Overview of the Niagara Tunnel Facility Project and Surveying Activities

By Dr. Ahmet Unlutepe, PhD.

1. Introduction

The Niagara Tunnel Facility Project comprises mainly the construction of a 10.4 km diversion tunnel that will divert water from the Niagara River, beneath the City of Niagara Falls, to Ontario Power Generation's (OPG) existing Sir Adam Beck Hydroelectric Power Plant. Other key elements of the project are the construction of an Intake Structure and Channel and an Outlet Structure and Canal.

Currently approximately 1,800 m^3 of water per second are available to the Power Plant from the Queenston Chippawa Power Canal and the two existing diversion tunnels. The new tunnel will provide an additional 500 m^3 per second for power generation.

The current project began in mid-2004 with pre-qualification of potential contractors and preparation of proposal documents. In 2005, through a competitive international proposal process, OPG awarded Strabag AG with the Design/Build Contract for the new Niagara Tunnel Project. The value of the design/build contract for the Niagara Tunnel Project is approximately $622 million. Strabag AG, based in Austria, is one of Europe's leading construction companies, with turnover of 10.4 billion Euros per year and a workforce of 53,000. (www.OPG.com).

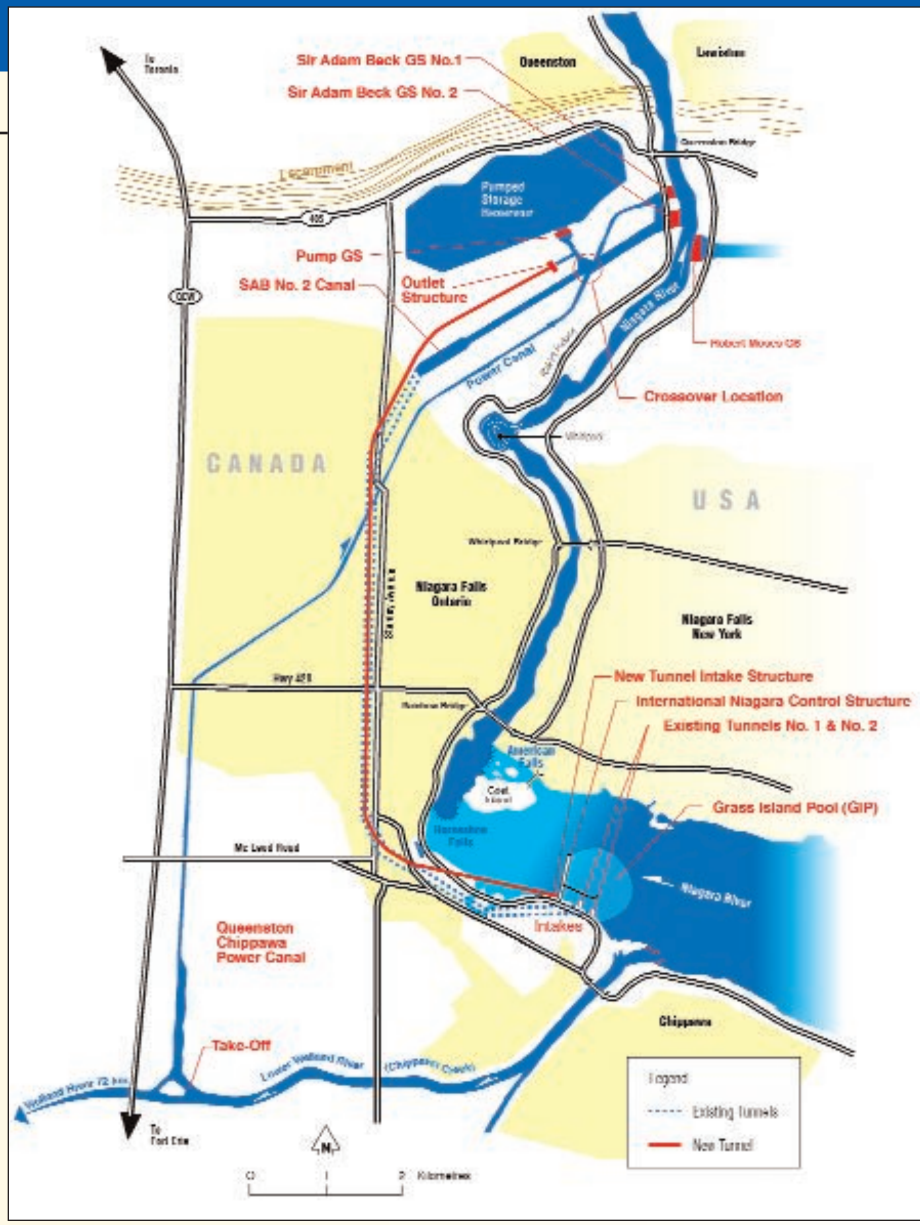

Figure 1.1 Project layout (OPG, 2005).

Strabag has partnered with several Ontario subcontractors for specific construction work on the diversion tunnel, intake and tunnel outlet. Dufferin Construction is the main subcontractor, responsible for the construction of the Intake-Outlet Structure and Canal. McNally International - Marine Division has constructed several in-water structures related to the Intake works at the International Niagara Control Works Structure (INCW). Consulting engineers, both local and from abroad include Morrison Hershfield of Toronto for the design of various surface structures and infrastructure engineering and ILF of Austria for the design of the tunnel, Intake and Outlet Structures. OPG has retained Hatch Mott MacDonald, with Hatch Energy, as Owner's Representative, to manage the project on their behalf.

Construction of the Outlet Canal began in September 2005 and was completed in April 2006. In water works at the Intake site began in April 2006 with in-water drilling and blasting, the construction of two precast block walls and the construction of a cellular cofferdam. The actual boring of the tunnel began September 1st, 2006. Construction is expected to be completed in 2010. (Figure 1.1)

