Strait of Belle Isle Crossing

Pre-feasibility Study

Immersed Tube Tunnel Option

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1. Introduction

At its narrowest point the Strait of Belle Isle (Strait) is approximately 18-kilometres wide. The construction of an immersed tube tunnel (ITT) of this length within a waterway whose depth can vary to a maximum of 110-metres, within an acceptable timeframe, represents an enormous logistical challenge.

Though many comparable studies for crossings with similar complexities been conducted in the recent past – such as a 19-km ITT alternative for the crossing of the English Channel and an 85-km crossing of the Bering Straits between Russia and Alaska, the construction of an ITT of the magnitude of the Strait of Belle Isle Crossing has never before been attempted.

Table 1 provides details of major existing and proposed ITT crossings worldwide for purposes of comparison. Currently, the worlds longest and deepest immersed tube tunnel is the Bay Area Rapid Transit (BART) Tunnel in San Francisco, CA. The BART tunnel, which opened in 1970, has a length of 5.8 km, and is located in water with a maximum depth of 40.5 metres. Though in the relatively near future tunnels will be constructed in deeper waters, these still do not approach the depths anticipated for the Strait of Belle Isle. Furthermore, the issue of crossing length and the logistical challenge of constructing an unprecedented number of tunnel elements within an acceptable timeframe remains.

Crossing	*Location*	*Function*	*Opened*	*Length (m)*	*Depth (m)*
Busan-Geoje Link	*South Korea*	*Road*	*2009 (est.)*	*3,384*	*50*
Bosphorus Crossing	*Turkey*	*Rail*	*2008 (est.)*	*1,800*	*58*
Oresund Crossing	*Denmark/Sweden*	*Road/Rail*	*1999*	*3,510*	*22*
Bay Area Rapid Transit	*USA*	*Rail*	*1970*	*5,825*	*40.5*

Table 1.1: World's Longest & Deepest ITT's

The following discussion outlines the logistical and environmental issues and constraints related to the successful construction of an ITT across the Strait of Belle Isle, and suggests how these combined constraints can be overcome, leading to the ultimate conclusion that the crossing is indeed feasible by ITT methods. The feasibility of the ITT construction is derived from the use of a combination of existing technologies, in conjunction with the assumption that some existing technologies can be further extrapolated to address the complications presented by the expected water depths.

2. Function & Geometry

Preliminary cross sections have been developed for both road and rail crossings for the Strait. The traffic envelopes including the provision for numbers of traffic lanes and tracks has been minimized to provide the most economically feasible crossing.

2.1 Road Tunnel

The cross-section of the road tunnel incorporates the running bore including a single traffic lane, and shoulders, ventilation ducts, and provision for egress in the event of an emergency. The width of the single traffic lane and shoulders will be sufficient to enable traffic to continue through the tunnel in the event of a breakdown. Users of the tunnel will be instructed to pull vehicles over to the side of the shoulder in the unlikely occurrence of breaking down to enable others to pass safely. The conceptual cross-section for the road tunnel is presented in drawing 213789-P005.

Horizontal Clearances

- Raised curb – 0.75 metres
- Shoulder – 1.25 metres
- Traffic Lane – 3.75 metres
- Shoulder – 1.25 metres

Vertical Clearances

Minimum clearances are measured form the top of ballast concrete.

- Surfacing depth – 75 mm
- Traffic clearance – 4.65 metres
- Signage/utilities envelope – 0.5 metres

Due to the length of the tunnel, the ventilation requirements for maintaining tenable air quality and visibility during operating conditions, and for allowing safe egress from the tunnel in an incident, are onerous. The proposed ventilation system for the road tunnel comprises a hybrid longitudinal system, using jet fans in conjunction with zoned supply and exhaust ducts. The spatial requirements for the combined supply and exhaust ducts are as indicated in Figure 2.1.

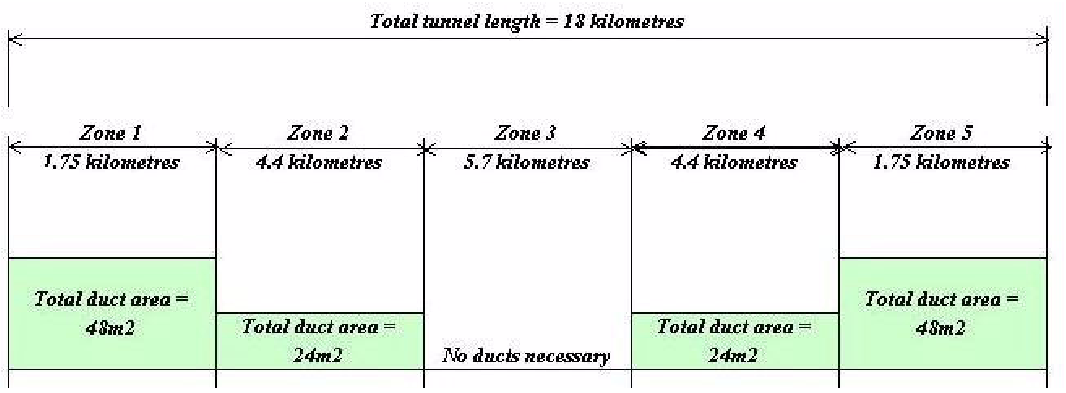

Figure 2.1: Ventilation Duct Zoning

As the ventilation ducts will extend for the full internal height of the tunnel, only the tunnel width will alter between zones, then the duct widths indicated below will be necessary.

- Zone 1 – 8.0 metres
- Zone 2 – 4.1 metres

A separate 2-metre wide egress corridor is provided for emergency use. Within this corridor provision has been made for HVDC cables. The cables will be buried below the surface of the walk of the corridor, and will be encased in a low strength sand/cement mixture. The cables will be laid in a series of ess-curves to prevent damage due to differential movements at tunnel joints. Given the solid foundation material for the tunnel, such movements will in any case be minimal.

2.2 Rail Tunnel

The cross-section of the rail tunnel provides for a single-track crossing. A separate enclosure is provided for egress in the event of an emergency. The cross-section also accommodates ventilation requirements for the tunnel, which are far less onerous than for the road tunnel due to the rail system electrification. The conceptual cross-section for the rail tunnel is shown on drawing 213789-SK005.

Horizontal Clearances

- Train dynamic envelope & walkway – 4.5 metres

Vertical Clearances

Vertical clearances are measured from top of ties, which will be embedded within the track ballast.

- Rail depth – 0.185 metres
- Vehicle clearance to contact wire – 6.165 metres
- Contact wire clearance from structure – 0.65 metres

As for the road tunnel, a separate 2-metre wide egress corridor is provided for emergency use. Again within this corridor provision has been made for HVDC cables.

As the rail system will be electrified, train emissions will be minimized. It is anticipated that the ventilation of the tunnel can be accomplished using a longitudinal system comprising a series of jet fans. As indicated on the aforementioned preliminary cross-section drawing, the jet fans can be accommodated above the egress corridor. It is also anticipated that banks of jet fans can be positioned in the cut-and-cover approaches to the ITT as necessary, where changes in cross section can more readily be accommodated.

3. Tunnel Alignment

While it is prudent in terms of ventilation, operational safety, and construction cost to minimize the length of the underwater crossing, it would be similarly prudent to avoid excessively deep sections of water for construction logistics purposes.

As mentioned in the introduction, the depth of the Strait is one of the major challenges to the expedient construction of the ITT, having significant impacts upon suitable means and methods of construction including types of dredging equipment employable, and duration of placement operations for the tunnel elements.

Other factors weighing in the selection of the tunnel alignment include the necessary grades to accommodate the mode of transport within the tunnel, and additional coverage requirements to minimize the potential for damage of the in-place tunnel elements from iceberg scour.

Therefore in assessing potential horizontal and vertical alignments, consideration has been to maintaining a minimal crossing length, while seeking to avoid excessively deepwater areas. The proposed principal alignment, and an alternative alignment, for the ITT are indicated in Figure 3.1.

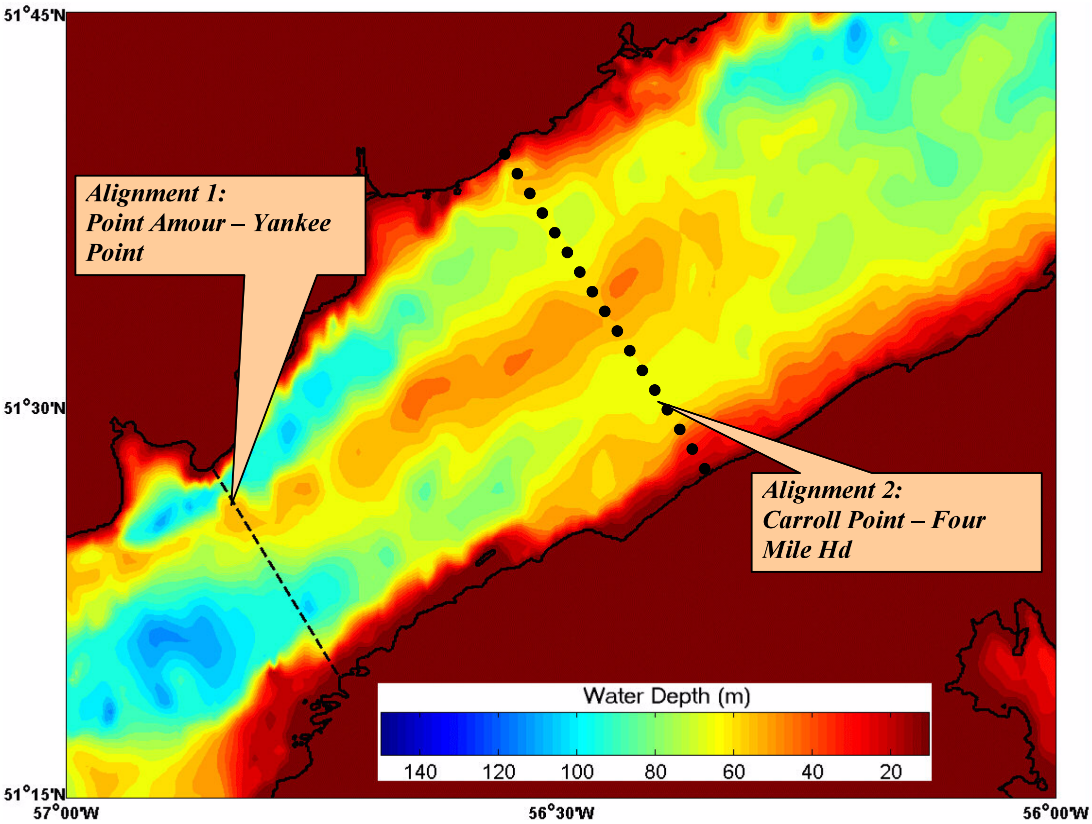

Figure 3.1: Potential ITT Alignments

Alignment 1

Alignment 1 generally follows the alignment of the previously conducted study for the HVDC Transmission Tunnel, linking Pointe Amour in Labrador and Yankee Point in Newfoundland, at the narrowest point of the Strait. This alignment yields a crossing length of approximately 18-km.

The preferred horizontal alignment for the crossing is indicated in Figure 3.2 below. The two principal goals of this alignment include:

- Locating the tunnel on a defined ridge in the Labrador Trough to minimize the depth of the crossing
- Minimizing the length of tunnel within the Labrador Trough.

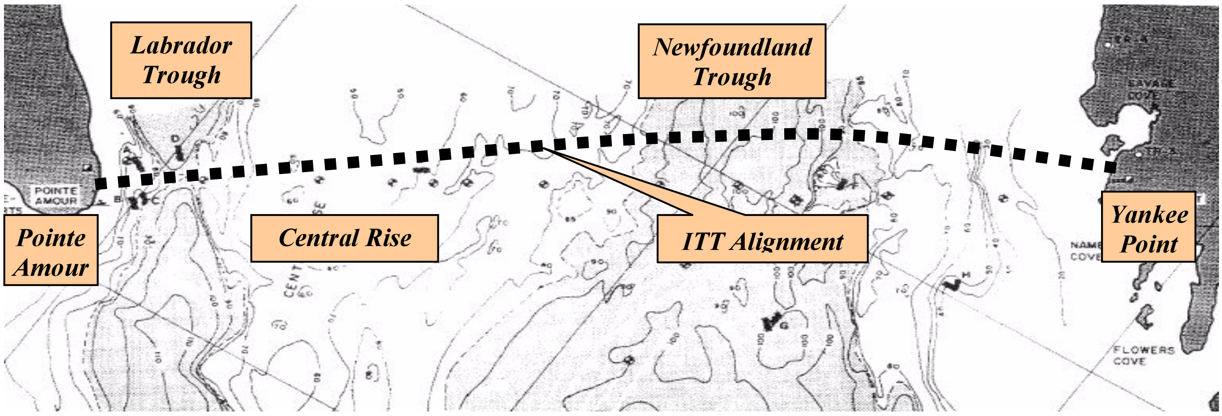

Figure 3.2: Alignment 1

The vertical profile of the tunnel will typically follow the profile of the bed of the Strait. The burial depth for the ITT elements will be based upon requirements for mitigating the risk of the tunnel being impacted by scouring and/or grounding of passing icebergs.

