Value Engineering Study

Project 11469-0002:

George Massey Tunnel Seismic Densification

South Coast Region

Detail Design by: Buckland and Taylor Ltd.

Final Report

April 20th, 2007

Performed for:

The British Columbia Ministry of Transportation

March 23rd to 28th, 2007

EVM Project Services Limited
Value Engineering Study for
Project 11469-0002: George Massey Tunnel Seismic Densification

April 20th, 2007

David Mintak
Senior Project Manager
Project Management Services
Ministry of Transportation
South Coast Region
7818 6th Street
Burnaby, BC V3N 4N8

Re: Value Engineering Services
George Massey Tunnel Seismic Densification

Please accept the enclosed Final Report for the Value Engineering Study for Project 11469-0002: George Massey Tunnel Seismic Densification.

On behalf of the Team assembled for this Value Engineering Study, I would like to thank you for the opportunity to complete this assignment.

Please feel free to contact me at (250) 888-0378, or at rwenglish@evmprojects.com, if you have any questions. We look forward to having the opportunity to work with you and the Region again in the future.

Ralph W. English, M.A.Sc., P.Eng.
President

EVM Project Services Limited
957 Shearwater Street
Victoria, B.C. V9A 4V3
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1. Executive Summary

EVM Project Services Limited (EVM) led a Team of consultant and Ministry experts in a Value Engineering (VE) Study for Project 11469-0002: George Massey Tunnel Seismic Densification. The project involves the densification of soils around the George Massey Tunnel, which subducts the South Arm of the Fraser River along Highway 99 between Richmond and Delta, BC. The design overview and the main VE sessions were held in Burnaby, BC.

The Study assessed opportunities for improved value based on the Detail Design performed for the Ministry by Buckland and Taylor Ltd.. The project is the second phase of a plan to seismically retrofit the tunnel to provide reasonable safety and reparability in the event of the design earthquake ground movements. The design ground movement has been determined to have a return period of 1 in 475 years, which produces liquefaction in the surrounding sands and silts.

The first phase of the seismic retrofit involved structural improvements to the tunnel itself. This work has been completed, and has improved the flexibility and strength of the tunnel. The densification work is proposed to complete the original objectives, by also limiting ground movements in a seismic event. Stone columns and seismic drains are intended to be installed to isolate the tunnel and the immediately surrounding soil mass from lateral and uplift movements resulting from liquefaction and increased pore pressures. The design as prepared represents extensive, state-of-the-art analyses by a wide range of specialists and researchers, including specific model testing.

In addition to the technical complexity of the design, the VE Study was further challenged by an interest in revisiting the commitment to proceed with the densification work in its proposed form. In this regard, the work was to step outside of the usual bounds of VE considerations for this stage of design development, to also consider what scope alternatives might be available to reduce capital costs, as well as to comment on the value of further investment in the tunnel.

Twenty-two (22) concepts to obtain life cycle cost efficiencies were generated for review, with 8 of those moving forward for further evaluation and analysis. Of those evaluated, all 8 are put forward herein as VE Proposals (VEPs) for Ministry and Designer consideration. Many of the VEPs are potential alternatives to the project scope, which would require the Ministry to pursue additional analyses to confirm their viability, and/or alter the current performance objectives. Therefore, while they are ‘recommended’ for consideration, it is highlighted that they are to be considered only in the case where the Ministry is averse to proceeding with the originally intended scope.

Recommendations in terms of refinements to the existing design are limited, as it was generally agreed that the design represented a very thorough and professional analysis. Therefore, a couple of VEPs are tabled that would require further analysis to prove out, while the best opportunities to refine the approach are embodied in the separate Notes to Ministry and Designer. These items are not costed alternatives as much as suggested means of confirming costs and reducing risk, by ensuring certain steps are undertaken through the course of completing the tender package.

Overall, the proposals and recommendations resulting from this VE Study should provide benefit in terms of providing confidence in the ultimate cost of the proposed work, and reducing the risk of escalation or overruns. In terms of value, the importance of the tunnel to the Regional network
and the uncertainty of the timing of a planned replacement suggest that spending in the order of magnitude of the currently budgeted cost is justified. However, the ability to provide effective comments on risks and alternatives was limited by a lack of an available analysis of the recently upgraded structure without soil improvements (refer to Idea 2 in Appendix C).

If an alternative to densification is to be pursued, those tabled herein would require analysis (or review, if already tabled), and the potential for up to $9M capital savings could then be considered. In the event that no further work is considered, a couple of lower-cost risk reduction measures are available, that would not however meet the current design objectives. Realization of the full potential savings identified in this report is contingent on the Designer and Ministry response to the concepts put forward.

2. Scope of the Study

Further to a request for proposal issued by the Ministry’s South Coast Region, EVM Project Services Ltd. provided a workplan for provision of Value Engineering (VE) services for the George Massey Tunnel Seismic Densification project. The primary objective of the Study, in keeping with typical industry practise, was to determine if the Detail Design prepared by the Design Team represents the most cost-effective solution to the project objectives. Additional consideration was to be made for alternative solutions and overall value. The objectives were therefore focused on:

- capital and net life cycle costs
- level of investment relative to asset objectives
- constructability
- state-of-the-art practises
- alternatives to reduce cost, and
- risk

EVM provided a Facilitator and Recorder, and consulted experts in the fields of Seismic and Densification (soils), Marine Structure Engineering, and Investment Risk Analysis. The Ministry provided Team expertise in the areas of Constructability, Geotechnical Engineering, and Structure Seismic Engineering (please refer to Section 3. Study Participants).

EVM was also responsible for all management and coordination associated with conducting the VE Study, including arranging for and providing all required resources, travel, facilities, reporting and support services. The Study was to generally adhere to the following structure:

- Preliminary Work: Review design information provided by the Ministry & Designer
- Arrange for and attend a design overview session
- Facilitate and record the Value Engineering Study workshop sessions
- Document the Study and recommendations in a draft report and submit it to the Ministry. Within ten working days of receiving the Ministry comments on the draft report, submit a Final Report.
3. Study Participants

The following Team of professionals was assembled to perform the Value Engineering Study. Participants were selected based on their:

- experience and qualifications relative to the desired areas of expert review, and
- ability to communicate ideas and work in a positive team environment.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Role</th>
<th>Company</th>
</tr>
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<tbody>
<tr>
<td>Ralph English, P.Eng</td>
<td>VE Study Facilitator</td>
<td>EVM Project Services</td>
</tr>
<tr>
<td>Kevin Gardner</td>
<td>VE Recorder</td>
<td></td>
</tr>
<tr>
<td>Dr. Upul Atukorala, P.Eng</td>
<td>Seismic and Densification</td>
<td>Golder Associates</td>
</tr>
<tr>
<td>Carlo Elholm, P.Eng.</td>
<td>Marine Structure Engineering</td>
<td>Westmar Consultants</td>
</tr>
<tr>
<td>Dr. Don Gillespie, P.Eng</td>
<td>Geotechnical Engineering</td>
<td>Ministry of Transportation</td>
</tr>
<tr>
<td>Sharlie Huffman, P.Eng.</td>
<td>Structure Seismic Engineering</td>
<td>Ministry of Transportation</td>
</tr>
<tr>
<td>Keith Kazakoff</td>
<td>Constructability</td>
<td>Ministry of Transportation</td>
</tr>
<tr>
<td>Dr. Alan Russell, Eng.</td>
<td>Investment Risk Analysis</td>
<td>University of British Columbia</td>
</tr>
</tbody>
</table>

4. Project Description

4.1. Overview

Project 11469-0002: George Massey Tunnel Seismic Densification involves the densification of soils around the George Massey Tunnel, which subducts the South Arm of the Fraser River along Highway 99 between Richmond and Delta, BC. The project is the second phase of a program to seismically retrofit the tunnel to provide reasonable safety and reparability in the event of a design earthquake. The design event has been determined to be movements which have a return period of 1 in 475 years, which produces liquefaction in the surrounding sands and silts.

The first phase of the seismic retrofit involved structural improvements to the tunnel itself. This work has been completed, and has improved the flexibility and strength of the tunnel. The densification work is proposed to complete the original objectives, by also limiting ground movements in a seismic event. Stone columns and seismic drains are intended to isolate the tunnel and the immediately surrounding soil mass from liquefaction, thereby reducing lateral and uplift movement. The design is considered state-of-the-art, and although rare in tunnel applications, is consistent with the approach proposed for the only other known tunnel densification scheme in Oakland, California.
Key features of the Detail Design as reviewed include:

- Preconstruction surveys, and installation of movement monitoring equipment
- Excavation of the existing rock, rip-rap, gravel and sand that overlies the tunnel
- Ground densification, in-river and on-shore, using stone columns and seismic drains
- Site restoration and backfill – replacement of the tunnel soil coverings.

The project estimate as drafted includes an effective 15% contingency on construction costs, as well as a nominal contract provisional sum. These are intended to address environmental requirements, utilities, and other yet to be finalized aspects of the work.
4.2. Marine Structure Engineering Summary

The Massey Tunnel is a masterpiece of clever design and construction engineering, and the structure is relatively simple. The roof is a one way slab spanning transversely to support external water pressure and overburden. The bottom slab is also a one way structure and distributes the net vertical forces to the ground. Five continuous walls act as compression struts between the two slabs and provide spatial separation between the tunnel compartments.

The foundation system is a bottom slab bearing directly on a layer of sand that was pumped between the tunnel and in-situ sands, without any special foundation structures or piling. The tunnel is nearly buoyant with low resultant loads on the soils. The support is continuous without any intended load concentrations on the bearing surface. Since the foundation support is continuous, there are no appreciable bending or shear stresses in the longitudinal direction, so the quantity of tunnel longitudinal reinforcing is quite light. Recent upgrade works have improved the strength and ductility in the longitudinal direction, and strengthened the tunnel joints which were identified as weak points of the structure.

Many of the seismic concerns of typical bridge structures are not applicable to the Massey Tunnel because of the form and the simplicity of the structure. For example, there are no girders to fall off supports, no piers to shear, no foundations to overturn, and no abutments to shift. The expected damage due to an earthquake is almost entirely related to deformation of the tunnel caused by ground movement. The deformation will cause longitudinal bending and transverse cracks which are not particularly serious for the strength of the tunnel because they would be parallel to the primary transverse reinforcing. If the tunnel were above ground, there would be little structural concern over the cracks - threat to safety would be negligible and the tunnel could be returned to service very quickly, if not immediately. But the tunnel is submerged which introduces a seismic risk unusual for bridge structures. This risk is the threat of water ingress and flooding. Because of the hydrostatic head, inflow rates could be substantial for any appreciable amount of cracking. If the public is unable to exit the tunnel in a timely manner due to any reason such as vehicle blockage, minor injury, darkness, confusion or panic, fatalities due to drowning are possible.

The current design of seismic improvements has focused on structural upgrades to mitigate brittle failures in longitudinal bending, and geotechnical ground improvements to reduce the deformation imposed on the structures. The strategy is intended to reduce the extent and width of concrete cracks so that water ingress rates are acceptably low to permit the public to escape. The VE Team has made proposals for structural strategies in lieu of geotechnical ground improvements for either limiting the seismic movement to mitigate cracking or for development of alternative strategies for managing water ingress.

From the perspective of structure seismic engineering, these observations are supported with the following points:

- The tunnel itself is buoyant, and held down primarily by the overburden of rock.
- The density of the underlying jetted sand is unknown. However, continuous support is assumed, and the original tunnel therefore had only light reinforcement.
• The recent upgrading improved strength and ductility, as well as released the stiff end joints at the ventilation buildings. This improvement is to be supplemented by the proposed ground works, to limit deformations on the structure.

• The seismic concerns relating to tunnels differ from those of a bridge or other above-ground structures. Seismic solutions must also consider the potential for reduced buoyancy.

4.3. Seismic and Soils Densification Summary

The current design calls for implementation of ground improvement measures on either side of the tunnel alignment over the full length. The goal is to densify the overburden soils using stone columns extending to Elev. -27m, and install a single row of seismic drains along the outer edges of the stone column zones to Elev. -27m or deeper, depending on location. The width of the stone column improvement zone is 10m. It is intended that this would isolate the tunnel and surrounding soil mass from movements induced by liquefaction in a seismic event, and complement the structural improvements already completed. The final retrofitted design currently as proposed can tolerate differential displacements of 0.2m and 0.6m per tunnel segment (i.e.: 100 m) in the lateral and vertical directions, respectively.

A similar approach has been examined for seismic ground improvements to the only similar structure in North America: the Posey-Webster Street Tubes in California (vibro-compaction has also been tested on the BART tunnel). Recent advancements in the industry suggest there should be reasonable capacity and qualifications in the market to support the proposed methodologies.

The design as presented is a very thorough and professional approach to the challenges. The expertise, analyses, and modelling all appear to be state-of-the-art, with a great deal of attention paid to assessing performance. However, due to the inherent nature of densification work, particularly in marine conditions, the work is subject to a great deal of uncertainty, and potential cost overruns.

The documents summarizing the soil-structure response, as submitted for VE review, are very brief, lacking a documented retrofit strategy and any results of detailed analyses that focus on optimizing ground improvement measures without comprising performance. It is also noted that some of the concerns raised by the current VE Team had also been raised during the 2004 Structural VE Study (e.g.: cut slopes on top of tunnel), but that the justification for their dismissal was not provided.

A number of refinements have been proposed for consideration herein, as well as a number of risk mitigating measures. Some of the more critical cost items relate to the expected spacing of stone columns required to achieve the performance specification – it is felt that a spacing narrower than 3.0m should be anticipated, and this would then to be relaxed if performance dictates. A more reasonable maximum spacing may be 2.5 – 2.75m. If hydraulic vibrators are permitted in the performance specification, then this consideration is even more important. Quality assurance would also be furthered by requiring a means of locating the vibro-probes and CPT probes accurately, especially given the expected currents.
It is highly recommended that testing be undertaken to help prove out the methodologies, and to obtain data to refine the design and specifications.

The specifications remain to be finalized, and a number of other items are suggested to be considered in their completion, to help mitigate risk:

- Payment for rock placement should consider the ability to accurately achieve design slopes and volumes, and should promote placement only where needed. If there is excessive settlement or drifting, and payment is on a volume placed basis, overruns could be significant (Ref. S.P. 2.6.10).
- The need for qualified operating personnel (for vibro-replacement work) should be highlighted (Ref. S.P. 2.6.7).
- With the likelihood of encountering materials of various size and composition, it would be important to define reasonable ‘obstructions’ (Ref. S.P. 2.6.8.1).
- With regard to the movement tolerances (Ref. S.P. 2.4.2.7), these seem tight when related to what we understand are the structural limits for design purposes (i.e.: 0.2m lateral and 0.6m vertical per tunnel segment). If the tolerances are to be set to invoke work stoppages, this could result in significant delays and additional costs if the limits are not set to reasonable bounds.

