1 Introduction

This note sets out the accepted approach for carrying out carbon calculations for bridges by the Net Zero Bridges Group to support assessment and comparison of carbon in bridges. Although the carbon factors provided in this guide have a UK and European focus, many aspects can be applied to bridge projects in different geographies.
This DRAFT version is shared for preliminary use by industry with opportunity to provide comment to the Net Zero Bridges Group at info@netzerobridges.org by 1 October 2023. The final version of this guidance will be published on a page of our website www.netzerobridges.org.

Contents

1.1 Introduction to Carbon Calculations

The format and overarching methodology are set out to match the IStructE's guide *How to Calculate Embodied Carbon* (HTCEC) (1) and draws on the guidance from PAS 2080 *Carbon Management in Infrastructure - 2016* (2), PAS 2080 *Carbon Management in Buildings and Infrastructure – 2023* (3) as well as BS EN 17472 *Sustainability of construction works - Sustainability assessment of civil engineering works - Calculation methods* (4) with specific application to bridges. Readers of this document are assumed to be familiar with the IStructE's HTCEC and PAS 2080.
As part of the development for the final version of this guidance, it will be updated to align with the latest version of PAS 2080 launched in April 2023.

Table 1 - Study goal and scope definition according to PAS 2080:2016

PAS2080 Study Scope Criteria	**Definition / Reference**
a) The goal of the GHG emissions quantification;	Project specific
b) The system that is the subject of a quantification;	A bridge (project specific)
c) The function of the system (i.e. its performance characteristics);	Provide safe crossing of an obstacle
d) The functional unit (Clause 7.1.2 where relevant);	Functional area – refer Section 2.3.2.
e) The system boundary (see Clause 7.1.3);	Refer Sections 2.1
f) Allocation procedures (where relevant);	-
g) The quantification methodology to be applied (see Clause 7.1.4);	Refer Section 2
h) How GHG emissions information will be interpreted and used in decision-making;	Project specific
i) Data quality requirements appropriate to the study goal and the life cycle stage at which an assessment has been made (see Clause 7.1.5.3);	Refer Section 2.2.7 for commentary.
j) Assumptions, limitations and constraints;	Project specific
k) The study review process, ensuring it is appropriate and proportionate to the intended use of the assessment and size of the asset or programme of works	Project specific

1.2 Life cycle stages and modules

Life cycle stages broadly follow BS EN 15978, and for infrastructure projects, including bridges, reference is made to PAS 2080 (2).

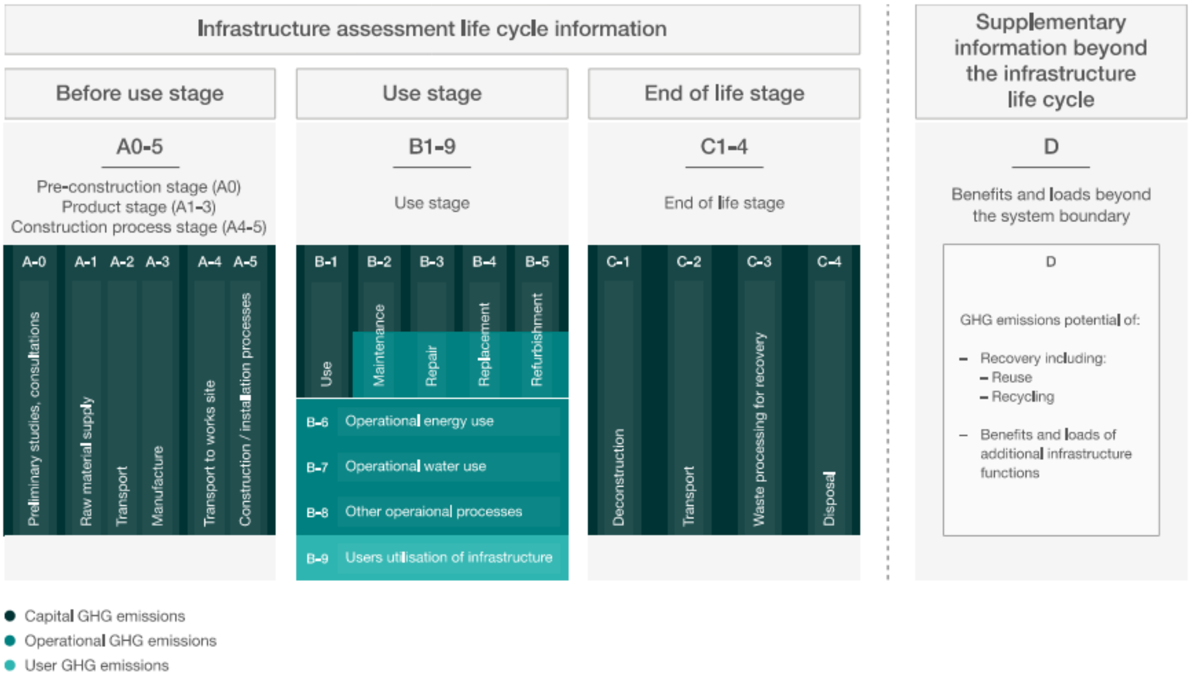

Figure 1: Life cycle stages as defined in PAS 2080 (2)

1.3 Terminology

Carbon (kgCO2e): Equivalent mass of carbon dioxide emissions, or 'carbon' for short. This measure is an equivalent measure for all greenhouse gas emissions (GHGs) in addition to carbon dioxide (CO2), expressing them in terms of CO2 normalised by their global warming potential (GWP) over a 100-year timescale.
Environmental Product Declaration (EPD): An independently verified and registered document that communicates transparent and comparable information about the life cycle environmental impact of products per BS EN 15804 (2012) + A2 (2019).
Upfront Carbon: Carbon associated with construction of the asset (corresponding to life cycle modules A1 to A5).
Embodied Carbon / Capital Carbon: GHG emissions associated with the creation, refurbishment and end of life treatment of an asset (corresponding to life cycle modules A1 to A5, B1-B5 & C1-C4).
User Carbon: Carbon associated with users' utilisation of the asset by the public (corresponding to life cycle module B9).
Operational Carbon: Carbon associated with ongoing energy use, maintenance, refurbishment or replacement works (corresponding to life cycle modules B1-B8).
Whole life Carbon: The total asset-related GHG emissions and removals, both operational and embodied, over the life cycle of an asset including its disposal (Modules A1–A5, B1–B9 and C1–C4). Overall whole life carbon asset performance includes separately reporting the potential benefit from future energy recovery, reuse, and recycling (Module D).

	A0	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	B8	B9	C1	C2	C3	C4	D
Up front carbon																				
Captial carbon																				
User Carbon																				
Operational carbon																				
Whole life carbon																				

Refer to HTCEC and PAS2080 for full list of relevant terminology.

2 Calculating Embodied Carbon

2.1 Minimum scope of calculation

2.1.1 Minimum scope: life cycle stages and modules

For a bridge, the minimum life cycle scope is A1 – A5 (upfront carbon).

2.1.2 Minimum scope: bridge elements

The relevant elements to include in the carbon assessment of bridges are summarised in the table below. The minimum required elements are highlighted with shaded cells. Some more traditionally civil elements are included as these commonly fall within the scope of the bridge designer and may have an appreciable impact on the carbon footprint of a bridge.

