3 THE PHYSICAL ENVIRONMENT OF THE STUDY AREA AND DESIGN CRITERIA/CONSIDERATIONS

3.1 Climate

The climate of the study area is influenced by the continental landmass, the Gulf of St. Lawrence and the North Atlantic. Conditions are very variable and may fluctuate rapidly over short periods. The Strait is notoriously foggy during summer with generally poor visibility in July and August.

Air Temperature

Long term temperature data are available from stations at St. Anthony and Flower’s Cove (on the Island) and Battle Harbour (in Labrador). The mean daily temperature in summer is about 13° C with mean maximum being 17° and mean minimum being 8° C. The maximum recorded temperature is 30° C at St. Anthony on August 11,1995. Daily mean temperature in January and February is –10° C with the maximum and minimum daily means being –6° and –16° C respectively. The extreme minimum on record is –34° C that was recorded at Flower’s Cove on February 4, 1995.

A reasonable minimum design air temperature is –30° C. The one per cent design temperature in the National Building Code for St. Anthony is –27° C.

Precipitation

The month with the greatest precipitation and magnitude varies from station to station, the highest mean monthly figure being about 125 mm at St. Anthony in September. The extreme daily rainfall, also at St. Anthony, is 88 mm occurring on September 2, 1999. The mean annual precipitation is about 1200 mm. Mean annual snowfall is approximately 400 cm and mean snow depth over the winter months is about 50 cm. The design ground snow loading for St. Anthony based on factors in the National Building Code is 4.2 kPa.

Winds

Maximum hourly wind speed recorded at St. Anthony is 97 kilometres per hour and maximum gust speed is 148 kilometres per hour. Prevailing directions are southwest in summer and northwest in winter although in April, northeast winds are more common. The 1 in 100 year design hourly wind pressure for St. Anthony from the National Building Code is 1.01 kPa.

Degree Days

Freezing degree days (below 0° C), which are indicative of ice growth potential, are 1323 at St. Anthony and 1166 at Flower’s Cove.

Icing

Icing of above-water structures can occur from both atmospheric and sea spray icing and would be a consideration for bridge superstructure components and, to a lesser extent, for riprap sizing related to the causeway concept. There is literature in the public domain on both types of icing; freezing precipitation studies generally pertain to transmission and communications lines and towers, while sea spray icing pertains to oceangoing vessels. Both types of icing may occur in the area.

Newfoundland and Labrador Hydro has done significant work on freezing precipitation on the Great Northern Peninsula and in Labrador. For the study area, they recommend a design value for rime icing of 11.5 cm of radial ice on transmission lines combined with a maximum wind gust of 115 kilometres per hour.

Chaine and Skeates (1974) computed accumulations of ice on various surfaces as a function of return period for a number of locations in Canada. For St. John’s Airport, the ice accumulation for a 50-yr return period was calculated to be 5.3 cm on a horizontal surface, 6.3 cm on a vertical and 3.1 cm on a 25 mm radial conductor.

A report by NORDCO (1981) on icing of a stationary, floating offshore oil platform on the Grand Banks presents a relationship between sea spray icing and height of a platform component above sea level. The authors conclude that sea spray icing would not affect components that are more than 1.5 times the wave height above the wave crest, or 15metresfor a wave height of 10 m. In all likelihood, potentially vulnerable components of a bridge across the Strait would be higher than this.

3.2 Oceanography

Bathymetry

Detailed bathymetry of the study area was compiled from a number of surveys during the proposed Lower Churchill Development of the late 1970’s and early 1980’s. (Woodworth-Lynas, et al, 1992) In this work, five physiographic zones were defined. The Labrador Coastal Zone consists of the northwestern slope of the Labrador Trough (with depths of up to 115metresand width of 1 to 2 kilometres) and has generally uniform slopes of 6 to 12 per cent; Centre Banks South and North with depths from 15 to 85 metres are separated by a narrow depression 85metresdeep; the Newfoundland Trough is 5 to 12 kilometres wide and from 70 to 125 metres deep; and the Newfoundland Coastal Zone, that is bounded by the coast and a linear escarpment separating it from the NF Trough. Figure 3.1 shows bathymetric contours within the intended locality of the proposed Fixed Link.

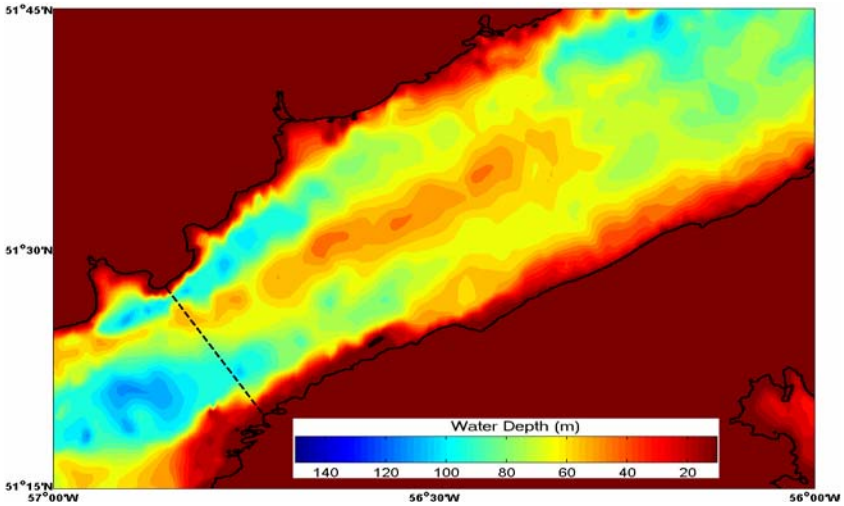

Figure 3.1 - Strait of Belle Isle - Bathymetry

Currents

The earliest record of current measurements in the Strait as reported by Ingram (1982) is that of Dawson (1907,1913) who made rough measurements from a vessel without the aid of modern self-recording current meters. Dawson reported that the dominant flow within the Strait was inward toward the Gulf of St. Lawrence along the Labrador side and in the opposite direction along the Island of Newfoundland side. The first significant program of current measurement was in 1966 by the Bedford Institute of Oceanography (BIO) and as reported by Farquharson and Bailey (1966). With meters installed across a line from Pointe Amour to Savage Point, they found that the mean flow of water consisted of a surface flow (to the Atlantic) on the south side and a compensating inflow at the surface on the north side and in the subsurface waters on both sides. In 1980, BIO conducted another program of current measurements along the same cross-section with meters placed at 15 metre and 50 metre water depths. The results of this program, according to Ingram, suggest that the maximum current when all components are combined (during spring tides) are as follows:

15 metres depth	3.6 metres per second (7.2 knots)
50 metres depth	2.5 metres per second (5.0 knots)

Other current measurement programs in 1978 and 1979 in support of a proposed submarine cable crossing did not result in any more conclusive results on the current regime in the Strait. These and the drilling programs associated with the same proposed development did show, however, that with appropriate equipment, it is possible to work in the Strait during the summer and fall periods.

Waves

Wave data were collected in the study area in 1979 and 1981 and wave contour charts were obtained from the Meteorological and Oceanographic Centre for Newfoundland Waters as part of the studies to support the cable crossing. A wave hindcast analysis was also carried out. The results of this work indicated that, during the period June through August, the significant wave height would be less than 3 metres, and waves with heights of 2 metres or more would occur for less than 2.5 per cent of the time. Waves with heights of 1 metre or greater would occur 40 per cent of the time. During winter, wave height will be affected by the amount of sea ice in the Strait as well as in the Labrador Sea and Gulf. Assuming no ice cover, the maximum wave height with a return period of 100 years would be approximately 10 metres and would occur in January. (SNC-Lavalin,1982).

