

# Reconstruction of a roadway over an active landslide using lightweight cellular concrete

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## ABSTRACT

Since the early 2000s, instability was noted along a section of Highway 762 located approximately 18 km southeast of Bragg Creek, Alberta, Canada. Distress to the pavement included significant cracking and surface undulation. Repairs consisting of pavement overlays and/or milling were conducted on approximately an annual basis in order to maintain an acceptable driving surface. A geotechnical investigation at the site revealed that the cause of the pavement distress was an underlying landslide. In late 2017, a 300 m section of the roadway was reconstructed. Key design elements used to unload the landslide included lowering the roadway grade and the novel use of lightweight cellular concrete (LCC) within the embankment. In total, approximately 5,600 m<sup>3</sup> of LCC with a density of 475 kg/m<sup>3</sup> were placed. Since reconstruction, no movement of the roadway has been noted and no maintenance has been required.

## RÉSUMÉ

Depuis le début des années 2000, une partie de l'Autoroute 762, située à environ 18 km au sud-est de Bragg Creek, en Alberta, au Canada, est sujette à une instabilité. La chaussée présente d'importantes fissures et ondulations de la surface. Des réparations, qui consistaient à refaire le revêtement de la chaussée et/ou à fraiser, ont été réalisées approximativement tous les ans de façon à maintenir une surface de conduite acceptable. Une étude géotechnique sur le terrain a montré que la dégradation de la chaussée était due à un glissement de terrain sous-jacent. Fin 2017, une section de 300 m de la chaussée a été reconstruite. Les éléments-clés pris en compte pour limiter les contraintes au niveau du glissement de terrain comprenaient l'abaissement du niveau de la chaussée et l'utilisation de béton cellulaire léger (LCC) pour le remblai. Depuis la reconstruction, aucun mouvement de la chaussée n'a été constaté et aucun entretien n'a été nécessaire.

## 1 INTRODUCTION

This paper presents a case study for reconstruction of a section of roadway over an active landslide. The reconstructed roadway used lightweight cellular concrete (LCC) in conjunction with grade reductions to reduce the embankment load believed to be causing the landslide movement.

## 2 BACKGROUND

### 2.1 Site Location

The site is located along Highway 762 approximately 18 km southeast of Bragg Creek, Alberta, Canada (see Figure 1). Highway 762 is a two lane paved rural highway with an average annual daily traffic count of 1,070 vehicles. It trends north-south and provides access to many residential acreages and agricultural properties. At the study location, the highway crosses a landslide located toward the west end of a distinct double curve in the highway. This site was added to Alberta Transportation's Geohazard Risk Management Program (GRMP) in 2006 and is known as the "S-Curve Landslide"; Site S022 in the GRMP system. The site plan is shown in Figure 2.

### 2.2 Roadway Geometry

At the landslide location, the valley slope transitions from a gentle slope to a steep hillside. The gentle slope extends at about 5° or less to an adjacent creek while the steeper slope corresponds to a protruding bedrock ridge feature. The road alignment is located on the gentle slope near the transition from gentler to steeper gradients. The road embankment fill, is up to about 6.5 m high. The road embankment fill generally abuts the steeper ridge. A trapped low area on the ridge side of the road might have been backfilled during or subsequent to original construction to facilitate drainage. The road embankment was constructed with sideslopes of approximately 3 horizontal to 1 vertical.

### 2.3 History

Instability at S022 has been evident since early in the 2000s. The resulting distress to the pavement was evident in the form of significant cracking and surface undulation along a roadway length of approximately 200 m. In order to maintain a reasonable driving surface, repairs consisting of milling, pavement overlays, or both were performed on approximately an annual basis. The relatively gentle slope below the road embankment and the presence of wet, areas upslope of the road segment exhibiting distress

suggested the possibility that the pavement distress was related to a wet, unstable subgrade; however, the monitoring of slope inclinometers installed in 2007 confirmed landslide movement. The large-scale cracking pattern in the road surface followed a discernable arcuate pattern that extended across both traffic lanes. The presence of bedrock exposures to the north of the distressed area suggested the landslide was bounded to the north by the bedrock ridge. Construction of the road embankment appeared to have created a poorly drained area on the north side of the road, which likely produced an elevated groundwater condition in the slide mass.

