Life Cycle Cost Assessment of a Stainless Steel Highway Bridge

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EXECUTIVE SUMMARY

This report describes detailed life cycle cost (LCC) comparisons for a typical highway bridge in which the main girders are made of painted carbon steel, weathering steel, lean duplex stainless steel and standard duplex stainless steel. The LCC comparisons included the cost of constructing the bridge as well as maintaining it over a service life of 120 years. Both real and present (i.e. discounted) costs were determined. The bridge was assumed to be situated in four different locations: over an A road, over a railway near and far from the coast, and over an estuary.

The study showed that the cost of constructing the bridge steelwork from lean duplex and standard duplex stainless steel is 80% and 125% respectively more expensive than constructing it out of painted carbon steel. However, when the cost of constructing the entire bridge is considered, the lean and standard duplex stainless steel solutions were only 20% and 31% more expensive than the painted carbon steel solution.

When the maintenance cost over a 120 year period is taken into consideration, the stainless steel solutions were more economical than the painted carbon steel solution when the bridge was located over a railway. This is because the present cost of having to re-paint the main girders is at least as high as constructing the steelwork in the first place - it can be up to 3.5 times higher, depending on the corrosiveness of the environment.

Considering only the cost of constructing the steelwork and re-painting the main girders when the bridge spans over a railway, the present cost of the stainless steel solutions was found to be around half of the painted carbon steel solution. If the present cost of constructing and maintaining the entire bridge was considered, the stainless steel solutions were found to be 20% and 14% cheaper than the painted carbon steel solution for the bridge far away from the coast and near the coast, respectively. These cost savings were mostly driven by the high cost of maintenance associated with the closure of the rail network, suggesting that for this type of bridge, the use of duplex stainless steel should be considered irrespective of the level of corrosiveness of the environment.

For the bridge over a main road, the cost saving from using duplex stainless steel was less pronounced due the lower cost of re-painting the main girders. However, the stainless steel solutions were still around 11% cheaper. For the bridge located over an estuary, both the stainless steel solution and the painted carbon steel solution costs were similar.

In all cases in which weathering steel was a viable option, this solution was found to be the most cost effective. However, the use of weathering steel is not recommended for certain situations, such as bridges located in coastal environments, or when the girders are exposed to deicing salts.

The LCC comparisons did not consider the indirect costs associated with the maintenance activities (such as those due to traffic congestion delays), which can exceed the direct costs by a significant amount. If these had been considered, the economic benefit of using duplex stainless steel for the main girders of the bridge, as opposed to painted carbon steel, would be more significant. The inclusion of indirect maintenance costs should not affect the comparisons between weathering steel and duplex stainless steel.

Contents

1 INTRODUCTION

Stainless steels are inherently corrosion resistant. In the presence of oxygen, a tightly adherent protective layer of chromium oxide spontaneously forms on their surface, which means they can perform satisfactorily in a wide range of environments without protective coatings. This intrinsic characteristic of stainless steel is particularly important for bridges, which often need a long service life with minimum maintenance in aggressive environments.

There is a wide range of stainless steels with varying levels of corrosion resistance and strength. Duplex stainless steels are the most widely used stainless steels for structural components in bridges due to their superior strength and excellent corrosion resistance, while austenitic stainless steels are mainly used for non-structural components on bridges.

The initial raw material cost of stainless steel is considerably higher than that of carbon steel. However, there may be some initial cost savings associated with eliminating corrosion resistant coatings. Moreover, the superior strength of duplex grades over typical S355 carbon steel leads to weight savings, which offsets to some degree the higher material cost, and means welding can be significantly faster, and handling and installation can be easier.

Eliminating the need for coating maintenance or component replacement due to corrosion leads to long-term maintenance cost savings that can far exceed the initial cost difference. This is particularly important for bridges over railways, water or busy roads, where access to maintenance is limited or where the cost associated with the temporary closure of the rail/road under it is high. The greater the area to be painted (i.e. the higher the surface area/tonne), the more cost-effective stainless steel becomes. (Pedestrian bridges generally have higher surface area/tonne than road bridges.) Indirect benefits of reduced maintenance for road bridges include less traffic disruption of the road under it and a reduction in the greenhouse gas particulate emissions associated with standing traffic.

Bridge owners and designers in Europe, US and India are becoming increasingly interested in the use of duplex stainless steel for bridge structures. The purpose of this study is to prepare objective and detailed cost comparisons of duplex stainless steel bridge girders against carbon steel bridge girders, including both construction costs and life cycle costs. The study aims to address the prejudice that stainless steel is always “too expensive” and hence rarely even considered. The study consisted of life cycle cost comparisons between a duplex stainless steel highway bridge and functionally equivalent bridges in weathering steel and painted carbon steel. Different locations were investigated, in which the bridge was exposed to different levels of corrosive environments and different levels of maintenance difficulty.

The scope of this study is limited to cost comparisons; potential savings in carbon emissions due to a reduction in weight and reduced maintenance requirements are not considered.

The work was carried out in collaboration with metallurgists and engineers from the Materials, Bridges and Transportation Infrastructure Asset Management departments of Arup. The contribution of Graham Gedge (Director, Arup Materials) and Vicky Vassou (Director, Arup Assets & Operations) is gratefully acknowledged.

2 MATERIALS

2.1 Steel

The following steels were used as part of the study:

- Carbon steel: S355 and S460 to EN 10025-2[1]
  Nominal yield stress = 355 N/mm^2 for S355 and 460 N/mm^2 for S460
- Weathering Steel: S355W and S460W to EN 10025-5[2]
  Nominal yield stress = 355 N/mm^2 for S355 and 460 N/mm^2 for S460
- Duplex stainless steel: 1.4162 and 1.4462 to EN 10088-4[3]
  Nominal yield stress = 450 N/mm^2 and 460 N/mm^2 respectively
  Surface finish: 1D in accordance with Table 6 of EN 10088-4 (hot rolled, heat treated, pickled and free of scale).

Duplex stainless steel 1.4162 is a lean duplex stainless steel (less highly alloyed) and is about two thirds of the cost of standard duplex stainless steel 1.4462.

The following densities in accordance with the Eurocodes were assumed for calculating the tonnage of material required:

- Carbon steel: 7850 kg/m^3
- Duplex stainless steel 1.4162: 7700 kg/m^3
- Duplex stainless steel 1.4462: 7800 kg/m^3

Table 1 compares nominal value of the mechanical properties for duplex stainless steels against those of carbon steel.

Table 2.1 Nominal value of the mechanical properties of duplex stainless steel and carbon steel plate

Alloy	Modulus of elasticity *E* (MPa)	Yield strength f_y (MPa)	Ult. tens. strength f_u (MPa)	Elong. (%)
Standard duplex stainless steel (1.4462)	200,000	460	640	25
Lean duplex stainless steel (1.4162)	200,000	450	650	30
Carbon steel (S355)	210,000	355	490	22
Carbon steel (S460)	210,000	460	540	17

The nominal yield stress of carbon steel and weathering steel reduces by 2.8 - 4.3% as the thickness increases from 16 mm to 40 mm. No equivalent reduction is required for stainless steels.

Although duplex stainless steels exhibit a ductile to brittle transition like carbon steels, they have adequate toughness for most low temperature applications, e.g. a lean duplex typically shows an average toughness of 40 J in base and weld metal at –40°C for up to 30 mm thick material. The more highly-alloyed duplexes show even better toughness.

The thermal conductivity of duplex stainless steel is about 30% of that of carbon steel, and the coefficient of thermal expansion of duplex grades is similar to that of carbon steel (see Table 2). The relatively low thermal conductivity of duplex stainless steel may lead to greater welding distortions.

Table 2.2 Thermal properties of stainless and carbon steel

Alloy	Thermal conductivity (W/mK)	Thermal expansion (10^{-6}/°C for T≤100°C)
Duplex stainless steel	15.0	13.0
Carbon steel	53.0	12.0

2.2 Corrosion protection

The corrosion protection for the painted steel solution was assumed to be Type II, Series 1900 HE (a high build, quick drying epoxy (two-pack) system or high build glass flake epoxy system with an epoxy acrylic, polyurethane or polysiloxane finish)[4].

2.3 Material selection

2.3.1 Weathering steel

According to CD 361 *Weathering steel for highway structures*[5], weathering steel shall not be used in highway structures without an additional corrosion protection treatment where any of the following exposure conditions apply:

- where the atmospheric corrosion classification has been determined as C5 or CX;
- where the airborne salinity level has been determined as S3;
- where the atmospheric pollution level has been determined as P3;
- where a source of atmospheric pollution other than atmospheric sulphur compounds has been identified that makes the use of weathering steel unviable due to the extent of corrosion that is likely to occur;
- where the weathering steel is likely to be continuously wet or damp;
- where the whole or part of the structure is likely to be subject to high concentrations of de-icing salts that can lead to substantial deposits of chloride on weathering steel surfaces, such as wide structures over salted roads, structures over salted roads at below the minimum standard headroom, structures located within 10.0 metres horizontally of a salted carriageway, or where salt-laden water could flow directly over the weathering steel;
- for crossings over water where the headroom is less than 2.5 metres; and
- where weathering steel is close to or in contact with the ground.

As currently written, CD 361 does not permit the use of weathering steel for structures closer than 15 km to the coast without undertaking 12 months of exposure trials and complying with certain other additional requirements. There are also some residual risks associated with the use of weathering steels, particularly around detailing, so if there are particular reasons to have a negligible risk solution, stainless steel may be a better option.

2.3.2 Stainless steel

One of the main reasons for selecting a stainless steel is to take advantage of its corrosion resistance properties, which ensure long-term durability and minimal maintenance.

Within the duplex family of stainless steels, there is a wide range of corrosion resistance. The stainless steel Eurocode part, EN 1993-1-4[6] introduces a simple grade selection procedure to guide the designer to an alloy with adequate corrosion resistance for the service environment. (It does not cover situations where the stainless steel is immersed or exposed to chemicals as part of a process flowstream.) Firstly, the service environment is characterised by a Corrosion Resistance Factor (CRF), based on considerations such as the risk of exposure to chlorides from salt water or de-icing salts and exposure to washing by rain. From the CRF, the required Corrosion Resistance Class (CRC) is then determined. Grades are grouped in one of the five CRCs based on their corrosion resistance. Lean duplexes 1.4662, 1.4362, 1.4062, and 1.4162 are in CRC 3 and standard duplex 1.4462 is in CRC 4. Super duplexes, with higher alloying additions of chromium, nickel and molybdenum, are in CRC 5. Further guidance is given in the Design Manual for Structural Stainless Steel[7].

3 BRIDGE DESIGNS

The bridge being studied was taken from one of the worked examples in the SCI Publication *Composite Bridge Design* (SCI P357)[8] and is typical of highway bridges constructed within the UK and the rest of Europe. The reference design comprises a two-span integral bridge, with each span being 28 m, as shown in Figure 3.1. A four-girder arrangement has been chosen, and a deck slab thickness of 250 mm has been assumed. The reinforced concrete deck acts compositely with the four main girders which are of constant depth and spaced at 3.7 m from each other. The deck cantilevers 1.6 m outside the centrelines of the outer girders. The bridge carries a two-lane single carriageway rural road. The carriageway has 1 m wide marginal strips and has a 2 m wide footway on either side. The main girders are divided into five portions where their cross-sectional dimensions are optimized to resist the load effects, and they are connected using splices with pretensioned bolts.

The designs were carried out in accordance with:

- BS EN 1993-1-1:2005+A1:2014 and the UK National Annex[9]
- BS EN 1993-1-4: 2006+A2:2020 and the UK National Annex[6]
- BS EN 1993-1-5: 2006+A2:2019 and the UK National Annex[10]
- BS EN 1993-2: 2006 and the UK National Annex[11]

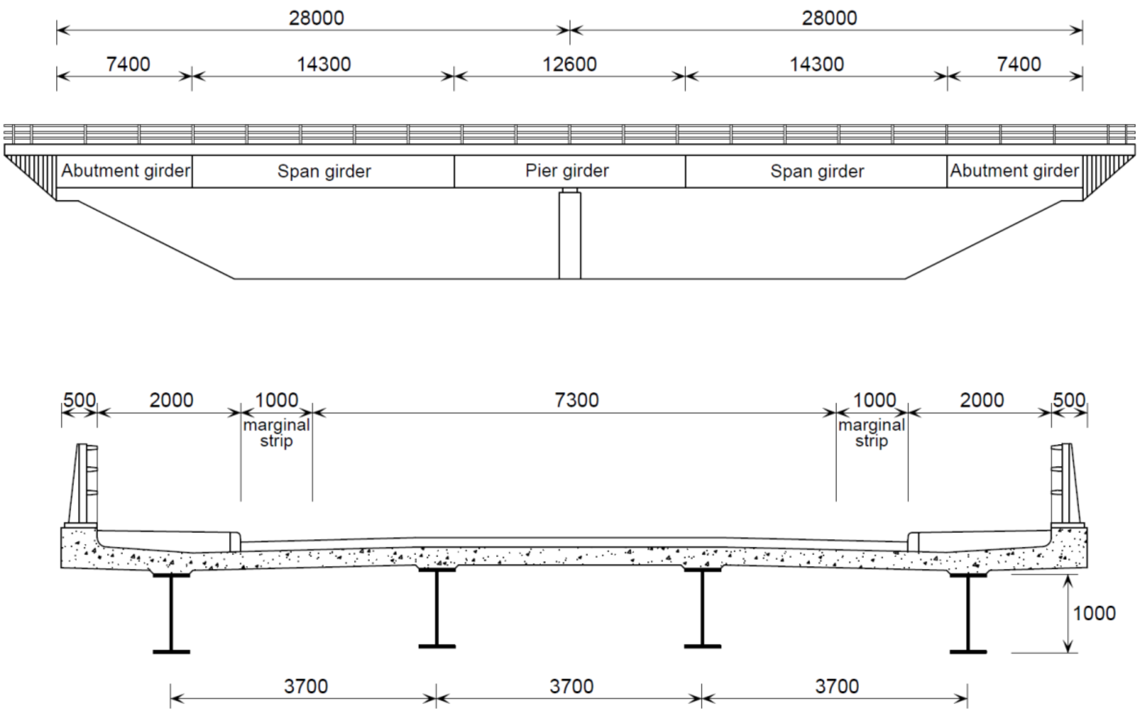


Figure 3.1 Layout of the bridge

Six different solutions regarding the type of steel used for the main girders were considered as design variations.

