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Financial Scrutiny Unit Briefing

The Forth Replacement Crossing First Principles

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The Forth Replacement Crossing project is expected to be the biggest single investment by the Scottish Government since devolution, with an outturn cost in 2016 estimated to be in the range £1.72 billion to £2.34 billion (median cost estimate - £2.044 billion).

This briefing looks at the rationale behind the decision to build a Forth Replacement Crossing and the options appraisal undertaken to decide on what type of crossing to go forward with.

This briefing draws partly from work commissioned by the Financial Scrutiny Unit and undertaken by Biggar Economics.

Source: Transport Scotland

The Scottish Parliament
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EXECUTIVE SUMMARY

The Forth Replacement Crossing

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The Forth Road Bridge was opened in 1964 and was originally predicted to have a 120 year design lifespan (taking it to 2084). However, the main cables are suffering from corrosion which has caused a loss of strength. The bridge may have to close to heavy goods traffic from as early as 2017 and general traffic some years after that. Remedial measures are being taken to halt further corrosion but the first indication of its success will not be available until 2011/12.

Scottish Ministers have decided that, to ensure continuity of cross-Forth vehicle traffic, the construction of a new Forth Crossing adjacent to the existing Forth Road Bridge is necessary and that construction should begin as soon as reasonably practicable so that there is no period where a bridge between North and South Queensferry is unavailable to all traffic.

The Forth Replacement Crossing Study was carried out between August 2006 and June 2007 with the intention of identifying the nature of a potential replacement to the existing Forth Road Bridge. The study undertook an appraisal of replacement options using Scottish Transport Appraisal Guidance.

Of all the crossing options considered, this process concluded that the best option was a cable-stay bridge located east of Rosyth and west of Queensferry. It was considered that this solution was cheaper than the tunnel alternatives, easier to implement, had a shorter construction time and had fewer risks associated with ground conditions.

This decision was supported by the Scottish Government and announced in December 2007 where the costs were given inclusive of inflation and the cost of capital (outturn costs) as between £3.2 and £4.2 billion. Transport Scotland carried out further planning during 2008 and in December 2008 the Government outlined further key decisions about the design of the bridge. These revisions and refinements mean that the cost of the project is now estimated to be in the range of £1.72 billion to £2.34 billion (median estimate £2.044 billion). To give an idea of scale, the median estimate is more than the cost of the M74, Edinburgh Trams, Borders Railway and Scottish Parliament Building projects put together in today's prices (£1.915 billion).

FIRST PRINCIPLES

This section considers the decision making process that led to the current specific Forth Replacement Crossing design being selected.

WHY WAS IT DECIDED THAT A FORTH REPLACEMENT CROSSING IS NEEDED?

The Forth Road Bridge was opened in 1964 and was originally predicted to have a 120 year design lifespan (taking it to 2084). However, the SPICe Briefing on the Forth Crossing Bill explains:

> "The main cables of the current Forth Road Bridge, a key traffic artery linking Fife and the Lothians, are suffering from corrosion which has caused a loss of strength. Remedial measures are being taken to halt any further corrosion and subsequent loss of strength, i.e. the installation of a dehumidification system which should reduce the level of humidity within the cables to a point where further corrosion is not possible. If this system proves unsuccessful then it is possible that the bridge may have to close to heavy goods traffic from as early as 2017 and general traffic some years after that….Scottish Ministers have decided that, to ensure continuity of cross-Forth vehicle traffic, the construction of a new Forth Crossing adjacent to the existing Forth Road Bridge is necessary and that construction should begin as soon as reasonably practicable so there is no period where a bridge between North and South Queensferry is unavailable to all traffic" (Rehfisch 2010).

Could the main cables be replaced?

A study undertaken by W A Fairhurst and Partners found that replacement of the main cables is technically possible at a cost of £122 million for the engineering works (2007 prices, not including optimism bias or risk). For the bridge to remain operational this maintenance could not be undertaken without temporary traffic management measures being put in place which would restrict the capacity of the crossing. The works would be expected to last seven to nine years with notional travel time delay costs of the order of £650,000 per day, if a carriageway were to be closed on the bridge on a weekday (Sources: Forth Estuary Transport Authority 2010 and Policy Memorandum to the Forth Crossing Bill (SP Bill 33) as introduced to the Scottish Parliament on 16 November 2009).