Table 2 - Bridge element categorisation

Element group	Element	Possible breakdown of structural elements for carbon assessment
Superstructure	Girder	Primary girder(s)
		Secondary members (cross beams, bracing, etc.)
		Deck
	Truss	Truss
		Deck
	Cable System	Cable system
Substructure	Abutment	Foundations
		Abutment (incl. wingwalls but excl. foundations)
		Transition slab
	Pier	Foundations
		Columns
		Walls
		Beams
	Arch	Arch
	Pylon (can be in super- or substructure depending on arrangement)	Pylon
Foundations	Shallow Foundations	Pad
	Deep Foundations	Pile Cap
		Piles
Ancillaries	Parapets	Vehicle impact parapets
		Pedestrian/cyclist parapets
		Anti-throw screens
	Pier Protection	Impact Protection
		Scour Protection
	Expansion joints*	Expansion joints
	Bearings*	Bearings
	Roadway/walkway	Surfacing
		Waterproofing

Element group	Element	Possible breakdown of structural elements for carbon assessment
	Railway	Rails
		Sleepers
		Ballast
	Drainage	Drainage
	Bridge Furniture	Non-structural edge beam/fascia
		Fencing
		Benches
		Planters
		Lighting Columns
Earthworks**	Excavation	Excavation
	Fill	Fill
	Earth Retention System	*Earth Retention System*
Construction Miscellaneous	Preliminaries	N/A
	Additional/specialist temporary works	N/A
	Transport of Personnel to Site***	N/A
	Disruption of traffic during construction	

* Where a suitable EPD is not available for the product, a rough estimate will generally suffice as these elements are not generally significant contributors to the overall carbon footprint.
** It is important to define the scope of your assessment clearly. Most bridge schemes involve some earthworks (e.g. excavation for foundation construction) which should be accounted for wherever possible and would be linked with the associated bridge element. On many infrastructure schemes, there are major earthworks packages related to approaches, cuttings, etc. Whilst these earthworks are separate to the bridge, when comparing different bridge lengths with associated approach earthworks, the embodied carbon for the approach earthworks should be included in the assessment.
*** For remote sites and/or projects with long construction programmes, this may be significant.

2.2 Inputs

Similar to the commentary in the HTCEC guide, modules A1 to A3 typically govern the structural embodied carbon of a bridge. However, when comparing infrastructure scheme options with varying bridge lengths and associated earthworks, the A4-A5 emissions should not be neglected since the emissions associated with excavation, transport and fill onsite could be a major component in the total carbon footprint.

2.2.1 Material quantities

As well as the structural materials in a bridge, it will typically be relevant to also consider the non-structural bridge elements, e.g. pavement or railway elements, when considering options at the concept stage.

2.2.2 Module A1 – A3 Carbon Factors

The principles of the IStructE guidance regarding building materials are largely retained as guidance for bridge materials. A reference set of carbon factors is provided for common bridge construction materials in Table 3. These are largely based on data provided within the IStructE's HTCEC and ICE v3.0 database (5).

2.2.2.1 Common construction materials

Table 3 - Reference Embodied Carbon Factors ($ECF_{A1-A3,i}$) for common bridge construction materials

Material	Type	Specification/details	Embodied Carbon A1-3 [tCO2e/t]	Source and notes
Aluminium	Sheet		6.58	ICE v3.0 database (European consumption 31% recycled) (5)
			13.0	ICE v3.0 database (Worldwide consumption 31% recycled) (5)
	Extruded Profile		6.83	ICE v3.0 database (European consumption 31% recycled) (5)
			13.2	ICE v3.0 database (Worldwide consumption 31% recycled) (5)
Brick	Single engineering clay brick		0.213	ICE v3.0, UK BDA generic brick, note that brick density to account for voids (average brick weight 2.13kg) (5)
Composites	General plastic		3.31	ICE v2.0, determined by the average use of each type of plastic used in the European construction industry (5)
	Polystyrene		3.43	ICE v2.0, general purpose polystyrene (5)
	Glass reinforced polymers		2.00	Based on average of GRP large-diameter pressured pipe EPD data from Future Piper Industries (Sweden), Subor (Turkey) and Superlit (Turkey) (6)
	Carbon fibre reinforced polymers		N/A	TBC, no industry data or EPDs available – if data is available to publicly, please share with NZBG at info@netzerobridges.org
	Fibre-reinforced foamed urethane (plastic rail sleepers)		N/A	TBC, no industry data or EPDs available – if data is available to publicly, please share with NZBG at info@netzerobridges.org
Concrete (unreinforced)	C20/25	Average UK mix	0.112	ICE v3.0 database, assumes total cementitious content 285kg/m3 of UK-average cement mix in concrete mix (5)
	C25/30	Average UK mix	0.119	ICE v3.0 database, assumes total cementitious content 305kg/m3 of UK-average cement mix in concrete mix (5)

Material	Type	Specification/details	Embodied Carbon A1-3 [tCO2e/t]	Source and notes
	C28/35	Average UK mix	0.126	ICE v3.0 database, assumes total cementitious content 325kg/m3 of UK-average cement mix in concrete mix (5)
	C32/40	Average UK mix	0.138	ICE v3.0 database, assumes total cementitious content 360kg/m3 of UK-average cement mix in concrete mix (5)
	C35/45	Average UK mix	0.149	ICE v3.0 database, assumes total cementitious content 390kg/m3 of UK-average cement mix in concrete mix (5)
	C40/50	Average UK mix	0.159	ICE v3.0 database, assumes total cementitious content 420kg/m3 of UK-average cement mix in concrete mix (5)
	C45/55	Average UK mix	0.170	Assumes total cementitious content 450kg/m3 of UK-average cement mix in concrete mix, calculated using ICE v3.0 Cement, Mortar and Concrete Model v1.1 (7)
	C50/60	Average UK mix	0.184	Assumes total cementitious content 490kg/m3 of UK-average cement mix in concrete mix, calculated using ICE v3.0 Cement, Mortar and Concrete Model v1.1 (7)
	Other specific concrete mixes		Varies	Use Concrete Embodied Carbon Footprint Calculator (7)
Mortar / screed	1:4 cement / sand mix	Average UK cement mix	0.149	ICE v3.0 (5)
Steel	Flat plate	Applicable for all typical strength grades for both carbon steel and weathering steel.	2.46	ICE v3.0 (world average) (5)
	Hollow sections		2.46	Based on ICE v3.0 steel plate (world average) (5)
	Open sections		1.55	ICE v3.0 (world average) (5)
	Rebar		1.99	ICE v3.0 (world average) (5)
	Prestressing bars / rods		1.99	Based on ICE v3.0 steel rebar (world average) (5)
	High strength low-relaxation prestressing strands		2.72	Maximum of European product suppliers' EPDs at the time of writing this document (Kiwa - Italy, Hjulsbro Steel, Fabricela - Sweden, Ferrometall - Norway) (6) (8) (9)
Stainless steel	Plate / Section		2.74	Outokumpu EPD (10)
	Rebar		3.78	Outokumpu EPD (10)
	Prestressing bars		3.78	Based on Outokumpu EPD for rebar (10)

Material	Type	Specification/details	Embodied Carbon A1-3 [tCO2e/t]	Source and notes
	Cold-rolled plate / section		3.39	Outokumpu EPD (10)
Stone	Granite		0.093	IStructE HTCEC based on UK quarry activity (1)
	Limestone		0.090	ICE v2.0 (5)
	Sandstone		0.060	ICE v2.0 (5)
Timber	Softwood		0.263	ICE v3.0, excluding sequestration (5)
	Hardwood		0.306	ICE v3.0, excluding sequestration (5)
	Plywood		0.681	ICE v3.0, excluding sequestration (5)]
	Cross-laminated timber (CLT)		0.250	IStructE HTCEC, excluding sequestration (1)
	Glulam		0.280	IStructE HTCEC, excluding sequestration (1)

Commentary related to each common bridge construction material is included below.

