DISPUTE REVIEW BOARD REPORT
Niagara Tunnel Project

Dispute Review Board Dispute No. 1

Differing Subsurface Conditions in Queenston Formation

Hearing Dates: June 23 through 26, 2008 **Report Date: August 30, 2008**

The Dispute Review Board (DRB) met with the Parties and their experts in Niagara Falls, Ontario to hear the Strabag Inc. (Contractor) dispute with Ontario Power Generation (Owner) regarding alleged differing subsurface conditions (DSC) encountered in the Queenston Formation (QF) portion of the tunnel between Stations 0+806 and approximately 2+200. In preparation for the hearing the DRB reviewed the Parties' position papers, reference documents and rebuttal papers, including expert reports and rebuttals to them. The hearing was closed on June 26,2008 following completion of testimony by the Parties and their experts, including their responses to questions from the Board. The Parties provided additional material as requested by the DRB.

1 SUMMARY OF DISPUTE

The following paragraphs summarize the Board's understanding of the Parties positions relative to the pertinent issues in dispute before the DRB and this hearing.

1.1 Large Block Failures

1.1.1 Contractor's Position

Large block failures within the Queenston Formation (QF) that occurred at cutterhead Sta. 0+815 and 0+839 were bounded by the overlying lithological contact with the Whirlpool Formation and natural discontinuities oriented sub parallel and sub perpendicular to the tunnel axis. These failures were structurally controlled, gravity failures with no evidence of any stress-related effects and were not anticipated based on the conditions described in the Geotechnical Baseline Report (GBR). The GBR reference to up to 3 m of slabbing implies progressive failure in layers and not sudden large block failure and these conditions constitute a DSC.

1.1.2 Owner's Position

The Owner maintains that block failure is not due to a geotechnical subsurface condition but a result of inadequate rock support. Further, that although some limited reduction of regional in situ stress field was expected in the QF immediately below the stiffer Whirlpool Sandstone, the stress reduction would not be of a magnitude that would promote block failures in the crown. Rather, the Contractor's failure to install closely spaced steel sets within or immediately behind the shield of the TBM, as agreed to in the Design Build Agreement (DBA) led to the large block failures and no DSC was encountered.

1.2 St. Davids Gorge

1.2.1 Contractor's Position

Clause 5.5e of the DBA states: "No request by the Contractor for relief for differing subsurface conditions will be allowed in respect of Work under the St. David's Gorge to the extent that the width of the gorge is within the width defined in the GBR." This clause was added by the Owner to reduce its risk exposure if rock conditions worsened as a direct result of the Contractor's raising the vertical alignment of the tunnel some 50 m. The Contractor maintains that it's acceptance of this clause relied on the GBR description of rock conditions under the Gorge (Article 4.4.4.4 of the GBR) as being "generally fresh and of excellent quality" at depths greater than "15 m to 25 m below the bottom of the gorge". Clause 5.5(e) of the DBA is not a waiver of entitlement to any DSC within the limits of the Gorge and Strabag's anticipated risk was limited to a potential narrow feature filled with sediment and water that may have gone undetected at the higher tunnel alignment by borehole investigations conducted prior to bidding. This risk was mitigated by additional vertical and horizontal boreholes drilled by Strabag and it is indisputable that the "excellent" rock conditions described in the GBR do not exist. As such, Strabag contends it is entitled to relief from the more adverse excavation conditions resulting from such DSCs encountered in the Gorge area.

1.2.2 Owner's Position

The Owner maintains that raising the tunnel alignment had real and potential benefits to the Contractor in the form of reduced grades and total length of tunnel and possible bonus payment from increased water delivery. Further, that the proposed raising of the tunnel could put the tunnel crown within roughly 15 m of the bottom of the Gorge. Clause 5.5e was added to the DBA because it moved the tunnel from more competent to less competent rock and the Owner wanted no part of this risk, and Strabag agreed that the Owner would have no part of this risk. Strabag cannot claim for DSCs under the St. Davids Gorge as such claims are expressly prohibited by the Agreement.

1.3 Insufficient Stand-Up Time

1.3.1 Contractor's Position

Stand-up time provides a time frame within which support must be installed and the Contractor maintains that, as defined by Bieniawski (1976 and referenced in the GBR), the stand-up times relative to RMR values of the rock (as provided in the GBR) and the tunnel span would imply sufficient stand-up time to allow installation of initial support throughout most of the QF. The Contractor maintains that 10 singular events were included in its proposal when the stand-up time would not be sufficient to allow installation of the intended regular support. The Contractor also maintains that it advised the Owner prior to award that, with an "open" TBM, standard rock support could only be placed in the L1 area, a distance of about 4-7 m from the face. The Contractor contends that the stand-up times interpreted from Bieniawski's relationships with RMR values (referenced in the GBR) together with the operational constraints of the TBM are in conflict with the actual stand-up time encountered during tunneling in the QF and that this condition was not anticipated from the information presented in the GBR and thus constitutes a DSC.

1.3.2 Owner's Position

The Owner maintains that the stand-up time relationships with RMR values, as developed by Bieniawski, are for ground conditions not subjected to high in situ stresses and therefore are not applicable to this situation. Further, the Owner maintains that stress induced failure in the QF, where tangential stresses are a high proportion of the rock's unconfined compressive strength, will occur at or immediately behind the cutterhead and, if not controlled by the TBM roof shield and immediate rock support, will continue into the rock mass and result in excessive overbreak. The Owner maintains that the Contractor agreed to install full and immediate support and closely spaced steel sets over ~75% of the QF to mitigate this. Therefore, if the Contractor recognized the need for full and immediate support, stand-up time could not have been expected. The Owner maintains that stress-induced failure has been the primary failure mechanism within the QF, exactly as indicated in the GBR, and therefore no DSC was encountered.

1.4 Excessive Overbreak

1.4.1 Contractor's Position

The Contractor maintains that the QF did not behave as a "generally massive" rock, as indicated in the GBR, and therefore, that the originally agreed on support method using steel sets could not be practically installed in a manner that would limit loosening of the remaining rock to the degree deemed necessary by its Designer. Also, "the principal reason for using steel sets were indications in the GBR of a high stress environment and significant potential for swelling and squeezing in the QF, with invert heave and sidewall distress". Further, the final liner approach with a prestressed unreinforced cast-in-place liner and a water tight membrane was a key factor in the selection of this Contractor. Considering the extraordinary 90-year service life specified in the Owner's Mandatory Requirements, combined with practical limitations on the ability to grout any remaining voids, the Contractor had to change its support means and methods to reliably and practically limit the amount of loosened rock left in place. Also, the reduced squeeze, sidewall spalling and invert heave actually encountered made the use of steel sets less important. The change in means and methods was driven by the DSCs, not vice versa, and the resulting excessive overbreak (several times greater than the average amount per meter that was anticipated) is, in itself, sufficiently material to entitle the Contractor to immediate relief under the contract provisions for DSCs.

