2 Description of D2M Options

2.1 General Arrangement

The general arrangement of each option has been developed to be largely consistent with the Multi-Modal Base Case with the bridge having two cable stayed main spans, each of 650 m and three towers with the central tower founded on Beamer Rock. The general arrangements of the D2M Options are illustrated in Drawings FRC/C/076/D2M/001 to FRC/C/076/D2M/003 contained in Appendix D.

A fundamental consideration for the general arrangement of the bridge is the provision of two cable stayed main spans. This arrangement requires special consideration of how to stabilise the central tower. As for the Multi-Modal Base Case this will be achieved by crossing stay cables which will overlap over approximately 25% of the length of the main span.

2.2 Functional Cross Section

The functional cross section of the bridge is designed to incorporate the following items:

- D2M: Dual two lane carriageway (urban motorway standard) with 3.6 m hard shoulders, (70 mph design speed)
- Vehicle restraint systems / parapets
- Windshields (designed to be difficult to climb)
- Highway lighting

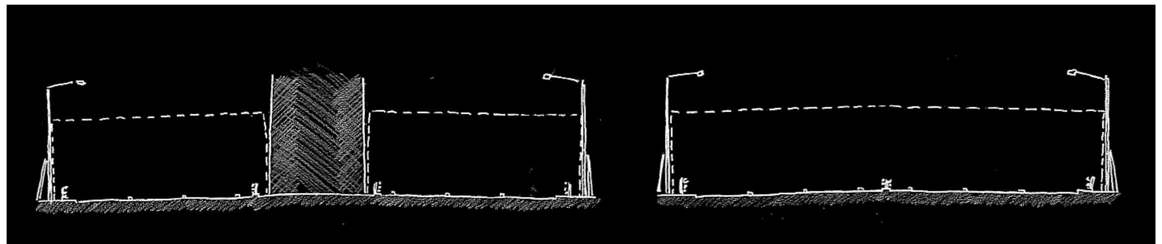
The widened hard shoulder is provided to allow it to be used as a bus lane during peak hours.

The provision of the widened hard shoulder also offers the potential for future conversion of the bridge to a D3 dual three lane carriageway (urban all purpose standard). However, an additional 0.6m width is required for each carriageway to achieve full compliance with urban all purpose road standards. To ensure safe operation of the bridge in the event of future conversion this additional width is provided.

DMRB standard TD27/05 – Road Geometry, Links, Cross-sections and headrooms - has been used as the basis for dimensioning the carriageway layouts.

Two configurations were selected for further development

- Two Corridor Layout
- Single Corridor Layout



Two Corridor Layout   Single Corridor Layout

2.2.1 Two Corridor Layout

The Multi-Modal Base Case is a Needle Tower piercing a wide deck. For the D2M configuration the multi-modal corridor is no longer required. However, the concept of a narrow tower penetrating through the deck is still attractive in order to avoid towers which visually dominate the existing Forth bridges.

For this configuration, one carriageway would pass either side of the towers. Away from the towers, the gap between the carriageways could be open with discrete structural cross girders connecting the deck beneath each carriageway or else closed with a single wide deck supporting both carriageways. For the open solution an additional verge is required adjacent to the offside parapet. The total functional width is approximately 37 m including the central structural zone.

2.2.2 Single Corridor Layout

A more conventional configuration of the cross section would be a single corridor with the carriageways separated by a standard central reserve. Each tower would have two legs at deck level – one either side of the roadway.

For the multi-modal bridge configurations the single wide corridor solution was rejected at concept stage because of the very poor tower aesthetics which would be associated with such a wide deck. However, for the D2M configuration the overall deck width is significantly less and it is possible to design a visually appealing tower for a single corridor. Therefore this option has been revived for the current studies. The total functional width is approximately 30 m.

2.3 Deck Type

A range of deck types are considered for the different functional cross section layouts.

Functional Cross Section	Deck Type
Two Corridor	▪ Single box girder ▪ Twin box girder ▪ Ladder beam
Single Corridor	▪ Single box girder ▪ Ladder beam

2.3.1 Single box girder

The single box girder deck will be a relatively conventional streamlined box shape which may be constructed either as an all-steel orthotropic deck or else in steel-concrete composite construction.

