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Forth Replacement Crossing – Scotland, UK

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Abstract

The Forth Replacement Crossing will be built across the Firth of Forth in Scotland to maintain and enhance a vital transport link. The wide estuary will be crossed by a cable stayed bridge with 3 towers and a pair of 650 m main spans. In the centre of each main span the stay cables will overlap to stabilise the central tower, a unique design feature for a bridge of this scale.

The scheme design of the crossing has been carried out by the Jacobs Arup joint venture in accordance with the Eurocodes and project specific design criteria. The structure will provide a fitting 21st century icon, to stand alongside the existing cantilever rail bridge from the 19th century and road suspension bridge from the 20th century, both Grade A listed bridges.

Keywords: cable-stayed bridge; Eurocode; wind tunnel testing.

1. INTRODUCTION

The Firth of Forth is a dramatic estuary which separates the Scottish capital of Edinburgh from the Kingdom of Fife to the north. The downstream crossings of the Forth at Queensferry are a pair of historic bridges - the iconic cantilever rail bridge constructed in the 1880's (Mackay 1993) and the Forth Road Bridge (Anderson et al 1965), Britain's first long span suspension bridge, which was opened in 1964.

Despite significant investment and maintenance over its lifetime, the Forth Road Bridge is showing signs of deterioration as a result of increased traffic and the influence of weather. In 2005, investigations of the main cables (Colford 2008) revealed serious corrosion, which if left unchecked could lead to the bridge being closed to heavy goods vehicles as early as 2014, and to all traffic by 2019. A comprehensive study into the future transport needs concluded that a replacement crossing is required.

The replacement bridge will be slightly to the west of the existing bridges, making use of a natural granite outcrop in the middle of the Forth to allow the wide estuary and two navigation channels to be

crossed by a cable stayed bridge with a pair of 650 m main spans, with an approach viaduct to the south. Selection of the scheme with the minimum impact on the environmentally constrained area and the reasoning behind the overall structural layout are described in Carter et al 2009.



Figure 1: Visualisation: Three centuries of engineering in the Firth of Forth

2. PROCUREMENT

The client, Transport Scotland, is procuring the crossing through a Design and Build contract. This will bring experience from contractors into the project at a suitable stage and allow the chosen contractor to tune the design to suit his preferred methods of working and maximise efficiency. The dialogue period with tenderers is being run in parallel with the parliamentary process which will lead to an Act enabling powers for construction.

Tenders will be submitted in January 2011, with contract award and start of construction anticipated for April 2011, aiming for completion of the bridge in 2016.

3. THE SPECIMEN DESIGN

The Specimen Design of the crossing is a scheme design incorporating a high level of detail which has been produced by the Jacobs Arup joint venture. Transport Scotland wanted to have this specimen design for several purposes: in order to verify the feasibility of the bridge arrangement, to define the overall form and geometry of the crossing, to inform the environmental assessment and the Bill of Parliament, to enable a detailed cost build up to be calculated, and to be an illustrative design as a starting point for the tendering contractors from which to prepare their design proposals.

The total length of the bridge is 2,638 m. Although the crossing is divided into a cable stayed bridge and a southern approach viaduct, the structure is continuous from abutment to abutment with no intermediate expansion joints. Longitudinal fixity is provided by a monolithic connection at the Central Tower located on Beamer Rock with transverse support provided at all towers and piers.

The towers are vertical reinforced concrete elements located in the centre of the deck with two planes of stay cables anchored centrally in the “shadow” of the tower between the carriageways. The stay cables overlap in the centre of the main spans. The deck itself is a streamlined box girder and stay cables are multi-strand type.

The key design requirements for the approach viaduct are long spans to minimise environmental impact, and visual continuity with the cable stayed bridge. One span in particular must cross the Port Edgar Barracks and adjacent road in a single span of 90 m. The aesthetic requirements are achieved by a

pair of constant depth box girders supported on V-shaped piers. The transverse separation of the carriageways is constant, and this also suits the road geometry to either side of the main crossing.

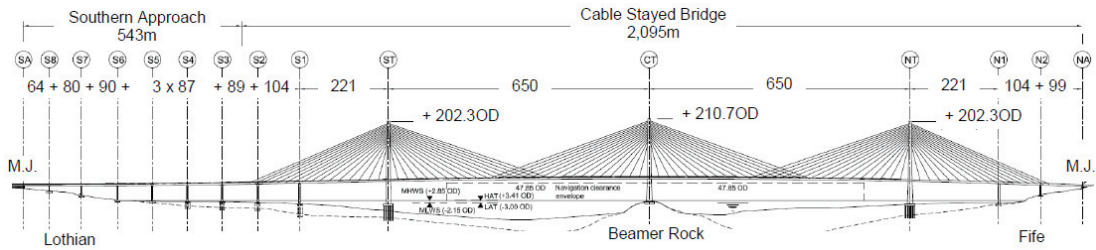


Figure 2: General Arrangement

During preparation of the Specimen Design it became clear that there was no clear advantage to distinguish between all-steel orthotropic and steel-concrete composite construction for the cable stayed bridge deck box. Therefore both options have been worked up as design solutions, and the contract permits either to be adopted. The heavier composite deck variant has stay cables spaced at typically 16.2 m whereas for the orthotropic variant a typical spacing of 25 m is adopted.

Similarly for the approach viaduct deck the choice between composite and prestressed concrete construction for the twin boxes was not driven by significant cost difference, so designs for both variants were completed and the option left open. Incremental launching is assumed for the composite option, and in-situ balanced cantilevering for the prestressed concrete.

