Technical Report

Foryd Harbour Lifting Bridge

Deck Structural Design Specifications

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Issue C

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Issue and Amendments

ISSUE	AMENDMENTS	DATE	CHECKED	APPROVED
A	First Issue	04 July 2012	Mark Hobbs	Mark Hobbs
B	Wind load, load combinations, minor amendments	16 July 2012	Mark Hobbs	Mark Hobbs
C	Load combinations updated and moved to GU3073-8001, minor amendments	30 November 2012	Mark Hobbs	Mark Hobbs

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Content

1. Introduction

This report summarises the general design specifications, including design criteria, codes and other technical references, loads and load combinations, partial factors and performance requirements for the detail structural design of the bridge deck of the Foryd Harbour Lifting Bridge, a footbridge due to be built across the Clwyd River, at its estuary, in the County Denbighshire, England.

The general layout of the bridge is shown in Figure 1.

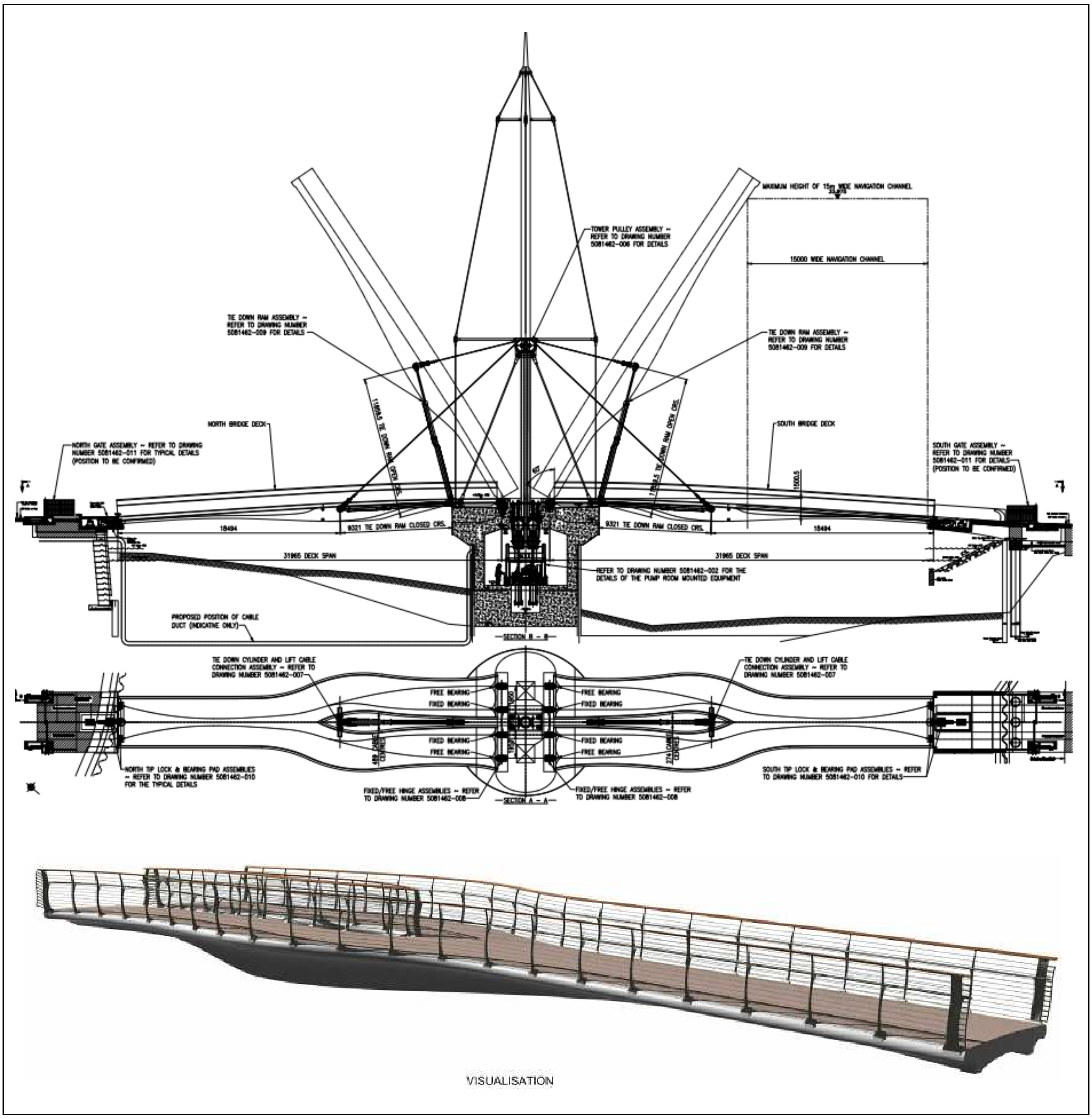

Figure 1: Bridge layout (by Ramboll)

The bridge is a two-span moveable bridge, with the two 32 *m* spans rotating about the central support by means of a hinge and a lifting cable and winches system.

The lifting cable has also the function of support for bridge in closed position, contributing to the stiffness of the bridge deck. The support offered by the cable is provided through a steel tube which transfers the load from the cable to the bridge deck.

The cross-section of the bridge deck varies along the span. Typical sections are reported in Figure 2.