Considering past practice it is known that composite decks can be more economical for short to medium span cable stay bridges but become uneconomical at long spans where minimising deck weight becomes more important. The current longest composite span is 605 m. The 650 m span proposed would therefore be a world record and is at the upper end of the boundary between medium span and long span by this definition.

Cost estimates carried out so far have not indicated a significant price difference between the two deck materials. It is anticipated that the relative economy of the deck types will be marginal and will be determined by market conditions, material costs at the time of construction and the preferred working arrangements of the tendering contractors.

Since the two material options will be aesthetically the same, the aim of the design is that both types be developed. Provided that during the design development neither material type is proven to be unfeasible it is recommended to tender the project on both material types, allowing the tendering contractors to select the one for which they are able to provide the most competitive price. If this strategy is followed then the tower design should be developed to have the same external shape for both deck material options although the wall thickness and other internal details may vary.

2.3.2 Twin box girder

For the Two Corridor option, one of the features of the single box girder deck is there will be additional deck area in the shadow of the tower. It may be possible to save material by splitting the deck into two separate longitudinal girders and providing a void in the space between them. It is not immediately apparent that this does result in material or costs savings since several compensatory factors have to be considered:

- Additional webs must be formed to close the separated decks
- The cross girders connecting the twin decks must carry concentrated transverse bending loads and in-plane vierendeel loads which may result in local thickening of the plates
- Additional deck area is required to provide offside verges
- Additional deck area is required at the deck edges to anchor the stay cables (which cannot be anchored in the shadow of the tower as for the single box due to the reduced torsional stiffness of the deck)
- Fabrication complexity is increased

Nevertheless, the potential for material savings coupled with the potential architectural interest of the split deck solution warrants study of a twin deck box girder. For this arrangement, the two box girders would be connected by cross beams at the cable anchorage positions with air gaps between the cross girder positions.

For this Scheme Assessment, the deck type is assumed to be orthotropic. However, in principle, a steel-concrete composite solution is also feasible and could be studied at a later stage with a view to tendering the project with the material choice left open to the contractor as described above for the single box girder.

2.3.3 Ladder beam

Ladder beam decks typically feature two parallel longitudinal steel girders at the edges of the deck which are connected by steel cross girders at regular intervals. The “ladder” term stems from the appearance of the steel grillage of beams when viewed from below. The cross girders and longitudinal girders act compositely with a reinforced concrete deck slab. This type of deck configuration is potentially advantageous as the steelwork fabrication is simpler than for other configurations.

However, ladder beam decks are torsionally flexible and generally less streamlined than box girders. These two attributes potentially lead to a greater possibility of aerodynamic instability. The requirement for windshielding tends to increase the risk of instability. The current world record spans for a ladder beam deck are 605 m without windshields (Ching Chau Min Jiang Bridge in China) and 456 m with windshields (Second Severn Crossing, UK). Therefore the 650 m span proposed for the Forth Replacement Crossing pushes the limits of what has previously been proven to work.

For the Two Corridor option, the deck would be vented by openings provided in the structural zone in the shadow of the tower. This venting would relieve the difference in air pressure that develops between the upper and lower surface of the deck and is expected to improve the aerodynamic performance.

Both fabricated box and plate girder solutions have been considered for the longitudinal edge girders.

2.4 Tower Forms

Four alternative tower forms have been developed, in each case the tower is a reinforced concrete hollow structure with a fabricated steel anchor box in the upper zone to house the stay cable anchorages. Provision is made within the towers for access during construction and for inspection and maintenance throughout the design life.

Tower Forms

Each tower form has been considered with a particular functional cross section and deck type as tabulated below:

Functional Cross Section	Deck Type	Tower Form
Two Corridor	Any	▪ Mono-Tower
Single Corridor	Single box girder	▪ H-Shape Tower
	Ladder beam	▪ Diamond Tower ▪ A-Frame Tower

The association between tower and deck type for the Single Corridor option is because the H-Shape is the preferred architecture for the tower form (compared to Diamond or A-Frame) but this form is not technically feasible in combination with a ladder beam deck (as described in more detail in Section 6.3.2(a)).

The tower forms are illustrated in Drawings FRC/C/076/D2M/201 to FRC/C/076/D2M/261 in Appendix D.

2.5 Approach Bridge Type

The key issues for the approach viaducts are visual continuity with the cable stayed bridge and long spans to reduce the numbers of piers to be constructed in the environmentally sensitive channel and inter-tidal zone.

