



Mechanically Stabilized Earth Retaining Walls, Glenmore Trail, Calgary

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ABSTRACT

Increased pressure on urban transportation infrastructure has led owners, engineers and contractors to utilize more innovative solutions in both design and construction. An example of the need to meet economic and time restraints is the upgrading of Glenmore Trail west of MacLeod Trail in Calgary, Alberta – the largest project undertaken by the City of Calgary in its history. In order to relieve traffic congestion in this busy section of the City, the alignment of Glenmore Trail was lowered up to 9.0 meters below surrounding grade. The project extended from Macleod Trail west to 14 Street SW, a distance of approximately two kilometres. The lowered alignment enabled the east-west traffic on Glenmore Trail to pass under the north-south street system without interruption. Mechanically Stabilized Earth (MSE) retaining walls with a total face area of 16,000 m² were provided along the north and south sides of Glenmore Trail to facilitate the grade differential. Three bridges and a pedestrian overpass were also constructed using MSE abutments.

Challenges facing the project included highly variable foundation soils as well as a water table above the elevation of the retaining wall foundations. The design and construction of a permanent drainage system was required to meet this challenge. The complex street alignment had to be built within a tight corridor between the properties on the north and south sides of the project. Allowances also had to be made to permit east-west traffic as well as to provide unobstructed access to the large shopping center bordering the north side of the project. The geogrid anchors used to support the MSE wall face had to be designed to be as short as possible at the same time as maintaining acceptable design safety factors. The tight geogrid design was carried out using variable geogrid lengths designed using trapezoidal cross section design procedures. In some cases, foundation shear keys were also installed to allow for realistic geogrid anchor lengths.

The tight construction schedule required earthwork and construction of the retaining walls to carry on, uninterrupted, throughout the winter months. Wall construction began in the summer of 2005. The construction schedule was met and the project was substantially completed, within budget, in November of 2007.

RÉSUMÉ

La pression accrue sur l'infrastructure urbaine de transport a mené les propriétaires, ingénieurs et entrepreneurs à utiliser des solutions plus innovatrices dans la conception et la construction. Un exemple de la nécessité de rencontrer les contraintes économiques et de temps est l'amélioration du Glenmore Trail, à l'ouest de MacLeod Trail à Calgary, Alberta. C'est le plus grand projet entrepris par la ville de Calgary dans son histoire. Afin de soulager la congestion du trafic dans cette section occupée de la ville, l'alignement de Glenmore Trail a été abaissé jusqu'à 9.0 mètres au-dessous de la catégorie environnante. Le projet s'est étendu de l'ouest MacLeod Trail en direction ouest à la rue 14 SW, une distance d'approximativement deux kilomètres. Des murs de soutènement (MSE) ayant une superficie de 16,000 m² ont été bâtis sur les côtés nord et sud de Glenmore Trail.

Les défis faisant face au projet ont inclus les sols fortement variables aussi bien qu'une nappe phréatique au-dessus des niveaux des murs de soutènement. La conception et la construction d'une canalisation permanente ont été exigées pour relever ce défi. Des allocations ont également dû être faites pour permettre au trafic de circuler en direction est-ouest aussi bien que de fournir l'accès dégagé au grand centre commercial encadrant le côté nord du projet. Les ancres de géogrille utilisées pour soutenir la face du mur de MSE ont dû être conçues pour être aussi courtes que possible en maintenant des facteurs de sûreté de conception acceptables. La conception de géogrille a été effectuée en avec des longueurs variables de géogrille conçues en utilisant des procédures trapézoïdales de conception de coupe. Dans certains cas, des clefs de cisaillement ont été également installées pour tenir compte des longueurs réalistes d'ancrage de géogrille. Le programme serré de construction a exigé du terrassement et de la construction des murs de soutènement de continuer, non interrompus, tout au long des mois d'hiver. La construction du mur a commencé en été de 2005. Le programme de construction a été rencontré et le projet a été accompli, dans le budget, en novembre de 2007.