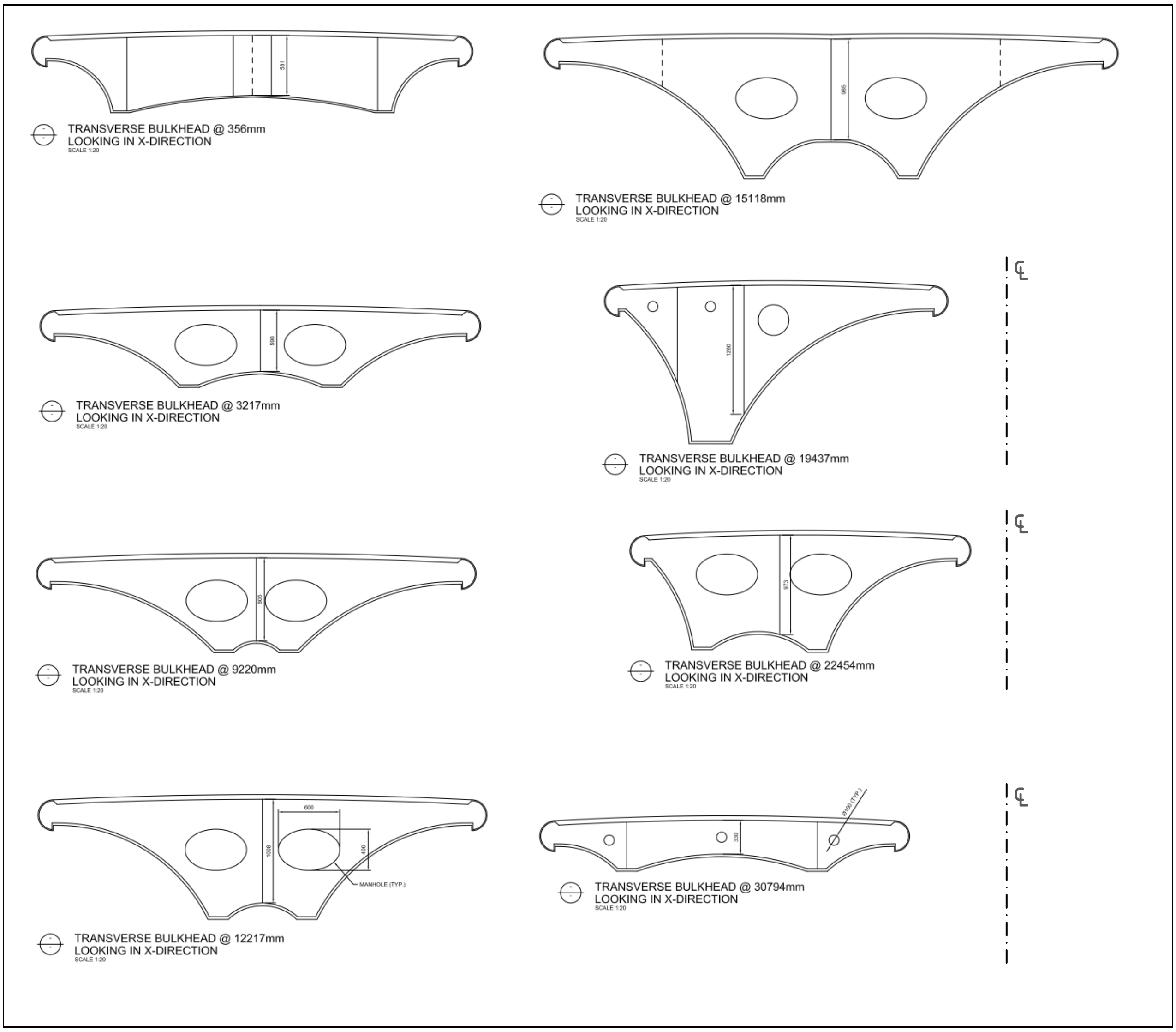

Figure 2: Typical cross-sections

The bridge deck will be realized with moulded FRP components, mainly in the form of sandwich panels, consisting in two wet laminated / vacuum consolidated epoxy glass laminates separated by and bonded to a foam core panel.

Each of the two spans of the bridge will be manufactured in two parts to be transported and bolted together along the centre line on site.

Where possible, access to the inside of the bridge deck shell will be provided by manholes on the top deck and in the internal structure (bulkheads and longitudinal webs). Where the depth of the bridge deck does not allow physical access, holes for visual inspection will be provided instead.

The bridge is supposed to be partially or fully open (respectively at 30° and 60°) only with Wind Force up to 7. For stronger wind the bridge will remain closed. In the open positions, the bridge deck is anchored to the concrete plinth of central pylon by means of a hydraulic ram, connected to the steel tube and hinged at the two ends.

In closed position, the bridge is locked down by means of a horizontal piston and wheel system at the landwards end.

The content of this document refers exclusively to the structural design of the moulded FRP bridge deck. The design of the mast, substructures, lifting system and other equipment is carried out by others.

2. General Design Criteria

Currently there are no specific design standards in force in the UK for the design of FRP structures. However, the design of the bridge deck will be carried out in accordance with the Limit State methodology as employed in the Eurocodes ([1], [2]).

Reference to Eurocodes will be also made for characteristic values of loads, load partial factors and load combinations ([3], [4]). Some of the loads, including wind loads and parapet loads, were provided by Ramboll ([5]).

