lebre en Saskatchewan. Le glissement se situe au sein d'un environnement sensible. Des options correctives pour stabiliser le talus de l'autoroute ont été développées pour ce projet. Le glissement était situé sur une pente escarpée, lourdement couverte de végétation avec un cours d'eau le long du pied du talus. Puisque le glissement est situé dans une région sensible les options typiques pour remédier le défaut, tels que réduire le degré de la pente ou construire une berme au pied du talus, seraient difficiles à effectuer et créeront des effets néfastes pour l'environnement. Il était déterminé que la solution optimale pour stabiliser le talus soit d'appliquer la technologie des clous de sol à lanceur d'air comprimé. Les clous de sol peuvent être installés avec de l'équipement qui reste sur l'autoroute, ce qui minimise l'impact sur l'environnement et qui réduit les soucis de sûreté. Les techniques de conception et d'installation sont basées sur des paramètres empiriques. Cet article décrit le glissement et les techniques de la technologie des clous de sol à lanceur d'air comprimé.

1 INTRODUCTION

The Saskatchewan Ministry of Highways and Infrastructure (SMHI) engaged MDH Engineered Solutions Corp. (MDH) to assist in the investigation of a shallow landslide in an environmentally sensitive area on Provincial Highway No. 56 north of the town, Lebre, Saskatchewan (Figure 1). A large mobilization of the valley slope created a shallow landslide that is approximately 12 m high and 30 m long (Figure 2 and Figure 3). The landslide had to be repaired due to the potential for further movement, which would impact the road surface.

There was a potential for the landslide to threaten the stability of Highway No. 56 and the safety of the motoring public. The vegetation was disturbed, exposing the silty till to a significant potential for erosion, which further increased the risk of a catastrophic landslide.

2 SITE INVESTIGATION

On August 1, 2008 MDH personnel inspected the site to determine the potential risk associated with a landslide adjacent to Highway No. 56. MDH utilized the SMHI Geohazard Risk Assessment System to characterize the site.

2.1 SMHI Geohazard Risk Assessment System

SMHI developed a geohazard risk management methodology to provide a systematic and consistent approach for evaluating the risks associated with geohazards and to identify the type of mitigation required to manage the geohazard. The SMHI Geohazard Risk Assessment System (Kelly et al, 2005) is based on the Alberta Transportation Landslide Management System (Alberta Transportation, unpubl.). It is a well documented, peer reviewed descriptive system that has been applied in several jurisdictions.

The SMHI Risk Assessment System characterizes a site using a probability factor and a consequence factor, ranging from 0 to 20 and 0 to 10 respectively. These factors are then used to determine the associated risk, ranging from 0 to 200. The associated risk is then categorized into four categories (Inactive, Routine, Priority, and Urgent) to provide a recommended response and management approach. SMHI utilizes this system for numerous landslide sites throughout Saskatchewan.

