Union Connectivity Review

A Fixed Link between Great Britain and Northern Ireland: Technical Feasibility

November 2021

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Foreword

In October 2020, I was asked by the Prime Minister to lead the Union Connectivity Review (UCR): a detailed review of how the quality and availability of transport infrastructure across the United Kingdom can support economic growth and improve the quality of life across the whole of the UK. This standalone report should be considered as a companion document to my final UCR report.

As part of the review, I was also asked to assess the technical engineering feasibility of constructing a fixed transport link between Great Britain and Northern Ireland. Undertaken as a separate workstream, in March 2021, world-renowned technical advisors Professor Douglas Oakervee CBE and Professor Gordon Masterton OBE were appointed to lead the study. At the same time, a partnership of Jacobs and COWI was appointed by the Department for Transport to provide independent engineering expertise to the technical advisors.

This in-depth, evidence-based assessment has concluded that cutting-edge, twenty-first century civil engineering technology would make it possible to construct either a bridge or a tunnel between Great Britain and Northern Ireland. A bridge crossing, however, would be the longest span bridge built to date. A tunnel would be the longest undersea tunnel ever built given the limited gradients on which trains can operate, the route it would need to take and the depths it would need to reach. In addition, based on today's technology and safety considerations, a tunnel crossing could only be constructed for railway use.

The need for a railway on either a bridge or tunnel would also require significant construction to connect it to the railway network at either end, introducing some complexity since the Irish railway gauge is different from that of Great Britain.

The consequence of these parameters for either a tunnel or a bridge is that they are expensive. The indicative cost estimate for the full route, including optimism bias (at P95), is £335bn for a bridge crossing and £209bn for a tunnel crossing. The bridge or tunnel, and the associated very significant works on either side for a railway and possibly for roads would take a very long time. Planning, design, parliamentary and legal processes, and construction would take nearly 30 years before the crossing could become operational, even given a smooth passage of funding and authority to proceed.

Whilst the economic and social effects would be transformational, the costs would be impossible to justify, given the Government’s already very significant commitment to long term transport infrastructure improvement for levelling up, and the further likely significant expenditure which would result from the further studies I am suggesting in my main UCR report.

Future transport technological advances, particularly autonomous vehicles, could allow for different tunnel and bridge designs, which could enable the construction of a fixed transport link and approaches at a lower cost. For now, though, the benefits could not possibly outweigh the costs to the public purse. **It is therefore my recommendation to Government that further work on the fixed link should not progress beyond this feasibility study.**

Despite my recommendation, I am clear that this was an excellent question to ask. For many decades, politicians and engineers have debated this proposal, but have done so without the evidence to show whether it was possible and, if so, what it would take to do it. This is the first comprehensive, conclusive study on the subject since the idea was first mooted over 150 years ago.

I am indebted to Doug and Gordon, and the teams, who have delivered this remarkable piece of work. Whilst I am unlikely to see such a link built in my lifetime, the march of technology, breakthroughs from UK infrastructure research, and ever-developing British engineering skills may yet be able to satisfy the ambition to join up Great Britain and Northern Ireland at an affordable price and timescale, and wise investment in UK research and development will bring this time closer.

Sir Peter Hendy CBE

Preface

During the four-month study period, the technical advisors and their supporting engineering team have undertaken a comprehensive evidence-based desktop study. Physical surveys and ground investigations were not within the scope of the assignment, but the desktop study provides realistic options for the fixed link crossing demonstrating that constructing either a bridge or tunnel crossing of the Irish Sea is technically feasible. However, this would not be without significant challenges, albeit not insurmountable.

This report summarises the preliminary findings and the engineering realities in constructing a fixed transport link between Great Britain and Northern Ireland. It also considers the indicative range of costs and timescales for construction, including high-level estimations of the carbon footprint during construction. However, the economic viability of the provision of such a link was not within the scope of this study.

As part of the UCR, Sir Peter Hendy issued a call for evidence (CfE) which ran from November to December 2020. Responses relating to the provision of a fixed transport link have been analysed and those most relevant to the scope of this study have been considered in this assessment. A full summary of the UCR CfE responses has been published alongside the main UCR report.

Introduction

The study has revealed that the ambitions of politicians, entrepreneurs and engineers over the past 150 years to link Great Britain with the island of Ireland are now feasible because of 21st century technology. That said, the physical challenges of the Irish Sea and the North Channel must not be underestimated. Both a tunnel and bridge option are technically feasible to construct, but they would be the longest undersea tunnel or the longest span bridge ever built. A combination of tunnel and bridge incorporating artificial islands as employed in Scandinavia and China is not possible due to the great depth of the Irish Sea and other inhibiting factors. It is also important to note that the road and rail infrastructure required to connect the fixed link crossing to the main transport networks in Northern Ireland and Great Britain are in themselves major construction works.

If a decision to proceed is taken, the recent history of major UK construction projects suggests that with planning, design, the parliamentary process necessary to provide the statutory instruments to proceed and then the construction of both the crossing and the approach infrastructure, it is unlikely that the project could commence for approaching 10 years, followed by at least 17 years of design, construction and commissioning. Therefore, unless some extraordinary steps were taken, it is unlikely that new transport links would be commissioned, constructed and opened for at least 25 to 30 years.

The capital investment for such a scheme would be significant, but the main spend would be spread over approximately 20 years. However, the economic viability of the provision of such a link would require a detailed benefits analysis, which is not within the scope of this study.

The project would generate tremendous demand on construction and engineering supply chains but, if properly planned and incentivised, could revitalise parts of the United Kingdom’s industry. The project would likely give rise to more than 35,000 new jobs and apprenticeships for the design and construction phase alone.

Before such a project could be allowed to go forward, a major exercise would be needed to evaluate the carbon impact over the whole life of the new assets. Preliminary work indicates that the fixed link, whether a bridge or a tunnel, should be carbon neutral within 40 to 60 years after construction. Both options would reduce the need for higher carbon intensity air transport and could help create renewable energy sources. The bridge could be used as a platform to generate renewable energy from wind, tidal and solar sources, whereas the tunnel could be a heat source through the tunnel lining for its whole length.

A fixed link crossing would allow cabled and piped utilities and services to replace current seabed crossings with enhanced reliability and reduced maintenance. It could also be a potential carrier for very high-speed transportation technologies such as hyperloop if they become viable. This technical feasibility study has, however, avoided making any assumptions on immature and untried technologies in determining both the modes of transportation expected to use the crossing as well as the materials and methods used in its design and construction. Like any long-term project, if it goes forward, it must be receptive to innovation from science and technology developments. It is also likely that, subject to continuing investment in infrastructure research, such advances could bring about cost and carbon savings compared with the indicative ranges provided.

Earlier Proposals

Speculative proposals for a fixed link between Great Britain and the island of Ireland have tantalised engineers and politicians since at least 1868.

But these early visionary prospects were not practical propositions—a line on a map rather than a credibly viable engineering project. The Severn Railway Tunnel was completed in 1886 and the Forth Bridge in 1890 which inspired more speculation on grander schemes.

In 1890, advocates of a North Channel tunnel linking Ireland and Scotland assembled in Belfast's council chambers. Frederick W. McCullough, the Chief Assistant to consulting engineer Luke Livingston Macassey, had laid out a plan for a tunnel beneath Beaufort's Dyke earlier that year. Macassey himself had proposed a tunnel to the Mull of Kintyre even earlier. And at the same meeting, James and John Barton first revealed their chosen route for a tunnel that bent round the northern end of Beaufort's Dyke.

Luke Livingston Macassey self-published a pamphlet *The Proposed Channel Tunnel and through trains between Edinburgh, Glasgow, Manchester, Belfast and Londonderry*[1] before the end of that year.

In 1897, J Ferguson Walker wrote an 18-page article *An Irish Channel Tunnel*[2] for the Contemporary Review. He reviewed every scheme proposed till then. The rapporteur and engineer, Harrison Hayter, concluded that there was every reasonable probability that the work could be accomplished.

James Barton and Frederick McCullough both attended the International Engineering Congress held in Glasgow on 3-5 September 1901, in the presence of the illuminati of British engineering, presided over by Lord Kelvin of the University of Glasgow and by James Mansergh, the President of the Institution of Civil Engineers. There would never again be such a prestigious engineering congress in the United Kingdom, nor one so widely reported in the world's press—the perfect forum to raise support for grand schemes and big ideas.

James Barton presented a paper on *The Proposed Tunnel between Scotland and Ireland*[3]. It begins by describing the three potential crossing points:

- The Mull of Cantyre (sic) (12.5 miles)
- Wigtownshire to Antrim (21-25 miles)
- Holyhead to Howth (52 miles)

The first is quickly dismissed as being of no benefit to England-Ireland trade, and little enough for Scotland-Ireland, with large costs and difficulties in creating new rail links to Glasgow. The third is dismissed on account of a 52-mile tunnel being six times the length of any tunnel yet constructed, and whilst of great value in facilitating England-Dublin trade, being of no value to Scottish-Irish traffic. His preferred route was the second, giving the best route for the North of England and Scotland to the whole of Ireland, and the best route for the whole of Great Britain to Belfast and the north of Ireland. The observation was made that the success of this route would go far to assuring the success of a longer tunnel to Dublin at a future time. He chose a route to the north of the deep trench of Beaufort's Dyke, with a fairly sharp deviation to take it to Antrim, emerging to the surface north of Carrickfergus (Figure 1).