Material partial factors will be taken from “EuroComp Design Code and Handbook for Structural Design of Polymer Composites” ([6]) which is based on a Limit State design method.

Mechanical properties of FRP laminates will be calculated by classical laminate theory and from the characteristic values of mechanical properties of individual plies. Detailed manufacturing specification will be produced and the manufacturer will be requested to carry out tests in accordance with recognised test standards to confirm the achievement of the characteristic values of the mechanical properties of the laminates assumed in the design.

A certain degree of pretension in the cable, after the bridge is locked in closed position, will be considerate in order to maintain the cable in tension under the uplift action of the wind. The precamber resulting from the cable pretension will be also considered to reduce the net deflection due to the gravity loads. However, the pretension in the cable will be limited to the value that induces zero reaction at the tip of the bridge under dead load (i.e. the simply supported landwards bridge end)

The bridge will be analysed using advanced FE modelling of composite materials (shell elements) to verify both its functionality under Serviceability Limit States (SLS) and its capacity under Ultimate Limit States (ULS). The bridge will be modelled in the closed position and in the partially and fully open positions. The interaction of the bridge deck with the suspension system and the hydraulic tie down ram will be modelled with springs.

Consideration will be also given to the installation sequences.

3. Loads

Details of superimposed dead loads, traffic loads and wind loads have been provided by Ramboll [5].

