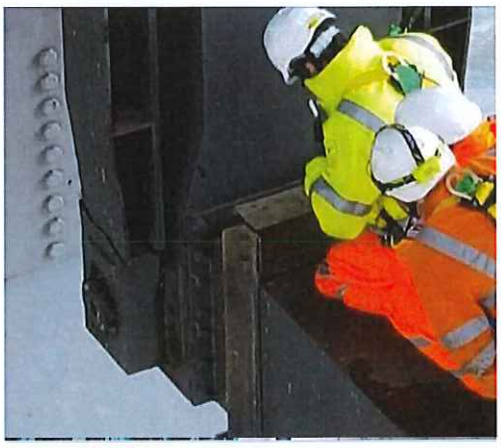
FORTH ROAD BRIDGE

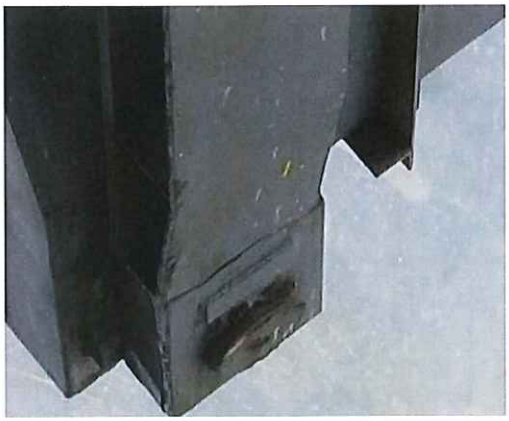
FORTH ROAD BRIDGE

End Link Repair

Approval in Principle
December 2015

amey





FAIRHURST

CONTROL SHEET

CLIENT: Amey

PROJECT TITLE: Forth Road Bridge - End Link Repair

REPORT TITLE: Approval in Principle

PROJECT REFERENCE: 109178C

Issue and Approval Schedule:

ISSUE 1	Name	Signature	Date
Prepared by			05/12/15
Reviewed by	C. A. Clark		05/12/15
Approved by	C. A. Clark		05/12/15

Revision Record:

Issue	Date	Status	Description	By	Chk	App
2	09/12/15		For Approval	GSDS	CAC	CAC
3	10/12/15		For Approval	GSDS		

This report has been prepared in accordance with procedure OP/P03 of Fairhurst's Quality Assurance System.

APPROVAL IN PRINCIPLE

Name of Project: End Link Repair

Name of Bridge: Forth Road Bridge.

Structure Ref No.: Not Applicable.

1 HIGHWAY DETAILS

1.1 Type of highway

Dual carriageway, two lanes each direction

1.2 Permitted traffic speed

50 mph (80 kph)

1.3 Existing restrictions

Following fracture and separation of the end link bottom pin casting from the end link member of the inner leg of the main span end link at the North East Tower, the bridge has been closed to all but emergency vehicles.

It is intended that once this link has been strengthened using the work covered in this AIP, the bridge will be reopened to traffic with the previous restrictions regarding high sided vehicles during high wind speeds imposed.

2 SITE DETAILS

2.1 Obstacle crossed

Firth of Forth

3 PROPOSED STRUCTURE

3.1 Description of Structure and design working life

The Forth Road Bridge spans the Firth of Forth and carries the A90 Trunk Road between Fife and Lothian. The bridge consists of two approach viaducts and a suspension bridge which forms the main section of the structure. The bridge carries two carriageways 7.3m wide and 2 footway/cycleways 4.6m wide.

Two stiffening trusses run along the length of the bridge between hangers and each truss is connected to the main tower by an End Link: a two

legged, articulated, vertical link member, one leg either side of the stiffening truss. These are attached to the bottom chord of the truss and to support brackets cantilevered from the main towers.

The link members each comprise a pair of asymmetric fabricated steel I sections nominally 127mm by 305mm with internal flange 1" thick and the outer flange $^{5}/_{8}$". The links are pinned at each end to allow the stiffening truss to articulate longitudinally. The pin at each end of the link is contained within a casting, welded to the link member.

A welded connection has failed between the pin casting and the link member in the inner leg of the end link, to the east main span stiffening truss at the north east tower. There is vertical separation of the pin casting and the end of the link in the order of 20mm and a horizontal displacement that has varied since separation.

This document deals with the proposed work necessary to rehabilitate the damaged link member and allow the bridge to carry normal traffic loads. Furthermore, the 15 other locations where there is the same end link detail will be similarly strengthened to prevent the same mode of failure.