3.3 Sea Ice

Sea ice in the Strait is a combination of locally formed ice and pack ice that drifts down from the Arctic and Labrador Sea. The thickness, configuration and strength of this ice pack change with time as individual ice floes collide, freeze together, raft and ridge with changes in the current and wind. While the thickness of an individual floe that forms solely due to thermal effects would generally be less than 1 metre, this collision interaction results in formations that can be many metres thick but the average strength of such formations will be less than that of a homogeneous sheet of ice which would have a compressive strength in the order of 2 MPa. The forces that such an ice pack might exert on a structure depend on the areal extent of the ice feature, the prevailing winds and currents, the thickness and the strength of the ice feature, and the configuration of the structure with which the ice interacts.

With respect to the extent and concentration of ice in the Strait, on average, local ice first forms in mid to late December. In January, the Labrador pack drifts into the area and by late January, the coverage is seven to nine tenths. Full ten-tenths coverage may happen in a severe year and may last for up to six weeks. The pack usually moves in and out of the Strait with the current and wind and only a small proportion of it moves into the Gulf proper. However, during persistent northeast winds, ice has been known to drift into the northeast arm of the Gulf.

Navigation by oceangoing vessels in the Strait normally continues into January although in a severe year navigation can become impeded by mid-December. Normally, navigation resumes in May although the ice may linger well into June. Local ferry operations are generally suspended from mid January to early May.

Several studies and at least one field measurement program of near shore ice conditions were conducted in support of the proposed cable crossing in the 1970's and early 80's. Thicknesses of undisturbed ice close to shore were generally less than 0.6 metres while rafted and rubble formations were several metres thick. No thickness measurements were made further out in the Strait because the central concern was the effect of ice on a submarine cable and appurtenances at the shoreline. An understanding of such thicknesses may be obtained, however, from programs conducted further north in the Labrador Sea, and in the Northumberland Strait with respect to the Confederation Bridge crossing to Prince Edward Island. In addition, information on the experience with ice around the Confederation Bridge piers since construction may be instructive in predicting ice-structure interaction behavior in the Strait of Belle Isle.

3.4 Icebergs

The origin and movement of icebergs in eastern Canada are generally well understood. For the purposes of this study, the concerns are with the potential for scouring and collision with bottom-founded structures. Scouring is a concern only for an immersed tube tunnel alternative crossing concept that would have shallow burial or be covered by armour stone.

A number of studies were conducted on the iceberg scour question in the 1970's and early 1980's in consideration of a submarine transmission cable from the proposed Lower Churchill development. A fundamental question relates to the potential for seabed scour at depths greater than 70 metres southwest of a shoal that is 45 kilometres upstream of the proposed crossing line. This subject is discussed at length in Woodworth-Lynas, et al (1992) and is summarized here.

Of the average of 600 icebergs that pass the latitude of the Strait each year from Baffin Bay to the Grand Banks, 60 to 90 drift into the Strait, the largest number being seen in May and June. Most of these enter on the Labrador side and exit on the Island of Newfoundland side in concert with the prevailing currents. A few of these icebergs (estimated at 6 to 12 with drafts of less than 55 metres) move into the Gulf and ground along the Quebec shore. (A few have been known to penetrate to Anticosti Island or the Bay of Islands area. One small berg reached the Cabot Strait in 1960 before melting.) The greatest number of icebergs observed in the Strait at one time was 496, recorded by the Belle Isle lighthouse keeper on May 30, 1858.

The shoal area previously mentioned was thought to act as an iceberg filter and prevent any deeper icebergs from drifting into the proposed cable crossing area. However, scours in deeper water further into the Strait have been observed, causing this theory to be questioned. A number of researchers have postulated that because icebergs roll, the previous draft may increase thereby permitting the iceberg to contact the seabed in water deeper than 70 metres. Risk analysis studies commissioned as part of the Lower Churchill program of work have suggested that the probability of an iceberg scouring along the proposed cable route is 0.5 events for every 100 icebergs in water depths greater than 75 metres and 0.1 events per 100 icebergs in depths greater than 85 metres. In the engineering studies of the cable crossing, the concept was to trench and bury the cable out to a water depth of 85 metres. While there is some doubt about the risk associated with scour, there is also no data on the depth of scour in the area thus making a recommendation of burial depth difficult. However, there is such data from other areas and reasonable extrapolations should be possible. In recent years, significant work has also been done on the subject relating to the protection of seabed equipment on the Grand Banks.

For the purposes of the current study, researchers at C-CORE undertook an analysis of the iceberg scour risk in the Strait of Belle Isle. Iceberg scour risk and required cover depths were determined for an underwater structure running from Yankee Point in the Island of Newfoundland to Pointe Amour in Labrador. Grounding rates were determined using a grounding model that uses mean iceberg drift speed, iceberg keel depth distribution, iceberg frequency, water depth and seabed slope. Iceberg drift speed was based on 21 iceberg trajectories collected off Pointe Amour in 1979 and 1980. (Iceberg monitoring programs were conducted by LCDC over several years). Iceberg frequency was determined from an analysis of Canadian Ice Service iceberg charts from 1988 to 2004. Iceberg keel draft distribution was based on observed iceberg waterline length data collected off the coasts of Newfoundland and Labrador. Water depth and seabed slope were determined using data from a bathymetric chart.

The results of the grounding model were then used to determine iceberg risk using iceberg scour and pit data from the White Rose region of the Grand Banks. Required clearances between scouring and pitting iceberg keels were based on pipeline risk analyses from the same site. Figure 3.2 illustrates the required cover depths over the top of the tunnel as function of the mean return periods of 100 and 1000 years to prevent damage from scouring and pitting icebergs. The required cover depths over the top of the tunnel are 3 and 5.5 metres for return periods of 100 and 1000 years respectively, to prevent damage from scouring and pitting icebergs.

C-CORE's report on the analysis of iceberg scour risk in the Strait of Belle Isle is provided in Appendix B.

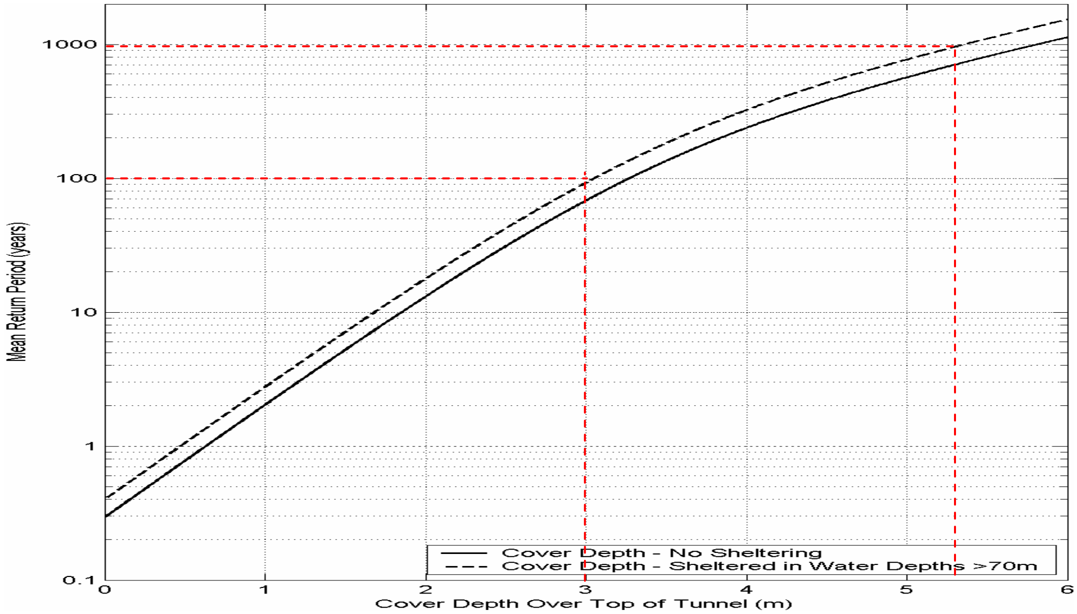

Figure 3.2 - Required Cover to Top of Tunnel to Prevent Iceberg Damage

3.5 Geology

An understanding of the geology of the Strait and adjacent coastal areas is obviously fundamental to the tunnel concept. The following description addresses both bedrock and surficial geology of the area.