4.4. Investment Risk Analysis Summary

It is useful to place risks associated with the project into four categories:

1. Price risk
2. Technical risk
3. Claims risk; and
4. Appropriate allocation of funds for value.

Items (1) through (3) are normally the purview of a Value Engineering exercise. Consideration of item (4) arose due to concerns, in the face of limited resources, that the proposed ground improvements around the Massey Tunnel represent a sound investment. Each of these risk categories is briefly touched upon in the following text.

Price risk was of considerable concern to the VE Team, given current market conditions, and material quantity risks (both in terms of volumes of material to be excavated and replaced, and whether lump sum or unit prices are adopted). Technical risks are mainly associated with achieving the remediation treatment as specified, and the associated construction methods risks. For this reason, several of the value engineering proposals considered wholly different ways to achieve the project objectives. Several of the Ideas and associated Notes also addressed price risk (reference Appendix C, Ideas 1, 11, 14, 16, and 19).

Technical risk also involves some concern as to the achieveability of tolerances as specified in the draft specifications, including soil densities. Ideas 19, 20 and 22 address these concerns, with the major suggestion being Idea 1: by adopting a two phase approach, a risk-reducing phase can be directed at determining the technical feasibility of remediating the soil,
including methods feasibility, limitations on tunnel movement, and soil performance objectives.

With regard to claims risk, given the complexity of the work contemplated and the desire to transfer to the contractor significant technical risk, the potential for claims is high. Great care is required in formulating achievable performance objectives, using contractual language that is as precise as possible, and having contingency plans in hand in the event that required performance cannot be achieved or unexpected events arise. The risk of claims is addressed in part through Ideas 1, 20 and 22.

A difficult issue to quantify is that of the value of ongoing improvements to the tunnel. It is a function of the likelihood of a significant seismic event, the range of outcomes and associated values given the occurrence of such an event, and the Ministry’s ability to accommodate the various potential outcomes. Some key factors relating to these considerations are:

- At this time, no replacement for the tunnel is planned. Current programming considerations suggest that funding may not be available until other major projects in the region are completed. A horizon of 15 - 20 years is assumed.
- Highway 99, while not a formal emergency response route, is nevertheless a key network link. In the event of an earthquake, the loss of connectivity would have significant impacts to recovery and service. A replacement crossing would be very difficult to implement if the tunnel is lost, and the premium associated with accelerated delivery would be very high.
- While the probabilities are uncertain with currently available data, there is a possibility of loss of life if the tunnel experiences catastrophic displacement in a seismic event.
- The tunnel is currently at capacity for accommodating traffic volumes.
- The proposed work is a second component of a comprehensive plan to seismically upgrade the tunnel. Structural upgrading is complete, and the outstanding work represents an additional investment of approximately $25M.

This issue of value achieved by completing the planned upgrade work was addressed through the formulation of a highly simplified decision tree, involving order of magnitude assumptions as to the likelihoods and ensuing outcomes for seismic events resulting in no damage, repairable damage, and facility lost states. These were viewed from the perspective of occurrence/non-occurrence of the design ground motions for the two decision alternatives - remediate or do not remediate the ground conditions as currently proposed.

In order to determine in a more definitive manner whether the proposed works represent a reasonable investment in the asset, one would need to make assumptions on the level of risk the Ministry is willing to accept (i.e.: its level of risk aversion), as well as the costs and impacts of certain events occurring. To provide a detailed set of calculations at this stage would be misleading, as the inputs would require far more scrutiny by a wider range of experts than can be accomplished in this assignment. Only very high-level assumptions were possible.
The main finding from this very approximate expected value analysis (which assumes risk neutrality) was that a level of investment in the range of the current project budget is justifiable to further improve the ability of the tunnel to withstand the design event.

A second observation from this analysis was that it would be useful to have more analysis directed at exploring the behaviour of the tunnel given its recent structural upgrade, with and without ground remediation, in order to better understand its likely behaviour when subjected to the design ground motions. However, this was not the mandate of this VE assignment. Such an analysis would be a very complex undertaking, assuming it could be accomplished.

Should alternatives to the proposed work be considered, or if the bids received for the work are considerably in excess of the project budget, then such an analysis might be warranted, enabling a more refined decision analysis. This refined decision analysis would require additional effort with regard to supporting expertise, as the inputs, scenario likelihoods, and assumptions would require much closer scrutiny before one could suggest the resulting figures could be used for decisions on alternatives, or investment timing, including replacement of the existing structure.

In subjective terms, this suggests that the proposed budget could be viewed as a form of insurance: it buys some assurance of improved likelihood of tunnel survival in a design event, and buys some time for strategically addressing an eventual replacement structure, and its timing.

5. Study Methodology

5.1. Approach

The overall structure of the VE Study conformed to the Ministry’s VA/VE Policy & Guidelines (1998) for a study defined as a combination of levels PJV1 and 2. The Policy & Guidelines are generally consistent with procedures endorsed by the Society of American Value Engineers (SAVE), and good industry practise.

The general approach to the work plan for the assignment is represented in the task breakdown within section 6. Study Schedule. Tasks and their sequencing were tailored to satisfy the original Proposal as well as the VA/VE Policy and Guidelines. To promote early progress and reduce Study risks, the tasks and approach were confirmed early with the Consulting Services Manager and the VE Study Team. The preferred Value Engineering Proposal (VEP) and reporting standards were created prior to the VE Sessions.

The Ministry and Design Team provided background material to initiate the Team review of Design material. Design drawings and the estimate were available prior to the VE sessions, and their review completed the Preliminary Work stage. Overall, the material included:

- The Detail Design, including drawings, draft special provisions, and estimate,
- The previous VE Study Report, performed on the now-completed structural component, by CH2MHiIl
- Full-size drawings from the completed structural component.
The balance of the work plan progressed through the Design Overview and the VE Workshop Sessions, which consisted of an introduction, Idea Generation, VEP Evaluation and Costing, and VEP Selection stages (extracts from the Introductory Presentation are included in Appendix D).

The context and facilitation of the work was equally as important as the tasks, in ensuring the success of the VE Study.

EVM promotes a study environment that embodies creativity, consensus building, and professionalism. By maintaining a challenging yet positive atmosphere, the sessions fostered constructive recommendations for improvements and value. It is also important to enrol the Designer in the spirit of the sessions, to ensure that recommendations are offered and accepted as welcome enhancements to the Designer’s professional work. Design constraints, stakeholder and agency influences, and Design Team objectives were respected in a cooperative approach that promotes maximizing life cycle value.

To prompt generation of ideas and value proposals (VEPs), the Team was briefed and guided with regard to the purpose of Value Engineering, and the additional objectives for this assignment. This was facilitated by breaking the work into components (or functions), and concentrating on those attributes with greatest potential for improving value. The Cost Model and Functions developed for the Sessions are addressed in Sections 5.2 and 5.3 following.

The VE Team then used the Model and Functions to generate a range of Ideas – initial concepts for potential evaluation - in a creative brainstorming atmosphere. The Ideas were subjectively assessed in a range of categories, for potential benefits and value. Ideas identified as warranting further analysis were assigned to various Team members as Value Engineering Proposals (VEPs). Those that did not warrant analysis were either rejected, or generated Notes to Ministry & Designer (see Appendix C).

The VEPs were then evaluated and costed relative to the rates in the current estimate (see Appendix B). VEPs that generated positive value improvements were put forward as VE recommendations. Others were rejected or generated additional Notes to the Designer & Ministry.

5.2. Cost Model

The Cost Model is derived from the Detail Design estimate, which was structured in Sections as follows:

- **Mobilization** – marine and on-shore efforts.
- **Pre-construction** – surveys, and installation of monitors.
- **Excavation** – removal of existing tunnel coverings.
- **Densification** - marine and on-shore columns.
- **Seismic Drains** - marine and on-shore applications.
- **Site Restoration and Backfill** – rock, rip-rap & gravel placement.
The Cost Model used the rates identified in the current Detail Design estimate. The Total Estimated Tender amount, for the sections listed above, is $20.3M. At this stage of development, there is a contingency of 15% of the current construction cost estimate (a single line provisional sum is included in the construction costs), and a further 15% is estimated for project management, engineering, and supervision. The Total Project Cost is therefore roughly $26.3M.

The breakdown of the costs was used to identify areas of greatest potential cost savings. The model is represented in the following Figures:
Figure 3 – Densification Cost Factors

Figure 4 – Seismic Drain Cost Factors

Figure 5 – Restoration & Backfill Cost Factors
5.3. Cost Functions

To address the major cost factors, the contributing cost elements were considered with the Team during the VE Overview Session. This looked at what elements affecting each cost component are most likely to influence capital and life cycle costs. The results guided analysis and brainstorming, with the following structure:

**Preconstruction**

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<tr>
<th>Capital</th>
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<td>Extent of Monitoring Equip.</td>
<td>Effectiveness of Monitoring Process</td>
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**Excavation**

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<td>Waste &amp; Haul Requirements</td>
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<td>Geotechnical Conditions</td>
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<td>Materials as Surveyed</td>
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<td>Construction Methodology</td>
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**Densification**

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<td>Containment Requirements</td>
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**Drains**

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<td>Materials Used</td>
<td>Infiltration of Fines</td>
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<td>Construction Methodology</td>
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6. Study Schedule

The schedule of activities for the VE Study initiated with assignment award. Initial activities involved early coordination with the Ministry and Designer, to confirm dates and travel arrangements.

Other early activities involved facility and service confirmations, and the preparation of draft materials and templates. Agendas and drafts were circulated and refined prior to the Design Overview session. Detail Design material was provided in advance of the VE Study, to permit review before the sessions.

The design overview kicked off the formal VE process in Burnaby. The VE sessions proceeded immediately following and progressed in sequence through all study phases, to the Summary Presentation.

Select draft report material was prepared during the sessions, to assist with meeting the overall schedule. This allowed a target of having the Draft Report submitted in the week following the VE sessions, and a Final Report completed within 10 working days of receiving comments on the Draft.
The following Gantt chart outlines the key activities and timelines:

7. Design Overview

The Design Overview Session was scheduled and coordinated with the Design Team and client. It immediately preceded the VE Sessions, and the following are the results of this session:

Date: March 23rd, 2007

Location:
  Boardroom 1 - South Coast Region
  Ministry of Transportation
  7818 6th Street
  Burnaby, BC

Attendees:

David Mintak  Project Management  MoT
John Schnablegger  Regional Management  MoT
Jay Porter  Project Management  MoT
Bill Szto  Bridge Engineering  MoT
Hisham Ibrahim  Lead Designer  Buckland & Taylor Ltd.
Earnest Naesgaard  Design – Geotechnical  Trow Associates Inc.
Dan Yang  Design - Geotechnical  Trow Associates Inc.

The Gantt chart shows:
- Value Engineering Sessions
- Duration
- Start Date
- Locations
- Attendees

The chart includes dates such as:
- March 23rd, 2007
- March 26th, 2007
- March 28th, 2007
- April 9th, 2007
- April 10th, 2007
Key issues and features of the project that were highlighted by the Ministry and Design Team include:

**Opening comments:**

David Mintak:

- Seismic upgrade is in two phases:

  - **Phase 1:** Structural retrofit is complete at cost of approx. $24 M,
  - **Phase 2:** Ground Improvement is estimated at $23.3 M with a $3 M contingency, plus MoT costs for design, project mgmt., etc.

John Schnablegger:

- Massey Tunnel is nearing end of its practical lifespan, but there is no current plan to replace it.
- The current objectives are to consider a new Highway 99 crossing upon completion of the Gateway Project. Current approvals suggest it would be 15 to 20 years before a new crossing (most likely a bridge) would be completed. The tunnel is already at its practical limit of lifespan, in the context of its ability to address increasing traffic.
- If the grand total of Massey Tunnel retrofit work exceeds $50 M, it will require a Treasury Board review.
- The project requires support in light of the risks, and the value in investing seismic retrofit funding on this option.
Ralph English:

- The objectives of the VE Study are to:
  - Provide comments on overall value, in terms of the level of investment relative to asset purpose
  - Confirm that the design adheres to state-of-the-art practises
  - Comment on the ability to reduce the capital budget
  - Review constructability and staging
  - Limit risk

- The study is not a typical VE Study, in terms of the extent of concept options to be considered, and unique complexity. However, the study will be conducted with a standard approach and context: to conduct a brief, independent overview of the existing design, to provide the client and Designer with additional confidence that the design is completed to optimum value.

Presentations:

The balance of the agenda consisted of presentations on the structural work completed to date, by Hisham Ibrahim of Buckland & Taylor Ltd., and on the associated densification work, by Ernest Naesgaard and Dan Yang of Trow Associates.

The full extent of these presentations is not reproduced here. However, the presentations were very extensive and thorough, and copies were provided for reference to support the VE Sessions. They provided a detailed summary in terms of:

- Tunnel history
- In-situ properties
- Field work
- Structural upgrading
- Approvals
- Modeling and testing
- Expertise employed
- Case studies and theories

Highlights and enquiries addressed:

- Ground improvement design has been optimized for the river segment (3D modeling), but not for on-shore work.

- The estimate reflects work to be completed over 2 years (assumed to be tendered this coming fiscal year).

- The current estimate of $23.3 M includes over $10 M in excavation and restoration. Therefore, reducing the amount of densification will only nominally reduce total cost. There are few opportunities to realize big savings by refining the densification work.
The conclusion of recent soil investigation and design effort is that ground improvement is still necessary.

There are three Vancouver firms that could handle the soil densification job.

The design priorities were defined as saving lives (i.e: evacuation), followed by reparability, or salvage, of the tunnel for continued use after a design seismic event. These fortunately do not act in isolation – seismic improvement will serve both.

Design objectives include the survival of the tunnel in a 1:475 year event.

The probability of liquefaction varies with the earthquake. Liquefaction is considered possible in the 1:200 year event, and likely in the design event.

The design was intended to include ground improvements that would allow for lateral movement of .2 m (20 cm) within a 100 m span, and vertical movement of .6 m over that 100 m span. Modelling indicates that this movement will be far exceeded without ground improvement. With densification, the movement is expected to be .13m and .26m respectively.

Flexible joints were examined and rejected.

FLAC analysis was performed in 2D. 3D modelling does not account for soil variability.

Estimate was refined with input from a contractor review session.

The test section is to be instrumented and monitored, to ensure tolerances are not exceeded, as a component of the overall contract.

Environmental and Navigation channel issues are dealt with through a Fraser River Estuary Management agency, for coordinated approvals. The Ministry will be taking these discussions further.

Hydro lines and Telus fibre optic cable go through the tunnel. On-shore locations are yet to be confirmed.

Retrofitting the towers was a previous VE topic, and was rejected. It was determined to increase structural stress concerns.