1.4.2 Owner's Position

The Owner maintains that the features originally provided on the TBM should have been sufficient to provide the necessary rock support until steel sets could be placed immediately behind the TBM shield and expanded behind the fingers. The Contractor removed the equipment on the TBM that was needed to install steel sets before reaching the QF and, hence, never attempted to install steel sets in the QF as stipulated in the GBR, let alone document an unacceptable degree of loosening of the remaining rock as required by Section 5.7(b) of the DBA. The Owner maintains that if the steel sets were properly installed, including the intermediate bolts, the resulting loosening of the rock could have been limited to levels that met the design requirements. Further, the conditions encountered were as defined in the GBR and it was the Contractor's decision to change its means and methods that caused the excessive overbreak. The DBA specifically states that the Contractor will not be entitled to make any claim for the impacts resulting from a change or deficiency in the designs, means and methods that causes a difference in the behaviour of the geotechnical subsurface conditions.

1.5 Inadequate Table of Rock Conditions and Rock Characteristics

1.5.1 Contractor's Position

The Contractor maintains that the rock mass behaviour encountered during tunneling in the QF is materially different and is not adequately described by the Table of Rock Conditions and Rock Characteristics included in the GBR. Further, the Contractor maintains that the table is not only insufficient and inadequate to define the actual conditions encountered; it is also inconsistent with the Rock Support Requirements stipulated in the GBR (Article 8.1.3.) and with standard practice. As a consequence it was necessary to develop two new rock support types (4R and 4S) for rock conditions and characteristics not included in the Table. This necessitated significant modifications to the TBM backup equipment and, in turn, modifications to the means and methods for supporting the tunnel. Thus, the Contractor maintains that this Table presented in the GBR does not accurately describe the in-situ conditions encountered during tunneling and thus constitutes a DSC.

1.5.2 Owner's Position

The Owner maintains that, as stated in the GBR, the in-situ rock condition is to be determined based on the "closest match" to the Rock Characteristics within each Rock Condition defined. Further, the Table must be read in conjunction with the remainder of the GBR and it deals with stress-induced failure as the predominant failure mechanism within the QF. Based on the characteristics in the Table, essentially all of the rock within the claimed length of tunnel has been classified by the Owner as Type 5. Should the Contractor's contention result in an agreement that greater support is required than Type 4Q or 5 can provide, then the rock would be classified as a Type 6 condition. The price and schedule would be adjusted accordingly following the completion of the tunnel excavation with no DSC required.

2 BACKGROUND

2.1 General

Strabag Inc., an Austrian contractor, and the Owner entered into a Design-Build Agreement (DBA) to construct the Niagara Tunnel Project, a 10,400 m long, 14.4 m excavated diameter tunnel to convey water from the Niagara River upstream of Niagara Falls to the existing canal system that feeds the Sir Adam Beck hydroelectric plants at Queenston, Ontario. The original Contract Price was $623M. This Work will add significant power generation to the existing facilities and prompt completion is critical, as is the continuous operation of the tunnel over a 90-year service life. The tunnel functions as an inverted siphon and, consequently, unwatering of the tunnel must be done by pumps rather than by gravity drainage. This would result in significant interruption of service (on the order of 3 weeks) just to unwater the tunnel. The contract includes a significant bonus for early completion and significant liquidated damages for late completion, both of which are limited to 20% of the Contract Price (~$125M).

The tunnel is being excavated with a main beam tunnel-boring machine (TBM). At the time of the hearing the TBM had excavated approximately 2,200 m of tunnel, of which roughly 1,400 m is within the QF, with an additional 5,500 m (~80% of the tunnel in the QF) remaining to be excavated.

2.2 Chronology

Proposal documents submitted to tenderers	12-22-04
Proposals received from tenderers	5-13-05
Contract awarded to Strabag Inc. and signed	8-18-05
Noticed to Proceed	9-1-05
First DRB meeting	2-7-06
Start tunnel excavation	9-1-06
Large fallout at start of QF	5-16-07
Notice of DSC from Contractor to the Owner	5-23-07
Excavation of St Davids Gorge portion of tunnel	11-07 through 5-08 (approx dates)
Dispute Request from Contractor to DRB	3-5-08
Original Substantial Completion Date	10-9-09

2.3 Pertinent DBA Provisions

Section 2.1 (a) states "The Contractor will ensure that all Work is performed in accordance with and complies with the Owner's Mandatory Requirements, the Contractor's Proposal Documents, Final Submittals, Applicable Law and the other terms of this Agreement."

Section 2.13 (a) states "... The Contractor will be solely responsible for the means, methods, ... used to perform the Work, ..."

Section 3.3 states "... The Contractor acknowledges exclusive control over and commercial responsibility for any and all means, methods, ... to complete the Work for the Contract Price and in accordance with the Contract Schedule."

Section 5.4 states "The Geotechnical Baseline Report (GBR) shall serve as the only basis for determining ... differing geotechnical subsurface conditions." The GBR has been developed jointly by the Owner's team and the Contractor and, as such, describes anticipated behaviors and conditions that are dependent on the Contractor's selected designs, means, methods ... anticipated or implied at the date of this Agreement. ...The Parties acknowledge that such means, methods, ... are the sole responsibility of the Contractor, and the Contractor is free to make changes at any time. To the degree that any difference in the behavior of the geotechnical subsurface conditions is attributable to a change or deficiency in the designs, means, methods ... then the Contractor will not be entitled to make any claim for the impacts resulting therefrom."

Section 5.5 (b) states that to be a DSC, the subsurface conditions:

(1) Must "... differ materially from the GBR;"
(2) "the material difference in the conditions is not attributable to a change or deficiency in the Contractor's designs, means, methods, sequences, timing and/or level of workmanship;"
(3) Must "... directly and materially impact performance of the Work; and"
(4) "such impact has the effect of materially increasing or decreasing the cost or time of performing the Work."