Bedrock Geology

Strait of Belle Isle

The Strait of Belle Isle forms the northern extremity of the St. Lawrence Lowland and lies within the Canadian Appalachian region. The St. Lawrence Lowland is bounded on the Newfoundland side by the Highland of the Great Northern Peninsula and Long Range Mountains, and on the Labrador side by the Labrador Highland and Mecatina Plateau.At the narrowest width of the Strait, between Pointe Amour, Labrador and Yankee Point, Newfoundland, where the distance from shore to shore is about 18 kilometres, the area is underlain by a vertical succession of sedimentary rock strata of Cambrian age overlying Precambrian basement rock. The northern Newfoundland region has been subject to sedimentation, volcanism and orogenesis resulting in the crossing area being extensively faulted and forming a possible collapse structure. Figure 3.3 shows an inferred geological section between Pointe Amour and Yankee Point.

The basement rocks under the Strait, in Labrador, and under the Northern Peninsula are Precambrian in age. They belong to the Grenville Province and consist of a complex of metamorphic and granitic rocks. On the Newfoundland side, the complex forms the Long Range Mountains where it consists of schists and gneisses. These rocks are cut by several granitic and gabbroic intrusive and by numerous steeply dipping diabase dykes striking northeasterly. On the Labrador side, the Precambrian Metamorphic Complex forms the Mecatina Plateau. The Complex is a large area consisting of granite and granodiorite intrusives and extends from the Atlantic Ocean to beyond the Provincial Boundary.

The contact between the Paleozoic sedimentary and the Precambrian rock strata is an angular unconformity. It occurs about 95 metres below the Labrador shoreline and about 460 m below the Newfoundland shoreline. Although the contact dips gently southerly between the above two points, it is frequently offset vertically by extensive faulting occurring in the Strait.

The sedimentary rock strata overlying the Precambrian basement rock in the crossing area are Cambrian and Ordovician in age. Their total thickness elsewhere is greatly in excess of 500 metres. These strata are nearly flat-lying or gently dipping southerly and are composed of sandstones, dolomite, limestone and shale.

The sedimentary rock strata and the Precambrian basement rock have been faulted extensively as indicated in previous off-shore seismic work and field mapping during 1975. Seismic interpretative results infer that fourteen faults are present in the rock beneath the Strait between Yankee Point and Pointe Amour. The predominant set of faults strikes northeasterly parallel with the direction of the Strait. These faults have vertical offsets as is typical with normal or reverse faults. Six of the faults are located in the vicinity of the Labrador trough along the north side of the Strait and more or less parallel with the shore. Less prominent faulting occurs striking at right angles to the first set. Joint sets generally follow the fault pattern.

The entire Strait has been extensively glaciated during Pleistocene time and such features as glacial till, erratics and striations are common on the seabed. The overburden is generally composed of sand, gravel, cobbles and boulders. It appears to be generally shallow and more or less uniformly distributed throughout the area.

Bedrock outcropping is frequent. A more recent deposition of a thin layer of shells and shell fragments overlies the soil and bedrock in many places on the floor of the Strait.

Labrador (Pointe Amour)

From 1973 to 1975, field mapping and drilling programs were conducted in the area of shaft locations on both sides of the Strait. Mapping on the Labrador side indicated that a vertical succession of nearly flat-lying Cambrian sedimentary rock strata totaling about 170 metres in thickness overlies the Precambrian basement rock. The sedimentary rock formations are composed of about 75 metres of interbedded limestones and shales belonging to the Forteau formation. These strata overlie about 92 metres of arkosic sandstone and orthoquartzite with minor siltstone and conglomerate of the Bradore formation.

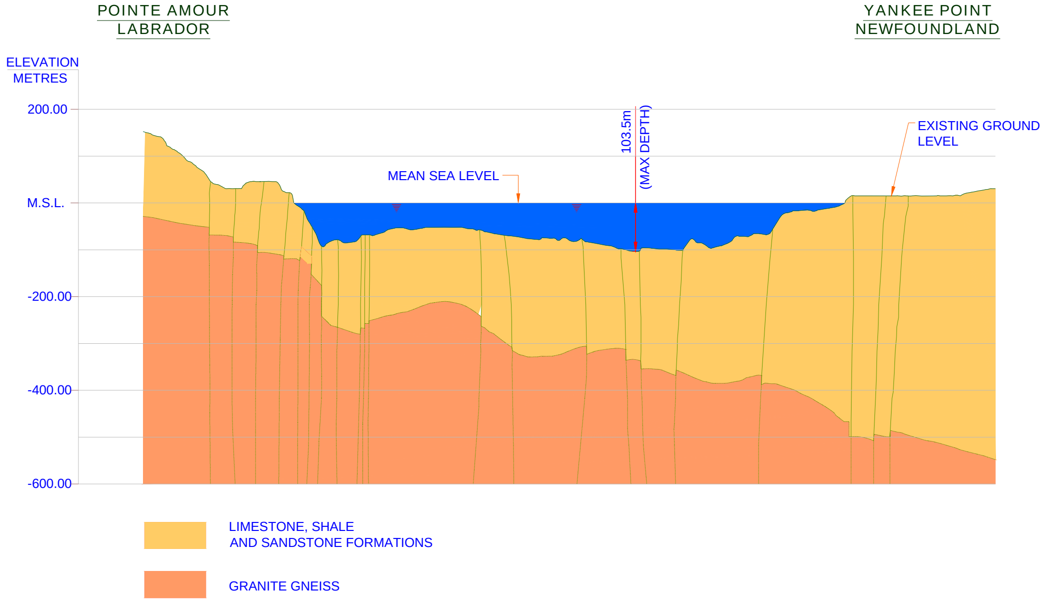

Figure 3.3 – Inferred Geological Section Between Pointe Amour and Yankee Point

The whole assemblage of sedimentary rock is down faulted along northeasterly trending faults strata in a series of blocks from inland to the vicinity of Pointe Amour at the shoreline. The Forteau and underlying formations are extensively faulted at Fox Point, about 1 to 2 kilometres east of Pointe Amour. The underlying Precambrian basement complex is composed of granitic gneisses and schists and intrusives of granitic composition. Surficial examination of the Forteau limestone exposures in the Pointe Amour area indicated that these strata are nearly flat-lying or dip at a maximum of 2 to 5 degrees north or south.

During 1973, a borehole was drilled at Pointe Amour to a depth of 151 metres and intersected Precambrian gneiss at a depth of 118 metres. An additional hole was drilled 151 metres west of the first Labrador hole to a depth of 301 metres in 1974; this hole terminated in gneiss. Although not drilled to the bottom elevation of the shaft at 560.5 metres the Precambrian granite gneiss is expected to continue with depth to this point and below.

Mapping of the shaft rock from an 8.5 metres deep excavation and examination of rock core recovered during drilling indicated that although there exists a slight inclination of the beds to the north or south, the strata are essentially horizontal or sub-horizontal at this location.

Seepage into the shaft collar was reported at two points, one at 1 metre depth and the other at 3.8 metres depth. The rate of inflow was estimated to range from 113 litres per minute following periods of rainfall to 9 litres per minute under normal condition and zero litres per minute during late winter.

Two sets of fractures varying in thickness from about 1 mm to about 8-10 mm were observed in the shaft collar rock. These fractures decreased in frequency in depth. The first set is subvertical with a strike and dip about parallel with the usual fracturing on surface rock. The second set is subhorizontal and reported to be very nearly parallel to the bedding.