For the broken end link, the proposed strengthening works will comprise the following:

- Addition of strengthening brackets onto the side of the broken link creating a jacking point below the pin casting
- Realignment of the pin casting relative to the end link so that the two components are vertically aligned.
- Jacking of the pin casting vertically to reinstate load into link, close the gap between the casting and the link member and minimise any misalignment of the pin as far as practical.
- Stabilise this position to allow a replacement solution to be designed and implemented which can be undertaken under overnight closures only.

For the unbroken 15 end link locations, the proposed strengthening comprises:

- Addition of strengthening brackets onto the side of the link and providing a positive load path from the pin casting to the new brackets
- Stabilise these positions to allow a replacement solution to be designed and implemented which can be undertaken under overnight closures only.

This repair addresses the failure and potential failure of the connections at the bottom of the end link between the end link pin casting and the end link member. The root cause of the failure has not yet been identified and this repair does not seek to solve any underlying issues.

The existing truss end links and bridge deck will be monitored using a combination of strain gauges, displacement transducers, inclinometers and temperature gauges. Details to be submitted.'

3.2 Structural type

The component being repaired is a pin ended tension member. The pin at the bottom ends is detached and displaced. This work seeks to realign the pin and restore it to its pre-failure articulation behaviour.

Repair work shall be completed using steel plate, shop fabricated into angled brackets that will be welded into position on site.

3.3 Foundation type

Not Applicable.

3.4 Span arrangements

The existing span arrangement will be retained.

3.5 Articulation arrangements

The articulation arrangement between the main tower and stiffening truss will be maintained as per the existing detail.

It is not known if the pin has been damaged or misaligned as a result of the failure, inspections will be carried out to identify if it is able to articulate as anticipated.

A level of friction between the pin and casing is assumed in section 5.3 that will need to be overcome before the pin can rotate. The effects of friction and potential locking of the pin at low moments/rotations will be considered in the design of the strengthening works.

3.6 Classes and levels

Not Applicable. The works are improvements to reduce the calculated overstress indices determined at assessment stage. As such the strengthening works have been designed on the basis of the most recent version of BS 5400 as the assessment standards are based on the principles of BS 5400.

3.7 Road Restraint System Type

Not Applicable.

3.8 Proposed arrangements for maintenance and inspection assessment

Given the nature of the works which involve welding to existing steelwork it is recommended that regular inspection and monitoring of the brackets following completion of the works is undertaken as part of the bridge inspection and monitoring regime until a replacement solution is adopted. Remote monitoring might be useful in detecting early changes that might not be visible to the human eye.

3.8.1 Traffic Management

Public traffic will be excluded from the bridge until this work has been completed.

3.8.2 Access

Bespoke scaffolding is required to provide access for the completion of this work. Once completed,access provision should be maintained to allow regular inspection of all faces of the new work.

3.9 Environment and Sustainability

Not applicable. The strengthening works are considered improvement works.

3.10 Materials and Finishes

3.10.1 Materials

All new steel plates will be manufactured from steel complying with BS EN 10025-3:2004. The grade of steel shall be S355.

All welds shall be in accordance with BS5400 part 6:1999.

The existing End Links are thought to be fabricated from mild steel plate to BS 15:1948. Original welding to BS 1856.

Welding procedures may need to be adjusted on site based on performance of welding..

3.10.2 Finishes

The new plates and existing prepared steel surfaces shall be left unpainted to assist monitoring and inspection until such time as it is deemed appropriate to paint the bare steel surfaces using an appropriate compatible paint system.

3.11 Risks and hazards considered for design, execution, maintenance and demolition

- Potential for further weld failure and sudden downward movement of stiffening truss. Estimated movements
  - scenario one: 250mm if other leg on same end link fails; and
  - scenario two: 350mm following scenario 1, end link at NW tower suffers similar failure. The effects of these events would warrant a new approach to the strengthening work.
- Working at height

- Erection of scaffolding in a difficult to access location with potential structural movements
- Handling and positioning of heavy fabricated steel elements
- Hot working on site
- Paint removal (existing internal paint systems from original construction comprise lead based paints) – Dust/Chemical residue

3.12 Estimated Cost of proposed structure with other structural forms considered (including where appropriate proprietary manufactured structure), and the reasons for their rejection (including comparative whole life costs with dates of estimates)

Not considered

3.13 Proposed arrangements for construction

3.13.1 Construction of the Structure

Access will be from temporary scaffold around the worksite providing an enclosed safe working environment. The design of this is not considered in this AIP.