It has been concluded that the repair/refurbishment of the existing crossing has too severe a set of impacts on the east of Scotland economy if it were to be closed (or even severely restricted) for a period of time for the cables to be replaced, and thus a replacement crossing is needed.

Is it possible that the Forth Road Bridge could last longer than expected?

Were the dehumidification system to stop further corrosion and loss of strength in the main cables, then the Forth Road Bridge could have a life span measured in several decades, or at least long enough to postpone taking any decision on a new crossing for some time without the concern that there may be a period where a crossing would not be available.

However, the first indication of its success will not be available until 2011/12 and even then the data will not be enough to enable firm predictions to be made. Data post 2012 will need also to be gathered to enable more accurate assessments to be made on the strength of the cables. The Forth Road Bridge will require to be continually monitored as long as it remains operational (Forth Estuary Transport Authority 2010).

The Policy Memorandum to the Forth Crossing Bill (SP Bill 33) states:

> "The policy objective is to provide, in the light of uncertainties about the future availability of the Forth Road Bridge, a continuing and reliable primary road link between Edinburgh and the Lothians and Fife and beyond in order to safeguard the economy, particularly of the east coast of Scotland".

The SPICe Briefing on the Forth Crossing Bill explains:

> "Essentially, this means that Scottish Ministers justify the construction of the Forth Crossing on the basis that there is uncertainty about the long term future of the Forth Road Bridge, particularly its ability to continue to carry vehicles past the middle of the next decade if the dehumidification system does not prevent further loss of strength in the main cables. If this situation were to arise then delaying the beginning of construction of the Forth Crossing beyond 2011 could lead to a period when there was no road crossing between North and South Queensferry. This could occur if the Forth Road Bridge had to shut to traffic, which could happen as early as 2014 (although the earliest date this is now considered likely is 2017 for heavy vehicles) and, given that it will take approximately five years to build a new crossing, a new crossing would not be ready before the predicted earliest date for the closure of the Forth Road Bridge" (Rehfisch 2010)

In 2006 Transport Scotland commissioned work which considered what the transport network around the Forth Road and Rail bridges would look like in 2010, 2017 and 2022. It concluded that, without intervention to augment the transport network over and above that planned, the objectives for it could not be met irrespective of the problems relating to the condition of the cables of the Forth Road Bridge.

WHY WAS A BRIDGE CROSSING CHOSEN?

The Forth Replacement Crossing Study (FRCS) was carried out between August 2006 and June 2007 with the intention of identifying the nature of a potential replacement to the existing Forth Road Bridge. The study undertook an appraisal of replacement options using Scottish Transport Appraisal Guidance (STAG). This process comprised of:

- **Pre-appraisal**
  - Option generation, sifting and development to derive a range of replacement crossing options which could meet transport planning objectives.
- **STAG part 1 appraisal**
  - An initial appraisal of the options generated during Pre-appraisal and a qualitative assessment of the likelihood of such options being able to meet the transport planning objectives.
- **STAG part 2 appraisal**
  - A more detailed appraisal of options taken forward from Part 1 and a detailed qualitative and quantitative analysis of an option's performance against transport planning objectives, STAG criteria, cost to Government, risk and uncertainty,

Of all the crossing options considered, this process concluded that the best option was a cable-stay bridge located east of Rosyth and west of Queensferry (Route D, as shown in Figure 1 overleaf). It was considered that this solution was cheaper than the tunnel alternatives, easier to implement, had a shorter construction time and had fewer risks associated with ground conditions.

The process by which the study arrived at this decision and the reasons why this option was chosen are described in more detail below.

Pre-appraisal

A list of 65 potential options to enter the Pre-appraisal stage were generated at a workshop held in 2006 where representatives of Transport Scotland, Scottish Executive, Jacobs and Faber Maunsell were encouraged to provide their thoughts on possible options (Transport Scotland 2006a). Of these, 19 were rejected as they did not satisfy objectives or were not technically feasible. For example arch and swing bridge options could not provide the required spans, hovercraft or ferry could not provide enough capacity and bridges or tunnels crossing between Leith/Portobello to either Kirkcaldy or Burntisland were rejected as being uneconomic or beyond practical engineering limits.