- Solution 1: Painted Carbon Steel S355
- Solution 2: Painted Carbon Steel S460
- Solution 3: Weathering Steel S355
- Solution 4: Weathering Steel S460
- Solution 5: Duplex Stainless Steel (grade 1.4162)
- Solution 6: Duplex Stainless Steel (grade 1.4462)

For each solution, the cross-sectional dimensions of the main girders were optimized to minimize the self-weight, and the splices were designed. All solutions required a total length of weld of 896 m to fabricate the main girders, and 6000 shear connectors. The location and size of the bracing system was also assumed to be the same for all solutions.

3.1 Partial factors

The relevant partial factors used in the design of the carbon steel and stainless steel solutions were taken from EN 1993-2 and EN 1993-1-4, respectively, and they are given in Table 3.1.

Table 3.1 Partial factors

Description	Partial factor	Carbon steel (EN 1993-2)	Duplex stainless steel (EN 1993-1-4)
Resistance of cross sections to excessive yielding including local buckling	γ_{M0}	1.00	1.10
resistance of members to instability assessed by member checks	γ_{M1}	1.10	1.10
resistance of cross sections in tension to fracture	γ_{M2}	1.25	1.25

3.2 Design of the main girders

The optimization design of the main girders was in accordance with the current version of the Eurocodes. For the stainless steel girders, the current design code (EN 1993-1-4:2006+A1:2020) includes different class limits compared to the 2006 version used in the Arup 2011 report[12]. This permitted a reduction in the plate thickness of the stainless steel girders while still being able to exploit their partially plastic bending resistance.

Another important difference with respect to the design presented in the Arup 2011 report[12] for the stainless steel girders is that in this study the provisions given in clause 5.5.2(11) of EN 1993-1-1, which stipulates that “Cross-sections with a Class 3 web and Class 1 or 2 flanges may be classified as class 2 cross-section with an effective web”, were also applied to the design of the stainless steel girders. This is justified by the fact that EN 1993-1-4 provide supplementary rules to EN 1993-1-1, and therefore, unless explicitly stated, all rules in EN 1993-1-1 should also apply to stainless steel. The use of this clause for the design with stainless steel permitted an increase in the bending resistance leading to a reduction in plate thicknesses for the stainless steel solutions compared to those presented in the Arup 2011 report[12], and consequently a slight reduction in tonnage.

The optimization design of the main girders adopted the same assumptions used for the optimized design reported in the Arup 2011 report[12], which are as follows:

- During the construction stage, it was assumed that the steel girders were laterally restrained to prevent lateral-torsional buckling while the concrete was still setting.
- The changes in plate sizes were assumed to have a negligible effect on the design effects, and therefore, all the design solutions were based on the same loads (i.e. those reported in SCI P357[8]).
- The effects of the change in material and section properties on the size and spacing of shear studs and deck slab reinforcement were not considered.
- All the optimized design solutions aimed to provide the most optimised design, removing any spare capacity.
- Each of the main girders was assumed to have four splices where the cross-section of the girder can be changed in order to remove excess material in parts of the bridge where it is not required.
- The dimensions of the flanges of the I-girder were limited not to exceed the class 2 limit given in EN 1993-1-4, while the web was limited not to exceed the class 3 limit.
- The top flange of the I-girder was set to have a width of at least 400 mm to allow for the positioning of the shear studs.
- The webs and flanges were set to have a thickness of at least 10 mm and 15 mm, respectively, to ensure sufficient robustness, avoid potential damage during construction and permit welding of the shear studs.
- The depth of all the steel girders was set to 1000 mm.
- It was assumed that fatigue was not critical, and therefore this limit state was not considered during any of the design solutions.

A typical cross-section of the main girders working compositely with the slab is shown in Figure 3.2. For all the solutions studied, the slab was made of concrete grade C40/50, and had a depth of 250 mm. The concrete slab was reinforced using carbon steel rebars of 25 mm diameter and a characteristic yield strength f_{yk} = 500 MPa. The reinforcing bars were spaced at 150 mm both in the transverse and longitudinal direction.

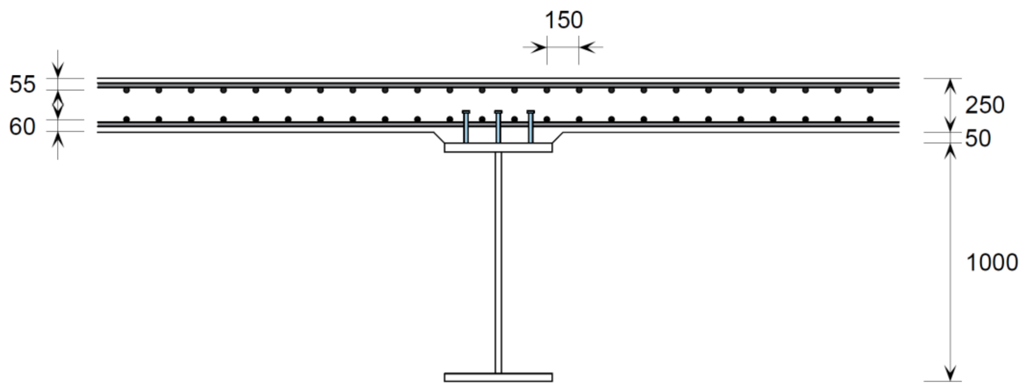


Figure 3.2 Composite cross-section

3.3 Design of the splices

Bolted splices were used on each of the main girders at the locations where the cross-sectional dimensions of the girder changed. Due to symmetry, two different spliced connections were designed, with the largest spliced connections located between the pier girder and the span girder, and the smallest located between the span girder and abutment girder (see Figure 3.1). A representative spliced connection is illustrated in Figure 3.3.

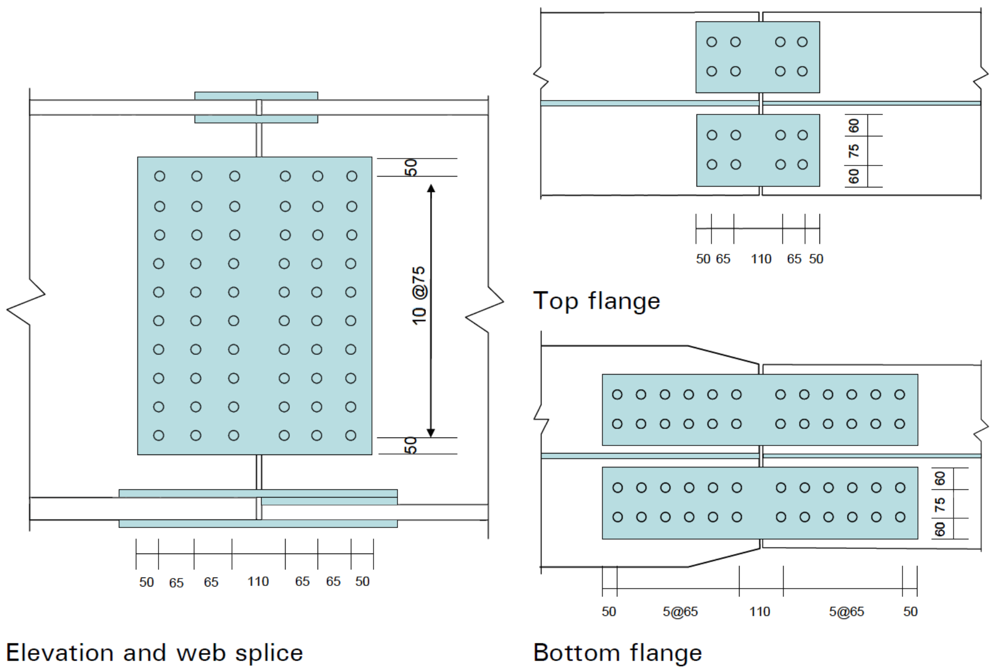


Figure 3.3 Spliced connection between the pier girder and span girder of bridge made of 1.4462

All the splices were designed as Category C bolted connections using a frictional coefficient of 0.5, and M24 preloaded bolts.

For the carbon steel and weathering steel designs, grade 8.8 galvanized or weathering grade bolts were assumed (f_u = 800 N/mm^2), in accordance with EN 14399[13]. A Class A friction surface is assumed (slip factor μ = 0.5). (It is acknowledged that tension control bolts (TCBs) are increasingly used in the UK for bridges, and these are Class 10.9 HRC bolts.)

For the duplex stainless steel designs the bolts were assumed to be either austenitic A4-80 (for the design with the main girders in 1.4162) or duplex D6-80 (for the design with the main girders in 1.4462), in accordance with EN ISO 3506-1 and -2[14] and EN 15048-1[15]. These stainless steel bolts have the same ultimate tensile strength as the grade 8.8 carbon steel bolts, and a corrosion resistance equivalent to that of the duplex stainless steel grade used for the main girders. The cover plates used in the spliced connections were made of the same material as the main girders.

The design of preloaded stainless steel bolted connections is not currently included in EN 1993-1-4. However, following the European project SIROCO[16], design rules have been developed for austenitic and duplex stainless steel preloaded bolted assemblies. These design rules have been incorporated in the current draft of prEN 1993-1-4[17], which is scheduled for publication in 2025. The splices in the stainless steel girders were designed based on these rules. In accordance with EN 1090-2, stainless steel preloaded bolt assemblies are treated as special fasteners, and a bolt tightening qualification procedure is necessary to confirm suitability for preloading and the relevant tightening parameters, lubrication etc. In addition, tests are required to confirm the slip factor μ = 0.5 can be used for surfaces blasted with clean stainless steel or non ferrous grit media in which Rz ≥ 55 ηm. The total cost of having these tests undertaken by an independent testing house are approximately £6,800 (€8,000).

3.4 Bracing system

All designs used the same type of bracing solution, which consisted of permanent bracing and additional temporary bracing during the construction stage. The dimensions and arrangement of the bracing members were taken from the reference design presented in SCI P357[8].

The arrangement for the permanent bracing is shown in Figure 3.4 (where dimensions are shown in mm).

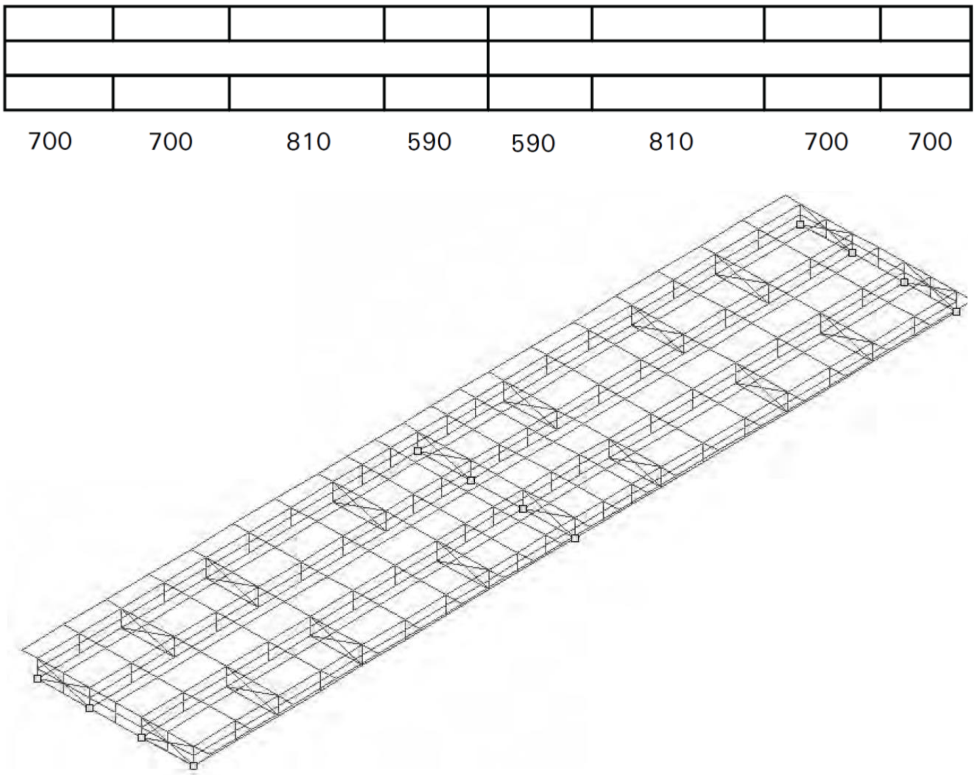


Figure 3.4 Arrangement of permanent bracing

The permanent bracing system was achieved by connecting two adjacent girders with angle sections of 120mm x 120mm x 12mm connected to web stiffeners, as shown in Figure 3.5. Eighteen connections were made in total.

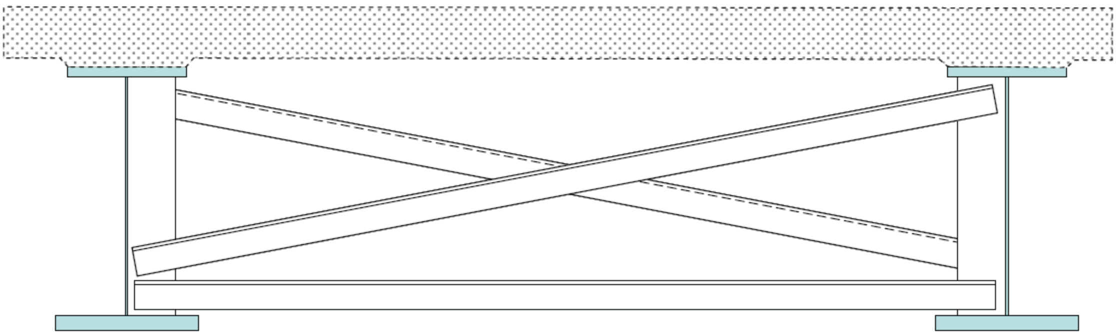


Figure 3.5 Detail of permanent bracing

Lateral displacement of the four main girders was also restrained at two locations along the bridge. The temporary bracing was placed at a distance of 18.05 m from each end of the bridge (i.e. mid-distance between the permanent bracing spaced at 810 mm).

3.5 Web stiffeners

For all the designs, the webs of the main girders were strengthened with 72 intermediate stiffeners and 24 bearing stiffeners. The dimensions of the stiffeners are those of the reference design example given in SCI P357[8]. The intermediate stiffeners consisted of single sided flat stiffeners with dimensions of 200mm x 20mm, while the bearing stiffeners consisted of double sided stiffeners with dimensions of 250mm x 25mm. The stiffeners were welded to the web and flanges of the main girders with a throat fillet weld of 6 mm.

3.6 Optimized solutions

Table 4.1 to Table 4.5 show the optimized cross-sectional dimensions of the main girders and the total tonnage of steel required for four identical bridge girders. The tables also list the total number of bolts required for the splices.