Section 5.5 (c) (1) states "...the Contractor will record the rock conditions (as defined in the GBR) encountered in the performance of the Work and measure the tunnel lengths thereof and OPG will review and verify such determinations. If the parties cannot agree, the positions of both parties shall be recorded. The resolution of any disagreements will be held in abeyance ..., unless the parties mutually agree that the issue is sufficiently material that the issue should be referred to dispute resolution in which event the matter be resolved in accordance with Section 11;..."

Section 5.5 (e) states "No request by the Contractor for relief for differing subsurface conditions will be allowed in respect of Work under the St. Davids Gorge to the extent that the width of the gorge is within the width defined in the GBR."

2.4 Contract

2.4.1 Design Build

Tunnels in North America have traditionally been constructed using Design-Bid-Build contracts, in which the Contractor has no involvement in preparing the contract documents, including the GBR. All bidders tender to the identical contract provisions, GBR conditions and design.

Design-Build (DB) contracting is becoming a more frequently used form of contract on large, challenging construction projects primarily to reduce the pre-bid time spent on design efforts and equipment procurement, thereby facilitating earlier completion. DB is used on this Project and four main parties are involved: the Owner, the Owner's Representative (OR), the Contractor, and the Designer, ILF Consulting Engineers, of Austria, who is retained by the Contractor. The three contractors that proposed for this Work and their designers prepared preliminary designs, design basis and methods statements, specifications, drawings and payment provisions in general accordance with the Owner's bidding requirements, mandatory requirements and conceptual design. However, after evaluating the conceptual tunnel design, Strabag proposed a different lining design that required a different type of TBM. This was accepted by the Owner and is being used to construct the tunnel.

On this contract the Owner's team prepared an initial GBR, called a GBR-A. Each proposal included a GBR-B, in which the tenderers supplemented and revised GBR-A, to be consistent with the bidder's proposed design approach and planned means and methods of construction. The GBR-C was negotiated with the selected tenderer and became the contractually binding GBR.

The Contractor is responsible for design and construction of the Work. The Owner is responsible for more adverse subsurface conditions than are represented in the GBR. The Owner **and** the Contractor are **jointly** responsible for preparation of the GBR.

2.4.2 Contractor's Proposal

The Contractor proposed a prestressed tunnel lining method, and listed nine hydroelectric tunnels where the method had been used between 1963 and 1988. This lining approach was judged by the Owner's team to be significantly superior, for the unique requirements of the Niagara project, to the methods proposed by the other two tenderers, each of which involved a fully-shielded TBM with a single pass, pre-cast segmental lining. The price and duration of the Strabag proposal, as negotiated, were acceptable. Therefore the Owner contracted with this Contractor to do the Work.

As the DRB understands it, Strabag was not the low bidder and acknowledged in their proposal that using a shielded TBM with a pre-cast segmental liner would make construction easier. However, Strabag considered a segmental liner too unreliable, under the unique site conditions, to meet the required service life of 90-years without unwatering the tunnel for repairs.

In the Contractor's proposed lining method a waterproofing membrane is placed between the initial lining and a cast-in-place, unreinforced final concrete lining. After the concrete cures, interface grout is injected under high pressures between the initial lining and the waterproofing membrane to prestress the final concrete lining. This is intended to ensure that the tunnel will not leak during operation at 14 bar internal water pressure. This is particularly important on this project since the QF swells on long-term contact with fresh water and leakage could cause the lining to fail, and consequently to require the tunnel to be unwatered for repairs. The inside surface of the initial shotcrete lining must be of a relatively uniform diameter since the membrane is prefabricated to fit the initial lining. According to the design, no loose rock can remain outside the initial lining as this could cause unacceptable deformations to occur during interface grouting that could cause the membrane to fail or possibly result in the inability to develop the planned prestress.

2.4.3 Negotiations

DB contracts require the Parties to jointly negotiate and prepare the contract according to the owner's requirements and the proposer's design, means and methods. Typically during DB negotiations the parties concentrate on getting the contract signed and the work started, often without adequate attention to details of the design, specifications, and payment provisions. It is not uncommon therefore that, after award of DB contracts, problems arise from provisions in the negotiated contract that were either not clearly written, were overlooked, or reflect misunderstandings during negotiations and final drafting of the contract. Subsequently the parties are often able to negotiate acceptable solutions to these problems.

This DBA involves a final lining method for a high-pressure water tunnel that, to the DRB's knowledge, has not been used in North America. Also, this project is using the largest diameter hard rock TBM ever built. These unique features, combined with the other unusual conditions mentioned elsewhere in this report made negotiations a monumental effort, characterized by the OR as "fast-tracked and extensive" over "a long, hot summer". In hindsight, all of these factors contributed to a contract that had a number of problems, particularly in the GBR and resulting DSC dispute resolution.

2.5 Construction

2.5.1 Planned Means and Methods

The Contractor chose a main beam TBM with a roof shield with 3 m long trailing fingers. The total distance from the face of the tunnel to the end of the fingers was originally 7 m. As with typical main beam TBMs, muck buckets are on the periphery of the cutterhead. There are grille bars on the periphery between the buckets that prevent large rocks from jamming or plugging the buckets. The TBM also has radial openings in the cutterhead faceplate through which muck also enters the muck buckets. The TBM and trailing equipment are configured to complete placing the initial support immediately behind the fingers, in the L1 area, and to complete the initial lining in the L2 area. There is a separate platform for low pressure cavity grouting at the far end of the trailing equipment, some 100 m behind the TBM face. The Contractor states in his proposal that the primary function the planned cavity grouting was to reduce inflows into the tunnel during construction.

Generally, two types of initial lining within the QF were listed in the GBR:

- Rock bolts holding steel channels that were pre-bent to the excavation radius and then further deformed as they were secured to the irregular contours of the excavated rock surface over 120 degrees of the crown (or more if required). This was followed by a full-circle of 130 mm thick shotcrete added in the L2 area to complete the initial lining. Type 4Q support was assumed in the GBR to comprise 27% of the tunnel length in the QF.