A pavement overlay was placed in 2015. The condition of the roadway in 2016 is shown on Figure 3. Significant cracking and surface undulation was evident at this time. Figure 4 shows the poorly drained condition on the northwest side of the road in August 2016.

A scheduled overlay planned for the entire Highway 762 corridor, in combination with the deteriorating site conditions, was the trigger for design and implementation of remedial measures at the site.

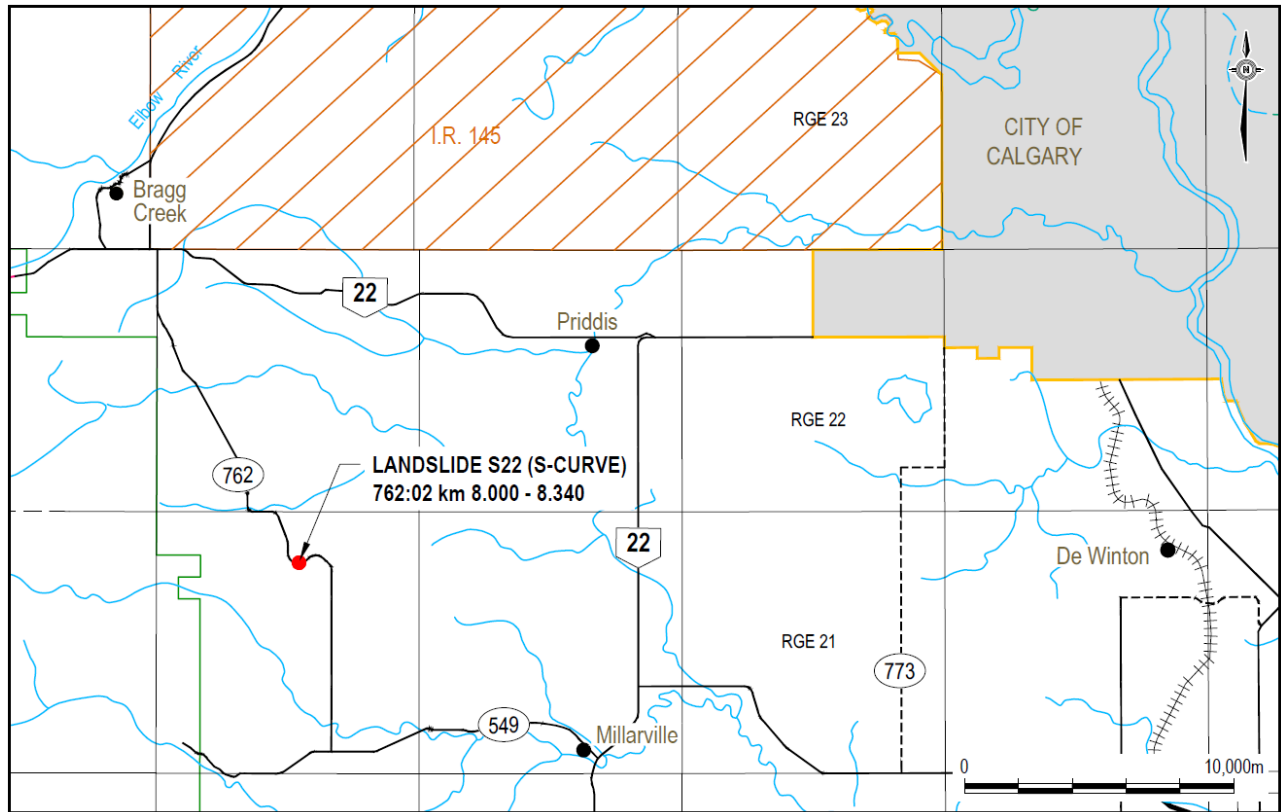


Figure 1. Site Location

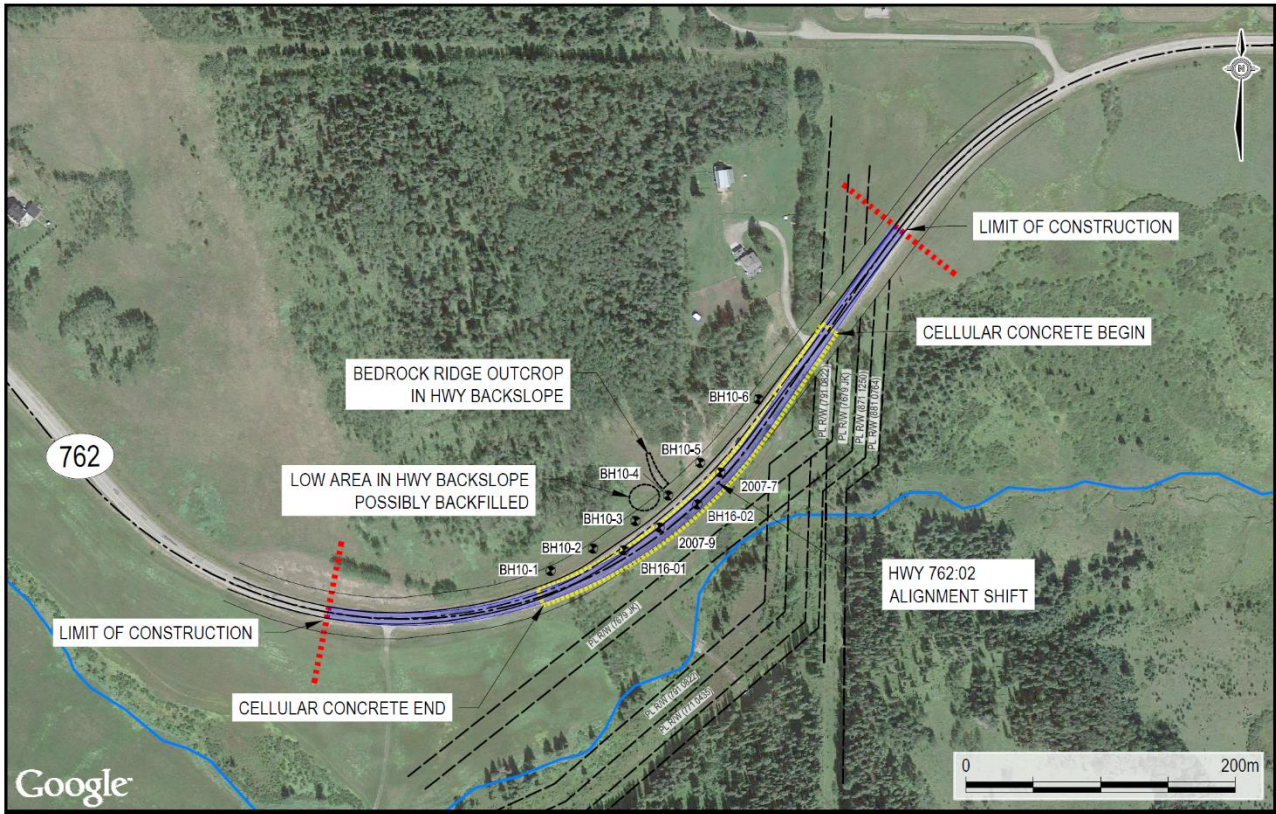


Figure 2. Site Plan



Figure 3. Photo of roadway looking SW, 2016





Figure 4. Photo of poorly drained area on NW side of roadway looking NE, August 2016

#### 2.4 Geotechnical Conditions

According to Moran (1986), surficial geology at S022 consists of lacustrine deposits and occasional localized deposits of more organic and recent pond deposits in the low-lying areas. Slopes above the low-lying areas generally comprise clay till draped over sedimentary bedrock. The origin of the till material is indicated to be superglacial-mudflow sediment and the site morphology is described as hummocky, glacial-collapse terrain.

Geotechnical investigations were performed in 2007 (two boreholes) and 2010 (six boreholes) by AMEC Earth & Environmental (AMEC 2007 and 2010). An additional two boreholes were drilled during the 2016 investigation by Tetra Tech Canada Inc.

Based on the borehole log information, road embankment fill generally consisted of a blend of clay, silt, and sand with some gravel and was typically low to medium in plasticity, possibly suggesting a clay till source. Organic inclusions in the fill were commonly noted.

