Mechanically Stabilized Earth Walls Northeast Stoney Trail, Calgary, Alberta

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ABSTRACT
The northeast leg of the Stoney Trail was the second phase of the ring road constructed within Calgary, Alberta. The overall project consisted of 21 kilometres of new highway and 23 bridge structures. Challenges for this project included year round construction coupled with complex geometrics. Architectural Full Height precast panels were selected as the system of choice for the bridge retaining walls, in conjunction with the innovative use of HDPE soil reinforcement. This paper will focus on the key aspects associated with extensible geogrid design for pile supported abutment walls.
Maximum wall heights up to 20.35 metres were constructed with the ARES system for this pile supported bridge deck system. The system consisted of approximately 15,296 m^2 of architectural wall face, along with 3,393 m^2 of soil reinforced abutment seat. Technical considerations relating to panel fabrication, erection, acute angle geometry, along with the typical Canadian challenge of winter construction will be discussed.

RESUMEN
El tramo Noreste de Stoney Trail fue la segunda fase de la autopista perimetral construida en Calgary, Alberta. En total el proyecto consistió de 21 kilómetros de carreteras nuevas y 23 puentes. Los desafíos de este proyecto incluyeron construcción bajo condiciones invernales durante gran parte del año así como geometrías complejas. Paneles arquitectónicos prefabricados de concreto de altura total fueron seleccionados para las estructuras de contención del puente junto con el uso innovativo de suelo reforzado usando geomallas de polietileno de alta densidad (HDPE). Este documento se centrará en los aspectos clave relacionados con el diseño con geomallas extensibles en los muros de contención para los estribos soportados sobre pilotes. Muros con altura máxima de 20.35 m fueron construidos usando el sistema ARES en este conjunto de estribos apoyados sobre pilotes. El sistema consistió de aproximadamente 15,296 m^2 de fachada arquitectónica para muros, junto con 3,393 m^2 de asientos para estribos en suelo reforzado. Se discutirán las consideraciones técnicas relacionadas con la fabricación, erección y geometría con ángulos agudos de los paneles de concreto así como los desafíos asociados con la construcción en clima frío típica del ambiente Canadiense.

1 INTRODUCTION

Northeast Stoney Trail (NEST) comprises the northeast quadrant of a ring road that will eventually circle the city of Calgary. During the 1980s and 1990s the Province of Alberta, who is responsible for the development of the Ring Road, purchased most of the lands required for this portion of the work. The project was contracted as a Public Private Partnership (P3) under a 30-year agreement with Stoney Trail Group (STG) to design, build, operate and partially finance the road. STG's Developer/Project Lead was Bilfinger Berger BOT Inc. Stoney Trail General Partnership hired design-build, joint venture partners Stoney Trail Constructors (STC), lead by Flatiron Constructors, along with Graham Construction and Parsons Engineering. STC were assigned to design, build, operate and maintain the project.

In partnership with the Alberta government, Stoney Trail General Partnership (STG) also partially financed this project over a 30 year period.

The northeast segment of the Ring Road, (Figure 1) extends east from Deerfoot Trail in the north of the city, to the eastern city limits, then south to 17 Avenue SE (Highway 1A). It is expected to eventually carry 30,000 to 40,000 vehicles per day. Construction started in the spring of 2007. The project included 23 bridge structure, six interchanges and 21 kilometres of new four and six lane divided freeway. Construction was completed and opened to traffic on November 2, 2009.

Figure 1. Overview map (from Alberta Transportation)

2 GEOTECHNICAL ASPECTS

The geotechnical investigation for the site was carried out by EBA Engineering Consultants who were retained by STC. The investigation included foundation investigations for six interchanges and 23 new bridges.

2.1 Surficial Geology

The general stratigraphy of the soils along the right of way consisted of a low plastic clay till overlying bedrock. Till thickness ranged from 3.5 m in the vicinity of the Deerfoot interchange to 16 m or more in the vicinity of 16th Avenue. Bedrock consisted of interbedded sandstone, siltstone and claystone of the Upper Paskapoo Formation. Non-engineered, surficial fill was also encountered in several locations.

2.2 Groundwater

Groundwater on the project varied from less than 1 m below existing elevations to approximately 7 m below grade. Shallow perched ponds were also encountered. Good drainage practice and construction management prevented any water related complications to the construction of the MSE structures. Groundwater was not generally a complication.

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 MSE design team was awarded the work by Stoney Trail Constructors, the project design-build team. The wall type selected for the project was Tensar's ARES[TM] 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. A typical cross section is shown in Figure 2.