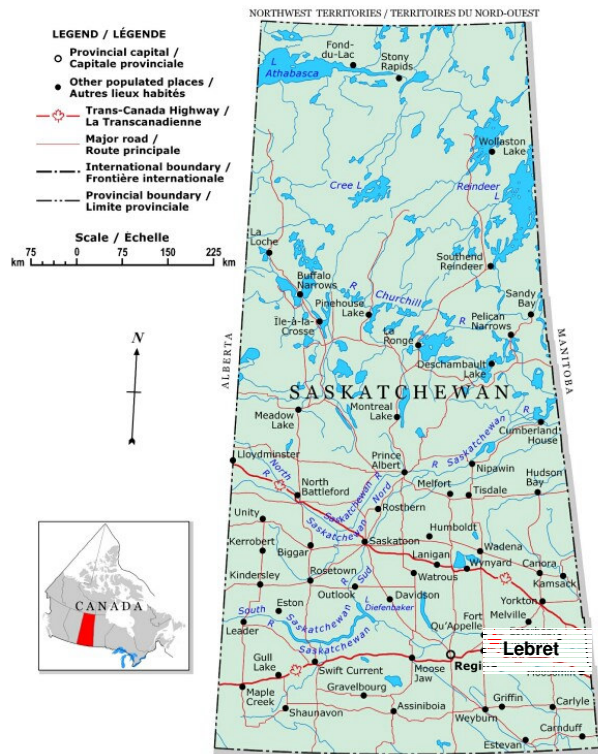


Figure 1: Site location



Figure 2: Looking southeast – 30 m scarp and 12 m drop



Figure 3: Looking northwest – Landslide head scarp adjacent to highway

2.2 Site Evaluation

Based on the SMHI Geohazard Risk Management System, MDH assigned a probability factor of 17 out of a possible 20. This factor was assigned based on the high rate of movement with additional associated hazards. MDH assigned a consequence factor of 10 out of a possible 10. This factor was assigned based on the fact the highway could be closed as a direct unavoidable result of the landslide's continued movement. In addition, the site posed a risk to public safety because rapid remobilization of a large-scale slide was possible and could occur without warning.

The risk score was 170, which ranked this landslide in an Urgent Response Level requiring immediate mitigation options.

2.3 Mitigation Alternatives

Several mitigation alternatives were considered for the slope remediation. Traditional repair techniques, such as slope flattening or a toe berm, would be difficult to construct and would have significant local environmental impacts. As a result, traditional slope repair techniques were eliminated as remediation options.

Considering the apparent depth of the landslide failure surface was shallow, air launched soil nails were considered as a favourable alternative. The existing soil conditions consisted of surficial silty till material. The full extent of the geology in the immediate area was not known with the absence of test holes, but air launched soil nails can penetrate most soil conditions. Perforated soil nails would be used with concerns that pore water pressures may be a contributing factor to the landslide because they allow pore water pressures to dissipate.

The recommended remediation alternative was to use perforated air launched soil nails. The soil nailing would stabilize the slope and using the perforated soil nails would reduce pore water pressures in the highway embankment and valley wall.

3 AIR LAUNCHED SOIL NAILING

Air launched soil nailing is a relatively new technology that has achieved increased acceptance as a technique to stabilize shallow landslides. Morsky Industrial Services (Morsky), the exclusive supplier of this technology in Canada, was contracted to perform the required soil nailing. This technology uses pressurized air to launch 6.1 m long perforated or imperforated nails into the ground (Figure 4). All penetrating force from the air pressure is located at the tip of the nail (Figure 6). The shear strength of the soil nails helps to stabilize the soil mass and resists movement along the shear plane. This reinforces the soil and forces potential slip circles back beyond the depth of penetration of the soil nails.

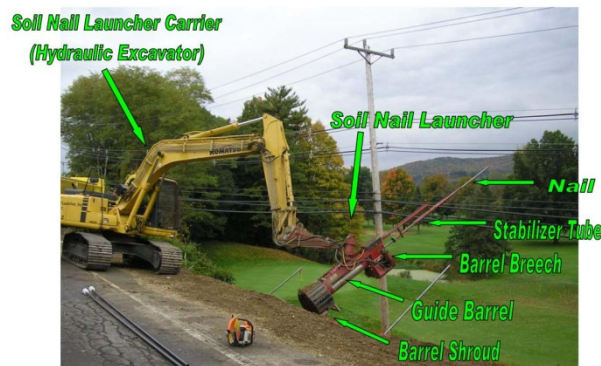


Figure 4: Soil nail launcher schematic

In 2005, MDH used this repair technique to effectively address an emergency landslide on Highway No. 20 along the Qu'Appelle River near Craven, Saskatchewan. All of the repairs were completed from the road surface, so there was virtually no environmental impact. This is extremely useful when working around bodies of water or environmentally sensitive areas. This option is also safer because there is no heavy equipment working on the disturbed slope (Antunes, 2006).

3.1 Soil Nail Design Parameters

The current soil nail design parameters are primarily empirical. Soil nail spacing is designed based on a simplified wedge analysis (New York State Department of Transportation, 2008 and United States Department of Agriculture, 2004). This design methodology is still in the developmental phase, therefore the minimum soil nail spacing was used for this landslide.

The soil nail design pattern consisted of a diagonal offset pattern of 1.0 m (Figure 5). A minimum distance of 1.0 m was required from the highway. The soil nails were extended to edges of the landslide area.