A significant organic zone, up to about 2 m thick, was noted beneath or at the base of the road fill in all the boreholes that encountered the fill.

Lacustrine clay was present beneath the road embankment fill and organics in all but one borehole, where shallow bedrock was encountered. The lacustrine clay layer thickness was typically 4 to 5 m but ranged from 0 to more than 9 m. The lacustrine clay was medium to high plastic and its consistency ranged from very soft to very stiff.

The boreholes that penetrated the lacustrine clay encountered clay till, which was about 1 to 6 m thick. The clay till was generally described as stiff and medium plastic.

Sandstone or siltstone bedrock was generally logged in the boreholes that penetrated the overburden soils. The bedrock surface level appeared to be highly variable. The piezometric data suggested a general groundwater level about 3.5 to 4.0 m below the road surface, consistent with the observation of ponded water in the backslope ditch and seepage downslope of the embankment toe.

Two slope inclinometers, which subsequently confirmed landslide movement, were installed during the investigation in 2007. The slope inclinometers were approximately 60 m apart. The depth of movement in the two locations was estimated at approximately 7.5 to 8.5 m and 10.5 to 11.5 m below grade. The movement depths indicated that the landslide was based near the transition between the lacustrine and clay till layers.

A typical interpreted stratigraphy section is shown on Figure 5.

#### 2.5 Design

The mitigation options available at this site were limited due to the presence of: pipelines downslope and parallel to the highway; a small creek downslope of the pipelines, and; adjacent landowners reluctant to sell portions of their land. The repair work was generally restricted to the existing highway right-of-way. Repair options were to somehow dewater the slide mass, install a pile retaining wall, or reduce the driving force through offloading and/or lightweight fill replacement. Based on a pragmatic assessment of the likelihood of long-term success and costs it was decided to pursue an offloading/lightweight fill option.

The final design to stabilize the roadway embankment incorporated the following key elements:

- Lowering of the roadway grade by 0.6 to 2.2 m. This required a shift of the alignment away from the bedrock ridge backslope. This slight realignment had the advantage of maintaining traffic on the existing roadway through the construction period.
- Replacement of some of the existing embankment fills and underlying native soils with lightweight cellular concrete (LCC). Design thicknesses of LCC ranged from 1.0 to 3.6 m.
- Deepening of the backslope ditch and installation of an additional culvert to enhance surface drainage.
- Placement of a gravel blanket drain beneath the LCC to lower the local groundwater level and prevent floating of, or accumulation of groundwater in, the LCC. Non-woven geotextile fabric was placed on top of the gravel blanket drain to prevent infiltration of LCC during placement. A specialized woven geotextile filter fabric was placed beneath the blanket drain.

Stability analysis for this project was undertaken using a limit equilibrium approach implemented in the computer program SLOPE/W (GEOSLOPE). To calibrate the analysis models, back analysis of the slope was undertaken considering the conditions prior to the original construction, at the end of original construction, and the