Where weathering steel is used, the design is identical to the corresponding carbon steel design, but with each plate thickness increased by 2 mm to account for any corrosion allowance, except for the top flange, for which the thickness was only increased by 1 mm as the top surface is not exposed[5].

Due to the similar nominal yield strength of lean duplex 1.4162 (450 MPa) and standard duplex 1.4462 (460 MPa), the optimized solutions for these two duplex grades was almost identical. Therefore, the tonnage obtained for the lean duplex solution is presented for both duplex grades.

The optimized solution achieved using duplex stainless steel led to a reduction in weight of around 16 % compared to the optimized solution using carbon steel S355, and is marginally lighter than the optimized solution using carbon steel S460.

When comparing the design of the main girders using carbon steel S460 and duplex stainless steel, there are two main differences, which have opposing effects, and therefore lead to optimized solutions of very similar tonnage. The first difference is that while in the design of the carbon steel solution, the partial safety factor that is used to calculate the cross-sectional resistance of the composite section is equal to 1.0, for stainless steel this factor is equal to to 1.1. Therefore, even though the nominal yield strength of the duplex solution is very similar to the nominal yield strength of S460 steel, the design resistance of the duplex stainless steel solution is reduced by around 10% compared to the carbon steel solution. On the other hand, the nominal yield strength of carbon steel plates reduces as the thickness of the plate increases, while for duplex the strength of hot rolled plates remains constant for all thicknesses. For the thicknesses used in the optimized solution for S460, the reduction in the yield strength was up to around 7%.

Table 3.2 Solution 1: Painted Carbon Steel S355

	Abutment Girder	Span Girder	Pier Girder	Span Girder	Abutment Girder
Length (mm)	7400	14300	12600	14300	7400
Top flange (mm x mm)	400 x 15	400 x 25	400 x 20	400 x 25	400 x 15
Web (mm x mm)	960 x 13	945 x 11	920 x 17	945 x 11	960 x 13
Bottom flange (mm x mm)	300 x 25	425 x 30	630 x 60	425 x 30	300 x 25
Girder depth (mm)	1000	1000	1000	1000	1000
Total tonnage (t)	66.1				
Total no. 8.8 HDG M24 bolts	1712				

Table 3.3 Solution 2: Painted Carbon Steel S460

	Abutment Girder	Span Girder	Pier Girder	Span Girder	Abutment Girder
Length (mm)	7400	14300	12600	14300	7400
Top flange (mm x mm)	400 x 15	400 x 18	400 x 25	400 x 18	400 x 15
Web (mm x mm)	970 x 11	962 x 14	930 x 15	962 x 14	970 x 11
Bottom flange (mm x mm)	300 x 15	425 x 20	610 x 45	425 x 20	300 x 15
Girder depth (mm)	1000	1000	1000	1000	1000
Total tonnage (t)	56.4				
Total no. 8.8 HDG M24 bolts	1760				

Table 3.4 Solution 3: Weathering Steel S355

	Abutment Girder	Span Girder	Pier Girder	Span Girder	Abutment Girder
Length (mm)	7400	14300	12600	14300	7400
Top flange (mm x mm)	400 x 16	400 x 26	400 x 21	400 x 26	400 x 16
Web (mm x mm)	960 x 15	945 x 13	920 x 19	945 x 13	960 x 15
Bottom flange (mm x mm)	300 x 27	425 x 32	630 x 62	425 x 32	300 x 27
Girder depth (mm)	1000	1000	1000	1000	1000
Total tonnage (t)	71.6				
Total no. 8.8 HDG M24 bolts	1712				

Table 3.5 Solution 4: Weathering Steel S460

	Abutment Girder	Span Girder	Pier Girder	Span Girder	Abutment Girder
Length (mm)	7400	14300	12600	14300	7400
Top flange (mm x mm)	400 x 16	400 x 19	400 x 26	400 x 19	400 x 16
Web (mm x mm)	970 x 13	962 x 16	930 x 17	962 x 16	970 x 13
Bottom flange (mm x mm)	300 x 17	425 x 22	610 x 47	425 x 22	300 x 17
Girder depth (mm)	1000	1000	1000	1000	1000
Total tonnage (t)	61.9				
Total no. 8.8 HDG M24 bolts	1760				

Table 3.6 Solutions 5 & 6: Duplex Stainless Steel 1.4162/1.4462

	Abutment Girder	Span Girder	Pier Girder	Span Girder	Abutment Girder
Length (mm)	7400	14300	12600	14300	7400
Top flange (mm x mm)	400 x 15	400 x 18	400 x 25	400 x 18	400 x 15
Web (mm x mm)	970 x 15	962 x 14	930 x 15	962 x 14	970 x 15
Bottom flange (mm x mm)	300 x 15	400 x 20	560 x 45	400 x 20	300 x 15
Girder depth (mm)	1000	1000	1000	1000	1000
Total tonnage (t)	55.7				
Total no. 8.8 HDG M24 bolts	2208				

4 FABRICATION AND PROCUREMENT

A fabrication specification was developed in accordance with:

- EN 1090-2[18]
- Specification for Highways Works, Series 1800 Structural Steelwork[4]
- Project-Specific Appendix 18/1 Requirements for Structural Steelwork (Appendix A of this document, based on SCI Publication 418[19])

Stainless steel is not a difficult material to work with, although it differs from carbon steel in some respects and should be treated accordingly. Many fabrication and joining processes used in the construction of bridge girders are similar to those used for carbon steel (e.g. cutting, drilling holes, welding), but the different characteristics of stainless steel require special attention in a number of areas[20]. It is important that effective communication is established between the designer and fabricator early in the project to ensure that appropriate fabrication practices are adopted. Where possible, it is preferable to use a fabricator with a proven track record of working with structural stainless steel.

The same mechanical fabrication techniques typically used for bending, straightening, or cutting carbon steel plate or sheet can also be used for stainless steels. However, power requirements are greater than those for similar thicknesses of S355 carbon steel due to the higher work hardening rate of stainless steels, and the higher strength of duplex stainless steels. Also, when bending or straightening stainless steel due allowance should be made for spring-back deformations.

Duplex stainless steels require control of the minimum and maximum heat input during welding. They are not normally preheated but special care must be taken to restore the full corrosion resistance of the welded zone, for example by post-weld acid cleaning.

All fabrication processes should be carried out in a clean environment, with tools dedicated exclusively to stainless steel to avoid contamination by carbon steel and iron which increases the potential for surface corrosion. If there is a risk of residual contamination when fabrication is complete, the structure could be sprayed with an acid formulation, and then rinsed. Greater care is also required in storing and handling stainless steel to avoid damaging the surface finish. An alternative approach to undertaking fabrication in a clean environment is to carry out comprehensive cleaning of the structure after fabrication is completed to remove any contamination.

Stainless steel structures are generally fabricated by specialist stainless steel fabricators. Fabricators experienced with welding duplex stainless steel plate will generally be making tanks or vessels for the chemicals or food and drink industries, which are required to comply with different standards to bridges, e.g. the welded details would have different fatigue requirements. Enquiries made for this project showed that no carbon steel bridge fabricator was familiar with fabricating duplex stainless steel plate girders. It is therefore very important that any fabrication specification for a duplex stainless steel bridge is comprehensive and clearly outlines all requirements, including testing and inspection.

Table 4.1 gives a list of specialist stainless steel fabricators who have experience in fabricating large structural stainless steel.

Table 4.1 Fabricators in Europe and US with experience in fabricating large stainless steel structures

Fabricator	Location	Previous bridges fabricated
Metalmecánicas Herjimar	Spain	Aquilas Bridge, Spain
Tecade	Spain	Hisingsbron Bridge, Sweden
Navec	Spain	San Fruitos Bridge, Spain
Megusa	Spain	Lusail Pedestrian Bridge, Qatar
M Tec	UK	Mead's Reach
WEC	UK	New Pooley Bridge
Shawton Engineering	UK	
Qualterhall	UK	
Victor Buyck	Belgium / UK	
Lanarkshire Welding Co.	UK	
Darchem	UK	
Stål & Rörmontage	Sweden	Many Swedish bridges
Cimolai	Italy	
Mariani Metals	US	Garrison Crossing
Vigor	US	
G&G Afco Steel	US	
PVS	US	
Northern Manufacturing	US	
Tate Metalworks	US	
Carolina Integrated Solutions	US	
Peikko	Finland	

Fabricators should be encouraged to procure plate directly from the stainless steel producer, in lengths up to 10.5 to 13.5 m, and/or in project-specific lengths and thicknesses that minimise wastage. Plate procured from stockists may only be available in 6 m lengths, which would mean that more splices would be required to fabricate a bridge, at greater cost.

It should be noted that stainless steel fasteners are usually non-stock items. It is important that the corrosion resistance of the fasteners is at least as good as that of the plates being joined.

A temporary plan bracing system will restrain the girders against lateral torsional buckling in the construction stage.

5 CONSTRUCTION COSTS

5.1 Cost of constructing the steelwork

The cost of constructing the steelwork was broken down into the following categories:

- Plate
- Bolts for the splices
- Shear connectors
- Fabrication
- Erection
- Painting

Two UK steel bridge fabricators supplied independent quotes for the carbon steel and weathering steel bridges. This study used an average of the two quotes, and the values used are shown in Table 5.1.

Quotes for the cost of the plates for the main girders, the bolts, and the shear connectors were obtained for the stainless steel bridges from an experienced stainless steel fabricator. However, when it came to the fabrication and erection costs, it was not possible to obtain directly comparable costs due to the significant effect detailing and assumptions made for the fabrication process, such as location of the bridge, access, terrain, etc. may have on the final quote. For this reason, the fabrication and erection cost for the stainless steel solutions were estimated based on the quoted values received for the carbon steel solutions. The following assumptions were made.

The cost of fabricating a stainless steel bridge girder is likely to be higher than the cost of fabricating an equivalent one in carbon steel for the following reasons:

- A dedicated fabrication area needs to be established and maintained, and higher standards of cleanliness are required for storage and handling.
- Duplex stainless steels show more “movement” during cutting (due to springback) and welding (due to their lower thermal conductivity). There will be additional costs associated with preventing these distortions, or correcting them afterwards.
- Better temperature control is required during welding (i.e. the interpass temperature should be kept below 150°C). Weld consumables will also be more expensive.
- Non carbon steel tooling is required to prevent contamination, which may be more expensive.
- The preparation of the faying surfaces for preloaded bolts may be costlier.
- There is a lack of competition due to a shortage of suitably qualified fabricators.

On the other hand, there may be savings in fabrication costs due to the higher strength of duplex stainless steel compared to S355 steel, which means that in some instances when thinner plates can be used, there will be fewer weld passes. An additional point to be made is that no painting is required (including all the necessary surface preparation).

Fabrication and erection costs for use in this study were derived based upon discussions with stainless steel fabrication experts and bridge designers. A lower bound fabrication cost of 1.3 times the cost of carbon steel fabrication was assumed, with an upper bound of 1.7 times the cost of carbon steel fabrication. For the erection costs, it was assumed that the cost of erecting the stainless steel bridge was 1.2 times the cost for a carbon steel bridge due to the special handling requirements.

Table 5.1 Material, fabrication and erection costs for each solution

	Solution 1 (S355)	**Solution 2 (S460)**	**Solution 3 (S355W)**	**Solution 4 (S460W)**	**Solution 5 (1.4162)**	**Solution 6 (1.4462)**
Main girders tonnage (t)	**66.1**	**56.4**	**71.6**	**61.9**	**55.7**	**55.7**
Bracing and stiffeners tonnage (t)	**12.6**	**12.6**	**13.9**	**13.9**	**12.3**	**12.5**
Grade of bolts	**8.8 HDG**	**8.8 HDG**	**8.8 HDG**	**8.8 HDG**	**A4-80**	**D6-80**
No. bolts	**1712**	**1760**	**1712**	**1760**	**2208**	**2208**
No. headed shear connectors	**6000 (carbon steel)**	**6000 (carbon steel)**	**6000 (carbon steel)**	**6000 (carbon steel)**	**6000 (austenitic)**	**6000 (austenitic)**
Main girders plate cost						
Cost estimate	£75,000	£73,000	£87,000	£86,000	£195,000	£301,000
Bracings and stiffeners material cost						
Cost estimate	£17,000	£17,000	£20,000	£20,000	£50,000	£78,000
Bolt cost						
Cost estimate	£5,000	£5,000	£12,000	£12,000	£16,000	£21,000
Shear connector cost						
Cost estimate	£6,000	£6,000	£6,000	£6,000	£20,000	
Fabrication cost						
Cost estimate	£119,000	£117,000	£123,000	£120,000	£155,000 – £202,000 [a]	
Painting cost						
Cost estimate	£32,000	£32,000	N/A	N/A	N/A	
Erection cost						
Cost estimate	£48,000	£48,000	£42,000	£42,000	£58,000 [b]	
Total cost						
Cost estimate	£302,000	£298,000	£290,000	£286,000	£494,000 – £541,000	£633,000 – £680,000
[a] fabrication cost estimated as 1.3 – 1.7 times the cost for Solution 1 [b] erection cost estimated as 1.2 times the cost of Solution 1						

5.2 Cost of constructing other parts of the bridge

The other costs of bridge construction were estimated from the values used in the Arup report in 2011. These costs were as follows:

Piles: £100,000

Substructure: £350,000

Deck slab and finishes: £230,000

According to construction cost indices prepared by the UK's Office of National Statistics, the inflation within the UK construction industry between the first quarter of 2011 and the first quarter of 2014 was 15.8%, while between the first quarter of 2014 to the second quarter of 2021 it increased by 15.6%, amounting to a total increase of 34% over the 10 year period from 2011 to 2021. As a result, the following costs for bridge construction were estimated.

Piles: £100,000 x 1.34 = £134,000

Substructure: £350,000 x 1.34 = £469,000

Deck slab and finishes: £230,000 x 1.34 = £308,000

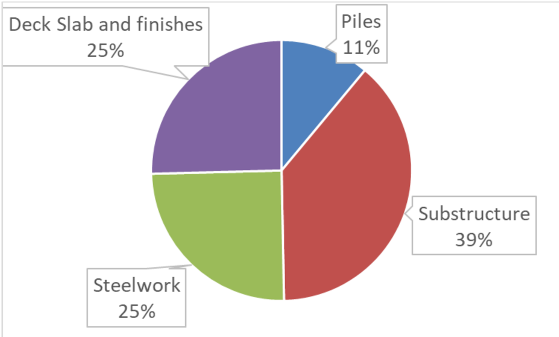
5.3 Construction cost comparison

The cost of constructing the bridge is given in Table 5.2 for each solution, while the breakdown of the different elements of the construction cost is illustrated in Figure 5.1. For Solutions 1 (S355) and 2 (S460), and Solutions 3 (S355W) and 4 (S460W), even though there are some differences in the amount and cost of the steel used for the main girders of the bridge, these differences are very small compared to the total cost of constructing the bridge, and therefore, have a negligible effect on the percentages displayed in the charts.