Core recovered from the Lower Forteau indicated a high interbedded shale content in the rock from the excavated shaft collar to the top of the Bradore formation varying from 20 percent to 80 percent but averaging about 50 percent, estimated. At three locations, interbeds of pure shale were observed in thicknesses ranging from 300 mm to 500 mm. The rock throughout was generally dense and fresh except at a depth of 10.9 to 14.0 metres where the rock had a weathered appearance. At surface, trenching near the shaft area indicated that weathered shale was present. Permeability of the rock was estimated to be low.

A water-bearing zone was reported at about mid-point of the Bradore Formation between depths of 68 to 94 metres. In the contact zone between Bradore and the underlying Precambrian, a zone of very soft volcanic rocks 7 metres thick was reported.

The Precambrian complex is composed of gneisses, schists and granitic intrusives rocks. The gneisses are composed of feldspar, quartz and variable amounts of mica (muscovite and biotite). The schists are mainly micaschists. The gneiss extended from the base of the altered volcanics to the bottom of the borehole at el 301 metres. The rock is dense and fresh and displays foliation of gneissosity at an inclination of 20°, 30°, 70° and 85° fractures. Eighteen fractures zones were reported. Of these, over 70 percent occur at intervals over a vertical length of 85 metres between depths of 182 and 267 metres below surface. Of the total number of fractures, about one-third showed evidence of weathering or alteration. Of the total number of fractures, 15 percent are present to 15 metres below the top of the formation and the remainder occur in the lower 120 metres, thereby leaving a vertical distance of almost 50 metres in which very little fracturing was reported.

Island of Newfoundland (Yankee Point)

The bedrock strata on the Newfoundland side are overlain by a thin layer of peat and grassland covering glacial deposits of sand and gravel containing rock fragments in size from a few millimeters up to 500 mm. The thickness of the overburden increases from a metre or so near the shore to about 3 metres inland. At Yankee Point bedrock is present about 2.5 metres below ground surface. Sedimentary rock strata (Hawke Bay, Forteau and Bradore Formations) extend from the bottom of the overburden 460 metres down to the gneiss. At the contact between the sedimentary rock and the gneiss, about 7 metres of altered volcanics or metasediments occur and these are included with the Precambrian at the top of this formation.

The almost flat-lying sedimentary rock strata of the Hawke Bay Formation outcrop along the shore at Yankee Point and overlie a vertical succession of sedimentary rock strata totaling 460 metres approximately. This series is composed of granite gneiss, feldspathic gneisses and mica gneisses. Normal and reverse faulting is present with the downthrown sides mainly in the direction of the Strait. Downthrusted and upthrusted blocks along these faults have been interpreted as typical of the faulted stratigraphy of the Strait.

During 1973 a borehole was drilled at Yankee Point to a depth of 197 metres in 1973, deepened to 396 metres in 1974 and further deepened to 546 metres in 1975, intersecting the Precambrian gneiss at 469 metres. The shaft collar was excavated to a depth of 15 metres in interbedded dolomitic limestone, dolomite and shale of the upper Hawke Bay Formation. These strata are horizontal, the rock at this depth consisting of crystalline limestone (54%) shaley limestone (40%) and shale (6%). The limestone beds in the uppermost 5 metres range in thickness from 50 mm to 500 mm. The shaley limestone beds average 100 mm in thickness and contain 30 percent shale and 70 percent limestone. Grey shale lamellae range in thickness from 1 to 10 mm. Inflows into the shaft collar rock occurred at 5 metres, 7 metresand 11 metres below surface approximately at shale/limestone contacts. Inflow rates were 34, 6 and 0.5 litres per minute respectively. Fractures occur in two sets, one set parallel with the bedding and the other normal to the bedding. The frequency of the fractures was found to be greatest in the top 3 metres of the shaft collar.

Below the collar excavation, borehole cores indicated that interbedded dolomite and shale extends for a depth of 72.4 metres. The carbonate rock contains an estimated 80 percent dolomite or dolomitic limestone, 18 percent shale and 2 percent shaley limestone or limey shale. The strata appeared to be horizontal or nearly so and relatively unfractured. Shales occur mainly in the uppermost 40 metres of the formation. The rock was generally dense and fresh throughout. Permeability throughout this dolomitic formation was estimated to be low although some inflow might occur at a depth of about 60 metres where return water was lost during the borehole investigation.

Underlying the carbonate section is the lower 155 metres thick section of the Hawke Bay Formation composed of sandstones, orthoquartzites and shales. These strata appear to be flat lying. Individual bed thicknesses where no shale occurs range from an estimated 150 mm to about 450 mm. Prominent shaley beds occur at depths of 79-87, 115-124, 164-170 and 180-188 m. Other less distinct shaley strata are also present. Two sections of sandstone and/or orthoquartzite occur at 139-149 metres and 170-180 metres. These beds are very strong and massive and contain little or no shale. At the bottom of the formation, sandstone breccia about 5 metres in thickness is present along with evidence of slickensides and fault gouge dipping 20-60°, indicating that faulting is present at this point. In this respect, fractures in the rock are present at several locations extending from about 9 metres above the contact with the underlying Forteau formation to about 15 metres below the contact and these may be associated with the possible faulting or other movement along the strata in this location. The rock throughout this lower section of the Hawke Bay is dense and fresh and only slightly fractured except as noted above. Permeability was estimated to be low for the most part throughout but may be low to medium at 72-115, 139-197, and 218-222 metres.

The Forteau (dolomitic) limestone and shale formation underlies the Hawke Bay sandstone. The formation is composed of an estimated 66 percent limestone and 34 percent shale. Borehole cores indicated the limestone beds to be fairly massive and occasionally may reach a thickness of 300 to 900 mm thick in the uppermost 40 metres of the formation in those individual beds where shale content is low or absent. In the uppermost shale layer located immediately below the contact with the overlying Hawke Bay sandstone, some fracturing occurs with slickensides at 40-60°. At a depth of 337 metres, some fault gouge was reported with an oblique fracture at 40° and slickensided. Rock core recovered from this formation contained very few fractures below a depth of about 15 metres below the top of this formation. The Forteau rests conformably on the underlying Bradore Formation.

The Forteau limestone and shale is generally dense and fresh and its permeability is estimated to be low. At a depth of 245 metres, artesian salt water with gas bubbles was encountered with an average inflow rate of 54 litres per minute and a back pressure on the water feed hose of 827 kPa (120 psi) after 12 hours of capping.

The Bradore formation is 121 metres thick and deposited unconformably on the underlying Precambrian. It is 28 metres thicker than the Bradore in the Pointe Amour shaft location. It is possible that much of the increased thickness on the Newfoundland side occurs above the contact with the Precambrian where the conglomerate content appears to be greater. As on the Labrador side the rock strata were found to be generally dense and fresh. Whereas joint fractures parallel to the bedding in the Labrador shaft location have been reported as being frequent to numerous and more or less uniformly distributed throughout the Bradore, in the Newfoundland shaft rock these joints were found to occur mainly in the lower half of the formation only. Estimated permeability ranges from low to medium. Bed thicknesses are probably similar to those in the Labrador shaft and shale is present in the uppermost 5 metres of the formation directly below the Forteau. The siltstone content is probably similar to that on the Labrador side of 2 percent. At the bottom of the formation close to the contact with the underlying Percambrian, a prominent gypsum horizon is present.

About 77 metres of the Precambrian quartz-feldspar-biotite gneiss was cored at Yankee Point. The rock was found to be dense and fresh and displayed foliation or gneissosity at an inclination of 40 to 60° (true dip). A possible shear zone 600 mm thick is located 3.6 metres below the top of the gneiss. A large number of factures and planes of weakness were reported, almost 90 percent of which are inclined at angles varying from horizontal to 20°. Of the remainder, 8 percent are inclined at 45°. The number of fractures per unit length was found to be much greater in this gneiss than that in the Labrador core. In the lower half of core recovered, a high percentage of the fractures was reported to have fresh or clean breaks so that the fractures may be reasonably tight in rock that has not been disturbed by superimposed mechanical forces such as drilling. Only one fracture of the total number was reported to exhibit slickensiding.