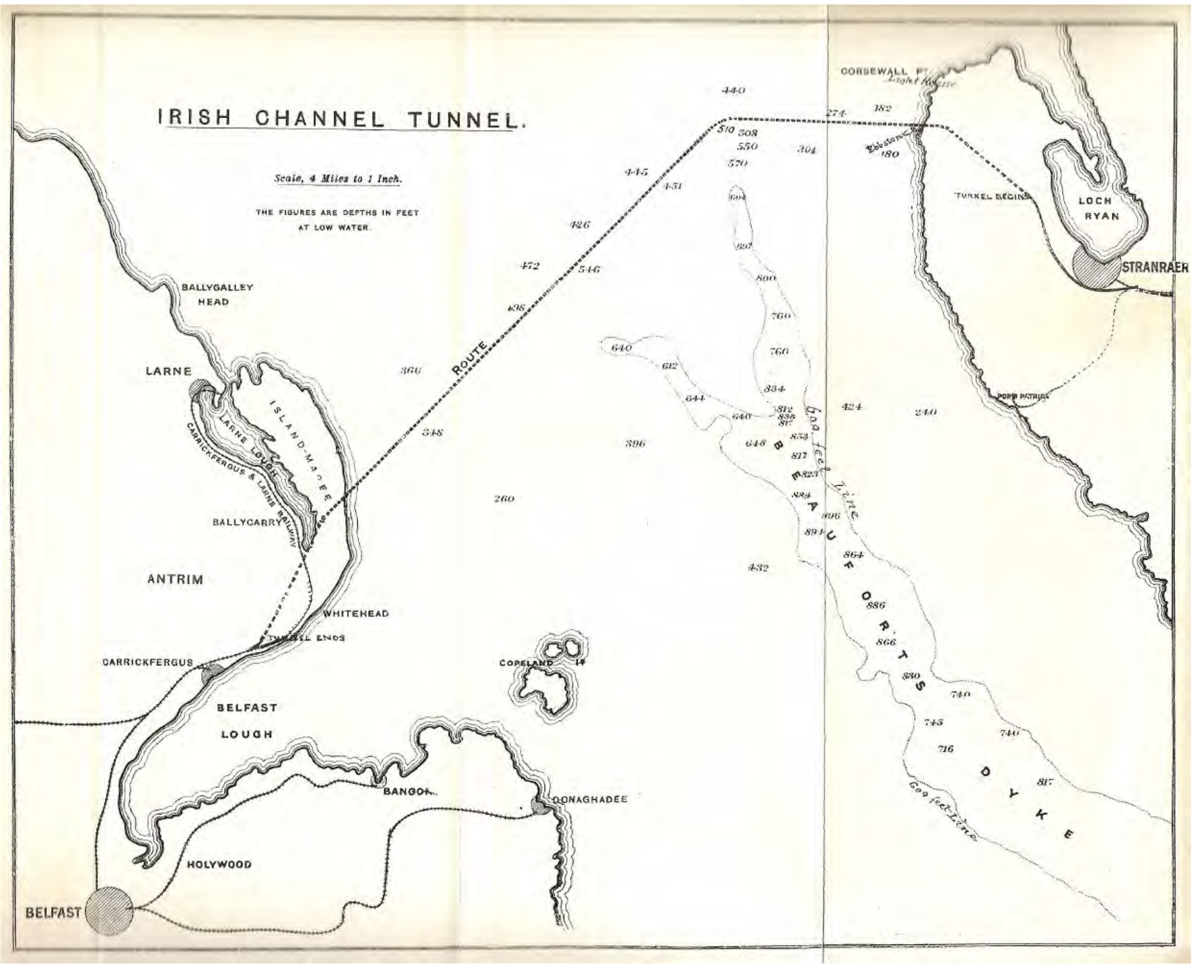

Figure 1: James Barton's proposed route for a tunnel between Scotland and Ireland[4].

He had consulted with the Irish and British Geological Surveys and the eminent engineer Sir Douglas Fox. He proposed electrically powered trains with a plausible explanation of how ventilation would be dealt with.

Sir Douglas Fox was in the audience and congratulated Barton on the quality of his research, and also challenged McCullough's chosen route below Beaufort's Dyke, saying that it gets “into the very difficulty we certainly ought to avoid”[5]. He was strongly of the opinion—from experience on the Mersey tunnel and other projects—that it would be “a very risky operation to go across that chasm which has been ploughed out in the bed of the sea”[6].

Despite the publicity gained, nothing became of the Barton proposal, and even if built at the time, it would have fallen short of meeting today’s safety standards for an operational railway tunnel.

The idea of a fixed link remained dormant through the two world wars, doubtless on the grounds of affordability, but was briefly revived in parliamentary debates in the mid-1950s, which again went no further.

Nothing became of these early proposals, mainly because engineering technology had not advanced sufficiently to be confident of completing them and costs had not been robustly estimated, a feature in common with more recent speculations.

This study has been more comprehensive than anything that has been done before and gives confidence that more recent advances in bridge and tunnel design, and their construction techniques, offer technically feasible means of constructing a fixed link, albeit at a considerable cost.

Existing Transport Links

Northern Ireland is the only nation of the UK that is geographically separated from the rest of the UK, it therefore relies on air and maritime connectivity to access Great Britain. In 2019, 6.47 million passengers flew between Northern Ireland and Great Britain, with Belfast-London being the most popular route[7].

The economic contribution of domestic aviation to the Northern Ireland economy is estimated to be around £2 billion per annum[8] with air freight services being responsible for around 6% of all economic activity in Northern Ireland[9]. Belfast International Airport was the second largest UK airport by domestic freight tonnage in 2019, handling around 14,000 tonnes[10]. There is a correlation between journey times and how many people choose to travel by rail over air. If it takes the same amount of time to travel by rail or by air, the evidence shows that people choose to travel by rail. Rail is typically favoured when the journey time is around three hours between city centres[11,12].

The other travel mode between Great Britain and Northern Ireland is by road with ferry crossings from Wales to Ireland (principally Dublin to Holyhead) or from Scotland direct to Northern Ireland (principally Belfast to Cairnryan) (see Figure 2). Journey times are of course significantly longer. There are significant passenger and goods flows between Belfast and Cairnryan and the Port of Belfast is the largest UK port for domestic freight, handling 12 million tonnes a year[13].

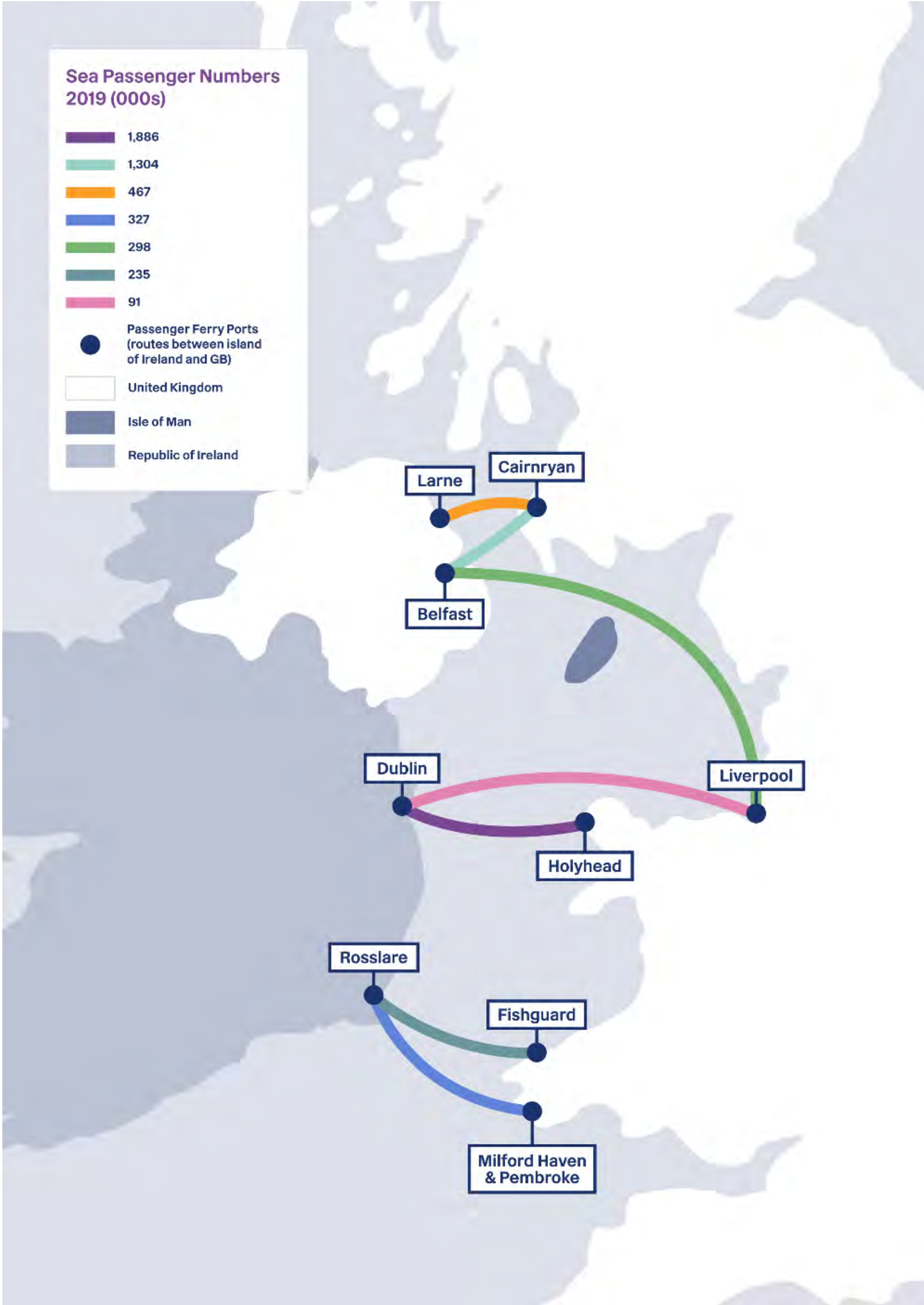

Figure 2: Passenger ferry crossings from Great Britain to the island of Ireland (2019)[14].

There are no existing rail connections between Great Britain and the island of Ireland. The road connection from the strategic road network in Great Britain to Cairnryan is via the A77 from Glasgow or the A75 from A74(M)/M6 corridor. Both roads are predominantly single carriageway with low average speeds. In Northern Ireland, the Port of Belfast is located a short distance from the city centre.

The proven operational model for benchmarking the fixed link feasibility is the Channel Tunnel between the UK and France, which is the only fixed link between the island of Great Britain and the European Mainland. The Channel Tunnel is a rail only crossing with services split as follows by market segment:

- High-speed passenger only rail services
- A dedicated HGV shuttle service
- A dedicated car and van shuttle service
- Rail freight trains connecting to the UK and French railways

The Channel Tunnel is now well connected to the rail and motorway networks in England and France. Shuttle trains are accessed via purpose-built terminals at Folkestone and Coquelles for efficient loading and unloading of shuttle trains. This wider connectivity from the fixed link is of paramount importance for maximising its potential and is an integral part of this study.