Carbon Steel
Steel within the ICE database is treated largely as a finished product. However, for some applications, such as welded plate sections, the additional fabrication carbon is not included within the ICE database. The fabrication carbon refers to the carbon emissions associated with assembling the flat plate into a section, through welding, cutting, bolting processes. It is recommended that the fabrication carbon, which has been calculated by the SCI to be approximately 0.3 tCO2e per tonne of steel produced (11), is included within the A5a associated with the relevant quantity of steel.
It is recognised that nearly all reinforcement in the UK is produced through EAF route and with very high recycled content, typically around 99%. This is reflected in the UK CARES EPD, where the declared A1-3 carbon factor is considerably lower than the ICE world average. However, not all reinforcement consumed in the UK is produced in the UK, which is why the ICE v3.0 world average factor is conservatively recommended. If the agreed supplier of the reinforcement on a particular scheme is part of UK CARES, then it is possible to adopt the UK CARES factor within the design (0.76 tCO2e/t average for UK CARES certified rebar (1)).
Steel open sections are covered by ICE v3.0 database, but hollow sections are not. Based on Arcellor Mittal and Tata Steel EPDs, which are largely based on European and UK manufacturing plants, it is thus recommended that the same carbon factor for plates is used for hollow sections as well.
It is recognised that the IStructE guide on how to calculate carbon suggests that pre-stressing bars should have the same carbon factor as rebar. However, given that reinforcing bars are produced from nearly 100% scrap metal via EAF route and prestressing strands are produced from steel coils produced through BF-BOF route, an alternative factor is provided in Table 3. Note that nearly all European suppliers state a much higher carbon factor for low-relaxation strands compared to UK CARES reinforcement bars and nearly always higher than the ICE v3.0 world average rebar carbon factor. Thus, a conservative approach is taken by taking the maximum carbon factor from the suppliers' published EPDs with respect to prestressing strands.
Weathering steel is considered to have the same carbon factor as regular carbon steel, based on correspondence with Steel Construction Institute (SCI) representatives.

Stainless Steel
Stainless steel is added to the list of construction materials below, as its use in bridges has become more feasible in recent years as an alternative to carbon steel. The ICE v3.0 database doesn't report any stainless steel data, whilst the ICE v2.0 database includes a single carbon factor for a high percentage virgin stainless steel, namely 6.15 tCO2e/t. This value doesn't reflect the current European production routes of stainless steel, which is typically the EAF process including a significant percentage of scrap. It is thus recommended that the stainless steel carbon factors from the Outokumpu EPD, a known supplier of stainless steel bridge plate and sections, is adopted. These Outokumpu emission factors compare reasonably well with other European producers of similar stainless steel products.

Aluminium
No changes to the aluminium carbon factors are proposed.

Concrete
There are many concrete mixes with different carbon factors available to structural engineers. It is possible to specify Portland cement replacements to reduce the carbon factor of the concrete mix, but most of the cement replacements available today are finite resources arising as by-products from the steel and coal industries, namely GGBS and PFA. The availability of these cement replacements is currently insufficient to

meet the rapidly increasing demand and are expected to decline as the world decarbonises, thus it is short sighted to use these finite resources as a sustainable method of concrete decarbonisation.
As a result, it is recommended that the ICE v3.0 UK-produced average concrete mixes, which are very similar to UK-consumed concrete mixes, should be adopted for most stages of a bridge project. When the specification for the concrete mix on a project is determined, then it is possible to re-evaluate the concrete carbon factor using the Concrete Embodied Carbon Footprint Calculator. However, any decarbonisation data resulting from this specification needs to acknowledge and if possible, account for the issue of resource availability described in the above paragraph. As is described in the IStructE HTCEC guide (1), designers are encouraged to firstly reduce the quantity of concrete required and secondly to consider using alternative concrete mixes which have less cement and have long-term decarbonisation potential.
The ICE v3.0 average UK-produced concrete mixes are based on an UK-average cement mix and an assumed total cementitious content per cubic metre of concrete. The average cement mix, taken as an average of the UK sector's cement EPDs, consists of 86.1% clinker (Ordinary Portland Cement), 0.04% GGBS, 3.4% fly ash, 4.8% gypsum, 5.1% limestone and 0.56% MACs, totalling a carbon factor of 0.832 kgCO2e per kg of cement mix. The largest contributor to the carbon footprint of the cement mix is by far the OPC. The UK-average cement mix is a snapshot in time when the ICE v3.0 database was published, specifically 2019. Cement mixes have developed since this time and it is reasonable to assume that greater additions of OPC-replacement materials with a lower carbon footprint will be applied to industry average cement mixes.
The UK-average concrete mix adopts the above-specified UK average cement mix and then assumes an actual used total cementitious content, as opposed to the specified minimum. When comparing the assumed total cementitious content in the ICE v3.0 database and comparing it to typical exposure classes, strengths, mixes and covers in BS8500-1 table A5, the actual cement contents are increased by approx. 5-25% above minimum cement contents in the tables, particular for strength classes above C28/35, thus indicating these cement contents are generally suitable to bridge applications.
Another further 2No. strength classes are added to the ICE v3.0 list, namely C45/55 and C50/60, as these higher strength concretes are more typical for bridge applications than for example C20/25. The carbon factor for these have been calculated using the ICE Cement, mortar and concrete model v1.1, by assuming a typical actual cementitious content and using the UK-average cement mix to calculate the total carbon factor for each strength class.

Mortar / screed
A single value of mortar and screed is provided, assuming a 1:4 cement to sand ratio and assuming adopting the average UK cement mix as discussed above.

Timber
No changes to the timber carbon factors declared in the IStructE guide (and by extension ICE v3.0) are proposed, except for the CLT and glulam factors. The values presented do not include any carbon sequestration in the timber product. This is a conservative approach, but due to the issues of unsustainable disposal, discussed further in the IStructE guide, this is deemed an appropriate approach when quantifying A1-5 carbon emissions.

Brick
Clay fired-bricks carbon factors are adopted based on the recommendations in the IStructE guide (and by extension ICE v3.0). The carbon factor provided is for a single brick, so the engineer has to consider the carbon in the mortar as well when assessing the emissions in new masonry structures.

Stone
Stone carbon factors are adopted based on the recommendations in the IStructE guide (and by extension ICE v3.0).

Composites

A number of general plastic types are presented below, including polystyrene which can be used as lightweight soil-replacement and fibre-reinforced polymers (FRP). EPDs from FRP product suppliers are very scarce at the time of writing this report.

A general glass-reinforced plastic (GRP) is presented based on an average of available EPDs for GRP large diameter pipes. These are thought to be appropriate due to similar fabrication processes and material strength with pultruded GRP structural sections. However, further EPD declarations are needed by bridge-specific product suppliers in this field.

2.2.2.2 Common Bridge Elements

Further to the basic material carbon factors provided in Table 3, carbon emissions by appropriate functional units for bridge components, such as bearings, expansion joints, barriers surfacing etc. are provided in Table 4. These carbon factors are largely calculated using the Carbon factors provided in Table 3 and the quantities obtained from a range of specialist bridge suppliers' technical details. As such, these carbon factors do not include any additional emissions due to material wastage, processing or assembly of the basic materials into the final product. The exception here are steel products, where the 0.3 kgCO2e/kg additional fabrication emissions are included.

Further revision of these carbon factors is recommended once specialist bridge suppliers provide product EPDs.

