Reconstruction of a high volume bus lane using cellular concrete

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ABSTRACT

Roadways constructed over frost susceptible soils often experience excessive heave as the subgrade soils freeze, followed by softening during spring thaw. This paper examines a case study for reconstruction of a high traffic bus lane over frost susceptible soils in the City of Calgary using lightweight cellular concrete (LCC). Subgrade conditions at the site were comprised of a wet, frost susceptible, silty clay. As a result, the roadway was experiencing severe frost heave during winter conditions. Also, the high volume of heavy bus traffic was creating rutting of the roadway surface, necessitating yearly repairs. Reconstruction was completed in the summer of 2000 using a layer of LCC to insulate and strengthen the roadway subbase. Benkleman Beam testing performed shortly after construction produced minimal deflections. Since reconstruction, no maintenance of the roadway has been required.

RÉSUMÉ

Le cycle gel/dégel de l'hiver et du printemps entraine souvent un soulèvement excessif des routes lorsque le sol de la fondation est sensible au gel. Cette étude porte sur un cas d’utilisation du béton léger cellulaire (LCC) pour la reconstruction d'un couloir de bus à fort trafic sur des sols sensibles au gel dans la ville de Calgary. La route était construite sur une fondation d’argile limoneuse humide. Par conséquent, les conditions hivernales entrainait sur cette chaussée des soulèvements très importants. Ces dégâts étaient aggravés par la formation d’ornières dues au trafic important de véhicules lourds, nécessitant des réparations annuelles. La reconstruction de la route a été achevée à l'été 2000 en utilisant une couche de LCC pour isoler et renforcer la fondation. Un contrôle réalisé avec une poutre de Benkleman peu de temps après la reconstruction, montrait une déformation minime. Depuis la reconstruction, aucun entretien de la chaussée n'a été nécessaire.

1 INTRODUCTION

Construction of roadways over frost susceptible soils often results in excessive heave as the subgrade soils freeze during winter months, followed by softening during spring thaw. This paper presents a case study for reconstruction of a high traffic bus lane over frost susceptible soils in the City of Calgary using lightweight cellular concrete (LCC).

2 BACKGROUND

2.1 History

Brentwood Station is a light rail transit (LRT) station in Calgary, Alberta, Canada. The station opened on August 30, 1990. As shown in Figure 1, the station is located along Crowchild Trail between 32 Ave and 40 Ave NW.

As part of the LRT station, a high traffic bus lane extends parallel to and along the south side of Crowchild Trail NW. Between 1990 and 2000, annual maintenance was required at the intersection of the bus lane and the south entrance to the LRT station parking lot. This location was experiencing severe frost heave and subsequent spring thaw weakening. Cold mix asphalt was commonly used as temporary repair in an attempt to reinstate an acceptable driving surface; however, the heavy bus loading caused severe rutting and shoving of the asphalt, as indicated in Figure 2 (photo taken during reconstruction). In 2000, a 60 meter long section of the bus lane was selected for reconstruction.

2.2 Geotechnical Conditions

The surficial soils at Brentwood Station are primarily comprised of the Calgary Formation (Moran 1986). Soils of this formation are commonly comprised of silt, clay and minor very fine sand deposited as suspended-load and traction-load sediment in glacial ice-marginal lakes. Figure 3 shows a portion of the surficial geology map in the vicinity of Brentwood Station. The Calgary Formation is labeled as CSSi.

For reference, California Bearing Ratio (CBR) and Standard Proctor Testing was performed on soil samples from a nearby location (Boulton Road NW) with similar surficial soils. The soil was visually described as a silt with traces of sand and clay. The results of the test indicated CBR values of 3.5 and 0.8% for unsoaked and soaked conditions, respectively. The maximum dry density was 1680 kg/m^3 with an optimum moisture content of 17.0%. The soil had a natural moisture content of 15.0%.