The remaining 46 options were taken forward for further consideration. These were made up of bridge crossings and tunnel crossings at five different crossing corridors as shown in Figure 1:

Figure 1: Crossing corridors considered during Pre-appraisal

Source: Transport Scotland 2006a

Assessment of the crossing corridor options

Each corridor was assessed against the eight objectives for the FRCS (see Table 1 overleaf). Corridor D performed the best against the objectives as it was the closest to the existing Forth Road Bridge and thus was best placed to maintain transport links and relatively straightforward to connect into the transport network again. In addition, Corridor D was the lowest cost option – two thirds of the cost of the next cheapest option. Corridors C & E, either side of D, were also taken forward for further consideration as they performed next best against the objectives.

Once a clearer picture of the feasibility of different crossing corridors was obtained, a tunnel and bridge options at crossings C, D & E went forward for STAG part 1 appraisal. The bridge could be a suspension bridge or a 3 tower cable-stayed bridge.

Table 1: Eight planning objectives set specifically for the FRCS

1	Maintain cross-Forth transport links for all modes to at least the level of service offered in 2006.
2	Connect to the strategic transport network to aid optimisation of the network as a whole
3	Improve the reliability of journey times for all modes
4	Increase travel choices and improve integration across modes to encourage modal shift of people and goods
5	Improve accessibility and social inclusion
6	Minimise the impacts of maintenance on the effective operation of the transport network
7	Support sustainable development and economic growth
8	Minimise the impact on people, the natural and cultural heritage of the Forth area

Source: Transport Scotland 2006a

STAG part 1 appraisal

A qualitative appraisal of performance against the planning objectives in Table 1 was undertaken for the STAG part 1 appraisal. Implementability and performance against Government objectives were also considered so that any options that failed to meet the objectives would be discarded before STAG part 2. The following areas set the options apart:

- **Connectivity to existing transport network** - Corridor C options were limited in terms of their connectivity to the existing transport network. As corridors D and E were closer to the existing bridge the requirement for traffic to divert from current routes was low and their ability to serve existing areas of economic development is higher.
- **Ability to accommodate additional lanes** - The tunnel options could not accommodate additional lanes without additional boreholes whereas the bridges have more flexibility to provide additional road space. Thus with the bridge options the reliability of journey times and ability to provide a public transport lane is improved and the impact of maintenance is reduced.
- **Impact on surrounding environment** - Corridor C and E bridges directly impact on designated environmental sites, the Special Protected Areas (SPA) and Gardens and Designated Landscapes (GDLs). With the corridor D bridges there is a risk of adverse environmental impact, but this option avoids direct impact on the SPA. All the tunnel options also avoid direct impact on the SPA but some may indirectly impact designated environmental sites and the SPA.
- **Visual impact** – There is a visual and cultural impact associated with the corridor E bridge given its location immediately to the East of the Category A listed Forth (Rail) Bridge (note that The Forth Road Bridge is also Category A listed).

Although advantages and disadvantages of different options began to emerge, the only options rejected at this stage were the bridges at corridors C and E since they performed very badly against the environmental objective. This was considered significant enough for them to fail the STAG part 1 appraisal. Thus the following were taken forward for option development:

Table 2: Options taken forward to STAG part 2 appraisal

Option	Length	Construction time	Capital cost 2006 Q4 prices
Corridor C – tunnel	8.5km	7.5 yrs	£2.3bn
Corridor D – suspension bridge	1.4km main span	6 yrs	£1.7bn
Corridor D – cable stayed bridge	1.3km main span	5.5 yrs	£1.5bn
Corridor D – tunnel	7.3km	7.5 yrs	£2.2bn
Corridor E – immersed tube tunnel	7.3km	7.5 yrs	£2.5bn

Source: Transport Scotland 2007

STAG part 2 appraisal

The objective of this stage was to find the most suitable option for a replacement crossing. A detailed qualitative and quantitative appraisal was undertaken against the Scottish Government's transport appraisal objectives. The following categories were considered:

- Implementability
- Environment
- Safety and security
- Economy
- Integration
- Accessibility and social inclusion
- Costs to Government
- Risks and uncertainty

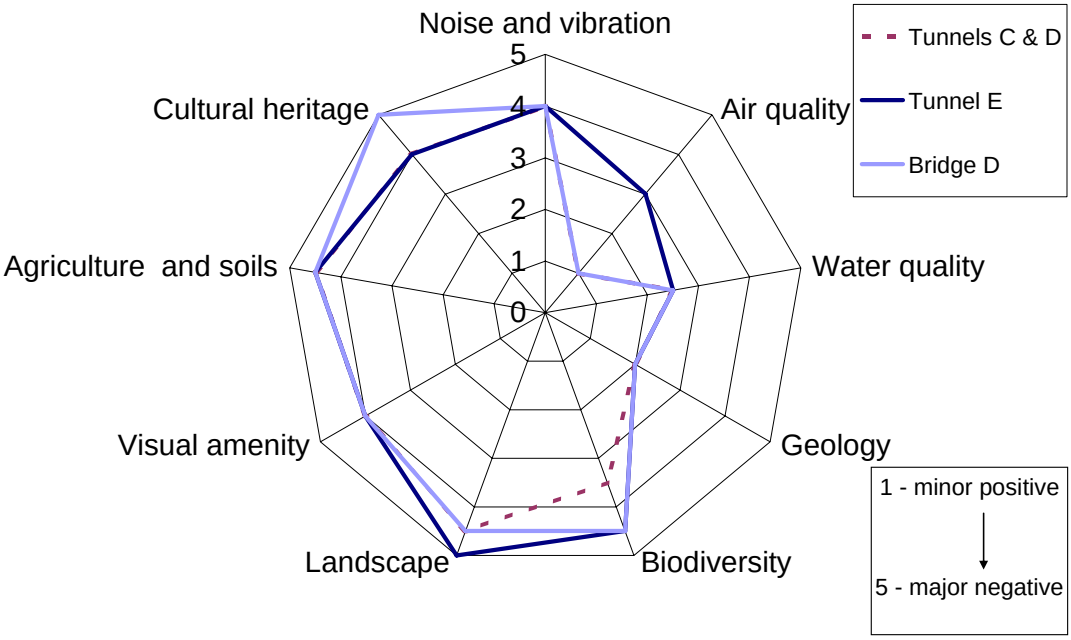
The key areas which set the options apart were as follows:

Implementability
A greater number of risks were identified for the tunnel options due to uncertainty relating to ground conditions and issues associated with the construction of an immersed tube tunnel.

Environmental impacts
Findings from the environmental appraisal are summarised in Figure 2. Most options returned minor-moderate adverse environmental impacts on average, with the exception of Tunnel E and Bridge D which returned major-moderate adverse impacts.

The former was due to Tunnel E being an immersed tube that would disturb sediments and have the potential to impact on the SPAs on the Firth of Forth and Forth Islands. The approach roads would also pass through the Dundas Castle GDL. The latter was due to Bridge D having the potential to disturb protected species which may impose seasonal constraints during construction to protect summer breeding and over-wintering birds. The North landfall would also pass through a marsh protected at national level and involve the loss of some ancient woodland.

Figure 2: Permanent environmental impacts of options



Source: Transport Scotland 2007

Economic efficiency
Although for all options there is a net economic benefit, Bridge D produced the most favourable results with the cable-stayed option costing less than the suspension option as shown in Table 3

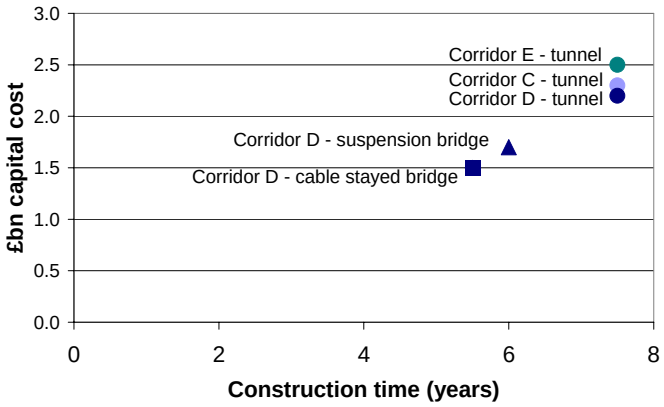
Table 3: Costs and benefits of each option (£ million, 2002)