2. Overview of the Project

The Niagara Tunnel Project consists of three main construction elements; namely the intake and outlet canals, the diversion tunnel, and the intake and outlet structures. The first phase of the project began with the excavation of the outlet canal. Upon completion, the Tunnel Boring Machine (TBM) was assembled and tunnel excavation began. The intake channel and structures will be constructed concurrently with the TBM drive.

2.1 Intake and Outlet

The tunnel's intake is being constructed inside a cofferdam, 35 m below the existing water control structure (named the INCW), upstream of the falls. The intake area will consist of an underwater approach channel, which funnels water through a submerged bell-mouth concrete structure into the tunnel. The intake structure will be equipped with a removable gate that may be installed to facilitate the future dewatering of the tunnel.

The outlet canal is 350 metres long - 23 metres wide and 35 metres deep. Once the tunnel is completed, the outlet structure will channel the flow into the existing system of power canals, which feed the Sir Adam Beck Generating Stations.

2.2 Tunnel

The primary component of the construction is a 10.4 km long water diversion tunnel, measuring 14.44 m in diameter and traveling 140 m below the City of Niagara Falls. The Tunnel Boring Machine (TBM) used for the excavation is a 14.44 m diameter full-face open gripper type TBM; one of the largest to ever be used in the world. In comparison, the Niagara Tunnel diameter is $2^{1}/_{2}$ times the size of the Toronto Subway tunnel and $1^{1}/_{2}$ times the size of the English Channel tunnels.

The primary tunnel support consists of a combination of steel ribs, wire mesh, rock bolts and shotcrete that varies according to the actual rock conditions encountered in the tunnel. Rock support is installed from a working platform immediately behind the cutter head.

The tunnel's final lining will consist of a 600 mm thick, cast in place concrete and waterproofing membrane. In lieu of steel reinforcing, the lining will be compressed by interface grouting at high pressures to ensure the tunnel will be able to sustain high internal water pressures during operation. (Figure 2.2.1) Because of the tight construction schedule, waterproofing works and final lining will also be executed concurrently with TBM excavation.