A span of approximately 90m is required to cross the combined obstacles of the Port Edgar Barracks and adjacent road at the southern side of the crossing. This is also a reasonable span length to minimise the number of piers without introducing an excessively deep deck structure. A structural depth of approximately 4.0 m is required for the approach bridges to achieve the 90 m spans.

For the two corridor layout the approach bridges will be twin decks, each approximately 16 m wide, with a 6.8 to 8.0 m gap between them (depending on type of mono-tower chosen). At the end of the south viaduct the road goes into cutting and it could be possible to reduce the gap towards the south abutment if this proved beneficial. A more detailed study is required on the layout of the approach viaducts to give the optimum layout to connect the approach roads to the main bridge taking into consideration the construction method of the approach viaducts, the volume of cutting required, the connection between the viaduct and the main bridge deck and the alignment of the road. At this stage it is assumed that the gap will be constant throughout the approach and that the viaduct will be straight and parallel with the main bridge.

For the single corridor layout (H-Shape, Diamond or A-Frame towers), the approach bridge would have a single deck approximately 31 m wide although this could be constructed as two girders connected together. Again it is assumed that this would be straight and parallel with the main bridge.

A total of six different approach bridge cross sections have been considered for the purpose of cost estimation, illustrated in Drawings FRC/C/076/D2M/301 to FRC/C/076/D2M/341 in Appendix D. The approach bridge configurations which have been costed are tabulated below.

At this stage it is assumed that for a given functional cross section type, any approach bridge could be combined with any cable stayed bridge.

Considering the number of different cable stayed bridge deck cross sections currently under consideration, there are too many permutations to look in detail at all combinations of cable stayed bridge and approach bridge. Therefore, for each type of approach bridge, conventional structures derived from engineering requirements have been developed, both in terms of deck cross section and pier form. This will then form the basis for considering the cost implications of any variations from the conventional structure type to achieve better visual continuity with the cable stayed bridge.

Functional Cross Section	Deck Type
Two Corridor	▪ Twin composite box girders ▪ Twin concrete box girders ▪ Twin ladder beam decks
Single Corridor	▪ Twin composite box girders ▪ Twin concrete box girders ▪ Multiple plate girders

2.6 Foundations

The foundation schemes assumed are generally similar to those assumed for the Multi-Modal Scheme Assessment. However preliminary results from the marine investigation carried out between May and August 2008 have been taken into account in developing the D2M scheme foundations. This investigation has established that rockhead is at about -40 mOD at the south tower location for the 650 m span bridge whereas a level of -50 to -55 mOD was assumed in the previous studies. In addition further design development has been carried out since preparation of the Multi-Modal Scheme Assessment report leading in particular to changes to the level of the central tower foundation.

For the cable stayed bridge, piled foundations socketed into rock have been assumed for the flanking towers and the side span piers S1, S2 and N1. Spread foundations bearing on rock have been assumed for the central tower located on Beamer Rock and pier N2 on the north shore. For the approach bridges piled foundations have been assumed for piers S3 and S4 and spread foundations bearing on rock for the remaining piers.

It is envisaged that the pile caps would be precast cellular structures including the lower section of tower or pier up to +5 mOD. At the flanking towers two or more piles would initially be installed and the caps then floated into position and located by the pre-installed piles. The remaining piles would then be installed through sleeves in the cap. The pile/pile cap connections would be formed by grouting the annulus between the piles and sleeve. At the north tower some dredging of the river bed will be required to provide sufficient draft to float the pile cap into position.

It is envisaged that for the central tower foundation a pocket would be formed at Beamer Rock using marine plant working underwater. A precast cellular foundation would then be floated and ballasted into position on preinstalled landing pads and the gap beneath the unit infilled by underwater grouting to form the contact with the excavated rock surface. The cells would then be filled with in-situ concrete.

The smaller pile caps for the side span piers would be brought to the pier locations on a barge and placed onto a prepared granular blanket placed within a dredged pocket. The piles would then be installed through sleeves in the cap and the connection with the cap formed in the same way as for the flanking tower foundations.

For piers S5 and S6 it has been assumed that a temporary access would be constructed and foundations constructed in situ with temporary works to allow an excavation to be formed in dry conditions.