Measure	Tunnel C	Tunnel D	C-S Bridge D	Spn Bridge D	Tunnel E
Present value of benefits	4,655	5,303	6,026	6,026	6,317
Present value of costs	-2,087	-1,968	-1,397	-1,575	-2,172
Net present value	2,568	3,335	4,629	4,451	4,145
Benefit to cost ratio	**2.2:1**	**2.7:1**	**4.3:1**	**3.8:1**	**2.9:1**

Source: Transport Scotland 2007

This is largely driven by the shorter construction period associated with the bridge options, delivering lower construction costs as shown in Figure 3.

Figure 3: Performance of options against cost and construction time



Insight into costing methodology

Tunnels: A detailed estimate for Tunnel C was undertaken with cost rates for each component derived from industry standards and projects elsewhere. This allowed unit costs per metre of tunnel to be ascertained to cost Tunnels D and E. The immersed tube section of Tunnel E was costed using information from comparable projects.

Bridges: The costs were derived from rates obtained from the Second Severn Crossing. A more detailed costing was undertaken for the superstructure which accounts for two-thirds of the overall cost.

Final recommendation

Corridor E Tunnel (immersed tube) was ruled out first due to the adverse environmental impacts, the implementability risks associated with tunnels and with it being the highest cost option.

The bridge options were viewed as offering several advantages over the remaining tunnel options, including the possibility for better facilities for pedestrians and cyclists, fewer risks associated with unknown ground conditions, shorter construction times and substantially lower costs. However, the tunnels performed better in the environmental assessment. On balance, it was considered that the bridge option in Corridor D provided the best overall solution for a replacement crossing.

Of the two bridge options in Corridor D, the cable-stayed bridge was selected as it could be delivered earlier and cheaper than the suspension bridge. Additional aspects considered were its greater potential in creating a vista across the Forth with three different types of bridge and the avoidance of the need for foundations where there is a methane risk.

This decision was supported by the Scottish Government and announced in December 2007 where the costs were given inclusive of inflation and the cost of capital (outturn costs) as between £3.2 and £4.2 billion. Transport Scotland carried out further planning during 2008 and in December 2008 the Government outlined further key decisions about the design of the bridge. These revisions and refinements mean that the cost of the project is now estimated to be in the range of £1.72 to £2.34 billion (median estimate £2.044 billion).

ANNEX 1 – TIMELINE OF EVENTS

	2004	2005	2006	2007	2008	2009	2011-12	2016-17
Forth Road Bridge	**Cable Deterioration identified** As part of cyclical maintenance, FETA decided to carry out a detailed inspection of the bridge's 2 main cables. A small number of broken cables and some corrosion was found.	**Further inspections undertaken.** Further inspections were carried out at different points of the cables and this confirmed the existence of further broken wires and corrosion. It was assessed that traffic restrictions may have to be in place from 2014.	**Measures taken to prevent further corrosion.** FETA installed monitoring equipment on the main cables. Dehumidification system installation began.			**System to prevent further corrosion fully activated.** Dehumidification system fully activated	**First indication of success available** Dehumidification system fully activated	**2017 - Earliest date could shut to traffic** Original estimates were that the bridge may have to shut to traffic as early as 2014, but 2017 is now the earliest date considered likely for heavy vehicles
Forth Replacement			**Scottish Government begins consideration of Forth Replacement Crossing.** Forth Replacement Crossing study begins August 2006.	**Decision taken to build replacement bridge** Forth Replacement Crossing Study completed June 2007 and Scottish Government announcement made Dec 2007	**Consultants appointed** Feasibility studies and surveys undertaken	**Parliamentary Bill introduced** Statutory consulation and Bill progress begins	**2011 - Construction begins** Construction tender awarded early 2011	**2016 - Construction ends and bridge opens**

Sources: Rehfisch 2010 and Transport Scotland 2010

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