The Challenge of the North Channel

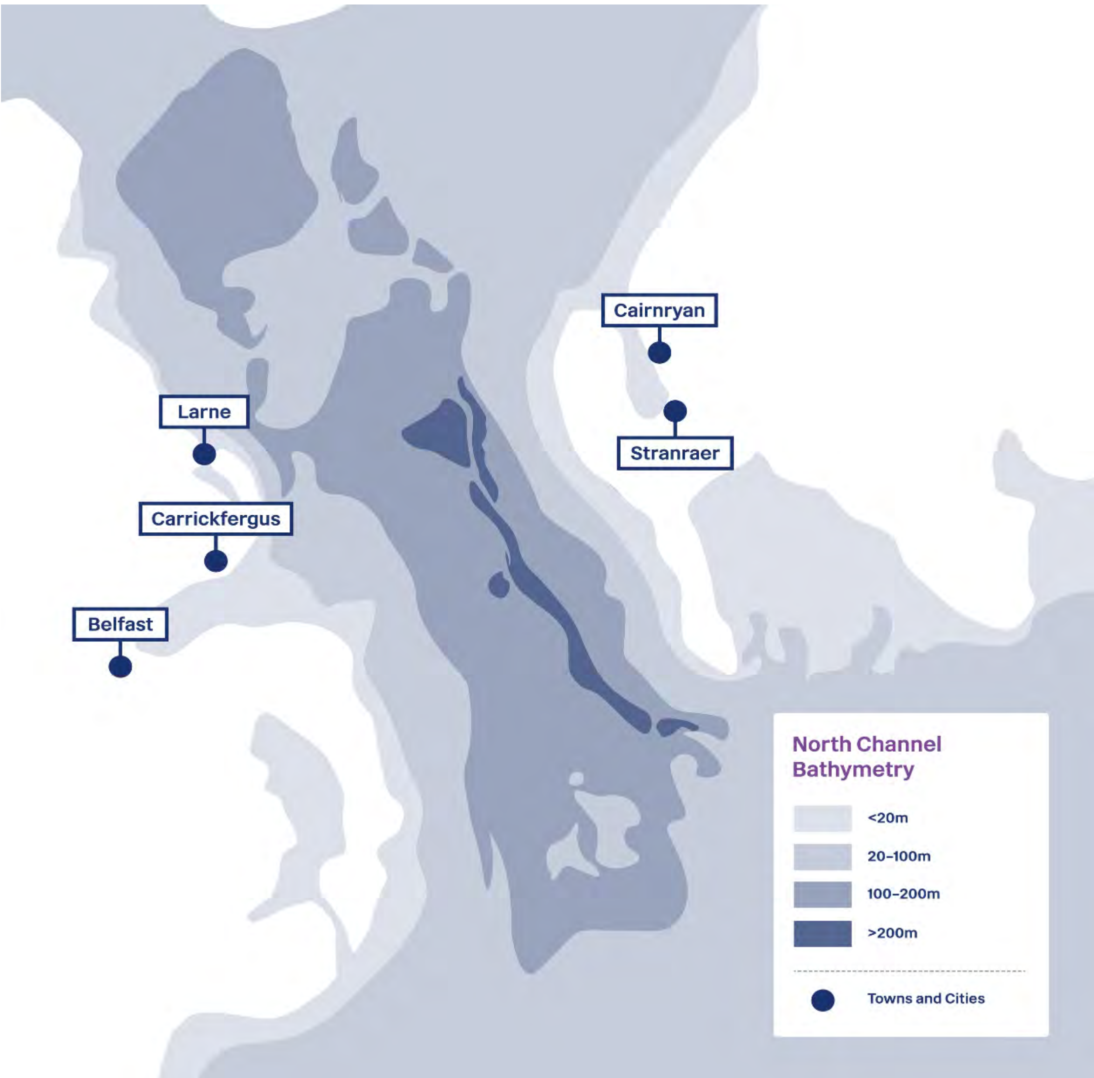

Figure 3: The North Channel.

The coastline and inland waters of both County Antrim and County Down in Northern Ireland and the Rhins of Galloway in Scotland are natural environments protected by both national and international law. Therefore, the introduction of any major infrastructure would need to be approached with great sensitivity and care.

Whilst the sea is on average about 160m deep, the greater engineering challenge for both bridge and tunnel options is Beaufort’s Dyke, a deep seabed trench that runs between 8 and 13km off and parallel to the Rhins of Galloway. It is more than 45 km in length and is approximately 3.5km wide at its broadest point. The charted water depth in the trench is more than 200m, while the deepest areas are over 300m below Chart Datum. From the information available, the bottom of the trench is filled with mixed deposits, and competent rock below that is at an estimated depth of around 380m. This would mean the top of the tunnel would need to be approximately 400m below Chart Datum. If at this depth an ingress of water were encountered, it would have a hydrostatic pressure of 40 bars. On the grounds of safety and cost alone this should be avoided. For a railway track with a designed maximum gradient of 1 in 100, it would require 40km to climb from the deepest point to reach to Chart Datum in each direction, which may still be below ground level, depending on the topography.

Beaufort’s Dyke also provides a challenge for the bridge, since it would have to span the trench and even at its narrowest point, this would result in spans approaching 4km on foundations set back from the edge. Whilst a suspension bridge of this span is yet to be built there have been several design concepts for such spans including those for crossings of the Messina Straits in Italy, the Red Sea linking The Yemen and Djibouti, and another over the Gibraltar Straits.

From World War 1 to the 1970s, in the order of a million tons of unexploded ordnance may have been dumped in Beaufort’s Dyke and the North Channel, much of it unrecorded. The bulk of material was dumped in the immediate aftermath of the two world wars. At the time, this was an internationally recognised disposal method for surplus munitions. This area would need to be carefully surveyed and the necessary mitigation built into the project plan. Whilst this would have an impact on both bridge and tunnel options, the former is most affected.

The Royal Navy also uses the trench and waters below 50m as an exercise ground for the submarines based at HM Naval Base Clyde, Faslane.

Selection of Possible Corridors for a Fixed Link

Once base information had been gathered and analysed, a long list of corridor options for potential crossing locations was defined. Corridors that could not readily be discounted due to physical, geographical or environmental constraints were progressed for further assessment.

The study has not been, and was not intended to be, an exhaustive study of all possible route corridor options, but instead focuses on selecting the most likely locations for a crossing to determine if any are technically feasible with current construction technology. Connections to the strategic road and rail networks were also included. However, physical surveys or ground investigations were not within the scope of the study.

Six corridors were progressed for further assessment (Figure 4). After discussion with Sir Peter Hendy it was subsequently agreed to add a seventh corridor to the study between Holyhead and Dublin.

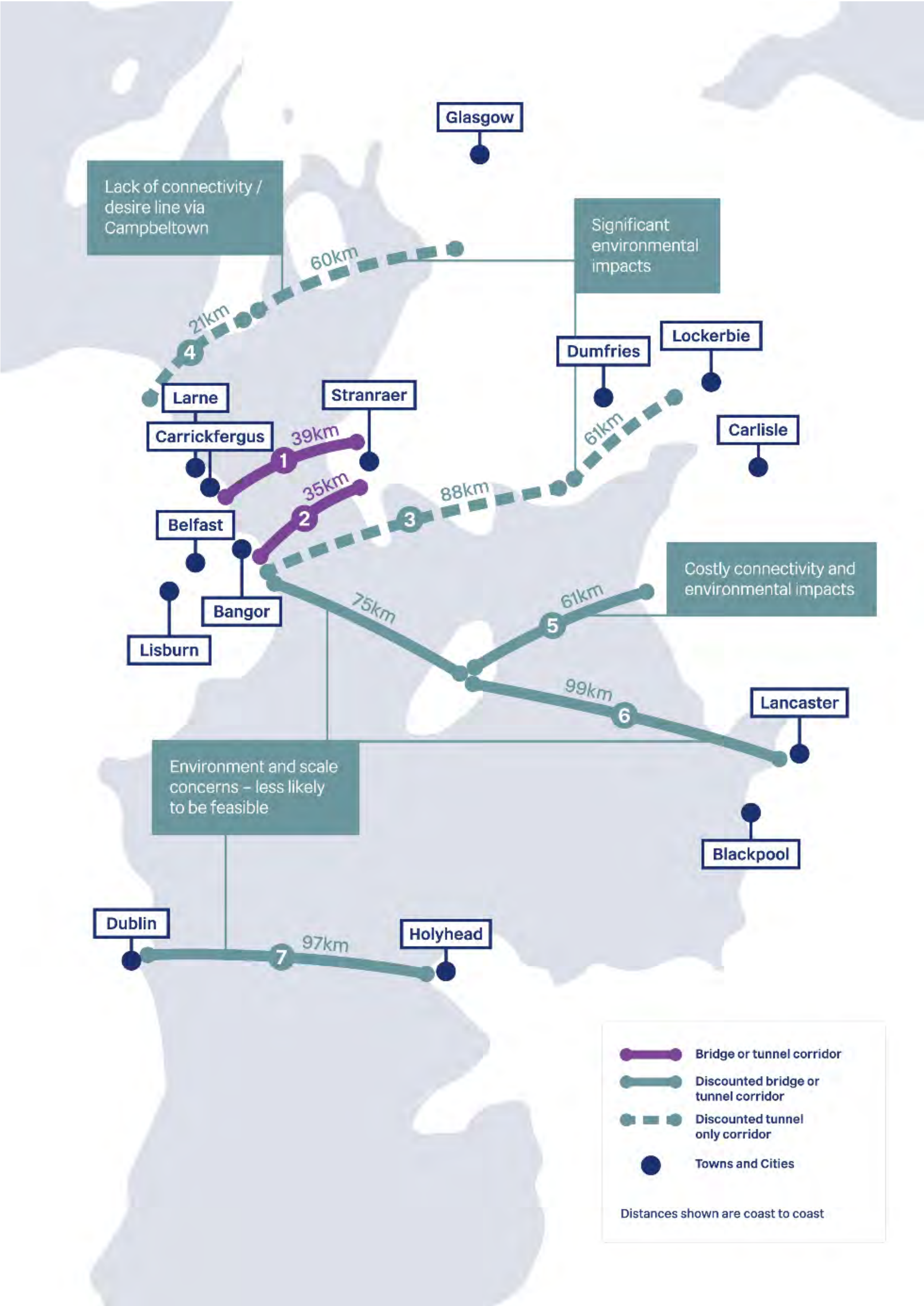

Figure 4: Preliminary crossing routes considered.

Further work narrowed down the most viable options (1 and 2). Corridor 1 was subsequently sifted out following further assessment.

Three indicative routes were identified within corridor 2, these being corridor 2 for a bridge solution and either corridor 2A (a route avoiding Beaufort's Dyke to the north) or corridor 2B (a direct route deep below Beaufort's Dyke) for a tunnel. Corridor 2B (tunnel option) was sifted out due to geological and sea-depth challenges. Corridor 2A for the tunnel and corridor 2 for the bridge were ultimately selected, as shown in Figure 5.