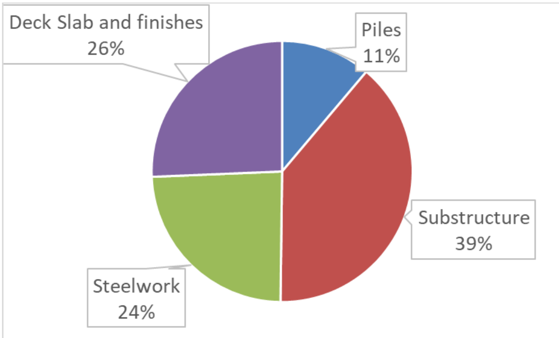
Table 5.2 Bridge construction cost comparison

	Steelwork	Other parts	Total cost	Increase in cost relative to Solution 1
Solution 1 (S355)	£302,000	£911,000	£1,213,000	-
Solution 2 (S460)	£298,000	£911,000	£1,209,000	0%
Solution 3 (S355W)	£290,000	£911,000	£1,201,000	-1%
Solution 4 (S460W)	£286,000	£911,000	£1,197,000	-1%
Solution 5 (1.4162)	£541,000	£911,000	£1,452,000	20%
Solution 6 (1.4462)	£680,000	£911,000	£1,591,000	31%

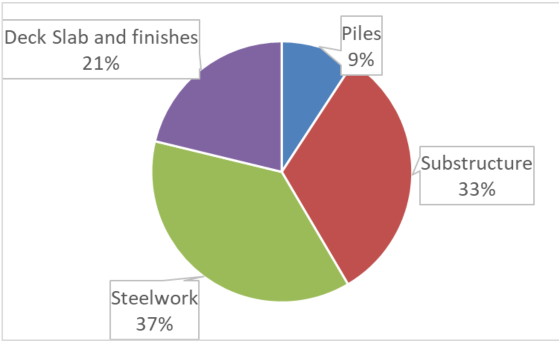
The cost of constructing the steelwork of the bridge comprises around 25% of the total construction cost for the carbon and weathering steel solutions, while for the lean duplex and standard duplex stainless steel solutions the cost of constructing the steelwork increases to around 40% of the total construction cost. The larger cost proportion of the steelwork in the lean duplex or standard duplex stainless steel solutions is primarily due to the higher cost of the stainless steel material, as well as the higher cost of fabrication. For lean duplex stainless steel 1.4162, the material cost is around 3.8 times more expensive than the cost of the S355 carbon steel material, while for standard duplex stainless steel 1.4462 the material cost is around 4.8 times more expensive than that of S355 carbon steel. As for the fabrication cost, the comparison assumed that the cost of fabricating the stainless steel solutions is 70% more expensive than the cost of fabricating the S355 carbon steel solution. This fabrication cost corresponds to the upper bound cost estimate, as described in Section 5.1. The cost of constructing the non-steel part of the bridge is the same for all the solutions considered. The larger material and fabrication cost associated with the stainless steel solutions results in an increase in the total construction cost of 20% for the lean duplex stainless steel solution and 31% for the standard duplex stainless steel solution.



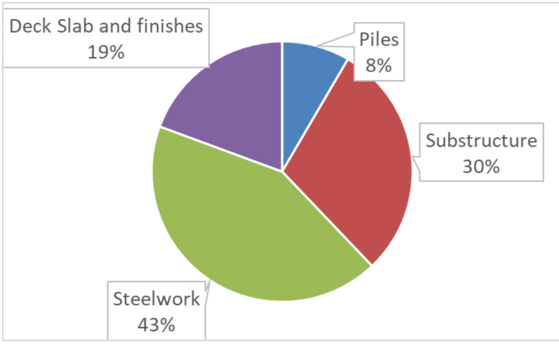
(a) Solutions 1 and 2 (S355 and S460)



(b) Solutions 3 and 4 (S355W and S460W



(c) Solution 5 (1.4162)



(d) Solution 6 (1.4462)

Figure 5.1 Breakdown of the total construction costs of the bridge solutions.

6 LIFE CYCLE COST ASSESSMENT

Life cycle cost (LCC) comparisons were conducted for the bridge solutions described in Section 3 in different locations. Comparisons were made following the recommendations given by Highways England in CD 355 Application of whole-life costs for design and maintenance of highway structures[21]. The comparisons were undertaken to assess the potential extent of the economic benefit of using stainless steel for the steelwork under the deck of the bridge.

The comparisons were only based on the construction costs and the direct maintenance costs (see Section 6.2).

In the LCC studies, either the solution involving the use of lean duplex 1.4162 (Solution 5) or standard duplex 1.4462 (Solution 6) for the steelwork supporting the bridge deck was compared with the solutions involving the use of carbon steel or weathering steel. As shown in Section 5.1, for the carbon steel and weathering steel solutions the construction costs were largely independent of the steel grades. Therefore, given that the maintenance costs can also be expected to be very similar for the different steel grades, for simplicity, it was decided to only present the results for the solutions involving S355 and S355W (Solutions 1 and 3) in the LCC studies. This decision was made because S355 and S355W steels are currently considered to be more commonly used in bridges.

Some of the locations included in the LCC study were based on those previously studied by Arup in 2012[22]. However, the service life of the bridge was extended to cover a period of up to 120 years, and some of the assumptions adopted were modified to reflect more up-to-date costs, deterioration profiles and common practice regarding the execution of the maintenance activities.

The study considered the following four locations. In all cases, the bridge carries a B road:

- Location 1 – Bridge over a main road (A road).
- Location 2 – Bridge over an electrified railway (Rail).
- Location 3 – Bridge over an electrified railway located near the coast (Rail coast)
- Location 4 – Bridge over an estuary (Estuary).

It should be noted that the “reference design” bridge may not necessarily be suitable for all the locations studied. For example, it is not common practice to design bridges over estuaries with a pier placed in the centre of the estuary. However, it was decided to use the same bridge for all locations in order to facilitate the comparison.

Compared to the 2012 Arup study, the case of a bridge spanning over a secondary road was not included in this study because for this location the use of duplex stainless steel for the main girders was considered to be less beneficial. Instead, the case of a bridge spanning over a railway located near the coast was added in this study, as in this case both the cost of maintenance and the corrosive environment can potentially require the use of duplex stainless steel for the main girders.

Locations 1 (A road) and 2 (Rail) were used to assess the benefit of the lean duplex solution (Solution 5) as this stainless steel grade has sufficient corrosion resistance to successfully withstand the level of corrosion associated with these two locations[17]. In Location 1 (A road) the bridge was assumed to be located far away from the coast. Therefore, in this case the corrosive environment the bridge was assumed to be exposed to was only due to the de-icing salts that are applied onto the secondary road (over the bridge) and the main road (under the bridge) during the winter periods. In Location 2 (Rail), the bridge is also assumed to be located far away from the coast, and therefore, the main source of corrosion was assumed to result from the de-icing salts that are applied onto the secondary road (over the bridge). Since de-icing salts are not applied under the bridge, the main girders are not subject to a very aggressive environment. However, they would still need to be regularly re-painted during the 120 year period if they were to be made of carbon steel. In order to minimize the disruption of the rail network, any type of intervention that needs to be carried out under the bridge (such as re-painting of the main girders) will be associated with significant maintenance costs. For Locations 1 and 2, the lean duplex (Solution 5) and weathering steel (Solutions 3 and 4) solutions avoid the need of having to re-paint the steelwork. Solution 6 was not considered in these comparisons because its material cost is larger than that of lean duplex 1.4162, and therefore, it would not be normally specified for these locations.

Locations 3 (Rail coast) and 4 (Estuary) were used to assess the benefit of the standard duplex solution (Solution 6). In Location 3 (Rail coast), the bridge was assumed to be located less than 2 km from the coast, and therefore, the corrosive environment the bridge is exposed to is due to high deposition rates of airborne chlorides from the sea. Since the use of weathering steel is not recommended in structures that are in coastal environments[23], for Location 3, only Solutions 1, and 6 were investigated. Even though, according to the Eurocode[17], lean duplex stainless steel 1.4162 has sufficient corrosion resistance for bridges that are located at more than 250 meters from the coast, the standard duplex alloy 1.4462 (Solution 6) was conservatively used for the comparison. In Location 4 (Estuary), the seawater runs directly under the bridge, constituting the most corrosive environment studied. This location was therefore used to compare the solution in which the main girders are made of standard duplex stainless steel 1.4462 (Solution 6) against the carbon steel solutions (Solution 1). The solution involving the use of lean duplex stainless steel 1.4162 is not suitable for this location.

6.1 Costs of maintenance activities

6.1.1 Modelling toolkit

The LCC was carried out using a modified version of the LoBEG (London Bridge Engineering Group) Lifecycle Planner for Structures toolkit, which was originally developed by the LoBEG Asset Management Working Group and Atkins in 2011[24] for bridges and other types of highway structures.

The original toolkit consists of an MS Excel spreadsheet that models the deterioration of the different components of a structure and the maintenance works carried out on them over a 60-year period. This maximum time period in the original toolkit was extended to 120 years, which corresponds to the service life of the bridges considered in this LCC study.

The lifecycle planning methodology embedded within the original LoBEG toolkit follows the guidance provided in BSI PAS 55: Asset Management[25,26], CSS Framework for

Highway Asset Management[27] and Management of Highway Structures: A Code of Practice[28].

The default data on deterioration rates/service lives, uplift factors, unit rates, etc. included in the original LoBEG toolkit can be found in the LoBEG Good Practice Guide[24]. The deterioration rates for the components and materials covered in the LoBEG toolkit were developed based on data, judgement, and experience gathered at the time, as well as the assumption that a routine maintenance regime is in place. These deterioration rates were changed in the modified LoBEG toolkit to reflect more up-to-date data, and they are aligned with those used in the Structures Asset Valuation and Investment Tool (SAVI)[29].

In the LoBEG toolkit the total cost of the maintenance activities is obtained by considering the following components:

- **Base Cost:** unit rate × quantity for each maintenance activity.
- **Engineering Difficulty (Eng Diff):** this is the additional cost associated with difficulty in carrying out the associated work e.g. working at height, working over water, etc.
- **Work Pattern and Traffic Management (wpat/T.M):** this is the cost of carrying out the work which is built up as follows:
    - Work Pattern: cost for carrying out work in restricted hours, e.g. normal working hours, night working, etc.
    - Traffic Management: cost for traffic management, e.g. installing contraflows.
    - Engineering difficulties for the scheme: cost due to the bridge being located in a remote site or lack of security, etc.
    - Preliminaries: cost for setting up site, welfare facilities, temporary works, landfill costs, etc.
    - Design Costs: general design costs including site investigations, testing, contract documents, etc.

The default unit rates included in the original LoBEG toolkit (which were derived more than 10 years ago) were updated to those used in SAVI[29] to reflect current costs.

6.1.2 Inspected elements

From all the bridge elements included in the LoBEG toolkit, those that are relevant for the type of bridge considered in this LCC study are listed in Table 6.1 and Table 6.2. While the elements in Table 6.1 are relevant for all the locations studied, those listed in Table 6.2 are only relevant for the bridge spanning over an estuary.

For each location, the only difference between the carbon steel solution, the weathering steel solution and the stainless steel solution is that while the former requires painting of the main steel girders, bracings and stiffeners (i.e. Finishes: deck elements) for the other solutions this element is not required.

Table 6.1 Elements inspected common for all case locations

Inspected element	Material/Component Type	Quantity
Primary deck element	Insitu Reinforced Concrete	0.3 x 688.8 m^2
Secondary deck element/s – beams	Fabricated Steel, Rolled Steel, Steel, or Steel Plate	-
Parapet beam or cantilever	Insitu Reinforced Concrete	0.3 x 74.4 m^2
Foundations	Deep Foundation: Piles	
Abutments (incl. arch springing)	Insitu Reinforced Concrete	0.3 x 72.5 m^2
Pier/column	Insitu Reinforced Concrete	0.3 x 168 m^2
Cross-head/capping beam	Insitu Reinforced Concrete	0.3 x 11.4 m^2
Bearings	Pot	12
Bearing plinth/shelf	Insitu Reinforced Concrete	0.3 x 11.4 m^2
Substructure drainage	Internal Drainage System	62 m
Waterproofing	Mastic Asphalt	825 m^2
Movement/expansion joints	Asphaltic Plug Joint	28 m
Finishes: deck elements	High Build Epoxy Hydrocarbon Resin Modified Finish	813 m^2
Finishes: substructure elements	Anti-Graffiti Paint	186 m^2
Finishes: parapets/safety fences	Other/Unknown Pain System	360 m^2
Handrail/parapets/safety fences	Steel	360 m^2
Carriageway surfacing	Asphalt	0.3 x 577 m^2 / 577 m^2
Footway/verge/footbridge surfacing	Asphalt	0.3 x 248 m^2 / 248 m^2
Revetment/batter paving	Precast Concrete Blocks – Open Jointed or Interlocking	318 m^2
Wing walls	Insitu Reinforced Concrete	0.3 x 14 m^2
Approach rails/barriers/walls	Fabricated Steel, Rolled Steel, Steel, or Steel Plate	24 m^2

Table 6.2 Additional elements inspected specific for the bridge spanning over an estuary

Inspected element	Material/Component Type	Quantity
Invert/river bed	Insitu Reinforced Concrete	1
Fenders/Cutwaters/collision protection	Gabion Mesh Mattresses	1
Revetment/batter paving	Precast Concrete Blocks – Open Jointed or Interlocking	1

6.1.3 Modelling assumptions

6.1.3.1 General assumptions

The assumptions made for the LCC study are similar to those adopted in the 2012 Arup study, and are as follows:

- The service life of the bridge was considered to be 120 years.