1 PROJECT OVERVIEW

The Glenmore Trail/Elbow Drive/5 Street SW Interchange has been on The City of Calgary's transportation improvements list for nearly 30 years. In the fall of 2001, The City of Calgary undertook a study to determine the long-term design and right-of-way requirements for the Glenmore Trail corridor between the west city limits and Deerfoot Trail (Provincial Highway #2) based on a future city population of 1.5 million. This study consisted of two phases. The first phase, referred to as the Network Analysis, was to assess the range of road network options to accommodate a city population of 1.5 million. The recommendations of the Network Analysis were submitted to City Council in December 2002. City Council in turn, directed the City administration to proceed with the second phase, the Functional Planning and Preliminary Design, for the interchange on Glenmore Trail at Elbow Drive and 5 Street SW.

In late 2003, City Council approved capital funding for the design and construction of the Glenmore Trail/Elbow Drive/5 Street SW Interchange to reduce congestion and improve the movement of goods and services along one of Calgary's primary east/west transportation corridors.

The Glenmore Trail/Elbow Drive/5 Street SW Interchange project, commonly referred to as GE5, is bounded on the west by a grade-separated interchange at 14 Street SW and on the east by a grade-separated interchange at Macleod Trail (Figures 1 and 2). There are two roadways that intersect Glenmore Trail within the project site, namely Elbow Drive and 5 Street SW. Both these roadways were controlled by at-grade signalized intersections at Glenmore Trail prior to the start of this project.

Glenmore Trail is designated as an expressway classification road and is the primary east/west traffic corridor south of the downtown. The average daily traffic is approximately 85,000 vehicles/day and is a heavily used truck route. Elbow Drive is classified as a collector roadway with an average daily traffic of approximately 23,000 vehicles/day and 5 Street SW carries approximately 13,000 vehicles/day and is designated a major roadway.

The plan for GE5 was to lower Glenmore Trail underneath Elbow Drive and 5 Street SW and to provide tight diamond interchanges at both these intersecting roadway locations. To accommodate this lowering of Glenmore Trail, over 500,000 m³ of material had to be excavated and removed along with the construction of: 26 permanent retaining walls with a combined area of over 13,000 m², four (4) bridges, 11,000 m of sewers, drains and waterlines and relocation of numerous third party utilities including over 22,000 telecommunication lines. The project also used 3000 m² of temporary walls. The project site is bordered by residential, office, institutional, and commercial developments including one of the busiest shopping centres in western Canada.

Relocation of third party utilities started in October 2004 and construction on the interchange started in April 2005. The project was substantially complete in

November 2007 with final completion scheduled for June 2008 within the Council approved budget of \$110.5 million.



Figure 1. Looking east along Glenmore from Elbow



Figure 2. Looking west along Glenmore from Elbow

2 GEOTECHNICAL ASPECTS

The geotechnical investigation for the site was carried out by Geo-Engineering (M.S.T.) in the spring of 2003 and between May and August 2004. Geo-Engineering was retained by Stantec Consulting Ltd., the Prime Consultants assigned the final design of the project. In addition to investigating the lowering of Glenmore Trail complete with an extensive area of MSE retaining wall, the work also included four new bridges consisting of overpass structures at Elbow Drive and 5th Street SW, a pedestrian bridge west of Elbow Drive and a basket weave bridge east of Elbow Drive.

2.1 Stratigraphy

The stratigraphy along the westernmost end of the project (representing approximately 80% of its length) consisted

of very stiff clay till, overlying Paskapoo Formation bedrock. The upper portion of this formation consisted of a highly weathered brown mudstone. This was underlain by a grey mudstone and/or cemented sandstone/siltstone. Of the site soils, the weathered brown mudstone was the most problematic for both retaining wall design and construction. Although its bearing strength is reasonable, its resistance to lateral sliding along its surface is low and it weathers quickly.

East of this, the subsoils transitioned into a preglacial channel deposit consisting of clay till overlying dense gravel. The change occurs approximately at the intersection of 5th Street SW and Glenmore.

2.2 Groundwater

During the drilling phase of the geotechnical investigation, groundwater was encountered at three to five meters below existing grade on the west side of the project and eight to eleven meters on the east end. With a proposed nine meter lowering of Glenmore Trail, special attention was required for design, construction and in-service phases of the project.

3 DESIGN OF MECHANICALLY STABILIZED EARTH WALLS

Engineering design and site assistance was provided by Tensar International in conjunction with its western Canadian distributor, Nilex, Inc. The design team was awarded the work by Graham Construction and Engineering, the project general contractor. The MSE wall type selected for the project was Tensar's ARES™ concrete wall panel system. The wall system consists of High Density Polyethylene (HDPE) structural geogrids mechanically attached as tie back anchors to the precast concrete face.