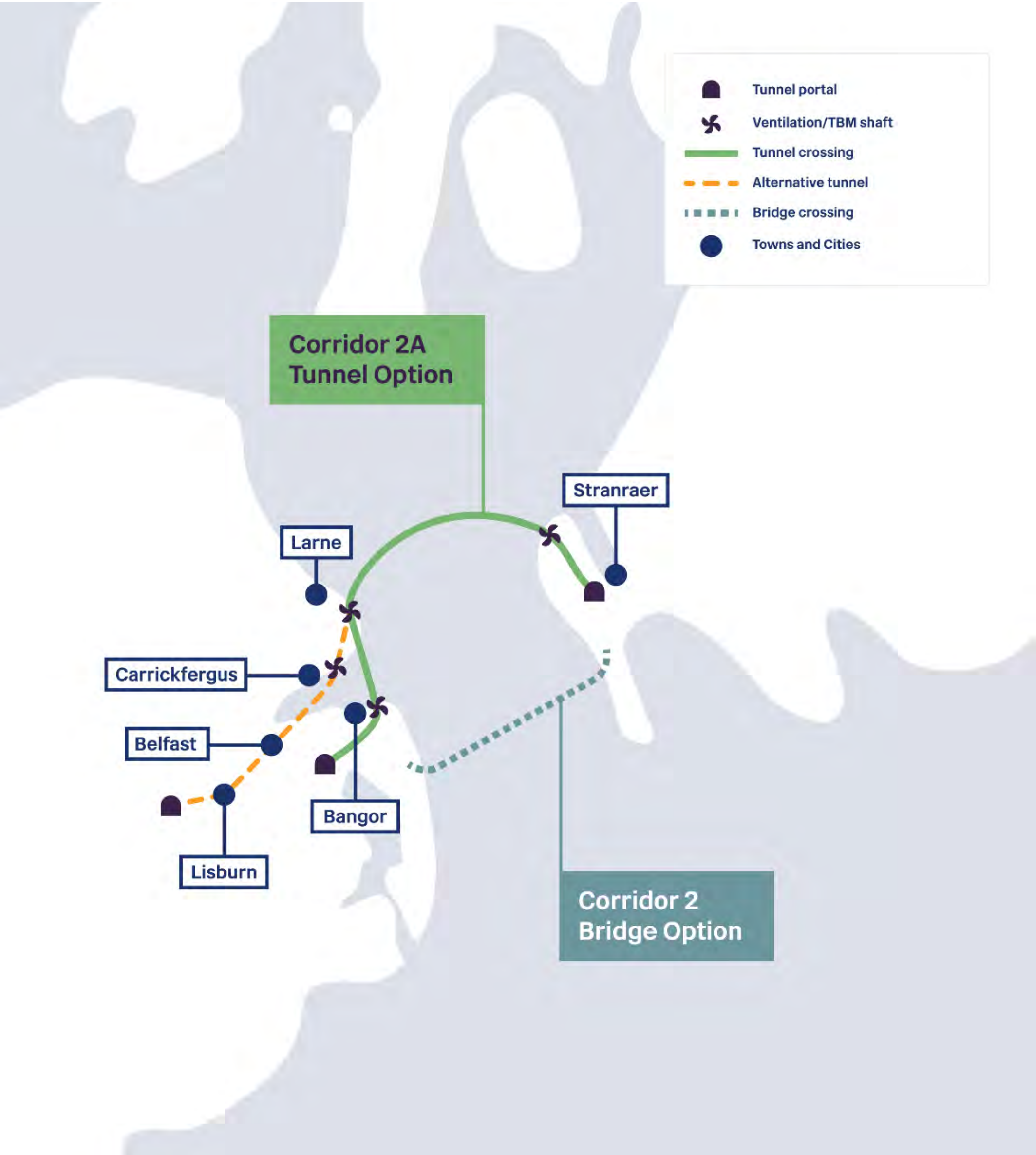

Figure 5: Potential routes considered for tunnel and bridge crossings. Tunnel boring machine has been abbreviated to TBM in the key.

To avoid the challenges presented by the Beaufort's Dyke, the more northerly corridor 2A, where the maximum depth can be reduced to 200m, was selected for the tunnel corridor. The route for the bridge was chosen to span the Beaufort's Dyke at its narrowest point, allowing foundations to be located clear of the areas likely to contain dumped ordnance.

Strategic Connections for the Bridge and Tunnel Options

Additional infrastructure would be needed to connect to strategic routes in Northern Ireland and Scotland in order to realise the full benefits of a fixed link. In Great Britain, land connections have been considered for the fixed link from the Stranraer area to the A74(M), the M6 and the West Coast Main Line (WCML). In Northern Ireland, connections have been considered from the Bangor area to the M1, the A2, the A20 and the Belfast to Dublin rail lines. The full extent of the project therefore extends from the A74(M) and the WCML in Scotland to south and west of Lisburn in Northern Ireland (Figure 6).

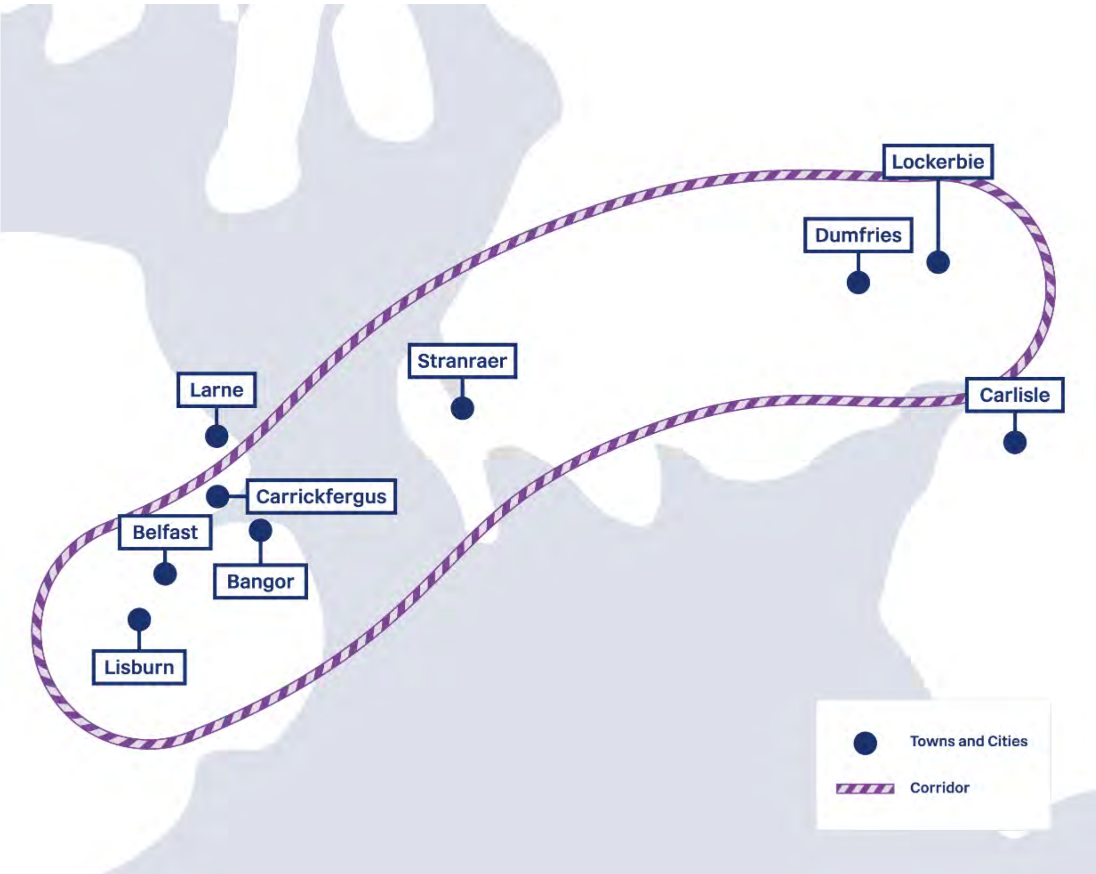

Figure 6: Connections to strategic routes.

The Terrain, Geology, and Environment of the Proposed Corridors

The corridor in Scotland is wholly contained within Dumfries and Galloway. The area to the east and west of Dumfries is characterised by rolling hills interrupted by the Nith and Annan River valleys. Further west, the terrain of Galloway Forest Park is more mountainous before entering the more gently undulating terrain on the approach to Stranraer. To the south and east of Stranraer there is an expanse of relatively flat land and to the west is the hillier area of the Rhins of Galloway. The coastline of the Rhins is characterised by the rocky headland and sheer cliff faces.

In Northern Ireland, the corridor is mainly in County Down and partially in County Antrim. The coastline is characterised by sandy beaches with rocky outcrops. Inland, the land rises from the coast into rolling hills between the towns of Bangor, Holywood and Newtownards before transitioning to the valley of the Enver River. From there the land rises again into the hills south and east of Belfast and Lisburn before reaching the flatter, lower lying areas of the Lagan and Ravernet rivers.

The superficial (soil) geological conditions in the study area arise mainly from glaciation and more recent sedimentation. With regards to the bedrock along the route, the northeast of the study area (in Scotland) and southwest of the study area (in Northern Ireland) are dominated by older sedimentary rocks. These rocks include wacké (a muddy sandstone), sandstone and limestone. The North Channel, and a thin slice into Northern Ireland around Belfast, comprises sediments such as the Hibernian Greensands Formation, the Ulster White Limestone Formation, the Sherwood Sandstone and the Mercia Mudstone.

The northwestern part within County Down comprises generally igneous rock, with basalts and tuffs present in County Antrim and Derry/Londonderry. Older igneous rocks are present in the northcentral part of the study area in Scotland. Igneous intrusions in the form of diorite and basalt dykes and sills are anticipated throughout the study area.

Onshore there are superficial deposits, with glacial till being the primary material present on both sides of the North Channel, and with peat and alluvium also present. The soils around Stranraer and Belfast are raised marine deposits. The offshore seabed surface material comprises predominantly marine sediments, such as sands and gravels. The offshore areas have undergone several periods of glaciation, therefore areas of glacial deposits predominate, although these are often covered by marine sediments. Areas of peat and alluvium may also be present.

The area in the vicinity of possible landfalls of a bridge in Northern Ireland is designated internationally for its importance for marine species such as waterfowl and porpoise. Notable designations include the Outer Ards site, which are wetlands of international importance designated under the Ramsar Convention, a Special Protection Area (SPA) and an Area of Special Scientific Interest and the North Channel Special Area of Conservation (SAC).

In Scotland, the corridor would make landfall close to an area of geological importance, the Grennan Bay Site of Special Scientific Interest (SSSI) and the corridor would continue eastwards, close to various sites of historic interest including scheduled monuments, listed buildings and areas of ancient woodland to the south of Stranraer. The Loch of Inch and Torrs Warren Ramsar site and SPA, Luce Bay and Sands (SAC) and Torrs Warren – Luce Sands (SSSI) lie a little further to the south at the northern coastline of Luce Bay.

From there, the corridor would run eastwards across Dumfries and Galloway. There are lengthy stretches of mountainous terrain, notably to the east of Newton Stewart towards Castle Douglas. The area is of considerable natural beauty and importance to biodiversity and cultural heritage. Example features of note include Ramsar and SPA sites at Loch Ince and Torrs Warren, Solway Firth, Loch Ken and River Dee Marshes; SAC sites at the Flow of Dergoals, River Bladnoch, Galloway Oakwoods; and a great number of important ancient woodlands, SSSIs, scheduled monuments and listed buildings.

The Tunnel Option

All conceptual designs envisaged to inform the assessment used scalable proven technologies and methods of construction. Despite the concept of a submerged floating tunnel now being developed in Norway, the technical immaturity of the concept poses significant risks and therefore was not assessed as a viable option. An immersed tunnel option was also briefly considered, but was not further assessed due to the water depth in combination with the length of the tunnel and the possibility that a large extent of the seabed excavations could be in rock.

The deepest under sea rail tunnel is currently the Seikan Tunnel, with a depth from tunnel to sea level of approximately 240m[15]. There are several examples of deep rail tunnels excavated in rock such as the Lotschberg tunnel, the Gotthard tunnel in Switzerland and the Mont d'Ambin tunnel which connects France and Italy. These tunnels were all constructed under mountains.

For benchmarking purposes, the lengths of individual tunnel drives most relevant for constructing a fixed link in corridor 2A is the Channel Tunnel with tunnel drives from the UK coast towards France of up to 25km. This is not considered to be an upper bound technological limit but it may be a practical limitation based upon the life of critical tunnel boring machine (TBM) parts. Tunnel drive length limits are therefore likely to be dictated by consideration of programme, ventilation and operational logistics, and this defines where access points for TBMs need to be provided.

The preliminary design basis for the tunnel crossing of the North Channel includes provision for:

- A rail track in each direction with continuous access platforms and overhead power lines;
- Rail tunnels to accommodate freight, vehicle shuttle and passenger trains;
- The transport of dangerous goods such as petroleum;
- A rail service tunnel for operations, maintenance and to support emergency evacuation and incident management; and
- Fresh air ventilation system to assume intakes (via shafts) at approximately 40km spacing.

Due to the scale of the project, the availability of resources and materials to develop and deliver the project on both sides of the North Channel would be a challenge common to either option. Investment in the local areas across manufacturing, engineering and construction would be essential to deliver this scheme successfully.

