2 REVIEW OF RELEVANT FIXED LINKS WORLDWIDE

A review was undertaken of fixed links worldwide that were considered to be of relevance to a fixed link across the Strait of Belle Isle. Fixed links crossing ocean channels and straits comparable to this location were selected. Examples were also selected to illustrate the different types of construction methodologies available for the provision of such fixed links. In general terms, the types are: multiple medium span viaducts or rock fill causeways; long span bridges, either cable-stayed or suspension; and tunnels, immersed tube or bored.

2.1 Øresund Link

The Øresund Link, that opened in 1999, connects Denmark and Sweden across the Øresund Channel. The crossing accommodates a four lane highway and a twin track rail line. The 22 kilometre channel is crossed by a combination of a 16 kilometre bridge and a 6 kilometre immersed tube tunnel (ITT). The tunnel section provides the primary shipping channel. A secondary shipping channel is accounted for by a long cable-stayed span within the bridge section.

The multi-functional requirement of the tunnel suits the low profile rectangular structure that can be easily provided by an ITT, as shown on Figure 2.1. The requirement for both rail and road resulted in a structure approaching 40metresin width that would have been very difficult to accommodate in a bored tunnel configuration. Further, the shallow channel (about 22 metres deep) lends itself to immersed tube construction within the overburden seabed.

The lesson learned from this crossing was that immersed tube tunnels are very applicable to, and efficient for, shallow channels and where the tunnel configuration requires a low profile rectangular cross-section.

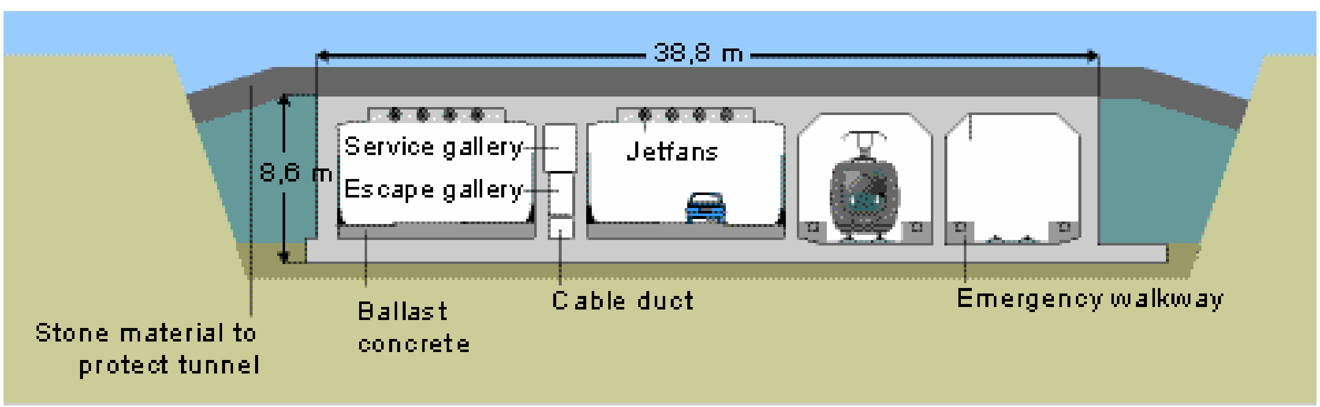

Figure 2.1 – Øresund Link Cross-Section

2.2 Storebælt Crossing

The Storebælt Crossing, as shown in Figure 2.2, between the islands of Funen and Zealand in Denmark opened in 1998 and is part of the highway and rail connection between Denmark and Sweden. Like the Øresund Link, the crossing provides a four lane road and a twin track rail line. The total crossing length of 16 kilometres is comprised of a bridge for rail and road from Funen to a small island within the channel, with a bridge for the road plus bored twin tunnels for the rail line across the primary shipping channel between the island and Zealand. The depth of the channel, at about 60 metres, and the tunnel cross-sections suited to bored tunnels, made an immersed tube tunnel not economically competitive. The twin tunnels are approximately 8 kilometres long and were constructed in overburden below the seabed using earth pressure balance tunnel boring machines.

The lesson learned from the tunnel section was that bored tunnels could be built in very challenging ground conditions. The tunnel construction experienced significant difficulties. It represented an early application of earth pressure balance tunnel boring machines and provided many lessons that have contributed to earth pressure balance TBMs now becoming the standard technique for soft ground and soft rock tunnelling.