Table 4 - Suggested embodied carbon factors (ECFA1–A3,i) for common secondary bridge elements

Element	Subdivision 1	Subdivision 2	Embodied Carbon A1-3 [tCO2e]	Unit of Measure	Source and notes
Bearings	Steel rocker/roller	Vertical load capacity <400 tonnes	2.00	No.	Average of NR standard design rocker/roller bearings for steel plate girders in U-type rail bridges up to 25m span range. Assuming steel carbon factor as in Table 3 with fabrication allowance of 0.3kgCO2e/kg.
	Elastomeric	Vertical load capacity <100 tonnes	0.20	No. (per bearing)	Based on the Freyssinet range of elastomeric, spherical and pot bearings . Averages taken across movement directions and magnitudes. Assuming elastomer carbon factor 4.26kgCO2e/kg. Assuming steel carbon factor as in Table 3 with fabrication allowance of 0.3kgCO2e/kg.
		Vertical load capacity 100t < X < 200t	0.80	No. (per bearing)	
	Spherical	Vertical load capacity <100 tonnes	1.21	No. (per bearing)	
		Vertical load capacity 100t < X < 200t	5.63	No. (per bearing)	
		Vertical load capacity 200t < X < 300t	10.26	No. (per bearing)	
		Vertical load capacity 300t < X < 400t	15.75	No. (per bearing)	
		Vertical load capacity 400t < X < 500t	21.57	No. (per bearing)	
	Pot	Vertical load capacity <100 tonnes	0.97	No. (per bearing)	
		Vertical load capacity 100t < X < 200t	5.09	No. (per bearing)	
		Vertical load capacity 200t < X < 300t	9.29	No. (per bearing)	

Element	Subdivision 1	Subdivision 2	Embodied Carbon A1-3 [tCO2e]	Unit of Measure	Source and notes
		Vertical load capacity 300t < X < 400t	14.28	Per bearing	
		Vertical load capacity 400t < X < 500t	18.07	No.	
Expansion joints	All types	Movement range Low <99mm	0.14	Length of joint [m]	Averages based on Maurer and Ekspan single-seal type expansion joints. Assuming EPDM carbon factor 4.49kgCO2e/kg. Assuming rubber carbon factor 4.49kgCO2e/kg. Assuming steel carbon factor as in Table 3 with fabrication allowance of 0.3kgCO2e/kg.
		Movement range Medium 100mm < X < 120mm	0.37		
		Movement range High >120mm	0.61		
Protective treatment	Polymer-based paint	Solvent-based - typical	0.0018	Applied surface area [m²]	ICE V2.0 for 3.76kgCO2e per kg of paint, assuming 1300kg/m^3 density of paint system and average total paint thickness of 360µm (3 coats), typical for C2-4 corrosion environments and 15 year lifespan
		Solvent-based - marine	0.0041		Based on Jotun (Jotamastic 90) paint system EPD, 4.16 kgCO2e/kg of paint, density of 1400 kg/m^3 and an average total thickness of 700 µm (4 coats), typical for C5 corrosion environments and 15 year lifespan. (9)
	Hot-dip galvanising	Zinc coating only	0.0031	Applied surface area [m²]	ICE v2.0 for 3.09kgCO2e per kg of zinc, assuming 7133kg/m^3 density of zinc and average total coating thickness of 140µm typical for C2-4 corrosion environments and approx. 50-year lifespan
Services	PVC pipe	<150mm diameter	0.01	Length of pipe [m]	Based on ICE v2.0 carbon factor for PVC pipe of 3.23kgCO2e/kg. Assuming 7.5mm wall thickness and density of PVC of 1300kg/m^3.

Element	Subdivision 1	Subdivision 2	Embodied Carbon A1-3 [tCO2e]	Unit of Measure	Source and notes
	Cast iron pipe	<150mm diameter	0.08		Based on ICE v2.0 carbon factor for iron of 2.03kgCO2e/kg. Assuming 10mm wall thickness and density of iron of 7393kg/m³.
	Vitrified clay pipe	<150mm diameter	0.01		Based on ICE v3.0 carbon factor for vitrified clay pipe of 0.46kgCO2e/kg. Assuming 14mm wall thickness and density of clay of 2100kg/m³.
Surfacing	Waterproofing	Flexible sheeting / spray applied	0.012	Area of waterproofing [m²]	Based on ICE v3.0 2.54kgCO2e/kg for general polyethylene, density of 940kg/m³ and average layer thickness of 5mm
		Bituminous layer	0.005		Based on ICE v3.0 0.326kgCO2e/kg for bitumen, bitumen density of 1400kg/m³ and average layer thickness of 12mm
	Asphalt	Average binder content	0.125	Volume of asphalt [m³]	Based on ICE v3.0 0.054kgCO2e/kg for asphalt and density of 2300kg/m^3
	Ballast	General	0.010	Volume of ballast [m³]	Based on ICE v2.0 0.0052kgCO2e/kg of UK-average general gravel / crushed rock, assuming density of 2000kg/m³
	Combined waterproofing and surfacing	General	0.026	Area of surfacing [m²]	Based on example product (12) with constituent material embodied carbon from (5) and (13). Assuming average layer thickness of 4 mm.
Barriers	Vehicular - reinforced concrete	High containment	0.67	Length of barrier [m]	based on conservative project example barrier design, UK average C50/60 concrete with 180kg/m³ reinforcement ratio
		Standard containment - vehicles adjacent to pedestrian walkway	0.26		Based on averages from suppliers Rebloc System, using C50/60 concrete with 180kg/m³ reinforcement ratio

Element	Subdivision 1	Subdivision 2	Embodied Carbon A1-3 [tCO2e]	Unit of Measure	Source and notes
	Vehicular - steel	Standard containment, 1-1.5m height (pedestrian)	0.18		Based on averages from suppliers Hill and Smith Ltd, Motorwaycare and Varley and Gulliver. Assuming steel carbon factor as in Table 3 with fabrication allowance of 0.3kgCO2e/kg. Assuming aluminium carbon factor of 5.58 kgCO2e/kg.
		Standard containment, 1.5-1.8m height (cycleway)	0.21		
		Standard containment, >1.8m height (equestrian)	0.25		
	Vehicular - aluminium	Standard containment, 1-1.5m height (pedestrian)	0.12		
		Standard containment, 1.5-1.8m height (cycleway)	0.13		
		Standard containment, >1.8m height (equestrian)	0.16		
	Pedestrian - steel	Standard containment	0.18		Based on averages from supplier Varley and Gulliver Assuming steel carbon factor as in Table 3 with fabrication allowance of 0.3kgCO2e/kg. Assuming aluminium carbon factor of 5.58 kgCO2e/kg.
		Cycleway containment	0.20		
		Equestrian containment	0.22		
	Pedestrian - aluminium	Standard containment	0.12		
		Cycleway containment	0.16		
		Equestrian containment	0.20		

2.2.3 Module A4 Carbon Factors

The information contained within the IStructE guide is valid and relevant, but consideration needs to be given to the areas where typically bridge construction differs from buildings. For known transport modes and distances the tables below from the Government Greenhouse gas reporting document can be used (14). For the full or most current set refer to:
[Government conversion factors for company reporting of greenhouse gas emissions - GOV.UK (www.gov.uk)](www.gov.uk)

Table 5 - Mode of transport cardon factors; Extracted values from government website; Greenhouse Gas reporting: conversion factors 2023

Mode of transport	Type	Carbon emission factor	Units
Road	HGV (diesel) - 0% laden	0.642	kgCO2e /km
Road	HGV (diesel) - 50% laden	0.119	kgCO2e /(tonne.km)
Road	HGV (diesel) - 100% laden	0.0722	kgCO2e /(tonne.km)
Sea	Average bulk carrier	0.00353	kgCO2e /(tonne.km)
Sea	Average container ship	0.0161	kgCO2e /(tonne.km)
Rail		0.0278	kgCO2e /(tonne.km)

Table 6 - Suggested A4 ECF values for the UK (Extracted values from government website; Greenhouse Gas reporting: conversion factors 2023)

Transport scenario	Type	Dist. road (km)	Dist. rail (km)	Dist. sea (km)	Carbon emission factor	Units
Locally manufactured	Road - 100% laden out and empty return*)	50			0.00682	tCO2e/t
Nationally manufactured	Road (100% laden out and empty return*)	300			0.0409	tCO2e/t
Nationally manufactured	Road (50% laden) + Rail	50	150		0.0101	tCO2e/t
European manufactured	Road (50% laden)	1,500			0.179	tCO2e/t
European manufactured	Road (50% laden) + Rail	500	1,000		0.0873	tCO2e/t
Globally manufactured	Road (50% laden) + Sea (Container)	200		10,000	0.185	tCO2e/t

* Assumes a 10t transported material mass. Carbon factor will decrease slightly with higher transport mass.