An undefined proportion of excavated material is assumed to be used in the restoration processes.

The Posey-Webster Tubes seismic retrofitting project in California was an available reference for the technology.

The history of scour holes is not well established.

Cost sharing with utilities is not seen as a productive pursuit.
8. VE Study Agenda

Mon., March 26th, 2007 – VEP Development & Evaluation

Location: Boardroom C
Executive Hotel & Conference Center
4201 Lougheed Highway, Burnaby

8:30am – 10:00am: VE Overview and Setup R. English
VE Study Objectives
Review Design Functions
Review Initial Opportunities

10:00am – 12:00pm: Formal Idea Generation All

1:00pm – 2:30pm: VEP Development All

2:30pm – 4:30pm: VEP Evaluation & Costing All

Tues., March 27th, 2007 – VEP Evaluation & Selection

Location: Boardroom A
Executive Hotel & Conference Center
4201 Lougheed Highway, Burnaby

8:30am – 2:30pm: VEP Evaluation & Costing All

3:00pm - 4:30pm: VEP Selection All

Wed., March 28th, 2007 – VE Summary Presentation

Location: Boardroom 1
Ministry of Transportation, South Coast Region
7818 6th Street, Burnaby

10:00am – 12:00pm: Summary Presentation R.English/K.Gardner

12:00pm Closing
9. Study Workshop Results

9.1. Idea Generation Phase

There were twenty-two (22) Ideas generated for Team evaluation. The entire Team evaluated each of the Ideas, in a subjective rating of increased or decreased value in the areas of:

- Capital Cost
- Traffic and Safety
- Operations, Maintenance & Rehabilitation (O,M & R) Costs
- Service Life
- Public, Social & Aesthetic Considerations
- Environment

Following Idea evaluation, eight (8) Ideas were assigned for further evaluation and costing as Value Engineering Proposals (“VEP’s”).

All of the remaining 14 Ideas were considered to warrant providing written considerations, as “Notes to Ministry and Designer”. As opposed to concepts which benefited from providing an estimated cost savings for an alternative, these issues were considered to offer opportunities for refining the current approach, limiting risk, or considering broader, programming issues. These are presented in Appendix C, and are considered equally as important to the results as the VEP’s.

Please refer to Table 1 – Idea Generation Results for a summary of this Phase, including VEP Team review assignments.
**IDEA GENERATION**

<table>
<thead>
<tr>
<th>Idea No.</th>
<th>Idea Description</th>
<th>Benefits</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Test section(s) on densification processes</td>
<td>Reduce contract risk, and improve confidence in design.</td>
<td>Information obtained may not result in cost savings.</td>
</tr>
<tr>
<td>2</td>
<td>Review as-upgraded structure performance, and egress criteria.</td>
<td>May reduce (eliminate) further geotechnical work.</td>
<td>May incur design costs with no benefit.</td>
</tr>
<tr>
<td>3</td>
<td>Investigate mass concrete buttresses</td>
<td>Eliminates densification. May deepen navigation channel.</td>
<td>Requires significant re-analysis.</td>
</tr>
<tr>
<td>4</td>
<td>Investigate anchoring with large diameter pipe piles</td>
<td>Eliminates densification, excavation and backfill.</td>
<td>Difficult driving, possible damage to tunnel, and significant re-analysis.</td>
</tr>
<tr>
<td>5</td>
<td>Limit densification to joint locations.</td>
<td>Reduced effort and cost.</td>
<td>Requires significant re-analysis.</td>
</tr>
</tbody>
</table>

**IDEA EVALUATION**

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>↑</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>Y</td>
<td>Alan</td>
<td>Upul</td>
<td>Keith</td>
</tr>
<tr>
<td>2</td>
<td>↑</td>
<td>O</td>
<td>Down</td>
<td>Down</td>
<td>O</td>
<td>Up</td>
<td>Y</td>
<td>Carlo</td>
<td>Sharlie</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>↑</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>Down</td>
<td>Y</td>
<td>Alan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>↑</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>Up</td>
<td>Y</td>
<td>Sharlie</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>↑</td>
<td>Down</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>Up</td>
<td>Y</td>
<td>Upul</td>
<td></td>
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</tr>
</tbody>
</table>

**Legend:**
- ↑ Improves Value
- O No Impact
- Down Decreases Value

**Table 1 – Idea Generation Results**

*EVM Project Services Limited*  
*March 23 – 28, 2007*
<table>
<thead>
<tr>
<th>Idea No.</th>
<th>Idea Description</th>
<th>Benefits</th>
<th>Disadvantages</th>
<th>IDEA EVALUATION</th>
<th>Lead</th>
<th>Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Mitigate structural movement with additional jointing, with watertight seals, to improve flexibility</td>
<td>Reduce crack size, eliminate densification.</td>
<td>Work required inside structure, and significant redesign.</td>
<td>Up</td>
<td>Y</td>
<td>Carlo</td>
</tr>
<tr>
<td>7</td>
<td>Eliminate densification in middle third of river section.</td>
<td>Reduce cost and schedule.</td>
<td>Requires significant re-analysis.</td>
<td>Up</td>
<td>O</td>
<td>Y</td>
</tr>
<tr>
<td>8</td>
<td>Move densification further away from structure.</td>
<td>Reduce excavation and backfill. Less risk to structure.</td>
<td>May be less effective in mitigating vertical movement.</td>
<td>Up</td>
<td>O</td>
<td>Y</td>
</tr>
<tr>
<td>9</td>
<td>Replace tunnel with bridge ASAP.</td>
<td>Scheduled replacement. More timely long term solution</td>
<td>Significant increased capital cost.</td>
<td>Down</td>
<td>Up</td>
<td>Y</td>
</tr>
</tbody>
</table>

**Legend:**  
- **↑** Improves Value  
- **O** No Impact  
- **↓** Decreases Value

**Table 1 – Idea Generation Results**
## Idea Generation

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Analyze performance with a flat river-bottom profile.</td>
<td>Reduce densification effort.</td>
<td>Commitment to maintaining the flat profile.</td>
<td>↑</td>
<td>O</td>
<td>O</td>
<td>↓</td>
<td>O</td>
<td>↓</td>
<td>Y</td>
<td></td>
<td>Don</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Owner to provide restoration &amp; backfill material.</td>
<td>Likely to reduce cost.</td>
<td></td>
<td>↑</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td></td>
<td>Y</td>
<td></td>
<td>Ralph</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Increase pumping capacity to meet expected water ingress.</td>
<td>Reduces or eliminates densification.</td>
<td>Tunnel may not be repairable in large seismic event.</td>
<td>↑</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>O</td>
<td>↑</td>
<td>Y</td>
<td></td>
<td>Keith</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Allow proprietary drains.</td>
<td>Likely to reduce cost.</td>
<td>Application in design conditions needs review.</td>
<td>↑</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td></td>
<td></td>
<td>Y</td>
<td>Don</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Confirm location of onshore utilities.</td>
<td>Reduces construction risk.</td>
<td></td>
<td>↑</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td></td>
<td>Y</td>
<td></td>
<td>Ralph</td>
<td></td>
</tr>
</tbody>
</table>

Legend:  
- ✈ Improves Value  
- ○ No Impact  
- ↓ Decreases Value

Table 1 – Idea Generation Results
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>15</td>
<td>Perform hydraulic study and review 2:1 cut slopes.</td>
<td>Reduces construction risk and improves available information.</td>
<td>Additional study may be required.</td>
<td></td>
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<td></td>
<td>Y</td>
<td></td>
<td>Don</td>
<td>Upul</td>
</tr>
<tr>
<td>16</td>
<td>Confirm allowed strategies for use of excavated material.</td>
<td>Reduces uncertainty in contract.</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
<td>Alan</td>
<td>Keith</td>
</tr>
<tr>
<td>17</td>
<td>Optimize densification on north and south approaches.</td>
<td>May produce savings proportional to optimization on marine segments.</td>
<td>Some additional analysis required.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
<td>Upul</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Implement emergency road closure system (beginning during construction).</td>
<td>Additional measure to protect against public impacts during seismic event.</td>
<td>Additional scope.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
<td>Sharlie</td>
<td>Upul</td>
</tr>
</tbody>
</table>

Legend: ↑ Improves Value  O No Impact  ↓ Decreases Value

Table 1 – Idea Generation Results
### IDEA GENERATION

#### Project No. 11469-0002: George Massey Tunnel Densification

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>Review three meter spacing of stone columns.</td>
<td>Helps confirm if current design will be achieved. Reduce risk.</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>Y</td>
<td>Don</td>
</tr>
<tr>
<td>20</td>
<td>Re-evaluate tunnel movement criteria in special provisions.</td>
<td>May relax design criteria, to reduce effort and cost. Some additional analysis required.</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>Y</td>
<td>Carlo</td>
</tr>
<tr>
<td>21</td>
<td>Further strengthen tunnel to withstand liquefaction.</td>
<td>Eliminate densification - reduces costs. Requires significant re-analysis.</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>Y</td>
<td>Alan</td>
</tr>
<tr>
<td>22</td>
<td>Develop contingency plan for exceeding specs</td>
<td>Reduce contract risk, and improve confidence in design.</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
<td>Y</td>
<td>Ralph</td>
</tr>
</tbody>
</table>

#### Legend:
- ☑ Improves Value
- ☐ No Impact
- ☐ Decreases Value

Table 1 – Idea Generation Results
9.2. VEP Evaluation and Costing Phase

VEPs generated during the Idea Generation Phase were assessed for areas of primary expertise, and assigned to a Lead Evaluator from the VE Team. In some cases, a supporting expertise was also assigned. The Team assessed each VEP in terms of costs, advantages and disadvantages. Costs were viewed primarily from the perspective of the current estimate unit rates, and consistent mobilization and contingency amounts were then applied (the ‘markup’). The VEP template circulated prior to the sessions provided the framework for evaluation.

In several cases, a statement of operational or design cost impacts was required to present the life cycle perspective. The intention here was to provide a reasonable, and hopefully conservative, placeholder against which to critique the assessed capital impacts.

Completed VEPs are contained in Appendix B.

Once the Team members had completed the evaluation and costing of each VEP, results were reviewed and confirmed in a Team exercise. Of the eight (8) assigned VEPs, all were considered to warrant consideration against at least one of the VE Study objectives:

- Three (3) of the VEP’s consider limited refinements to the current densification scheme.
- Five (5) of the VEP’s consider potential alternatives to densification, if project objectives and risks are to be re-assessed to reduce capital costs.
- VEP 12, addressed as an alternative, may also be considered in conjunction with other VEP’s and Ideas, as a risk mitigation measure.

Please refer to Table 2 – VEP Evaluation & Costing Results for a summary of this Phase.
<table>
<thead>
<tr>
<th>VEP #</th>
<th>Title</th>
<th>Recommend VEP (Y/N)</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Investigate mass concrete buttresses</td>
<td>Y</td>
<td>If an alternative to densification is desirable, investigating this option could be considered.</td>
</tr>
<tr>
<td>4</td>
<td>Investigate anchoring with large diameter pipe piles</td>
<td>Y</td>
<td>If an alternative to densification is desirable, investigating this option could be considered.</td>
</tr>
<tr>
<td>5</td>
<td>Limit densification to joint locations</td>
<td>Y</td>
<td>Depending on previous options looked at, this option may be reviewed to determine if projected savings are valid.</td>
</tr>
<tr>
<td>6</td>
<td>Accommodate structural movement with additional jointing</td>
<td>Y</td>
<td>Savings could be significant, if further analysis confirms viability of this idea. However, this would imply an assumed level of repair after a seismic event.</td>
</tr>
<tr>
<td>7</td>
<td>Eliminate densification in middle third of river</td>
<td>Y</td>
<td>Depending on previous options looked at, this option may be reviewed to determine if projected savings are valid.</td>
</tr>
<tr>
<td>12</td>
<td>Increase pumping capacity to meet expected water ingress</td>
<td>Y</td>
<td>If densification is not pursued, limiting treatment to increased pumping capacity may add value. In combination with other measures, would help reduce risk in a seismic event.</td>
</tr>
<tr>
<td>13</td>
<td>Allow proprietary drains</td>
<td>Y</td>
<td>Anticipated savings suggest considering this alternative.</td>
</tr>
<tr>
<td>21</td>
<td>Further strengthen tunnel to withstand liquefaction</td>
<td>Y</td>
<td>If an alternative to densification is desirable, investigating this option could be considered.</td>
</tr>
</tbody>
</table>

Table 2 - VEP Evaluation & Costing Results
9.3. VEP Selection Phase

The initial recommended VEPs were reviewed with the entire Team, to ensure consensus and consistency of approach and evaluation.

The recommended VEPs are summarized in Table 3 – VEP Recommendations Summary. The listing provides costs for each VEP, if each were to be addressed independently.

It is important to ensure that the cumulative proposed savings do not contain any conflicting or overlapping cost savings potential. In this regard, most of the VEP’s would not be combined, and their potential is exclusive. That is, VEP’s 3, 4, 6 and 21 could only be considered independently of one another, or any other measures. One exception is VEP 12, which could be applied to any solution. VEP 13 would apply to the current design in any form, while only one or the other of VEP’s 5 and 7 could also apply.

The costs contained in each VEP have been developed from a ‘conservative’ point of view. That is, every effort has been made to provide realistic, if not understated, estimates of the intended benefits. This will help alleviate any undue optimism in achieving drastic cost reductions, mindful of the limitations in effort available for the study, and the need to prove out many concepts with detailed modelling and re-analysis.

Some items, such as the benefits to having the Ministry identify material sources, are spoken to in the Notes to Ministry and Designer as support for the concept, rather than treated as quantified, speculative savings in the cost calculations. Their discussion is presented as subjective support for whether the concept warrants reasonable consideration at this stage of design. In this way, they become considerations primarily for reducing risk and obtaining further confidence in the costs. This value to the project cannot be quantified, but is substantial.