3.1 Design Methodology

The design was based upon the method proscribed by American Association of State Highway and Transportation Officials in its specification *AASHTO LRFD Bridge Design Specifications, SI Units, Third Edition, 2004* and *CAN/CSA-S6-06 Canadian Highway Bridge Design Code*. The older working stress design (WSD) is now being supplemented in Canada, USA and much of Europe with Load-and-Resistance Factor Design (LRFD). As required by the project specification, the Glenmore project was designed using the AASHTO LRFD method but using CSA load and resistance factors (a common design practice in Canada).

As described in AASHTO LRFD, "WSD establishes allowable stresses as a fraction or percentage of a given material's load-carrying capacity, and requires that calculated design stresses not exceed those allowable stresses". For example, Resisting Force divided by Driving Force might be required to be more than 1.5 as a safety factor. A corresponding LRFD example could be that a Factored Resisting Force (factor say of 0.8) divided by a Factored Driving Force (say 1.25) would have to

exceed 1.0 as a safety factor. Actual factors are specified in both the Canadian and American codes. In reality most designers use both methods. CSA requires an LRFD design also be checked by WSD (if a WSD design is applicable).

3.2 Internal Design

Within the reinforced mass, stability is achieved using the strength of the soil being reinforced in conjunction with the tensile force and anchorage characteristics of the geogrid. On the Glenmore project, "winter" rock fill (referred to as "winter fill") was also used on several retaining walls to permit construction to be carried out during the freezing winter months. The low unit weight of the rock fill (16.4 kN/m³) combined with its high strength (internal friction value of 39.9 degrees) was also used to reduce the length of the geogrid anchors required. Geogrids used on the project were from a family of Tensar MSE type Geogrids with ultimate tensile strengths varying from 58.0 to 175.0 kN/m. Design methods used ensured that the geogrids were long enough not to pull out of the fill behind the Rankine failure plane and that the geogrid was well distributed within the reinforced mass and that there was sufficient tensile stress to preclude rupture (either short or long term).

3.3 External Design

Outside of the reinforced mass, the MSE wall has to be designed for stability against lateral sliding, bearing capacity and eccentricity. All three are a function of the depth of the reinforced mass (i.e. the length of geogrid) and the site soils. Most soils encountered on the Glenmore project did not present problems from a standpoint of design for the MSE retaining walls. Retained soils (behind the reinforced mass) varied from sand/gravels to clay till to sand. Foundation soils varied from sandstone/siltstone to mudstone to gravel to clay till. Internal friction angles varied from 29 to 35 degrees and unit weights varied from 19.5 to 33 kN/m³. On the Glenmore project, however, the presence of the weathered, brown mudstone presented a problem when it occurred near the footing elevation of the MSE walls. The mudstone had good bearing capacity (2000 kPa) but, with an unfactored friction angle of 25 degrees it offered poor resistance to sliding along its surface. When factored in LRFD by 0.8, this friction angle dropped to 20.5 degrees. In order to mitigate this, three solutions were available to be used separately or all together in a critical design case; lightweight fill, shear keys and/or AASHTO's trapezoidal design method.

3.3.1 Lightweight Fill

The rock fill used to achieve winter construction also had a benefit in increasing the sliding stability of some of the walls. In the cases where it proved effective, the driving force of the retained fill (fill behind the reinforced mass) was reduced by both the low fill weight and the increased strength of the rock fill. This also, (however), reduced the sliding resistance beneath the reinforced mass due to a decrease in the normal force acting on the sliding plane.

Where the reduction in the driving force was greater than the reduction in the sliding resistance, rock fill was a viable alternative.

3.3.2 Shear Keys

In some of the structures a granular shear key was installed beneath the base of the reinforced mass. In general the depth of the keyways used were in the order of 1.4 meters below the footing of the wall and extended toward the back of the reinforced mass for approximately two thirds of the length of the overlying geogrid.

3.3.3 Trapezoidal Design

AASHTO usually requires that the length of geogrid used in design must be at least 0.7 times the height of a retaining wall no matter what soil characteristics the foundation has. One of the exceptions to this requirement is the use of trapezoidal design. Using this method, the vertical cross section through the reinforced mass is divided equally into thirds. The length of geogrid in the bottom third is the shortest (minimum of 0.45 wall height, H) and the length of geogrid in the remaining two increases uniformly in maximum increments of up to 0.15 H (Figure 3). The trapezoidal cross section then has to be checked externally to ensure that the sliding and bearing characteristics of each of the three reinforced zones is acceptable. The overall average geogrid still has to meet the 0.7 H requirement.