Surficial Geology

An understanding of the surficial geology is needed for an assessment of the immersed tube tunnel concept as well as for the nearshore and offshore excavations for the tunnel approaches.

Additional information to that obtained in the programs reported above was obtained as a result of a borehole program carried out in 1981 along six potential submarine cable routes (as opposed to a cable tunnel scheme). Twelve boreholes were drilled along Route 1 between Pointe Amour and Yankee Point. The results of this drilling program show that the overburden consists of thin deposits of sand and gravel in places overlying shallow deposits of dense till. Along the route from Pointe Amour to Yankee Point, the average thickness of overburden is 1.8metres. Including the till, the depth to the interbedded limestone and shale bedrock, is 2.5 to 3 metres. Sandstone was encountered only over a distance of 2.1 kilometres near the Newfoundland side. The amount of shale within the formation was less than had been expected from earlier assessments, indicating that the bedrock is of a relatively high strength. The work also indicated that a number of ledges and slopes were evident that would require remedial blasting for submarine cable embedment. Ledges were defined as any rock face with a slope greater than 20 per cent. Along the cable route (essentially the same as the proposed tunnel route), the number of such ridges identified was six, and the average and maximum height was 3.2 and 6.0 metres. The length of rock trenching to achieve an objective of a depth of 85 metres below mean sea level (to accommodate iceberg scour) was 11.9 kilometres (of a total distance of 17.8 kilometres), and the length of overburden trenching was the remaining 5.9 kilometres.

On shore on the Labrador side, the overburden has an estimated thickness of 1 to 3 metres and is composed of glacial till and raised beach deposits underlying a thin layer of peat and grassland. On the Island of Newfoundland side, in the vicinity of the tunnel access, the overburden consists of sand and gravel of up to 2.5 metres in thickness that is overlain by peat. The soil, which contains rock fragments ranging in size from a few millimeters to cobbles and boulders, overlies sedimentary rock strata which is approximately 460 metres deep.

Geological Faulting and Water Ingress Considerations

As noted previously, the bedrock geology of the Strait has been inferred from seismic surveys and the drilling results of the shore-based program. It was also noted that, according to seismic interpretation, there are 14 faults in the structure. A further discussion of these faults and the potential for water ingress in a tunnel concept is presented in a report by SNC-Lavalin (1980) and that discussion is largely repeated here.

The faults are high angle normal (gravity) or reverse faults and their interpreted locations were shown on the profile of Figure 3.3. These faults have been responsible for upthrusting and downfaulting of individual large blocks or rock along them. Variation in vertical offsets range from a possible 75 metres in the vicinity of the Labrador trench to a possible 45 metres at the Newfoundland shore. In the vicinity of the Central Bank, vertical offsets along the faults appear not to exceed 15 metres. The faults have been interpreted as extending continuously with depth from the bedrock surface at the floor of the Strait through the sedimentary rock strata thence deep into the underlying Precambrian.

Geological mapping of the faults has indicated that those located in limestone may be associated with a zone of brecciation and fracturing up to 15 metre width. Faults in sandstone are generally not associated with brecciated zones although some brecciation is present at the bottom of the Hawke Bay sandstone a few metres above the Forteau contact. It is probable that although the depth of faulting cannot be estimated accurately from offshore seismic data, it can be assumed that some major faults have penetrated beyond the Cambrian sedimentary rocks into the Precambrian metamorphic complex. The depth of these faults is not established and it can only be concluded that some, if not all, will intersect a tunnelled crossing of the Strait.

It is also assumed that in many cases the faults in the Palaeozoic rocks have occurred along zones of weakness in the Precambrian rocks caused by existing faults of Precambrian age. Interconnections between faults of different ages are possible.

The amount of water, if any, in these fault zones and the rate at which it would flow should they be intersected by the tunnel, cannot be estimated from seismic work. Surface observations of faults indicate that brecciated and fractured zones are frequent on both sides of the Strait. In some cases zones of brecciation and fractures in the faults are recemented with secondary calcite. Such zones should be regarded as impervious. The water well drilling on the Labrador side, located approximately 240 metres west of the shaft site for the cable tunnel concept and hydrogeological studies on the Newfoundland side strongly indicate that aquifers of significant size occur only in fault or fracture zones. The water wells drilled through such zones have been productive with an estimated capacity of over 45 litres per minute while those drilled away from the fault zones were dry. This indicates that some fault zones located under the Strait might be water bearing. The risk of further movement along existing fault planes or even the occurrence of new faults is considered to be low for the Strait of Belle Isle. However, earthquakes with magnitudes of 3 to 4 on the Richter scale have occurred within 160 to 240 kilometres of the tunnel area.

The selection of the invert elevation of the cable tunnel was made so as to ensure that it would be located in the Precambrian basement rocks in order to reduce the risk of excessive water inflows into the essentially unlined drill and blast tunnel. It was assessed that sedimentary rock strata could prove to be water bearing, much more so than the underlying gneiss. Inflows into the tunnel located in gneiss were considered to be restricted to those directed along existing faulting.

In the cable tunnel cable concept, the minimum amount of granite roof cover was fixed at about 46 metres so that, with consideration of the interpretive geological profile under the Strait, 46 metres would then exist below the lowest sedimentary rock strata on the Newfoundland side. This 46 metres roof thickness measurement was apparently determined from the possible vertical offset along faulting at Flowers Cove. If such vertical offset were more than 46 metres, sedimentary rock strata might then intersect the tunnel horizon. Insofar as the tunnel invert would be located below the lowest elevation of the southerly dipping sedimentary strata, the tunnel would be located in gneiss for the remainder of the distance across the Strait.

It was considered that the individual proportions of schist, biotite gneiss, feldspar gneiss and granitic rocks cannot be estimated at this time. The foliation in the granite gneiss varies from 20° to 40° in the Labrador shaft to 40° to 60° in the Newfoundland shaft. It is possible that the content of schistose rock probably relates to the mica content in the rock and so may not be significantly large. Wherever the granitic rocks have been observed on shore and in the boreholes, the rock is reasonably fresh and unweathered. Its condition in the vicinity of faults is not known.

The 1980 studies concluded that a substantial increase in the amount of geotechnical detail would be required through additional borings.

Boreholes would be located so as to confirm the predicted amount of vertical displacement of strata produced as a result of faulting. In addition, it was considered to be of particular importance to investigate the condition of the rock at the upper and lower contacts of the Forteau Formation and at the top of the Precambrian granite gneiss on both sides of the Strait. Studies of these areas have indicated occurrence of fractures, water inflows, drilling water losses, gypsum, fault gouge and areas of soft rock as indicated on the borehole logs. In all borehole investigations on both sides of the Strait, permeability testing of the rock in situ was suggested. Two inclined boreholes were recommended on the Labrador side to intersect and partially determine the condition of the faults underlying the north side of the Labrador trench that were interpreted to extend into the cable tunnel horizon.

In addition, it was suggested that a program be conducted from the cable tunnel during the construction period by means of investigative boreholes in advance of each tunnel heading. This procedure would allow pre-grouting considerations and final design criteria to be assessed immediately in advance of shaft and tunnel construction.

3.6 Design Criteria and Considerations

Environmental Design Criteria

The design criteria associated with the physical environmental parameters of the study area may be summarized as follows from the above discussion.