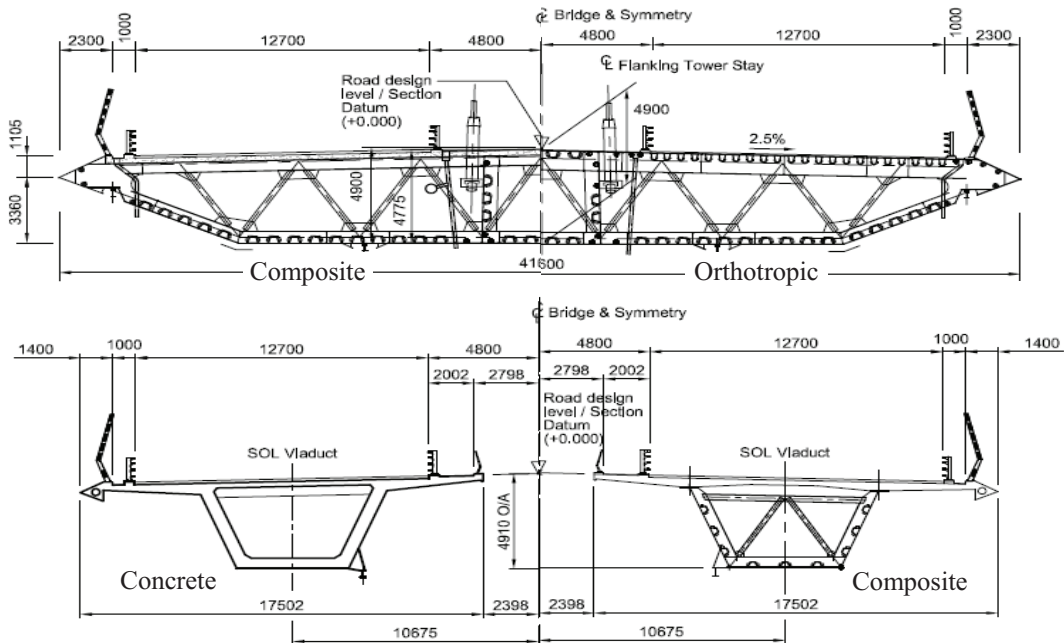


Figure 3: Deck sections, showing all variants

4. DESIGN PROCESS

4.1. Basis of Design

The Forth Replacement Crossing is one of the first major bridges in the UK to be designed to the Eurocode, implemented in April 2010. Work on the Specimen Design commenced in early 2008 when not all of the UK National Annexes and other implementation documents were available. The design criteria to be used for the structural design are set out in a project specific Design Basis document which has been updated and simplified as more national documents have been published. The final version forms part of the contract, providing additional rules and criteria appropriate to the bridge as well as clarifying how some of the Eurocode rules should be interpreted. Aspects such as the site specific wind climate and the rules for ship impact criteria have been defined.

4.2. Analysis

The overall structural analysis was carried out using 3D global computer models. Additional local and semi-local analysis models were established to examine more closely the distribution of stresses and to aid in calibration of the behaviour of the global models.

4.3. Wind Tunnel Testing

Extensive wind tunnel tests were carried out to determine suitable cross sectional shapes for the deck and the towers, determine the aerodynamic properties, identify effective wind shields, and confirm the aeroelastic stability of the bridge. Preliminary sectional tests were carried out at BMT in London. More extensive tests at larger scales were then undertaken in the 14 m wide by 4 m high wind tunnel at the Politecnico di Milano in Italy. These included 1 to 30 scale tests of the deck and tower sections, and a full aeroelastic model at 1 to 170 scale of the whole bridge in key stages of construction and in the completed state.



Figure 4: Wind Tunnel Testing: deck section and balanced cantilever from Central Tower

5. CONCLUSIONS

The Forth Replacement Crossing is a major infrastructure project for Scotland, designed to safeguard a vital connection in the country's transport network. The crossing is located in a historic and environmentally constrained area, and great consideration has been given to allowing the contractor sufficient freedom in his design to bring economy, whilst ensuring the final form of the bridge will not deviate from the client's expectations. This has been achieved through the production of different variants of a Specimen Design, with options left open to the contractor for an orthotropic or composite main deck, and a composite or prestressed concrete approach viaduct.

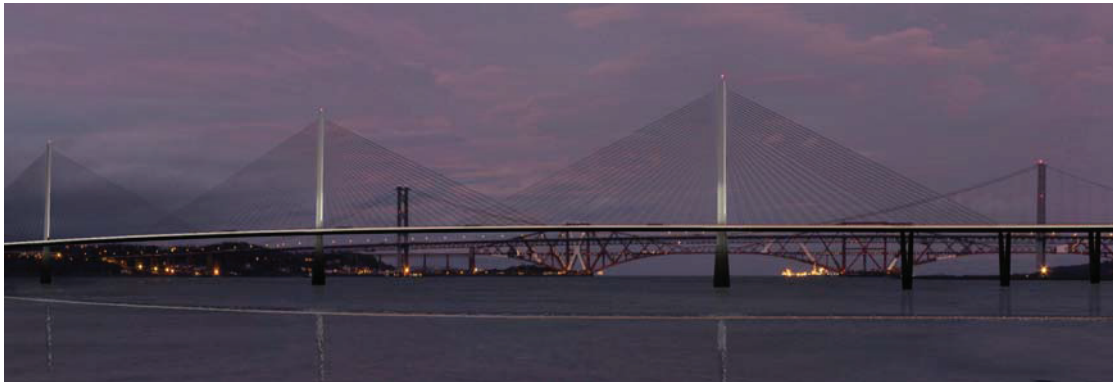


Figure 5: Night time visualisation

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