- For all locations, the bridge is assumed to carry a local road with low annual average daily traffic (i.e. <10,000 per lane).
- The height of the bridge is assumed to be no greater than 8m.
- The deterioration rates and unit rates are taken from SAVI except where noted in the summary tables for each location given in Appendix B to Appendix E.
- A nominal value of maintenance is included every 10 years to allow for principal inspection and miscellaneous repairs.
- The stainless steel girders and the weathering steel girders are assumed to be able to withstand the 120 years period without requiring any maintenance based on durability studies.
- For each location, the only difference between the carbon steel and the weathering steel or duplex steel bridges is that the weathering steel and the duplex steel solutions do not require painting of the steelwork under the deck.
- For the carbon steel solution, the paint system for the steelwork under the deck is assumed to be high build epoxy hydrocarbon resin modified finish for all locations (see Section 2.2).
- Although the different environment exposure/traffic conditions the bridge is subjected to in the different locations have a direct effect on the timing of the maintenance activities, the type of maintenance applied to the elements (i.e. concrete repair, painting, etc.) is assumed to be the same for all cases.
- The model only includes planned maintenance and does not consider unplanned interventions such as emergencies, accidental damage, unexpected repairs.
- Only key elements of the bridge have been selected when determining maintenance costs e.g. maintenance of services has not been included. Secondary costs such as costs associated with traffic delays are also not considered in this study.

6.1.3.2 General maintenance assumptions

It was assumed that maintenance of the inspected elements of the bridge was carried out based on the damage severity and extent, as given by Table 6.3 and Table 6.4, respectively.

In all cases, the initial condition of the bridge was considered to be as new (condition 1A). Maintenance of the components or materials is carried out once the condition of the inspected element reaches condition 3D. If the type of maintenance consists of “repairing” the inspected element, the condition of the element is assumed to return to condition 2B, while if it consists of “replacing”, “cleaning” or “complete repainting, including surface treatment” the element, the condition is considered to return to condition 1A.

Table 6.3 Description of damage extent[30]

Extent	Description
A	No Significant defect.
B	Slight (no more than 5 percent of surface area or length)
C	Moderate (5 to 20 percent of surface area or length)
D	Wide (20 to 50 percent of surface area or length)
E	Extensive (more than 50 percent of surface area or length)

Table 6.4 Description of damage severity[30]

Severity	Description
1	As-new condition or defect has no significant effect on the element (visually or functionally).
2	Early signs of deterioration; minor defect; no reduction in functionality of element.
3	Moderate defect/damage; some loss of functionality could be expected.
4	Severe defect/damage; significant loss of functionality and/or element is close to failure.
5	The element is non-functional/failed.

For most inspected elements, all the maintenance interventions were modelled as “repair”. Inspected elements for which this was not the case are listed below:

- Bearing (replacement)
- Substructure drainage (clean)
- Waterproofing (replacement)
- Movement/expansion joints (replacement)
- Finishes: deck elements (re-paint/re-paint with surface treatment)
- Finishes: substructure elements (re-paint)
- Finishes: parapets/safety fences (re-paint)
- Carriageway surfacing (repair/replacement)
- Footway/verge/footbridge surfacing (repair/replacement)
- Revetment/batter paving (replacement)
- Approach rails/barriers/walls (replacement)

For “Bearing”, “Waterproofing”, “Movement/expansion joints”, Revetment/batter paving” and “Approach rails/barriers/walls”, the type of maintenance adopted was “replacement” for all interventions, while for “Substructure drainage” the maintenance consists of “cleaning” the elements.

For “Finishes: deck elements”, the maintenance strategy consisted of re-applying paint on top of the existing paint system (repair type of maintenance) for two consecutive interventions, and then for the next intervention, the maintenance activity involved in a wet/dry surface preparation and re-application of the paint.

For “Carriageway surfacing” and “Footway/verge/footbridge surfacing”, given that the bridge is assumed to carry a local road (B road), and therefore disruption of the traffic has less significant impact than if the bridge was carrying a primary road (A road), the maintenance strategy consisted of defining a “replacing” type of maintenance at around 60 years period, and “repair” type of maintenances for the other required interventions.

For the “repair” type of maintenance, given that the intervention is applied when the element reaches condition 3D, the area over which the maintenance was applied was assumed to be 30% of the total area of the element (i.e. somewhere between 20 to 50% of surface area, see Table 6.3). However, when a “replacement”, “cleaning”, or “complete repainting, including surface treatment” was chosen, this was applied over the entire area or length of the element.

The duration of each maintenance intervention was derived using the estimations given in SAVI. In those cases where this information was not available in SAVI, the duration was taken from the 2012 Arup study. The engineering difficulty and traffic management schemes were discussed with an expert, and it was concluded that the assumptions made in the 2012 Arup study are generally applicable to this study. The unit rate for each maintenance activity were generally taken from SAVI. However, in those cases where the SAVI unit rates were not available, the unit rates were derived from those used in the 2012 Arup study by multiplying them by a factor of 1.468 to reflect inflation. It should be noted that this factor does not reflect the higher rates experienced in the UK in the very recent past.

6.1.3.3 Assumptions specific to each location

An overview of the assumptions specific to each design location, highlighting the major differences between them, is given below. For each location, the overview is focused on the carbon steel solution. However, the discussion is also applicable to the weathering steel and duplex stainless steel solutions by considering that the only difference is that the latter do not require painting of the steelwork under the deck.

In addition, summary tables are included in Appendix B to Appendix E indicating for each location:

- the inspected elements,
- the elements’ exposure,
- maintenance action and costs,
- engineering difficulty to carry out maintenance,
- work patterns,
- traffic management, and
- any further model specific assumptions.

Table 6.5 to Table 6.8 list the exposure class and the type of maintenance for the elements of a bridge spanning over an A road (Location 1), an electrified railway (Location 2), an electrified railway located near the coast (Location 3) and an estuary (Location 4), respectively. In those cases where no type of maintenance is specified, the element does not require maintenance over the studied period.

The exposure classes assumed in this study are almost identical to those assumed in the 2012 Arup study, with the only exception being the exposure class for the “Parapet beam or cantilever” element for the cases where the bridge spans over an A road and over a railway, which in the 2012 Arup Study were assumed to be “severe”. This modification was made after consultation with an expert who considered that for these cases a “mild” exposure class is more suitable.

For all four cases, any maintenance required that affects the highway carried by the bridge is anticipated to be straightforward as it is not a “major” highway, and therefore work can be carried out during “normal” daytime hours with minimal traffic management.

In addition to that, the following maintenance activities have an additional cost due to the engineering difficulty associated with having to carry out the work at height:

- Primary deck elements
- Pier/column
- Cross-head/capping beam
- Bearings
- Bearing plinth/shelf
- Finishes: deck elements
- Finishes: substructure elements
- Finishes: parapets/safety fences
- Revetment/batter paving

Table 6.5 Element exposure class and maintenance action for bridge over an A road (Location 1)

Element	Exposure to Environment/Traffic	Maintenance
Primary deck element	moderate	Moderate concrete repair
Secondary deck element/s - beams	mild	
Parapet beam or cantilever	mild	
Foundations	mild	
Abutments (incl. arch springing)	moderate	Minor concrete repair
Pier/column	severe	Moderate concrete repair
Cross-head/capping beam	moderate	Minor concrete repair
Bearings	moderate	Replace
Bearing plinth/shelf	moderate	Minor concrete repair
Substructure drainage	mild	Cleaning
Waterproofing	n/a	Replace
Movement/expansion joints	low	Replace
Finishes: deck elements	moderate	Paint/Surf. Prep. and Paint
Finishes: substructure elements	moderate	Paint
Finishes: parapets/safety fences	severe	Paint
Handrail/parapets/safety fences	mild	
Carriageway surfacing	low	Surf. Repair/Surf. Replace
Footway/verge/footbridge surfacing	mild	Surf. Repair/Surf. Replace
Revetment/batter paving	moderate	Minor concrete repair
Wing walls	moderate	Minor concrete repair
Approach rails/barriers/walls	severe	Replace

Location 1 – Bridge over an A road: In this case, due to the presence of the “major” highway road that passes under the bridge, maintenance activities that need to be carried out under the bridge are associated with additional costs due to having to carry out the work during restricted daytime hours and the need for traffic management.

Table 6.6 Element exposure class and maintenance action for bridge over a Railway (Location 2)

Element	Exposure to Environment/Traffic	Maintenance
Primary deck element	mild	
Secondary deck element/s - beams	mild	
Parapet beam or cantilever	mild	
Foundations	mild	
Abutments (incl. arch springing)	mild	
Pier/column	mild	
Cross-head/capping beam	mild	
Bearings	mild	Replace
Bearing plinth/shelf	mild	
Substructure drainage	mild	Cleaning
Waterproofing	n/a	Replace
Movement/expansion joints	low	Replace
Finishes: deck elements	mild	Paint/Surf. Prep. and Paint
Finishes: substructure elements	mild	Paint
Finishes: parapets/safety fences	severe	Paint
Handrail/parapets/safety fences	mild	
Carriageway surfacing	low	Surf. Repair/Surf. Replace
Footway/verge/footbridge surfacing	mild	Surf. Repair/Surf. Replace
Revetment/batter paving	mild	Minor concrete repair
Wing walls	mild	
Approach rails/barriers/walls	severe	Replace

Location 2 – Bridge over an electrified Railway: In this case, the necessity for maintenance has a significant weighting on the cost. Any work that has an impact on the running of the rail network incurs a large penalty as possessions and restricted night or public holiday working are required.

The assumptions adopted in this study regarding the “work pattern” chosen for carrying out the maintenance activity that requires access to “railway land” differ from the assumption adopted in the 2012 Arup study. While in the 2012 Arup study it was assumed that these activities are carried out during 24 hours of consecutive 8 hours shifts over a public holiday or weekend possession, in this study it was assumed that these activities are carried out during weekends or public holiday possessions lasting 8 hours each day. This has been acknowledged to be a more realistic “work pattern” for these type of maintenance activities, as rail networks generally do not “shut down” for lengthy block periods[22].

Table 6.7 Element exposure class and maintenance action for bridge over a Railway less than 2km from the coast (Location 3)

Element	Exposure to Environment/Traffic	Maintenance
Primary deck element	moderate	Moderate concrete repair
Secondary deck element/s - beams	mild	
Parapet beam or cantilever	mild	
Foundations	mild	
Abutments (incl. arch springing)	moderate	Minor concrete repair
Pier/column	severe	Moderate concrete repair
Cross-head/capping beam	moderate	Minor concrete repair
Bearings	moderate	Replace
Bearing plinth/shelf	moderate	Minor concrete repair
Substructure drainage	mild	Cleaning
Waterproofing	n/a	Replace
Movement/expansion joints	low	Replace
Finishes: deck elements	moderate	Paint/Surf. Prep. and Paint
Finishes: substructure elements	moderate	Paint
Finishes: parapets/safety fences	severe	Paint
Handrail/parapets/safety fences	mild	
Carriageway surfacing	low	Surf. Repair/Surf. Replace
Footway/verge/footbridge surfacing	mild	Surf. Repair/Surf. Replace
Revetment/batter paving	moderate	Minor concrete repair
Wing walls	moderate	Minor concrete repair
Approach rails/barriers/walls	severe	Replace

Location 3 – Bridge over an electrified railway less than 2km from the coast: This case is similar to the previous one. However, the more corrosive environment resulting from the proximity of the bridge to the coast will result in more frequent maintenance.

Table 6.8 Element exposure class and maintenance action for bridge over an Estuary (Location 4)

Element	Exposure to Environment/Traffic	Maintenance
Primary deck element	moderate	Moderate concrete repair
Secondary deck element/s - beams	mild	
Parapet beam or cantilever	severe	Minor concrete repair
Foundations	moderate	
Abutments (incl. arch springing)	moderate	Minor concrete repair
Pier/column	severe	Moderate concrete repair
Cross-head/capping beam	moderate	Minor concrete repair
Bearings	moderate	Replace
Bearing plinth/shelf	moderate	Minor concrete repair
Substructure drainage	mild	Cleaning
Waterproofing	n/a	Replace
Movement/expansion joints	low	Replace
Finishes: deck elements	moderate	Paint/Surf. Prep. and Paint
Finishes: parapets/safety fences	severe	Paint
Handrail/parapets/safety fences	mild	Paint
Carriageway surfacing	low	Surf. Repair/Surf. Replace
Footway/verge/footbridge surfacing	mild	Surf. Repair/Surf. Replace
Invert/river bed	severe	scour protection
Fenders/cutwaters/collision protection	severe	Moderate concrete repair
Revetment/batter paving	severe	Minor concrete repair
Wing walls	moderate	Minor concrete repair
Approach rails/barriers/walls	severe	Replace

Location 4 – Bridge over an Estuary: The estuary is assumed navigable and tidal, and therefore, in this case the additional cost incurred due to maintenance activities that need to be carried out under the bridge is partly due to the associated engineering difficulty. Since the bridge is also assumed not to be a critical shipping route (which is the case for most bridges over estuaries), the work can be carried out within the estuary during "normal" daytime hours.

6.2 Indirect costs of bridge maintenance

Indirect costs (also known as user costs) are associated with users of the bridge. For example, the extra time for users of the bridge to take a longer route whilst the bridge is being maintained, or for the same journey taking longer due to delays caused by congestion.

Studies have shown that user costs can far exceed the direct cost of maintenance.

User costs can fall into the following categories:

- Traffic congestion delays
- Environmental damage (traffic congestion and diversions increase air-pollution emissions)
- Business effects (represents uncompensated costs imposed on road users and the public at large by disruptions to normal business activity. Enterprises whose customers, suppliers, or delivery vehicles encounter delays, diversions, or other disruptions of their normal activity patterns may suffer loss of business, increased production costs, or both)

They can be direct cash expenses (increased fuel use), in-kind losses (e.g. time spent in congestion caused by lane closure), and other losses (reduced sales for a business affected by the maintenance activities).

These costs are difficult to define with any certainty and depend on vehicle volumes, maintenance scheduling and work-zone controls (e.g. lane rental), mechanisms for reducing traffic disruption etc.

Indirect costs typically must be inferred and monetised, e.g., from observations of increased fuel consumption and time lost due to increased congestion.

Due to the difficulty in the estimation of the indirect costs, and their high dependency on the specific characteristics of individual projects (e.g. number of vehicles using the bridge, type of areas being connected, possibility of alternative road, etc.), it was decided not to include the indirect cost in the LCC analyses. However, this assumption clearly benefits the painted carbon steel solutions.

6.3 Real and present cost

An LCC analysis may be based on the real cost or the present cost. The real cost assumes that all the cost incurred during the life of the bridge is paid at once, at the start of the project. The present cost, on the other hand, accounts for when each expenditure is made, and therefore permits comparing costs that are incurred at different times throughout the life of the bridge.

Future expenditure, for example maintenance of a bridge, is discounted based on the social time preference rate (STPR). In this LCC study, the STPR values recommended in the Green Book issued by HM Treasury[31] were used. The STPR accounts for the value society attaches to present, as opposed to future, consumption, and is measured by the real interest rate on money lent or borrowed but does not account for inflation.