- Full circle steel sets, pre-bent to the excavation radius, expanded against a relatively uniform excavated rock surface (i.e.not further deformed), with a row of rock bolts and anchor plates in the crown on each side of each set, followed by full-circle shotcrete added in the L2 area to complete the initial lining. These sets are Type 5 or 6 support, depending on the size and spacing of the steel set and the thickness of shotcrete. Type 5 consisted of 150 mm steel sets with 160 mm of shotcrete while Type 6 consisted of 200 mm steel sets with 260 mm of shotcrete. Types 5 & 6 comprised a total of 73% of the tunnel length in the QF, as assumed in the GBR.

The steel channels were to be on 0.9 m centers and the full circle steel sets on 1.8 m and 1.2 m centers. Wire mesh was used as reinforcing for the shotcrete and for safety to support the rock between the bolts, channels and sets. Shotcrete was placed some 25m behind in the L2 area to complete the full-circle initial lining, providing full support.

The initial lining design drawings included in the proposal clearly state: "loose rock to be removed". Loose rock contained by the wire mesh was to be removed through openings in the mesh or by cutting the mesh. The extent of loose rock removal was not delineated as "all", or otherwise defined.

It appears that the Contractor may have realized that there was a misunderstanding with respect to the anticipated QF rock conditions, either through discussions with the Owner's personnel on site or through more detailed analysis before starting to drive tunnel. This is illustrated by the Contractor's drawing NAW 130-DOV-29230-0033 Rev. 00 issued in June of 2006, less than 3 months prior to the start of tunneling, that indicates it's intention to install rock support Type 4Q throughout approximately 90% of the tunnel length within the QF (Ref. Doc. No. S10 in the Contractor's Position Paper).

2.5.2 Actual Means and Methods

The Contractor discontinued using full circle steel sets after the first 175 m of tunnel (a total of 123 sets were installed). The fingers were shortened from 3 m to 1.9 m soon thereafter, to allow better access to place steel channels held with rock bolts. Parts of the steel set erector were also removed prior to reaching the QF and all parts were finally removed after the block failure at Sta 0+806, in September 2007, and were never reinstalled.

There were many reasons to not install steel sets. The lack of sidewall spalling, invert heave, and short term squeezing and swelling negated the need for immediate support of the full perimeter of the tunnel. In addition, loosening in the crown gave the Contractor concern over the use of steel sets while still meeting the design requirements to remove loose rock. In the Designer's judgment, loose rock had to be removed and this was impractical as well as quite unsafe with steel sets. Further, removal of loose rock over the sets was highly undesirable as it slowed the tunnel advance rate and thus contributed to further loosening of the rock in the crown, as well as posing safety issues.

To support most of the QF, steel channels were deformed to the irregular rock surface as rock bolts were installed over 90 to110 degrees of the crown. Channels were installed on about 1 m centers, as required by rock conditions. A 70 mm preliminary layer of shotcrete was added to the crown in the L1 area, to complete the initial support. The full-circle of minimum 130 mm thick shotcrete was placed from the L2 area to complete the initial lining. This is referred to as Type 4R support.

In particularly bad areas of overbreak, spiling was used to pre-support rock over and ahead of the TBM. This consists of 2 in. diameter, heavy-wall pipes, 9 m long, placed in 90 mm holes drilled over the TBM cutter head. Spiles generally cover some 90 degrees of the tunnel crown, are spaced on less than 1 m centers and look up at 10 to 15 degrees. The spile pipes could not be grouted in the holes, as the rock was too open and fractured to contain the grout. Steel channels, rock bolts and shotcrete, as above, supported the spiles. A preliminary layer of shotcrete in the crown was added in the L1 area to complete the initial support. A full-circle of minimum 130 mm thick shotcrete was added in the L2 area to complete the initial lining. This is referred to as Type 4S support.

In both Types 4R and 4S additional shotcrete was placed as needed in the L2 area to fill out the initial lining to the uniform diameter required for the membrane.

The design (1921/PR-00-3001 / Rev 1, page 5) stated that a condition of no voids behind the lining was to be "achieved by contact grouting, interface grouting and cavity grouting where required." Cavity grouting at low pressure is frequently done with Type 4S from the far end of the trailing equipment after the initial lining is complete, but cannot be expected to fill all voids with certainty. Interface grouting at high pressure will be done after placement of the final cast-in-place lining and contact grouting. Interface grouting is to be done through tubing placed between the initial lining and the membrane and, therefore, cannot be expected to fill voids outside the initial lining with any degree of certainty. A condition of no voids in the rock is best achieved by removal of all loosened rock before rock support is installed to the intact rock surface. According to the Contractor, in order to have confidence in the prestressing of the final lining there is no practical and safe solution other than to remove all loose rock that forms in the QF and support the remaining rock with Type 4R or 4S initial support. Because the Contractor cannot delay his mining operations to see if the rock will fall under gravity, the Contractor bars down what it believes to be loose rock before pushing steel channels tight against the rock surface and then installing rock bolts to hold the channel and remaining rock in place.

3 DISCUSSION and FINDINGS

3.1 Large Block Failures

The DRB believes this was adequately forewarned in the GBR and no DSC is warranted. Some examples from the GBR are as follows:

- 6.3.2: "... the RMR values are slightly lower than average below the Whirlpool/Queenston contact primarily due to a slightly higher joint frequency."
- 6.3.3: ".information from the Generation area to provide a further assessment of the QF near the contact with the overlying Whirlpool" states "... the RMR value

is relatively low within the first 10 m below the Whirlpool/Queenston contact and gradually increases with depth …".

- 8.1.2.3 "The weathered zone below the contact with the Whirlpool Formation … represents a weaker zone."
- 8.1.3.4 "… support must be full and immediate for a 25 m length before and after the intersection, at the tunnel crown, of a major lithological boundary."

In addition, ten days before the first large block fell, the OR sent the Contractor an RFI asking when the Contractor would start installing full circle rock support, noting that the GBR stipulated this.

Based on the information presented in the GBR, the strength and Young's modulus of the Whirlpool is on the order of 4 to 5 times greater than the underlying QF causing the Whirlpool to carry more of the horizontal stresses with less deformation. This will create a stress shadow effect (reduction in horizontal stress) within the upper portion of the QF that should have been anticipated, and it appears that the Designer did anticipate this. Further, if the Contractor's impression of the QF was that it was "generally massive", the potential for such large block failures beneath a much stronger formation in a high horizontal stress environment would seem likely.