As identified within the C-Core Study on iceberg scour risk within the Strait (Ref. 3), the depth of cover required over the tunnel varies depending upon the mean return period selected. Based upon the length of the crossing, it can be readily understood that designing the tunnel for a return period of 200 years (3.8m cover) as opposed to 100 years (3.25m cover) represents a significant difference in construction cost.

It is anticipated that the tunnel structure will have a design life of at least 100, and possibly 120 years. As, based on experiences elsewhere, it is likely that the tunnel will remain in service beyond this design life, a 150-year return period, corresponding to a depth of cover of 3.5m typically, and 3.25m in depths of water greater than 70m has been assumed for this study quantification and cost estimating purposes.

It is possible that, with greater study, and based upon probabilistic risk, that in certain locations these figures could be reduced. For instance, in relatively shallow waters of 25 metres or less, the tunnel structure itself could be designed to accommodate impacts and grounding loads imposed by bergy bits and growlers.

The principal issue with the Pointe Amour – Yankee Point alignment is the water depth, and the effects of the water depth on dredging/excavation methods for the trench for the immersed tube tunnel.

As mentioned within the introduction, the deepest ITT, either in planning or construction is sited at a maximum of 56 metres deep. Based upon the bathymetry contours, approximately 65-70 percent of the crossing length will be at a depth greater than 60 metres. This presents an enormous challenge for the construction of the trench, requiring significant advances in currently available technologies.

Alignment 2

Alignment 2 seeks to address the water depth related issues of the first alignment. Situated further west of the Pointe Amour – Yankee Point crossing site, the alignment approximately links Carroll Point in Labrador with Four Mile Head in Newfoundland.

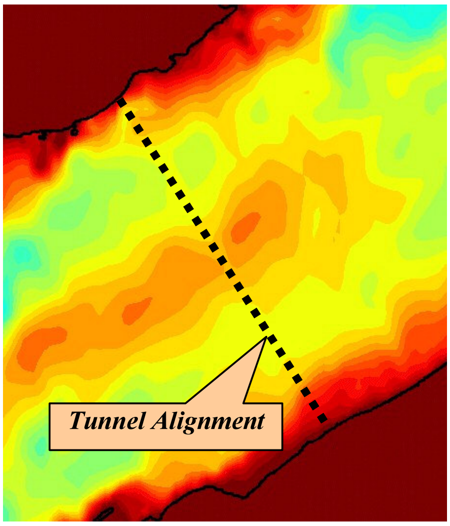

Figure 3.3: Carroll Point – Four Mile Head Alignment

The depth of the crossing is much reduced at the indicted location, with a maximum anticipated depth of approximately 65 metres, which is much more feasible in terms of dredging technologies.

However, the crossing is approximately fifty percent longer than the Pointe Amour –Yankee Point alignment, measuring approximately 27-km, which raises equally significant issues on tunnel cost and construction schedule.

In terms of the study of the feasibility of the crossing, Alignment 2 will only be considered further if it is demonstrated conclusively that the construction of the tunnel on Alignment 1 is not feasible.

4. Surficial and Bedrock Geology

A general understanding of the geology, and in particular the surficial geology, of the Strait is fundamental to the immersed tube tunnel concept. This brief description addresses both the bedrock and surficial geology of the area, and is based largely upon the boring program conducted in 1981. This program was the only offshore program to retrieve core, and drilled 22 shallow borings from a pressurized diving bell. Of these 22 borings approximately 12 are on the proposed alignment.

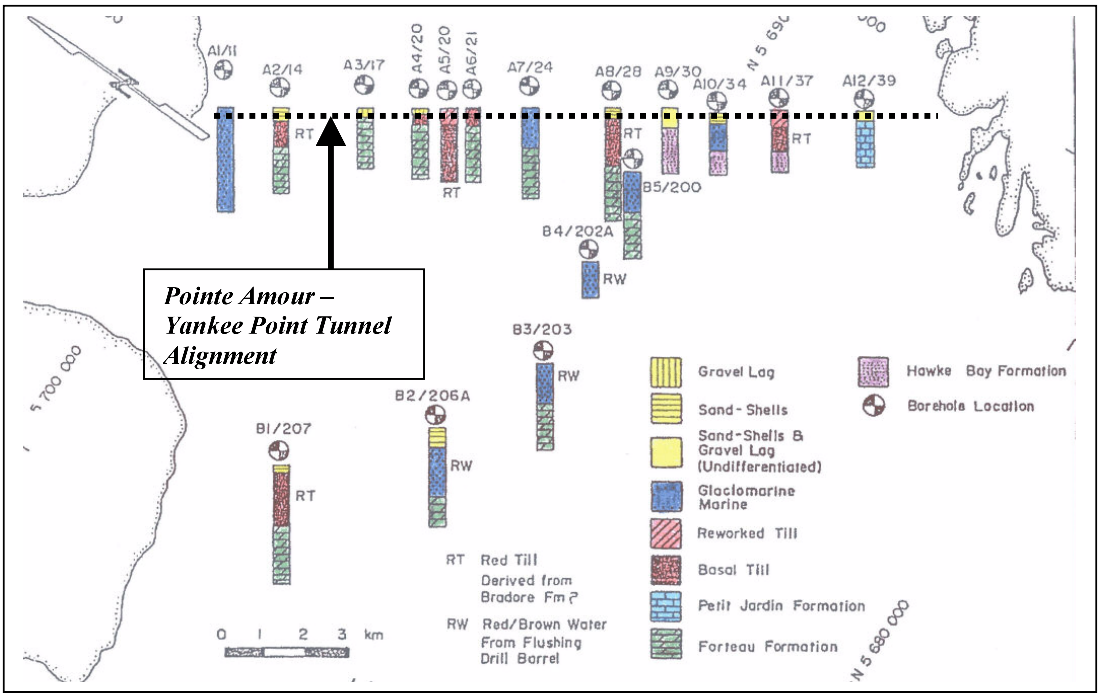

Figure 4.1: 1981 Offshore Boring Program

The borings indicate that the overburden consists of thin deposits of shells, sand, gravel, glaciomarine marine deposits and dense till. Along the route from Point Amour to Yankee Point, the average overburden thickness, including the till, is approximately 2.5 to 3 m. Two of the borings, A1 and B4, did not however reach the bedrock and encountered either the Glaciomarine marine deposits or tills to full depth. The maximum thickness of these surficial deposits is not known and estimates vary depending upon the source. It does however seem likely that depths will exceed 5m, and perhaps reach 10-12 meters in localized depressions. The maximum drilled depth of bedrock in this investigation was 3.69m with an average depth of 2.5m. The bedrock consisted primarily of limestone and shale, with some sandstone, and is generally described as dense and fresh.

The borings revealed that on the Labrador side of the Strait, the bedrock consists of the Forteau Formation, which is a red to gray limestone and gray shale. In the area of the Newfoundland Trough, the Hawke Bay formation is encountered, which is composed of interbedded microcrystalline limestone, black shale and orthoquartzites. Along the Newfoundland coast the Petit Jardin Formation is found and is generally described as a gray and brown dolostone.

In addition to the seabed borings a number of seismic studies have been conducted in the area with varying degrees of success. What is clear is that there are faults in the area and that rock ledges may exist.

Although it is reasonable to assume that the available geotechnical information is adequate for this phase of the study, future planning and design will require a substantial increase in the amount of available geotechnical data. At present there is on average more than 1.5 km between seabed borings. The variation in terms of strata and profile between borings can therefore be considerable, which makes accurate determinations of the quantities difficult. Further laboratory testing may also be appropriate.

Material Properties and Trench Stability

Geotechnical analyses were performed on the soil retrieved during the 1981 offshore program and a summary table of the thickness, grain size, and geotechnical properties of the surficial map units is included in the 1992 report on Surficial and Bedrock Geology by Woodworth–Lynas et al (Ref. 4). A selection of relevant properties has been reproduced in Table 4.1.

Description	Strength	N Value	Preconsolidation Strength (kPa)
Sand - Shells	Very Loose to loose	0-15	Not applicable
Glaciomarine - Marine	Very soft to loose	2-4	2.6
Glacial Drift	Medium Dense	9-46	
Lodgement Till	Very Dense	29-35	394-1089

Table 4.1: Geotechnical Properties (reproduced from Woodworth-Lynase et al)

The stability of the trench side slopes in the overburden is principally governed by the material properties and the angle of the slope. Other parameters including the thickness of each layer and slope history having a secondary effect. In order to estimate stable slope angles a number of assumptions have had to be made. These would need to be verified by testing and additional investigation at a later stage. As the layer thickness is unknown, the stable slope angle estimates in the table below are based primarily on experience and assessment of the material properties.

Overburden unit	Estimated Slope angle for a stable slope based on an submerged infinite slope analysis
Sand – Shells & Gravel Lag	1 vertical to 2 horizontal
Glacio Marine – Marine	1 vertical to 4 horizontal
Glacial Till	1 vertical to 3 horizontal

Table 4.2: Estimated Stable Slope Angles for the Soil Strata

Rock slopes generally fail along existing geological weaknesses and it is only with very weak rocks or very high cuts that the intact strength of the material becomes significant. It is therefore likely that the side slopes of the trenches are governed by the geometrical relationships between discontinuity planes. Currently little information exists regarding the state of the bedrock near the seabed surface, so it has also been assumed that there is negligible weathering. If future investigation shows that significant weathering has occurred the side slopes may need to be assessed as per a soil.

The geological information that has been reviewed to date suggests that the sedimentary rock strata are nearly flat lying or gently dipping. We have therefore assumed that the slopes will need to be cut so that they will be sufficiently off vertical to prevent loose blocks toppling down. This assumption about the failure mechanism would need to be verified at a latter date, and in particular the influence of vertical fracture spacing examined. The information available to date also suggests that there is no significant difference between the different geological units, and the same slope angles for each have therefore been adopted. This is an area worthy of further study and economies may be possible once more detailed information about each unit is available for analysis.

Bedrock Formation	***Estimated Slope angle for a stable slope***
Forteau Formation – limestone and shale	5 vertical to 1 horizontal
Hawke Bay Formation – white Orthoquartzite	5 vertical to 1 horizontal
Petit Jardin Formation – Grey & Brown dolostone	5 vertical to 1 horizontal

Table 4.3: Estimated Stable Slope Angles for the Bedrock

5. Fabrication Sites

Significant research was undertaken by Husky Energy as part of the White Rose Development project, to identify and characterize offshore fabrication facilities in Eastern Canada. The results of the investigations were published in the White Rose Development Application Volume 1 report, dated January 2001.

The general fabrication requirements defined for the White Rose facility have many similarities to those of the ITT including large drydock facilities, craneage, concrete batching plant, reinforcement bending shops, and deepwater storage areas.

In particular two of the sites identified within the Husky report appear to offer ideal conditions for the fabrication of the tunnel elements. These sites are:

- Cows Head Fabrication and Marystown Shipyard site
- Bull Arm Site

The location of both sites in relation to the project area is indicated in Figure 5.1 below. Approximate towing distances for tunnel elements are also indicated.

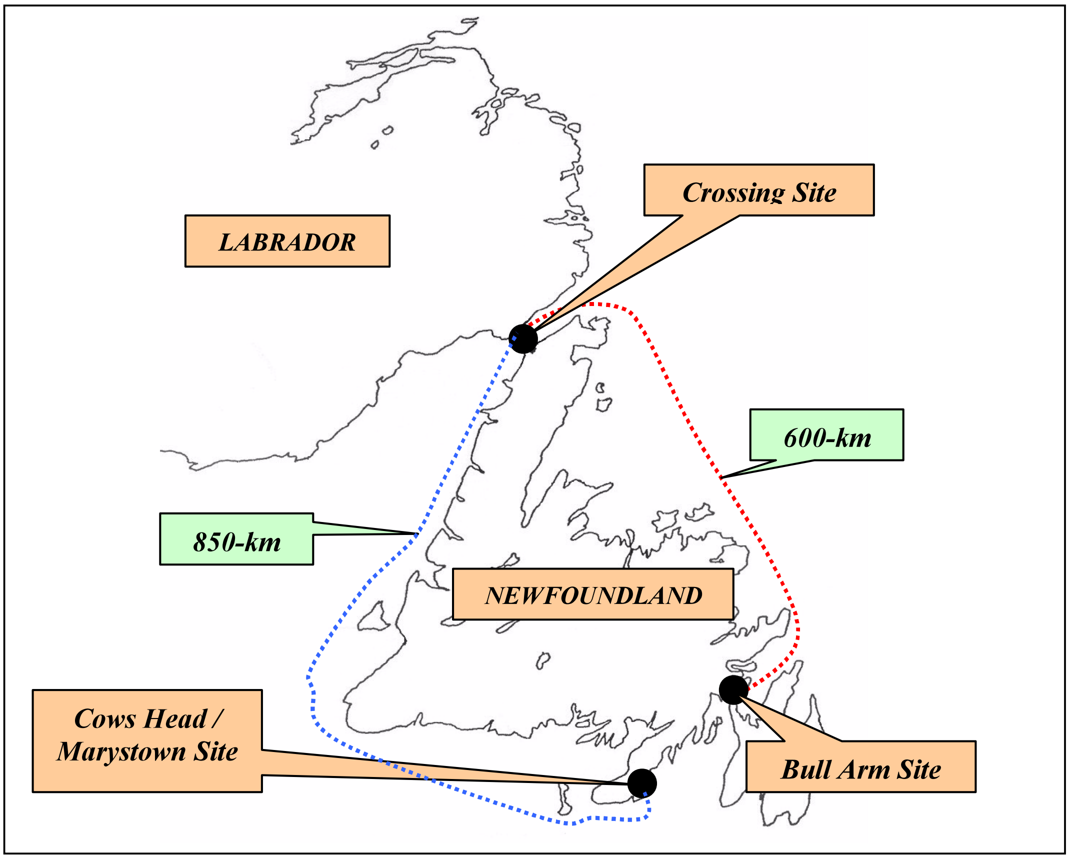

Figure 5.1: Potential Tunnel Element Fabrication Sites

Using an average tow speed of 2 metres per second for a fully weighted unit, and with calm conditions, the journey from the fabrication sites to the tunnel location will be in the order of 4-5 days.