The STPR recommended by the Green book is set at 3.5% in real terms for the first 30 years. Between 31 and 75 years the STPR is reduced to 3.0%, and after that it is reduced to 2.5%. The reduction of the STPR over long periods of time is to account for uncertainties about future values of its components.

A number of bridge designers were consulted about whether material selection decisions were made on the basis of real or present costs. It appeared that for projects with maintenance programmes that last less than 5 years, the real cost is mainly considered. However, for longer programmes, the present value is more appropriate. In this LCC study, both the real and the present cost values are reported.

6.4 LCC comparison

6.4.1 LCC comparison considering only the steelwork

Figure 6.1 compares the cost of constructing and maintaining the steelwork of the bridge for the different options investigated.

By comparing the results in terms of the present cost, the cost of having to re-paint the steelwork over a service life of 120 years was found to be at least as significant as the construction cost the steelwork. For the two cases in which the bridge spans over a railway, the present cost of having to re-paint the steelwork is more than twice the cost of constructing the steelwork. This highlights the importance of considering the cost of having to re-paint the steelwork when choosing the most cost effective solution, and the need to find solutions in which this maintenance cost can be avoided.

For all the locations investigated, the painted carbon steel solution was found to be the most expensive when the comparison is based on the real cost. This is due to the significant cost of having to re-paint the steelwork, which significantly outweighs the higher cost of constructing the bridge using lean duplex stainless steel 1.4162 or standard duplex stainless steel 1.4462. When the comparison is based on the present cost, however, the difference between the painted carbon steel solution and the stainless steel solution is significantly less pronounced. For the case of the bridge spanning over an A road (i.e. Location 1) the stainless steel solution was found to be only slightly less expensive, while for the bride spanning over an estuary (i.e. Location 4) the painted carbon steel solution was found to be as expensive as the duplex stainless steel solution.

The reason for the different outcome when using the real and the present value for the comparison is that with the stainless steel solution, all the cost has to be covered upfront (real and present cost are the same), while with the carbon steel solution the cost due to having to re-paint the steelwork is spread over 120 years. While the real cost does not account for 'when' the cost in incurred, the present cost applies a significant reduction to expenditures that are made in the future.

For the cases in which the bridge is located over a railway (Locations 2 and 3), the economic benefit the lean duplex and standard duplex stainless steel solutions offer over the painted carbon steel solution is irrespective of whether the bridge is located in a corrosive environment. For this type of bridge, the justification for using lean duplex or standard duplex stainless steel, as opposed to painted carbon steel, was found to be mostly driven by the high cost of maintenance associated with the closure of the network. The economic benefit of using lean duplex or standard duplex stainless steel for these types of bridges becomes more compelling as the severity of the corrosive environment increases, as shown by the case in which the bridge is located near the coast. For this location, the adoption of the standard duplex stainless steel solution, as opposed to the painted carbon steel solution, results in a reduction of the present cost of 50%. If the lean duplex solution had been used for this location, an even higher reduction in cost of 60% would have been achieved. It should be noted, however, that in all the cases in which the use of weathering steel is also a viable option, this solution was found to be more cost effective than the lean duplex or standard duplex stainless steel solutions.

As mentioned previously, these LCC comparisons only included direct costs. The omission of the indirect cost associated with maintenance can be expected to underestimate the cost calculated for the painted carbon steel solution. The comparison between the lean duplex/standard duplex stainless steel solution and the weathering steel solution should not be affected by the omission of the indirect costs.

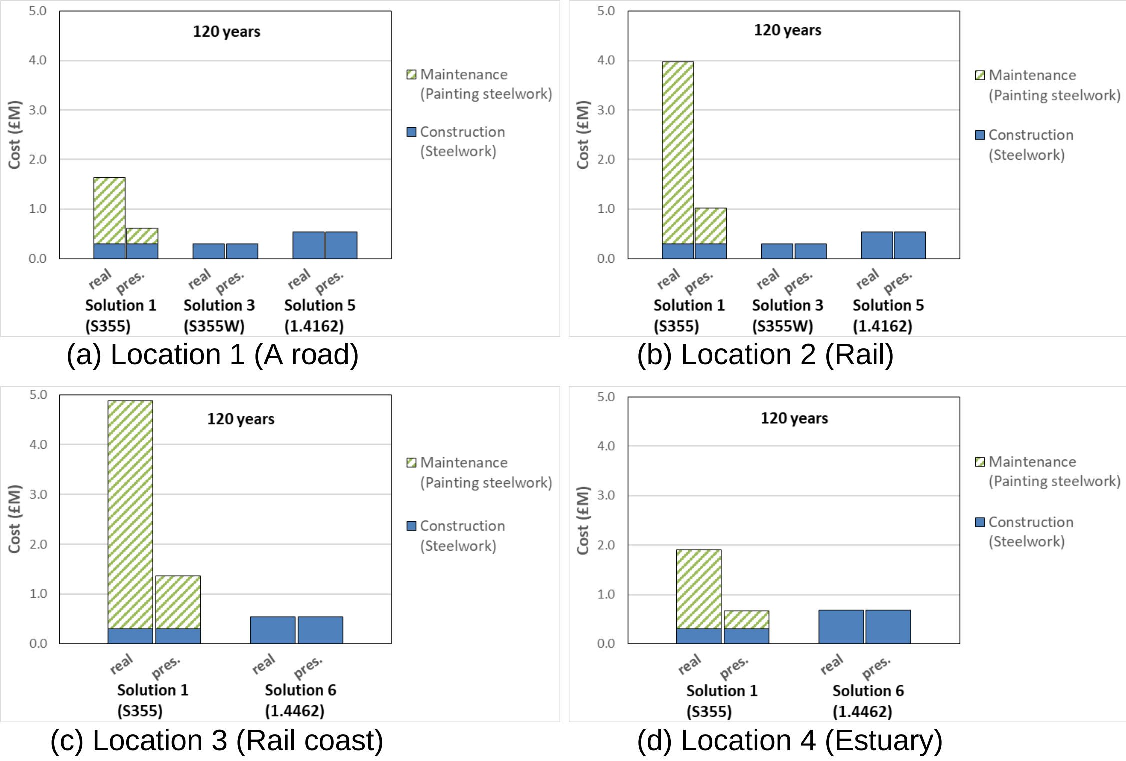


Figure 6.1 LCC comparison for steelwork only over a service life of 120 years.

6.4.2 LCC comparison considering the entire bridge structure

The cost of constructing and maintaining the bridge over the 120-year service life associated with each solution is compared in Table 6.9 to Table 6.12, and in Figure 6.2 for the different locations investigated.

With the exception of the bridge over a railway (Location 2), in all the other locations investigated, the present cost associated with the maintenance of the painted carbon steel solution was at least as high as the cost of constructing the carbon steel bridge, and in the case of the bridge over a railway near the coast (Location 3) the cost of maintenance was almost three times more expensive.

Table 6.9 Construction and maintenance cost over a service life of 120 years (Location 1 – A road)

	Construction Cost	Maintenance Cost			
		Painting		Other	
	real	real	present	real	present
Solution 1 (S355)	£1,213,000	£1,339,000	£306,000	£6,197,000	£988,000
Solution 3 (S355W)	£1,201,000	£0	£0	£6,197,000	£988,000
Solution 5 (1.4162)	£1,452,000	£0	£0	£6,197,000	£988,000

Table 6.10 Construction and maintenance cost over a service life of 120 years (Location 2 – Rail)

	Construction Cost	Maintenance Cost			
		Painting		Other	
	real	real	present	real	present
Solution 1 (S355)	£1,213,000	£3,672,000	£713,000	£2,322,000	£397,000
Solution 3 (S355W)	£1,201,000	£0	£0	£2,322,000	£397,000
Solution 5 (1.4162)	£1,452,000	£0	£0	£2,322,000	£397,000

Table 6.11 Construction and maintenance cost over a service life of 120 years (Location 3 – Rail coast)

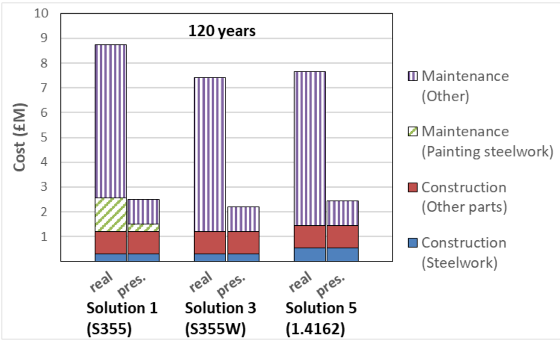
	Construction Cost	Maintenance Cost			
		Painting		Other	
	real	real	present	real	present
Solution 1 (S355)	£1,213,000	£4,573,000	£1,053,000	£15,931,000	£2,447,000
Solution 6 (1.4462)	£1,591,000	£0	£0	£15,931,000	£2,447,000

Table 6.12 Construction and maintenance cost over a service life of 120 years (Location 4 – Estuary)

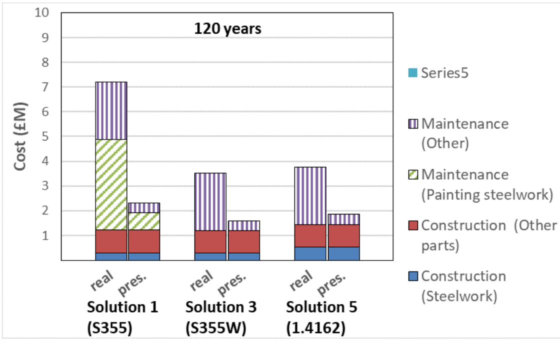
	Construction Cost	Maintenance Cost			
		Painting		Other	
	real	real	present	real	present
Solution 1 (S355)	£1,213,000	£1,601,000	£369,000	£8,517,000	£1,432,000
Solution 6 (1.4462)	£1,591,000	£0	£0	£8,517,000	£1,432,000

For the weathering and duplex stainless steel solutions, the present cost of maintenance constitutes a smaller proportion of the total cost (i.e. construction plus maintenance). However, its proportion is still significant, particularly in the locations where the bridge is exposed to a more corrosive environment. For example, for the duplex stainless steel solution in Locations 1 (A road), 3 (Rail coast) and 4 (Estuary), in which the bridge is subject to a corrosive environment, the present cost associated with the maintenance was around 70%, 155% and 90% of the cost of constructing the bridge, respectively. For Location 2 (Rail), on the other hand, where the bridge is located in a less aggressive environment, the present cost associated with the maintenance was only around 25% of the cost of constructing the bridge. This shows that the maintenance cost can dominate the total cost of the bridge even when the need for re-painting the main girders is eliminated. Therefore, in order to maximize the benefits of using stainless steel for the main girders of the bridge, the maintenance of the other elements of the bridge should also be considered. For example, for the type of bridge studied, the need to repair the concrete slab or the concrete piers constituted a large proportion of the total maintenance cost, particularly for the most corrosive environment. The cost of maintaining these elements could be reduced by using more durable concrete.

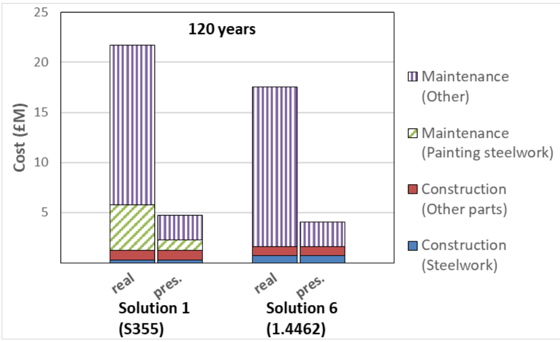
For the painted carbon steel solution, even though the cost associated with painting the steelwork increases as the severity of the corrosive environment increases, its proportion with respect to the total maintenance cost reduces. This is because as the severity of the corrosive environment increases, there are other elements of the bridge, such as the primary deck element or the concrete pier, that may require more frequent interventions. The intervention of these elements is required for all the solutions studied, irrespective of the type of steel used for the steelwork part of the bridge.



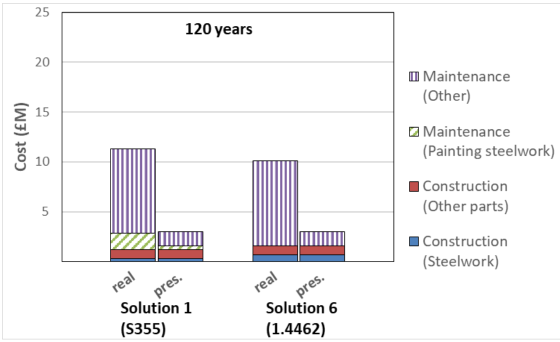
(a) Location 1 (A road)



(b) Location 2 (Rail)



(c) Location 3 (Rail coast)



(d) Location 4 (Estuary)

Figure 6.2 LCC comparison for the entire bridge over a service life of 120 years.

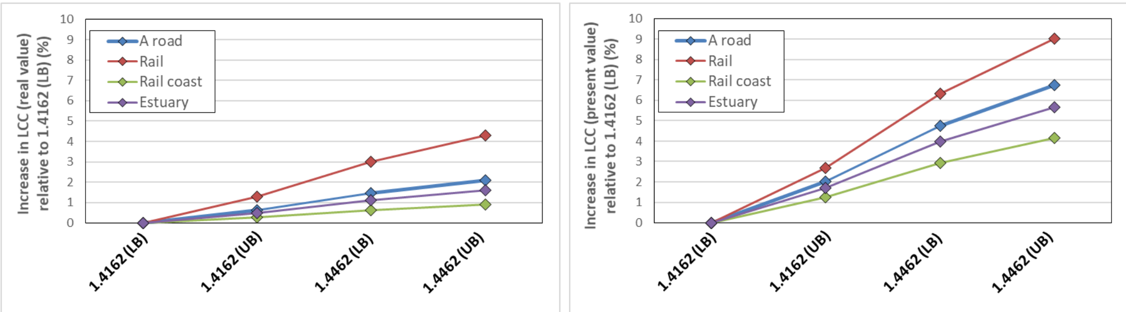
6.4.3 Effect of construction cost and service life on LCC comparison

This section investigates the effect that the uncertainty in the fabrication cost estimated for the stainless steel solutions (Section 5), the difference in cost of lean duplex and standard duplex stainless steel, and the service life selected for the bridge has on the LCC cost for each location investigated.