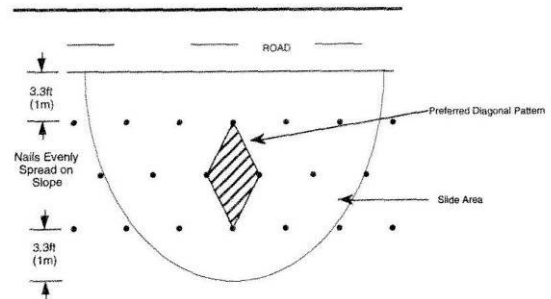


Figure 5: Soil nail design pattern

3.2 Site Preparation

The landslide adjacent to Highway No. 56 needed to be prepared before the proper mitigation measures could be installed. Excess disturbed material was removed from the slope to remove the driving force from the existing slide and help reduce further movement. It also allowed any cracks in the soil to be closed before the soil nailing started. Along with soil nailing, turf reinforcement matting (TRF) was used to minimize and control future erosion potential until vegetation could be re-established. The soil nails were launched through the TRF.

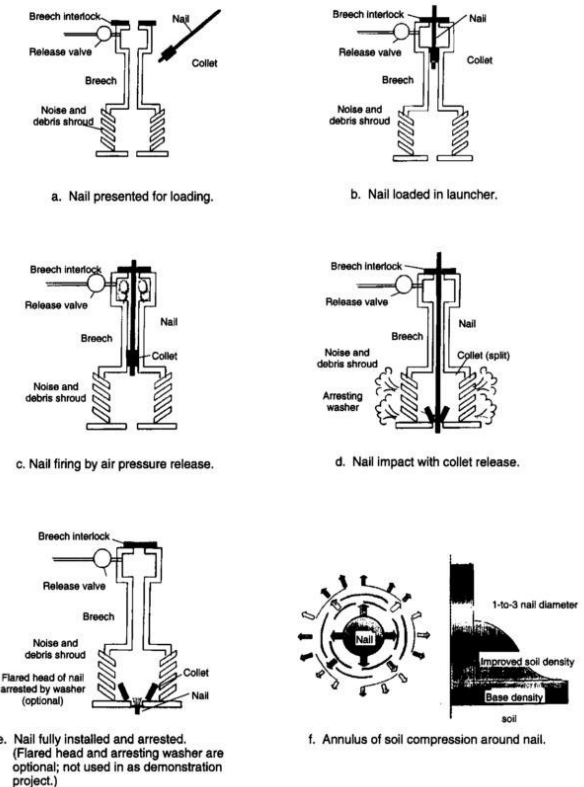


Figure 6: Soil nail launcher schematic of operation

Site preparation began on October 20th, 2008. This process involved removing all excess disturbed soil from the slide and closing any cracks in the disturbed slope (Figure 7). Additional preparation for the TRF involved digging a small trench at the crest of the highway embankment to secure the TRF (Figure 8). This is required to anchor the TRF and ensure surface water stays on top of the TRF.

Site preparation was completed in one day, minimizing the amount of time heavy equipment operated on the unstable slope.



Figure 7: Removal of excess disturbed soil



Figure 8: TRF trench at crest of embankment

3.3 Site Mitigation

Soil nailing started on October 21, 2008. Initially, soil nail penetration into the soft soil was variable using the air pressure typically used for soil nail launching. Some nails penetrated to the target 6.1 m depth while others did not (Figure 9). Examination of the soil nails' penetration locations after nailing showed that the launched soil nails had not penetrated into the embankment, but they created small cavities and voids from the impact (Figure 10). Typical air pressures used to launch soil nails ranges from

12 400 kPa (1800 psi) to 22 000 kPa (3200 psi) depending on soil conditions. All penetrating force from the air pressure is located at the tip of the nail. Air pressure is generally increased to achieve greater soil nail penetration.

The apparent depth of the landslide failure was shallow, so the full 6.1 m soil nail penetration was not required. However, the greater the soil nail penetration the more effective the reinforcement. A soil nail penetration of 5.0 m or greater was desired to mitigate the risk of further retrogressive failures developing.

To solve the penetration issues, the air pressure was increased to launch the soil nails. Increased air pressures proved to be ineffective, therefore construction was stopped to evaluate if mechanical issues were preventing proper soil nailing penetration.