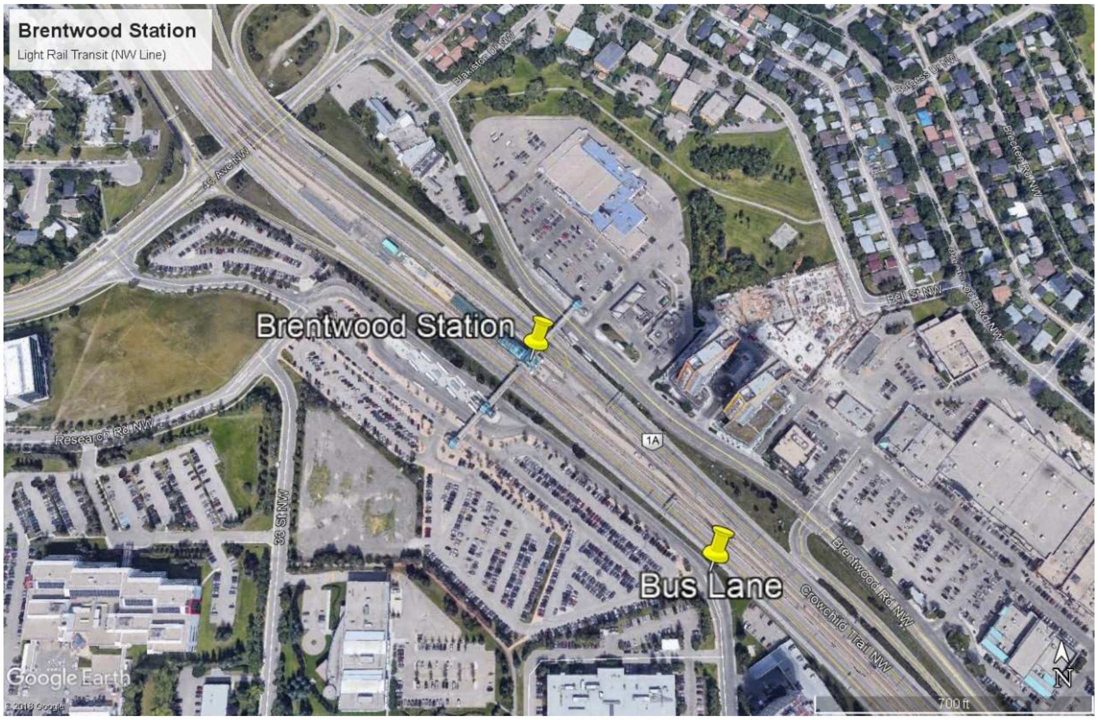

Figure 1. Site location (courtesy Google Earth)

Figure 2. Condition of bus lane (taken during reconstruction)