However, based on an assumed collection of accepted recommendations, it is projected that the capital cost saving potential of the VE recommendations could be in the range of $1.5M – $5.5M against the current design, and depending on revised objectives and re-analysis, up to $9M if a complete change of scope were to be considered.
<table>
<thead>
<tr>
<th>VEP #</th>
<th>Title</th>
<th>Capital Savings (Increase)</th>
<th>Maint., Rehab., or Ops. Savings (Increase) - NPV</th>
<th>Design / Markup Savings (Increase)</th>
<th>Net Life Cycle Savings (Increase)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Investigate mass concrete buttresses</td>
<td>$9,000,000</td>
<td>$850,000</td>
<td>$9,850,000</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Investigate anchoring with large diameter pipe piles</td>
<td>$8,500,000</td>
<td>$800,000</td>
<td>$9,300,000</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Limit densification to joint locations</td>
<td>$5,000,000</td>
<td>$840,000</td>
<td>$5,840,000</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Mitigate structural movement with additional jointing, with watertight seals</td>
<td>$12,100,000</td>
<td>$1,500,000</td>
<td>$13,600,000</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Eliminate densification in middle third of river section</td>
<td>$4,000,000</td>
<td>$650,000</td>
<td>$4,650,000</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Increase pumping capacity to meet expected water ingress</td>
<td>$19,000,000</td>
<td>-$100,000</td>
<td>$2,700,000</td>
<td>$21,600,000</td>
</tr>
<tr>
<td>13</td>
<td>Allow proprietary drains</td>
<td>$1,500,000</td>
<td>$250,000</td>
<td>$1,750,000</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Further strengthen tunnel to withstand liquefaction.</td>
<td>$11,700,000</td>
<td>$1,400,000</td>
<td>$13,100,000</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 – VEP Recommendations Summary
10. Recommendations

In summary, the VE Study assessed a wide range of ideas for improving life cycle costs and other measures of value. The Design represents what we see as a thorough analysis of the requirements, and the recommendations put forward are intended to be complementary to measures likely to be considered through the course of completing the design.

The VE Team recommends that the Ministry and Designer consider the 8 Value Engineering Proposals (VEPs) put forward in this report, as well as the measures put forward in Appendix C for reducing risk and improving confidence.

A rough risk model was considered during the course of the assignment (see Section 4.4 - Investment Risk Analysis Summary). Although it used assumptions in terms of risk, cost, and probability figures, a high level review suggests that expenditures on the tunnel in the realm of the current budget can be justified. A refinement of this approach could be made if one wished to also examine the implications on timing of the work, or alternatives to the work, but this implies some additional effort with regard to ensuring all of the inputs receive proper scrutiny.

In general terms, the Study has suggested the following approach:

1. Some effort is justified in reducing the seismic risks to the tunnel, at least to the level suggested by completing the second phase of the currently proposed works. This will address the original goals, and provide some additional time to address an ultimate replacement crossing, while gaining some insurance on this important network link.
2. A number of refinements to the existing design are tabled for consideration, although the greatest value appears to be in adopting risk reduction measures as detailed in this report.
3. Time is of the essence both with regard to exposure to a seismic event, and escalating costs.
4. If capital costs remain a concern, a number of major scope alternatives are tabled that could be reviewed, in conjunction with additional formal re-analyses.
5. If the densification work is not pursued, other risk reducing measures are considered herein. However, a new structure should be accelerated to offset the risk exposure.

Recommendations are provided in this report through the benefit of the flexibility afforded VE Study idea generation efforts. Many require a reconsideration of design objectives by the Ministry, before they could be seen as options. Where ideas anticipate design effort may be necessary, over what might normally be assumed for completing the outstanding components of the current design, rough estimates of design cost have been included. However, this is done without any information on current design contracts and resources.

Several VEPs may involve design effort that has already been addressed in work to date, or additional work that could affect established design budgets, and design schedules. This should be considered in determining if a given VEP or Idea warrants further investigation. Likewise, a decision to investigate alternatives to the current scope and objectives should be made with an understanding of the impacts to schedule. The time to accommodate approvals, contract amendments, and redesign should be anticipated.
APPENDIX A

Attendees and Observers
### VE Summary Presentation Attendees

<table>
<thead>
<tr>
<th>Attendees</th>
<th>Position</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keith Kazakoff</td>
<td>VE Team</td>
<td>Ministry of Transportation</td>
</tr>
<tr>
<td>Carlo J. Endholm</td>
<td>VE Team</td>
<td>Westmar Consultants</td>
</tr>
<tr>
<td>Dr. Alan D. Russell</td>
<td>VE Team</td>
<td>University of British Columbia</td>
</tr>
<tr>
<td>Dr. Don Gillespie</td>
<td>VE Team</td>
<td>Ministry of Transportation</td>
</tr>
<tr>
<td>Sharlie Huffman</td>
<td>VE Team</td>
<td>Ministry of Transportation</td>
</tr>
<tr>
<td>Hisham Ibrahim</td>
<td>Design Representative</td>
<td>Buckland &amp; Taylor</td>
</tr>
<tr>
<td>John Shnablegger</td>
<td>Programming, Partnerships and Planning</td>
<td>Ministry of Transportation</td>
</tr>
<tr>
<td>David Mintak</td>
<td>Project Management</td>
<td>Ministry of Transportation</td>
</tr>
<tr>
<td>Jay Porter</td>
<td>Project Management</td>
<td>Ministry of Transportation</td>
</tr>
<tr>
<td>Ernest Naesgaard</td>
<td>Design Representative</td>
<td>Trow</td>
</tr>
<tr>
<td>Bill Szto</td>
<td>Bridge Engineering</td>
<td>Ministry of Transportation</td>
</tr>
<tr>
<td>Ralph English</td>
<td>VE Study Facilitator</td>
<td>EVM Project Services</td>
</tr>
<tr>
<td>Kevin Gardner</td>
<td>VE Recorder</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX B

Value Engineering Proposal (VEP)

Results
VALUE ENGINEERING PROPOSAL NO. : VEP 3

Proposal Title: Investigate Mass Concrete Buttresses

Current Design Approach:

The current design calls for ground improvement measures on either side of the tunnel alignment over the full length. It is proposed to densify the overburden soils using stone columns, with seismic drains along the outer edges of the stone column zones.

Value Engineering Proposal Description: (see attached sketches)

Examined here in conceptual terms is a possible structural solution as an alternative to the geotechnical improvements proposed. Although the notion was identified in the previous VE study – anchor tunnel, no ground improvements - the reason for rejecting it without further consideration was cited as being “difficult to connect to tunnel.”

Key components of the concept proposed herein involve locating buttresses at the upstream and downstream sides of the tunnel at the north and south ventilation tunnels, and likewise roughly at stations 8+000, 9+000 and 10+000. The buttresses are proposed to be supported with piles, and a direct connection to the tunnel is avoided.

Cost Savings Summary:

<table>
<thead>
<tr>
<th>Capital Savings (Increase)</th>
<th>O, M &amp; R Savings (Increase) - NPV</th>
<th>Design / Mark Up Savings (Increase)</th>
<th>Net Life Cycle Savings (Increase)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$9,000,000</td>
<td>$0</td>
<td>$850,000</td>
<td>$9,850,000</td>
</tr>
</tbody>
</table>

**Advantages**

1. Avoids much of the uncertain ground improvement work.
2. Possibly less risk of weather, and river current impacts.
3. Greater certainty of quantities.
4. Likely improved schedule, and less environmental exposure.
5. Potential to allow improved navigation.

**Disadvantages**

1. Extensive reanalysis needed - technical feasibility needs to be established.
2. Additional structural work on tunnel may be needed.
3. Larger range of trades required.
4. Additional time to develop concept. Prices continue to rise in the meantime.
Discussion and Considerations:

(1) Locate buttresses at the upstream and downstream sides of the tunnel at the north and south ventilation tunnels and at stations 8+000, 9+000 and 10+000. For rough calculation purposes, in cross section the buttress is 8m high, 15m wide, is full height for 5m immediately adjacent to the tunnel, and tapers to 2m in height 15m from the tunnel. In terms of depth (dimension parallel to the tunnel), a dimension of 15m has been assumed – 7.5m on either side of a tunnel joint. (See the schematic for buttress shape and dimensions).

(2) In between the buttress locations, no ground improvement would be undertaken saving excavation, stone columns, seismic drains, etc.

(3) In between buttresses (especially 6+000 approx and 8+000 and 10+000 and 12+000 approx) further structural strengthening of the tunnel might be required, but possibly not. In the steps that follow, attention is focused on the buttresses at stations 8+000, 9+000 and 10+000:

(4) At each buttress location i.e: stations 8+000, 9+000 and 10+000, excavation would have to be performed. Assuming a buttress width of 15m parallel to the tunnel and side slopes of excavation of 3H/1V, the volume of material to be removed per buttress would be (approximate cross section area taken from drawing 1509-132):

\[ 31 \text{m} \times 6.28 \text{m} \times 25 \text{m} = 4867 \text{ m}^3 \]

and for 6 buttresses, \( 4867 \times 6 = 29,202 \text{ m}^3 \)

Using the same unit rates for excavation as per the engineer’s estimate (removal of rock, rip rap = $40/\text{m}^3$, removal of sand and gravel river deposits = $20/\text{m}^3$) then the cost of excavation would be \( 29,202 \text{ m}^3 \times 30 = \$876,060 \).

(5) Following excavation, pipe piles would be driven on each side of the tunnel at each buttress location. These pipes would serve to:

(a) Help densify the soil below the buttress, reducing the potential for liquefaction. 
(b) Assist in resisting lateral movement of the buttress assuming a seismic event occurs. 
(c) Contributes to uplift resistance.

To develop an order of magnitude estimate, assume 9 pipe piles under each buttress, each 20 m long.

For one buttress, using maximum unit rates from bids received from a MOT project in April 2006:

- Piles: $600 / \text{m}$
- Install: $15,000 / \text{pile}$

Cost = 6 buttresses x 9 piles/buttress x (20 x 600 + 15,000) = 54 (27,000) = $1,458,000
(6) Buttresses would be formed using precast panels, and then concrete placed inside the form. Assuming a buttress dimensioned as follows (somewhat arbitrary – no force analysis performed because of limited time – i.e., what uplift and lateral forces have to be resisted for the design seismic event):

Volume of concrete = 15 \times (5 \times 8 + 2 \times 10 + [10 \times 6] / 2 = 15 (40 + 20 +30) = 1350 \, \text{m}^3

Assuming an all-in unit rate of $500/\text{m}^3$, including pre-cast panel forms:

Cost/buttress = 1350 x 500 = $675,000. For 6 Buttresses, 6 x 675,000 = $4,050,000

(7) The need to include seismic drains that penetrate through the buttress or be immediately adjacent to the buttress should be examined. Carry an allowance of:

6 buttresses x 12 drains/buttress x 10m/drain x $250/m = 720 x 250 = $180,000

(8) Embed in the buttress either precast concrete or steel “eyelets” for purposes of connecting a concrete beam that spans across the tunnel and attaches to the buttress – 4 eyelets per buttress say $7500/eyelet =

$30,000/buttress x 6 buttresses = $180,000

(9) Fabricate precast beams (say 1 m wide, 2 m length) – Make hollow, fill in place to avoid overly heavy lift.

Volume concrete in place = 1 \times 2 \times 33 = 66 \, \text{m}^3 / \text{beam}

For 6 beams = 6 x 66 x 500 = $198,000

Place beam through eyelets and insert steel pins.

24 x 10,000 = $240,000

(10) Restore rip rap, etc around sides of buttress and on top of tunnel

$65 / \text{m}^3 \times (10 \times 31 \times 6.28) \times 6 = $759,252

Summary of costs for the six marine buttresses:

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removal of material</td>
<td>$876,000</td>
</tr>
<tr>
<td>Pipe Piles</td>
<td>$1,458,000</td>
</tr>
<tr>
<td>Buttresses</td>
<td>$4,050,000</td>
</tr>
<tr>
<td>Seismic Drains</td>
<td>$180,000</td>
</tr>
<tr>
<td>Eyelets</td>
<td>$180,000</td>
</tr>
<tr>
<td>Beams</td>
<td>$198,000</td>
</tr>
<tr>
<td>Place beams and connect</td>
<td>$240,000</td>
</tr>
<tr>
<td>Restore rip rap</td>
<td>$760,000</td>
</tr>
<tr>
<td><strong>TOTAL Marine</strong></td>
<td><strong>$7,942,000</strong></td>
</tr>
</tbody>
</table>

(Per buttress = $7,942,000 / 6 = $1,323,700)

For on-shore buttresses next to ventilation buildings, assume cost equal to 40% of marine cost/buttress = $530,000. Require four on-shore buttresses = $2,120,000
Therefore, total costs:

<table>
<thead>
<tr>
<th>Costs</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine buttresses</td>
<td>$7,942,000</td>
</tr>
<tr>
<td>On-shore buttresses</td>
<td>$2,120,000</td>
</tr>
<tr>
<td>Mobilization</td>
<td>$600,000</td>
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<tr>
<td>Monitoring</td>
<td>$315,000</td>
</tr>
<tr>
<td>Prov. Sum @ 3%</td>
<td>$330,000</td>
</tr>
<tr>
<td><strong>TOTAL Capital</strong></td>
<td><strong>$11,307,000</strong></td>
</tr>
</tbody>
</table>

Current comparable capital estimate = $20,333,000

Proposed Capital Savings = $20,333,000 - $11,307,000 = $9,026,000

Use $9,000,000

**Cost Summary:**

<table>
<thead>
<tr>
<th>CAPITAL SAVINGS (INCREASE) Incl. PROPERTY</th>
<th>SAVINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approximate Savings (as above)</td>
<td>$9,000,000</td>
</tr>
<tr>
<td>15% Tender Contingency</td>
<td>$1,350,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RE-DESIGN AND OTHER COST SAVINGS (INCREASE)</th>
<th>SAVINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redesign and analysis</td>
<td>($500,000)</td>
</tr>
</tbody>
</table>

**TOTAL VEP SAVINGS (INCREASE)** $9,850,000

Value Engineering Team Recommendation:

**The Value Engineering Team DOES recommend this proposal.**

**Justification:**

In the event that an alternative to densification is desired, one could consider undertaking some nominal analysis, to confirm if the feasibility and potential savings suggested with this high-level review are achievable.

**Prepared by:** Alan Russell, Ph.D., Eng.

Lead Evaluator

**Reviewed with:** Upul Atukorala, Ph.D., P.Eng.

Team Member

**Reviewed with:** Keith Kazakoff

Team Member

EVM Project Services Limited

March 23 – 28, 2007

VEP 3 - Page 4
Potential buttress locations – plan view.

Conceptual scheme.
VALUE ENGINEERING PROPOSAL NO.: VEP 4

Proposal Title: Anchor Tunnel With Large Diameter Pipe

Current Design Approach:
Protect tunnel from lateral and vertical liquefaction forces by densifying ground and installing seismic (rock) drains.

Value Engineering Proposal Description: (see attach sketches)
Drive large diameter pipes (perforated in top section) at each joint location, including at tunnel on-shore ends. Clean out and fill the top perforated sections with rock. Ideally, one would investigate placing high strength cables over the tunnel top, from pipe to pipe, to see if the lateral resistance can be augmented with some uplift resistance.

Cost Savings Summary:

<table>
<thead>
<tr>
<th>Capital Savings (Increase)</th>
<th>O, M &amp; R Savings (Increase) - NPV</th>
<th>Design / Mark Up Savings (Increase)</th>
<th>Net Life Cycle Savings (Increase)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$8,500,000</td>
<td>$0</td>
<td>$800,000</td>
<td>$9,300,000</td>
</tr>
</tbody>
</table>

Advantages
1. Lower cost & time requirements.
2. Less environmental impact.
3. Less risk to tunnel from excavation.