3.13.2 Traffic management

Traffic shall be removed from the bridge until after the completion of these works

3.13.3 Service diversions

N/A

3.13.4 Interface with existing structures

The proposed work deals with a single component within the complex bridge structure. The construction sequence will take into account the changes in load distribution within the joining structural components. The loads carried by the end link are dependent on the global loading on the bridge.

4 DESIGN CRITERIA

The global analysis of the bridge has been undertaken using a 3D finite element model. The actions considered are set out in section 4 below. The results of this analysis in relation to the load in the links will be provided to the checker for the structural design of the end link strengthening system.

To maintain a consistent approach for all link strengthening works, including ongoing work to the brackets, the loadings will be derived and the design undertaken to codes and standards set out in Appendix A and the criteria stated below.

4.1 Actions

The approach taken will be as previous assessment and strengthening works. The design of the strengthening works will provide **resistance to for an ultimate load of 2.00 MN at ULS in each leg of the end link.**

The design figure has been set with reference to two earlier loading scenarios:

- 2010 BSALL Recommended lane factors
- 2010 BSALL Reduced Lane Factors

The full load in the links in each case is summarised in the following tables.

The loads in **Table 4.1a** have been extracted from the earlier assessment Report: "Suspended Structure Assessment Report February 2011" prepared by Fairhurst & Partners for the Forth Estuary Transport Authority.

DEAD	0.8707
DEAD+ wind 50mph	0.9760
DEAD + wind 78mph	1.0250
DEAD+BSALL	3.9675
DEAD+BSALL+wind 50mph	3.6521

Table 4.1a *ULS Loads per 2 legged link (MN).*
2010 BSALL Recommended Lane Factors

Lane 1	Lane 2	Lane 3	Lane 4
1.00	0.67	0.33	0.33

The loads in **Table 4.1b** use the same model but adopt the reduced lane factors described in Departure 3 in section 4.6.

DEAD	0.8707
DEAD+ wind 50mph	0.9760
DEAD + wind 78mph	1.0250
DEAD+BSALL	3.6131
DEAD+BSALL+wind 50mph	3.3858

Table 4.1b *ULS Loads per 2 legged link (MN).*
2010 BSALL Reduced Lane Factors (see 4.6 on Departures):

Lane 1	Lane 2	Lane 3	Lane 4
1.00	0.46	0.14	0.14

BSALL with reduced lane factors is used for the basis of the repair works.

Assessment work on the suspended structure was subject to independent Cat III check by AECOM (formerly Faber Maunsell). This confirmed the model behaviour and load effects within the model. The check was based on the 2006 BSALL Assessment which is between 4% and 6% lower than the 2010 BSALL depending on the loaded length considered. The underlying model used for the assessment to both 2006 and 2010 BSALL is the same.

During the jacking operation to redistribute load, there is the potential for the permanent loads in each leg to differ. The stiffnesses of the two legs will be similar assuming that both legs are repaired/strengthened as planned. This means that the imposed load will share approximately equally but dead load may differ. Each leg of the repaired end links have the capacity to accommodate:

Dead load 64% + BSALL 52.5%
Dead load 70% + BSALL 50.0%

4.1.1 Permanent actions

The following permanent actions will be considered:

- Dead loads representing the permanent bridge loading ,
- Superimposed dead loads representing the weight of removable loading such as surfacing on the carriageways and footways and services

The calculated dead load of the structure is detailed in the report W. A. Fairhurst & Partner's report, Evaluation of the Current Self Weight of the Suspended Structure 2006.

4.1.2 Snow, Wind and Thermal actions

Wind loads acting on the stiffening trusses and deck structure will be based on the results of wind tunnel testing. Refer to the Wind Tunnel Testing of Deck Structure report by the University of Glasgow dated April 2006. This loading replaces the wind loading given in Clause 5.3 of BD 37. The application of the wind loading will be based on BD 37/01 which allows for the greater loaded lengths considered in the assessment. The load factors quoted in Table 1 of BD 37/01 will be adopted for the assessment.

Wind load acting on the main towers will be based on the results of wind tunnel testing undertaken for the proposed design of the towers for Humber Suspension Bridge. Refer to the National Physical Laboratory Report, A Further Aerodynamic Investigation for the Proposed Humber Suspension Bridge dated June 1972.

Where wind loading is applied in conjunction with live loading the wind load is based on a reduced maximum wind gust speed of 50mph. This is based on the operational procedures which the Forth Road Bridge have in place under high wind situations. At wind speeds 50mph and above the Forth Road Bridge restrict traffic to cars and light vans.