6.4.3.1 Effect of construction cost

To determine the effect of the uncertainty in the fabrication cost estimated for the stainless steel solutions, the LCC of these solutions was calculated considering the lower bound (LB) and upper bound (UB) estimate for the fabrication cost (i.e. 1.30 and 1.70 times the fabrication cost of the S355 carbon steel solution). For both stainless steel solutions, considering the UB of the fabrication cost resulted in an increase in the steelwork construction cost of around 8% compared to that obtained considering the LB of the fabrication cost. The increase in the LCC of the stainless steel solutions, relative to the cost of the lean duplex stainless solution considering the LB for the fabrication cost, is shown in Figure 6.3 for each location investigated.

The figure shows that the uncertainty in the estimation of the fabrication cost for the stainless steel solutions has only a small impact on the LCC, with a maximum difference of less than 3% of the present value. When comparing the standard duplex and the lean duplex solutions, despite the cost of the steelwork of the former being 26% more expensive than the latter, this only translates to an increase in the LCC of less than 6% of the present value. As could be expected, the impact the construction cost has on the LCC reduces as the cost of maintenance increases.

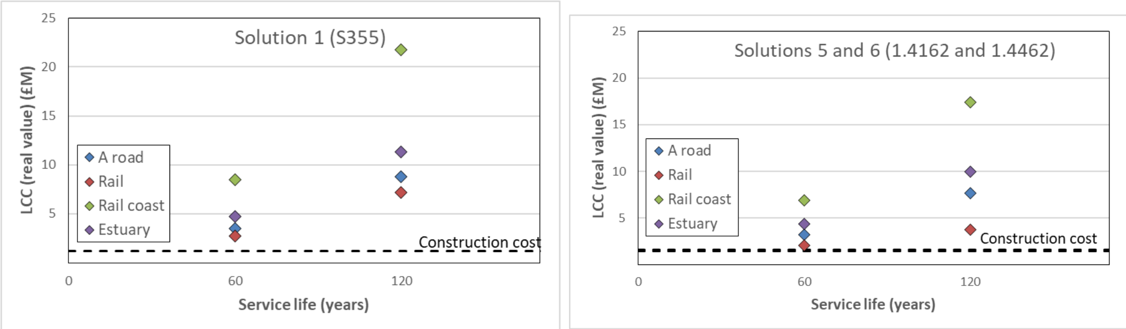


(a) Real cost (b) Present cost

Figure 6.3 Increase in LCC for the stainless steel solutions relative to the lean duplex solution (LB) fabrication cost.

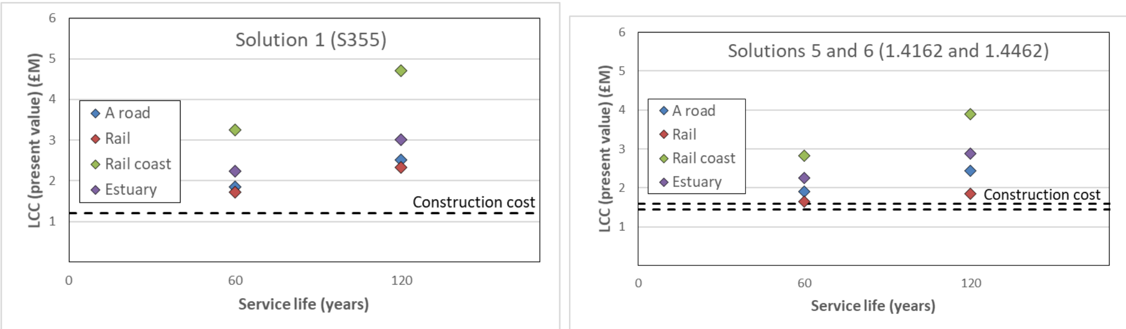
6.4.3.2 Effect of service life

To investigate the effect the service life has on the LCC of the bridge, Figure 6.4 and Figure 6.5 compare the LCC for a service life of 60 and 120 years. The comparison is made for the painted carbon steel solution with steel grade S355 (Solution 1) and the stainless steel solutions (Solutions 5 and 6). The results shown in Figure 6.4 are presented in terms of the real cost, while those shown in Figure 6.5 are presented in terms of the present cost. For reference, each figure also shows the cost of constructing the bridge. It is evident that the impact the maintenance cost has on the LCC for a 60 year period is significantly smaller than when the bridge is designed with a service life of 120 years. However, this is still significant, especially for the painted carbon steel solution, and for the cases in which the bridge is located near the coast. For example, for Location 3 (Rail coast), the maintenance cost over a 60 year period for the painted carbon steel solution (Solution 1) is 68% more expensive than constructing the bridge itself, when the present value is considered, while for the standard duplex stainless steel solution (Solution 6) the maintenance cost falls slightly below the cost of constructing the bridge due to the avoidance of having to repaint the main girders.



(a) (b)

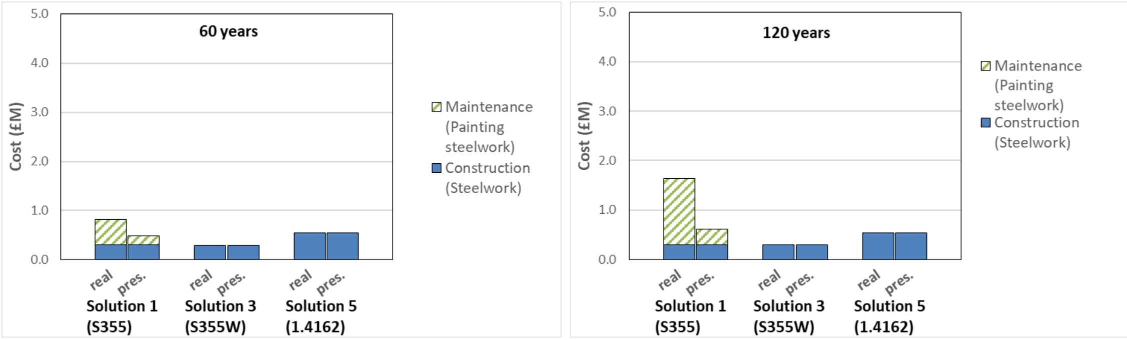
Figure 6.4 **Real cost comparison of constructing and maintaining the bridge for 60 years and 120 years periods.**



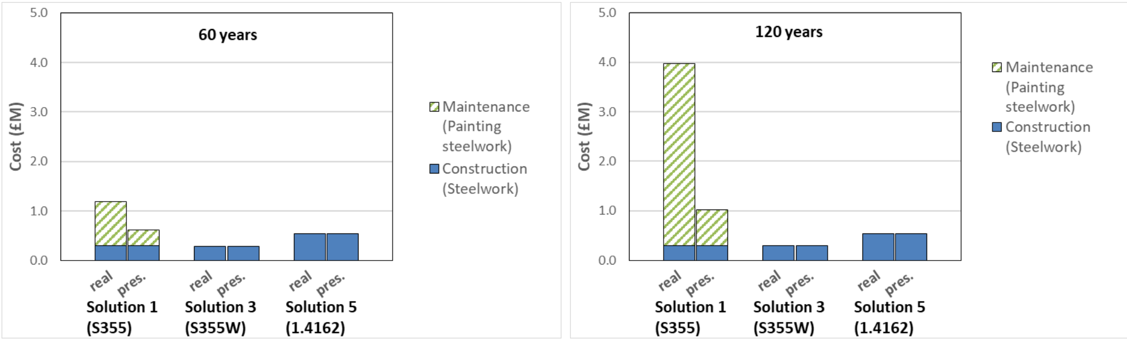
(a) (b)

Figure 6.5 **Present cost comparison of constructing and maintaining the bridge for 60 years and 120 years periods.**

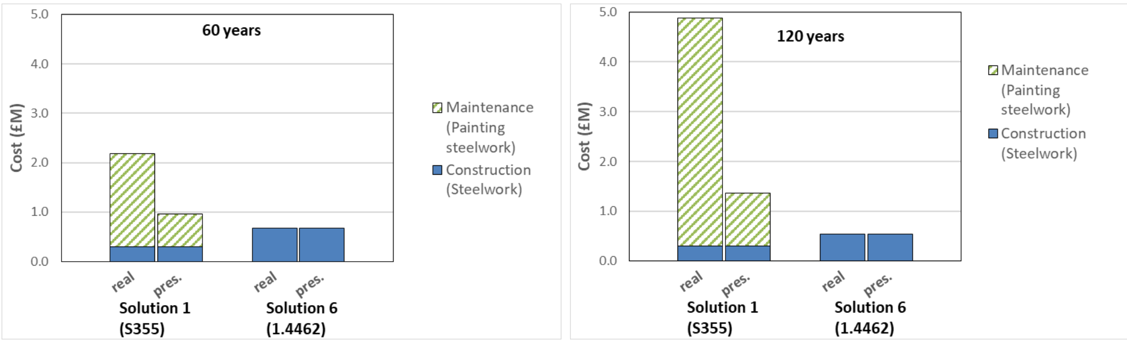
A comparison of the cost of constructing and maintaining the steelwork over 60 and a 120 year periods is illustrated in Figure 6.6 for the painted carbon steel solution (Solution 1), the weathering steel solution (Solution 3) and the stainless steel solutions (Solutions 5 or 6). For all locations, when considering the real costs, the stainless steel solutions are still demonstrated to be more economical than the painted carbon steel solution over a 60 year period. The benefit is most noticeable for the cases in which the bridge spans over a railway (i.e. Locations 2 and 3), with a reduction in the real cost of around 64% for Location 2 and around 69% for Location 3. If the comparison is based on the present cost, the difference in the cost of constructing and maintaining the steelwork of the painted carbon steel solution and the stainless steel solutions reduces, and the use of stainless steel only becomes justified for the cases in which the bridge spans over a railway (i.e. Locations 2 and 3). The largest reduction in the present cost is 29% and occurs for the case in which the bridge spans over a railway that is near the coast (Location 3). As for the bridges with a service life of 120 years, in all the case in which the use of weathering steel is a viable option (i.e. Locations 1 and 2), this was found to be the most cost effective solution.



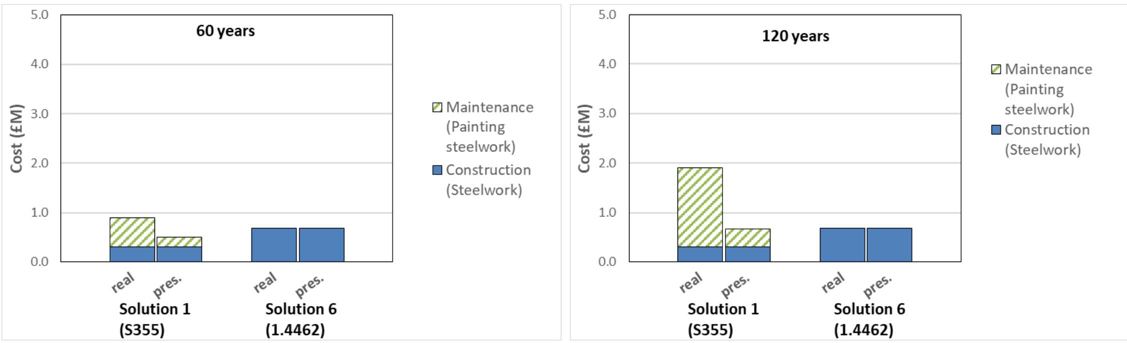
(a) Location 1 (A road)



(b) Location 2 (Rail)



(c) Location 3 (Rail coast)



(d) Location 4 (Estuary)

Figure 6.6 LCC comparison for the bridge steelwork only over a service life of 60 and 120 years.

7 CONCLUSIONS

This report describes detailed life cycle cost (LCC) comparisons for a typical highway bridge in which the main girders are made of painted carbon steel, weathering steel or duplex stainless steel. The duplex stainless steel grades investigated included lean duplex 1.4162 and standard duplex 1.4462. The LCC comparisons included the cost of constructing the bridge as well as the cost of maintaining it over a service life of 120 years, as well as over a 60 year period. Both real and present (i.e. discounted) costs were determined. The bridge was assumed to be situated in four different locations, each with a different level of corrosivity and/or maintenance accessibility. The locations were a bridge over an A road, over a railway near or far from the coast, and over an estuary. The study aims to address the prejudice that stainless steel bridge girders are always "too expensive" and hence rarely even considered.

The study showed that the cost of lean duplex and standard duplex stainless steel plate is around 3.8 and 4.8 times more expensive than the cost of S355 carbon steel plate, and that the cost of constructing the steelwork part of the bridge using lean duplex or standard duplex stainless steel is around 80% and 125% more expensive than constructing it out of S355 painted carbon steel. However, when the cost of constructing the entire bridge is considered, the lean duplex and standard duplex stainless steel solutions were found to be only 20% and 31% more expensive than the S355 painted carbon steel solution.

Importantly, when the maintenance cost over a 120 year period is taken into consideration, the stainless steel solutions were more economical than the painted carbon steel solution for both rail locations investigated. In fact, the present cost of having to re-paint the main girders for these cases can be up to 3.5 times more expensive than constructing the steelwork, depending on the corrosiveness of the environment.

If only the cost of constructing the steelwork and re-painting the main girders are considered for the bridges spanning over the railways, the present cost of the stainless steel solutions was found to be around half of the painted carbon steel solution. If the present cost of constructing and maintaining the entire bridge was considered, the stainless steel solutions were found to be 20% and 14% cheaper than the painted carbon steel solution for the case in which the bridge is located far away from the coast and near the coast, respectively. It is worth noting that for these cases, the economic benefit of using lean duplex or standard duplex stainless steel for the main girders of the bridge, as opposed to painted carbon steel, was found to be mostly driven by the high cost of maintenance associated with the closure of the network, suggesting that for this type of bridge, the use of duplex stainless steel should be considered irrespective of the level of corrosiveness of the environment.

For the case in which the bridge is located over a main road, the economic benefit of using duplex stainless steel was less pronounced than for the cases in which the bridge spans over a railway due the lower cost associated with re-painting the main girders. In this case, the stainless steel solution was around 11% cheaper when compared to the present cost of constructing the steelwork and re-painting the main girders of the carbon steel solution. For the bridge located over an estuary, the stainless steel solution and the painted carbon steel solution costs were very similar.

Although the cost of maintenance over a 60 years period was found to be noticeably lower than over a 120 years period, it still constituted a large portion of the total LCC.

The economic benefit of using duplex stainless steel for the main girders of the bridge was still clear over a 60 year period for the cases in which the bridge spans over a railway. However, for the cases in which the bridge spans over a main road or over an estuary, the painted carbon steel solution was found to be slightly more cost effective when considering the present cost. When the real cost is considered, the stainless steel solutions were found to be more cost effective than the painted carbon steel solution for all the locations investigated.