Climate

Minimum design air temperature	-30° C

Maximum hourly wind speed	97 kilometres per hour
Maximum gust wind speed	148 kilometres per hour
Design hourly wind pressure	1.01 kiloPascal
Atmospheric Icing	11.5 cenimetres with 115 kilometres per hour wind gust
Ground snow loading	4.2 kiloPascal
Freezing Degree-Days	1323 ° C-days

Oceanography

Currents	
-at 15 metres depth	3.6 metres per second
-at 50 metres depth	2.5 metres per second
Maximum Wave Height -100 year return period	10 metres

Sea Ice

Uniform ice floe thickness	0.6 metres
Ice compressive strength (uniform ice)	2 megaPascal

Icebergs

Mass	1 million tonnes
Speed	1 metres per second
Ice strength	5 megaPascal
Scour depth (1000 year return period)	5.5 metres

3.7 Capacity and Dimensional Requirements for the Fixed Link

Projected traffic demand, emergency egress and ventilation are the principal factors in determining the spatial requirements of a tunnel. Each of these items is addressed below for road and rail configurations. Consideration is also given to accommodating HVDC cables in the tunnel.

Traffic volumes and mode of transit

As an early activity during the study it was necessary to carry out a scoping level assessment of the traffic that a fixed link across the Strait of Belle Isle would attract in order to determine the capacity required for the facility. This assessment was made to establish the size of the structures in terms of the number of traffic lanes or the number of tracks. A preliminary forecast was made of traffic volume generated 30 years after construction. Traffic could develop from a number of sources as follows:

- Diversion from existing established routes
- New developments to attract automobile tourism and induced demand
- New economic developments to attract long term commercial vehicle traffic
- Major projects that may generate elevated demand for defined periods

The traffic that presently crosses on the existing ferry service was assumed to transfer totally to the new fixed link after the closure of that service. Further, half of the present traffic using the Gulf ferries was also assumed to divert to this crossing. This was considered to be an optimistic assumption but appropriate for an initial sizing assessment. Similarly, a generous annual traffic growth of 2.5% was assumed.

The resulting traffic volumes in equivalent Passenger Car Units (PCU) are shown in Table 3.1. Cars are considered as one PCU per vehicle and commercial vehicles are considered as three PCU per vehicle.

Table 3.1 - Preliminary Traffic Volume Summary

Description	Base Volume at Year 1		Sizing Volume (PCU) at Year 30
	Existing Peak per day	Diversion Peak per day	Total Daily Volume
Passenger Cars	160	315	2,042
Commercial PCU	22	350	1,621
Total PCU	182	665	3,642

Highway lane capacity is normally assessed in terms of peak hour volume that can safely operate in fluid conditions. For a two-lane undivided highway in Canada, the rule-of-thumb is 1,200 PCU per hour per direction.

Since the route under consideration is rural and remote, peak periods are spread over a number of hours, say 5 hours each day. During this time, 50% of the average daily volume could be accommodated and the balance of the demand would be spread over off-peak periods. Based on the above estimates of 3,642 PCU per day, the peak design hour should accommodate 364 PCU in aggregate for both directions or 182 PCU per hour per direction. This is well below the rule-of-thumb for two-lane undivided highways.

Since the expected traffic is significantly less than the capacity of a two-lane highway it is appropriate to investigate lower capacity options. An alternative to two-lanes is a managed single lane operation with periodic single direction operation. However, for the causeway or bridge alternative means of providing a fixed link, the incremental cost differential between providing a two lane crossing compared with a single lane is so small that it would not be economically feasible to construct such a facility at less than a two-lane configuration. Conversely, for the tunnelled options, the cost increment associated with providing two lanes compared with one lane is very large and there is significant justification to minimize the area of the tunnel cross sections and to select a single-lane configeratoin.

A single lane (with an emergency lane) could operate alternately in opposite directions in a controlled environment. An operating speed of 50 kilometres per hour would imply under 30 minutes to enter, traverse and exit the crossing. If the window of operation was 30 minutes at the entrance, with 30 minutes to clear the tunnel then after one hour the direction of operation could change after the last vehicle clears the portal. The traffic would then operate in the opposite direction for a period of 30 minutes plus 30 minutes clearing time. Therefore for 25% per cent of the time, traffic could enter in one direction, and 25% of the time could enter in the opposite direction. This would provide a capacity of 300 PCU (1200 x 25%) per hour in each direction. An alternating-direction single-lane tunnel therefore appears to be a feasible alternative based on capacity considerations.

Based on the above, a traveller would experience a total crossing time, including waiting time, of between 30 and 90 minutes.

Another option is an electric rail shuttle, single-track operation. This could be made to operate at a higher speed than might be safe for road vehicles, (design speed assumed at 100 kilometres per hour) and it could be designed for different capacities per train. For example, in order to provide sufficient capacity for 250 vehicles per hour per direction, there would have to be two trips, each with 125 vehicles per direction. A 21-car train with six vehicles per car, and seating capacity for passengers (likely remaining in their vehicles) would accomplish this. This option is close to the upper limit of projected capacity requirements, however.

The rail shuttle option assumes a 12 hour operating day during which trains would leave Newfoundland at 30 minute intervals and would leave Labrador at 30 minute intervals. Train loading and unloading allowances are between 5 and 15 minutes depending on time of traveller arrival. The trip time has been calculated at 15 minutes. Based on this operating scenario, a traveller would experience a total crossing time including waiting, loading and unloading, of between 25 minutes and 60 minutes.

Therefore the three options to consider for costing and preliminary design are; for the bridge and causeway alternatives, (i) two lane road, and for the tunnelled options, (ii) managed one lane configuration for motor vehicle operations, and (iii) electric train shuttle operation for passenger cars and commercial vehicles with capacity for simultaneous load/discharge of at least two 21-car train sets.

Road Tunnel

Clearances

The traffic analysis discussed above indicated that a single-lane tunnel operated in a cycle with flow in one direction followed by flow in the opposite direction will satisfy the projected traffic demands. There are no specific vertical and lateral clearance standards for single-lane uni-directional tunnels, and in North America, general standards for clearances in tunnels are not well established. The following documents were therefore referenced in order to obtain guidance on appropriate clearance standards for the highway tunnel option:

- PIARC: World Road Association “Cross Section Geometry in Unidirectional Road Tunnels”
- AASHTO Standard Specification for Bridges, Section 2.5 Highway Clearance for Tunnels

Using the guidelines within these documents and HMM’s experience on similar highway tunnel projects, the following parameters were adopted for development of highway tunnel cross-sections:

◆ Maximum truck width	2.6 metres
◆ Maximum truck height	4.2 metres
◆ Lane width	3.75 metres
◆ Vertical clearance from vehicle running surface	4.65 metres
◆ Off-roadway distance	0.75 metres + shoulder width
◆ Shoulder width	1.25 metres

This configuration permits vehicles to pass a truck or other vehicle that has broken down within the tunnel as shown in Figure 3.4.