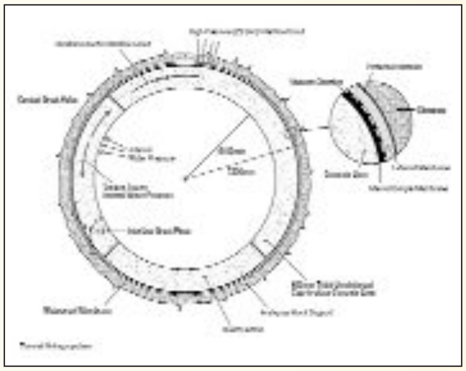

Figure 2.2.1 Typical tunnel cross-section.

2.3 Alignment and Geology

The tunnel alignment remains mainly below the two existing OPG diversion tunnels, parallel to Stanley Avenue, beneath the City of Niagara Falls. The tunnel excavation began from the outlet, descending at -7.82% over a length of approximately 1,400 metres before reaching a depth of approximately 140 metres below the surface. At the low point, five dewatering shafts will be constructed to facilitate future dewatering of the tunnel. From the low point, the tunnel proceeds with a relatively horizontal grade over a distance of approximately 7,500 metres until it begins its final ascent at 7.1% towards the intake channel, some 40 m below the Niagara River bed. (Figure 2.3.1).

The tunnel is being driven through hard rock formations consisting of limestone, dolostone, sandstone, shale, and mudstone. Mainly, the Diversion Tunnel will be driven into the Queenston formation, which is made up of moderately hard and dense shale. The tunnel penetrates all the upper formations when driving to the lowest level and rising again to where the intake structure is located. The rock formations above the Queenston formation can be classified as moderately hard and dense to very hard and dense. Very little groundwater is predicted throughout most of the tunnel drive, with exception of the final portion of the tunnel excavation, which will pass beneath the Niagara River.

2.4 Hard rock Tunnel Boring Machine (TBM)

The world's largest hard rock tunnel boring machine (TBM), is boring the tunnel 14.44 m in diameter under the City of Niagara Falls.

The TBM, named 'Big Becky', has been designed and manufactured by The Robbins Company and is currently the world's largest diameter hard rock tunnel boring machine. It is an open, hard rock main beam TBM that utilizes the floating gripper design. Its total length is 24 m and it weighs 1900 tons. Cutter head thrust is 18,426 kN and maximum gripper force is 71,500 kN. The TBM is being guided with the Poltinger Precision Systems (PPS) guidance system.

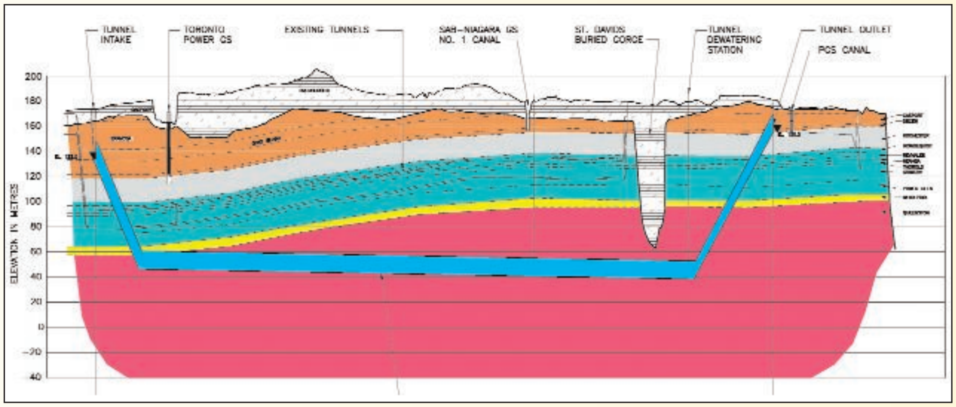

Figure 2.3.1 Tunnel route under the ground.