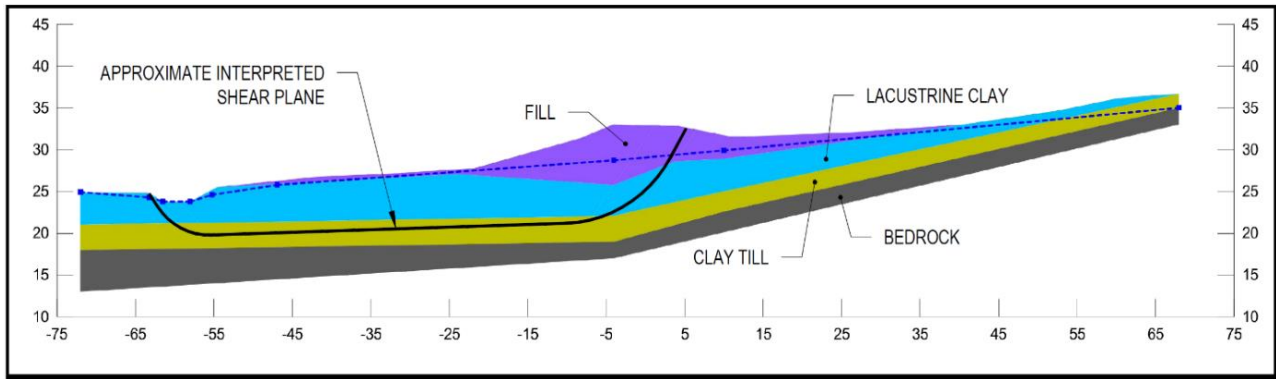


Figure 5. Typical Interpreted Stratigraphy Section

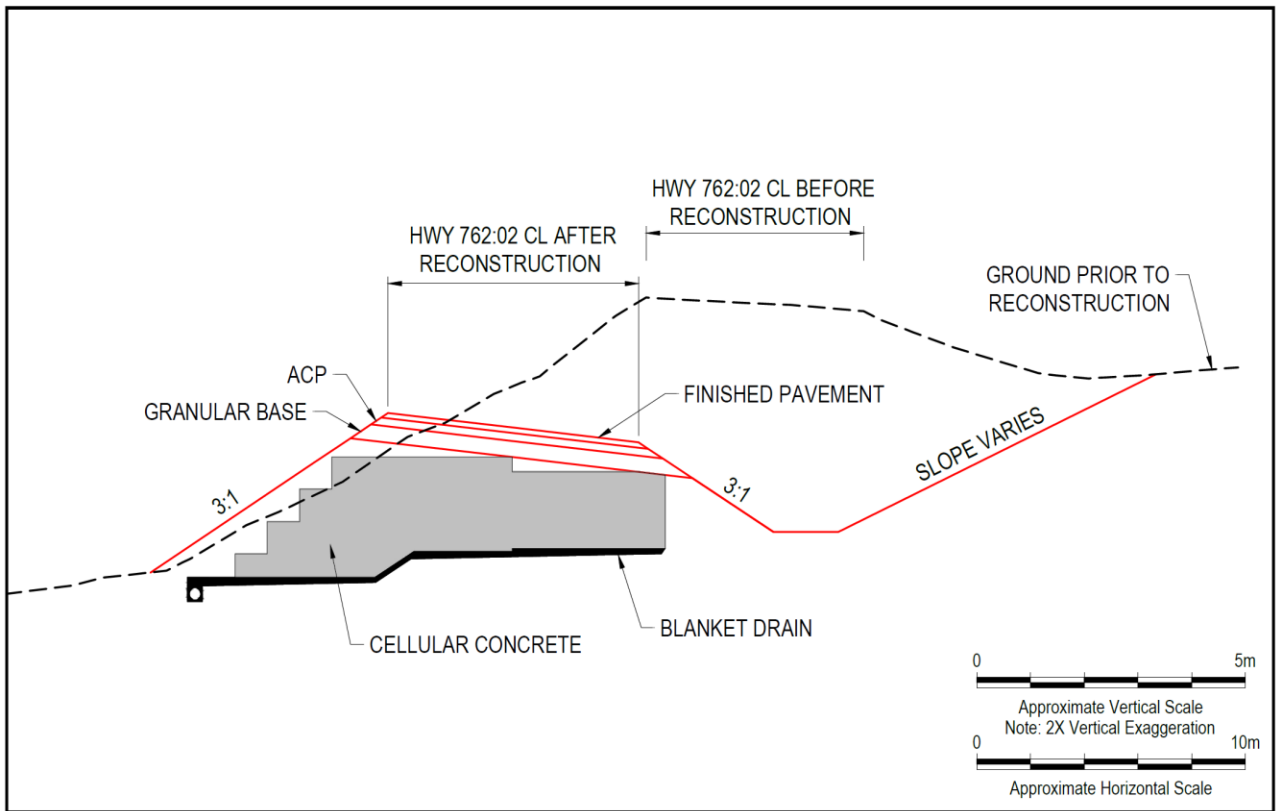


Figure 6. Typical section for reconstructed roadway embankment

2016 stability conditions. A target slope stability factor of safety of 1.3 was adopted for the design.

The design pavement structure on top of the LCC consisted of a minimum 300 mm granular and 150 mm asphalt. An additional 100 mm asphalt was placed immediately after the stabilization construction as part of a general overlay program for the highway.

A typical section for the reconstructed roadway embankment is shown on Figure 6.