Wind loading applied in conjunction with permanent loading only is based on a maximum wind speed of 78mph

4.1.3 Actions relating to normal traffic under AW regulations and C&U regulations

The live loading due to vehicular traffic will be based on the 2010 Bridge Specific Assessment Live Loading (BSALL) with a 5% probability of occurring within a 10 year period as detailed in the addendum report by W. A. Fairhurst & Partners dated 9th February 2011. This facilitates the use of reduced lane factors.

The use of a reduced return period was previously agreed with FETA and was considered appropriate on the basis that a new Forth Crossing is being constructed and that permitted loading on the existing structure will be limited following opening of the new crossing. For this strengthening, it is considered appropriate to adopt a 10 year return period for the repair and a replacement solution with a 60 year design life will follow.

Load pattern considered for design of end link strengthening:

On lanes 1 and 2, 362m of BSALL has been applied in conjunction with 50m of BSALL on lanes 3 and 4. The BSALL loading was factored by 1.2 from the nominal

loading to provide a characteristic value for the assessment which was used for all load cases. This was done to represents an appropriate realistic loading which the links are likely to be subjected to in the anticipated life of this strengthening.

Departures 3 and 4 in section 4.6 refer.

4.1.4 Actions relating to General Order Traffic under STGO regulations

Abnormal vehicles will be excluded following completion of these works, subject to further assessments and potential works on other elements of the bridge. Such loading or HB loading will not be considered to act in combination with Bridge Specific Live Loading.

4.1.5 Footway or footbridge variable actions

Normal observed footway loading from pedestrians and cyclists is extremely low in comparison to that described in BD21. Minimal Live loading on the footways will not be considered in addition to the BSALL for the design of the end link strengthening covered in this AIP.

4.1.6 Actions relating to Special Order Traffic, provision for an exceptional abnormal indivisible loads including location of vehicle track on deck cross section

As 4.1.4, no abnormal vehicles will be considered.

4.1.7 Accidental actions

Not Applicable.

4.1.8 Action during construction

The construction sequence imposes loads into the strengthening works that need to be accommodated, items in bold will impose loads into the new steelwork.

a) Prepare surfaces in end link to be cast
b) Align detached end link above casting:
c) Locate and weld on bracket 1
d) Locate and weld on bracket 2
e) Clamp together brackets to achieve intimate contact with sides of casting
f) Weld together the two brackets to form the lifting frame
g) Insert and secure jacks and packers
h) Jack up casting until in contact with End Link. The intention is to match up the fractured surfaces.
i) Lock off jacks.

4.1.9 Any special action not covered above

Not Applicable.

4.2 Heavy or high load route requirement and arrangement being made to preserve the route, including any provision for future heavier loads or future widening.

Not Applicable.

4.3 Minimum headroom provided

Not Applicable.

4.4 Authorities consulted and any special conditions required

Bridge Operator (AMEY): None.

4.5 Standard and documents listed in the Technical Approval Schedule

See Appendix A.

4.6 Proposed departures from Standards given in 4.5

Departures from standard are as proposed for the design of strengthening works to the end link brackets. The approval of these is part of a separate approval process. For expediency, it is assumed for the design of this strengthening that these are all approved.

Applications for the Departure from Standards can be found in the AIP Addendum "documents number 109178A / CIV / AIP – A1". A summary of each departure is as followed;

- Departure Number 001:

A reduced load factor γ_{fl} of 1.08 for the dead load of the concrete deck will be adopted. The reduced load factor is based on the results of tests undertaken on samples of the concrete deck to determine the thickness and density of the concrete. Details of the testing are given in, Report on Loading and Structural Integrity Volume IIIby W. A. Fairhurst & Partners Dated July 1986.

- Departure Number 002:

A reduced load factor γ_{fl} of 1 and 1.2 for SLS and ULS respectively will be used in the model for the superimposed dead load carriageway surfacing in accordance with Clause 5.2.2.1 of BD 37/01.

- Departure Number 003:

Assessment of the main tower link arrangement have previously shown that elements of the links are overstressed under the application of recommended 2010 BSALL loading as set out in Fairhurst's 2010 Bridge Specific Assessment Live Loading + Addendum reports. In order to prioritise essential maintenance and upgrading works FETA requested that Fairhurst review the assessment of the link arrangements for a lower level of 2010 BSALL. The review determined the lowest levels of stress indices associated with a 2010 BSALL which can be safely accepted thereby limiting the extent of any upgrading required to the brackets in the short term. It was accepted that amended lane factors based on statistical analysis of actual vehicles carried using Weigh in Motion (WIM) calculations of 1, 0.46, 0.14, and 0.14 can be adopted for lanes 1, 2, 3,

and 4 respectively for a reduced return period of 1 in 10 years. These are known as reduced lane factors.