Disadvantages
1. Difficult driving through top rock.
2. Significant re-analysis required.
3. Primarily addresses lateral resistance.

Discussion and Considerations:
A major cost in terms of construction and other risk, as well as environmental impact, is from removal of the tunnel cover and replacement and densification. This option would avoid that, provide lateral support for tunnel against liquefaction loads, and may even be able to act as limited seismic drains. If sufficient holddown can be provided by the pipes and the potential cables, this could reduce the required top load and increase ship draft capacity.
Value Engineering Study for
Project No. 11469-0002 George Massey Tunnel Densification

Cost Summary:

<table>
<thead>
<tr>
<th>CAPITAL SAVINGS (INCREASE) Incl. PROPERTY</th>
<th>SAVINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approximate Savings (as per attached calculations)</td>
<td>$8,500,000</td>
</tr>
<tr>
<td>15% Tender Contingency</td>
<td>$1,300,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RE-DESIGN AND OTHER COST SAVINGS (INCREASE)</th>
<th>SAVINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redesign and analysis</td>
<td>($500,000)</td>
</tr>
</tbody>
</table>

**TOTAL VEP SAVINGS (INCREASE)** $9,300,000

Value Engineering Team Recommendation:

The Value Engineering Team DOES recommend this proposal.

Justification:

In the event that an alternative to densification is desired, one could consider undertaking some nominal analysis, to confirm if the feasibility and potential savings suggested with this high-level review, are achievable. Costs and benefits would be weighed against those proposed in VEP 3, using concrete ballast.

Prepared by: Sharlie Huffman, P.Eng.
Lead Evaluator

Reviewed with: Alan Russell, Ph.D., Eng.
Team Member

Reviewed with: Carlo Elholm, P.Eng.
Team Member

Potential pile schematic.
Potential pile locations – plan view.

Calculations:

Pipes – assume:
- width = 3000mm
- length = 30,000mm

Estimate pipes at $3100/m, per 30m pile = $93,000
Assumed installation = $15,000 per pile
Total pile cost = $108,000,

- 56 piles assumed = $6,048,000
- Cables – 30 m each, with associated anchoring, assumed at $1,000,000
- Clean out pipes, fill with rock and redress tops = $3,500,000

Need to also accommodate:
- Mobilization = $500,000
- Monitoring = $300,000
- Provisional Sum = $450,000

Proposed Total Capital Cost = $11,850,000

Current contract price = $20,333,000

Savings = $8,500,000
VALUE ENGINEERING PROPOSAL NO. : **VEP 5**

Proposal Title: **Limit Densification to Joint Locations.**

Current Design Approach:

The current design calls for implementation of ground improvement measures on either side of the tunnel alignment over the full length. It is proposed to densify the overburden soils using stone columns extending to Elev. -27 m and install a single row of seismic drains along the outer edges of the stone column zones to Elev. -27 m or deeper depending on location. The width of the stone column improvement zone is 10 m (Ref. Drawing No. 1509-101, Rev. PA, dated January 26, 2007; B&T Memorandum dated November 29, 2006).

Value Engineering Proposal Description: *(see attached sketch)*

Implement stone column ground improvement measures and seismic drains at tunnel joints only. Assess the seismic performance of the structurally retrofitted tunnel (i.e.: as is now in place) to confirm performance expectations. For preliminary costing purposes, a 50 m wide zone of ground improvement at each joint and on both sides of the tunnel has been considered.

Cost Savings Summary:

<table>
<thead>
<tr>
<th>Capital Savings (Increase)</th>
<th>O, M &amp; R Savings (Increase) - NPV</th>
<th>Design / Mark Up Savings (Increase)</th>
<th>Net Life Cycle Savings (Increase)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$5,000,000</td>
<td>$0</td>
<td>$840,000</td>
<td>$5,840,000</td>
</tr>
</tbody>
</table>

**Advantages**

1. Reduces excavation, removal, and replacement rock fill volumes.
2. Reduces the volume of marine soil requiring vibro improvement.
3. Reduces the amount of seismic drains installed in the river.
4. Reduces cost and shortens schedule.

**Disadvantages**

1. Increased risk of floatation of the tunnel. Mitigating measures may be required.
2. Needs additional engineering analyses to confirm performance expectations.
Discussion and Considerations:

2D FLAC analyses have been carried out to assess the seismic deformations experienced by the tunnel at a number of sections along the tunnel in the river section. It is understood that these analyses have been carried out both with and without ground improvement measures on either side. A 3D structural model has also been developed that can incorporate the tunnel deformations via a series of non-linear compliance springs. The resulting performance of the improved tunnel is assumed to be assessable without the need to develop new models.

This proposal suggests determining if the structurally retrofitted tunnel meets the required performance objectives with a reduced extent of ground improvement. By implementing ground improvement measures only at the tunnel joints, the potential to generate differential lateral and vertical movements at the joints will be reduced.

Cost Calculations: (all costs derived from current estimate unit rates)

<table>
<thead>
<tr>
<th>CAPITAL SAVINGS (INCREASE) Incl. PROPERTY</th>
<th>SAVINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost savings (see attached calculations)</td>
<td>$5,000,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RE-DESIGN AND OTHER COST SAVINGS (INCREASE)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Assumed Reanalysis</td>
<td>($50,000)</td>
</tr>
<tr>
<td>Net Savings (Increase)</td>
<td>$4,950,000</td>
</tr>
</tbody>
</table>

| 3% for Mobilization                         | $150,000 |
| 15% Tender Contingency                     | $740,000 |

**TOTAL VEP SAVINGS (INCREASE)** $5,840,000

Value Engineering Team Recommendation:

The Value Engineering Team DOES recommend this proposal.
Justification:

Depending on whether such work has already been looked at in previous options, one could consider undertaking additional analysis to see if desired objectives can be achieved with isolated reductions in the areas to be densified. Savings potential is generally proportional to the total length of densification eliminated, and seems to warrant a reasonable amount of additional analysis if necessary.

Prepared by: Upul Atukorala, Ph.D., P.Eng.
Lead Evaluator
Cost Calculations:

(1) Reduce treatment area to 50 m x 10 m / side / joints to 10 m depth
(2) Reduce seismic drains on 55m x 5 / side
(3) Reduce excavation to access the 55m x 5 / side
(4) Reduce new rock fill on tunnel
(5) Reduce new rock fill on sides
(6) Reduce new backfill
No. of joints treated = 5 (in river section)

(1) Reduction in stone column area
Volume = 55m x 10m / tunnel section / side / m depth
= 55 x 10 x 5 x 2 x 10 = 55,000 m$^3$
Cost @ $33 / m$^3$ = $1,815,000

(2) Eliminate seismic drain (Type B)
No. of drains = 55 / 2 = 28 drains / side / tunnel
Assume 10 m depth
lineal meter of drains = 28 x 10 x 2 x 5 = 2800 lineal metres
Cost @ $250 / m = $700,000

(3) Eliminate excavation to access no-improvement zones:
Excavation area ~ 52.5 m$^2$ / side / m
Assume vertical cuts, total volume = 52.5 x 2 x 55 x 5 = 28,875 m$^3$
Reduce by 30% to allow for side slopes
Net volume = 0.7 x 28,875 = 20,210 m$^3$
Assume:
50% s + a = 10,105 m$^3$
50% rock rip rap = 10,105 m$^3$
Cost = 10,105 x 20 / m$^3$ + 10,105 x 40 m$^3$ = $606,300
(4) Eliminate new rock fill on tunnel roof
Area ~ 32 m$^2$/m
Affected length 55 x 5 = 275 m
Therefore volume = 32 x 275 = 8,800 m$^3$

Cost @ $65/m$ ^3 (1500kg rock) = $572,000

(5) Eliminate new rock fill on sides
Drain rock = 13 m$^2$/side/m = 13 x 2 x 55 x 5 = 7150 m$^3$
500 lb rockfill = 7 m$^2$/side/m = 7 x 2 x 55 x 5 = 3850 m$^3$

Cost:
- drain rock @ $40/m^3 = $286,000
- 500 lb rock fill @ $55/m^3 = 211,750

TOTAL = $497,750

(6) Eliminate new backfill
(Ignore side slopes in longitudinal direction in calculation, allow 30% reduction)
Total area /side/m (incl. drain rock + 500 lb rock) = 52.5 m$^2$/side/m
Area of drain role + 500 lb+ 20 m$^2$/side/m
Net backfill area = 32.5 m$^2$/side/m
Volume = 32.5 x 2 x 55 x 5 = 17,875 m$^3$
Allow 30% for side slope = 0.7 x 17,875 = 12,512 m

Cost @ $65/m^3 (1500 lb rock) = 12,512 x 65 = $813,310

Total Proposed Capital Cost Savings: $5,000,000

Other: Engineering reanalysis
Assume $50,000
**VALUE ENGINEERING PROPOSAL NO. : VEP 6**

**Proposal Title:** Mitigate Tunnel Movement With Control Joints

**Current Design Approach:**  
Improve the ground to reduce tunnel movement, and therefore control concrete cracking and water ingress.

**Value Engineering Proposal Description:** *(see attached sketch)*  
Reduce or eliminate the extent of ground improvement. Manage tunnel movement and water ingress by saw-cutting to concentrate hinging at selected locations and mitigate water ingress with a form of seal.

**Cost Savings Summary:**

<table>
<thead>
<tr>
<th></th>
<th>Capital Savings (Increase)</th>
<th>O, M &amp; R Savings (Increase) - NPV</th>
<th>Design / Mark Up Savings (Increase)</th>
<th>Net Life Cycle Savings (Increase)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$12,100,000</td>
<td>$0</td>
<td>$1,500,000</td>
<td>$13,600,000</td>
</tr>
</tbody>
</table>

**Advantages**

1. Reduced cost.
2. Less geotechnical risk.
3. Less risk of damaging tunnel compared to densification work.
4. Less environmental risk.

**Disadvantages**

1. Increased seismic displacement.
2. Potential for saw-cuts to leak in regular service if seals are ineffective.
3. Greater traffic impacts during construction.

**Discussion and Considerations:** *(Also see attached sketch)*  
The current design intent is to reduce differential ground movement to limit the longitudinal bending imposed on the tunnel.

Recent structural upgrades have mitigated the risk of brittle fracture due to the light quantity of longitudinal reinforcing in the original design. The tunnel is very heavily reinforced in the transverse direction to resist water pressure and soils loading, but it is assumed that in the longitudinal direction, the original designer considered the loadings...
to be minor because the support is continuous. A significant seismic concern is that the imposed deformation will cause cracking and leaking. If leaking can be reduced to an acceptable flow rate, then the public can have time to safely exit the tunnel in an event. It is noted that the objective is mitigation of inflow to a rate which will allow public egress; zero inflow is not required.

The intent of this VE proposal is to control leaking by inducing the deformation cracking at control joints. At a control joint, the newly upgraded steel plates would be cut, and the new reinforced concrete and inside layer of the original longitudinal reinforcement would be saw-cut. The concrete would also be cut to a partial depth that would promote concrete cracking.

The saw-cut joint would be sealed with a product that can resist hydrostatic head. An evaluation of various flexible sealants would be required to confirm allowable cracking widths to provide acceptable performance. The evaluation should include full-scale mock-ups to simulate the movements and water pressures.

The selection of joint spacing is a function of allowable crack widths, and imposed tunnel deformation. A larger joint spacing would require a sealant capable of bridging a wide crack. While a larger joint spacing would reduce the scope of work required for this VE proposal, there may be a practical limit for allowable movement of the sealant. It is not the intent of this VEP to locate a control joint at the existing tunnel joints.

For pricing purposes, the spacing of control joints is assumed to be ~ 17 m (6 per segment). It is believed that this spacing is close enough to keep crack widths small enough to be sealed. Thus, 36 control joints would be installed.

**Cost Calculations:**

All found crew and equipment - $6,000/day x 5 days = $30,000/week
Traffic management – average $1,000/day x 5 days = $5,000/week
Allow one week for each air duct x 2 = 2 weeks
Allow one & one-half weeks for each roadway tube x 2 = 3 weeks
Total of 5 weeks
Labour and equipment = $175,000
Materials = $25,000
= $200,000 per joint x 36 joints = $7,200,000

Utilities allowance - $500,000
Mock up testing - $300,000
Mobilization/demobilization - $200,000

Total Capital Estimate = $8,200,000
Current comparable capital estimate = $20,333,000

Proposed Capital Savings = $20,333,000 - $8,200,000 = $12,100,000
Assumed Re-engineering - $300,000

<table>
<thead>
<tr>
<th>CAPITAL SAVINGS (INCREMENT) Incl. PROPERTY</th>
<th>SAVINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approximate Savings (as above)</td>
<td>$12,100,000</td>
</tr>
<tr>
<td>15% Tender Contingency</td>
<td>$1,800,000</td>
</tr>
<tr>
<td>RE-DESIGN AND OTHER COST SAVINGS (INCREMENT)</td>
<td>SAVINGS</td>
</tr>
<tr>
<td>Redesign and analysis</td>
<td>($300,000)</td>
</tr>
<tr>
<td><strong>TOTAL VEP SAVINGS (INCREMENT)</strong></td>
<td><strong>$13,600,000</strong></td>
</tr>
</tbody>
</table>

Value Engineering Team Recommendation:

**The Value Engineering Team DOES recommend this proposal.**

Justification:

Savings could be significant, if further analysis confirms viability of this idea. However, this would imply an assumed level of repair after a seismic event, and considering this alternative requires a revisiting of design objectives.

Prepared by: Carlo Elholm, P.Eng.
Lead Evaluator

Proposed control joint locations.
VALUE ENGINEERING PROPOSAL NO. : VEP 7

Proposal Title: Eliminate Densification in Middle Third of River Section

Current Design Approach:
The current design calls for implementation of ground improvement measures on either side of the tunnel alignment over the full length. It is proposed to densify the overburden soils using stone columns extending to Elev. -27 m and install a single row of Type B seismic drains along the outer edges of the stone column zones to Elev. -27 m (or deeper depending on location). The width of the stone column improved zone is 10 m (Ref. Drawing No. 1509-101, Rev. PA, dated January 26, 2007 and B&T Memorandum dated November 29, 2006).

Value Engineering Proposal Description: (see attached sketch)
Eliminate stone columns in the area extending from Sta. 8+00 to 10+00. Re-analyze the seismic response of the structurally retrofitted tunnel to confirm performance expectations.