3.2 St. Davids Gorge

The Contractor's Proposal included raising the Owner's conceptual design low-point of the tunnel's vertical alignment some 50 m. The Owner was concerned about the added risk of encountering less competent rock at this higher elevation, as well as the added risk of intersecting the buried channel itself. However, the Owner approved raising the vertical alignment on the condition that no DSCs could be claimed for the 800m long section of tunnel under St. Davids Gorge. The Contractor recognized that raising the tunnel this amount increased the risk of difficult ground conditions but agreed to the Owner's condition and the following provision was added to DBA Section 5.5(e): "No request by the Contractor for relief of DSCs will be allowed in respect of Work under the St. Davids Gorge …".

Even though the GBR states that the QF becomes "generally fresh and of excellent quality" at depths of 15 to 25 m below the bottom of the Gorge, the DRB believes the amount of overbreak encountered at this location is likely to have been influenced by more adverse conditions associated with raising the tunnel this much closer to the bottom of St. Davids Gorge. Further, even though the tunnel did not intersect St. Davids Gorge, boring explorations are not reliable in defining the exact depth of a buried channel such as this and it is uncertain how close the tunnel may have come to the bottom of the Gorge.

Consequently, the Board finds that the Contractor is not entitled to make a claim of DSCs within the 800 m width of St. Davids Gorge stipulated in the GBR.

3.3 Changes or Deficiencies in the Means and Methods

The OR claims that the initial support means and methods were changed. The Contractor acknowledges that changes in the means and methods were made to facilitate the changes in support types as noted in the prior section of this report. However, the Contractor maintains that these changes were driven by the DSCs that were encountered and not vice versa.

According to the OR and their experts, steel sets could be installed when using a hard rock TBM and the rock supported sequentially and simultaneously in three places:

- First, close behind the cutter head, supported with the roof shield,
- Then, at the back of the roof shield, supported with the fingers, which are firmly supported by partially expanded steel sets (with wire mesh),
- Then finally, past the fingers, supported with the steel sets (and mesh) fully expanded into final position as soon as possible after each set emerges from under the fingers as the TBM moves ahead.

The Owner's team agrees that the rock over the steel set supports would be fractured and could dilate slightly, but maintains that the remaining rock would not fail and become loose. They believe that subsequent low pressure cavity grouting and high pressure interface grouting would provide sufficient filling of voids to obtain tight embedment for the final lining.

The DRB believes that this support method would be adequate on tunnel projects with less stringent final lining design criteria.

However, this TBM cannot prevent loss of rock from outside the excavated surface in the crown over the cutter head, at the grille bars/buckets. QF rock in this area can relax, crack, break apart and fall past the grille bars and into the muck buckets. Further, rock cannot be completely supported for the width of the steel set spacing at the end of the fingers. QF rock in this area can also relax, fracture, break apart and would have to be left in place or removed by hand from outside the wire mesh. In the Board's opinion, this relaxation, fracturing and breaking apart in the QF cannot be prevented with steel sets and wire mesh. This condition will also leave an irregular rock surface and steel sets (unlike steel channels) cannot be further deformed to expand tightly against the contours of an irregular rock surface.

In addition, the combination of a very large tunnel diameter, high horizontal overstress in the QF shale, serious grouting limitations and a prestressed final lining design with a waterproof membrane make it questionable whether a condition of no voids behind the lining could be achieved with adequate certainty using steel sets. Ultimately this is a judgment call and since the Contractor is assigned the risk, he and his Designer's judgment must prevail.

The Contractor is using Type 4 supports in accordance with the provisions of Note 11 on the drawing of Types 3 and 4 Initial Support (NAW130-DOV-29230-0019, rev 05) dated February 28, 2007 states: "In case of significant overbreak, the position of rock dowels and mesh shall follow the contours of the rock surface." All of the drawings issued with the proposal, however, show only bolts through steel channels for Type 4 support whereas only bolts with anchor plates (no steel channels) are shown for Types 5 and 6 supports. Types 2 and 3 support drawings in the proposal, for rock formations above the QF, show both bolts with anchor plates and bolts through steel channels. Based on the Board's experience, bolts with anchor plates and wire mesh are only effective in fairly massive rock, whereas less massive rock requires the bolts to be installed through steel channels or pans to effectively support the ground. All of these drawings before tunneling began, including NAW 130-DOV-29230-0033 Rev 00 discussed in Section 2.5.1, and the subtle differences in bolt support methods shown on these drawings, leads the Board to believe that the Contractor, through further evaluation, had revised its understanding of the subsurface conditions in the QF following signing of the DBA, but prior to actually encountering the ground in the tunnel.

Although this might be construed to mean that no DSC has been encountered (i.e. the Contractor had correctly anticipated the ground conditions prior to encountering the ground within the tunnel), the DBA clearly states that the identification of a DSC shall be based on the information contained in the GBR. If the GBR is ambiguous or imprecise in its description of the subsurface conditions such that the Contractor reasonably misunderstood those conditions at the time the DBA was signed, then a DSC would exist. In this regard, one of the main differences in Rock Characteristics between Rock Condition 4 and Rock Conditions 5 & 6 as presented in the GBR is the inclusion of "rock pressure generally exceeding rock mass strength" for Types 5 & 6, but not for Type 4. Nonetheless, over 25% of the tunnel length in the QF is identified in the GBR as Rock Condition 4Q. This is inconsistent with the conditions actually encountered in the QF where stress induced fracturing has been encountered throughout, as evidenced by its classification as Type 5 by the Owner.

The addition of shotcrete in the L1 area to the Type 4 support described above is called Type 4R support. In the Board's opinion, this addition of shotcrete does not constitute a change in means and methods that would justify invoking the provision of DBA Section 5.5(b)(2) regarding "...a change or deficiency in the Contractor's designs, means, methods...".

Type 4S is a new support method necessitated, based on subsurface conditions actually encountered, by the QF overbreaking higher than the Contractor anticipated from the descriptions provided in the GBR. Types 4R and 4S are required by the design note: "loose rock to be removed".

The DRB believes that loose rock formed faster than the Contractor anticipated, largely due to the stress induced fracturing, and the Board is also of the opinion that full circle steel sets are unnecessary and impractical to use to support only the crown (i.e. no significant sidewall spalling or invert heave). In the Board's opinion, rock bolts and steel channels, following removal of loose rock, are the optimum initial support in the QF in this tunnel under the actual ground conditions encountered and the final lining requirements, although this will probably result in greater overbreak quantities than indicated in the GBR.