Though potential fabrication sites can be identified as part of any study, ultimately the choice of where the elements are built rests with the successful contractor, who will have priced the lease requirements for a particular fabrication site into his bid. Also, though the identified sites seemingly offer ideal fabrication conditions, circumstances may dictate that they cannot be used for tunnel element fabrication. For instance:

- Depending upon the project schedule, the sites may not be available at the required times
- Given the multi-year construction duration, the fabrication of the tunnel elements for a one-off project may result in the facilities having to turn away long-standing customers, which they may be reluctant to do.
- The successful contractor may determine that the towing distances for the tunnel elements present an unacceptable risk to the project schedule, and may decide instead to construct an ad-hoc facility close to the tunnel location.

The crossing is certainly long enough to warrant the construction of a purpose built casting facility, suited to the project needs and schedule constraints. A similar facility, constructed for the Oresund Tunnel, which forms part of a fixed link between Denmark and Sweden, is indicated in Figure 5.2.

Conversely, in order to generate sufficient element production to meet an agreeable construction duration, the use of multiple fabrication locations may be a necessity.

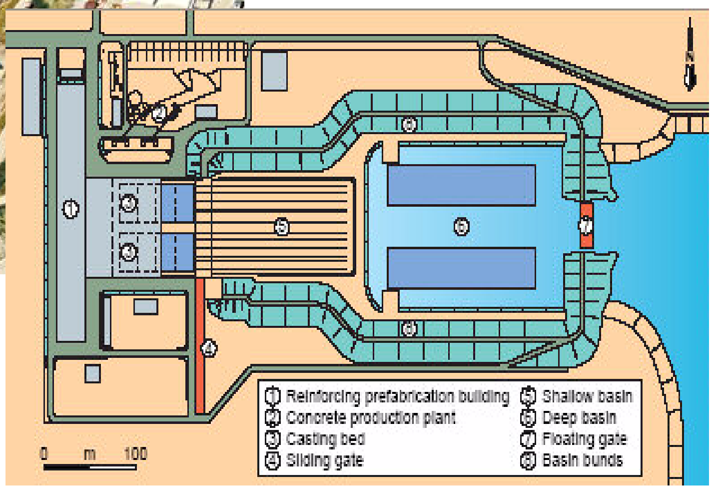

Figure 5.2: Oresund Tunnel Casting Facility

6. Tunnel Construction Methods

6.1 Historical Trends

Since the construction of the very first transportation ITT in 1910 - the Detroit River Tunnel, linking Windsor, Canada with Detroit in the US - two very different, largely geographically based methodologies for the design and construction of subsequent tunnels have developed.

In the US, the use of steel tunnel sections has been prevalent, whereas in Europe and the Far East reinforced concrete tunnel sections are almost exclusively used, and an attitude of 'never the twain shall meet' has existed between the proponents of each technology. The reasons for the development of the separate technologies has not been documented, but can be speculated. After the construction of the Detroit River Tunnel, the US continued to build a number of ITT's in the early 1900's. These were mainly steel tunnels, which could be attributed to the strength of the US steel market and the availability of suitably skilled resources. The first European ITT however, the Maas Tunnel in the Netherlands, was not built until 1941. It can be imagined that in 1941 all steel in Europe was assigned for other purposes, setting a resulting precedent for the use of concrete technology.

Both construction methods have general rule-of-thumb advantages and disadvantages, which are presented in Table 6.1, below.

Reinforced Concrete Sections	***Steel Sections***
Advantages	***Advantages***
Conventional construction methods using readily available materials. *Construction carried out in ideal conditions enabling a high degree of quality control.* *Rectangular tunnel cross-section is tailored to suit the traffic envelope, providing efficiency in design and construction.*	*No elaborate casting facility is necessary.* *Initial steel fabrication accomplished quickly.* *The inner steel shell acts as an impermeable membrane.* *The circular shape of the structural shell components is efficient for carrying loads in ring compression.*
Disadvantages	***Disadvantages***
A purpose built casting facility is typically required. *Concrete is brittle by nature with a tendency to crack due to flexure and thermal strain. Incidence of cracking must be carefully controlled to ensure the structure remains durable.*	*Requirements for minimum negative buoyancy results in much of the steel being an additional cost.* *Much of the keel concrete is placed when the element is afloat, under difficult conditions, resulting in poorer workmanship.* *The circular shape generally does not fit well with rectangular traffic profiles, resulting in additional void space which translates to cost.* *Tunnel element length is limited by flexure induced by concrete placement while afloat.*

Table 6.1: General Comparison of Concrete & Steel ITT's

Other than the Detroit River Tunnel there are two other ITT's in Canada, the George Massey Tunnel, in Vancouver, and the Lafontaine Tunnel in Montreal. Both tunnels utilized concrete element construction. It can again be speculated that the presence of European based design and construction firms on both projects resulted in the selection of concrete technology.

In recent years there have been exceptions to these general rules. Since the construction of the Detroit River Tunnel, twenty-five immersed tube tunnels have been constructed in the US, and twenty-one of these are steel. However, the two most recent US ITT projects have involved concrete element construction for crossings of the Fort Point Channel in Boston. Also, recent studies for potential ITT's in New York and Virginia have also indicated that concrete construction would be the preferred approach.

Conversely, in Japan, relatively recent ITT's have been constructed with external steel membranes, serving a dual purpose as both structural member and waterproofing.

Significant research has since been undertaken in the UK and Japan regarding the viability of a true composite, or steel-concrete-steel (SCS) sandwich ITT option. In the UK, the Steel Construction Institute, in association with Cardiff University in Wales, has produced a number of publications demonstrating that composite construction is appropriate for consideration with ITT projects.

The findings of the British studies have been borne out in Japan, with the construction of the Kobe Kou Minatojima Tunnel, which was completed and opened in 1997. The ITT, linking Kobe with Kobe Port Island, is recognized as being the first in the world to employ full sandwich construction. Based upon the success of this project it appears likely that further ITT's in Japan will also be constructed using SCS methods.

The preceding paragraphs intend to suggest that though historically, location has largely determined the preferred choice of tunnel construction method, more recently more logical choices have been made, based upon reasoned comparison of all feasible construction methods.

6.2 ITT Construction Alternatives

An understanding of the construction process for the ITT is required to enable the reader to appreciate more fully the issues related to the construction of the structure. A description of a ***typical*** process for each of the potential construction methods for the tunnel sections follows.

Reinforced Concrete Tunnel Construction

Reinforced concrete tunnel elements are normally constructed in a purpose built casting facility, constructed on a parcel of land with access to a waterway with sufficient draft to accommodate the tunnel elements. The fabrication site can be adjacent to or remote from the tunnel site with the choice of the actual site being left to the Contractor.

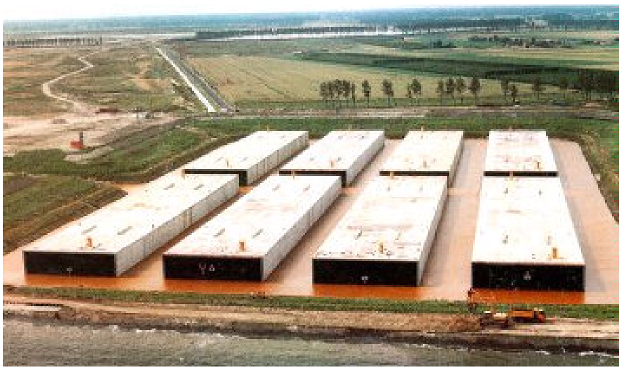

Figure 6.1: ITT Elements in Casting Basin, Liefkenshoekt Tunnel, Belgium

The reinforced concrete ITT elements are typically cast in a number of segments, each in the region of 20-metres in length, to form a unit in the region of 120-metres long, though much larger sections can be achieved where hydrodynamic conditions permit. Segments are normally cast in a predetermined sequence to minimize the effects of shrinkage and thermal cracking. Element construction begins with base slab pours followed by construction of the tunnel internal walls. Finally the external walls and roof slab for each segment are poured together in a single pour, again in an effort to reduce the incidence of shrinkage and thermal cracking.

Figure 6.2: Tunnel Construction & Channel Dredging, Medway Tunnel, UK

Steel frames are cast into either end of the tunnel unit. These frames are installed to close tolerances, and are used to locate the tunnel immersion joint seals, the Gina and Omega gaskets. Normally an additional construction joint is provided close to the ends of the elements to facilitate positioning of the end frames.

On completion of the tunnel concrete, the elements will be outfitted for flotation. Large ballast tanks will be constructed within the elements, typically of steel/timber construction with a membrane liner. The ends of the elements will be sealed with steel or concrete bulkheads. The primary immersion joint seal, the Gina gasket, will be fitted to the leading end of the unit and waterproofing will be applied as necessary.

When ready, the dock or casting basin will be flooded. At this time the tunnel ballast tanks shall be full of water to prevent the tunnel elements from rising to the surface and damaging each other. While held on the basin floor the tunnel elements will be inspected. Any noticeable leaks or damp patches will be repaired by the Contractor prior to transport.

Figure 6.3: Element prior to Immersion, Western Harbor Crossing, Hong Kong

The tunnel elements will be brought to the surface in a controlled manner by removing water ballast. The amount of water in each ballast tank will be trimmed to ensure the tunnel floats with a desired, constant freeboard of around 300 mm, though this dimension will ultimately be selected to suit the length of tow and significant wave heights.

The elements will be towed from the basin and transported to an outfitting area adjacent to the tunnel site where pontoons, access shafts, bollards and miscellaneous other fittings required for the immersion process will be positioned on the tunnel roof. Once outfitted, the tunnel elements will be towed to their final location, which will be accurately assessed by surveys from several locations, and lowered from the pontoons into the pre-dredged trench by opening valves in the end bulkheads and allowing the ballast tanks to fill with water.

Pin jacks will be lowered from the bottom of the unit to provide temporary support in the trench before a pumped sand foundation is placed to fill the void between the bottom of the trench and the base of the unit. The sand can be pumped from a barge through a series of pipes cast into the walls of the tunnel to provide a series of overlapping sand 'pancakes' which provide a continuous foundation.

Remaining elements will be sequentially brought from the casting basin, outfitted, and lowered into position. Close tolerances can be achieved on unit position through survey and couplings between alignment brackets on adjacent elements.

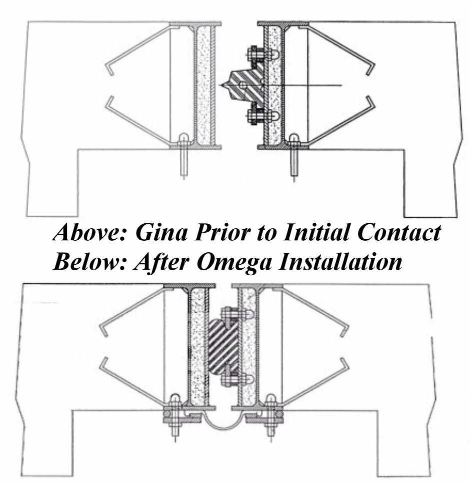

Figure 6.4: Tunnel Immersion Joint

As mentioned, tunnel joints comprise a pair of rubber gaskets, the Gina and Omega seals. The Gina seal is attached to the tunnel unit prior to immersion. As the unit being lowered approaches a previously placed unit, alignment brackets ensure the elements contact at the correct location. The two elements are pulled together, compressing the soft nose of the Gina gasket to form an initial water seal. The space between the bulkheads of the two elements is then dewatered via valves in one of the bulkheads. This creates an air gap causing an out of balance hydrostatic force at the opposite end of the placed unit which causes significant compression of the Gina seal thus creating a watertight joint. The remaining tunnel elements are jointed in a similar fashion.