Although there are very significant challenges, none of them are considered of sufficient complexity or magnitude to render the construction of a tunnel crossing of the North Channel infeasible.

Ground Conditions and Design

The alignment is expected to traverse geological faults with large blocks of unstable rock and the TBM and the tunnel lining would need to be designed to cope with these adverse conditions. Treatment of the ground ahead of the tunnelling using grout to stabilise loose material can also be undertaken. However, the alignment is expected to be predominantly within a mudstone material which is well known and very suitable for tunnelling (Figure 7).

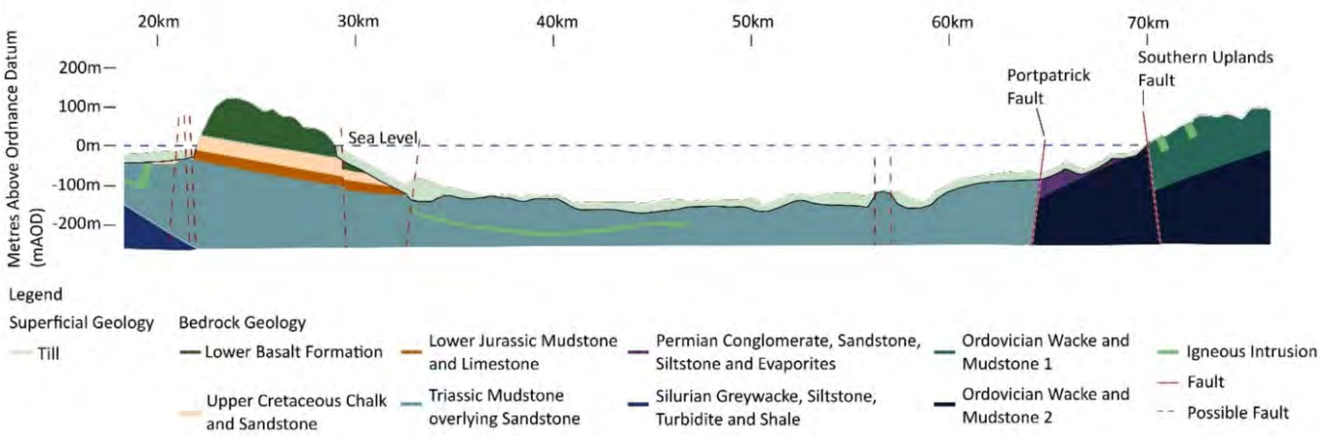

Figure 7: Longitudinal section through indicative tunnel alignment.

The rail tunnel has been assumed to have a maximum gradient of 1%. The tunnel portals would be inland due to the topography on both sides of the channel being steeper than the tunnel gradient. This is schematically shown in Figure 8. Permanent shafts would need to be constructed as close to the shore as possible for construction and afterwards to provide permanent ventilation and emergency access and egress.

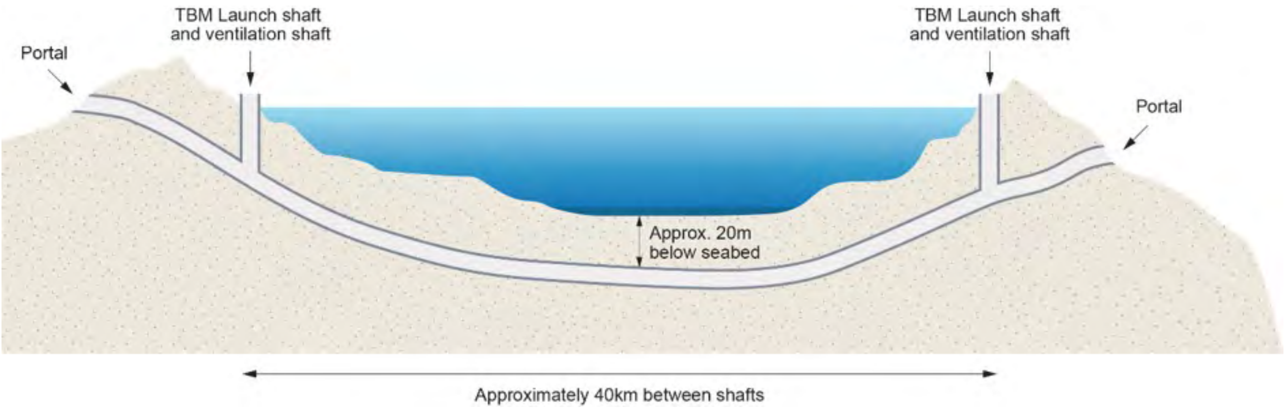

Figure 8: Indicative tunnel vertical alignment.

Tunnel Design and Construction

After consideration of many tunnel projects it was decided to assume a configuration similar to the Channel Tunnel but with two running tunnels with a larger diameter of 9m to avoid the need for costly piston relief ducts. The third tunnel for operation and rescue services has also been enlarged because of the lessons learnt by the Channel Tunnel operators (Figure 9).

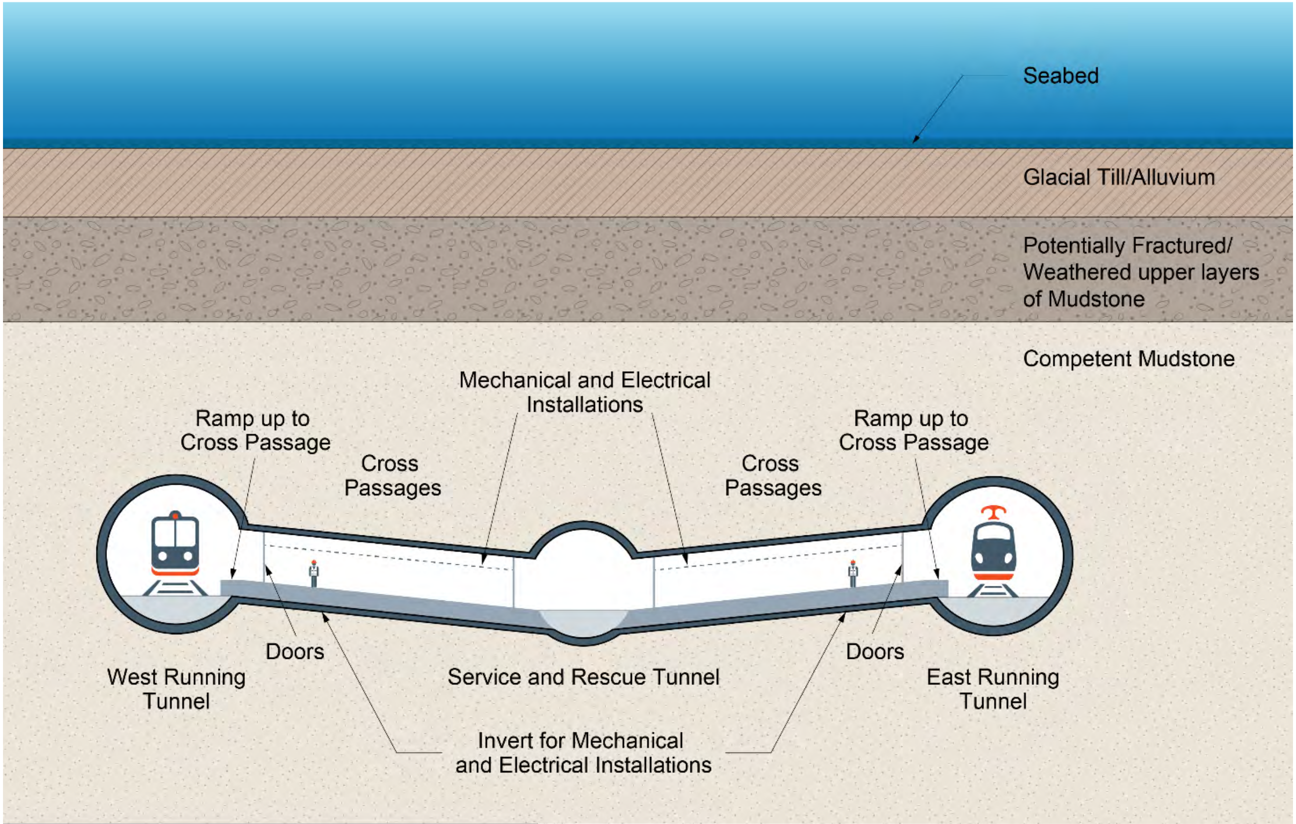

Figure 9: Indicative tunnel cross-section.

Figure 10: Visualisation of the proposed tunnel. © COWI 2021.

It would be necessary to build two caverns approximately a third of the way into the undersea tunnel from either end to allow the trains to crossover onto the other track. This provides a degree of resilience and allows railway operations to continue during periods of maintenance and in the case of an incident. These caverns would require a different excavation method.

Launch shafts for the TBMs would be located on the coastline of Scotland and Northern Ireland. From each of these shafts, three TBMs (two for the running tunnels and one for the service tunnel) would be launched to bore the marine tunnels and meet somewhere under the North Channel. A further three land tunnels would be needed from the shafts on either coast, boring inland to a portal. The locations of the launch shaft should be sited to allow sea transport of materials and equipment to minimise environmental impact and disruption to communities.

The Bridge Option

The principal challenges for the design, construction and operation of a major bridge crossing of the North Channel are the deep water, Beaufort’s Dyke and unexploded ordnance, as well as sub-sea utilities, large shipping volumes and the geology and seabed. Although very significant, none of these challenges are considered of sufficient complexity or magnitude to render the construction of a bridge crossing of the North Channel as infeasible.

However, the cost and complexity of constructing foundations and substructures in deep water is high, and this work would be on the critical path for the overall programme. Therefore, to reduce construction cost and programme length, the study has concluded that it would be necessary to minimise the number of supports in water depths greater than approximately 40m. This inevitably leads to solutions involving multiple and very long spans.

Data gathered during the study shows various power, telecommunications and gas pipelines on the seabed. These are of international strategic importance, and it would be important to avoid the risk of interfering with them. Any bridge foundations must avoid any live and active utilities, so their presence affects the location of the bridge and its abutments.

The North Channel experiences very busy and heavy shipping traffic, running both north-south and east-west. Figure 11 shows a trace of vessels passing through the area from which the most frequently used channels can be seen. The shipping traffic passing through this area includes very heavy tankers and vessels weighing greater than 150,000 DWT. The risk of vessel impact with bridge supports is one of the key design factors associated with any major sea crossing. The location and design of the bridge crossing must consider the principal shipping routes and place the supports far enough apart to minimise the risk of vessel impact. The bridge supports would be designed to withstand the high impact forces generated by large vessels, potentially with the addition of suitable ship impact protection systems.

The Ministry of Defence has been consulted relating to submarine activity as part of this study and they have no fundamental objections to a bridge crossing on the understanding that the piers are widely spaced, and this further supports the principle of adopting a suspension bridge with multiple long spans.