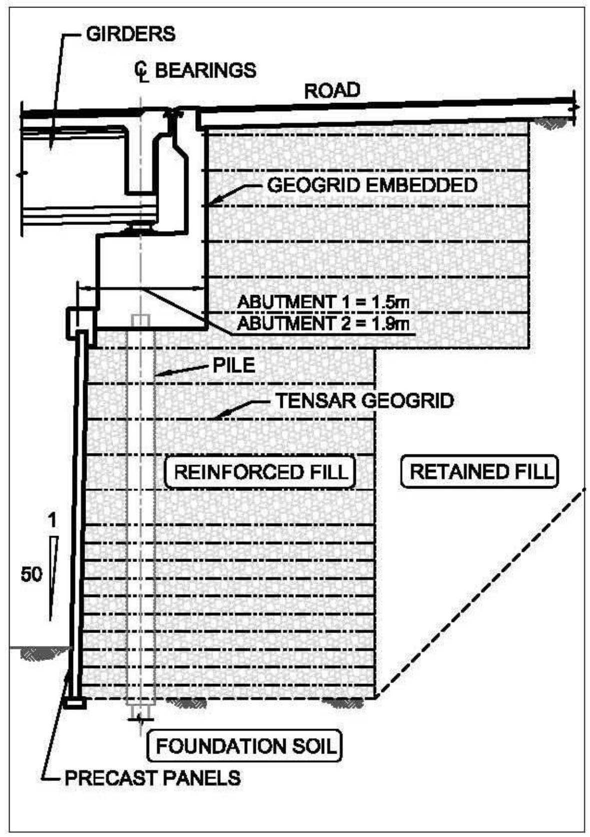

Figure 2. Typical cross section

3.1 Design Methodology

The wall design, including polymeric reinforcement, 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 replaced in Canada, USA and much of Europe with Load-and-Resistance Factor Design (LRFD). As required by the project specification, the Stoney project was designed using the AASHTO LFRD method but using CSA load and resistance factors (a common design practice in

Canada). Recent large projects designed with this method include Glenmore Trail and the LRT expansion in Calgary, Port Mann Bridge project in Vancouver and Anthony Henday Drive in Edmonton.

As described in AASHTO LFRD, “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 LFRD 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 LFRD 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.

HDPE geogrid is recognized by AASHTO as providing a distinct advantage of not being adversely affected by corrosion due to road de-icing salts typically utilized under Canadian winter conditions.

On the Stoney 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 (Figure 3). Although a higher (conservative) unit weight was used for design purposes, the actual weight of the rock fill (16.4 kN/m^3) combined with its high strength (internal friction value of 39.9 degrees) added an additional level of stability to the structure. 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 Stoney project did not present problems except for the higher walls where sub-cutting and replacement with granular fill was required to support the applied bearing stress from the higher walls (up to 475 kPa). Retained soils (behind the reinforced mass) varied from sandy gravel to clay till. Foundation soils mainly consisted of clay till and the occasional bedrock outcropping. In some cases engineered granular fill was used to overcome soft areas or to increase bearing capacity in the case of high walls. Friction angles for soils external to the reinforced mass varied from 25 to 40 degrees and unit weights varied from 20.6 to 22 kN/m^3.

Figure 3. Rock fill

4 PANEL MANUFACTURE

The MSE walls consisted of precast concrete panels with a nominal width of three metres and individual panel heights of up to 10.42 metres. This presented challenges in both structural design and erection. Panels were designed and manufactured by Lockwood Brothers Concrete Products Ltd. in their Armstrong plant in British Columbia.

4.1 Panel Geometry

Full height single panels or combinations of 2 to 3 panels were stacked to achieve the up to 20.35m high walls. Full height panels were used to minimize the number of joints thereby enhancing the aesthetic appearance of the wall, particularly with the mountainscape architectural requirement. The larger panel sizes also reduced the number of total units thereby speeding up installation and reducing installation equipment costs.

Due to the variable geometry of the walls, structure-specific geogrid arrangements and the aesthetic finish required, there were 967 different panels required (of a total 1040 precast wall units). This required tight control on production scheduling, quality control and delivery and installation co-ordination

4.2 Concrete Specifications

HPC concrete was specified with silica fume additive. Extended wet curing was also required along with a 100 year design life.

4.3 Special Precast Considerations

Precast panels were designed for a 1H: 50V permanent batter. The implication from a precast standpoint would require panels slightly narrower at the top, so to allow the entire bridge corner to lean-in at the required batter.

When viewed in plan view (Figure 4.) The top of wall (T/O Wall) is noted to incline inward on both abutment and wing wall. The underside of wall (U/S Wall) is located further outward.