3.1 Permanent Actions

Besides the self-weight of the structural components to be assessed according to the densities of the materials used, the other permanent and variable loads to consider will be:

- surfacing: 0.10 kN/m^2
- parapets: 0.15 kN/m

3.2 Variable Actions

3.2.1 Traffic actions

- traffic load (q_{fk}): 5 kN/m^2
- service vehicle (Q_{serv}): 2.5 kN/wheel, 4 wheels, spacing 1050 mm
- Balustrade load: loads as provided by Ramboll (see [7])

PARAPET POST LOADS			
	INTERMEDIATE POST	END POST	CENTRE POST
Mx	4.4kNm	4.4kNm	4.4kNm
My	0.5kNm	41kNm	74kNm
Sx	0.5kNm	60kNm	108kNm
Sy	3.2kN	3.2kN	3.2kN

3.2.2 Wind actions

- wind load with bridge closed:
  - uplift and downward load: 0.70 kN/m^2
  - transverse load: 1.43 kN/m^2
- wind load with bridge open at 30º to the horizontal:
  - uplift and downward load: 0.40 kN/m^2
  - transverse load: 0.75kN/m^2
  - longitudinal load: 0.84 kN/m^2
- wind load with bridge open at 60º to the horizontal:
  - uplift and downward load: 0.40 kN/m^2
  - transverse load: 0.75 kN/m^2
  - longitudinal load: 0.84 kN/m^2

Coherently with the Eurocode and Ramboll's directions, the above wind loads will be applied over the projected area of the bridge deck orthogonally to the wind direction (i.e. the reference area A_{ref} mentioned in the [3]). The uplift and downward loads will be assumed to act simultaneously only with the transverse wind load and orthogonally to the top deck, that is in the direction orthogonal to the wind direction. The two different open positions are considered to account for the variation of the hydraulic ram effectiveness with angle.

3.3 Partial Factors and Factors for Representative Values of Actions

Assumptions made regarding the values of factors for representative values of actions and of partial factors for actions are summarized in the following table.

Parameter				Assumptions/Comments/References
Factors for Representative Values of Actions	ψ_0	ψ_1	ψ_2	BS EN 1990:2002, cl.A2.2.6, Table A2.2
Traffic Loads				
g_{r1}	0.4	0.4	0	
g_{r2}	0	0	0	
Q_{fwk}	0	0	0	
Wind Forces				
F_{wk}	0.3	0.2	0	

Partial Factors for Actions

Ultimate Limit States

Parameter				Assumptions/Comments/References
Persistent/Transient Design Situations				BS EN 1990:2002, cl.A2.3.1, Table A2.4(B). NA to BS EN 1990:2002, Table NA.A2.4(B) Note that the values of the partial factor for actions account for model uncertainties and dimensional variations.
Permanent Actions				
	$\gamma_{G,sup}$	=	1.35	
	$\gamma_{G,inf}$	=	0.95	
Variable Actions				
Traffic Actions	$\gamma_{Q,sup}$	=	1.35	
	$\gamma_{Q,inf}$	=	0.00	
Parapet Loads	γ_Q	=	1.35	
Service Vehicle	γ_Q	=	1.50	
Wind Actions	γ_Q	=	1.55	Wind speed adjusted for design life of 120 years

Table 1. ψ and γ factors

3.4 Load Combinations

The load combinations to be investigated will be defined in the Design Report coherently with the load partial factors and the load combination factors defined in the previous paragraph.

4. Materials

The bridge deck will be realized with moulded FRP components, mainly in the form of sandwich panels, consisting in two wet laminated / vacuum consolidated epoxy glass laminates separated by and bonded to a foam core panel.

Details on the materials, including characteristic values for the mechanical properties, will be given in the Structural Design Report.

4.1 Material Partial Factors

The material partial factors for composite materials reported in the following table are taken from the EuroComp Design Handbook ([6]).

For the material partial factors for steel plates and bolts reference will be made to BS EN 1993-1-1: 2005 and BS EN 1993-1-8: 2003 as appropriate.