Remote site locations

The nature of bridge construction can mean that the location can be more remote than a usual building structures site. As a result, the journey to site and the unloaded return journey should be considered. It is unlikely that the material being transported will reach 100% capacity of the HGV with a completely empty return trip, but for simplicity, these values are included as a starting point. The data in Table 5 and (14) can be used for detailed transport assessments.

Two-part fabrication processes
For accurate transport emissions, it is important to account for the full material journey distance. A common example is for transport of steel within large fabricated bridge elements for which the transport distance should include both the journey of the base steel elements (e.g. plate, section, etc.) to the fabricator; and, the journey of the fabricated components to site. The transport modes may also be different for each leg. The journey of the raw materials to the steel member/element manufacturers is covered in A2.
In the absence of project information for steel fabrication, it is suggested to adopt a European journey for the first steel member transport leg and then a national journey for the second leg.

Large earthworks
It will be difficult to quantify what volume/tonnage of earthworks should be attributed to the bridge. The choice of bridge span and configuration on a scheme, especially a greenfield scheme can have a significant influence on the earthworks balance and volume shifted to/from site, e.g. for an underbridge vs an overbridge.
The overall transportation of earthworks should be calculated separately to the bridge, refer Table 2. However, in the optioneering phase, basic calculations to compare different options and inform a decision on the best carbon option should include any earthworks that varies between options. In this case the volume of earthworks immediately above or below the bridge, plus any approach embankments or cuts should be taken into account.

Specialist transport
Wide loads and specialist HGV's were not found in publicly available data at the time of writing. For these specialist road transport modes, it is recommended to use the 'All HGV's' value as a starting point with input sought from a specialist logistics company to estimate the quantity of fuel required, with the associated carbon estimated based on the carbon factors in (14).
Sea and rail transport can be calculated assuming 100% laden on a one-way journey.

Transportation of personnel
This can be solved based on the transport mode and distance travelled using data available here:
[Government conversion factors for company reporting of greenhouse gas emissions - GOV.UK (www.gov.uk)]

2.2.4 Module A5 Carbon Factors

2.2.4.1 Permanent Works Wastage (A5w)
Material wastage per IStructE guide (1), except where more detailed information is available.
Details from (1) are repeated below for convenience:

$$ECF_{A5w,i} = WF_i \times (ECF_{A13,i} + ECF_{A4,i} + ECF_{C2,i} + ECF_{C34,i})$$

$$WF_i = \left(\frac{1}{1-WR_i} - 1\right)$$

Table 7 - Waste rates repeated from IStructE guide (1)

Material/product	Waste Rate (WR)
Aluminium	1%
Brick	20%
Glass	5%
Concrete, insitu	5%
Concrete, precast	1%
Mortar/screed	5%
Steel plate/members	1%
Steel reinforcement	5%
Stone	10%
Timber frames	1%
Timber formwork	10%

2.2.4.2 Temporary Works (A5w)

Bridges may be significantly influenced by the construction methodology, with varying structural systems and arrangements potentially requiring very different temporary works.

Due to the scale of some temporary works, their carbon impact may not always be insignificant and requires explicit consideration. Temporary works items to consider include: form travellers, erection gantries, launching noses, falsework*, temporary foundations, temporary kingpost, temporary cables, trestles*, crane pads, etc. (*generally significant material re-use is possible).

The recommended method to capture major temporary works is described below. For full details reference is made to guidance published by the Temporary Works Forum (TWf), developed in collaboration with the NZBG (Low carbon temporary works - Temporary Works Forum (twforum.org.uk)).

Temporary Works

$$EC_{A5w,i} = \left(\frac{ECF_{A13,i}+ECF_{C34,i}}{N} + ECF_{A4,i} + ECF_{C2,i}\right) \times Quantity_1 \text{ [Component 1]}$$
$$+WF_i\left(ECF_{A13,i} + ECF_{A4,i} + ECF_{C2,i} + ECF_{C34,i}\right) \times Quantity_2 \text{ [Component 2]}$$

Where:
Component 1 Wastage = 'As designed' material quantities for temporary works elements; and,
Component 2 Wastage = Material wastage above the as-designed amount per use/project considered.

Where WF_i is > 50%, this should be considered 'as designed' wastage with N = 1.

N = Total number of times a material is re-used before it reaches end of life (EoL):

$$N = \begin{cases} 1\ for\ single - use\ material \\ > 1\ for\ finite\ re - use\ material \\ > 100\ (say) for\ high\ re - use/proprietary\ material \end{cases}$$

Note: Care should be taken to stick to the life cycle assessment of the bridge and not the temporary works item.

The principles set out in Section 2.2.7 regarding recommended accuracy throughout design stages should be applied for temporary works. Generic values can be used at feasibility/concept stage and refined to account estimated values at pre-construction stage by the Contractor's quantity surveyor and then finally with actual values supplied as part of as-built records using EPDs as much as possible.

When considering temporary works, there is generally significant cross-over with other parties. The permanent works designer will not typically carry out the detailed design for temporary works but should be able to estimate the majority reasonably accurately.

2.2.4.3 Transport disruption during construction (A5c)

Specialist input required from a transport planner with a traffic model (e.g. using WEBTAG data) to account for impact of construction works.
It is important that the impact to traffic is shared with any other assets for which works are being carried out during the period of any disruption to traffic.

2.2.4.4 Construction Activities (A5a)

For site activities, it is suggested that specific calculations are carried out. This can be done using carbon factors for fuel consumption directly from the Contractor and using carbon factors from (14) or using time/fuel estimates from SPONS (15) or a similar cost/time/resource reference or using specific carbon estimates included texts like the CESMM4 Carbon & Price Book (16).

The following table includes a suggested list of preliminary ECFs for common construction activities generally based on the method described above using SPONS (15), unless noted otherwise.

Activity / Process	Sub-activity description	Sub-activity Comment	A5a Carbon Factor	Units	Notes/Reference
Excavation - Foundations (not rock up to 5 m depth)			4.7	$kgCO_2e/m^3$	Average using SPONS
Excavation - General (not rock up to 5 m depth)			3.7	$kgCO_2e/m^3$	Average using SPONS
Excavation (rock)			15.2	$kgCO_2e/m^3$	Average using SPONS
Filling			2.2	$kgCO_2e/m^3$	Average using SPONS
Earthworks Movement	Rigid HGV (50% laden)		0.215	kgCO2e/(tonne.km)	(14)
Deep Foundations - Bored Piles			0.042	kgCO2e/kgCO2e(A1-3)	EFFC-DFI calculator (17)*
Deep Foundations - Displacement Piles			0.043	kgCO2e/kgCO2e(A1-3)	EFFC-DFI calculator (17)*
Sheetpiles Walls			0.017	kgCO2e/kgCO2e(A1-3)	EFFC-DFI calculator (17)*
Lifting	Crane (<= 20 t capacity)		0.004	kgCO2e/kg	Average using SPONS assuming 4 hr total lift time