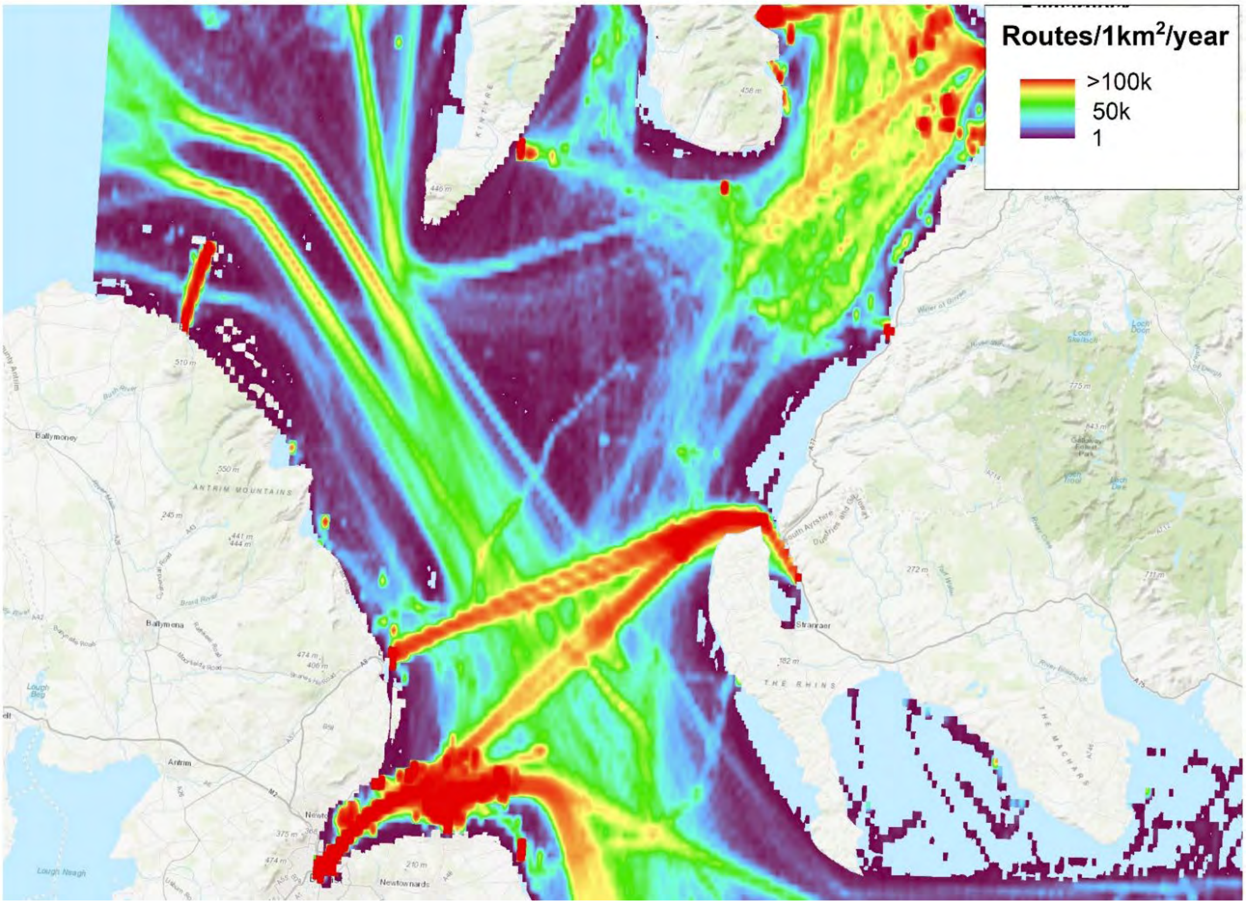

Figure 11: Shipping volumes in the North Channel[16].

The risk of unexploded ordnance being encountered during marine geotechnical investigations and during construction is real and must be managed and allowed for in project planning. However, it is feasible to identify and remove individual items in the vicinity of proposed bridge foundations. It is intended that the design of the foundations themselves would include a sacrificial outer layer which can be allowed to fail locally in the event of a local detonation without causing extensive damage to the structure and without creating a risk to the integrity of the bridge.

Ground Conditions and Design

Geology and seabed conditions significantly influence the design and location of the foundations. The general character of the expected ground conditions has been determined from limited data available. The conditions would vary significantly along the length of the alignment and the design of the individual support foundations would therefore need to take this into account.

Figure 12 shows an indicative geological section through the North Channel looking north along Corridor 2. There is good rock available for the major bridge foundations. The layer of overlying softer deposits on the seabed varies from zero, where there is exposed rock in places, to perhaps 50m or more. The foundation type and design would need to be able to cope with this variability.

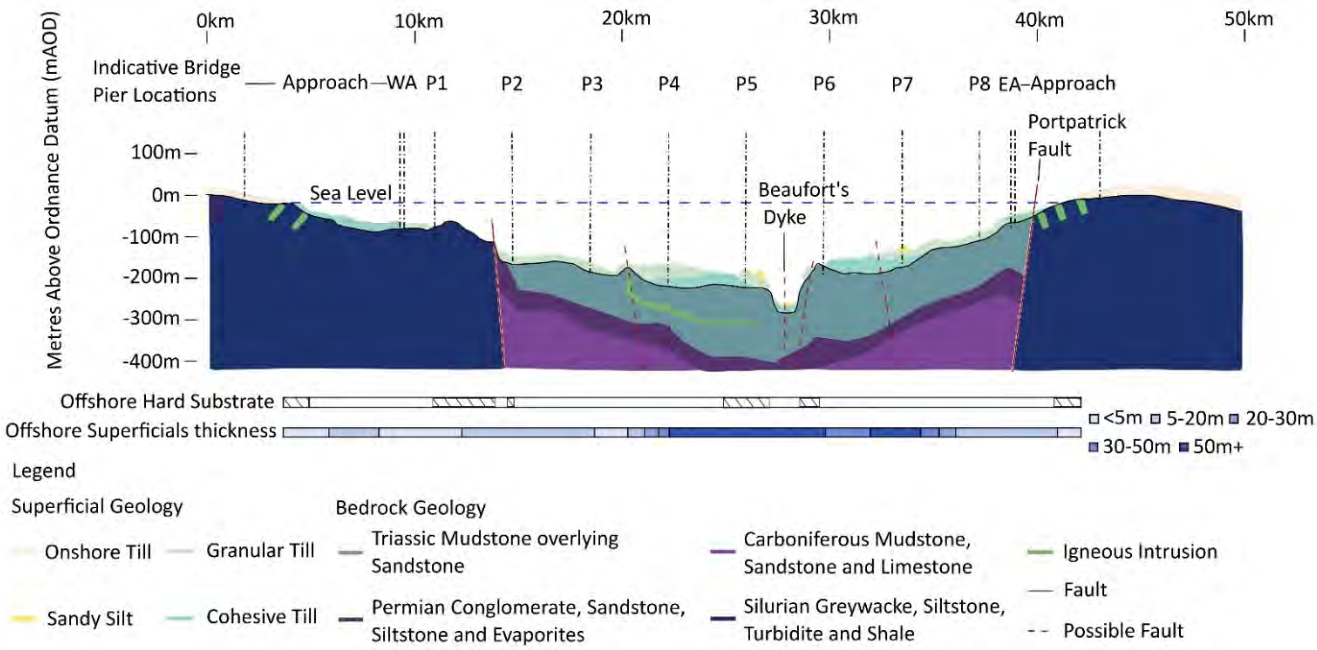

Figure 12: Geological section through the North Channel approximately on the line of the bridge route.

The environmental conditions influencing the location and design of a fixed crossing and several environmental assets have been identified in Corridor 2. This would demand special care and attention in the construction stages but is unlikely to be a serious concern for the permanent condition after the bridge is built, particularly because the long spans proposed would minimise the number of bridge piers required.

On the Scottish side there are fewer environmental constraints, but there are ancient woodlands which need to be avoided when deciding upon the approach to road and rail alignments, and this affects the location of the bridge abutment. Any future study would need to optimise these alignments to avoid these constraints.

High Winds

The bridge would be exposed to strong winds and all types of adverse weather conditions. Modern bridges in such environments tend to be fitted with windshields along the sides of the bridge which are designed to control the wind flow over the bridge deck and substantially reduce the wind speeds experienced by vehicles and trains using the bridge. This reduces the risk of the bridge being closed to high-sided vehicles which tend to be susceptible to the effects of strong winds. Windshields have been used on bridges in the

UK for over 30 years and there is a lot of experience with their design, construction and maintenance worldwide. For example, the Prince of Wales Bridge between England and Wales has continuous windshields fitted along both sides. It opened to traffic in 1996, and there have been no closures of the bridge or restrictions to traffic due to strong winds in the 25 years since then. This is very different to the Severn Bridge which was designed and built without windshields.

Bridge Design and Construction

Multi-span suspension bridges are an efficient solution for long fixed link crossings in deep water where the cost of constructing foundations and sub-structure is prohibitively high and so the number of foundations must be minimised. The high capital cost of long, deep water crossings means that multi-span suspension bridges are comparatively rare, however they are not without precedent. A good design example of a suspension bridge is at the proposed Red Sea Crossing between The Yemen and Djibouti (Figure 13).

Figure 13: The Yemen-Djibouti Bridge (proposed) is a model for the type of bridge crossing envisaged here. © COWI 2021.

The proposed alignment of the bridge means that pylon foundations would be required in water depths up to about 165m. Bridge foundations have not been constructed in these depths before. However, the technology for building offshore platforms in deep water has been used for many decades and is well understood. A form of concrete gravity base structures, designed to be founded on or just below the seabed, depending on the seabed conditions has been assessed as the preferred option. Shallow footings allow transfer of load to the load-bearing strata. They comprise reinforced and prestressed concrete elements and usually have a very large base to ensure the bearing pressures are small. The preliminary design for the pylons anticipates that they would rise 545m above sea level (for reference, The Shard in London is 310m above ground level).

The width of the deck required for structural strength and stability needed for long spans can accommodate two traffic lanes plus an emergency lane and a maintenance access lane on either side of the bridge in addition to a railway. The emergency and maintenance lanes are essential even if the opportunity to provide traffic lanes is not taken up (Figure 14).

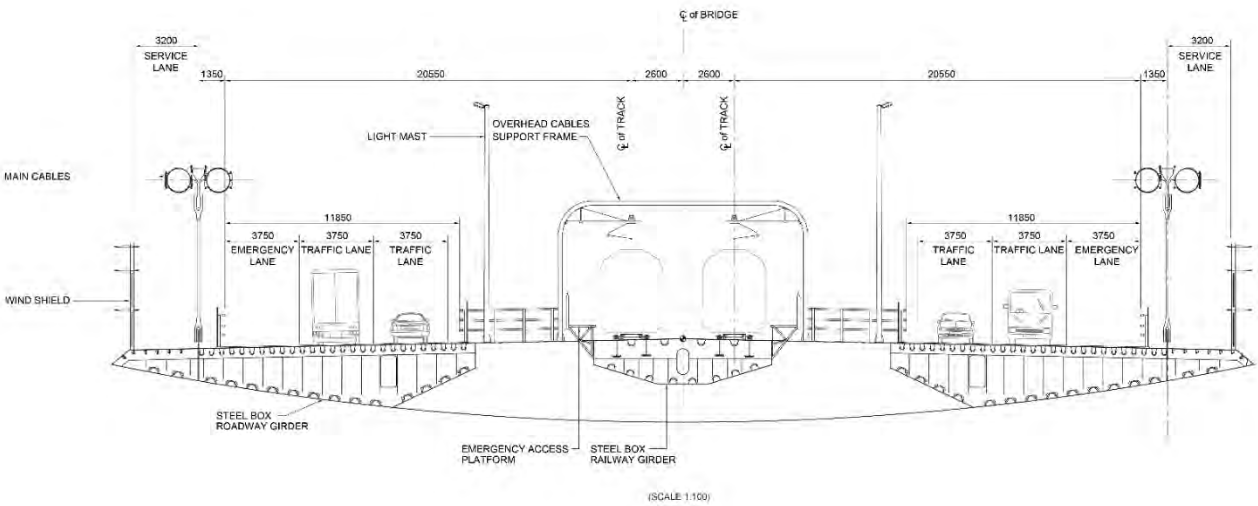

Figure 14: Indicative bridge deck cross-section.