Cost Savings Summary:

<table>
<thead>
<tr>
<th>Capital Savings (Increase)</th>
<th>O, M &amp; R Savings (Increase) - NPV</th>
<th>Design / Mark Up Savings (Increase)</th>
<th>Net Life Cycle Savings (Increase)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ 4,000,000</td>
<td>$0</td>
<td>$650,000</td>
<td>$4,650,000</td>
</tr>
</tbody>
</table>

Advantages | Disadvantages
---|---
1. Limits excavation, removal, and replacement of existing rock fill within the navigational channel. | 1. Increased risk of damage during the design earthquake motions.
2. Reduced cost of construction. | 2. Needs additional engineering analyses to confirm performance expectations.
3. Less impact on environment. | |
4. Improves schedule, and reduces work in the middle of the river channel. | |
Discussion and Considerations:

The CPT profiles shown on Drawing Nos. 061-02427-G3 and -G4 dated September 20, 2006 contained in B&T’s Memorandum indicate the presence of fine-grained soils to the proposed treatment elevation (i.e. -27 m) at and near Sections C, D, and E. It is suggested that only minor improvement in density can be achieved in these soils when vibro methods are used. Also, a significant increase in shear stiffness can only be achieved by adopting a spacing of close to 2 m c/c or a high area replacement ratio.

This is the main zone where the benefits of stone column and seismic drain installation on improved performance under seismic loading conditions could be questionable or marginally effective.

Cost Calculations: (all costs derived from current estimate unit rates)

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPITAL SAVINGS (INCREASE) Incl. PROPERTY</td>
<td>$4,000,000</td>
</tr>
<tr>
<td>Cost savings (see attached calculations)</td>
<td></td>
</tr>
<tr>
<td>RE-DESIGN AND OTHER COST SAVINGS (INCREASE)</td>
<td></td>
</tr>
<tr>
<td>Assumed Reanalysis</td>
<td>($50,000)</td>
</tr>
<tr>
<td>Net Savings (Increase)</td>
<td>$3,950,000</td>
</tr>
<tr>
<td>3% for Mobilization</td>
<td>$115,000</td>
</tr>
<tr>
<td>15% Tender Contingency</td>
<td>$585,000</td>
</tr>
<tr>
<td><strong>TOTAL VEP SAVINGS (INCREASE)</strong></td>
<td>$4,650,000</td>
</tr>
</tbody>
</table>

Value Engineering Team Recommendation:

The Value Engineering Team DOES recommend this proposal.
Justification:

Depending on whether such work has already been looked at in previous options, one could consider undertaking additional analysis to see if desired objectives can be achieved by eliminating a portion of the zone to be densified mid-river. Savings potential is generally proportional to the total length of densification eliminated, and seems to warrant a reasonable amount of additional analysis if necessary.

The goal of this analysis would be to see if the as-updated structure can meet the desired performance objectives by eliminating a certain length of work in undensifiable soils, while greatly easing complications in working in the navigation channel.

Prepared by: Upul Atukorala, Ph.D., P.Eng.
Lead Evaluator
Cost Calculations:
Assume a total of 220m between Sta 8+00 to 10+00

Eliminate:
1. Type B seismic drains
2. Vibro stone columns
3. New rockfill on sides (Over drain + stone columns)
4. Rockfill on top of tunnel
5. Excavation volume
6. Backfill volume

(1) Type B drain on 220 m on either side (2 m c/c)
Average length:
10 m at sta. 8+12.1 m, 10 m at sta. 9+81.7 m
200 m /2 – 100 drain / side
Therefore 100 x 10 = 1000 lineal metres / side
On both sides = 2000 lineal metres
(16.7%) @ 250 m = $500,000

(2) Vibro stone column treatment
average depth 10 m at sta. 8+12.1 m & 9+81.7 m
Treatment area / side = 10 x 10 / side / metre
= 10 x 10 x 200 / side
= 20,000 m³ / side, both sides = 40,000 m³
(19.2%) @ 33 / m³ = $1,320,000

(3) New rockfill + drain gravel (Over drain + stone columns)
Top 8 m x 0.5 m / side / m = 4 m² / side / m
Bottom 7 m x 1 m / side / m = 7 m² / side / m
Middle (500 lb) 9 m x 1 m / side / m = 9 m² / side / m
Drain rock (top and middle) = 13 m² / side / m
Rock fill (500 lb) = 7 m² / side
Therefore

- Volume: drain rock = 13 \times 200 \times 2 = 5200 \text{ m}^3 \\
 500 \text{ lb rock fill} = 7 \times 200 \times 2 = 2800 \text{ m}^3 \\

- Cost: drain rock @ 40 / \text{ m}^3 = $208,000 \\
 500 \text{ lb rock fill} @ 55 \text{ m}^3 = $154,000 \\
 \text{TOTAL} = $362,000

(4) Rockfill on top of tunnel

Volume of rockfill req’d = 32 \times 200 = 6400 \text{ m}^3 \\
Assume 1500 rock @ $65 / \text{ m}^3 \\
(13.9\%) Cost = $416,000

(5) Excavation volume

Approx area / side = \frac{1}{2} \times (20+15) \times 3 \sim 52.5 \text{ m}^2 / \text{ side / m} \\
(Ignore side slopes in longitudinal direction) \\
Total volume = 52.5 \times 200 \times 2 = 21,000 \text{ m}^3 \\
Assume 50\% s + a ($20 / \text{ m}^3) = 10,500 \text{ m}^3 \\
50\% rock rip rap ($40 / \text{ m}^3) = 10,500 \text{ m}^3 \\
(11.7\%) Cost = 10,500 \times (20+40) = $630,000

(6) Backfill Volume

Total Area / side / m (incl. drain rock) = 52.5 \text{ m}^2 / \text{ side / m} \\
Area of drain rock + 500 lb rock = 20 \text{ m}^2 / \text{ side / m} \\
Net backfill area = 32.5 \text{ m}^2 / \text{ side / m} \\
Ignoring side slopes in longitudinal direction \\
volume = 32.5 \times 2 \times 200 = 13,000 \text{ m}^3 \\
backfill (1500 lb rock) @ $65 / \text{ m}^3 = $845,000

Total Proposed Capital Cost Savings: $4,000,000

Other: Engineering reanalysis

Assume $50,000
VALUE ENGINEERING PROPOSAL NO.: VEP 12

Proposal Title: Increase Tunnel Pumping Capacity

Current Design Approach:
The current design calls ground improvement measures on either side of the tunnel alignment over the full length. It is proposed to densify the overburden soils using stone columns, with seismic drains along the outer edges of the stone column zones.

Value Engineering Proposal Description:
Increase the pumping capacity of the tunnel to meet the expected water ingress due to the level of cracking anticipated with the now-modified structure. Eliminate or reduce densification, if the design objectives are relaxed.

Cost Savings Summary:

<table>
<thead>
<tr>
<th></th>
<th>Capital Savings (Increase)</th>
<th>O, M &amp; R Savings (Increase) - NPV</th>
<th>Design / Mark Up Savings (Increase)</th>
<th>Net Life Cycle Savings (Increase)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$19,000,000</td>
<td>($100,000)</td>
<td>$2,750,000</td>
<td>$21,650,000</td>
</tr>
</tbody>
</table>

Advantages | Disadvantages
---|---
1. Eliminate or reduce densification. | 1. Damage to tunnel following seismic event may not be repairable. Does not meet current design objectives.
2. Reduces cost, and construction risk. | 2. Repair may be difficult.
3. Highway 99 could be closed to traffic following an event. | 4. If not repairable, replacement structure could take 10-15 years to complete.
Discussion and Considerations:
In this scheme, one would be accepting that some level of tunnel cracking is likely, and pumping capacity is increased to better control ingress of water. After a seismic event, it would be anticipated that more repair would be required on the tunnel, and there is increased risk that this could be extensive (or even not repairable). In the worst case, one is risking that the structure is no longer functional, and a bridge replacement will have to be accelerated, while Highway 99 would be closed.

Cost Calculations:

<table>
<thead>
<tr>
<th>CAPITAL SAVINGS (INCREASE) Incl. PROPERTY</th>
<th>SAVINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eliminate Densification</td>
<td>$20,000,000</td>
</tr>
<tr>
<td>Install additional pumps (incl. mobilization)</td>
<td>($1,000,000)</td>
</tr>
<tr>
<td>Net Savings (Increase)</td>
<td>$19,000,000</td>
</tr>
<tr>
<td>15% Tender Contingency</td>
<td>$2,850,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OPS, MAINT &amp; REHAB (O,M &amp; R) SAVINGS (INCREASE)</th>
<th>NPV (@10%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional pump maintenance ($5000/year over 20 years)</td>
<td>($ 100,000)</td>
</tr>
<tr>
<td>NPV = $57,000. Round up:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RE-DESIGN AND OTHER COST SAVINGS (INCREASE)</th>
<th>SAVINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Re-design and testing</td>
<td>($ 100,000)</td>
</tr>
</tbody>
</table>

**TOTAL VEP SAVINGS (INCREASE)** $21,650,000

Value Engineering Team Recommendation:
The Value Engineering Team DOES recommend this proposal.

Justification:
In the event that the Ministry wishes to consider an alternative strategy for mitigating safety and risk during a seismic event, this alternative would provide a means of increasing pumping capacity and response time. However, it does not meet current objectives for improving the likelihood of structure integrity.
Design Suggestions:
While this may not be a reasonable alternative in terms of current project objectives, and longer term protection of the structure, at the estimated cost it could be considered as a complementary measure to the current design, or other VEP alternatives tabled in this report. It could be implemented in any scenario where additional comfort was sought with regard to public exiting the tunnel, maintaining working access for repairs, and reducing risk.

Prepared by:  
Keith Kazakoff  
Lead Evaluator

Checked by:  
Ralph English, P.Eng.  
Team Member

Current new tunnel pump configuration.
VALUE ENGINEERING PROPOSAL NO.: VEP 13

Proposal Title: Allow Proprietary Drains

Current Design Approach:
Seismic drains are proposed as follows:
   Type ‘A’ drains onshore – 14,788 m
   Type ‘B’ drains onshore – 4,788 m
   Type ‘B’ drains marine – 9,523 m

Value Engineering Proposal Description:
Allow proprietary drains (e.g.: “Nilex” or alternative) at a proposed cost of $50/m onshore and $100/m marine.
Type ‘A’ drains are assumed to be at a one-to-one equivalent.
Type ‘B’ onshore drains are assumed to be at a one-to-one equivalent.
Type ‘B’ Marine drains are assumed to be at a two-to-one equivalent.

Cost Savings Summary:

<table>
<thead>
<tr>
<th>Capital Savings (Increase)</th>
<th>O, M &amp; R Savings (Increase) - NPV</th>
<th>Design / Mark Up Savings (Increase)</th>
<th>Net Life Cycle Savings (Increase)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1,500,000</td>
<td>$0</td>
<td>$250,000</td>
<td>$1,750,000</td>
</tr>
</tbody>
</table>

Advantages
1. Allows use of efficient innovation.
2. Reduces risk of softening ground
3. Reduced cost.
4. Potential contingency measure within compaction zone.

Disadvantages
1. Requires construction details.
Discussion and Considerations:

Offshore, marine installations of proprietary drains require a separate operation and different equipment from that used in compaction. This may notionally be a disadvantage, but could allow work to proceed during any vibro maintenance. One could possibly consider application for onshore and/or offshore work.

It should be highlighted that there is some concern regarding the $33/m estimate for Type A drains on-shore. The team felt this would be more likely to be approximately $79/m, and calculations will be better represented by using a revised figure for the comparison.

Cost Calculations:

<table>
<thead>
<tr>
<th>CAPITAL SAVINGS (INCREASE) Incl. PROPERTY</th>
<th>SAVINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type ‘A’ based on a revised estimate of $79/m</td>
<td>$425,000</td>
</tr>
<tr>
<td>Type ‘B’ onshore $600,000; marine $475,000</td>
<td>$1,075,000</td>
</tr>
<tr>
<td>Net Savings</td>
<td>$1,500,000</td>
</tr>
<tr>
<td>3% for Mobilization</td>
<td>$50,000</td>
</tr>
<tr>
<td>15% Tender Contingency</td>
<td>$225,000</td>
</tr>
</tbody>
</table>

RE-DESIGN AND OTHER COST SAVINGS (INCREASE) | SAVINGS |
Likely by proprietary supplier, but contingency included: | ($25,000) |

**TOTAL VEP SAVINGS** | **$1,750,000**

Value Engineering Team Recommendation:

**The Value Engineering Team DOES recommend this proposal.**

Justification:

This proposal suggests a cost saving potential for using alternative seismic drain designs. (Figures include comparison to a revised estimate of $79 / m for Type ‘A’ drains.)

Prepared by: Don Gillespie, Ph.D., P.Eng.
Lead Evaluator
VALUE ENGINEERING PROPOSAL NO. : VEP 21

Proposal Title: Further Strengthen Tunnel to Withstand Liquefaction

Current Design Approach:
Protect the tunnel from liquefaction forces by densifying the ground and providing seismic drains.

Value Engineering Proposal Description: (see attached sketch)
Provide the tunnel with sufficient strength / ductility to accommodate liquefaction forces by attaching additional steel plates in the air ducts, and consider potential for post-tensioning to reduce cracking if event occurs. This proposal is focused mainly on lateral movement of the tunnel as opposed to uplift, given that a seismic event occurs.

Cost Savings Summary:

<table>
<thead>
<tr>
<th>Capital Savings (Increase)</th>
<th>O, M &amp; R Savings (Increase) - NPV</th>
<th>Design / Mark Up Savings (Increase)</th>
<th>Net Life Cycle Savings (Increase)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$11,700,000</td>
<td>$0</td>
<td>$1,450,000</td>
<td>$13,150,000</td>
</tr>
</tbody>
</table>

Advantages

1. Eliminate construction vibration risk to tunnel.
2. Eliminate environmental and navigation impacts.
3. Less risk of uncertainty in costs and quantities.
4. Reduced costs.

Disadvantages

1. Requires extensive re-analysis.
Discussion and Considerations:

To pursue this alternative, the existing tunnel (with retrofit) would need to be analyzed in light of not doing ground improvement work. The densification approach was to protect the structure from seismic loads rather than to accommodate the loads in the structure. This proposal considers addressing the ability of the structure to withstand further loading.

Structural work is usually attainable with less risk to costs and quantities. Capacity and achieved performance is more certain than geotechnical areas. By restricting additional steel (assumed to be a doubling of the amount of steel added as part of the completed structural retrofit) to air ducts, traffic disruption is minimized. Post-tensioning was also considered but ruled out as being impractical.