Activity / Process	**Sub-activity description**	**Sub-activity Comment**	**A5a Carbon Factor**	**Units**	**Notes/Reference**
Lifting	Crane (> 40 t capacity)		0.002	tCO_2e/t	Average SPONS assuming 4 hr lift time
In-situ concreting	Structural Concrete	Bases, footings, pile caps and ground beams	7.6	$kgCO_2e/m^3$	Average using SPONS
In-situ concreting	Structural Concrete	Walls	7.1	$kgCO_2e/m^3$	Average using SPONS
In-situ concreting	Structural Concrete	Suspended slabs, Deck slabs, parapets	10.9	$kgCO_2e/m^3$	Average using SPONS
In-situ concreting	Structural Concrete	Columns, piers and beams	19.1	$kgCO_2e/m^3$	Average using SPONS
In-situ concreting	Blinding	Blinding	9.8	$kgCO_2e/m^3$	Average using SPONS
In-situ concreting	Formwork	General formwork construction	2.2	$kgCO_2e/m^2$	Average using SPONS
In-situ concreting	Reinforcement	General reinforcement fixing	0.01	tCO_2e/t	Average using SPONS

Activity / Process	Sub-activity description	Sub-activity Comment	A5a Carbon Factor	Units	Notes/Reference
Surfacing	Sub-base	Spread and graded	1.2	$kgCO2e/m^3$	Average using SPONS
Surfacing	Tarmac	Surface and binder course	5.7	$kgCO2e/m^2$	Average using SPONS
Surfacing	Asphalt	Surface and binder course	5.7	$kgCO2e/m^2$	Average using SPONS
Surfacing	Tarmac	Single course	2.9	$kgCO2e/m^2$	Average using SPONS
Surfacing	Asphalt	Single course	2.9	$kgCO2e/m^2$	Average using SPONS
Steel Fabrication		General	0.3	tCO2e/t	BSCA building study (11)

* Since A5a is linked to the A1-A3 value, this should be based on A1-A3 associated with average materials. Further carbon data linked with piling/foundation works would assist in improving carbon estimates for construction of these elements.

From a sensitivity study carried out, if the upper bound fuel consumption was adopted for each operation, the estimated carbon approximately doubles.

2.2.5 Module B and C Carbon factors

Information can be found in the IStructE HTCEC (1) and PAS 2080 (2) on these modules.

2.2.5.1 Module B9 User Carbon

Module B9 is important to consider for a bridge, at least from a qualitative perspective, as the emissions associated with the traffic using the infrastructure (UseCarb) can dwarf the capital carbon in some instances. Scenarios where it is considered appropriate to quantify the UseCarb include:

1. Where traffic staging during construction will lead to increased journey lengths (user carbon generated during construction should be included within A5 and shared with all works completed during a closure).

2. Where maintenance, repair, replacement or refurbishment require closure of the bridge leading to increased journey lengths. This may, for example, influence the selection of one repair option over another.

3. Where a proposed bridge is part of a wider transport route option assessment. For example, it could be misleading to neglect UseCarb when comparing a highway route option with a longer bridge but a shorter overall length vs a shorter bridge within a longer route.

4. When comparing different transport mode options, e.g. light rail vs a highway.

These will require input from a suitable traffic model to estimate the total additional journey lengths and traffic types associated with these scenarios. The traffic types should also account for anticipated future decarbonisation of transport modes where appropriate.

User Carbon may generally best be considered at system level rather than the bridge level. User Carbon associated with vehicular traffic is expected to reduce over time and there is no generally agreed method for calculating that at this time, so care is needed.

2.2.6 Module D Carbon Factors

Additional information follows the module description from PAS 2080. Touching on two common aspects for Module D:

- Future recycling (e.g. structural steel) - the benefits can only be realised outside the study period (PAS 2080 7.1.3.4) and are therefore normally excluded.
- Sequestration – for upfront carbon, this should be neglected. Over the study period, this may be included provided it can be assured that the replacement trees are protected, etc.

2.2.7 Carbon assessment methodology with project progression

A project goes through a number of phases. Those involved with bridges are likely to be familiar with the six appraisal to disposal phases for highway structures in the Design Manual for Roads and Bridges (DMRB), the phases of the Project Acceleration in a Controlled Environment (PACE) or for footbridges the eight definition to use phases of an architects work plan (RIBA). The project phases for DMRB, PACE and RIBA are not identical, and they do not all clearly define when carbon calculations are made. The DMRB, PACE and RIBA project phases do indicate when cost estimates are made. As current data (18) indicates, there is a close corelation of cost and carbon (as costs increase so does carbon content) then for this guide it is recommended that carbon estimates are updated with cost estimates. As with cost, the accuracy of carbon emission estimates will improve as the project phases develop.

For this guide the carbon is recommended to be estimated at the following stages with the following level of accuracy:

Table 8 – Carbon assessment methodology with project progression

Project Stage	**Bridge Information**	**Carbon Assessment Information**
Inception / Definition *At this stage there is significant scope to reduce carbon by considering if works are required or if the size of any bridges can be significantly reduced.*	Approx. bridge functional area	Estimate can be made by comparisons with similar projects, published per km or per m^2 data, or by multiplication of the cost data by a cost to carbon factor*. If establishing a carbon budget, appropriate allowance for risk and optimism bias should be included.
Concept Development / Options Assessment *At this stage multiple options (construction form and materials) will be considered, which may include additional options when carbon is included within the assessment criteria.*	High level quantities; or, Total bridge area + span arrangement + structural form + primary construction material	It is recommended that the previous carbon estimates using published data or costs from the inception stage are supplemented and compared with estimates made using material quantities, etc. (BS EN 15978 A1 to A5). The material (A1 to A3) carbon factors for the optioneering phase should be based on world average values (refer Section 2.2.2 of this guide) to allow a more consistent comparison of different options. The construction (A4 and A5) carbon should generally use the default values in this guide (Sections 2.2.3 and 2.2.4) as detailed specifications or construction method statements will generally not be defined. Modifications to risk and optimism bias may be made at this stage.
Preliminary Design *At this stage the key bridge geometry of the preferred option should be refined to minimise material usage and construction effort.*	Quantities schedule and planned construction sequence.	At this stage the carbon estimate should still be based on worldwide averages and default values, but the variations from using local materials or a higher recycled content should be explored.
Detailed Design	Detailed quantity schedules, specifications, Drawings, BIM models, etc.	If design documents clearly stipulate reduced material specification details, which include, for example maximum cement content, minimum recycled content, restrictions on transport distances, etc.

Project Stage	**Bridge Information**	**Carbon Assessment Information**
At this stage Value Engineering or Lean procedures can assist in reducing material and carbon content. Where possible, this stage the transport and construction processes (A4-A5) can also be reviewed.		then improved carbon factors can be adopted. Conversely, where no modifications are made to standard specifications, due to the market limitations then a higher than average carbon factor may be necessary. Where specifications call for a particular product, then the manufacturers environmental product data (EPD) can be used.
Construction *Early in this stage Value Engineering or Lean procedures utilising construction expertise, as well as engaging with the supply chain, can again assist in reducing carbon content.*	Final construction quantities, including a review of the material wastage factors and estimated fuel use onsite.	During the construction stage: - Supplier/manufacturer EPD's can be used to refine A1-A3 carbon factors. - Actual transport distances for suppliers can be used (A4). - Construction methods and onsite fuel use/material wastage will be estimated in detail/measured (A5)
As built *At the end of construction, a final estimate of the carbon emissions of the project should be completed and shared.*	Final as built information.	As above but confirmed based on as-built data.

* When using cost data care should be taken as the relation between cost and carbon is changing; as costs increase with inflation, and carbon reduces as we progress towards net zero.

2.3 Process

2.3.1 Calculation

Refer to IStructE guide – no specific description is necessary for bridges.