### 3 DESCRIPTION OF CELLULAR CONCRETE

Cellular concrete, sometimes referred to as foam concrete (CROW 2003), is a lightweight construction material consisting of Portland Cement or Portland Limestone Cement, water, foaming agent, and compressed air. Fly ash, silica fume, and slag are often added to the mix to customize compressive and flexural strengths. Cellular concrete usually contains no sand or aggregate. Fresh cellular concrete is highly flowable and can be pumped into place over large distances (up to 1,000 m) through flexible hoses. In the vast majority of cases, cellular concrete is cast-in-place.

By trapping air bubbles within the concrete, a lightweight, insulating material is formed. The bubble structure inhibits bleeding of water.

Cellular concrete can have wet densities from 250 to 1600 kg/m<sup>3</sup>; however, most below-ground applications are placed at wet densities of 400 to 600 kg/m<sup>3</sup>.

Lightweight cellular concrete (LCC) may be produced using either “wet” or “dry” mix processes.

“Wet” mix processes use a cement and water slurry batched by a ready mix supply company. Once onsite, the temperature, density and viscosity of the slurry is measured to confirm compliance with the requirements to make LCC. After quality is verified, the slurry is delivered into the LCC equipment, which then injects foam into the slurry and pumps the LCC into place.

“Dry” mix processes are commonly used to produce LCC for high volume and/or high production rate (approximately 100 m<sup>3</sup> per hour) projects. “Dry” mix refers to the process whereby all of the constituents of the LCC are blended on site, first by mixing the cement and water into a slurry, followed by injecting the foam and pumping the LCC into place. Cement is delivered to site using bulkers. The Highway 762 project used a “dry” mix process.

#### 4 CONSTRUCTION

Reconstruction of the roadway was completed in late Summer/Fall 2017.

Construction commenced with excavation of the existing road embankment to reach the drain construction level beneath the LCC zone. During construction, highway traffic was maintained on temporary lanes in the backslope ditch area, which required delaying the final excavation of the ditch until traffic could be diverted onto the new construction.

The drainage measures required beneath the LCC zone effectively drained the minor seepage experienced on the excavation base. A perforated drainage pipe was installed beneath the location of the road embankment toe to transport collected seepage to a suitable outfall.

Placement and compaction of the wedge of fill covering the downslope side of the LCC and forming the finished road embankment slope proceeded behind the LCC placement.

The roadway had a complex geometry that included both horizontal and vertical curves, and superelevation. The cellular concrete section was conformed to this geometry to the extent that was practical. Placement of cellular concrete commenced at the lowest elevation of the roadway, and progressed uphill.

In light of the relatively large volumes, a “Dry” mix unit was mobilized to the site. These units are capable of pumping a distance of up to 1 km; therefore, the cellular concrete was produced from one location only. The “Dry” mix setup on the site is shown in Figure 7. In the photo, a bulker is evident delivering cement into the silos located at the rear of the cellular concrete pump unit. Water was delivered to site and stored in the tank shown at the left side of the photo.

As a result of the highly flowable nature of cellular concrete, the maximum slope that can be maintained is approximately 1%. In order to construct the LCC on the

slope, nonwoven geotextile partitions were used to stabilize the fresh material. Wooden formwork lined with polyethylene sheets was also provided to contain the LCC during placement. The wooden forms were held in place using steel rods hammered into the underlying soil or cured cellular concrete. After the placement of each layer, the LCC was allowed to cure overnight. Formwork was removed the following morning, and reused to contain the next layer of LCC. A photograph of the formwork and geotextile partitions is shown in Figure 8.

The maximum allowable LCC layer thickness for this project was 0.6 m, based on foaming agent selection. It should be noted that other foaming agents can be used to increase allowable lift heights, if desirable. However, in this case, the thickness of the LCC was governed by the complex geometry of the site.

Snow or water accumulation must be removed before LCC is placed. In addition, given that construction was progressing in the fall, provisions were made for insulation (tarps and/or heating) of the pours should the weather conditions dictate. However, none of these measures were deemed necessary given precipitation and temperatures encountered at the site.