Backfilling of the dredged trench proceeds sequentially with the tunnel unit placement. The sides of the tunnel are backfilled with granular material and regular fill to the top of the tunnel. A rock protection layer is placed over the tunnel elements to protect the structure from impacts from grounding vessels and dragging or dropping anchors. During backfilling some settlement of the tunnel elements may be expected, but such settlements will be minimal, and can be estimated and accommodated within the design process. During backfilling, water ballast within the tunnel elements is replaced by permanent concrete ballast in the form of roadway or track slab, and refuge walkway. The ballast transfer process must be carefully staged to maintain minimum factors of safety against flotation at all times.

Figure 6.5: Completed ITT, River Lee Tunnel, Ireland

Typically an underwater closure joint is required to complete the tunnel. The final tunnel unit to be placed will be constructed approximately 1.5-2 metres shorter than the other tunnel elements, ensuring that the unit can be deposited in the dredged trench without difficulty. Divers will then place struts in the gap between the two elements around the perimeter of the tunnel, and place gasketed steel dam plates around the external perimeter of the tunnel, closing off the gap. The water inside the gap can be pumped out into a ballast tank. Reinforcement can be connected to couplers left in the face of the tunnel elements, and the joint concreted in stages, to allow the struts to be removed.

After initial elastic settlements are complete, the secondary expansion joint seal, the Omega, is fitted. The seal is clamped across the expansion joint and tested to a significantly higher pressure than required by design.

Once the primary structural elements are complete, the various M&E components, finishes, etc. can be installed.

Steel Shell Tunnel Construction

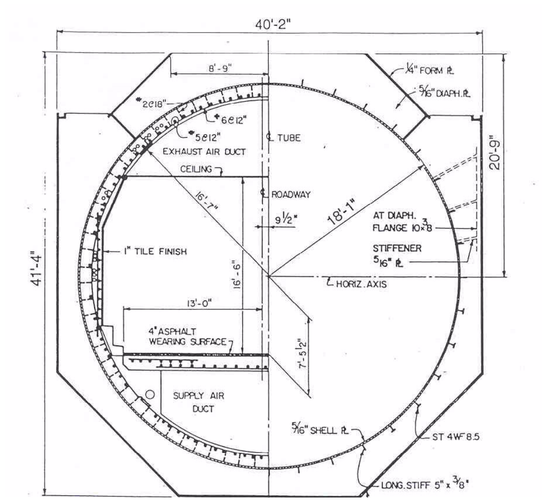

Figure6.6: Steel Shell Tunnel Cross-Section

The steel shell tunnel would likely be similar to that indicated in Figure 6.6, which was used for the Second Hampton Roads Tunnel in Virginia. Variations on the pictured cross-section, such as with a flat invert to give a horseshoe shaped section, would also be fully investigated in future stages of the project.

Fabrication of steel elements customarily takes place within an existing shipyard, dry dock facility, or a steel fabrication plant with slipway access to a waterway. If necessary, elements can also be constructed in purpose built areas adjacent to the tunnel site with waterway access, if land is available.

Once a site is identified and construction is underway, the structural steel shell plate, form plate, intermediate diaphragms and stiffeners are fabricated in convenient subassemblies and fitted together on slipways to exacting tolerances. Reinforcement for the shell plate liner concrete is normally fixed at this time. Steel bulkheads are then fitted at both ends of the elements.

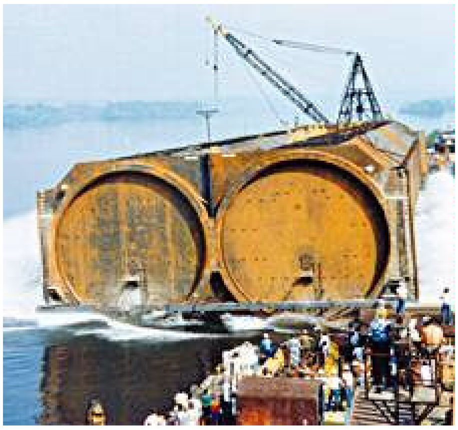

Figure 6.7: Launching Steel Element, Fort McHenry Tunnel, Baltimore, MD

Prior to launching, the shell plate and bulkhead welds are tested for watertightness by coating the outside of the plate with a soap solution and jetting compressed air against the inside of the shell. Any required weld repairs are made as necessary. External keel concrete is placed to give the tunnel unit additional stability when afloat.

The tunnel elements can be launched sideways or endways into the waterway. The elements are more suited for a sideways launch during which they are supported by launching sleds on a series of parallel ways located under intermediate diaphragm positions. The elements are held in place until launching by a number of triggers, which are released simultaneously. Jacks can also be provided to start the tube, if necessary. Chains or similar restraining methods control the launch speed of the tunnel unit and control the distance the tube runs into the waterway. End launching of the tunnel elements is carried out in a similar manner, but again can induce significant bending of the tunnel section when the unit is part in the water and part on the slipway.

Once afloat the elements are transported to an outfitting pier adjacent the tunnel site in preparation for placement in a pre-dredged trench. The remaining concrete for the steel shell plate liner, external cap concrete and ballast between form and shell plates is placed in a carefully staged sequence to control longitudinal bending and floating stability of the tunnel unit. Pontoons, access shafts, bollards and miscellaneous other fittings will also be positioned on the tunnel roof. Dredging and tunnel foundation placement will proceed concurrently with the fitting out of the elements.

Figure 6.8: Transport of Steel Element, Ted Williams Tunnel, Boston, MA

After fitting out, the tunnel unit will be negatively buoyant and will be supported by the pontoons. The tunnel elements will then be towed the short distance to the dredged trench and lowered to their final position on a pre-placed, screeded gravel foundation. The foundation is placed to close tolerances, typically in the region of ± 25 millimetres. The steel shell is sufficiently ductile to allow the elements to overcome any local variations in the gravel placement. Remaining elements will be sequentially brought from the fabrication yard to the outfitting pier and lowered into position. Alignment brackets on the ends of adjacent elements allow sequential placement to strict tolerances.

The tunnel elements can either be jointed using a gasketed connection similar to that described for the concrete option, or by forming a rigid tremie concrete joint between steel plates connected to the ends of interfacing elements. A closure joint will be formed, in a manner similar to that described for the concrete option.

Backfilling and placement of the rock fill protection layer shall proceed sequentially with tunnel unit placement, also as previously described for the concrete option.

Finally, internal work can be completed comprising liner concrete, roadway or track slab and refuge walkways, and installation of M&E systems and finishes.

Composite (SCS) Tunnel Construction

The SCS tunnel elements can be fabricated in a manner similar to that described for either the reinforced concrete or steel shell tunnels depending upon the availability and suitability of any existing casting facilities. The SCS tunnel appears to offer principal advantages of both the concrete and steel alternatives. The tunnel cross section can assume the rectangular profile offered by the concrete option and can thus be tailored to suit a specific traffic envelope, and the external plate offers the watertightness of the steel option. The tunnel elements comprise of internal and

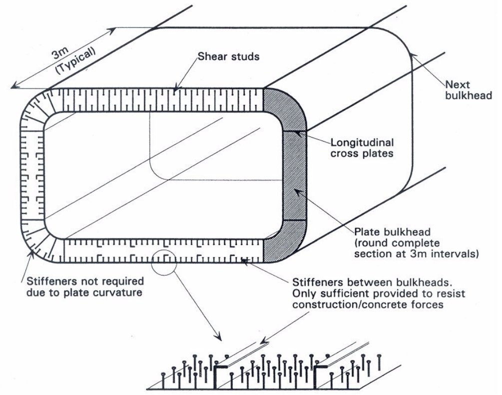

Figure 6.9: Composite Tunnel Components

external steel plates, sandwiched by a layer of highly fluid concrete, which is required to ensure all potential voids between plates at stiffener locations etc. are completely filled. The internal and external plates are welded together to form continuous shells, supported at regular intervals by internal diaphragms and stiffeners.

The construction process for the tunnels can be as described for either the reinforced concrete or steel shell tunnels.

6.3 Dredged Trench Construction

Section 4 of this report describes the expected surficial and bedrock geology in some detail. However, in terms of the methods necessary to construct the trench only two classifications of material exist, namely overburden and bedrock.

At this stage it is believed that all overburden materials could be removed using either clamshell or hydraulic equipment without the need for pretreatment. However, the upper limit for a cutter suction dredger at depth is approximately 5,000 psi, which is well below the current strength estimates for the bedrock. Consequently blasting or some other method will be necessary to break up the limestone and sandstone layers along the majority of the route. The possible exceptions being small areas in the vicinity of the faults which may be breciated and fractured. Once the bedrock has been broken up, the trench profile can be cleared using a clamshell grab or possibly a suction dredger depending upon typical blast rock size.

A description of current technologies for dredging, underwater blasting, and submersible equipment is provided. It is foreseeable that a combination of all the technologies presented will be required for the excavation of the trench.

Current Dredging Technologies

Figure 6.10: Vasco da Gama in operation

Until very recently little or no suction dredging was done in water greater than 50 metres deep. Below this depth the suction tube becomes too long for the pumps inside the hull of the dredger to maintain a proper vacuum. However, in the last few years dredging operators have been developing equipment and in particular submerged booster pumps, to enable them to dredge at much greater depths, primarily to obtain sand in areas where no viable shallow deposits exist. The result of this technological advance is that large, modern hopper dredgers such as Vasco da Gama owned by Jan de Nul have dredged in water depths of around 135 metres, with capacity to go to 160 metres. There are very few vessels capable of suction dredging at these depths, although more are likely to exist in the future. As the water depth decreases more and more vessels are able to operate and there are, in comparison, many that are capable of suction dredging at depths of up to 80 metres.

Normal clamshell grabs are typically limited to around 40 metre depths, with some of the larger equipment can reach 50 metres. As an alternative, at least two remotely operated vessel (ROV) steered clamshell grabs (10 and 16 m^3 respectively) has been developed in the last few years which can operate at water depths of up to 1,000 metres, with tolerances of only a few centimeters. These ROV's were used successfully in 2003 in water depths of around 125 metres from the Seahorse, owned by Boskalis, which in conjunction with Vasco da Gama created three 9m deep glory holes for the White Rose Project and Husky Energy, 350 km East of Newfoundland.

It is anticipated that either hydraulic or clamshell dredging, or a combination of both will be employed in 'shallower waters in depths up to 50 metres. In the deep water sections, large dredge equipment such as Vasco de Gama or similar will be required.

Current Blasting Technologies

Seabed blasting is normally carried out from jack-up barges. The legs or spuds of the barge rest on the seabed, providing stability and greatly simplifying the drilling, charging and firing of the holes. With current limitations on below water spud length of between 40 and 50 metres, this construction method may be practical for part of the crossing length, but is not possible within the deeper reaches of the Labrador and Newfoundland Troughs.

Based upon current technology, the drilling for the deeper areas will have to be conducted from floating vessels, which would be either anchored, or constantly manoeuvring to maintain position. By using offshore industry techniques and equipment, the necessary holes could be drilled, charged, and fired from the surface. However, this operation is likely to be slow and difficult. Although blasting in 100 metres or more of water is achievable, it is not common, and some of the technology is not well proven. Some development work is likely to be needed in terms of techniques and equipment. For example, it may be possible to use a ROV for some of the latter stages to improve production rates.

Again, in the defined 'shallower ' water, trench excavation will completed by either hydraulic methods or through the use of clamshell in conjunction with underwater blasting. For the latter scenario, jack-up barges would be used to facilitate the blasting process. For deeper waters the use of floating vessels will be necessary for blasting purposes.

Current Submersible Equipment Technologies

An alternative to blasting is the use of seabed-based equipment. In the last 10 years a number of tracked, land-based construction machines have been modified and developed to operate at depths of up 1,000 metres. The equipment can be fitted with a variety of tools including hydraulic crushers and breakers, rotating excavating tools, or standard buckets. Given the scale of this project, widespread use of this technology is probably uneconomic, though it may prove useful for localized excavation and trimming.

Submersible cutters have been developed for specific projects such as the Cross Channel Interlink and one could be developed for this project. The principle involves the creation of an ROV with some kind of rotating cutter. The ROV is then "driven" along the alignment, excavating the trench. The equipment is expensive to develop, but given the length of the crossing, it may prove economical.

The use of submersible equipment has not been considered in the development of the preliminary construction and cost estimates, though the technology will warrant further investigation as the project develops.

Dredge Production & Duration

The presence of winter sea ice will have a significant effect on the dredging operation. It is currently predicted that dredging will not be possible between January and May, which means that the effective work year will consist of approximately 7 months or 213 days. Therefore, the dredging schedule will have to extend over a number of years.

Although trailing suction dredging is likely to be capable of higher production rates in ideal circumstances, clamshell grabs are considered to be more versatile and are capable of dealing with a wider range of materials and conditions. In order to estimate the expected dredge duration it has been assumed that drag and drop dredging will be used. In this method, material is picked up, moved sideways underwater and dropped adjacent to the trench using a clamshell. Based on the available duration and typical deepwater cycle times it has been estimated that the dredging will take 7 vessel years for the rail tunnel and 9 vessel years for the road tunnel. It has been assumed that any necessary preparatory work such as blasting is carried out in parallel to the dredging and has little effect upon the overall durations.