The maximum loading applied to the end links makes reference to these reduced lane factors.

- Departure Number 004:

The characteristic BSALL loading was adopted for design, this load being derived by multiplying the nominal BSALL loading by 1.2 for all load cases. Factoring for ULS loadings in accordance with BD37/01 would greatly reduce the probability that the loadings are actually realised and therefore conservative for the short time period until the New Queens Ferry Crossing is opened. The new crossing will divert traffic away from the Forth Road Bridge resulting in reduced loadings;

- Departure Number 005:

Where wind loading is applied in conjunction with live loading the wind load is based on a reduced maximum wind gust speed of 50mph and applied in accordance with BD37/88. This is based on the operational procedures which the Forth Road Bridge have in place under high wind situations. At wind speeds 50mph and above the Forth Road Bridge restrict traffic to cars and light vans.

4.7 Proposed methods of dealing with aspects not covered by standards in 4.5

N/A

5 STRUCTURAL ANALYSIS

5.1 Methods of analysis proposed for superstructure, substructures & foundations

Loadings in the truss end link have been determined using a global model of the bridge (refer to diagram provided in Appendix B). Finite element structural analysis software LUSAS was used for the global modelling. The loadings in the end links determined by Designer Fairhurst and Checker Arup and an agreed set of loadings taken into the detailed design. This approach is necessary due to the limited time available to complete and check the design.

5.2 Description and diagram of idealised structure used for analysis

The global analysis of the bridge was modelled as a 3D frame with each structural member represented by a line beam element in the computer model. The arrangement of the computer model used is shown in diagram provided in Appendix D. The connections between stiffening truss members was considered as being rigid.

The supports from the side tower to the stiffening truss and deck was modelled by providing structural support points with rotational releases to represent the articulation of the structure.

Rotational and translation constraints between elements were used to model the connections of the stiffening truss to the main towers where the use of line beams is not appropriate.

5.3 Assumptions intended for calculation of structural element stiffness

Friction coefficient within the pinned connections at each end of the end links shall be taken as 0.5.

Gross section properties shall be used for the analysis. Section properties to be used in the design will be determined in accordance with relevant British Standards. Steel strengths for the original main tower sections are based on the following:

- High tensile plates (Main plate sections forming the tower legs including cell cover plates) – BS 968: 1943 Type A.
- Mild steel plates and sections (all other plates such as link brackets, diaphragm plates and stiffeners) – BS 15: 1948.

5.4 Proposed range of soil parameters to be used in the design of earth retaining elements

Not applicable

6 GEOTECHNICAL CONDITIONS

6.1 Acceptance of recommendations of the Geotechnical Design Report to be used in the design and reasons for any proposed changes.

Not Applicable

6.2 Summary of design for highway structure in the Geotechnical Design Report.

Not Applicable

6.3 Differential settlement to be allowed for in design of the structure:-

Not Applicable

6.4 If the Geotechnical Design Report is not yet available, state when the results are expected and list the sources of information used to justify the preliminary choice of foundations

Not Applicable

7 CHECKING

7.1 Proposed Category and Design Supervision Level

Category 3

7.2 If Category 3, name of proposed Independent Checkers

Arup

7.3 Erection proposals or temporary works for which Types S and P Proposals will be required, listing structural parts of the permanent structure affected with reasons

Not Applicable

8 DRAWINGS AND DOCUMENTS

8.1 List of drawings (including numbers) and documents accompanying the submission

None.

9 THE ABOVE IS SUBMITTED FOR ACCEPTANCE

Signed: ....

Name:

Engineering Qualifications:

Name of Organisation: **FAIRHURST**

Date: 10 December 2015

The Design organisation named above is engaged as a sub-contractor to the organisation stated below. I formally acknowledge the submission of this Certificate to Transport Scotland in support of our contract obligation for provision of the Design on behalf of Amey.

Signed: ....

Name:

Engineering Qualifications:

Name of Organisation: **Amey**

Date: 10/12/2015

---

10 THE ABOVE IS AGREED SUBJECT TO THE AMENDMENTS AND CONDITIONS SHOWN BELOW

Signed:

Name: V.J. Wayne Hindshaw

Position held Chief Bridge Engineer

Engineering Qualifications BSc(Hons) C.Eng M.I.C.E MC.I.H.T.

TAA Transport Scotland.

Date: 10 December 2015

Appendix A

Relevant Documents and Standards used in the Design

Technical Standards Schedule

It is the responsibility of the complier of the AIP and/or the design or check certificate complier to ensure that the Standards, references and clauses used, including amendments and corrigenda are relevant and current at the Base Date.