The combination of “slippery” mudstone and an extremely tight right-of-way warranted the use of at least one, and sometimes all three, of the above techniques on critical structures.

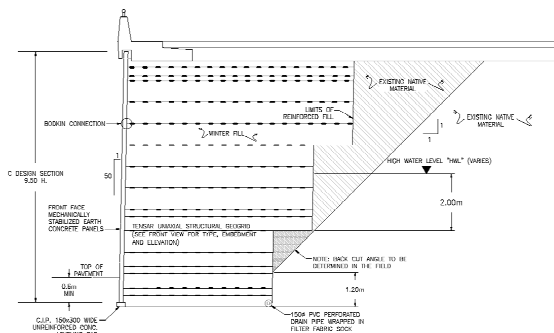


Figure 3. Trapezoidal design

4 CONSTRUCTION

One of the main challenges of the project included 16,000 m² of 'Design and Build' Mechanically Stabilized Earth (MSE) retaining walls. This includes temporary walls used to maintain right-of-way as well as traffic flow during construction.

4.1 Right-Of-Way Restrictions

Due to the tight nature of the right-of-way available, the extent of excavation had to be seriously limited as well as

minimizing the geogrid anchorage length used to tie back the MSE walls (Figure 4). The limited space available was due primarily to the proximity of existing utilities and bordering structures. Space restrictions were also created by the need to maintain traffic flow through the corridor as well as having to maintain site access to one of Calgary's major shopping centers, immediately bordering the north edge of the site. A number of temporary walls were also constructed to facilitate wall construction and detour staging requirements.



Figure 4. Limited right-of-way

4.2 Foundation preparation

Foundation preparation was complicated by the presence of a water table above the footings of the MSE walls in combination with a potentially unstable, under-lying mudstone strata. Mudstone was encountered at much of the design sub-grade elevation, and special procedures were required to mitigate this problem. These included delaying excavation beyond 600 mm above final sub-grade elevation until sub-drains could be installed. Once this was achieved, the final 600 mm of excavation could proceed and the exposed surface was immediately covered with geotextile and granular fill in order to minimize deterioration of the mudstone surface. Geotextiles and geogrids were also used to enhance site access by reinforcing soft spots encountered on the construction site where the grade elevations started to dip below the water table. This was particularly beneficial when the girders for the Elbow street bridge were raised. It is probable that the access road would have been inaccessible due to artesian conditions resulting from the high water table on either side of the Glenmore excavation.

4.3 Lightweight Aggregates

In order to maintain the project schedule, lightweight aggregate (no fines rock) was used to extend wall construction through the winter months (Figure 5). The rock also had a secondary benefit; it's low weight and higher relative strength helped the stability of the MSE walls by reducing both sliding and applied bearing stresses. Geotextile fabric was used prevent migration of

finer into the structural rock fill. Challenges were also encountered in scheduling the pre casting of 16,000m² of 152 mm thick, high strength wall panels during an aggressive construction economy never seen before in the province.



Figure 5. Lightweight winter fill

4.4 Project Artwork

MSE walls included a Project Artwork component that included 144 coloured Rainbow and Brook Trout fish running thru the Bow River wave along the project wall lengths. The artists were Violet Costello and Bob Thomasson. These coloured fish (Figure 6 and 7) were a pre-cast contract design using the Lafarge high strength Ductal concrete product. These pre-cast elements were bolted to the wall after wall erection and prior to roadway opening, and add a three-dimensional effect to this artwork while allowing the project to maintain the aggressive construction schedule.



Figure 6. Artwork



Figure 7. Artwork

5 CONCLUSION

The project was substantially completed in November 2007 with final completion scheduled for June 2008 (Figures 8 and 9). The project was completed on time and within the \$110.5 million dollar budget approved by Calgary City Council. This was due in no small part to the innovative design and construction techniques utilized by the project team working in partnership with the City of Calgary. To date, the structures on the project are performing to the standards set for the work.



Figure 8. Looking east along Glenmore from Elbow



Figure 9. Looking west along Glenmore from Elbow

ACKNOWLEDGEMENTS

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REFERENCES

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