A total of 5,600 m<sup>3</sup> of cellular concrete were placed over twenty three pour days between September 8 and October 8, 2017, inclusive. Although the dry mix unit can produce up to 100 m<sup>3</sup>/hour, daily pour volumes were limited due to the LCC geometry. Daily production ranged from 129 to 582 m<sup>3</sup>/day, with an average of 246 m<sup>3</sup>/day. Figure 9 below shows an aerial view after LCC was in place.

The project specified cellular concrete material properties to be a wet (as-cast) density of 475 kg/m<sup>3</sup> (+/- 10%) with a minimum compressive strength of 0.4 MPa at 28-days. Quality Control (QC) was conducted continuously throughout the operation to measure cellular concrete properties. Wet densities ranged from 442 to 520 kg/m<sup>3</sup>, with an average of 487 kg/m<sup>3</sup>. Cylinders were cast to verify compressive strength as per ASTM C495, Standard Test Method for Compressive Strength of Lightweight Insulating Concrete. Based on QC data, the average cellular concrete 28-day compressive strength was 1.1 MPa. Minimum and maximum compressive strengths were 0.6 and 1.7 MPa, respectively.

Quality Assurance (QA) testing was also performed by Tetra Tech Canada Inc. The results were similar to the above-noted QC testing. Wet densities ranged from 436 to 511 kg/m<sup>3</sup>, with an average of 456 kg/m<sup>3</sup>, and 28-day compressive strengths were measured at 0.9 to 1.9 MPa, with an average of 1.3 MPa.

Typically, granular base material may be placed and compacted the day after LCC placement. For this project, the majority of the base gravel was placed and compacted approximately one week after all the LCC was in place. Construction traffic was not allowed to drive directly on the LCC without the gravel in place. A dozer and skid steer were used to spread out the gravel once it was delivered to site. Static (no vibration) compaction was used to compact the gravel. Vibratory compaction was permitted during placement of the asphalt. Figure 10 shows an aerial view of the site after asphalt was placed.





Figure 7. Photo of Dry mix unit with cement bulker onsite



Figure 8. Photo of wood formwork on sides of cellular concrete, and transverse nonwoven geotextile partitions



Figure 9. Photo showing completed placement of cellular concrete prior to backfill with granular



Figure 10. Photo after placement of asphalt

## 5 ROADWAY PERFORMANCE

Since completion of 2017 construction, no significant movement of the roadway has been noted by visual monitoring, and no repairs of the roadway have been performed.

A photograph of the current roadway condition is shown on Figure 11.

Four landslide repairs were included in the overall construction contract, including the subject site. Allocating repair costs, it is estimated the cost of the repair work for this site alone was about \$3.4M. By comparison a pile retaining wall of sufficient size and length to provide comparable improvement to the factor of safety would be in the order of \$4.8M.

In recognition of the innovative solution to stabilization of the landslide, the project was honored with an Award of Merit from the Consulting Engineers of Alberta. The award was presented in February 2019.

## 6 POSSIBLE FUTURE APPLICATIONS FOR LCC

Building on the success of the project at S022, additional consideration could be given to use of LCC for small scale road subsidence repairs undertaken without extensive investigations or analysis. Often, these small scale repairs use gravel fill to reinstate the roadway subgrade surface; however, the success of this type of repair could be limited if a landslide or deep compressible zone is involved. Some embankment replacement with lightweight fill should improve the site conditions in most cases.

In this application, use of LCC has some advantages over the use of preformed lightweight fills. For instance, a repair using LCC would typically not require safe excavation access or substantial excavation/base preparation. LCC can be placed in deep (>2 m) lifts if necessary, and LCC can withstand traffic loading with relatively little cover.

It is therefore recommended that further consideration be given to the use of LCC for small scale repairs. Development of standard specifications and details for these repair types may also be beneficial.



Figure 11. Photo looking SW, April 2019

## 7 CONCLUSION

The landslide at S022 on Highway 762 was a serious situation that required a well-considered and innovative engineered solution to prevent further deterioration of the roadway. Since reconstruction in 2017, the roadway has not undergone any noticeable movements, and there have been no associated maintenance costs for the highway. The project is considered a successful application of lightweight cellular concrete to remediate the highway instability at this location.

## 8 ACKNOWLEDGEMENTS

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