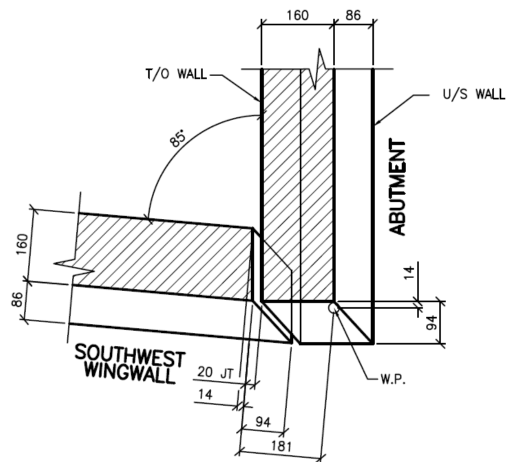

Figure 4. Isometric View of Precast Corner Detailing

Acute corners (minimum 34.3˚) required special design and special hardware to distribute forces laterally to zones of fully embedded Geogrid. This special constraint was particularly complicated by proximity to 1.5 metre diameter concrete piles supporting the bridge deck. Economic solutions were generated to meet these special conditions.

5 CONSTRUCTION

One of the main challenges of the project included over 18,000 m^2 of Mechanically Stabilized Earth (MSE) precast panel wall and abutment seat backwall.

Calgary is a city of extreme temperatures ranging from historical lows of -45°C to highs of 36°C. Construction proceeded during the cold winter months with outdoor construction work being limited when temperatures plummeted below -30°C. Fortunately temperatures this low only occur for about 5 days in a typical Calgary winter.

5.1 Foundation Preparation

The insitu clay was classified as a stiff, over consolidated till and therefore provided a good foundation support for low to medium height walls. For the tallest structure applied bearing pressures were up to 475 kPa. This exceeded the allowable bearing pressure of the insitu soils. This was overcome by sub-cutting the foundation and replacing the foundation soil with select granular fill. Excavation depths were in the order of one meter and varied from structure to structure depending upon the specific applied bearing stress and the bearing capacity at the location of each structure. This technique was also used where isolated soft areas were encountered. These soft areas were encountered in areas of random existing fills and in areas of previous sloughs.

5.2 Panel Erection

Scheduling, fabrication, and shipment of over 15,000m^2 of precast occurred over a 10 month time frame. Erection of the 160 mm thick panels commenced in the fall of 2007 during an aggressive but robust construction economy

The wall alignment on several structures required very tight acute corners with interior angles as low as 34.3° (Figure 5). Such corners required a complex inter-layering of reinforcement. Although these constraints were overcome using a combination of polymer reinforcement and steel strapping (Figure 6) attaching adjacent panels together. It would be simpler to design the initial panel layout to mitigate this complication.

Space was further constricted by the close proximity of either 1300 mm drilled concrete columns, or H Piles (Figure 7.) Foundation improvement required to support the stresses applied by the highest retaining wall panels which were located immediately behind the pile supported bridge seat on the return walls.

Figure 5. Acute angle of 34.3°

Figure 6. Acute Angle Hardware

5.3 Winter Fill Aggregates

In order to maintain the project schedule, winter fill aggregate (no fines rock) was used to extend wall construction through the winter months (Figure 7). The fill could be compacted where other types of fill could not. Geotextile fabric was used prevent migration of fines into the structural rock fill. The rock also had a secondary benefit; its low unit weight (16.4 kN/m^3) and higher shear strength (39.9 degrees) helped the stability of the MSE walls by reducing both sliding and applied bearing stresses. Sliding behaviour was enhanced by reducing the driving force of the retained fill (fill behind the reinforced mass). This was a result of both the low unit 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. The rock fill proved to be a two edged sword. However, where the reduction in the driving force was greater than the reduction in the sliding resistance, rock fill was a viable alternative.

Figure 7. Winter construction with rock fill

6 PROJECT ARTWORK

The project requirements necessitated an aesthetic component whereby a minimum of 25% of the exposed wall surface consisted of architectural treatment. The pattern selected by the design team was termed "Mountain-Scape Finish" as depicted in Figure 8 below to simulate the mountainous terrain typical of the region.

Figure 8. Mountain-Scape Finish

The artistic features were detailed by the precaster during design and fabrication through a combination of smooth and fractured finish.

After completion of all above bridge deck work, a contrasting pigmented sealer was applied by the contracting forces to further accentuate architectural relief, and top of wall treatment. To add a further compliment select panels were also embossed at the precast facility with the provincial "Wild Rose" flower (Figure 9).

Figure 9. Alberta Wild Rose Emblem

CONCLUSION

This project was completed on time and on budget, opening to traffic on November 2, 2009 (Figure 10). All structures are performing successfully to date. The challenge with tight, acute wall angles and panel erection have been somewhat mitigated through updated MSE codes. Alberta Transportation, for instance, have restricted corner angles to > 70°, and individual panel heights as well as increased clearance between the back of facing panels and adjacent piles.

Figure 10. Completed project

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Alberta Transportation and Infrastructure

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REFERENCES

AASHTO LRFD Bridge Design Specifications, SI Units, Third Edition, 2004.

CAN/CSA-S6-06 Canadian Highway Bridge Design

Flatiron Project Sheet Calgary Ring Road (Northeast Stoney Trail) – Revised 4/14/10