Cost Calculations:

<table>
<thead>
<tr>
<th>CAPITAL SAVINGS (INCREASE) Incl. PROPERTY</th>
<th>SAVINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eliminate densification work</td>
<td>$19,900,000</td>
</tr>
<tr>
<td>Additional Steel <em>(see attached calculations)</em></td>
<td>($8,200,000)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Savings</td>
<td>$11,700,000</td>
</tr>
<tr>
<td>15% Tender Contingency</td>
<td>$1,750,000</td>
</tr>
<tr>
<td>RE-DESIGN AND OTHER COST SAVINGS (INCREASE) SAVINGS</td>
<td></td>
</tr>
<tr>
<td>Assumed re-analysis &amp; design</td>
<td>($300,000)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL VEP SAVINGS (INCREASE)</strong></td>
<td><strong>$13,150,000</strong></td>
</tr>
</tbody>
</table>

Value Engineering Team Recommendation:

The Value Engineering Team DOES recommend this proposal.

Justification:

If an alternative to densification is desired, investigating this option further could be considered. If an analysis of the retrofitted structure is not already available, one might consider allocating a nominal amount of analysis funding to ascertain if the concept warrants further attention. If it were determined from analysis that more steel was required, there is room for it in the traffic tunnels running longitudinal between the steel joint strips, making them continuous, thus not further reducing tunnel clearance. The
costs of additional steel and traffic control would reduce but likely not eliminate the savings of this option.

**Prepared by:** Sharlie Huffman, P.Eng.  
Lead Evaluator

**Checked by:** Alan Russell, Ph.D., Eng.  
Team Member

**Additional Notes:**

Steel in air ducts $1,000,000  
Steel in Main areas $1,000,000

Installation ~ $2,600,000 for main ducts plates (x 2)

Therefore, to double existing steel:
  Install - $5,200,000  
  Supply - $2,000,000  
  Mobilize and traffic control - $1,000,000

**Total Capital Comparison** - $8,200,000

*Assumed re-engineering* - $300,000

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Potential additional steel locations.
APPENDIX C

Notes to Ministry & Designer
NOTES TO MINISTRY and DESIGNER

The following notes are provided as recommendations for Ministry consideration of capital programming, risk mitigation, or scheduling strategies, and where appropriate, to the Designer for consideration of optimisation through the course of design completion.

Idea 1 – Test Section(s) on Densification Processes

The concept proposed herein is to adopt a 2-phase approach to the ground improvement work. Phase I would be to execute the proposed work at a representative location to assess technical feasibility, and reduce risks. Phase II would be to let the contract for the main body of the work, incorporating the findings from Phase I.

The current plan appears to assume a lump sum tender for all items as opposed to unit prices, or a combination of lump sum and unit price items. Thus, a major risk for government is that the prices bid will be considerably in excess of the estimate, including the government’s contingency allowance. In addition, given the nature of the work, the government could be exposed to a significant risk of claims. Major risk drivers relate to:

- Current market conditions (high profit margins and risk premiums, industry at capacity, a limited number of capable bidders, and shifting prices on inputs)
- The extended period over which the work is to conducted (2 or 3 years depending on cash flow constraints).
- Technical risks related to design requirements (see Special Provisions, page 28, re: tolerance levels and their achievability)
- Material quantities
- Workability of methods adopted.

While market risks cannot be easily mitigated (other than perhaps through decisiveness), technical risks can be reduced by conducting a field test on say a 30 – 50m long section of tunnel, that has a range of geotechnical conditions likely to be encountered, and can yield beneficial inputs to Phase II (Section B would appear to be the best candidate).

As an example of the technical uncertainties, the boreholes drilled in 2006, along with CPTs, identify zones labelled as “gravelly sand to boulders” that vary in thickness from 1m to in excess of 4m (Ref. B&T Memorandum dated November 29, 2006). These “gravelly sand to boulder” zones have been identified at elevations at or below the underside of the tunnel (i.e. at Sections B, C, D, and E), lower than the elevations to which rock fill was placed during initial construction of the tunnel.

The bottom-feed vibro probe system is expected to penetrate gravelly sands via water jetting. However, there is a high risk of probe refusal and/or damage to the probe and feed pipe system, if coarse gravel, cobbles, and boulders are encountered in greater numbers, within a gravelly sand matrix, due to the formation of a nested zone of large size stone at the neck of the probe.
It is recommended that the zones labelled as “gravely sand to cobbles” be better defined with respect to the estimated proportions of material sizes in the IFC drawings. The possible reasons for encountering these coarse-grained materials at depths deeper than the reinforced concrete mattress and tunnel invert should be investigated, especially in light of the 10+m deep scour holes that have been observed both upstream and downstream of the tunnel alignment within the southern half of the tunnel. This could be achieved by examining historical bathymetry data that has been obtained since completion of the tunnel.

A test section would also allow for the examination and testing of a number of other ideas tabled in this report.

**Advantages** of pursuing a test section in advance of the main work include:

- Develops a much better understanding of the conditions to be encountered
- Demonstrates that the performance objectives and tolerances specified are achievable
- Information garnered provides an opportunity to refine the design
- Providing key results to bidders should help reduce the risk premium that would be included
- Reduces the likelihood and extent of claims

**Disadvantages** would include:

- Potential loss of up to 1 year’s time
- Additional information obtained may end up being of limited value
- Combined cost of Phases I & II may exceed budget. Savings pursued by taking the approach may not offset incremental mobilization costs.

A similar approach was used to limit risk and refine design input, on the seismic retrofit of the Posey-Webster Street Tubes, between Oakland and Alameda California\(^1\). The twin tubes are likely the most comparable structures to the Massey Tunnel in North America, with very similar conditions, and seismic upgrading needs. The test sections addressed a number of options, including vibro-compacted stone columns and drains. It is understood that the Designer of the George Massey densification has considered the California work, and may be obtaining further data as the design is completed. If a dialogue or information sharing has not been established between the Ministry and CalTrans, it is highly recommended that this be pursued as well, to further establish a history of what is possibly the only other known application of the proposed approach to tunnel isolation.

---

\(^{1}\) Lee, Thomas S., Jackson, Thomas, and Anderson, Randy; “Innovative Designs of Seismic Retrofitting The Posey & Webster Street Tubes, Oakland/Alameda, California”
Idea 2 – Review As-Upgraded Structure Performance, and Egress Criteria

The structure has been upgraded to be more ductile and stronger. The analysis results presented to the VE Team suggest that the now-upgraded structure has not been further analysed for earthquake movements if no further ground improvements were to be undertaken.

If the structural analysis were to be redone on the upgraded structure, it is expected that the spacing of cracks will decrease and the potential water ingress reduced. A reanalysis may show that predicted inflow rates are not excessive for public safety, and that the densification may not appreciably improve life safety.

In considering the safety of travellers during a seismic event, the primary risk is due to water ingress. The Designer’s approach included limiting water ingress by improving the structural ductility and improving the ground to limit tunnel deformation, and bound cracking to an acceptable level. A one-hour evacuation criterion was employed.

A reconsideration of the one-hour evacuation period is suggested herein. This may not be sufficient for a severely injured person, mid-tunnel, but is probably generous if the person is able to move. Regarding the Posey & Webster Street Tubes project in California, it is understood that original design criteria included a 30-minute operating requirement, following a design seismic event.

The B&T report of March 26, 2001 (page 93) suggests water ingress in the order of 57,000 gal/min, or about 260m³/min. Using an area of the 3rd and 4th tunnel segments of 20x200 = 4000m² with negligible pumping, the water level would initially rise 65mm/min. Therefore, in the first 10 minutes after a design seismic event, the water level in the middle 2 elements would be 650mm deep. The middle two elements are at the bottom of a sag curve, so that the water would rise more slowly in elements 2 and 5, and would be analogous to a rising tide. The extent of water would advance up elements 2 and 5 more slowly in an hour, as shown in the enclosed schematic. As a result, a person in the middle of the tunnel would have 10 minutes to travel the first 100m, and then 50 minutes to traverse the next 100m. A review of the exit scenarios would also want to consider to what extent it is reasonable to assume people will traverse small water depths without their safety being compromised (e.g.: 300mm vs. 600mm).

A high-level review of safety objectives is recommended if an alternative strategy to ground densification is sought. (please see VEP 12 for an associated concept involving increased pumping capacity).
Water Levels as a function of time, at 260m$^3$/min ingress.

**Idea 8 – Move Densification Further Away From Structure**

Initially, this Idea was tabled as a potential cost saving alternative. However, while relocating the zone of densification away from areas of heaviest existing rip-rap would undoubtedly save money, it is not recommended as an alternative that would meet equal design performance. In particular, the VE Team agrees with the Designer that the bearing capacity (or flotation) failure mechanism would not be addressed as well.

This note is therefore intended as a suggestion to consider the effectiveness of using an alternative compaction zone that is shifted up to 7.5m away from the tunnel. This would be helpful in the event that construction results in unacceptable tunnel movement, and an alternative measure is required. As a complement to the Note regarding Idea 22, having a sense of how far away, upstream & downstream, the work can be located to still provide positive benefits, will offer some support to contingency planning.
Idea 9 – Replace Tunnel With a Bridge ASAP

Identified Issues:

1. The structural condition of the tunnel is likely good for 50 years if there is no earthquake.
2. The functional capacity of the tunnel is already exceeded.
3. An on-site operation facility is desired.
4. Even with the completed seismic retrofit, the structure does not meet the Lifeline capacity of new structures to current codes:
   - New structures are designed to 3 seismic load levels, 10%, 5% and 2% in 50-year events.
   - The retrofit is designed to only the 10% in 50-year seismic load.
   - If only the 10% event is exceeded, the use of the tunnel could be lost abruptly.

Discussion:

If the current structure is lost abruptly, the delivery methods for a replacement structure would be limited (the overwhelming probability is that it would be a bridge). Design and construction would take place in an environment of heavy demand on limited local resources. Material supply, labour, construction expertise, equipment and design capacity would all be scarce. The usual emergency bridging (Acrow) would be inadequate in this location and supplies would be as scarce as other resources. The loss of this crossing would impact post-disaster recovery for the region and the Province. There is uncertainty as to the exact capacity of the tunnel in a seismic event.

If the current structure is replaced now with a more robust bridge to current code, then the crossing could be available in time of disaster to assist in economic recovery. Further, pursuing a replacement structure now would enable thoughtful, strategic delivery and a more economical use of resources. This option is further supported by the fact that the cost of replacement in an urgent environment could be double the cost to do it now.

The budget for the ground improvement could be re-directed toward advancement of a bridge plan and design. The added risk due to leaving the proposed ground improvements undone would be offset by the reduction in risk after the bridge is completed – to what extent is subject to strategic objectives, and the horizon for replacing the bridge due to other drivers (such as traffic capacity). If a replacement structure is pursued early enough, exposure to a potential seismic event is reduced greatly, and the lower the overall risk. (Further contemplation of risk and cost implications is presented in Section 4.4 - Investment Risk Overview).

EVM Project Services Limited

March 23 – 28, 2007

Notes to Ministry & Designer - Page 5
Idea 10 – Analyze Performance With a Flat River-Bottom Profile.

If available sonar data or hydraulic studies suggest that a relatively flat zone of river bottom could be maintained adjacent to the tunnel, the need to maintain a sloped profile in the tunnel analyses could be relaxed. It is understood from the Designer that if transverse movement is limited, there remains a concern for increased vertical movement (flotation) in a liquefaction event.

The present configuration seems to include cross-sections with flatter profiles, while others show sloping profiles. Further consideration could be given to filling localized scour holes to smooth the profile, especially on the south side. Sand and gravel to be excavated is in the order of 160,000 m$^3$, and disposal in the scour location(s) to level the ground profile may be no more environmentally contentious than off-shore disposal. This concept would require a formal hydraulic analysis, and review of existing data and models to confirm its viability.

A multibeam survey should be considered following the 2007 freshet, which is expected to be large. This represents an ideal opportunity to evaluate the scour risk.

Idea 11 – Owner Provides Restoration and Backfill Materials

At this stage of design development, final decisions on the suitability, re-use, and disposal of excavated material may not be at hand. It is understood that the estimate currently accommodates re-use of a portion of the excavated material as rip-rap or gravel in the restoration process, and that the contractor would be responsible for supply of any new material to complete the design backfill placement.

It is suggested that the Designer and Ministry consider the economy of specifying supply of all rock by the Ministry. This would eliminate some cost risk, by taking advantage of available Ministry sources and/or any surplus from projects underway at the same time. (In terms of the disposal of unsuitable excavated material, if filling adjacent scour holes is not desirable, the material could be of value in other Ministry projects which could have surcharge needs, or a projected deficit). While this would have to consider haul costs, there is a possibility that this would otherwise have to be accounted for in the estimate in its current form as well, as applied to the haul and disposal of any currently projected unsuitable portion of the excavated material. (See also Idea 16 – Confirm Allowed Strategy for Use of Excavated Material).

Idea 14 – Confirm Location of On-shore Utilities

It is understood that the location of utilities in the area of the approaches is currently unconfirmed. Hydro and other existing underground utilities may or may not conflict with the proposed on-shore densification work in these areas.

While some work remains to be undertaken before the contract documents are completed, the VE Team felt it was important to ensure that the location of the utilities be confirmed prior to tendering. The design and/or specifications should be refined based on the confirmed locations, to minimize the risk of delays and damages if the work zone...
encroaches on utility paths. The earlier this is undertaken, the more likely that any
relocations that are necessary can be accommodated without negatively affecting the
schedule for implementing the densification work.

**Idea 15 – Perform Hydraulic Study & Confirm 2:1 Cut Slopes**

The drawings (No. 1509-133 dated January 26, 2007) illustrating ground improvement
procedures specify work to be undertaken in 100m sections in the longitudinal direction.
A minimum of 3m of rock fill and river deposits is specified to be placed on the tunnel
roof at an estimated slope of 2H:1V. Neither the construction specifications nor the
drawings refer to river currents and the associated instability of material placed on top of
the tunnel, or the stability of the excavations carried out to remove the existing rock fill.

Loose submerged river deposits consisting of sands and silts are unlikely to remain stable
at unprotected slopes of 2H:1V in the project environment, which involves river currents
that are likely in the range of 2 to 4 knots. Also, placement of material over the tunnel
roof and the geometry created by the excavation on either side of the tunnel have a high
risk of generating sufficient turbulence and/or localized currents to undermine the
stability of the exposed slopes, resulting in delays and additional costs.

It is recommended that a hydraulics study be undertaken to assess the impact of river
currents on the stability of the temporary slopes considered for the ground improvement
work. Loose river deposits are likely to be stable at slopes of 4H:1V or flatter depending
on river currents. If the weight of materials that correspond to these flatter slopes is
insufficient to prevent the risk of tunnel flotation, additional measures need to be
implemented to prevent flotation of the tunnel during excavations.

**Idea 16 – Confirm Allowed Strategies For the Use of Excavated Materials**

It is understood that at this stage of design development, a detailed prescription for the
use of excavated material, and its suitability for re-use in backfill and restoration
processes, has yet to be finalized.