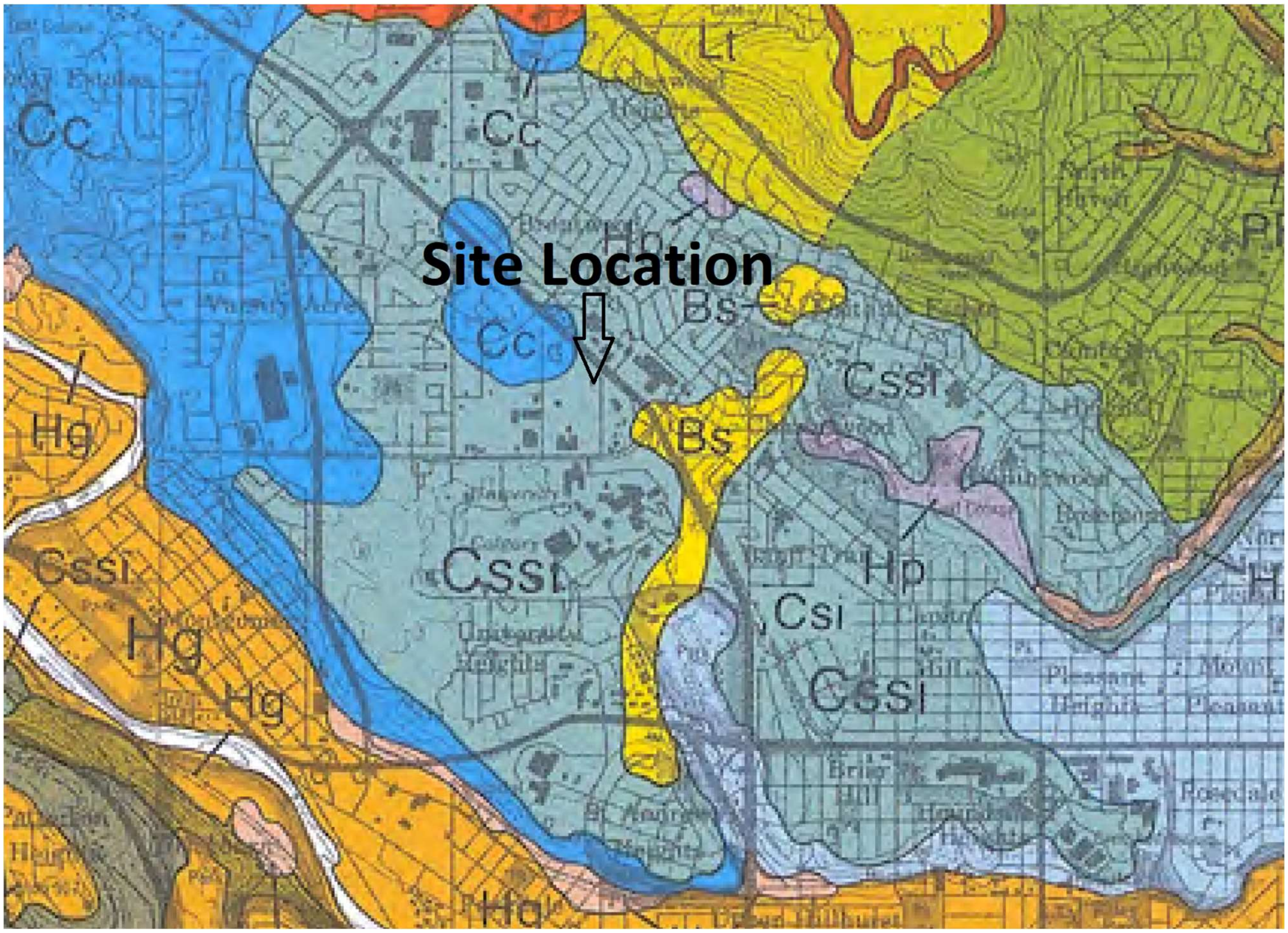

Figure 3. Quaternary geological map in the vicinity of Brentwood Station (Moran 1986)

2.3 Description of frost action

Frost action involves the combined effects of frost heave during the downward movement of the freezing front, followed by a loss of strength during the spring thaw.

Frost heave is defined as the upward movement of the pavement surface caused by freezing of trapped water beneath the roadway. This upward movement is often uneven in nature, resulting in cracking and potentially permanent damage to the roadway surface. This in turn allows for additional water infiltration below the roadway surface, thus exacerbating the problem.

When water freezes, it expands in volume by approximately 9%. In granular soils with less than 3% soil particles (by weight) less than 0.02 mm, soil expansion may be negligible, as there is often sufficient room for the ice to expand. However, soils with a higher percentage of fine particles (such as silts and fine sands) are highly frost susceptible and prone to ice lens formation during the winter months. Ice lenses are defined as bodies of ice that form in a localized zone. As ice forms in the soil, it induces a pressure deficiency (suction gradient) which draws water upward to form ice lenses.

During the spring thaw, the soil may thaw from the top down and/or from the bottom up. Sudden spring thaw can result in melting occurring almost entirely from the surface downward, and the underlying frozen soil will block drainage of water. This results in development of excess pore water pressures in the soil, and a severe loss of support for the pavement structure.

2.4 Design

Options for addressing frost action for roadways constructed on frost susceptible soils include:

- removal and replacement of frost susceptible soils to below the seasonal frost depth,
- enhancing drainage of water,
- establishing seasonal (i.e. spring) road bans to reduce damage to the roadway, and
- insulating the roadway to prevent frost heave from occurring.

The City of Calgary chose to address the frost heave issue at Brentwood Station by using LCC as a roadway subbase to provide both insulation and structural support. Also, measures were taken to address drainage of water below the pavement structure. The reconstructed roadway consisted of the following (in ascending order):

- Non-woven geotextile fabric,
- 50 mm of drainage rock (with subdrains beneath the curb & gutter),

- 200 mm of cellular concrete with a wet (cast) density of 475 kg/m^3,
- 200 mm of granular base course, and
- 150 mm of asphalt.