Documents in *italics* are under preparation at the time of preparation of this document.

Schedule of Documents Relating to Design of Highway Bridges ad Structures using UK National Standards

BRITISH STANDARDS (HMSO publications)		
~~BS 5268~~	~~Part 2: 1996~~	~~Structural Use of Timber~~
BS 5400		Steel, Concrete and Composite Bridges
	Part 1: 1988	General Statement, see BD 15
	Part 2: 1978	Specification for Loads, see BD 37/01
	Part 3: 2000	CP for design of steel bridges, see BD 13/04
	~~Part 4: 1990~~	~~CP for design of concrete bridges, see BD 24/92~~
	~~Part 5: 1979~~	~~CP for design of composite bridges, see BD 16/82~~
	Part 6: 1999	Specification for materials and workmanship, steel
	~~Part 9: 1983~~	~~Bridge Bearings, see BD 20/92~~
	~~Part 10: 1980~~	~~CP for fatigue, see BD 9/81~~
~~BS 5628~~		~~Code of Practice for Use of Masonry~~
	~~Part 1: 1982~~	~~Structural use of Unreinforced Masonry~~
	~~Part 2: 1995~~	~~Structural Use of Reinforced and Prestressed Masonry, see BD 41/97~~
	~~Part 3: 1985~~	~~Materials and Components, Design and Workmanship, see BD 41/97~~
~~BS 5930~~	~~1999~~	~~Code of Practice for Site Investigations~~
~~BS 6031~~	~~1981~~	~~Code of Practice for Earthworks~~
~~BS 8002~~	~~1994~~	~~Earth Retaining Structures~~
~~BS 8004~~	~~1986~~	~~Foundations, see BD 32/88~~
~~BS 8118~~		~~Structural Use of Aluminium~~
	~~Part 1: 1991~~	~~Code of Practice for design~~
	~~Part 2: 1991~~	~~Specification for Materials, Workmanship and Protection~~
~~BS EN 1317-1~~	~~1998 Road Restraint Systems – Part 1~~	~~Terminology and general criteria for test methods~~

BRITISH STANDARDS (HMSO publications)		
~~BS EN 1317-2~~	~~1998 Road Restraint Systems – Part 2~~	~~Performance classes, impact test acceptance criteria and test methods for safety barriers~~
~~BS EN 1317-3~~	~~2000 Road Restraint Systems – Part 3~~	~~Performance classes, impact test acceptance criteria and test methods for crash cushions~~
~~ENV 1317-4~~	~~2002 Road Restraint Systems – Part 4~~	~~Terminals and transitions~~

Execution Standards	
BS EN 1090-1:2009	Execution of steel structures and aluminium structures – Part 1: Requirements for conformity assessment of structural components
BS EN 1090-2:2008	Execution of steel structures and aluminium structures – Part 2: Technical requirements for the execution of steel structures
~~BS EN 1090-3:2008~~	~~Execution of steel structures and aluminium structures – Part 3: Technical requirements for aluminium structures~~
~~EN 13670~~	~~Execution of concrete structures~~

Miscellaneous
~~Circular Roads No 61/72 – Routes for heavy and high abnormal loads (refer to the website http://www.ocdal.com)~~
Traffic Management Act 2004
Construction (Design and Management) Regulations 2007

The Manual of Contract Documents for Highway Works (MCDHW) *(Designers should consult and agree with the TAA on the version of MCDHW to be used with Eurocode design)*
Volume 1: Specification for Highway Works
Volume 2: Notes for Guidance on the Specification for Highway Works
Volume 3: Highway Construction Details