Due to the length of the crossing, it is reasonable to assume that multiple dredges can be operating simultaneously without impacting each other. However, initial enquiries have suggested that there are currently no vessels on the Eastern Seaboard with sufficient depth range to dredge the deeper sections of the alignment although there are suitable vessels for the shallower sections. Specialist deep dredging vessels, such as the Vasco de Gama, will need to be mobilized from around the world. Although this does not present any insurmountable difficulties, as all the appropriate vessels are capable of open ocean journeys, we understand certain safety inspections will need to be carried out, before operations can start in Canadian Waters. Some risk will also exist as to the availability of the dredger at the required times, as vessels may be gainfully employed elsewhere. Importing such vessels will also induce large mobilization fees.

Observations within the Strait (Ref. 4) suggests that bottom currents frequently move sediment. Visual examination from a submersible along a test plough route approximately 1 year after plowing showed that at a depth of 90 metres, the trench had filled with shell hash, consisting of loosely packed fragments 1 to 2 cm in diameter. This suggests that during the interval between dredging and placing of the ITT elements, and certainly in the winter period where marine operations are suspended, any open excavation will have a tendency to accumulate shell hash or other sediments. Redredging of the trench will therefore be required prior to placing the elements. At this stage it is difficult to estimate the quantities of redredging that may be required and this should be the subject of a future study. For cost estimating purposes an allowance equivalent to 15 % of the original total excavation has been assumed. Removal of the material by hydraulic methods can be accomplished rapidly.

The scale and nature of this project are unique, and will necessitate the use of cutting edge techniques, perhaps developed specifically for this project and its environmental conditions.

Consequently, estimating the cost of constructing the trench is difficult and a significant contingency sum is included. Details of the cost estimate are included in Appendix A.

6.4 Site Constraints

For the Strait of Belle Isle Crossing, many of the general advantages and disadvantages of each ITT construction technology apply. These must be considered in conjunction with the many critical, site-specific issues which exist for the tunnel, in making an impartial assessment of the preferred tunnel construction methods.

Significant factors in determining the feasibility and preferred construction methods for the ITT include:

- Crossing length
- Water depth
- Geology
- Hydrodynamic conditions
- Meteorological factors
- Environmental factors

The implications of each of these issues for the construction of the ITT follow.

Crossing Length

The primary implication of the length of the crossing, at approximately 18-km is upon construction schedule. A method of fabrication which allow rapid production and placement of the tunnel elements is fundamental to the viability of the crossing.

As indicated in Table 1, currently the longest ITT constructed to date is the BART Transbay Tubes, which measure 5,825 m. The construction of the BART tubes began in 1967, and was completed in 1969. Construction of the basic tubes lasted two and a half years. To accommodate the schedule the 58 tunnel sections, each measuring 111-metres in length, were placed at a rate of approximately two per month.

This production rate, though exceptional in terms of ITT construction, will be inadequate for the crossing. Using a similar dimension for the length of the elements as the BART tube, approximately 162 elements would be required to complete the crossing. Placed at a rate of 2 per month, 81 months, or 6-3/4 years would be needed for basic tunnel placement – based upon year round production. As marine operations at the crossing site are not possible between January and the end of May each year due to pack ice, elements constructed in this period would be stored until operations could resume. The rate of placement of the elements would have to be increased to 4 per month to compensate.

For the Oresund tunnel linking Denmark and Sweden, elements were constructed at the rate of 2 every 2 months, using the facility shown in Figure 5.2. As the proposed elements for the Strait of Belle Isle crossing will be significantly smaller that those used for the Oresund Tunnel, increasing production to the rate of approximately 2 elements per month should be achievable.

Therefore, the preliminary construction schedule is based upon the assumption that 25 tunnel elements can be fabricated in one year and placed within one marine season between June and December.

Methods of minimizing the overall duration of the project would be investigated in further project phases. These would include:

- Maximizing the length of the tunnel elements, to minimize the number of elements and placement operations
- Dredging at multiple locations simultaneously
- Fabricating and placing the tunnel sections at several locations simultaneously
- Minimizing the project design process through the use of design/build procurement

Water Depth

The depth of the water poses the most significant challenges for the design, construction – in terms of constructability, cost and schedule, and long-term durability of the tunnel elements. As mentioned previously, the deepest ITT under consideration to date is the Bosphorus Crossing in Turkey, with a water depth of 56m. The Strait of Belle Isle Crossing would represent a quantum leap in many of the technologies typically employed for ITT construction. Specific project impacts related to the depth of the water include:

- Dredging feasibility, means and methods
- Tunnel element placement
- Tunnel foundation placement
- Tunnel structure design
- Tunnel joint design
- Tunnel durability

The implications of water depth on the design components and construction operations are expanded below, with the exception of dredging means and methods, which are discussed more fully in Section 6.3. It is believed that though the water depth raises many issues related to the tunnel construction, these can be addressed through use of, or extrapolation of existing technologies, in the belief that these technologies will be more readily defined and available by the time tunnel construction commences.

Tunnel Element Placement

The placement of tunnel elements is a carefully controlled process conducted to tight tolerances to ensure elements are set on the correct alignment, and at the correct level. The placement process is controlled from a console located on top of the element, using digital GPS systems.

The process is a careful one, but is typically conducted as quickly as practically possible to avoid conflicts with shipping, speedier currents, and the chance for inclement weather. The water depth complicates many of these issues . The placement process in the Labrador and Newfoundland Troughs will be lengthy. Maintaining the position of the element as it is lowered into deeper water will be challenging.

Perhaps the most onerous depth induced consideration relates to the use of divers to assist with the placement process. It is likely due to the variation in depth of the crossing, that a number of diving methods can be used. However, for the deeper sections, in excess of 50 metres, the divers will be using a mixture of gases – hydrogen, oxygen and helium which will limit the time they can stay with the element during placement. Decompression chambers will be necessary, and decompression times will be significant, all of which will have adverse cost impacts for the placement operation.

Tunnel Foundation Placement

As with the placement of the tunnel elements, tunnel foundation placement is also required to tight tolerances. The two types of tunnel foundation most commonly used are screeded gravel and pumped sand. The difference between the two, other than material, is that the gravel foundation is prepared prior to tunnel immersion, and the sand foundation is placed after the unit is positioned in the trench.

The gravel foundation is typically placed from a barge, and screeded to line and level using a gantry mounted steel rail. To prepare the foundation to the correct profile it is necessary to stabilize the gantry, through the use of jack-up legs. Large jack-up barges have leg lengths up to 46 metres, some distance short of the required length for the trough sections of the crossing. Though drilling rigs can operate in over 100 metres of water, it is unlikely that they could easily be reconfigured to undertake the foundation preparation. Therefore, it seems likelier that the tunnel foundation would comprise a layer of pumped sand. This will necessitate further use of divers to couple the sand pipe to conduit cast into the tunnel walls or sides.

Tunnel Structure Design

Most underground structures are sized to accommodate imposed loads, and checked to ensure they satisfy project specific requirements against uplift from groundwater. With ITT's the reverse is true. The elements are sized to accommodate the required factors of safety for buoyancy while afloat and when placed. Thereafter strength and serviceability requirements are satisfied. Therefore the dimensions of the tunnel will be the same whether it is submerged in 10 or 100 metres of water. The implications for the structural design of the deeper tunnel sections for the Strait of Belle Isle can be imagined.

However, the proposed tunnels have relatively small spans, and at-depth the water pressures will induce significant axial forces in the structural members which will behave as columns in flexure rather than beams in flexure, helping to keep reinforcement quantities manageable.

The use of a binocular steel tunnel section would enable these high loads to be carried more efficiently in ring compression, but the oversized nature of the elements raises separate, and potentially more critical issues regarding dredge quantities and duration.

The implications of the deeper water for the structure are that reinforcement quantities required – whether steel plate for a steel or SCS tunnel, or high yield bar for a concrete tunnel and hence construction cost will be significantly greater than for a shallower tunnel.

Tunnel Joint Design

ITT's are most commonly jointed using a combination of rubber gaskets, known as the Gina and Omega seals. The construction of the joints is described in Section 6.2. The design and performance of both joints is a function of water depth, but the capacities of existing pre-moulded sections are limited. Calculations will determine whether existing sections can be utilized, based upon initial hydrostatic compressions, plus subsequent movement tolerances for creep, thermal effects and seismic events. It is conceivable that new, larger seals would have to be developed and fabricated specifically for the crossing.

Tunnel Durability

The tunnel will have a service design life of at least 100 years. In reality it will be in service for much longer. At depths of up to and greater than 100 metres, the tunnel structure will be subject to significant hydrostatic pressures. It is likely that the majority of the maintenance issues related to the upkeep of the tunnel will result from water ingress, and its subsequent deterioration of tunnel structure and systems.

It would therefore be prudent to take all necessary steps to prevent water ingress through careful design and detailing of the tunnel structure, even though the proposed concept may cost more initially to construct. The tunnel owner will ultimately realize substantial benefits in the longer term through reduced maintenance.

Geology

ITT's are normally located in waterways such as rivers, harbors, and estuaries, where soft alluvial settlements predominate, and dredging of material is relatively uncomplicated. However, tunnels have been successfully constructed in rock. Dredging for the Oresund Tunnel linking Denmark and Sweden largely involved the removal of limestone. While the surficial rock anticipated for the Strait of Belle Isle does offer some benefits to the ITT construction and durability such as those listed below, overall, in combination with the water depth, the extraction of the rock for the trench will be a laborious process.

- steep side slopes for the trench can be accomplished
- Tunnel bearing pressures can be easily accommodated
- Long term settlements of the tunnel elements will be negligible

Hydrodynamic Conditions

The local conditions in the Strait, related to current, significant wave height and water density can potentially be problematic to the transport and placement of the tunnel elements, and can limit the types of dredging which can be successfully undertaken.

Current

Currently conflicting information exists on current speed. The HVDC Transmission Tunnel Study undertaken in 1980 (Ref. 5) suggests a maximum current of less than 3.5 knots, or 1.8 m/s.

This conflicts with Bedford Institute of Oceanography (BIO) testing results conducted near the tunnel alignment and also undertaken in 1980, which suggested that the maximum current when all components are combined (during spring tides) are as follows:

- 15m depth 3.6m/s (7.2 kn)
- 50m depth 2.5m/s (5.0 kn)

Though tunnel elements have been placed successfully in currents approaching 3 m/s, ideal placement operations for an ITT will exist where currents of 1m/s or less prevail.

As the BIO figures are maximums measured during spring, it is more likely that normal maximum currents will be as indicated in the HVDC Transmission Tunnel Study.

As the current of 1.8 m/s is again a maximum figure, it is likely that for significant periods the actual current in the Strait will be much less. Tunnel placement operations must be staged to try and avoid speedier currents, which as stated previously may complicate operations for the deeper elements.

However, though it appears that based upon the velocities indicated, tunnel placement is feasible, a more complete understanding of the current regime will be necessary during design development to assess current induced forces on the elements. If currents remain as high as indicated above for significant periods, then the achievable length of the ITT elements will be reduced.

Wave Height

In exposed offshore areas, swell and waves can have a number of effects on the transport and immersion of the tunnel elements, which can be considerable in magnitude. These include:

- Waves will cause significant longitudinal bending moments which must be accommodated in the design of the tunnel reinforcement
- Wave action can induce motions of the tunnel element with significant amplitude, if the wave excitation frequency and natural frequency of the floating tunnel are similar.
- Waves overtopping a tunnel element with small freeboard can induce a longitudinal pitch of the element, which can cause rapid loss of stability, resulting in the unit being pulled underwater.

Based upon information collected to date, and the results of a wave hindcast analysis it is estimated that during the period June through August, waves with heights of 1m or greater would occur 40 per cent of the time. Furthermore, waves with heights of 2 m or more would occur less than 2.5 per cent of the time, and the maximum significant wave height would approach 3 metres.

To ensure that the ITT elements can be safely transported and placed in such conditions, extensive hydraulic modeling would be recommended.

Water Density

Water density can greatly effect the placement of ITT elements in tidal waterways where fresh and salt-water mix, or where sediment has remained in suspension from the dredging process creating a more dense water layer. Neither of these conditions should exist for this crossing, where a relatively constant density is anticipated.

Meteorological Factors

Pressure, wind, rain, temperature and visibility will all have an effect upon the transport and placement of the tunnel elements. However, the most significant meteorological factor related to the ITT design and construction is ice.

The extent and duration of pack-ice coverage at the site is approximately known. The icing over of the Strait will typically result in the suspension of all marine activities for the period between January and May. The implications of the pack-ice on the construction schedule are documented elsewhere in the report.

The passage of icebergs through the site will also be of great concern. The random nature of the iceberg frequency and location will be of concern for tunnel transport and placement operations. An early warning system will be necessary to ensure there is no risk of impact to a tunnel element during the placement process. The in-place tunnel structure will be located at a depth sufficient to avoid the effects of iceberg scour over the design life of the structure.

Environmental Factors

The Strait of Belle Isle is a well recognized migration route for many species of whales and other marine mammals. Whales including humpback, fin, pothead, and minke are frequently sighted in the Strait of Belle Isle during summer and early fall. Killer whales are occasionally spotted. Porpoises and dolphins are also common.