The TBM was launched from the Outlet Canal and will continue to advance until it breaks through into a Grout Tunnel, which will be driven starting from the intake by drill and blast methods. The TBM is currently about 1150 m beyond the outlet portal on its way down with a -7.82 % grade. The TBM is being operated 24 hours a day. Approximately 1.6 million cubic metres of material is being excavated from the tunnel and being transported to the storage site on OPG property by a continuous conveyor.

Rowa Tunneling Logistics manufactured a 105 m long backup system consisting of 4 main units, which carry the equipment required to support the TBM excavation. Rowa provided the essentials for the continuous conveyor belt to remove excavation material, air ventilation, rock bolt-drilling machines, and 360° round shotcreting robots. (Figure 2.4.1)

3. Surveying Tasks for the Tunnel Construction

Surveying applications for the tunnel construction are being executed relative to the established horizontal and vertical control networks. Underground traverse measurements cannot be verified until the tunnel breaks through at the end of the excavation. Hence, measurements for guiding the tunnel excavation are very crucial throughout tunnel construction. Basic surveying tasks for the tunnel construction are as follows:

-Establishment of tunnel control network
-Tunnel control surveys
-Guidance system control
-Construction layout and deformation monitoring

Figure 2.4.1 TBM is seen at the start position and while disappearing on its route.

3.1 Establishment of Control Network

The basic control network is the basis for all surveys carried out both on the surface and in the tunnel including measurements for guiding the TBM, tunnel traverse network measurements, and setting out surveys inside the tunnel.

OPG's surveyors, Monteith and Sutherland Limited, established a basic surface control network by means of GPS and conventional surveying techniques in September 2005. As typical with tunneling projects, the surface control network was formed over an area encompassing the entire project area from Intake to Outlet.

The control network consists of four ground monuments at the Intake site area and five at the Outlet site area. The main network for the project area consists of two known horizontal NAD83 UTM 2nd order control points. An additional eight control points were installed around the Outlet area to enter the tunnel with a stronger shaped network that will assist in minimizing breakthrough error. Pillar type installations were used as monumentation to increase the speed and accuracy of the measurement process. (Figure 3.1.1)

Figure 3.1.1 Pillar type of survey monument at Outlet area.

3.2 Establishment of Tunnel Control Network

The two fundamental elements of the underground control network, namely 3D control, and elevation control, are being executed accurately with the use of state of the art methods and instrumentation. Generally, the establishment of tunnel control networks is restricted due to the confinement of underground areas. Survey brackets and prism bolts are being installed on the right and left sides of the tunnel walls at approximately 200 m intervals. Additional prism bolts are installed between the bracket sections at a spacing of 100 m. Temporary stations are set up using a tripod, which leads to a better breakthrough accuracy. Figure 3.2.2 shows the arrangement of the survey monuments used in the tunnel.

Benchmarks for leveling surveys inside the tunnel are being installed in

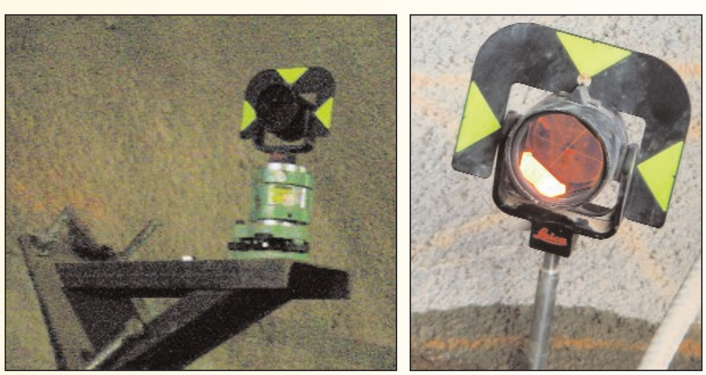

Fig. 3.2.1 Tunnel prism bolt and bracket installations on the tunnel wall.

approximately 100 m intervals and precise level measurements are being performed with a Leica DNA 03 digital level and invar rods. Level surveys are being performed back and forth along the tunnel. Tunnel control network point elevations are verified using the level benchmarks.