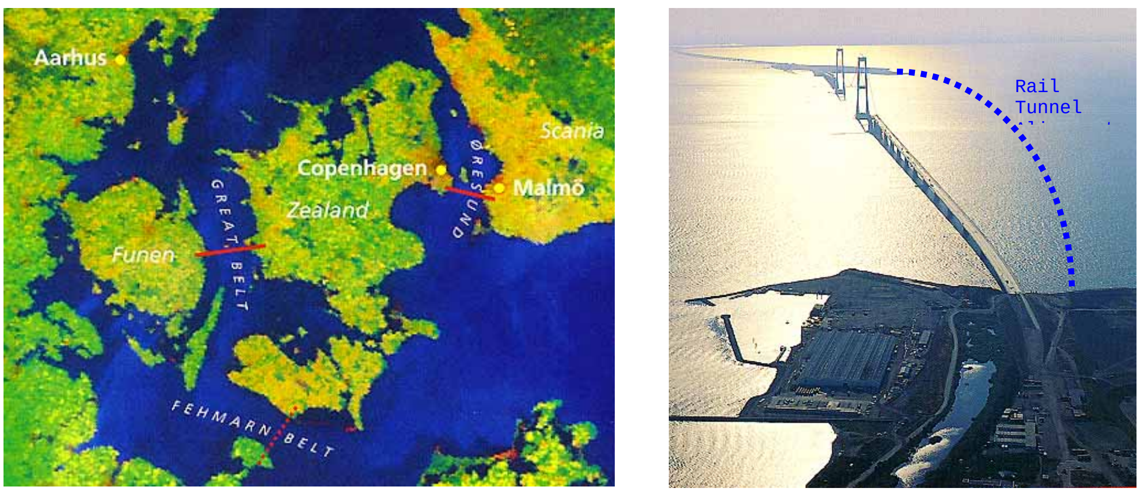

Figure 2.2 – Storebælt Crossing

2.3 Channel Tunnel

The Channel Tunnel, as shown in Figure 2.3, was opened in 1994 and is probably the most famous fixed link in the world. The tunnel is actually three 50 kilometre-long parallel tunnels; two running tunnels carrying rail tracks and one service tunnel for maintenance vehicles and for emergency egress. The tunnels were constructed by tunnel boring machines excavating in a layer of chalk marl that extends across the Channel. The tunnels are used by high speed Eurostar trains operating at 160 kilometres per hour through the tunnel as well as by custom-built shuttle trains conveying passenger cars and trucks loaded and unloaded at the terminals.

The lessons learned from the Channel Tunnel are numerous. The following are considered relevant to this study. The chalk marl was predicted to be an almost ideal tunnelling material. It was expected to be virtually impermeable, to be easily excavated and to stand up generally with a minimum of support. These properties eventually allowed very impressive advance rates to be achieved by the TBMs and the tunnels to be completed on schedule even after significant problems at the beginning of the drives where the geology was much worse than expected. At the start of the drives, the marl was found to be blocky and requiring immediate support. The marl was also permeable resulting in significant salt water ingress affecting the performance of the electrical locomotives for muck hauling and reducing the grip on the upgrades at the end of the tunnel. In this zone the choice of an unsealed tunnel lining on the UK side was put into question. On the French side, the marl was expected to be fractured and earth pressure balance TBMs with a gasketted lining were selected. These selections proved to be prudent as difficult ground conditions were encountered and the TBMs dealt with these and the 11 atmospheres of water pressure, albeit with somewhat reduced advance rates.

The Channel Tunnel costs became inflated due to several reasons mostly unrelated to the actual construction. Included in these reasons was the inefficiency of a complex organisation for procuring the project with five French Contractors and five British contractors working for a newly created company called Eurotunnel that had no experience managing a project of this magnitude. Further, the fact that the tunnel connected two countries that had a history of disagreeing created arduous decision processes. These were particularly demonstrated within the vehicle procurement when the shuttle railcars were redesigned many times, greatly increasing their cost and complexity and delaying the operation date for the facility. Therefore the Channel Tunnel cannot be used as a simple comparator to the fixed link proposed across the Strait of Belle Isle due to the size and complexity of the facility as well as the issues described above.