3.4 Insufficient Stand-Up Time

The Contractor testified that RMR values stated in the GBR led it to believe the QF would not fail so fast that adequate initial support could not be installed within the L1 and L2 areas. Although GBR 6.3 states that RMR values were used to assess rock mass strengths in the concept design, it neglected to point out that the RMR method of rock mass classification was not applicable as an indicator of stand-up time in rock subject to stress-induced failure, such as the QF. Even for rock not subjected to a high horizontal stress, the reported RMR values, when compared to Bieniawski graphs showing opening spans, should have raised serious concerns over stand up times when installing initial support

However, the configuration of the selected TBM suggests to the DRB that the Contractor did not expect that rock in the crown in the QF (over 80% of the tunnel) would fail almost immediately due to overstress. If immediate overstress failures had been anticipated, the DRB believes the TBM would have been designed so all passages for muck to enter the cutterhead would have been radial openings in the cutterhead faceplate without peripheral buckets. With the TBM used on this project, there is an unsupported distance of 1.2 m over the cutterhead with the peripheral buckets comprising some 0.6 m of this distance. The rock can relax, fracture, break apart and fall into theses buckets before it can be supported by the TBM roof shield. Even with stress induced fractures, such a condition may not have been anticipated if the rock was believed to be "generally massive".

In the DRB's opinion, the Contractor's original plan to use steel ribs as a regular means of initial support in the QF suggests that it anticipated the rock to be "generally massive" with reasonably good stand up time throughout much of the QF formation. Under such a scenario, the need for full circle steel ribs to resist sidewall spalling and invert heave would make sense, while feeling that stress induced fracturing in a "generally massive" rock would not produce serious crown stability problems or loosening of crown rock to a degree that would raise concern over performance of the final liner under high interface grouting pressures.

It appears to the Board that there was a serious misunderstanding between the Parties with respect to the anticipated rock conditions and rock behavior at the time the contract GBR was being negotiated. Since both Parties developed the GBR jointly, any misunderstanding is the shared responsibility of both Parties.

3.5 Geotechnical Baseline Report

It is noteworthy that Appendix 5.4 – Geotechnical Baseline Report states in item 1.4 that "the GBR will be used during the execution of the Contract for comparison of the *assumed subsurface conditions with actual subsurface conditions* as encountered during construction." The wording contained in this Appendix 5.4 is consistent with the usual concept of a GBR on a Design-Bid-Build project.

Section 5.4 of the DBA, however, states the GBR "describes *anticipated behaviors and conditions that are dependent on the Contractor's selected designs, means, methods....anticipated or implied* at the date of this Agreement." The wording in the DBA expands and complicates the GBR concept and purpose by (1) changing "*assumed*" to "*anticipated*" or "*implied*" and (2) by including "*behaviors and conditions that are dependent on the Contractor's selected designs, means, methods...* ", both of which require a mutual understanding between the Parties. The DRB assumes the objective of these modifications is to avoid DSCs based on subsurface conditions set by one party to the contract. This may seem achievable, especially when the GBR is "jointly developed" by the Owner and Contractor. However, neither Party is likely to anticipate all of the conditions and behaviours that will be encountered and would influence the performance of the Work, let alone have a clear mutual understanding of those conditions and behaviours. In the Board's opinion, the wording in the DBA makes the application of the GBR concept much more complex and increases the likelihood of misunderstandings.

The GBR concept was originally developed and generally used as a risk allocation tool. It should be noted that rock behavior is generally dependant on both the ground conditions (Owner's responsibility) and the means and methods (Contractor's responsibility) and, therefore, identification of a DSC based on behavior makes allocation of the risk inherent in the work extremely difficult, if not impossible.

The Owner's conceptual design assumed that a precast segment lining would be used. Thus, at the time the GBR-A was prepared, the Owner's team anticipated that a precast, gasketed segmental liner would be used, erected within a fully shielded TBM. Under such conditions, the rock surrounding the excavation is never exposed; the rock is allowed to slab, loose rock is not removed, and continuous support is provided by the shield, segments and annular backfill. Consequently, greater emphasis in the GBR-A may have been placed on anticipated problems with squeezing and swelling rock over the long term, with lesser emphasis placed on the immediate support problems associated with main beam TBM excavation in the QF under high horizontal overstress. This would be misleading to a Contractor contemplating the use of a main beam TBM.

The Contractor and Designer could have also been misled by statements within the GBR that were incorrectly or imprecisely drafted according to guidelines in "Geotechnical Baseline Reports for Construction", ASCE, 2007, Section 6.4, page 27. Specific quotes from the GBR that illustrate this point include:

- 8.1.2.2: "...As a result, there is a *potential* for thin rock wedges to develop at any bedding plane." To the optimistic contractor bidding for the work, *potential* is likely to be interpreted as seldom likely to occur.

- 8.1.2.3 "The Queenston Formation is *generally* massive." Without defining the extent more quantitatively, this could, in the Board's opinion, lead to a reasonable interpretation of massive rock. Other descriptions in the GBR warn of less massive conditions that "must be accounted for", but these could be interpreted as local conditions.

- 8.1.2.3: "significant slabbing *can* occur in the crown" which could also be interpreted that slabbing might not occur; when in actuality it occurred throughout the QF.

- 8.1.3.2: "initial support must be installed within or *immediately behind* the shield". This can be interpreted that installation of initial support could be delayed to immediately behind the shield.

Consideration of such statements may have led the Contractor to propose Rock Condition 4Q in the QF that does not include *slabbing* as one of the rock characteristics, while actual conditions show *slabbing* should have been expected throughout the horizontally overstressed QF.

Other statements in the GBR that describe conditions that may have influenced the Contractor or his Designer, but never developed or were more severe than expected include:

- 8.1.2.5 "*Slabbing* and plucking of rock blocks *around* and above the TBM shield..." was apparently written for a TBM using a full circle shield and erecting pre-cast concrete segments. A main beam TBM roof shield does not have an "*around*" portion and no substantial *slabbing* of rock blocks *around* the TBM shield can occur.

- 8.1.2.6 "Stress induced spalling will occur at the sidewalls...within ½ hour of excavation", when in actuality it has not occurred in the sidewalls within the QF to any measurable degree, even after days of the sidewalls standing unsupported.

- 8.1.2.6 "Invert heave is *expected.*", when actually invert heave does not appear to have been a problem, although some fracturing of the invert has been reported.