The migration of these species will occur concurrently with the dredging process, which is largely anticipated to be carried out using underwater blasting. To satisfy environmentalists blasting may have to be suspended when whales are sighted in the close vicinity of the tunnel alignment. The effects of this random event upon the tunnel construction schedule may be significant.

6.5 Preferred Construction Methods

It would be unwise at this early stage to rule out, or conclusively propose one single method of construction for the ITT's without undertaking a more rigorous study involving preliminary analysis for each option.

However, having considered the site specific constraints, a brief list of advantages and disadvantages for each construction method has been compiled leading to a preliminary recommendation for a construction method. This method has subsequently been used in the derivation of the preliminary construction cost and construction schedule for the project.

Concrete Tunnel

Advantages	*Disadvantages*
Economic cross-section, tailored to suit traffic envelope, thus minimizing dredging quantities. *Changes in cross section at ventilation zones can be easily accommodated.* *Longest tunnel elements minimizes the number of transport, placement and jointing operations.* *Suitable casting facilities available.* *Appropriate labor available.*	*Concrete is a brittle material by nature with a tendency to crack raising issues of long-term durability of structure and internal systems.* *Long tow over a period of 4-5 days will be required from the identified casting facilities, with higher risk to schedule due to inclement weather.* *Elements will be heavily reinforced to accommodate imposed loads.*

Table 6.2: Advantages and Disadvantages of Concrete Tunnel Construction

Steel Shell Tunnel

Advantages	*Disadvantages*
Tunnel section will carry the significant imposed loads efficiently in hoop compression. *Watertightness achieved through continuous welding of shell plate.* *No special casting facility required. The element fabrication can be conducted on any available land adjacent to a waterway - which could be at the tunnel site.* *Rapid fabrication of steel assemblies gives potential schedule benefits.* *Steel elements can be barge mounted to minimize effects of wave induced bending, and inclement weather, making long tows in open water less risky.*	*Tunnel elements are short due to imposed stresses during concreting operation while afloat, maximizing costly tunnel transport, placement, and jointing operations.* *The circular profile of the steel shell is not well suited to the traffic clearance profile, resulting in inefficient use of space, and hence additional cost.* *The tunnel elements will have the deepest profile, even with a flat invert, resulting in increased dredge quantities versus the other options – with inherent schedule impacts.* *Changes in cross-section of the circular section at ventilation zones cannot be easily accommodate, and would require specialized fabrication.* *Steel prices are currently high, and climbing rapidly. The cost for the steel shell tunnel is likely to be higher than the concrete tunnel, and the estimate provided will be most susceptible to rapid change due to the volatility of steel prices.* *Cathodic protection will be required to maintain long-term durability of structure.*

Table 6.3: Advantages and Disadvantages of Steel Shell Tunnel Construction

Composite (SCS) Tunnel

Advantages	*Disadvantages*
Economic cross-section, tailored to suit traffic envelope, thus minimizing dredging quantities. *Changes in cross section at ventilation zones can be easily accommodated.* *Watertightness achieved through continuous welding of shell plate.* *No special casting facility required. The element fabrication can be conducted on any available land adjacent to a waterway - which could be at the tunnel site.* *Rapid fabrication of steel assemblies, in conjunction with pouring of highly fluid concrete gives potential schedule benefits.*	*Structure behaves in bending/shear unlike the circular steel shell tunnel, which carries loads in compression. Steel plate thickness required to accommodate impose loads may be prohibitively thick.* *Steel prices are currently high, and climbing rapidly. The cost for the steel shell tunnel is likely to be higher than the concrete tunnel, and the estimate provided will be most susceptible to rapid change due to the volatility of steel prices.* *Cathodic protection will be required to maintain long-term durability of structure.*

Steel elements can be barge mounted to minimize effects of wave induced bending, and inclement weather, making long tows in open water less risky.	*Fireproofing of the internal steel plate will be necessary to maintain structural integrity during an incident.*

Table 6.4: Advantages and Disadvantages of Composite (SCS) Tunnel Construction

Conclusion

On the basis of the preliminary assessment undertaken, it would appear that either the concrete or SCS options present the most realistic solutions for an ITT crossing for either the road or rail tunnel. However, based upon the prevailing local labor conditions, it is the concrete option which offers the preferred solution. Given the volatility in current steel prices, the concrete option can be estimated most accurately for the level of study undertaken, and the estimate developed will be valid for longer.

The one major drawback of the concrete tunnel - its tendency to crack – does raise serious durability concerns, given the depth at which the tunnel shall ultimately be placed. To overcome such concerns, it is recommended that a continuous steel plate of nominal thickness only, 6 mm, is used as a waterproofing membrane for the tunnel. The plate will be welded watertight at joints. The additional construction outlay for the plate and welding, will be more than offset by the design life of the tunnel, and the savings on maintenance costs achieved.

7. Tunnel Systems Requirements

The tunnels must accommodate a number of mechanical, electrical, and security systems to maintain serviceability during operating conditions, and to maintain a tenable environment in the event of an incident. Items to be incorporated into the tunnel will include the following:

Mechanical

- Ventilation, including HVAC for egress corridor
- Drainage. The profile of the ITT follows the bed of the Straits, requiring multiple low point sumps.
- Sump pumps

Electrical

- Lighting, including lighting for egress corridor
- Heat
- Normal and emergency power supply and distribution
- SCADA

Fire and Life Safety/Security

- Standpipes
- Extinguishing systems
- Emergency telephone
- Heat and smoke detectors
- Emergency walkways
- CCTV

Corrosion Protection

- Cathodic protection, using sacrificial anodes or impressed current for SCS and steel options only. For the concrete tunnel the steel plate will be sacrificial.

Other

The tunnel may accommodate HVDC power lines. These lines and their potential locations have been indicated upon the preliminary tunnel cross-sections. Additional space will also exist which could potentially carry additional utilities and conduit within the available void space.

Rail Systems

Specific to the rail operation, multiple additional systems will be necessary. These will include:

- Track
- Traction power
- Signaling
- Communications

8. Costs

Preliminary construction cost estimates for both road and rail alternatives have been developed, based upon the preferred concrete construction methodology identified in Section 6.4, and indicated upon the accompanying drawings. The cost estimate is based upon information gleaned from several sources including on-line databases, historical project information, and from discrete enquiries made to vendors and equipment owners.

8.1 Construction

The Strait of Belle Isle crossing will be a unique endeavour using ITT methods, requiring extrapolation of current construction technologies, particularly in terms of underwater excavation and blasting, which would be undertaken on a largely unprecedented scale. Therefore, while every effort has been made to accurately define a unit rate for dredging, some uncertainty does exist over the price.

Cost Estimate Assumptions

In developing the cost estimate, multiple sources of information have been used including:

- Enquiry to Bull Arm Site Corporation for lease costs for drydock, batching plant, reinforcement shop and the deep-water storage site.
- Extensive use of the Newfoundland Heavy Construction Cost database, available through www.get-a-quote.com for principal quantities including cast-in-place and precast concrete, formwork, reinforcement, structural steel, surfacing etc.
- Use of historic information for tunnel joint prices for Gina and Omega seals, escalated to 2004 prices, with applied contingency for anticipated larger seal requirements.
- Rates for dredging, and backfilling for the tunnel are based upon conversations with multiple dredging contractors.
- Due to pack ice, remobilization costs will be incurred each dredging season and have therefore been included in the cost estimates

Derivation of Quantities

As stated previously, the costs of the ITT have been developed based upon the use of concrete tunnel technology. To derive basic tunnel quantities, in conjunction with the proposed traffic clearance envelopes and stipulated ventilation requirements, minimum factors of safety for the ITT sections while afloat and in-place were assumed, which allowed the development of concrete member sizes. The only figure which has been estimated id that of reinforcement. Concrete ITT's at normal depth will typically have a reinforcement density in the region of 110 kg/m^3. As can be seen from the cost spreadsheets in Appendix A, far higher reinforcement densities have been assumed, to reflect the higher imposed loadings presented by the deeper water.

For the dredged trench, representative sections were developed, with variations in the depth of the overburden or surficial deposits. As mentioned in Section 4, on average the overburden deposits are between 2.5 and 3m thick. The deposits themselves vary from the relatively weak and unstable glaciomarine - marine deposits to the much more stable sands, gravels, and tills. Correspondingly, the weaker soils will be cut back at shallower angles to maintain trench stability.

Sections were developed for each of the tunnel geometry options, providing high-end and low-end dredge quantities by varying the overburden geology and thickness. Side slope angles were in accordance with the recommendations made in section 4.

The two extreme values were averaged to obtain the quantity estimate. At the same time this approach provided an indication of the influence that overburden variations could have on the quantities and hence costs. It is conceivable that within a certain area the cross-sectional area of the trench could be significantly higher or lower than predicted. However until the surficial deposits are investigated further, and their limits more accurately defined, this "averaging" approach is considered the most appropriate.

8.2 Operations & Maintenance

Operations Costs

Primary sources for operations costs will include the following:

- Power consumption for tunnel systems – primarily the tunnel ventilation and pumped drainage system, but also for traction power for the rail option only.
- Salaries for personnel such as a tunnel manager, and tunnel staff employed for monitoring, cleaning, and routine maintenance functions, within the tunnel control buildings.

Power usage can be estimated based upon the proposed equipment. Salaries for employees can also be calculated based upon prevailing wage rates for the Province.

Maintenance Costs

Through the use of the external steel plate, little water ingress into the ITT is anticipated. Little degradation of the tunnel structure will therefore be expected for many years. Sources of structural maintenance will largely be limited to portal and approach areas including the control buildings, which are exposed to the brunt of the prevailing weather conditions. Some deterioration within the tunnel may occur at connections to ventilation ducts from the control buildings. Costs for such maintenance is hard to define.

More regular maintenance and replacement costs will be required for the many tunnel systems, which with design lives of 15-20 years, will undoubtedly be replaced several times over the life of the structure, and based upon current roadway and rail configurations, may require closure of the tunnel for prolonged periods. This loss of tunnel revenue must also be added to the maintenance cost.

9. Construction Schedule

Preliminary construction schedules have been prepared for the road and rail tunnels. The methodology and assumptions made in arriving at the presented schedules, are listed below.

As has been mentioned throughout the report, the major critical path items for the development of a feasible timeline for the ITT construction are:

- Dredging of the trench
- Fabrication of the tunnel elements
- Placement of the tunnel elements

The tunnel placement operation has been used as the basis for deriving the tunnel construction duration. The Strait is accessible in the months of June to December, typically comprising a period of approximately 30 weeks.

It has been assumed that in these months, tunnel elements will be placed approximately at the rate of one per week. However, provision should be made within this schedule for factors such as the required tow length from identified facilities, inclement weather, including prolonged winter, and drifting icebergs. For these reasons we have assumed that 25 elements will be placed per season. This remains a demanding figure.

Other assumptions include:

- Sufficient dredging must be performed each season to accommodate placement of 25 elements. The dredging operation will be continuous, 24 hours per day, 7 days per week. It is also assumed that multiple dredgers will be in operation at any given time.
- Similarly, suitable fabrication facilities can be leased or constructed, and sufficient skilled labor can be identified to accommodate the construction of 25 elements per year. Due to the size of the project, the potential exists for more than one fabrication facility to be engaged. It is assumed that sufficient facilities can be available to meet the recommended production requirement.
- A tunnel element length of 150 metres has been assumed. This is longer than average, but within current technological limits. The longest concrete elements to date, for the Oresund Tunnel, measure 175 metres, and the longest steel plated elements measure 135 metres approximately. The 150-metre length is a usable figure on the basis that further study would be necessary to fully define a preferred construction method.
- It is assumed that Newfoundland will provide the majority of the fabrication facilities, and will be the primary source of labor for the project. Therefore, it is assumed that the construction of the Newfoundland approach could proceed more rapidly, and be available sooner to interface with the ITT. Subsequently, placement of tunnel elements will proceed from the Newfoundland side, enabling internal concrete works to begin from this location.
- Approach construction includes cut and cover tunnel sections including ITT interface, open trough sections, and retaining walls or stabilized rock cuts to grade as necessary.
- Internal fitting-out of the tunnel can continue year-round.
- Internal concreting of the tunnel sections, including emergency corridor, and roadway ballast or track slab, will proceed after placement of several elements.

10. Results of Preliminary Risk Assessment

The history of ITT construction reveals few major incidents or events which have had an effect on the projects themselves or third parties. However, two major incidents which are worthy of attention have occurred in the recent past. These incidents are referenced in Table 9.1 below. The risks involved with both all construction options are similar and can be grouped under the headings of cost, time/schedule, technical matters and the towing and placement process.