The Design Manual for Roads and Bridges (DMRB) **General Requirements, Standards (GD Series)**	
GD 01	Introduction to the Design Manual for Roads and Bridges (DMRB)
GD 02	Quality Management Systems for Highway Design
The Design Manual for Roads and Bridges (DMRB) **Bridges and Structures, Advice Notes (BA Series)**	
~~BA 26/94~~	~~Expansion Joints for use in Highway Bridge Decks~~
~~BA 28/92~~	~~Evaluation of Maintenance Costs in Comparing Alternative Designs for Highway Structures~~
~~BA 36/90~~	~~The use of permanent formwork~~
~~BA 41/98~~	~~The Design and Appearance of Bridges~~
~~BA 42/96~~	~~The Design of Integral Bridges~~
~~BA 44/96~~	~~Assessment of Concrete Highway Bridge and Structures~~
~~BA 47/99~~	~~Waterproofing and Surfacing of Concrete Bridge Decks~~
~~BA 56/10~~	~~The Assessment of Steel Highway Bridges and Structures~~
~~BA 57/01~~	~~Design for Durability~~
~~BA 59/94~~	~~Design of Highway Bridges for Hydraulic Action~~
~~BA 67/96~~	~~Enclosure of Bridges~~
~~BA 68/97~~	~~Crib Retaining Walls~~
~~BA 72/03~~	~~Maintenance of Road Tunnels~~
~~BA 74/06~~	~~Assessment of Scour at Highway Bridges~~
~~BA82/00~~	~~Formation of Continuity Joints in Bridge Decks~~
~~BA 84/02~~	~~Use of Stainless Steel Reinforcement in Highway Structures~~
~~BA 85/04~~	~~Coatings for Concrete Highway Structures & Ancillary Structures~~
~~BA 92/07~~	~~The Use of Recycled Concrete Aggregates in Structural Concrete~~
~~BD 7/01~~	~~Weathering Steel for Highway Structures~~
The Design Manual for Roads and Bridges (DMRB) **Bridges and Structures, Standards (BD Series)**	
~~BD 10/97~~	~~Design of Highway Structures in Areas of Mining Subsidence~~
~~BD 12/01~~	~~Design of Corrugated Steel Buried Structures with Spans greater than 0.9 metres and up to 8.0 metres~~
~~BD 20/92~~	~~Bridge Bearings, Use of BS 5400: Part 9: 1983~~
BD21/01	The Assessment of Highway Bridges and Structures
~~BD 29/04~~	~~Design Criteria for Footbridges~~
~~BD 33/94~~	~~Expansion Joints for use in Highway Bridge Decks~~

~~BD 35/06~~	~~Quality Assurance Scheme for Paints and Similar Protective Coatings~~
~~BD 36/92~~	~~Evaluation of Maintenance Costs in Comparing Alternative Designs for Highway Structures~~
BD 37/01 & BD37/88	Loads for Highway Bridges (for defining an HB rating only)
~~BD41/97~~	~~Reinforced clay brickwork retaining walls of pocket type and grouted cavity type construction – use of BS 5628:Part 2:1995~~
~~BD 43/03~~	~~The impregnation of Reinforced and Prestressed concrete Highway Structures using Hydrophobic Pore-Lining Impregnants~~
~~BD 45/93~~	~~Identification Markings of Highway Structures~~
~~BD 47/99~~	~~Waterproofing and Surfacing of Concrete Bridge Decks~~
BD50/92	Technical Requirements for the Assessment and Strengthening programme for Highway Structures – Stage 3 Long Span Bridges
~~BD 51/98~~	~~Portal and Cantilever Signs/Signal Gantries~~
~~BD 53/95~~	~~Inspection and Records for Road Tunnels~~
~~BD 57/01~~	~~Design for Durability~~
~~BD 62/07~~	~~As-built, Operational and Maintenance Records for Highway Structures~~
~~BD 63/07~~	~~Inspection of Highway Structures~~
~~BD 65/97~~	~~Design Criteria for Collision Protection Beams~~
~~BD 67/96~~	~~Enclosure of Bridges~~
~~BD 68/97~~	~~Crib Retaining Walls~~
~~BD 70/03~~	~~Strengthened/reinforced Soils and other Fills for Retaining Walls and Bridge Abutments. Use of BS 8600:1995 incorporating amendment no. 1 (Issue 2 March 1999)~~
~~BD 78/99~~	~~Design of Road Tunnels~~
~~BD 82/00~~	~~Design of Rigid Buried Pipes~~
~~BD 90/05~~	~~Design of FRP Bridges and Highway Structures~~
~~BD 91/04~~	~~Unreinforced Masonry Arch Bridges~~
~~BD 94/07~~	~~Design of Minor Structures~~

The Design Manual for Roads and Bridges (DMRB) **Traffic Engineering and Control, Standards and Advice Notes (TD and TA Series)**	
~~TD 9/93~~	~~Highway Link Design~~
~~TD 19/06~~	~~Requirement for Road Restraint Systems~~
~~TD 27/05~~	~~Cross Sections and Headroom~~
~~TD 36/93~~	~~Subways for Pedestrians and Cyclists, Layout and Dimensions~~
~~TD 89/08~~	~~Use of Passively Safe Signposts, Lighting Columns & Traffic~~