- 8.1.3.2 "… initial support must be installed … immediately … and must provide full coverage to the rock surface." Initial support cannot be installed immediately when using a main beam TBM. This apparently is also written for a TBM with a full circle shield.

The statement that stress induced spalling *will* occur at the sidewalls within ½ hour of excavation, in addition to the statement that invert heave is expected, could have led the Contractor to accept steel sets as the predominant support method within the QF, considering this to be the only method to effectively support both the sidewall spalling and invert heave.

There are also potentially misleading portions in Section 7.4.1.2 of the GBR "Observed Performance of the Trial Enlargement", such as:

- (a) "numerous incidences of …sidewall spalling developed." Sidewall spalling in the Trial Enlargement probably occurred because it was excavated in four levels. Sidewall spalling would not be expected in a circular tunnel, excavated with a TBM in rock expected to fail due to high horizontal overstress. Sidewall spalling has not occurred in the QF; although some joint controlled and gripper induced fallout has occurred.

- (b) "The depth of crown slabbing (up to 0.5 m) was controlled by the presence of the overlying bedding plane." The fact that rock bolts were promptly installed to support the rock above the bedding plane may have limited the depth of crown slabbing and the degree of loosening of the crown rock. In addition, testimony noted that crown-slabbing observations were minimized because the roadheader operator over-excavated the crown to remove slabbing as it formed. Crown slabbing in the QF to Sta. 2+200 has varied from <0.5 m to 3 m in depth and is expected to continue.

- (c) "…slabbing of rock in the invert, up to 1.4 m in depth, was noted … when the invert was excavated to a horizontal … profile." The wide flat invert was most prone to invert heave in the high horizontal overstress environment; whereas the circular invert of a TBM tunnel might show only minor invert cracking under the same subsurface conditions. Only fracturing and minor slabbing of rock in the invert has occurred.

The Board considers that the Contractor's design, means and methods for support were changed based on the subsurface conditions encountered (4R & 4S) and as a result of serious misunderstandings as to the rock characteristics and behaviour within the QF.

The DRB believes that during preparation of the GBR, the Owner, the OR, the Contractor and the Designer did not realize these misunderstandings. Further, the DRB believes that these misunderstandings led to misinterpretations that resulted in the current dispute over the subsurface conditions that were anticipated in the QF and delineated in the GBR. Since both Parties worked together to develop the GBR, the consequences of the resulting misunderstandings should be shared between the Parties.

As noted previously, the DBA states "the GBR shall serve as the only basis for determining changes in or differing geotechnical subsurface conditions". However, the GBR states under Rock Support Requirements (Section 8.1.3.7) that "the in-situ Rock Condition shall be determined based on the **closest match** to the Rock Characteristics within each Rock Condition defined below" (in the Rock

Conditions and Rock Characteristics Table). With this provision, there is no possibility of a DSC because no matter how different the actual conditions may be from the assumed or anticipated conditions described in the GBR, there will always be a "closest match".

Similarly, the Type 6 Rock Condition defines the Rock Characteristics as, among other things, "all other conditions requiring greater support than under Conditions 4Q and 5". Again, use of the provision "**all other conditions**" eliminates the possibility of a DSC since this wording would cover all other possibilities not assumed or anticipated in the GBR.

Therefore, the Board concludes that the language used in the GBR may have been misleading to one or both Parties. More importantly, the provisions "closest match" and "all other conditions" used in the GBR would make the DSC clause in the contract essentially meaningless, contrary to the intent of both Parties and contrary to case law disallowing exculpatory language.

Since both Parties jointly developed the GBR, any misunderstanding or inappropriate wording should, in the Board's opinion, be the shared responsibility of both Parties.

3.6 Excessive Overbreak

During hearing testimony, the Contractor explained that it anticipated only ~15,000 m^3 of overbreak using its anticipated means and methods in the QF (27% steel channels bolted against the rock surface in the crown of the QF and 73% steel sets for immediate support within the QF, followed by shotcrete installed over the entire perimeter to resist long term loads associated with swelling and further squeeze). The OR, on the other hand, indicated that it had estimated ~ 45,000 m^3 of total overbreak (3 times as much as the Contractor) even though the OR maintains it anticipated full round steel sets on closely spaced centers and installed under or immediately behind the TBM shield (retaining any loose rock behind the wire mesh) throughout most of the QF portion of the tunnel excavation. This is the exact opposite of what the Board would have expected for the two support methods and when the DRB queried the Parties for an explanation of this apparent inconsistency, there was no logical explanation forthcoming. Nonetheless, the GBR set the total overbreak quantity at 30,000 m^3, the average of the two estimates. This leads the DRB to believe there was a serious misunderstanding between the Parties with respect to overbreak.

As discussed in the foregoing sections of this report, the Board considers that the large overbreak quantities in the QF are the result of the means and methods being employed by the Contractor. Normally steel set support retains the loose rock and would lead to less overbreak. The Board, however, also considers that the support methods being used are appropriate for the ground being encountered, considering the type of TBM being used, the Designer's concern over possible voids left outside the initial liner, and the potential impact of such voids on the construction and long term performance of the final liner.

The Owner's Mandatory Requirements require that the Contractor design and construct a final liner that will perform without significant repair for an extraordinarily long 90-year service life and the Board understands this was an important factor in the Owner's award of the contract to Strabag. The Contractor's design requires that no voids remain outside the initial liner and the Designer stated on its rock support drawings contained in the Contractor's proposal: "loose rock to be removed". The decision as to what means and methods satisfactorily ensure that no voids remain outside the initial liner must lie with the Contractor.

Based on the GBR provisions "closest match" and "all other conditions requiring greater support" that would invalidate the concept of a DSC, as discussed previously, the DRB would conclude that the GBR is defective. In addition to being defective, the DRB concludes that the GBR was misleading based on imprecise terms used in the document and the exclusion of "rock pressure generally exceeding rock mass strength" in the rock characteristics for rock condition 4Q in the QF. In combination, these led the Contractor to a reasonable but incorrect interpretation of anticipated subsurface conditions within the QF at the time the DBA was signed. Thus the DRB concludes that, were it not for the defective GBR, a DSC with respect to excessive overbreak would exist.

Whether the GBR was defective or simply misleading, both Parties developed the GBR jointly and therefore both Parties must share in the consequences in resolving the issue.