The vertical clearance under the bridge deck in the main navigation channels needs to comply with international shipping requirements for all ocean-going vessels. This clearance envelope would normally be to a height of approximately 70m above mean sea level. However, due to specialist traffic in the North Channel, a minimum clearance of 76m has been assumed.

The following preliminary design arrangement is proposed to suit the principal challenges and constraints presented by this project, as a feasible and robust solution for crossing the North Channel:

- A multi-span suspension bridge with seven main spans of 3,750m and two side spans of 1,500m is the proposed design. This roughly 30 km long structure would occupy most of the length of the crossing in the deepest water and be supported by eight tall concrete pylons and two cable anchorages founded on the seabed.

- The approaches at each end of the suspension bridge comprise multiple cable stayed spans which follow a gently curving plan alignment. Relatively modest spans of about 370m are currently proposed since this suits the planned geometry of the alignment although longer spans would be feasible.

- A conventional viaduct with short spans of about 75m over the land sections at each end completes the crossing which is about 41 km long overall between the abutments.

Land Connection Feasibility

In Great Britain, the aim would be to connect the railway to the WCML and the road would need to connect to the A74(M) and M6 corridors.

The railways throughout the island of Ireland have a track gauge of 1600mm, which differs from the gauge of 1435mm adopted in Great Britain and most countries in Europe. Therefore, it has been assumed that the railway would need a direct or interchange connection subject to resolving the different track gauge both to central Belfast for passengers and the wider rail network across the island of Ireland for both freight and passengers. It has been assumed that road connections would be required to provide access to the wider Belfast area and the wider strategic network via the M1.

Rail Connection

The study has assumed that an operational model similar to the existing Channel Tunnel would be adopted. This includes a shuttle service using new rail connections on both sides of the North Channel, an all-Ireland interchange and a passenger service to the centre of Belfast. In Northern Ireland, car and lorry road traffic would join the shuttle train services at a terminal in the vicinity of Lisburn. Due to the rail gauge differences between Great Britain and Northern Ireland, bulk and intermodal freight would have to be unloaded and reloaded onto Great Britain and Europe bound trains using the fixed link at the terminal. This double handling would happen in reverse on the return journey. Changing bogies is another possibility but is expensive and time consuming.

In Scotland, for a tunnel or bridge crossing of the North Channel, a rail connection would need to be provided from the WCML to the Stranraer and Rhins of Galloway area. There are two main options to achieve this connection. Option 1 would be to utilise and upgrade the existing rail network from Gretna via Annan, Dumfries, Ayr and onto Stranraer. Option 2 would be to construct a new direct rail line from the WCML, north of Gretna, via Dumfries and onto the Stranraer.

For the purposes of this feasibility study, Option 2 has been considered as the most strategic and transformational opportunity. Based on the old “Port Road” railway route, a feasible alignment has been identified, adopting modern railway alignment design standards and a maximum gradient of 1%. The route takes account of the significant environmental assets that require protection, minimising any potential impact. The gradient restrictions and more relaxed curves of a modern railway lead to significant numbers of new structures including tunnels and viaducts.

An initial assessment indicates that approximately 30% of the route would need to be tunnelled, 15% on viaduct and 55% broadly at grade or with conventional cut and fill earthworks. The route would have the potential to connect the sea crossing to the WCML in the Lockerbie area or the Glasgow and Southwest railway at Dumfries and then onto the WCML at Gretna.

In Northern Ireland, it is anticipated that a new rail line would be required. The operational scenario adopted requires mixed-use of freight and passenger services. To make the strategic connections envisaged for this scheme, rail connections would need to be made for both long distance freight and passengers as well as a shuttle service terminal. A terminal location somewhere near Lisburn is assumed given its proximity to the Belfast – Lisburn – Dublin railway and its strategic connectivity to the island of Ireland rail network.

For a tunnel sea crossing, the landfall is near to Bangor. A railway alignment that then connects to the existing Belfast – Lisburn – Dublin line is feasible towards the south of Lisburn. Due to the hilly nature of the land in the area, it is anticipated that the tunnel would be extended under the hills and through towards the lower lying areas around Lisburn. This would result in approximately 70% of the route being in tunnel and 30% delivered broadly at grade or with conventional cut and fill earthworks. Due to the depths of the sea tunnel crossing, it is envisaged at this early stage that a connection to the Belfast – Bangor line would not be feasible. Passenger only services into Belfast city centre could be provided utilising the Belfast – Lisburn line with a parkway station in the Lisburn area combined with a shuttle terminal.

A bridge sea crossing would approach the land at a height above sea level of around 25m and at a point further south along the coastline from Bangor. From the landing, a rail route could then be delivered at grade or with conventional cut and fill earthworks to a point near Bangor where it would then need to be tunnelled to Lisburn. Passenger services direct to Belfast city centre could be made from a bridge sea crossing using an upgraded Belfast - Bangor line to overcome the gauge differences between Great Britain and Northern Ireland. Alternatively, the existing line could be used without an upgrade to provide a shuttle feeder service to a parkway station near to the bridgehead.

Road Connection

Road connections to the fixed link are dependent on the final operation of the fixed link crossing and the type of sea crossing provided. It is assumed for the purposes of this study that a tunnel sea crossing would be rail only. The road connections required would be limited to providing links from the strategic road network to shuttle terminals. It is assumed that the terminals would be located, for customer convenience, near to the strategic network. In Great Britain, this would be the A74(M) and the M6 corridor where it is close to the WCML. In Northern Ireland, this would be the M1 where it is close to the Belfast – Lisburn – Dublin railway line.

The bridge could be operated for rail only but that would seem unlikely, given that the necessary width of the bridge deck would readily accommodate road traffic lanes.

It is assumed that the road links would at least be to a high-quality dual carriageway two lane all-purpose road with full grade separation at major road junctions and a design speed of 70mph.

In Scotland, the principal connection would be via improvements to the A75. This is the primary existing route to the current ferry crossings and connects to the A74(M) and the M6 corridor providing access to the wider strategic road network in Great Britain. The A77 carries the remaining ferry traffic towards Glasgow and the north. Upgrades to these routes would also support the construction of a fixed transport link. It is also envisaged that the A701 from Dumfries to the A74 (M) is also improved, providing access to the north.

In Northern Ireland, a bridge landing in the area to the south and east of Bangor on the coast would then require a new high-quality dual carriageway link to the M1, a length of approximately 50km. This would provide access to the strategic road network in Northern Ireland and Ireland. There is no existing road corridor that could be used with most existing significant roads to the south of Belfast running radially out of the city. The desktop study has shown that it is feasible to provide a new high-quality dual carriageway from the M1, west of Lisburn, to the potential bridge landing site. There are significant constraints in the corridor including environmental assets that are internationally or nationally protected, existing conurbations, existing transport infrastructure and the hilly landscape, particularly between Lisburn and Bangor and the Newtownards area.

It is anticipated that more direct connections would be required to central Belfast. The project team has identified that it would be feasible to connect the new dual carriageway to the main radial routes from the city centre such as the A22, the A20, the A24 and the A2, either directly or through new link roads with grade separated junctions.

Shuttle Service Terminals

In all potential operation scenarios explored, it is assumed that a shuttle service would form part of the overall fixed link operation model. It is envisaged that there would be a facility for road vehicles to access the new fixed link railway at one side of the North Channel at a loading terminal and travel across it on shuttle trains to an unloading terminal on the other side. This would not be unlike the existing Channel Tunnel operation currently operated by Eurotunnel in Folkestone, England and Calais, France. Thus, this operation would need similar train loading facilities as well as train stabling lines adjacent to the major road corridors.

Carbon Footprint Estimates During Construction

To satisfy the government’s ambition to meet net zero carbon emissions by 2050, this project would need to consider and deliver greener alternatives to existing methods of crossing the sea between Great Britain and Northern Ireland.

As set out above, this study has considered the high-level estimations of carbon footprint during construction for both a bridge and a tunnel fixed crossing. The carbon footprint estimates during construction are high level and represent a mid-point of a wider range.

There are also significant uncertainties associated with deriving the embodied carbon resulting from transport and construction, therefore, average percentages based on engineering market analysis have been used to uplift the embodied carbon due to material manufacture, to provide an indicative mid-point estimate for the embodied capital carbon.

	Option	Tunnel (Sea crossing with rail connections into strategic networks)	Bridge (Sea crossing with road & rail connections into strategic networks)
Land Connections	Traditional	4.0	10.4
	Lean	2.5	6.6
Sea Crossing	Traditional	3.3	8
	Lean	2	6.1
Totals	**Traditional**	**7.3**	**18.4**
	Lean	**4.5**	**12.7**

Table 1: Mid-point range estimates for embodied carbon based on high level concepts ($MtCO_2e$ - Million tonnes of equivalent carbon dioxide).

- **Traditional** – Assumes world-wide average embodied carbon for construction materials, namely concrete and steel.
- **Lean** – Assumes higher recycling rates and cleaner energy grids similar to the UK in the last five years but excludes any offsetting.

It is estimated that if the crossing replaced a reasonable proportion of flights between Great Britain and the island of Ireland with lower carbon intensity surface transport, the capital carbon of a bridge crossing would be offset in approximately 42 to 61 years, and a tunnel in 15 to 24 years.