Parameter			Assumptions/Comments/References
Partial Factors for Composite Laminate Materials			Reference is made to EUROCOMP Design Code. Note that he values there suggested correspond to the partial factor indicated in EN 1990 with γ_M (i.e. including the conversion factor η - see BS EN 1990:2002,cl. 6.3.3) Partial factors also assumed for materials of bonded and mechanical joints. Partial factors for metal and other components forming mechanical joints will be in accordance with the corresponding Eurocodes and specified later.
Ultimate Limit States			EUROCOMP Design Code, cl. 2.3.3.2
Persistent/Transient Design Situations			
Short-term loading			
γ_{M1}	=	1.50	Derivation of properties of individual plies from test, of laminates and panels from theory (γ_{M1} = 1.15 for bearing strength – Property derived from test)
γ_{M2}	=	1.40	Method of manufacture: Hand lay-up fully postcured
γ_{M3}	=	1.20	Operating design temperature: 25-50 ºC; Heat Distortion Temperature: 55-80 ºC
$\gamma_M = \gamma_{M1}\gamma_{M2}\gamma_{M3}$	=	2.52	Value also assumed for local buckling checks (γ_M = 1.93 for bearing strength)
γ_M	=	1.50	Value assumed for global buckling checks
Long-term loading			
γ_{M1}	=	1.50	Derivation of properties of individual plies from test, of laminates and panels from theory (γ_{M1} = 1.15 for bearing strength – Property derived from test)
γ_{M2}	=	1.40	Method of manufacture: Hand lay-up fully postcured
γ_{M3}	=	3.00	Operating design temperature: 25-50 ºC; Heat distortion temperature: 55-80 ºC
$\gamma_M = \gamma_{M1}\gamma_{M2}\gamma_{M3}$	=	6.30	(γ_M = 4.83 for bearing strength)
Serviceability Limit States			BS EN 1990:2002, Par. 6.5.4, cl. (1)
γ_M	=	1.00	Elastic modules

Table 2: Material partial factors

Parameter			Assumptions/Comments/References
Partial Factors for Core Materials			Reference is made to EUROCOMP Design Code. Note that he values there suggested correspond to the partial factor indicated in EN 1990 with γ_M (i.e. including the conversion factor η - see BS EN 1990:2002,cl. 6.3.3)
Ultimate Limit States			EUROCOMP Design Code, cl. 2.3.3.2
Persistent/Transient Design Situations			
Short-term loading			
γ_{M1}	=	1.15	Derivation of properties from test specimen data
γ_{M2}	=	1.10	Method of manufacture: pultrusion fully postcured
γ_{M3}	=	1.00	Operating design temperature: 25-50 ºC; Heat Distortion Temperature: > 90 ºC
$\gamma_M = \gamma_{M1}\,\gamma_{M2}\,\gamma_{M3}$	=	1.30	Value also assumed for local buckling checks
Long-term loading			
γ_{M1}	=	1.15	Derivation of properties from test specimen data
γ_{M2}	=	1.10	Method of manufacture: pultrusion fully postcured
γ_{M3}	=	2.50	Operating design temperature: 25-50 ºC; Heat Distortion Temperature: > 90 ºC
$\gamma_M = \gamma_{M1}\,\gamma_{M2}\,\gamma_{M3}$	=	3.20	
Serviceability Limit States			BS EN 1990:2002, Par. 6.5.4, cl. (1)
γ_M	=	1.00	Elastic modules

Table 2: Material partial factors (continued)

Parameter			Assumptions/Comments/References
Partial Factors for Adhesive			Reference is made to EUROCOMP Design Code. Note that he values there suggested correspond to the partial factor indicated in EN 1990 with γ_M (i.e. including the conversion factor η - see BS EN 1990:2002,cl. 6.3.3)
Ultimate Limit States			EUROCOMP Design Code, cl. 5.1.10
Persistent/Transient Design Situations			
Short-term loading			
γ_{M1}	=	1.25	Derivation of properties from test
γ_{M2}	=	1.25	Manual application; adhesive thickness controlled
γ_{M3}	=	1.00	Short-term loading
γ_{M4}	=	2.00	Service conditions outside the adhesive test conditions
$\gamma_M = \gamma_{M1}\, \gamma_{M2}\, \gamma_{M3}\, \gamma_{M4}$	=	3.20	
Long-term loading			
γ_{M1}	=	1.25	Derivation of properties from test
γ_{M2}	=	1.25	Manual application; adhesive thickness controlled
γ_{M3}	=	2.80	Long-term loading
γ_{M4}	=	2.00	Service conditions outside the adhesive test conditions
$\gamma_M = \gamma_{M1}\, \gamma_{M2}\, \gamma_{M3}\, \gamma_{M4}$	=	4.70	