The problem was initially attributed to an equipment malfunction or faulty soil nail collars. After inspecting and completing maintenance on the launching mechanism and the soil nail alignment mechanism (Figure 11) and using different soil nail collars, soil nailing was attempted again. Further attempts to launch soil nails proved to be ineffective after these changes were made.

MDH then recommended that Morsky decrease the air pressure used for launching the soil nails. Air pressure was decreased below levels normally used for launching soil nails. The air pressure was decreased to approximately 5515 kPa (800 psi). The soil nails were then able to penetrate the soil to the expected depth into the highway embankment. Minor air pressure adjustments were required for the remaining soil nails that were installed in order to achieve the required penetration depth.

Concluding the installation of all the soil nails, the exposed ends of the soil nails were cut and plates were welded on the soil nails to secure the TRF.

The soil nailing was successfully completed on October 24, 2008 (Figure 12). SMHI installed asphalt curbing along the 30 m section of highway above the landslide scarp (Figure 13). The curbing will direct highway surface runoff away from the landslide area to half culverts to direct drainage safely down the slope (Figure 14).



Figure 9: Unsuccessful soil nail penetration



Figure 10: Small void created in ground post soil nail launch



Figure 11: Inspection and maintenance on soil nail launcher



Figure 12: Completed soil nailing and TRF installation



Figure 13: Asphalt curbing installation

3.4 Soil Nailing Advantages

Soil nailing provided the ideal mitigation measure for this site considering the minimal time available before winter season and the potential environmental concerns associated with traditional slope repair techniques. The steep slope would have created difficult working conditions for traditional slope remediation. The majority of the repair work was completed from the road surface. The time required and costs associated with approving large earthworks projects in an environmentally sensitive area would have delayed the project and potentially impacted the motoring public's safety.

Traditional techniques for slope remediation would have required extended site occupation and additional equipment and, in this case, construction would likely have extended into the early winter during which conventional slope repair methods (e.g. earthworks) would have been extremely difficult in freezing conditions.

Not only was the stability of the roadway embankment enhanced, the perforated soil nails will dissipate the pore water pressures in the embankment and valley wall. Due to the late season repair, no visual pore water pressure dissipation was observed.



Figure 14: Asphalt curbing for installed half culvert

The required equipment for air launched soil nailing has the ability to mobilize quickly and to perform the intended work in a timely fashion. Soil nailing has an exceptionally low local environmental impact which avoids the lengthy environmental approval process associated with traditional repair techniques.

3.5 Soil Nailing Performance

The site will be monitored by SMHI to ensure continued performance and report, if there is any progression in the landslide.

To further monitor the soil nails' performance, MDH also recommended that SMHI conduct a geotechnical site investigation to complete a global stability analysis of the valley wall where the landslide occurred. This investigation and analysis would provide SMHI with an indication if additional measures are needed to monitor and manage the associated risks that have developed at this site. It would also support the evaluation of the potential remediation options.

In the event that the soil nails are insufficient to control movement at this site, a Geosynthetic Reinforced Soil (GRS) Wall or other reinforced retaining wall structure is one of several options that could be installed to increase the highway embankment stability. A GRS wall would enhance the embankment stability and have minimal environmental impacts during construction.

4 CONCLUSION

The soil nailing used to remediate the landslide adjacent to Highway No. 56 revealed that typical air pressures for launching soil nails were not suitable for all soil conditions. Increasing air pressure for soil nailing may not be the solution for increasing the penetration depth in very soft soil conditions. Air pressures need to be adjusted according to soil conditions.

For future soil nailing projects, air pressures should be calibrated until the optimal soil penetration is achieved. Developing a record of soil types, air pressures, penetration depths and locations of soil nailing projects will make it easier to calibrate air pressures to soil types at the start of an air launched soil nailing project.

ACKNOWLEDGEMENTS

The writers would like to acknowledge the contribution of a number of individuals to this paper. In particular, members of Saskatchewan Ministry of Highways and Infrastructure, Morsky Industrial Services, and MDH Engineered Solutions Corp. who contributed to the investigations summarized in this paper.

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