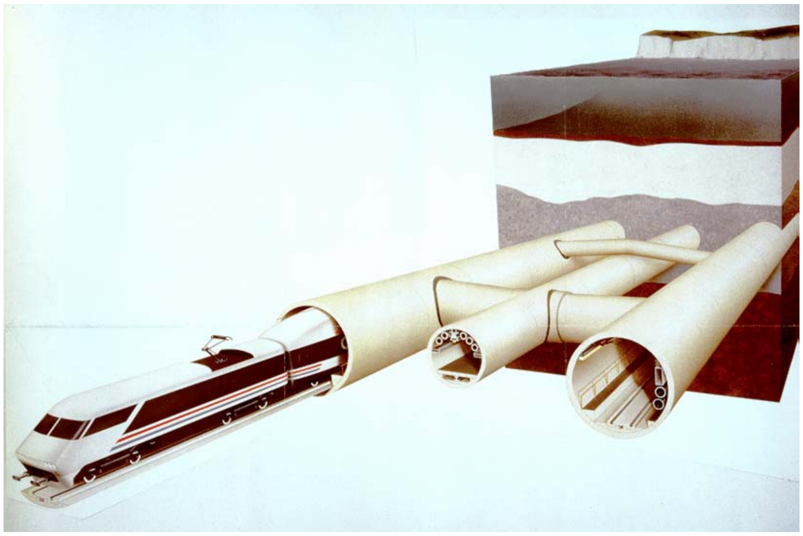

Figure 2.3 – Channel Tunnel

2.4 Lantau Link

The Lantau Link, as shown in Figure 2.4, is a series of bridges to connect the new Chek Lap Kok Airport to the Hong Kong mainland. This relatively short (3.5 kilometres) crossing is a very high capacity facility with two bridge decks, the upper deck carrying a six lane highway and the lower deck accommodating a two track rail line plus two emergency road lanes.

The main lesson learned from this fixed link is that long span suspension and cable stayed bridges can be designed for high traffic capacity and to withstand severe weather conditions in the form of typhoon strength winds.

Figure 2.4 – Lantau Link

2.5 Chesapeake Bay Bridge-Tunnel

The Chesapeake Bay, as shown in Figure 2.5, fixed link is a 28 kilometre crossing of the shallow Chesapeake Bay made up of multi-span bridge viaducts connected to an immersed tube tunnel under the shipping channel. The initial crossing was constructed in 1964 as a two-lane road structure. The two viaduct structures were duplicated in 1999 but both presently connect to the single two-lane tunnel.

The major lesson learned on this fixed link is that any structure that limits the depth of the shipping channel should be located to allow for future increases in shipping drafts. The present Chesapeake Tunnel draft will not accommodate the latest Panamax container ships and studies are underway to investigate the lowering of the existing tunnel as well as duplicating the facility. The link also demonstrates that multi-span bridges provide an economical alternative where the channel is reasonably shallow.

Figure 2.5 - Chesapeake Bay Bridge Tunnel

2.6 Confederation Bridge

The Confederation Bridge, as shown in Figure 2.6, was completed in 1997 and provides a two lane road fixed link between Prince Edward Island and New Brunswick across the 13 kilometre wide Northumberland Strait. This channel is relatively shallow at 30 metres deep and is therefore suited to a multi-span bridge. The limited amount of shipping that uses the Strait is accommodated by a single high clearance long span. The design of the bridge included allowances for ice floe loadings.

This crossing demonstrates that, where conditions are suitable, multiple span bridges can be economical. However, conditions, such as deep water, icebergs and significant shipping traffic, make their application more difficult or even impracticable.

This fixed link is also of interest in that it was built as a largely privately funded project with investment recovery through tolls and annual subsidies from government equivalent to those provided for the ferry it replaced.

Figure 2.6 – Confederation Bridge

2.7 Summary of Fixed Links

Table 2.1 provides a summary level comparison between the listed fixed links. The data contained in this table has been obtained from published sources and costs have been converted to Canadian dollars using present currency conversions and inflated to 2004 dollars using published inflation rates. Considering this process, the costs in this table should be recognised as being indications of comparative rather than absolute costs.

Table 2.1 – Summary of Fixed Links

	Crossing Length	Water Depth	Vehicles/day	Road	Rail	Rail Passengers/day	Year Opened	Cost $M(2004CAD)	Cost/km $M(2004CAD)
Øresund Link	22 km	30 m	9,300	✓	✓	14,800	1999	4800	300
Storebælt Crossing	16 km	60 m	20,600	✓	✓	30,000	1998	7700	430
Channel Tunnel	50 km	50 m	8,300		✓	17,600	1994	34400	690
Lantau Link	3.5 km		40,500	✓	✓	250,000	1997	2300	660
Chesapeake Bay Bridge/Tunnel	28 km	30 m	8,800	✓		-	1964	2000	75
Confederation Bridge	13 km	30 m	N/A	✓		-	1997	1200	90

2.8 Other Relevant Tunnels

Also of relevance to this study are two tunnels recently constructed in Europe. These are the Vereina Tunnel in Switzerland and the Laerdal Tunnel in Norway. These are both tunnels of significant length for relatively low traffic applications. The Laerdal Tunnel is the longest road tunnel in the world. This two lane tunnel was constructed by drill and blast techniques through gneiss. The Vereina Tunnel has a single track rail shuttle for conveying road vehicles. This tunnel was constructed partially by drill and blast and partially by tunnel boring machine, again in gneiss. Both these tunnels demonstrate the ability in Europe to build low cost tunnels. Table 2.2 shows the features of these tunnels.

Table 2.2 Other Relevant Tunnels

	Crossing Length	Vehicles/day	Road	Rail	Rail Passengers/day	Year Opened	Cost $M(2004CAD)	Cost/km $M(2004CAD)
Vereina Tunnel	19 km	1500		✓	4000	1999	440	23
Laerdal Tunnel	25 km	1000	✓		-	2000	245	10