Risk	*Description*	*Mitigation*
Cost	*Unforeseen ground conditions, such as higher than anticipated rock elevation, or contaminated deposits are encountered.*	*Risks can be minimized with appropriate level of site investigation and testing of deposit samples.*
Schedule	*Contractor is unable to locate suitable fabrication or casting facility.*	*Client may see fit to make advance arrangements for casting basin site or identify suitable fabrication facilities and charge contractor for the use of the site.*
	Cold winter results in pack-ice coverage beyond May.	*Contingency plan for schedule recovery, including use of additional equipment will be required.*
	Poor weather prevents transport and placement of tunnel elements	*Contingency plan for schedule recovery.*
	Iceberg interference with tunnel element immersion	*Early warning system to indicate presence of approaching icebergs in path of tunnel. Either suspend placement operation for icebergs, or divert growlers and bergy bits.*
	Environmental limitations on dredging timing and duration to protect habitat.	*Obtain advance information on such restrictions and make all parties aware of construction envelopes prior to bidding contract.*
	Fast moving currents depositing sediment on trench bottom.	*Minimizing period for which trench is open before element placement will keep sediment flow to a minimum. Cleaning off trench prior to placement of elements will be necessary.*
	Plant/equipment failure	*For construction activities with a risk of plant failure, back up equipment should be made available to replace defective machinery as necessary.*
Technical Matters	*The tunnel may be subject to a number of extreme conditions over its intended design life. These would include the following:*	*The risks of extreme loads can be minimized through appropriate design, detailing, and vertical alignment selection for the tunnel*

	◆ *Iceberg scour* ◆ *Sunken ship* ◆ *Dragging/falling anchor* ◆ *Extreme high tide* ◆ *Flooded tunnel* ◆ *Explosion* ◆ *Fire* ◆ *Loss of tunnel support due to seismic event.*	*structure.* *Tunnel detailing will be sufficient to remain serviceable for a fire of agreed intensity and duration.* *Tunnel design will investigate conditions where tunnel support has been lost over an agreed length.*
	Interface joint failure between ITT and land approach.	*The interface between the ITT and approach must be recognized as a critical design element. A contractors value-engineering proposal on the Fort Point Channel ITT in Boston resulted in the failure of a closure joint, resulting in inundation of the adjacent excavation, loss of months of schedule with resulting cost impacts totalling millions of dollars.*
Towing and Placement	*Sinking of tunnel element during towing and immersion. This could be a result of the tunnel being overtopped by a series of significant waves, or failure of a bulkhead.*	*Check all projected weather and tidal information prior to towing for a period of calm for the duration of the tow, and maintain such checks during the towing process.* *A bulkhead failure is an extreme event, but happened during construction of the Oresund Tunnel. The element sank, but was recovered. Quality control and adequate supervision during construction is necessary.*
	Catastrophic failure of tunnel element during long tow involving significant wave heights and wave induced bending moments.	*Tunnel shall be designed with sufficient longitudinal strength to accommodate wave induced bending moments. Tunnel route shall be carefully selected to provide safe havens should rough waters be predicted during the towing process.*
	Collapse of dredged trench.	*Determine safe slopes from testing. Minimize duration of open trench prior to tunnel element placement.*

Table 10.1: ITT Preliminary Risk Assessment

Major risks to the safe and successful construction of the project can be identified and quantified during the design process through risk analysis and constructability review procedures leading to the development of strategies to mitigate risk through design or allocation of contingency.

11. References

1. Strait of Belle Isle Navigation Chart, Sheet 14415, Defense Mapping Agency Hydrographic/Topographic Center, 1991.
2. White Rose Development Application Volume 1 Report, Husky Energy, January 2001.
3. Iceberg Scour Risk in the Strait of Belle Isle, C-Core Report R-04-004-011, April 2004.
4. Surficial and Bedrock Geology Beneath the Strait of Belle Isle in the vicinity of a Proposed Power-Cable Crossing, C.M.T. Woodworth-Lynas, J.Y. Guigne, and E.L. King.
5. Strait of Belle Isle Crossing HVDC Transmission Tunnel Scheme, Engineering Report, Cost Estimate & Construction Schedule, Report No. 11.99.05, SNC-Lavalin Newfoundland Ltd., March 1980.

Appendix A
Construction Cost Estimates

Appendix B
Construction Schedule

Hatch Mott MacDonald

Strait of Belle Isle Crossing
Preliminary Immersed Tube Tunnel Cost Estimate - Rail Tunnel

Item	Unit	Quantity	Rate	Total
General Details				
Tunnel Length	18,000	metres		
Tunnel Element Length	150	metres	No. Elements =	120
1 *Tunnel Element Fabrication*				
Miscellaneous				
Mobilisation/demobilisation @ 3% of subtotal structure cost	ls	1	$41,116,424.03	$41,116,424
Fabrication facility lease (2 facilities assumed @ 5.5 yrs each)	year	11	$3,500,000.00	$38,500,000
Concrete				
Structural grade 4,000 psi placed by pump - slab on grade	m^3	165,150	$157.32	$25,981,398
Structural grade 4,000 psi placed by pump - elevated slab	m^3	135,270	$169.62	$22,944,497
Structural grade 4,000 psi placed by pump - walls	m^3	251,100	$175.31	$44,020,341
External Protection Layer, 2,500 psi, placed by pump	m^3	22,410	$153.34	$3,436,349
Keyed control joints transverse (at 20m centres approx)	m^2	32,310	$13.25	$428,108
Keyed control joints longitudinal (2 total at base/wall junction)	m	36,000	$13.25	$477,000
Curing, sprayed membrane, internal surfaces only	m	505,800	$1.32	$667,656
Formwork				
Walls, multiple use forms	m^2	626,400	$78.92	$49,435,488
Elevated Slab, multiple use forms	m^2	113,400	$81.48	$9,239,832
Reinforcement: grade 60 high yield				
Wall & Slab reinforcing, 130 kg/m^3	tonnes	71,698	$1,501.87	$107,680,475
Bending, cutting & splicing	tonnes	71,698	$270.44	$19,389,899
Waterproofing Membrane				
Steel skin plate, A36, 8 mm thick	tonnes	30,436	$3,132.11	$95,328,117
Shear connectors, 150 mm x 12 mm, including stud welding	each	2,592,000	$0.10	$259,200
Automated Welding	m	309,240	$14.86	$4,595,306
Tunnel Joints				
Structural Steel End Frames (2/element)				
Embedded steel beams, 180 kg/m	tonnes	1,542	$2,709.04	$4,177,340
Front plates, 20 mm thick	tonnes	677	$3,132.11	$2,119,812
Gina fabrication, installation	each	120	$18,524.00	$2,222,880
Omega fabrication, installation & testing	each	120	$23,335.00	$2,800,200
Joint concrete, shear keys, cover plates etc.	each	120	$20,000.00	$2,400,000
			Page Total	***$477,220,322***

Strait of Belle Isle Crossing

Preliminary Immersed Tube Tunnel Cost Estimate - Rail Tunnel

Item	Unit	Quantity	Rate	Total
			Total Brought Forward	**$477,220,322**
Temporary Works Items (Per Element)				
Structural Steel Bulkheads (2/element)				
Support Columns, 250 kg/m	tonnes	1,920	$2,709.04	$5,201,357
Skin plate, 12 mm thick	tonnes	1,440	$3,132.11	$4,510,238
Plate siffening angle, 18 kg/m	tonnes	360	$3,174.03	$1,142,651
Embedded perimeter angle, 18 kg/m	tonnes	120	$3,174.03	$380,884
Welding	m	53,880	$14.86	$800,657
Field Welding Premium	m	53,880	$40.06	$2,158,433
Misc. Structural Steel				
Alignment & pulling brackets etc., 5 tonnes per element	tonnes	600	$3,132.11	$1,879,266
Ballast Tanks (2/element)				
Steel support columns, 100 kg/m	tonnes	2,640	$2,709.04	$7,151,866
Timber lagging, 150 mm deep	m^2	42,768	$60.40	$2,583,187
Membrane liner	m^2	42,768	$27.84	$1,190,661
2 Tunnel Transport & Placement				
Element Transport: tug rental etc.	each	120	$500,000.00	$60,000,000
Element placement: barge/pontoons,divers, survey etc.	each	120	$1,000,000.00	$120,000,000
Tunnel Closure				
Underwater joint completion	each	1	$2,500,000.00	$2,500,000
3 Internal Structural & Civil Finish Works				
Ballast				
Track ballast concrete, 2,500 psi, placed by chute	m3	54,000	$140.06	$7,563,240
Track ballast reinforcement: welded wire fabric 6 x 6 x #4, 2.8kg/m^2	m^2	81,000	$9.36	$758,160
Deduct in excess of 4.5 tonnes	tonne	222	-$41.01	-$9,104
Emergency corridor sand/cement mix for HVDC cables	m3	20,250	$140.06	$2,836,215
Precast Divider for Emergency Egress Corridor				
Panel fabrication, 8" thick, incuding reinformcement & lifting points	m^2	103,500	$196.98	$20,387,430
Panel setting, based upon max panel weight of 6 tons.	each	9,000	$285.70	$2,571,300
Seal and caulk panels	m	36,000	$5.48	$197,280
Sprayed fireproofing for precast panels	m^2	103,500	$20.77	$2,149,695
			Page Total	**$723,173,737**

Strait of Belle Isle Crossing
Preliminary Immersed Tube Tunnel Cost Estimate - Rail Tunnel

Item	Unit	Quantity	Rate	Total
			Total Brought Forward	$723,173,737
4 Marine Operation				
Dredging				
Mobilization/Demobilzation per season, 6 seasons, 2 vessels	each	24	$150,000.00	$0
Stage 1 bulk dredging of material	m3	4,028,049	$84.00	$0
Stage 2 fine tolerance dredging & additional trench cleaning	m3	604,207	$43.00	$665,000,000
Foundation and Backfill				
Screeded gravel foundation	m3	157,275	$35.00	$5,504,625
Selected locking fill	m3	377,496	$35.00	$13,212,360
Backfill	m3	550,368	$35.00	$19,262,880
Rock armor protection	m3	470,790	$51.00	$24,010,290
Subtotal Structure Cost				**$1,450,163,892**
Tunnel MEP Systems	ls	10 % of structure cost		$145,016,389
Rail Systems	ls	15 % of structure cost		$217,524,584
Contingency on Tunnel Costs	ls	30% of subtotal structure cost		$435,049,168
"Soft" Costs				
Engineers design & construction supervision fee	ls	10% of construction cost		$224,775,403
Estimated Construction Cost				**$2,472,529,435**
Estimated Construction Cost per linear metre				**$137,363**

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Strait of Belle Isle Crossing

Preliminary Immersed Tube Tunnel Cost Estimate - Road Tunnel

	Item	Unit	Quantity	Rate	Total
	General Details				
	Tunnel Length	18,000	metres		
	Tunnel Element Length	150	metres	No. Elements =	120
	The cross sectionof the tunnel element varies across three ventilation zones.				
	Zone 1 from stations 0 to 1+800, and 16+200 to 18+000	3,600	metres	24	elements
	Zone 2 from stations 1+800 to 6+150, and 11+850 to 16+200	8,700	metres	58	elements
	Zone 3 from stations 6+150 to 11+850	5,700	metres	38	elements
1	***Miscellaneous***				
	Mobilisation/demobilisation @ 3% of subtotal structure cost	ls	1	$5,547,109.65	$5,547,110
	Fabrication facility lease (2 facilities assumed @ 5.5 yrs each)	year	11	$3,500,000.00	$38,500,000
2	***Tunnel Element Fabrication - Zone 1***				
	Concrete				
	Structural grade 4,000 psi placed by pump - slab on grade	m^3	94,968	$157.32	$14,940,366
	Structural grade 4,000 psi placed by pump - elevated slab	m^3	80,640	$169.62	$13,678,157
	Structural grade 4,000 psi placed by pump - walls	m^3	58,572	$175.31	$10,268,257
	External Protection Layer, 2,500 psi, placed by pump	m^3	10,746	$153.34	$1,647,792
	Keyed control joints transverse (at 20m centres approx)	m	10,161	$13.25	$134,633
	Keyed control joints longitudinal (2 total at base/wall junction)	m	7,200	$13.25	$95,400
	Curing, sprayed membrane, internal surfaces only	m	210,600	$1.32	$277,992
	Formwork				
	Walls, multiple use forms	m^2	146,700	$78.92	$11,577,564
	Elevated Slab, multiple use forms	m^2	61,920	$74.27	$4,598,798
	Reinforcement: grade 60 high yield				
	Wall & Slab reinforcing, 150 kg/m^3	tonnes	35,127	$1,501.87	$52,756,187
	Bending, cutting & splicing	tonnes	35,127	$270.44	$9,499,746
	Waterproofing Membrane				
	Steel skin plate, A36, 6 mm thick	tonnes	19,143	$3,132.11	$59,957,982
	Shear connectors, 150 mm x 12 mm, including stud welding	each	812,880	$0.10	$81,288
	Automated Welding	m	91,044	$14.86	$1,352,914
	Tunnel Joints				
	Structural Steel End Frames (2/element)				
	Embedded steel beams, 180 kg/m	tonnes	480	$2,709.04	$1,300,339
	Front plates, 20 mm thick	tonnes	216	$3,132.11	$676,536
	Gina fabrication, installation	each	24	$29,128.00	$699,072
	Omega fabrication, installation & testing	each	24	$36,693.00	$880,632
	Joint concrete, shear keys, cover plates etc.	each	24	$20,000.00	$480,000
				Page Total	***$228,950,765***