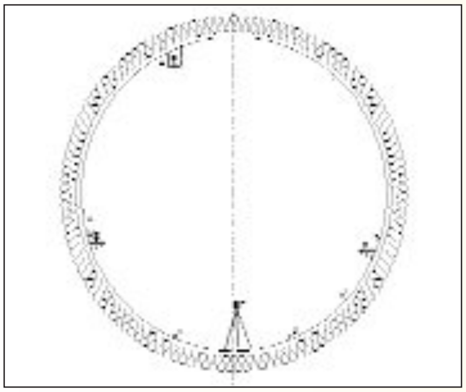

Figure 3.2.2 Tunnel survey monuments typical section (Unlutepe, 2007).

LEGEND

A: TBM Guidance Bracket (X,Y,Z)
B: Traverse Bracket (welded or bolted)
C: Prism Bolts (X,Y,Z,) (for measurement)
D: Level bolts (Z)
E: Temporary Ground Point (X,Y,Z)

3.2.1 Tunnel Control Surveys

The tunnel excavation began from the Outlet Canal, which allowed the transfer of control directly from the surface to underground, thus eliminating the need for shafts, or adits. A control survey closure will be performed at the end of the 10.381 m TBM drive at the Intake area.

Survey control will be transferred into the tunnel in two different ways:

1- Survey control is being extended directly through the Outlet Canal into the tunnel.

2- Survey control will also be transferred down dewatering shafts at chainage 1+410. Three control points will be established at the top of three shafts and transferred down to the tunnel bottom.

The control network surveys are being performed at approximately 500 m intervals, as the tunnel advances. The surveys are initiated from the surface network in order to check the stability of tunnel control points. Once the tunnel lining formwork is installed in the tunnel, control surveys may be started from the previously measured tunnel control points. Surveys initiated inside the tunnel will overlap the previous survey to ensure movement has not occurred in the brackets.

The Leica TCA1800 Robotic total station, equipped with ATR and software entitled “Sets of Angles”, make the observing procedure faster and more accurate. Once the underground network measurements are completed, the data is adjusted and the coordinates (E, N, H) of all brackets and prism bolts are updated.

A group of Gyrotheodolite surveys will be performed as a part of the control network surveys during mining prior to breakthrough. The number and location of the surveys to be conducted will be chosen in order to minimize error propagation and achieve the required breakthrough accuracy. A state of the art tunnel surveying software called EUPALINOS of Geodata is being used for the data evaluations and Least Square network adjustments.

Profiling surveys are being performed with the Leica TCA1800 and Leica TCRA 1201 to compare the as-built tunnel surface to the required design surface. The Leica TMS (Tunnel Measurement System) and EUPOLINOS profiling modules are being used for data processing. Profile measurement intervals are chosen to be 3 to 4 m and 30 to 40 points are measured for each section. Profiling measurements will be repeated to guide the inner lining applications.

3.3 Guidance System Control

The TBM is being guided with Poltinger Precision Systems (PPS) based on the tunnel control network. The PPS guidance system continuously defines the TBM position and compares it with the design tunnel axis. The PPS system receives input measurements from a Leica TCA1800 total station, which is placed on a bracket attached to the left upper wall of the tunnel (Figure 3.3.1). The guidance station bracket is incrementally moved forward as the TBM advances.

Two motor prisms are installed at the predetermined locations on the TBM. The total station measures the position of motor prisms based on the reference station at continuous intervals and sends the data to the PPS computer. A dual axis inclinometer is installed under the TBM main beam to measure the TBM roll and pitch. Design tunnel axis coordinates are entered into the PPS computer in a global coordinate system for the calculations. The PPS system collects all measurement data coming from the total station and inclinometer to the computer placed in the TBM control cabin, and calculates the TBM position and TBM deviation from the design line. These measurements and calculations are being repeated every 10 seconds and the TBM position is updated. The PPS screen in the TBM control cabin displays both the design line and the