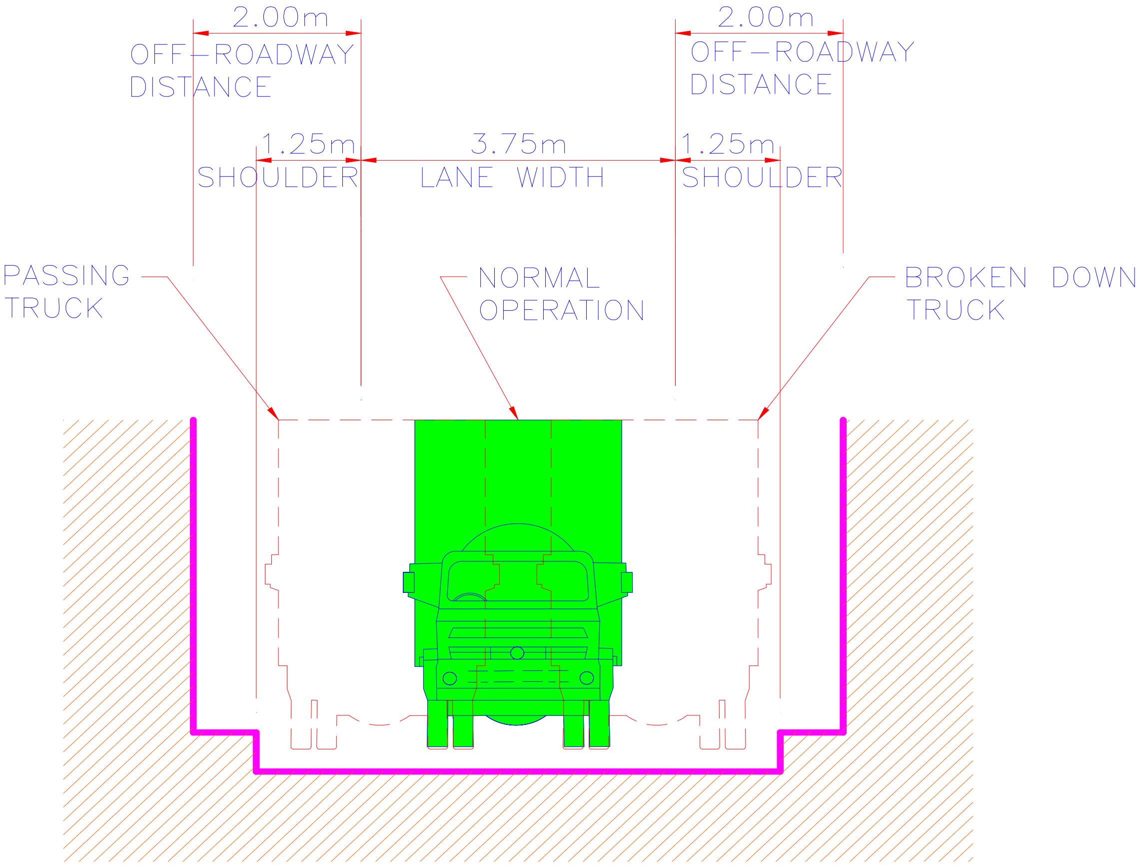

Figure 3.4 – Road Tunnel Clearance Details

Emergency Egress

A fundamental consideration in the selection of cross-section is the provision of emergency egress from the tunnel. The National Fire Protection Agency code; “NFPA 502 – Standard for Road Tunnels, Bridges and Other Limited Access Highways” requires that emergency exits shall be provided at 300 metres intervals. With a single tunnel, this feature can only be provided by a passageway, fire-separated from the vehicular space.

Ventilation

Spatial allowances for ventilation in road tunnels can have a significant impact on the tunnel dimensions. There are two principal systems for ventilating road tunnels as follows:

- Longitudinal ventilation – this system of ventilation uses jet fans spaced along the length of the tunnel to drive a continuous flow of fresh air through the tunnel. The system is only suited to short road tunnels as required velocities to overcome frictional resistance become very high in longer tunnels. The system can be used for longer electric train rail tunnels.

- Transverse ventilation – this system of ventilation passes fresh air transversely across the tunnel at discrete locations throughout its length with separate supply and exhaust ducts being used for supply of fresh air and removal of polluted air. Such a system is generally adopted for long road tunnels.

A preliminary analysis of the ventilation requirements was undertaken assuming a 20.5 kilometre road tunnel with six percent grades and using the projected traffic from the preliminary traffic demand analysis undertaken during Phase 1 of the study. The study also recognized the planned operation of the tunnel as a single-lane facility with traffic operating periodically in one direction and then in the other direction. This analysis indicated that the optimum method of ventilating the road tunnel is likely to be a combination of longitudinal and transverse ventilation with the tunnel divided into five separate ventilation zones as shown in Figure 3.5 below. This method would have jet fans installed within the tunnel at intervals to encourage longitudinal flow. However, these jet fans alone would not provide enough ventilation for a tunnel of this length. Therefore, additional fresh air would be introduced and stale air removed at four discrete points along the length of the tunnel. These four points divide the tunnel into five ventilation zones as shown in Figure 3.5. To deliver and remove air from the discrete ventilation points large dimension conduits are required. For Zones 1 and 5 these requirements are doubled, as parallel conduits are needed to reach the inner ventilation points. In the conceptual configuration, as Zones 1 and 5 are largely under land, it may be possible to deliver this additional ventilation via shafts and parallel tunnels.

With this scheme, there would be an advantage to provide a variable cross-section tunnel with the spatial arrangement adjusted to the requirements of the various zones. This is possible for drill-and-blast excavation but would likely not be practicable for TBM driven tunnels since a change in TBM size would be required.

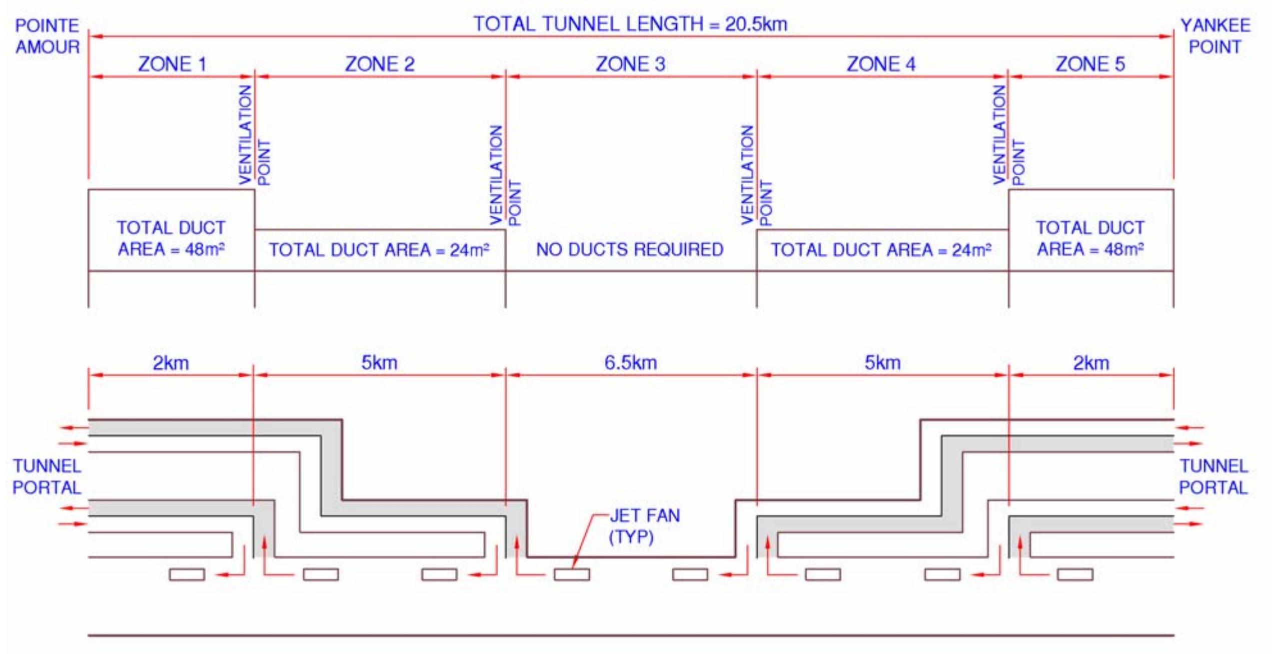

Figure 3.5 – Road Tunnel Ventilation Duct Requirements

Consideration was also given to the use of mechanical air scrubbers as a means of providing a constant supply of clean air within tunnel. This concept has been used in the Laerdal Tunnel in Norway, in one or two tunnels in Japan, and is under consideration for tunnels in Australia. Research on these applications revealed that the technology is in its infancy and that there have been problems with maintaining the scrubbers and with their high energy usage. In the Leardal tunnel, the air cleaning facility has not really been tested since the traffic and related pollutant levels have not required their use. One particular problem, yet to be resolved, is that the scrubbers only remove particulate matter and do not address other chemical pollutants. These are presently removed by passing tunnel air over beds of activated charcoal. These beds require large surface areas that are difficult to accommodate underground.

Therefore, for the purposes of this study, in-tunnel cleaning of the air has been considered to be unreliable and has not been considered further. This is an area of technology that may be more developed when this project is progressed further and should not be discounted completely if the road tunnel scheme were pursued.