It is suggested that the uncertainty in the quality and quantities of excavated materials
could significantly affect risk and prices, as variables include stockpiling and processing
requirements (the material is not expected to be homogeneous), the sourcing of new,
suitable replacement materials, haul, environmental suitability, etc.

(a) The simplest treatment, subject to adherence to environmental requirements,
would be to remove and dispose of all excavated materials offsite, and replace
by new material. There is some anecdotal evidence to suggest this may be the
most cost-effective approach. Please also refer to the associated Note
regarding Idea 11, wherein greater value and clarity could be furthered by the
strategic application of suitable excavated material, and/or using it as fill
material on other local projects.
(b) Depending on the true nature of the excavated material, another question relates to the allowable use for other purposes. It is possible that placing the material in adjacent scour locations, away from the tunnel and out of the navigation channel, without bringing the material to the surface, may be more palatable.

(c) In the event that it remained advantageous to use a portion of the excavated material in backfill operations, it may be necessary to limit the use to specific areas of the new template. To this end, it may be necessary to pursue further sampling and testing to ascertain its suitability, and draft the specifications accordingly. This way, the contract can clearly identify the level of risk transfer to the contractor.

Idea 17 – Optimize Densification on North and South Approaches

It was presented to the VE Team that some additional field investigations were undertaken to provide refined inputs to the FLAC model, to optimise the marine component of the densification design. The result of this work included a reduction in the extent of proposed in-river work. Additional field investigations were not performed for the proposed approach sections of densification.

While on-shore work is less extensive and risky than the marine component, it nevertheless represents a non-trivial proportion of overall cost. It is suggested that if scheduling permits, the cost of additional field investigation in the area of the approaches, and possible re-analysis, would be quite small relative to the potential savings a similar refinement may lead to. That is, one would anticipate that in the absence of contrary data, savings from the exercise would be proportionally similar to the reduction realized in the marine section.

Any additional investigations could be undertaken in conjunction with Idea 14 discussed above, to ascertain the locations of on-shore underground utilities.

Idea 18 – Implement Emergency Road Closure System

The current design does not call for an Early Warning System (EWS) and Emergency Road Closure System (ERCS) to be implemented to warn the tunnel users of a potential breach during construction, or following implementation of ground improvement measures.

There is a low risk of accidental damage to the tunnel during implementation of ground improvement measures. This may result from a number of activities including, but not limited to, loss of anchor support of the barges (that support the vibro equipment, coarse rock fill, etc.), high river currents, and movement of submerged logs near the river bed. It would also be beneficial to warn users of unsafe conditions in the tunnel during and following strong earthquake shaking. It is understood that the tunnel and approaches will be instrumented to monitor risk of damage during construction. It is also understood that the tunnel has already been instrumented to detect strong shaking from an earthquake.
Identified Issues:

1. Risk of damage to tunnel during construction (hence the need for monitoring and “stop work criteria”)

2. Accidents in the tunnel requiring traffic diversion will engage the red ‘X’ lane controls, requiring an abrupt stoppage

3. There are no truck over-height warning devices to protect against trucks hitting the tunnel or overhead lights

4. The current message signs are at 17th Street Overpass, and Steveston Overpass, placing them ahead of incoming loops to Highway 99 at both ends of the tunnel

5. A tunnel is not a recommended place to be in an earthquake

6. Drivers entering or in the tunnel during an earthquake may panic, brake, and experience accidents, particularly if they are in the first half of the tunnel (drivers who can see daylight ahead will likely proceed to the exit)

7. It takes 45-60 seconds to travel the enclosed portion of the tunnel

8. There are up to 1200vph/lane in heavy periods.

Discussion:

There is a risk that a large number of drivers would not interpret use of the current red ‘X’ system as cause for emergency avoidance, and may even speed up anticipating a simple counterflow shift. Another consideration is that the weigh scale is being decommissioned, and while incidents are few, damages by over-height trucks could close the lane for 2 – 3 months.

Warning of a seismic event would enable vehicles to not enter the tunnel at all. It would take 20 – 30 seconds of warning to ensure all vehicles in the tunnel could get clear, and see the exit, before shaking starts. While the attainable warning time varies with earthquake type and location, every second of warning could be significant to protecting travellers. The same system of warning lights could operate automatically, triggered by P-wave detection by the Provincial Strong Motion Network, by over-height monitoring, or manually by an operator based on accident or construction incidents.

It is recommended that an Early Warning System (EWS) and an Emergency Road Closure System (ERCS) be implemented to warn the tunnel users and to minimize the risk of injury due to damage resulting from construction activities, as well as from post-construction strong earthquake shaking. An EWS could potentially minimize traffic congestion by preventing entry of vehicles. The resulting reduced congestion will assist egress of users who may have already entered the tunnel.

Warning signs would be installed closer to the tunnel than the last entry to Highway 99, and a means of educating the public or communicating intent undertaken. Likewise, one would tie-in over-height sensors to optimise use of the warning system, and ensure that construction monitoring data was fed into the network, probably via the control facility.
Idea 19 – Review 3m Spacing of Stone Columns

This Note is due to a concern by the VE Team that the 3 meter spacing of columns may be optimistic in terms of budgeting for densification objectives that will be confirmed during construction. An initial spacing of 2.5m would provide some additional risk mitigation. If performance specifications are met at this spacing, it is then possible to relax the spacing upward in 0.25m increments, but ideally not beyond a maximum 3m.

Some additional confidence in the spacing could be achieved by specifying the use of electric vibrators – they have better performance than hydraulic, and in this case one could more reliably expect a maximum 2.75m spacing. This also permits the submission of amperage records to support quality-monitoring processes.
The quality testing (CPT) is conducted underwater, and is difficult to place at the centroid of the compaction pattern in the expected currents. Therefore, better assurances of quality and accuracy can be achieved by specifying a minimum standard for guiding the vibro-probes (i.e.: gyroscope or other location systems). Ref. S.P. 2.6.6.2 & 2.6.6.3


The current Special Provisions prescribe limits on the movement of the tunnel during construction, and the tolerances in SP 2.4.2.7 appear to be restrictive with regard to the likely movements the structure could experience during an earthquake.

Given the properties of the existing soils, it is also likely that the movements could be exceeded due to construction activities (compaction undertaken at bridge piers and abutments has resulted in larger movements). The measurement of these movements, and in particular the relative movement of tunnel elements, requires accurate survey and monitoring. False readings are also possible.

The VE Team recommends the Ministry and Designer re-consider the allowable tolerances for construction displacements, to ensure reasonable, achievable goals consistent with the expected performance of the recently strengthened structure. This will also lead to a reduced risk of delays and cost overruns during construction. A full transfer of remediation of any movements to the contractor may be unreasonable and indefensible.

Idea 22 – Develop Contingency Plan For Exceeding Construction Specifications

The current Special Provisions prescribe limits on the movement of the tunnel during construction, to protect the integrity of the structure in the event that excavation, densification, or other construction activities produce other than the desired results. The contract includes extensive pre-construction surveys, and the installation of monitoring equipment, to support the effort to observe movements, and limit works if the tolerances are exceeded. (see also Notes above, regarding Ideas 8 and 20).

While it is understood that the Special Provisions remain to be finalized, and further work may be intended, it is proposed that a strategy be developed that would be employed in the event that certain unexpected results in the field result in work stoppages. In this way, a clear plan will be immediately available to the Ministry upon occurrence of undesirable impacts, with pre-prescribed responses. Without such a plan, it is likely that traffic could be impacted and construction delayed, while experts are consulted and approvals are sought. The expected response options could be tied to the project and/or construction contingency allocations, such that funding authorization is in place to support rapid decision-making and action.

Examples of responses to anticipate could include inspections with identified experts, strain or crack measurements, unloading, alternative densification methodologies, etc.
Other Notes:

Environmental and Navigational Approvals

Formal approvals from environmental agencies, and for navigational purposes, are required prior to tendering. It is understood that all waterway approvals are coordinated through a Fraser River Estuary authority, and that initial discussions have been undertaken. No problems have been anticipated to date.

It is recommended that any necessary agreements be pursued well in advance of any anticipated tender schedule. Obtaining such agreements in writing as soon as possible will help:

- define costs for any mitigation or protection requirements
- allow rapid initiation if opportunities present themselves on short notice
- confirm the options available for excavated material handling and disposal
- define all restoration and backfill material options
- define channel navigation impacts and strategies, and
- eliminate considerable construction risk.

Contingency Considerations

With regard to contingency and risk, expected prices should be reviewed as noted herein, with an eye to respecting the escalation that can occur over the planned tender timeframe, and the likelihood of achieving “neat line” quantities in the field. By pursuing the recommendations in this study, completing field investigations and approvals, and advancing the design through its intended level of refinement, the current level of contingency will be able to be reallocated as necessary to address newly-identified items, while leaving some portion (say a minimum 10%) available as general contingency when the package is tendered.

Depending on the results of any contingency planning (as suggested in the Note for Idea 22 above), there may be an opportunity for the Ministry to identify “exceptional contingency funds” to be approved only if certain undesirable results occur as a result of the innovative methods (e.g.: excessive movement). This could be assigned outside of the project level, perhaps with the Sponsor or Region, with a clear process established for justifying its timely release and application.
APPENDIX D

Presentation Extracts
Value Engineering Study

George Massey Tunnel
Densification Project

Value Engineering Study Overview

March 23rd – 28th, 2007
Burnaby, B.C.

VE Study Objectives

• In accordance with the Ministry’s VA/VE Policy & Guidelines, and good industry practice, assess the existing Design and make recommendations with regard to:
  ✓ overall value - level of investment relative to asset objectives
  ✓ state-of-the-art practices
  ✓ reducing scope to minimize budget
  ✓ constructability and staging, and
  ✓ limiting risk

Focus Points

• Lowest net life cycle cost
• Seismic protection of the structure
• Construction methodologies
• Value for investment
• Opportunities to minimize risk
• Current project budget estimate – comment on ability to achieve lowest reasonable capital cost

VE Study Team

Upul Atukural, P.Eng. – Seismic and Soils Densification
Carlo Enholm, P.Eng. – Marine Structure Engineering
Don Gillespie, P.Eng. – Geotechnical Engineering
Sharlie Huffman, P.Eng. – Structure Seismic Engineering
Keith Kazakoff - Constructability
Prof. Alan Russell, P.Eng. – Investment Risk Analysis

VE Study Facilitator - Ralph English, P.Eng.
VA Recorder – Kevin Gardner
VE Study Outline

- Pre-Study: Documentation Review & Preparation
- Design overview & Site Review
- Idea Generation
- Value Engineering Proposal (VEP) Evaluation & Costing
- VEP Selection & Summary Presentation
- Reporting

VE Study Schedule

VE Study Context

- Creativity & professionalism
- Challenging yet positive atmosphere
- Offer constructive recommendations to the designer’s professional work
- Cooperative effort to provide confidence to the Ministry of best value approach
- Respect design constraints, stakeholder and agency influences, and Design Team objectives

Project Location
**Project Limits**

**Key Project Features**

- Preconstruction survey and monitoring instrumentation
- Test sections
- Excavation of existing rock, sand & gravel covering tunnel
- Ground Densification using stone columns, and seismic drains
- Site restoration and backfill

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**Design: Current Configuration**

**Design: Densification Scheme**
Design: *Marine Excavation*

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Design: *Typical Marine Section*

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**Design Alternatives**

- Limiting scope to achieve reduced cost?
- Previous options examined?
- Construction methodology?
- Designer overview session – issues raised to consider through the VE.

---

**Tender Schedule Cost Categories**

- **Mobilization** – marine and on-shore
- **Pre-Construction** – survey & monitors
- **Excavation** – remove existing coverings
- **Densification** – marine and on-shore
- **Seismic Drains** – tunnel and approaches
- **Site Restoration and Backfill** – rock, rip-rap & gravel placement
Project vs. Construction Estimates

- Tender Schedule covers expected construction costs only (probable = $20.3M)
- The Project estimate also includes:
  - Contingency ($3.0M) – will address any utility impacts, environment, and other risks
  - PM, Engineering & Supervision (15%) ($3.0M)

  Current Project Estimate = $26.3M

Cost Model:
Areas of Relative Value Potential

Excavation Cost Elements

Densification Cost Elements
Seismic Drain Cost Elements

- Type 'A': Approaches
- Type 'B': On-shore
- Type 'B': Marine

$ Thousands

0 500 1,000 1,500 2,000 2,500

Restore & Backfill Cost Elements

- Other Gravels
- Drain Gravel
- 500lb Rock: On-shore
- 500lb Rock: Marine
- 1,500lb Rock: Marine

$ Thousands

0 200 400 600 800 1,000 1,200 1,400

Current Contingency Items

- **General contingency** – 15% relative to total tender cost elements
- **Provisional Sum** – roughly 3% on all construction cost elements

Idea Generation & Evaluation Framework

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Legend: □ | □ | □ | □ | □
**Value Engineering Proposal (VEP) Evaluation & Costing**

- Follows framework of the VEP Template
- Will generally apply current estimate unit rates to costing VEPs
- Any comments on the currently applied unit rates should be highlighted separately
- Net Life Cycle cost savings
- Confirms viability of the VE Proposal
- May result in design suggestions, or comments on Ministry program strategies

**VEP Selection**

- Select VEPs that move forward as recommended proposals to the Ministry and Design Team
- Summarize separate Notes to Designer & Ministry

**Reporting**

- Draft Report of results provided to Ministry within 5 days of completing VE sessions
- “Discipline Summary” by each VE Team expert.
- Review and confirm VEP calculations, sketches, explanations, etc.
- Final VE Report completed within 10 days of receiving comments on the Draft Report

**IDEA GENERATION**

- Brainstorming by cost category & discipline
- “Anything goes”
- Priority on areas of greatest net cost savings potential
- Group ‘subjective’ evaluation of each idea generated, to achieve consensus on those that become VEPs for detailed evaluation.
Influences on Value

• Mobilization:

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• Preconstruction:

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• Densification:

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### Influences on Value

#### Seismic Drains:
- Capital
- Ops., Maint., & Rehab.
- Volume/Extents
- Functionality
- Materials Used
- Infiltration of Fines
- Construction Methodology
- Others?

#### Site Restoration & Backfill:
- Capital
- Ops., Maint., & Rehab.
- Design Volume/Extents
- Functionality
- Slumping & Slopes
- Materials Used
- Construction Methodology
- Others?

#### Environment:
- Capital
- Ops., Maint., & Rehab.
- Treatment/mitigation needed
- Fisheries impacts
- Fed./Prov. Approvals
- Navigation Impacts
- Siltation & Containment
- Navigability
- Others?

#### Contingency:
- Capital
- Ops., Maint., & Rehab.
- Environmental Requirements
- Seismic Performance
- Actual Material Volumes
- Functionality
- Weather
- Environmental Damages
- Structure Impacts
- Price risk
- Others?