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, specialized pre-formed 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 1,000m) 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. It has fireproofing, insulation, sound attenuation and energy absorbing characteristics.

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

Geotechnical applications for cellular concrete include, but are not limited to:

- lightweight backfill within mechanically stabilized earth (MSE) walls, roadways, and bridge abutment and approach fills;
- insulation and structural support for roadways to prevent frost heave;
- tunnel grouting;
- energy absorption for military ranges, engineered material arresting systems to slow down aircraft that overrun runways, and rock fall protection;
- insulated tank bases to prevent heat damage to underlying liners;
- insulated process facility slabs;
- void fill;
- backfill material that does not require compaction;
- filling abandoned underground fuel tanks (ACI523.1R-06, 2006)
- high performance pipe bedding material.

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 100m^3 per hour) projects. “Dry” mix refers to the process whereby all of the constituents of the LCC are blended onsite, 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 Brentwood Station bus lane project used a “wet” mix process. Photographs of “dry” and “wet” mix units are shown on Figures 4 and 5, respectively.

Figure 4. Dry mix equipment

Figure 5. Wet mix equipment

4 CONSTRUCTION

As the bus lane is critical for the operation of Brentwood Station, the work was staged to allow for construction over two consecutive weekends. It was decided that half of the 60 meter long section would be reconstructed at a time to minimize disruption to the bus traffic. A total of approximately 150 m^3 of cellular concrete was placed over two separate pour days (Saturday, July 22 and Saturday July 29, 2000). Figures 6 and 7 show photos of the excavation immediately prior to the placement of LCC for the westbound and eastbound lanes, respectively.

Figure 6. Excavation prior to July 22, 2000 placement of cellular concrete

Figure 7. Excavation prior to July 29, 2000 placement of cellular concrete. Note exposed LCC from previous pour.

Figure 8. Photo taken during placement of cellular concrete.

The project specified that the LCC was to have a wet (as-cast) density of 475 kg/m^3. Typical compressive strengths of this material are approximately 1.0 MPa at 28-days (minimum specified compressive strength of 0.5 MPa). Photos taken during and after placement of LCC are shown in Figures 8 and 9, respectively.

Gravel backfill was placed the day following LCC placement. Construction traffic was not allowed to drive directly on the LCC without the gravel in place. Gravel was brought to the site using a dump truck, then spread out using a skid steer loader. Static (no vibration) compaction was used to compact the gravel. Figure 10 below shows placement of gravel on top of the LCC. The section was paved immediately after gravel was placed.

Figure 9. Photo taken after placement of LCC.

Figure 10. Photo taken during gravel placement.

5 ROADWAY PERFORMANCE

5.1 Pavement Structural Evaluation

In 2001, a Benkelman Beam Survey was conducted at this location by McIntosh Lalani Engineering. The Benkelman Beam Survey is a test method used to determine the deflection of the road from an 80 kN (18,000 lb) loading on a rear axle of a loaded single axle dual wheel truck with a tire pressure of 480 to 550 kPa (70 to 80 psi). Measurement is made by placing the tip of the beam between the dual tires and measuring the pavement surface rebound as the truck is moved away.

The average deflection for the road reconstructed with LCC was 12 mils (0.012 inches or 0.305 mm). The City of Calgary requires that the maximum allowable deflection for an industrial street is 35 mils (0.035 inches or 0.889 mm). Therefore, the structure of the roadway exceeds the City of Calgary requirements.

5.2 Current Roadway Condition

Since completion of construction in 2000, no frost heave of the roadway has been noted, and no maintenance of the roadway has been performed. Photographs of the current roadway condition are given below in Figures 11 and 12.

Figure 11. Photo taken in October 2017.

Figure 12. Photo taken in October 2017.

6 CONCLUSION

The frost heave and thaw weakening problem along the Brentwood Station bus lane was a serious maintenance issue that was causing traffic disruption at this busy location. Since reconstruction in 2000, the bus lane has not undergone any noticeable frost heave, and there has been no associated maintenance costs for the roadway. The project is considered to be a successful application of lightweight cellular concrete to address problems related to constructing over frost susceptible soils.

ACKNOWLEDGEMENTS

The writers would like to acknowledge Marine Peinnequin, Quality Control Technologist at CEMATRIX (Canada) Inc. for her valuable contribution to this paper.

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