Rail Tunnel

Clearances

Tunnel size requirements are reasonably well defined for railway tunnels, and for the purposes of this study it has been assumed that a ‘shuttle’ railcar similar to that used for the Channel Tunnel and associated tunnel clearance envelope are appropriate. Figure 3.6 shows the required dynamic clearance envelope for such a vehicle.

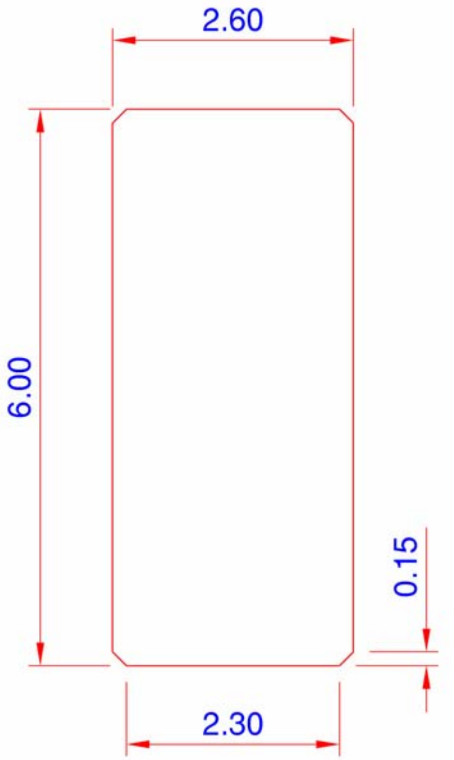

Figure 3.6 – Dynamic Clearance Envelope for Shuttle Railcar

Emergency Egress

Although tunnel fires and similar emergencies are less likely to occur in railway tunnels, it is essential to provide a means of emergency escape. A continuous escape passage for the full length of the tunnel has therefore been provided. The National Fire Protection Agency code, NFPA 130, requires that emergency exits be provided at 240m intervals.

Ventilation

Preliminary analysis of the ventilation requirements for the railway tunnel option was based on the use of electric trains and 1.5 percent grades on either side of the Strait. A 27 kilometres long railway tunnel can be adequately ventilated using longitudinal ventilation with jet fans distributed along the tunnel.

HVDC Cabling Requirements

The proposed fixed link could accommodate the installation of High Voltage Direct Current (HVDC) power cables, a component of the proposed transmission link between the Island of Newfoundland and the proposed hydroelectric developments on the lower Churchill River in Labrador. The expected basic parameters of the transmission system as provided by Newfoundland and Labrador Hydro are as outlined below:

Power transfer capacity of the link	800 MW.
Proposed circuit voltage	+/-400 kV
Minimum nominal cable current capacity	1000 Amperes
Nominal cable power capacity per cable	400 MW
Number of cables proposed in service	2, one positive, one negative
Number of spare cables	1, connectable positive or negative.
Circuit length, Gull Island to Soldiers Pond	1100 kilometres

The aerial (overland) component of the circuit is not the subject of this discussion, but for interest sake it may be assumed that each pole of the circuit, positive and negative, will be composed of 2 conductors with roughly 2000 Amperes total capacity to allow for possible temporary overload operation of 800 MW per pole. The conductors would probably be ACSR of a size range between 1033 and 1590 kCMil.

Each cable in the tunnel is expected to be capable of carrying 1000 Amperes, on a steady state basis, with temporary overload capability for between 10 to 20 minutes of 2000 Amperes. It is expected the cable would thus be oversized to some extent to allow for this overload capability; a rating of 1150 Amperes was proposed in previous design exercises. There are a limited number of different cable types that could be used for the cable circuit, as listed below:

- High-pressure pipe-type cable, either gas or oil-pressurized
- Gas pressurized cable
- Low-pressure oil-filled cable
- Solid dielectric cable

These various cable types have been reviewed in detail in the engineering studies referred to previously. The high-pressure alternative was not favoured on the basis of high cost, and the lack of applicability of this cable type to dc cable circuits, particularly those in protected environments such as tunnels. The gas-pressurized paper-impregnated cable type has existed for many decades, and experience has generally been favorable; however, its use has been limited. As there is very little of this type of cable being manufactured at this time, and there are concerns with its use in cases where significant elevation changes occur, due to cable impregnation compound migration, this cable type was also not favored. The cable type that was recommended previously is the low-pressure oil-filled type of cable. This cable has been in use for many decades and it is still the only cable that is normally considered for ac circuits at the 500-kV voltage level. The use of this type of cable is of concern when proposed for use over routes that have a significant variance in elevation. There are, however, existing well-proven design practices that allow a solution to these problems. For instance, the Churchill Falls Powerhouse has some thirty-three 230-kV low-pressure oil-filled cables with approximately 300 metres in elevation difference from one end to the other, and these have proven satisfactory in operation for more than 30 years. Thus, this cable type can be considered suitable for use in the current application.

The fourth type of cable, solid dielectric power cable, meaning cable with cross linked polyethylene insulation was not considered suitable during the original engineering study because its reliability wasn’t considered proven at the proposed voltage level. In the intervening years, solid dielectric cable designs have been the subject of much improvement; and they have now come into common usage at the 230-kV ac level, and they are also being used fairly routinely at the 345-kV ac level. The cable in the tunnel, operating at +/-400-kV dc, would be subject to voltage stresses slightly above standard 230-kV ac levels; however, solid dielectric cables should be considered suitable for use in the fixed link tunnel at this time. As this type of cable has no liquid in its composition, the major problem experienced with oil-filled cables, namely excess pressures inside the cable due to changes in elevation, would not exist. One benefit of using solid dielectric cables is that the elaborate fire prevention and extinguishing systems needed with oil-filled cables are not essential, although some fire detection measures are required, because cross linked polyethylene does burn, and when doing so it gives off noxious gases.

A nominal conductor size of 800 mm^2 copper, or 1150 mm^2 aluminum, should be adequate to provide a continuous nominal current rating of 1150 Amperes for both the low-pressure oil-filled cable type, or the solid dielectric cable type. Copper has been the more commonly used conductor material in the past; but aluminum is becoming used more often, due to its lower cost and lighter weight. Copper conductor, oil filled cables, would have an outside diameter of approximately 100 mm, with the aluminum conductor alternative being slightly larger.

There are a number of different ways in which the cables can be supported within the tunnel. The original design study assumed the cables would be laid in open concrete trenches, presumably located to one side of the tunnel. Two other ways of installing the cables would be to either fix them to the side walls or ceiling of the tunnel using appropriate supports. Hardwood clamps dowelled into the walls or ceiling of the tunnel have proven suitable in previous installations; or the cables could be supported as they traditionally are in underground mines, by suspension from strands supported from dowels in the walls or ceiling of the tunnel.

The space envelope required in which to accommodate HVDC cables would be in the order of 1 metres along the face of the tunnel by 300 mm deep. The space needed for splicing would be larger than this envelope. The splices should be staggered so that they are not all in the same longitudinal space. When finished, a splice itself, along with its two companion cables, would not require an area significantly larger than the envelope described above. In order to make a splice, a minimum working space approximately 6 metres long by 2 metres wide would be required, with an appropriate height allowance for working room. Once the splices are made, they should be permanent and need no further attention; but to cater to the possibility of a splice failure, provision would have to be made during the construction phase of the project to replace one or more splices if needed. Replacement of a splice could take as long as a week. Given the size of the cable to be installed, a reel length of between 800 to 1000 metres may be assumed. During the actual execution of the work, every reasonable attempt should be made to maximize the reel length employed so as to ensure the minimum number of splices, which will be the most failure-prone portion of the circuit, as well as the most time-consuming portion of the installation exercise. Enough spare splicing materials should be kept near the site to ensure a replacement splice can be installed if, and when required, without a significant wait to obtain suitable materials.