Table 2: Material partial factors (continued)

4.2 Mechanical Tests

Coupon tests should be carried out in accordance with recognised test standards to confirm the achievement of the characteristic values of the mechanical properties of the laminates assumed in the design. In particular, tests will have to characterise the following properties of FRP laminates:

- in-plane tensile strength and modulus
- in-plane compressive modulus
- interlamina shear strength
- bolt bearing strength
- bonding lap shear strength on representative laminates

Test data on fibre dominated properties should be normalised to a reference fibre volume fraction as specified in the design report and characteristic values calculated at 95% population with 95% confidence.

Test data are typically assumed to follow a normal variation. It should be assumed that the population variance and mean value are unknown.

5. Suspension System and Hydraulic Ram Stiffness

Equivalent stiffness for the suspension system and the hydraulic ram were provided by Ramboll ([5]) and reported in the following.

5.1 Suspension System Equivalent Stiffness

For each of the two cables the stiffness is:

- closed bridge position: 2640 kN/m
- partially open (30°): 3010 kN/m
- fully open (60°): 3350 kN/m

5.2 Hydraulic Ram Equivalent Stiffness

The equivalent stiffness of the hydraulic ram will be worked out from the following graph, where the curve in red represents the force required to extend the tie down ram when the lifting system is raising the bridge (the hydraulic valves are open and the oil can freely flow) whilst the curve in blue refers to the case of hydraulic valves closed (i.e. bridge locked in open position).