Further, the large overbreak quantity encountered throughout much of the QF mined to date has impacted the rate of advance of the TBM and it appears that the total quantity of overbreak will exceed the GBR quantity by a significant amount. Although the DBA indicates that if DSCs are encountered, the resolution of such claims should be held in abeyance until tunnel excavation is complete, the DRB believes that the consequences of the misunderstandings that have led to both the large overbreak quantities and the related impacts have been so material that some form of resolution is needed at this time in the best interests of the project.

3.7 Inadequate Table of Rock Conditions and Rock Characteristics

The Table of Rock Conditions and Rock Characteristics included on page 37 of Appendix 5.4 – Geotechnical Baseline Report is the Table referred to in Section 8.1.3 of the GBR that states, "The in situ Rock Condition shall be determined based on the closest match to the Rock Characteristics within each Rock Condition defined below." Some of the Rock Characteristics referred to in this Table are rock behaviors that are dependent on both the subsurface conditions and the means and methods for supporting the rock. As the DRB understands it, this Table was developed jointly by both Parties in an effort to identify the type of support that was anticipated over estimated lengths of the bored tunnel. Further, the Rock Condition on this Table is, in fact, the specific rock support type (4Q, 5 or 6 in the QF) that was anticipated for the "closest match" to the Rock Characteristics given. Type 6 includes a "catch all" phrase of "all other conditions requiring greater support than under Conditions 4Q and 5" that would imply that all DSCs would be included under Rock Condition 6.

Review of the Table indicates several unworkable Rock Characteristics. For instance, each of the Rock Conditions in the QF referred to "continuous overbreak due to any of: sidewall spalling and invert heave", yet neither of these conditions were particularly noticeable in the tunnel. Type 4Q is different from Types 5 and 6 in that it omits "continuous overbreak due to slabbing" which occurs throughout the QF. "Continuous overbreak due to discontinuities" was listed for the Formations above the QF but not included in the QF Rock Characteristics, yet overbreak in the QF was often a combination of stress induced fractures and existing discontinuities.

The Rock Characteristics for each of the Rock Conditions within the QF refers to the "crown being more than 3 m of bedding plane"(4Q) or "within 3 m of bedding plane" (5 or 6). DRB observations in the tunnel suggest regular sub horizontal bedding planes in the QF were commonly on fairly close spacing (<0.5 m) and were readily apparent in the crown and upper haunches of the tunnel, especially in overbreak areas. The influence of such bedding planes on overbreak was particularly apparent to the DRB when fairly large portions of the crown were pushed up several inches by the hydraulic drills when installing steel channels and rock bolts, even though such loosening was not visually apparent from the L1 area.

The only different Rock Characteristics between Rock Condition 5 and 6 were the addition to type 6 of "closely broken shear and thrust zones" and the catch all "all other conditions requiring greater support than under Conditions 4Q and 5". This explains why all of the QF encountered in the claimed length of the tunnel has been classified by the Owner as Rock Condition 5.

The Contractor refused to record the conditions encountered in the QF in accordance with this Table, even though the DBA (Section 5.5(c)(1) instructed him to do so. The DRB suspects this was because the Rock Characteristics described in this Table were inadequate to define the rock in a manner that would enable identification of a DSC, i.e. mapping in accordance with the Table would force the Contractor into classifying the rock as one of the 3 rock types listed for the QF.

The DRB agrees that the Table of Rock Conditions and Rock Characteristics is inadequate to be used for the identification of DSCs and, further, that the inclusion of such terms as the "closest match" and "all other conditions" essentially renders the concept of DSCs meaningless and makes the GBR defective. Other contract language has been used in the U.S. in Design-Bid-Build contracts in an effort to avoid DSC claims. Such disclaimer language is contrary to case law and has consistently been thrown out by the U.S. courts. In this DB contract, both Parties jointly developed the GBR document and both Parties should share the shortcomings of the resulting documents.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Large Block Failures

There is no DSC. The actual conditions were adequately described in the GBR.

4.2 St. Davids Gorge

Given the provision of the DBA Section 5.5 (e), the Contractor has no claim for any DSC in this 800m long section of QF.

4.3 Insufficient Stand-Up Time

There is no DSC based on insufficient stand-up time, as the Contractor's reported reliance on RMR values stated in the GBR was inappropriate.

4.4 Excessive Overbreak

There is a DSC with respect to the excessive overbreak, provided the defective provisions of the GBR are overlooked, because the GBR contained potentially misleading statements that make the Contractor's position reasonable. Any substantial changes in the designs, means and methods of the support (i.e. Type 4S) were the result of DSCs encountered and not vice versa. Since the development of the GBR was the mutual responsibility of both Parties, we recommend that the Parties negotiate a reasonable resolution based on a fair and equitable sharing of the cost and time impacts resulting from the overbreak conditions that have been encountered and the support measures that have been employed. Both Parties must accept responsibility for some portion of the additional cost, but at the same time the Contractor must have adequate incentives to complete the Work as soon as possible.

4.5 Inadequate Table of Rock Conditions and Rock Characteristics

The Table of Rock Conditions and Rock Characteristics is inadequate to define the subsurface conditions that were encountered. More importantly, the classification of support types based on the "closest match" to rock conditions and rock characteristics given in this Table, together with rock characteristics defined as "all other conditions", renders the concept of DSCs essentially meaningless and the GBR defective. The DRB recommends that the Parties jointly revise the Table of Rock Conditions and Rock Characteristics in such a manner that it describes the rock characteristics to be assumed in terms that are mappable (or otherwise quantifiable) so that it can serve as a clear basis for defining DSCs throughout the remainder of the tunnel excavation. The DRB also recommends that the terms "closest match" and "all other conditions" be removed from the GBR.

This report and the Conclusions and Recommendations presented herein reflect the unanimous views of the Dispute Review Board.

Additional Comment:

The DRB members have rarely experienced such an excellent, cooperative atmosphere between the Parties on a tunnel project. This is especially impressive considering the pioneering nature of the Work and the problems and issues encountered. The Board is confident that the Parties can negotiate an amendment(s) to the DBA that, while not commercially optimum for either Party, will allow the Project to proceed to optimum completion.

Respectfully submitted,

Date: 8/30/08

Peter M. Douglass, DRB Chair

Date: 8/30/08

Dennis McCarry, DRB Member

Date: 8-30-08

P.E. Sperry, DRB Member