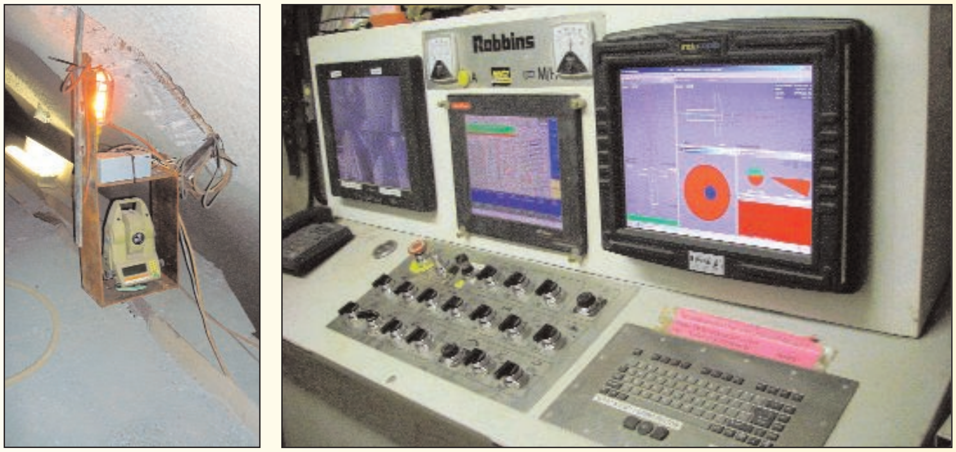

Figure 3.3.1 PPS guidance system total station bracket and computer in the TBM control cabin.

horizontal and vertical offsets of the TBM position numerically and graphically. The TBM operator uses the offset information shown on the PPS screen to guide the TBM on the correct path.

The TBM guidance stations are being measured as a part of the tunnel 3D control network to correct for any error that may have accumulated on to the TBM guidance control system.

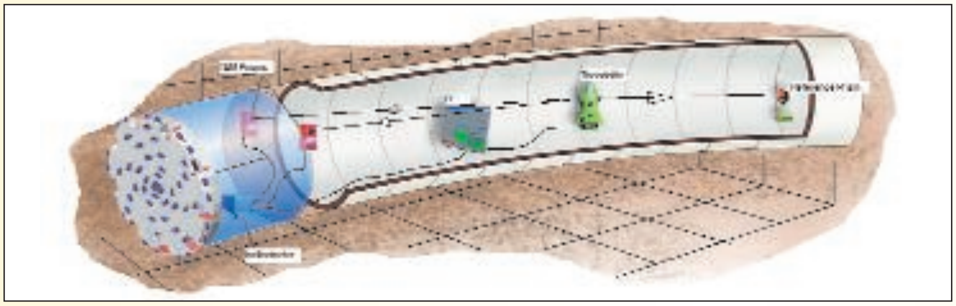

Figure 3.3.2 PPS guidance system units

3.4 Construction Layout and Deformation Monitoring

In addition to the TBM guidance surveys, other types of surveys performed inside the tunnel include construction layout and deformation monitoring. Construction layout surveys are executed based on the coordinate system of the tunnel control network to guide temporary or permanent works inside the tunnel.

Tunnel convergences are being measured with the Geokon Ealey tape extensometer while the measurement section is within the length of the TBM. Once the TBM leaves the measurement section, 3-D measurements are performed with Leica TCA1800 and TCRA1201 total stations. Settlements are also being monitored using level measurements. Tunnel control network survey monuments are being used for the measurements.

4. Conclusion

The Niagara Tunnel will deliver an additional 500 cubic metres per second of water to the Sir Adam Beck Generating Complex. When completed, this additional water will increase generation output from the Beck complex by about 1.6 TWh every year. That's enough electricity to more than meet the needs of a city about twice the size of Niagara Falls. This additional electricity will be clean, and renewable and will benefit both Ontario and the environment.

The use of the most up to date survey methods, instrumentation and software will ensure the successful completion of the project.

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