2.3.2 Normalising results

Normalise using the functional unit (Cl. 7.1.2 from PAS 2080) functional area of the deck as mentioned in the main guide and depicted in Figure 2.

Width

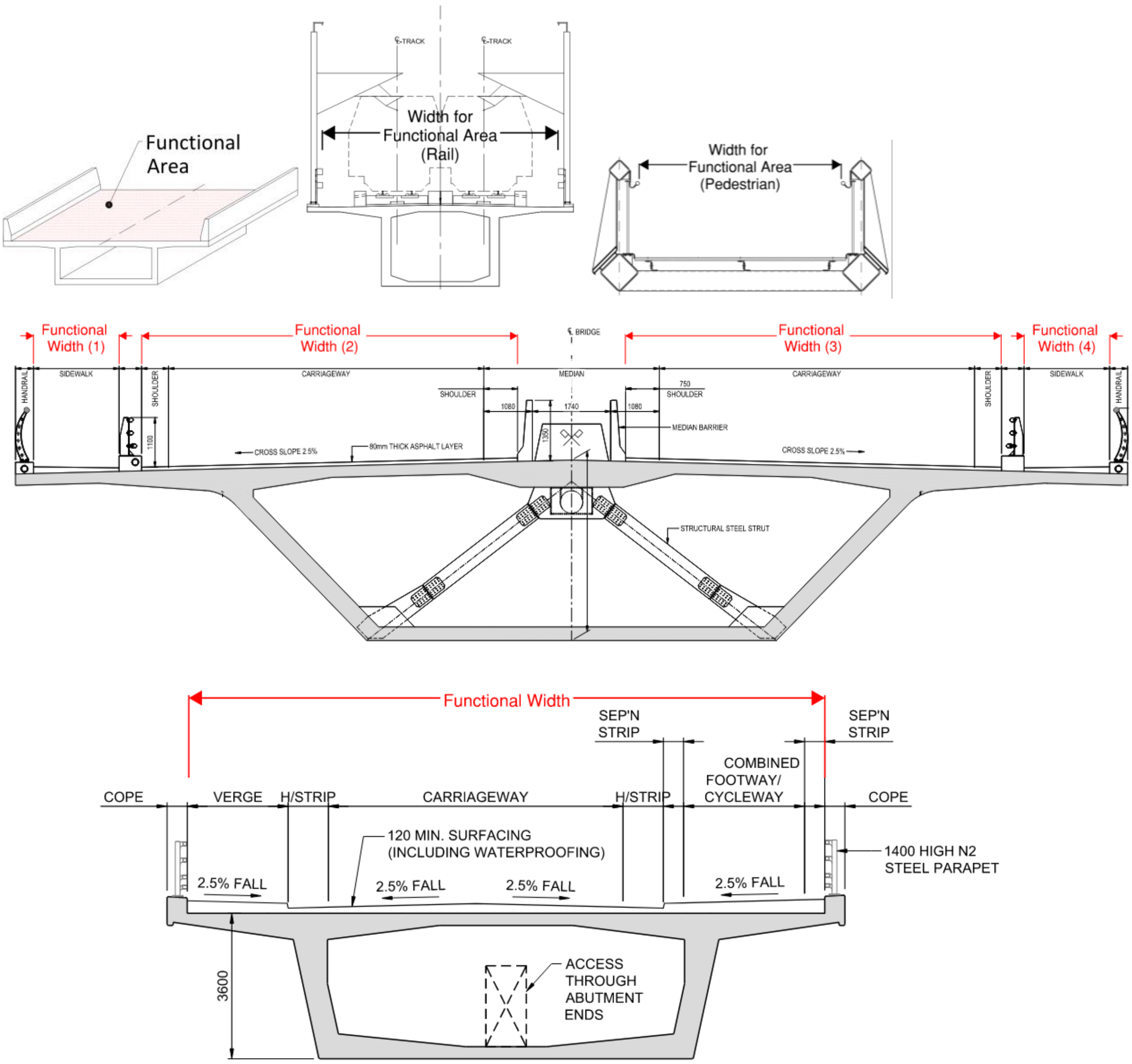

Figure 2 - Bridge deck functional area for normalising carbon estimates.

Length

Length is based on the total length of the bridge deck up to the end joints.

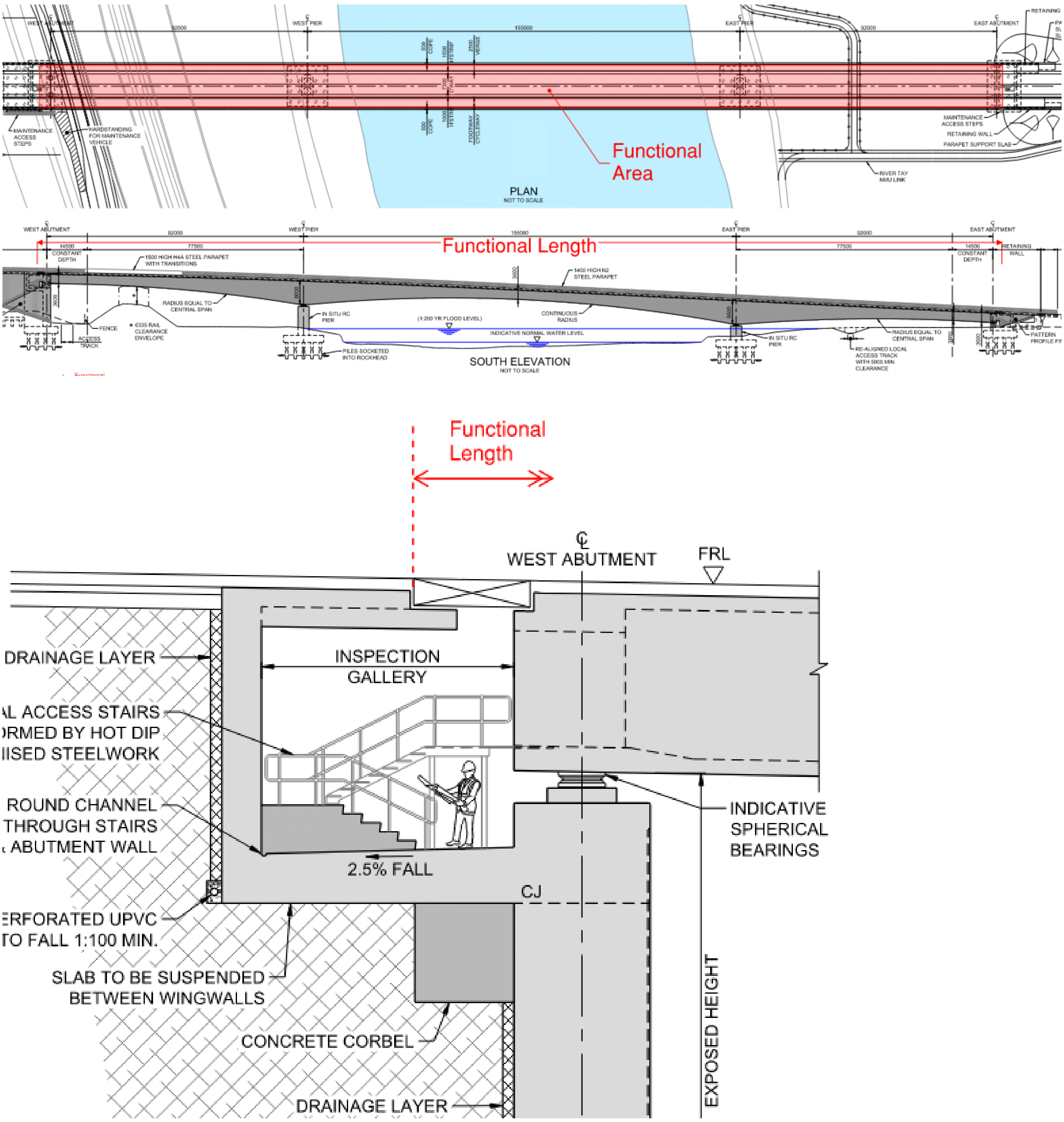

Figure 3 - Bridge deck functional length for normalising carbon estimates.