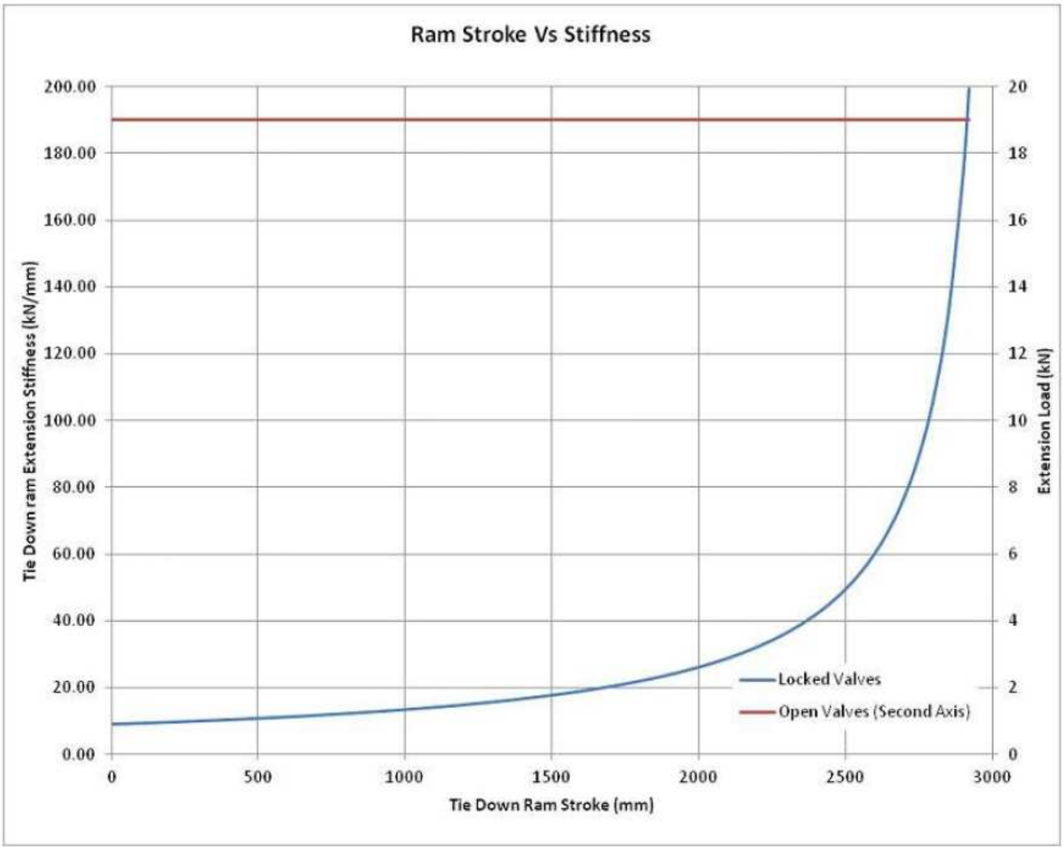

Figure 3: Hydraulic ram stiffness (by Ramboll)

6. Design Requirements

Design requirements are summarised in the following section. Where appropriate, design requirements from Eurocodes will be considered.

It has to be noted that the Eurocode does not provide directions in case of moveable bridges (see BS EN 1990: 2002+A1: 2005, Par. A2.1.1, cl. 2) and no special requirements have been provided by the client.

6.1 Deformation Limits

The Eurocodes do not provide explicit limits in terms of footbridge deflections, but require a check of potential issues related to vibrations induced by pedestrians (see Par. 6.2).

In addition to the check on pedestrian induced vibration, in order to avoid matrix cracking at SLS under characteristic load combinations, the maximum strain in the laminates will be checked against resin cracking strains. This should minimise the risk of fatigue of the laminates. The following limits will be used:

- longitudinal strain: $\varepsilon_x < 0.70\%$
- transverse strain: $\varepsilon_y < 0.40\%$ (transverse to fibres in uni-directional plies)
- shear strain: $\varepsilon_{xy} < 0.80\%$

6.2 Pedestrian Comfort Criteria

As required by the Eurocode (BS EN 1990: 2002+A1: 2005, A2.4.3.2 (2)), the verification of pedestrian comfort criteria will be performed if the fundamental frequency of the deck is less than:

- 5 Hz for vertical vibrations
- 2.5 Hz for torsional vibrations

In such an eventuality, the dynamic models of pedestrian vertical actions on footbridges and associated comfort criteria given in the NA to BS EN 1991-2: 2003, NA.2.44 will be used and the following assumptions will be made:

- Bridge class: B (i.e. suburban location likely to experience slight variations in pedestrian loading intensity on occasional basis)
- Bridge function: suburban crossings (i.e.: $k_1 = 1.3$)
- Route redundancy: alternative routes readily available (i.e. : $k_2 = 1.3$)
- Bridge height: up to 4 m (i.e. : $k_3 = 1.1$)

The design acceleration limit will be assumed equal to:

$$a_{lim} = k_1\, k_2\, k_3\, k_4\ m/s^2 = 1.86\ m/s^2$$

with:

$k_4 = 1$ exposure factor

The risk of unstable lateral response due crowd loading will be investigated in detail only if the frequency of the lateral mode of vibration is less than 1.5 Hz (see NA.2.44.7 (2)).

6.3 Failure

Failure of laminates under ULS will be checked using maximum strain failure criteria, with failure checked on a ply by ply basis. Transverse resin cracking of unidirectional plies will be reviewed to determine whether this is a critical failure mode where necessary. The allowable strains will be provided in the design report for the material being used.

6.4 Temperatures

Maximum service temperature for the FRP components is 50ºC.

6.5 Lightning Strike

It is assumed that the deck is adequately protected against lightning strike and that the FRP components do not require any specific protection.

References

[1] BS EN 1990:2002+A1:2005, Basis of structural design

[2] NA to BS EN 1990:2002+A1:2005

[3] BS EN 1991-2:2003, Traffic loads on Bridges

[4] NA to BS EN 1991-2:2003

[5] Foryd Harbour Sustainable Transport Bridge – Deck Loading Report; Report No. 15621/REP/DL/01 Rev A by Ramboll

[6] EuroComp Design Code and Handbook for Structural Design of Polymer Composites, The European Structural Polymeric Composite Group, 1996

[7] Foryd Harbour Sustainable Transport Bridge – Deck Details 1/2; Drawing No. 15621-BR-061 Rev A by Ramboll

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