Hatch Mott MacDonald

Strait of Belle Isle Crossing

Preliminary Immersed Tube Tunnel Cost Estimate - Road Tunnel

Item	Unit	Quantity	Rate	Total
			Toal Brought Forward	**$228,950,765**
Temporary Works Items (Per Element)				
Structural Steel Bulkheads (2/element)				
Support Columns, 250 kg/m	tonnes	936	$2,709.04	$2,535,661
Skin plate, 12 mm thick	tonnes	480	$3,132.11	$1,503,413
Plate siffening angle, 18 kg/m	tonnes	168	$3,174.03	$533,237
Embedded perimeter angle, 18 kg/m	tonnes	96	$3,174.03	$304,707
Welding	m	22,656	$14.86	$336,668
Field Welding Premium	m	22,656	$40.06	$907,599
Misc. Structural Steel				
Alignment & pulling brackets etc., 5 tonnes per element	tonnes	120	$3,132.11	$375,853
Ballast Tanks (2/element)				
Steel support columns, 100 kg/m	tonnes	672	$2,709.04	$1,820,475
Timber lagging, 150 mm deep	m^2	10,776	$60.40	$650,870
Membrane liner	m^2	10,776	$27.84	$300,004
3 Internal Structural & Civil Finish Works - Zone 1				
Ballast				
Road ballast concrete, 2,500 psi, placed by chute	m3	18,810	$140.06	$2,634,529
Road ballast reinforcement: welded wire fabric 6 x 6 x #4, 2.8kg/m^2	m^2	25,200	$9.36	$235,872
Deduct in excess of 4.5 tonnes	tonne	66	-$41.01	-$2,707
Emergency corridor sand/cement mix for HVDC cables	m3	4,410	$140.06	$617,665
Precast Divider for Emergency Egress Corridor & Vent Duct				
Panel fabrication, 8" thick, incuding reinformcement & lifting points	m^2	50,490	$196.98	$9,945,520
Panel setting, based upon max panel weight of 6 tons.	each	3,600	$285.70	$1,028,520
Seal and caulk panels	m	14,400	$5.48	$78,912
Sprayed fireproofing for precast panels	m^2	50,490	$20.77	$1,048,677
Roadway Surfacing				
Surface treatment, prepare & clean surface	km	3.6	$4,188.69	$15,079
Bituminous surface course, 75 mm thick	m3	1,890	$75.08	$141,901
4 Tunnel Element Fabrication - Zone 2				
Concrete				
Structural grade 4,000 psi placed by pump - slab on grade	m^3	169,563	$157.32	$26,675,651
Structural grade 4,000 psi placed by pump - elevated slab	m^3	149,205	$169.62	$25,308,152
Structural grade 4,000 psi placed by pump - walls	m^3	106,401	$175.31	$18,653,159
External Protection Layer, 2,500 psi, placed by pump	m^3	20,384	$153.34	$3,125,698
Keyed control joints transverse (at 20m centres approx)	m^2	20,097	$13.25	$266,285
Keyed control joints longitudinal (2 total at base/wall junction)	m	17,400	$13.25	$230,550
Curing, sprayed membrane, internal surfaces only	m	337,125	$1.32	$445,005
			Page Total	**$328,667,722**

Hatch Mott MacDonald

Strait of Belle Isle Crossing

Preliminary Immersed Tube Tunnel Cost Estimate - Road Tunnel

Item	Unit	Quantity	Rate	Total
			Toal Brought Forward	**$328,667,722**
Formwork				
Walls, multiple use forms	m^2	241,860	$78.92	$19,087,591
Elevated Slab, multiple use forms	m^2	117,885	$74.27	$8,755,319
Reinforcement: grade 60 high yield				
Wall & Slab reinforcing, 200 kg/m^3	tonnes	85,034	$1,501.87	$127,709,713
Bending, cutting & splicing	tonnes	85,034	$270.44	$22,996,541
Waterproofing Membrane				
Steel skin plate, A36, 6 mm thick	tonnes	19,140	$3,132.11	$59,948,585
Shear connectors, 150 mm x 12 mm, including stud welding	each	1,642,560	$0.10	$164,256
Automated Welding	m	186,528	$14.86	$2,771,806
Tunnel Joints				
Structural Steel End Frames (2/element)				
Embedded steel beams, 180 kg/m	tonnes	986	$2,709.04	$2,671,113
Front plates, 20 mm thick	tonnes	464	$3,132.11	$1,453,299
Gina fabrication, installation	each	58	$24,355.00	$1,412,590
Omega fabrication, installation & testing	each	58	$30,680.00	$1,779,440
Joint concrete, shear keys, cover plates etc.	each	58	$20,000.00	$1,160,000
Temporary Works Items (Per Element)				
Structural Steel Bulkheads (2/element)				
Support Columns, 250 kg/m	tonnes	1,682	$2,709.04	$4,556,605
Skin plate, 12 mm thick	tonnes	870	$3,132.11	$2,724,936
Plate siffening angle, 18 kg/m	tonnes	348	$3,174.03	$1,104,562
Embedded perimeter angle, 18 kg/m	tonnes	116	$3,174.03	$368,187
Welding	m	77,024	$14.86	$1,144,577
Field Welding Premium	m	77,024	$40.06	$3,085,581
Misc. Structural Steel				
Alignment & pulling brackets etc., 5 tonnes per element	tonnes	290	$3,132.11	$908,312
Ballast Tanks (2/element)				
Steel support columns, 100 kg/m	tonnes	1,508	$2,709.04	$4,085,232
Timber lagging, 150 mm deep	m^2	24,360	$60.40	$1,471,344
Membrane liner	m^2	24,360	$27.84	$678,182
5 *Internal Structural & Civil Finish Works - Zone 2*				
Ballast				
Road ballast concrete, 2,500 psi, placed by chute	m3	36,540	$140.06	$5,117,792
Road ballast reinforcement: welded wire fabric 6 x 6 x #4, 2.8kg/m^2	m^2	60,900	$9.36	$570,024
Deduct in excess of 4.5 tonnes	tonne	166	-$41.01	-$6,808
Emergency corridor sand/cement mix for HVDC cables	m3	10,658	$140.06	$1,492,689
			Page Total	**$605,879,194**

Hatch Mott MacDonald

Strait of Belle Isle Crossing

Preliminary Immersed Tube Tunnel Cost Estimate - Road Tunnel

Item	Unit	Quantity	Rate	Total
			Toal Brought Forward	$605,879,194
Precast Divider for Emergency Egress Corridor				
Panel fabrication, 8" thick, incuding reinformcement & lifting points	m^2	137,460	$196.98	$27,076,871
Panel setting, based upon max panel weight of 6 tons.	each	13,050	$285.70	$3,728,385
Seal and caulk panels	m	52,200	$5.48	$286,056
Sprayed fireproofing for precast panels	m^2	167,040	$20.77	$3,469,421
Roadway Surfacing				
Surface treatment, prepare & clean surface	km	8.7	$4,188.69	$36,442
Bituminous surface course, 75 mm thick	m3	4,568	$75.08	$342,928
6 Tunnel Element Fabrication - Zone 3				
Concrete				
Structural grade 4,000 psi placed by pump - slab on grade	m^3	71,193	$157.32	$11,200,083
Structural grade 4,000 psi placed by pump - elevated slab	m^3	58,767	$169.62	$9,968,059
Structural grade 4,000 psi placed by pump - walls	m^3	55,475	$175.31	$9,725,366
External Protection Layer, 2,500 psi, placed by pump	m^3	9,320	$153.34	$1,429,052
Keyed control joints transverse (at 20m centres approx)	m^2	10,616	$13.25	$140,665
Keyed control joints longitudinal (2 total at base/wall junction)	m	11,400	$13.25	$151,050
Curing, sprayed membrane, internal surfaces only	m	169,005	$1.32	$223,087
Formwork				
Walls, multiple use forms	m^2	152,190	$78.92	$12,010,835
Elevated Slab, multiple use forms	m^2	52,440	$74.27	$3,894,719
Reinforcement: grade 60 high yield				
Wall & Slab reinforcing, 150 kg/m^3	tonnes	27,815	$1,501.87	$41,774,946
Bending, cutting & splicing	tonnes	27,815	$270.44	$7,522,366
Waterproofing Membrane				
Steel skin plate, A36, 6 mm thick	tonnes	9,975	$3,132.11	$31,242,797
Shear connectors, 150 mm x 12 mm, including stud welding	each	424,650	$0.10	$42,465
Automated Welding	m	99,465	$14.86	$1,478,050
Tunnel Joints				
Structural Steel End Frames (2/element)				
Embedded steel beams, 180 kg/m	tonnes	504	$2,709.04	$1,365,031
Front plates, 20 mm thick	tonnes	222	$3,132.11	$696,268
Gina fabrication, installation	each	38	$19,221.00	$730,398
Omega fabrication, installation & testing	each	38	$24,213.00	$920,094
Joint concrete, shear keys, cover plates etc.	each	38	$20,000.00	$760,000
			Page Total	$776,094,627

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Strait of Belle Isle Crossing

Preliminary Immersed Tube Tunnel Cost Estimate - Road Tunnel

Item	Unit	Quantity	Rate	Total
			Toal Brought Forward	**$776,094,627**
Temporary Works Items (Per Element)				
Structural Steel Bulkheads (2/element)				
Support Columns, 250 kg/m	tonnes	749	$2,709.04	$2,027,987
Skin plate, 12 mm thick	tonnes	371	$3,132.11	$1,160,447
Plate siffening angle, 18 kg/m	tonnes	129	$3,174.03	$410,085
Embedded perimeter angle, 18 kg/m	tonnes	42	$3,174.03	$132,674
Welding	m	18,392	$14.86	$273,305
Field Welding Premium	m	18,392	$40.06	$736,784
Misc. Structural Steel				
Alignment & pulling brackets etc., 5 tonnes per element	tonnes	190	$3,132.11	$595,101
Ballast Tanks (2/element)				
Steel support columns, 100 kg/m	tonnes	836	$2,709.04	$2,264,757
Timber lagging, 150 mm deep	m^2	13,543	$60.40	$818,009
Membrane liner	m^2	13,543	$27.84	$377,043
7 Internal Structural & Civil Finish Works - Zone 3				
Ballast				
Road ballast concrete, 2,500 psi, placed by chute	m3	17,813	$140.06	$2,494,819
Road ballast reinforcement: welded wire fabric 6 x 6 x #4, 2.8kg/m^2	m^2	39,900	$9.36	$373,464
Deduct in excess of 4.5 tonnes	tonne	107	-$41.01	-$4,388
Emergency corridor sand/cement mix for HVDC cables	m3	3,563	$140.06	$498,964
Precast Divider for Emergency Egress Corridor				
Panel fabrication, 8" thick, incuding reinformcement & lifting points	m^2	32,063	$196.98	$6,315,671
Panel setting, based upon max panel weight of 6 tons.	each	2,850	$285.70	$814,245
Seal and caulk panels	m	11,400	$5.48	$62,472
Sprayed fireproofing for precast panels	m^2	32,063	$20.77	$665,938
Roadway Surfacing				
Surface treatment, prepare & clean surface	km	5.7	$4,188.69	$23,876
Bituminous surface course, 75 mm thick	m3	2,993	$75.08	$224,677
8 Tunnel Transport & Placement				
Element Transport: tug rental etc.	each	120	$500,000.00	$60,000,000
Element placement: barge/pontoons,divers, survey etc.	each	120	$1,000,000.00	$120,000,000
Tunnel Closure				
Underwater joint completion	each	1	$2,500,000.00	$2,500,000
			Page Total	**$978,860,556**

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Strait of Belle Isle Crossing

Preliminary Immersed Tube Tunnel Cost Estimate - Road Tunnel

Item	Unit	Quantity	Rate	Total
			Toal Brought Forward	**$978,860,556**
9 Marine Operation				
Dredging				
Mobilization/Demobilzation per season, 6 seasons, 2 vessels	each	24	$150,000.00	$3,600,000
Stage 1 bulk dredging of material	m3	5,255,299	$84.00	$441,445,116
Stage 2 fine tolerance dredging & additional trench cleaning	m3	788,295	$43.00	$33,896,685
Foundation and Backfill				
Bedded sand foundation	m3	263,385	$35.00	$9,218,475
Selected locking fill	m3	298,955	$35.00	$10,463,425
Backfill	m3	416,616	$35.00	$14,581,560
Rock armor protection	m3	664,488	$51.00	$33,888,888
Subtotal Structure Cost				**$1,525,954,705**
Tunnel MEP Systems	ls	10 % of structure cost		$152,595,470
Rail Systems	ls	15 % of structure cost		$228,893,206
Contingency on Tunnel Costs	ls	30% of subtotal structure cost		$457,786,411
"Soft" Costs				
Engineers design & construction supervision fee	ls	10% of construction cost		$236,522,979
Estimated Construction Cost				**$2,601,752,772**
Estimated Construction Cost per linear metre				**$144,542**

Strait Of Belle Isle Crossing

Preliminary Immersed Tube Tunnel Construction Schedule