2.3.3 Bridge Extents

To ensure consistency in the extents of a 'bridge' for the purposes of a carbon assessment, at the abutments, all elements that are supported on the abutment foundations, i.e. are integral with the abutment, should be included within the 'bridge'.

In Figure 4, the portion of wingwalls in red, which is structurally separate from the foundation structure that is supporting the bridge, is not part of the 'bridge' for the total carbon sum and comparison. These elements would however form part of the approaches and should be included within the total carbon for the crossing.

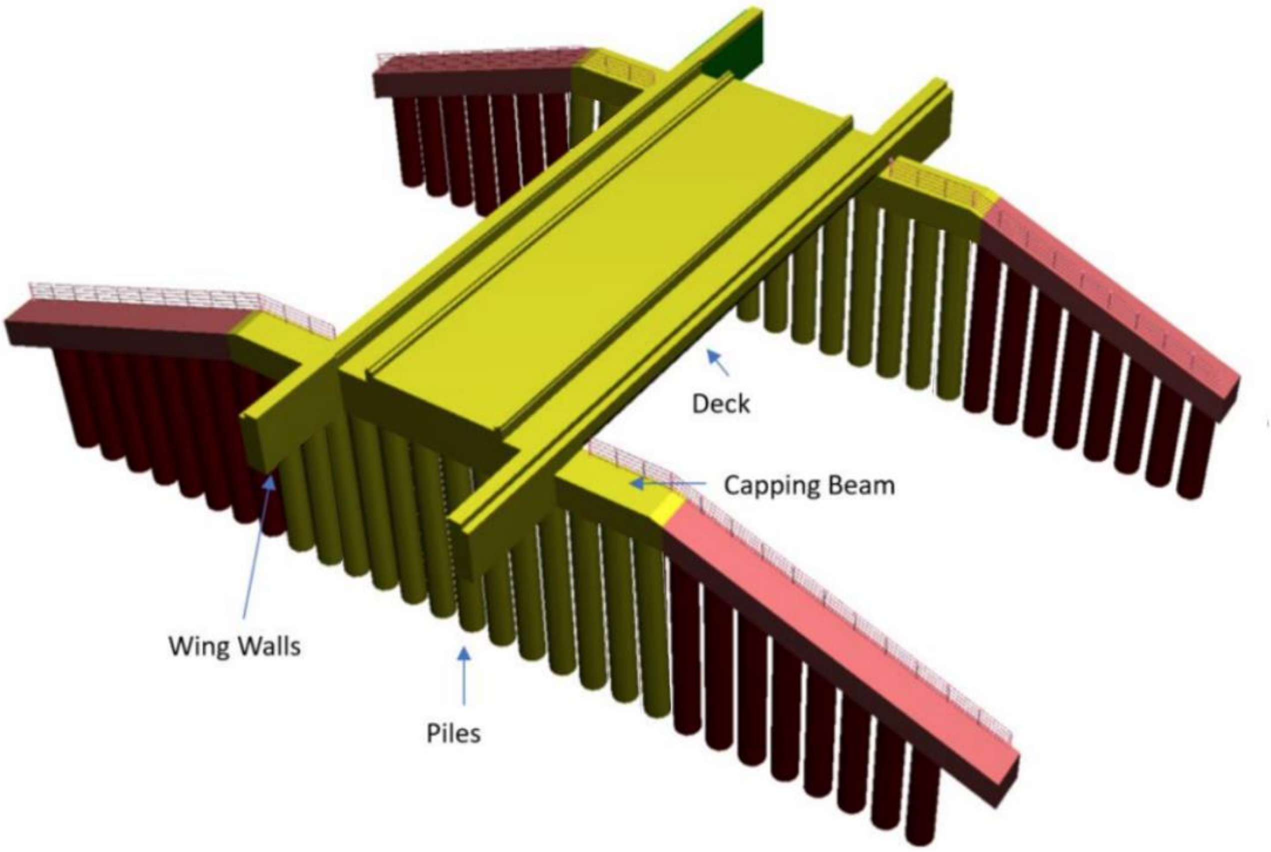

Figure 4 - Bridge extent definition example.

The intention of this distinction is to create a clear and consistent bridge extent to allow for carbon data comparison and benchmarking.

2.3.4 Approaches

As noted in Section 2.3.3, including the approaches within the overall carbon assessment for the crossing is important to compare options with different bridge lengths, etc. Another example of elements which form part of the approaches is shown in Figure 5.

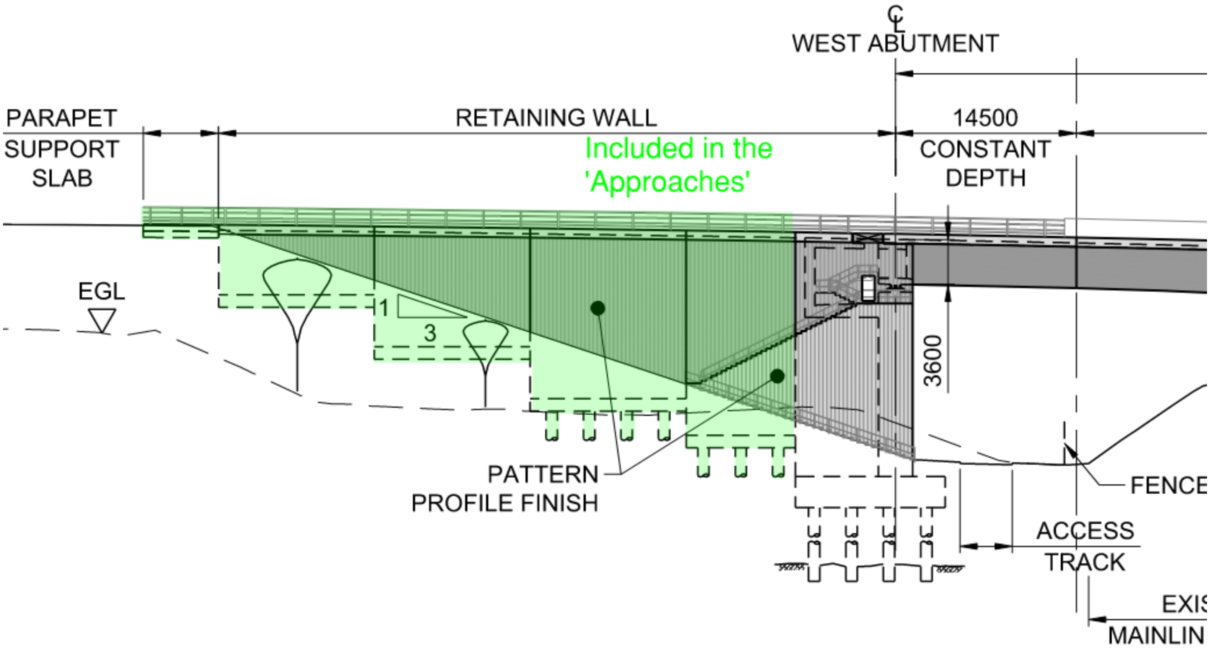

Figure 5 - Approach definition example.

2.4 Outputs

Similar to the main guidance, a final carbon count should be uploaded to a shared database, such as that being compiled by the Net Zero Bridges Group (reach out via email to info@netzerobridges.org) or the Built Environment Carbon Database (www.becd.co.uk – in development), to drive progress around industry understanding of carbon in bridges.

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