Anticipated Programme and Indicative Costs

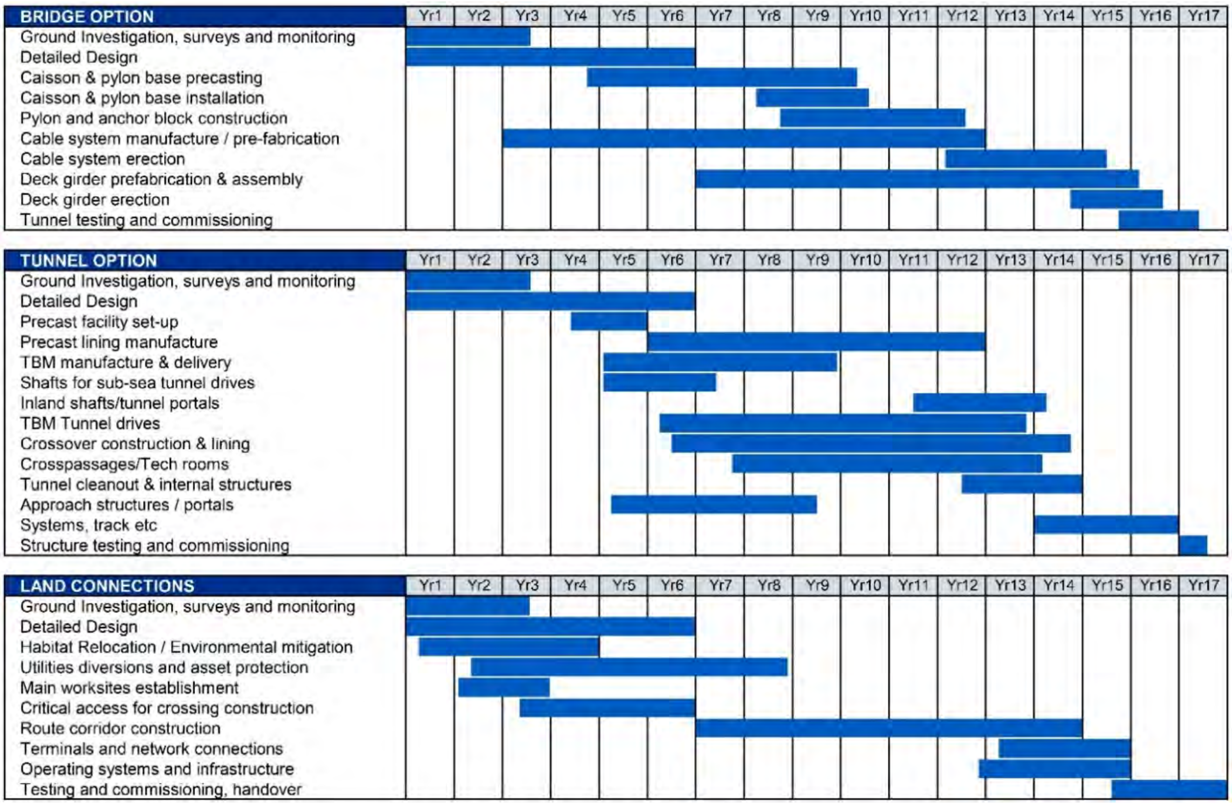

Table 2: Estimated construction programme.

As can be seen from the above programmes the overall time required to design and construct either the bridge or tunnel is in the order of 17 years from the time the project is issued with the “Notice to Proceed”. Additionally, it is expected that a period approaching 10 years would be required for the conceptual design, environmental studies, public consultation and statutory approvals.

The land connections have been programmed to take a similar period to complete although with higher risk, so it is reasonable to assume 20 years for the construction phase for the entire programme.

Figure 15: Indicative spend profile – tunnel. Optimism bias has been abbreviated to OB.

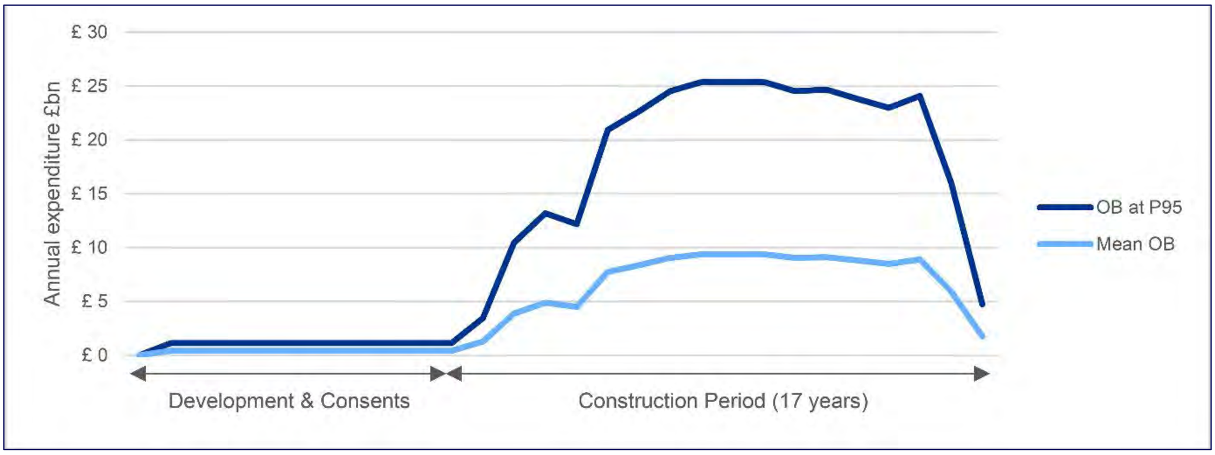

Figure 16: Indicative spend profile – bridge. Optimism bias has been abbreviated to OB.

As can be seen from the indicative spend profiles, both the tunnel and bridge options represent a substantial capital expenditure, although the annual rate of expenditure over 17 years is in keeping with relatively smaller projects.

Further investigations would be recommended during the development stage and before the consent stage. Whilst this has not been done previously for major projects, given the significant challenge the fixed link crossing presents, it would be prudent to consider such an investment to identify any possible major areas of risk at an earlier stage to enable mitigation measures and cost contingencies to be more confidently estimated prior to submitting documents for consent. The most important investment would be for an advanced marine seabed geological investigation. More ground investigation on land would be beneficial to provide more confident predictions of ground conditions for tunnels, bridge foundations, embankments and cuttings.

Tunnel Sea Crossing	Approx Length (km)	Estimated Cost (billion)
Rail connections – Northern Ireland	47	£5
Rail connections – Scotland	125	£12
Tunnel	84	£19
Rail terminals (including road connections – 5km)		£1
SUB-TOTAL		£37
Ground investigation & surveys		£1
Design & project management (10%)		£4
SUB-TOTAL		£42
Supply chain capacity (20%)		£8
SUB-TOTAL		£50
Indicative Cost Estimate P95 Optimism Bias Allowance (320%)		**£209**
Indicative Cost Estimate Mean Optimism Bias Allowance (55%)		**£77**

Table 3: Indicative cost range estimate for construction phase of the tunnel. Sub-totals are cumulative.

Bridge Sea Crossing	Approx Length (km)	Estimated Cost (billion)
Rail connections – Northern Ireland	67	£7
Rail connections – Scotland	143	£14
Road connections – Northern Ireland	46	£1
Road connections – Scotland	184	£5
Bridge	41	£32
SUB-TOTAL		£59
Ground investigation & surveys		£1
Design & project management (10%)		£6
Dry dock construction		£1
SUB-TOTAL		£67
Supply chain capacity (20%)		£13
SUB-TOTAL		£80
Indicative Cost Estimate P95 Optimism Bias Allowance (320%)		**£335**
Indicative Cost Estimate Mean Optimism Bias Allowance (55%)		**£124**

Table 4: Indicative cost range estimate for construction phase of the bridge. Sub-totals are cumulative.

To determine the base cost, other projects have been benchmarked but few in the world compare with this scheme. Nevertheless, the rates used are deemed to be as reasonable as possible within the limitations of this early concept-stage desk study. It should also be noted that a special line item for ground investigation surveys and surveys has been included for the reasons indicated above. A further 20% has been added to the base cost to allow for the huge demand that would be made on the supply chain to meet the programme within budget. Further work would need to be done to underpin this early assumption.

The optimism bias percentages of 320% against a P95 probability and a mean optimism bias of 55% conform with the latest advice from the Infrastructure and Projects Authority.

Summary

The study has considered the technical feasibility of constructing a fixed crossing across the Irish Sea or North Channel via a tunnel, bridge or combination solution, identifying the most viable solutions using current construction technology. The study has also considered the land connections on both sides of the sea to ensure that a connection is technically feasible to either the strategic road or rail network or both.

It has concluded that, it is technically feasible to construct, maintain and operate a fixed link crossing between Great Britain and Northern Ireland. The team has identified potential solutions and options to the provision of the fixed link and its associated connections to the wider strategic transport network. The study provides an indicative range of costs and timescales for construction, including high-level estimations of the carbon footprint during construction. However, the economic viability of the provision of such a link is not within the scope of this study.

References

[1] Macassey, L.L. (1890, November). The Proposed Channel Tunnel and Through Trains between Edinburgh, Glasgow, Manchester, Belfast, and Londonderry. 24pp with map inserts. Glasgow and Belfast.

[2] Walker, J.F. (1897, March). An Irish Channel Tunnel. Contemporary Review, No. 71, pp 406-423.

[3] Barton, J. (1902). The Proposed Tunnel Between Scotland and Ireland. International Engineering Congress, Glasgow, 3rd - 5th September 1901 - Volume of Proceedings, Section 1 Railways, pp 62-77.

[4] Ibid.

[5] Ibid, p.73.

[6] Ibid. p.73.

[7] Northern Ireland Statistics and Research Agency. (2021, June). Northern Ireland Air Passenger Flow Publications. https://www.nisra.gov.uk/publications/northern-ireland-air-passenger-flow-publications.

[8] WPI Strategy. (2020, October). Back to Business: How Aviation Can Boost Economic Recovery Across the UK.
https://media.londoncityairport.com/download?n=London%20City%20Airport%20Business%20Travel%20Economic%20Report%20-%2012%20October%202020-pdf&id=3389

[9] Airlines UK. (2018, October). Assessment of the Value of Air Freight Services to the UK Economy.
https://airlinesuk.org/wp-content/uploads/2018/10/Assessment-of-the-value-of-air-freight-services-to-the-UK-economy-Final-Report-v22-Oct-2018-b-SENT.pdf

[10] Civil Aviation Authority. (2019). Airport data 2019 [dataset]. Table 14.
https://www.caa.co.uk/uploadedFiles/CAA/Content/Standard_Content/Data_and_analysis/Datasets/Airport_stats/Airport_data_2019_annual/Table_14_International_and_Domestic_Freight.pdf

[11] Organisation for Economic Co-operation and Development. (2013, December). High Speed Rail Performance in France: From Appraisal Methodologies to Ex-post Evaluation. https://www.itf-oecd.org/sites/default/files/docs/dp201326.pdf

[12] Centre for Transport Studies Stockholm. (2012). Forecasting Demand for High Speed Rail.
www.transportportal.se/SWoPEc/CTS2012-12.pdf

[13] Department for Transport. (2020). Port and domestic waterborne freight statistics [Dataset]. Table PORT0304. www.gov.uk/government/statistical-data-sets/port-and-domestic-waterborne-freight-statistics-port

[14] Department for Transport. (2018, August). Sea passenger statistics: data tables (SPAS) [Dataset]. Table SPAS0102 and Table SPAS020. https://www.gov.uk/government/statistical-data-sets/sea-passenger-statistics-spas

[15] Mitchell, S.K. (2008, September). Mega Structures: the Longest Tunnels. Gareth Stevens Publishing, p.21.
https://books.google.co.uk/books?id=oi1X9WzjvXAC&pg=PA21&lpg=PA21&dq=seikan+tunnel+%22240m%22+deepest+undersea+rail&source=bl&ots=5iM_bVAc5N&sig=ACfU3U1kYLzrDHpA8ebYPho-0YxrOFda9A&hl=en&sa=X&ved=2ahUKEwi4k4zSo7bzAhWJasAKHWotAM8Q6AF6BAgfEAM#v=onepage&q=seikan%20tunnel%20%22240m%22%20deepest%20undersea%20rail&f=false

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