	~~Signal Posts to BS EN 12767~~

The Design Manual for Roads and Bridges (DMRB) **Highways, Advice Notes (HA Series)**	
~~HA 59/92~~	~~Mitigating Against Effects on Badgers~~
~~HA 66/95~~	~~Environmental Barriers – Technical Requirements~~
~~HA 80/99~~	~~Nature Conservation Advice in Relation to Bats~~
~~HA 81/99~~	~~Nature Conservation Advice in Relation to Otters~~
~~HA 84/01~~	~~Nature Conservation and Biodiversity~~
~~HA 97/01~~	~~Nature Conservation Management Advice in Relation to Dormice~~
~~HA 98/01~~	~~Nature Conservation Management Advice in Relation to Amphibians~~

The Design Manual for Roads and Bridges (DMRB) **Highways, Standards (HD Series)**	
~~HD 22/08~~	~~Managing Geotechnical Risk~~

Transport Scotland Interim Advice Notes	
~~TSIA 22~~	~~Implementation of new reinforcement standards (BS 4449:2005, BS 4482:2005, BS 4483: 2005 and BS 8666:2005)~~
~~TSIA 23~~	~~Implementation of BS8500-1:2006 Concrete – Complementary British Standard To BS EN 206-1~~
~~TSIA 24~~	~~Guidance on implementing results on research on bridge deck waterproofing~~
TSIA 27	Implementation of the Construction (Design and Management) Regulations 2007 and the withdrawal of SD 10/05 and SD 11/05
~~TSIA 31~~	~~Use of Eurocodes for the design of bridges and road related structures~~

Appendix B

Diagrams of Idealised Structure to be used for Analysis

3-Dimensional View of the FE model of the structure

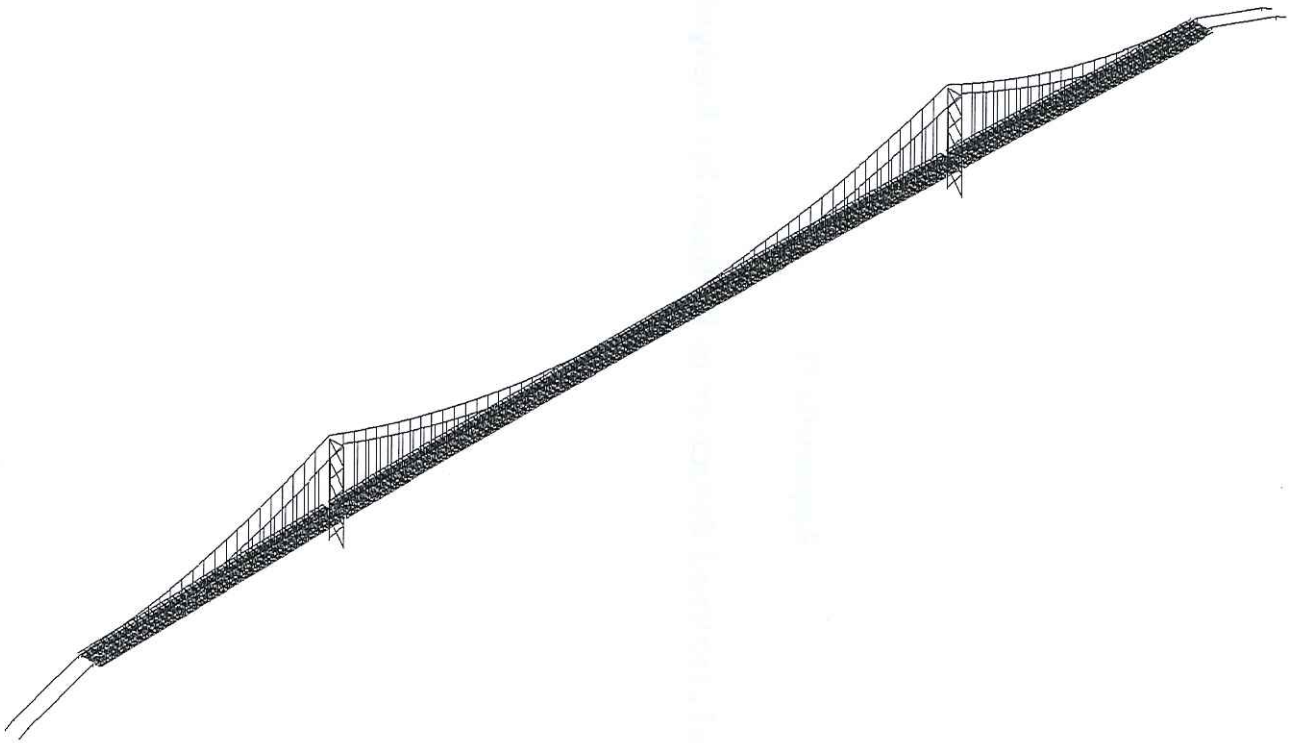


Figure 1 – Bridge model