An important consideration is that in all cases in which weathering steel was a viable option, this solution was found to be the most cost effective. This suggests that stainless steel can only be the most cost effective solution for bridges in locations where weathering steel is not a viable option (e.g. bridges that are located in coastal environments, bridges in which the main girders are exposed to de-icing salts, or bridges with certain aesthetic requirements).

It should be emphasised that the results from the LCC comparisons did not consider the indirect costs associated with the maintenance activities, which can exceed the direct costs by a significant amount. This omission is clearly beneficial for the painted carbon steel solution, and therefore, it can be expected that if indirect cost were to be considered, the economic benefit of using duplex stainless steel for the main girders of the bridge, as opposed to painted carbon steel, would be more significant. The inclusion of indirect maintenance costs should not affect the comparisons between weathering steel and duplex stainless steel.

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Appendix A APPENDIX 18/1 FOR STAINLESS STEEL BRIDGE SOLUTIONS

Contract Title: Stainless Steel Bridge LCC Study

Structure Reference: OSM 692

Series 1800 Clause Reference:	**Additional Information Required**	**Not Applicable** *[Ticked if not applicable]*	**Drawings and Documents that give related structural steelwork requirements**	
			See Drawings Listed in …	**Additional requirement(s)** Blue text: specific stainless steel requirements Black text: Recommendations from UK Steel Bridge Group for all highway bridges
1805	**Constituent Products**			
1805.3.1	**Structural Steel Products, General** - grades, qualities and, if appropriate, coating weights, finishes and any required options permitted by product standards for steel products.			Duplex stainless steel – Solution 5: 1.4162 and Solution 6: 1.4462 in accordance with EN 10088-4. The tolerances are to EN ISO 18286.
1805.3.3	**Surface conditions** - additional requirements related to special restrictions on either surface imperfections or repair of surface defects by grinding in accordance with BS EN 10163, or with BS EN 10088 for stainless steel.			The surface finish should be 1D in accordance with Table 6 of EN 10088-4 (hot rolled, heat treated, pickled and free of scale).
1805.6.11	**Special fasteners** - special fastener not standardised in CEN or ISO standards, as well as any tests necessary - stainless steel preloaded bolts			Stainless steel preloaded bolts to be used for all the splices. All bolts and nuts to be A4-80 (for Solution 5: 1.4162 plate) or D6-80 (for Solution 6: 1.4462 plate) in accordance with EN ISO 3506. (Grade of washer to match grade of bolt and nut.) Assembly: one bolt, one nut and two washers. Bolt: EN ISO 4014 or EN ISO 4017 Nut: EN ISO 4032 Washer: EN ISO 7089, Minimum hardness: 200 HV.
1807	**Welding**			
1807.5.17	**Execution of welding** - requirements for grinding and dressing of the surface of completed welds.			See 1810.10.2
1807.7.2	**Amendments to EN 1011-3 requirements** - the surface finish of the weld zones on stainless steels.			See 1810.10.2
1808	**Mechanical Fastening**			
1808.4	**Preparation of contact surfaces in slip resistant connections** - requirements related to contact surfaces in slip resistant connections for stainless steels.			Surfaces blasted with clean stainless steel or non ferrous grit media with Rz ≥ 55 μm (permitting the use of a slip factor μ = 0.5)

Series 1800 Clause Reference:	**Additional Information Required**	**Not Applicable** *[Ticked if not applicable]*	**Drawings and Documents that give related structural steelwork requirements**	
			See Drawings Listed in …	**Additional requirement(s)** Blue text: specific stainless steel requirements Black text: Recommendations from UK Steel Bridge Group for all highway bridges
1808.8	**Use of special fasteners and fastening methods** - requirements for procedure tests.			The following procedure tests shall be carried out: The torque method, combined method and HRC method can be used to tighten stainless steel bolts, although tests are required to determine specific guidelines and any restrictions which may need to be imposed, e.g. avoid over-tightening in case galling occurs. Refer to Bolt Tightening Qualification Procedure, Appendix C of prEN 1993-1-4 April 2020.
1810	**Surface Treatment**			
1810.10.2	**Cleaning of stainless steel components** - the method, level and extent of cleaning of stainless steels.			General - surfaces shall be protected to minimise contamination and damage to the surface finish. Particular care is required at lifting points to avoid damage to the finish and embedding contaminants in the stainless steel surface. Post weld cleaning - all welds and parent plates shall be cleaned to remove all welding flux, weld spatter, and arc strikes by controlled grinding using non-metallic abrasive wheels. Where heat tint has discoloured the heat affected zone (HAZ) adjacent to the weld, the heat tint shall be removed by either mechanical (using non-metallic abrasives) or chemical means. All residues from cleaning shall be removed from the surface after cleaning. Surface damage - mechanical damage to the surface finish of plates shall be reinstated to the specified quality after fabrication. Surface cleaning - on completion of fabrication the surface shall be cleaned by pressure washing. Where fabrication has taken place in workshops also used for carbon steel fabrication and/or where carbon steel tools are used in the fabrication of stainless steel, stainless steel surfaces shall be checked to ensure they are not contaminated with steel or iron. Test shall be taken at representative areas of the surfaces on each complete member and be in accordance with the Ferroxyl Test for free iron as given in ASTM A380 Clause 7.3.4[1]. If free iron is detected the affected area shall be recleaned and the test repeated. ([1] ASTM A380 / A380M - 17 Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems)

Series 1800 Clause Reference:	**Additional Information Required**	**Not Applicable** *[Ticked if not applicable]*	**Drawings and Documents that give related structural steelwork requirements**	
			See Drawings Listed in …	**Additional requirement(s)** Blue text: specific stainless steel requirements Black text: Recommendations from UK Steel Bridge Group for all highway bridges
1811	**Geometrical Tolerances**			
1811.1	**Tolerance types** - additional information related to special tolerances if these tolerances are specified.			The following special tolerances on steelwork dimensions and levels at completion shall apply: i) On level, relative to that specified: • at the supports: 5 mm; • at midspan: span/1000, up to a maximum of 35 mm. ii) On level, of one main girder relative to another, adjacent, main girder: 20 mm. iii) On plan position of steelwork at bearings (structure at datum temperature): • Transverse position of bearing top and bottom plates relative to substructure: ±15 mm • Longitudinal position of bearing top plate relative to bottom plate: ±(10 mm+Ls/10000) • Longitudinal position of bearing bottom plate relative to substructure: ±10 mm Where Ls is distance from the fixed point. iv) On spacing of top flanges where permanent formwork is to be used: ±10 mm.
1811.3.2 (2)	**Tolerance types, additional information** - tolerance on steelwork dimensions and levels at completion.			The tolerance on steelwork dimensions and levels at completion, on the verticality of main girder webs at supports, is as follows: Depth/300 or 3 mm, whichever is greater.
1812	**Inspection, Testing and Correction**			
1812.5.2.1	**Inspection of friction surfaces** - requirements for the inspection and testing of preloaded bolts used for stainless steels connections.			The inspection requirements in EN 1090-2 Clause 12.5.2 apply, as appropriate for the tightening method.

Appendix B LOCATION 1 (A ROAD)

B.1 Maintenance assumptions

Route Supported	Local Road - B Class		
Annual AV. Daily Traffic	Low (<10,000 vehicles per lande)		
Obstacle Crossed	Local Road - A Class		
Total Length	62	m	(beams are 56 m in total)
Average Width	14	m	
Average Height	6	m	

					Maintenance Work					Eng Difficulty of maintenance activity							Work Pattern		T. Management (WK. Pattern & T. Management)				
ID	CSS Element Description	Starting Condition (Severity & extent)	Material/Component Type	Exposure to Environment/ Traffic	Action	Quantity	Unit	Rate	Condition After	over water (navigable)	over water (tidal)	over railway	over road	at height	Stats	Others	Type	Duration (days)	Type	Duration (days)	Type	Duration (days)	Eng. Diff.
1	Primary deck element	1A	Insitu Reinforced Concrete	moderate	moderate	207	m2	1468	2B	N	N	N	A	5 to 8m	N	N	restrict. Daytime	37	lane closure(1lane)	37	single way controlled	37	N
2	Secondary deck element/s - beams	1A	Fabricated Steel, Rolled Steel, Steel, or Steel Plate	mild																			
6	Parapet beam or cantilever	1A	Insitu Reinforced Concrete	mild	minor	22.3	m2	367	2B	N	N	N	N	N	N	N	daytime	4	single way controlled	4			N
8	Foundations	1A	Deep Foundation: Piles	mild																			
9	Abutments (incl. arch springing)	1A	Insitu Reinforced Concrete	moderate	minor	72.5	m2	367	2B	N	N	N	N	N	N	N	daytime	2	Hard-shoulder closure	2			
11	Pier/column	1A	Insitu Reinforced Concrete	severe	moderate	50.4	m2	1468	2B	N	N	N	A	5 to 8m	N	N	restrict. Daytime	9	single way controlled	9			
12	Cross-head/capping beam	1A	Insitu Reinforced Concrete	moderate	minor	3	m2	367	2B	N	N	N	A	5 to 8m	N	N	restrict. Daytime	0.5	lane closure(1lane)	0.5	single way controlled	0.5	
13	Bearings	1A	Pot	moderate	replace	12	No.	1101	1A	N	N	N	A	5 to 8m	N	N	restrict. Daytime	3	lane closure(1lane)	3	single way controlled	3	
14	Bearing plinth/shelf	1A	Insitu Reinforced Concrete	moderate	minor	3	m2	367	2B	N	N	N	A	5 to 8m	N	N	restrict. Daytime	0.5	lane closure(1lane)	0.5	single way controlled	0.5	
16	Substructure drainage	1A	Internal Drainage System	mild	cleaning	62	m2	30	1A	N	N	N	N	N	N	N	daytime	3	Hard-shoulder closure	3			
17	Waterproofing	1A	Mastic Asphalt	n/a	replace	825	m2	477	1A	N	N	N	N	N	N	N	daytime	32	Contra-flow	32			
18	Movement/expansion joints	1A	Asphaltic Plug Joint	low	replace	28	m2	275	1A	N	N	N	N	N	N	N	daytime	2	single way controlled	2			N
19	Finishes: deck elements	1A	High Build Epoxy Hydrocarbon Resin Modified Finish	moderate	paint	728	m2	90/176	2B/1A	N	N	N	A	5 to 8m	N	N	restrict. Daytime	20/40	lane closure(1lane)	10/20	lane closure(2 lane)	10/20	N
20	Finishes: substructure elements	1A	Anti-Graffiti Paint	moderate	paint	168	m2	44	1A	N	N	N	A	2 to 5m	N	N	restrict. Daytime	1	lane closure(1lane)	1			
21	Finishes: parapets/safety fences	1A	Other/Unknown Paint System	severe	paint	360	m2	44	1A	N	N	N	A	5 to 8m	N	N	daytime	5	pedestrian man.	5			N
23	Handrail/parapets/safety fences	1A	Steel	mild	paint	360	m2	0	1A	N	N	N	N	N	N	N	n/a	n/a	n/a	n/a	n/a	n/a	n/a
24	Carriageway surfacing	1A	Asphalt	low	resurf	173/577	m2	154/246	2B/1A	N	N	N	N	N	N	N	daytime	1.5/5	single way controlled	1.5/5			N
25	Footway/verge/footbridge surfacing	1A	Asphalt	mild	resurf	74/248	m2	81/123	2B/1A	N	N	N	N	N	N	N	daytime	0.5/2	pedestrian man.	0.5/2			N
30	Revetment/batter paving	1A	Precast Concrete Blocks - Open Jointed or Interlocking	moderate	minor	318	m2	29	2B	N	N	N	A	2 to 5m	N	N	restrict. Daytime	2	lane closure(1lane)	2			N
31	Wing walls	1A	Insitu Reinforced Concrete	moderate	minor	4	m2	367	2B	N	N	N	N	N	N	N	daytime	0.5	Hard-shoulder closure	0.5			
35	Approach rails/barriers/walls	1A	Fabricated Steel, Rolled Steel, Steel, or Steel Plate	severe	replace	24	m2	147	1A	N	N	N	N	N	N	N	daytime	2	single way controlled	2			N

General Assumptions

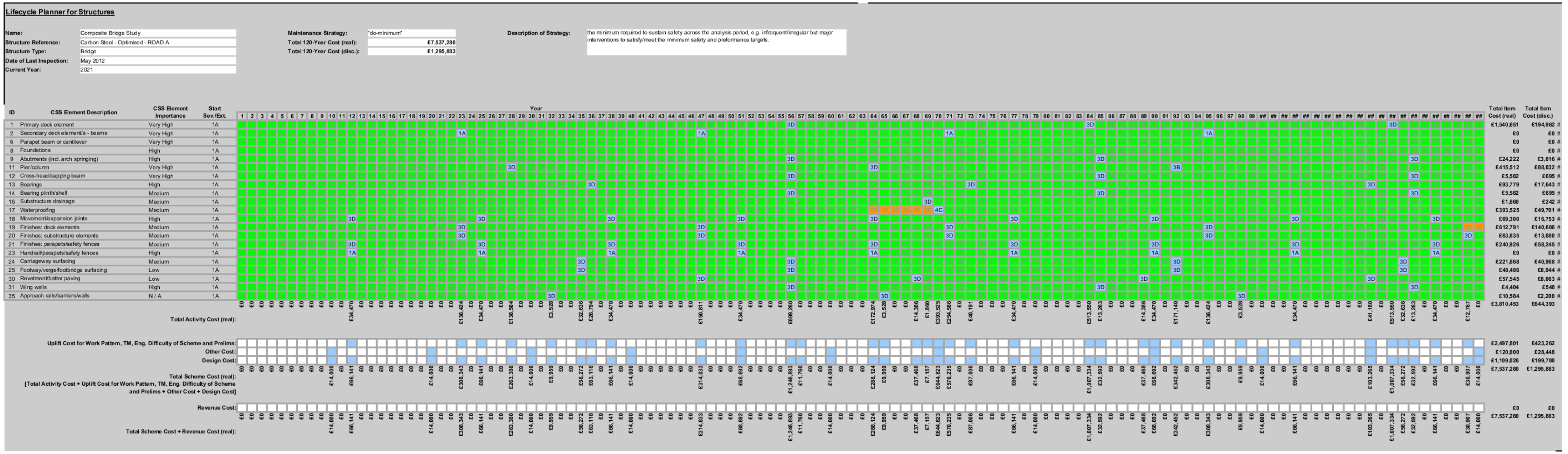
No bracing

Maintenance of services not included but considered for maintenance of bridge elements where applicable

Pot Bearings

Add routine inspection of £10000 every 10 years

B.2 Maintenance activities for painted carbon steel solutions

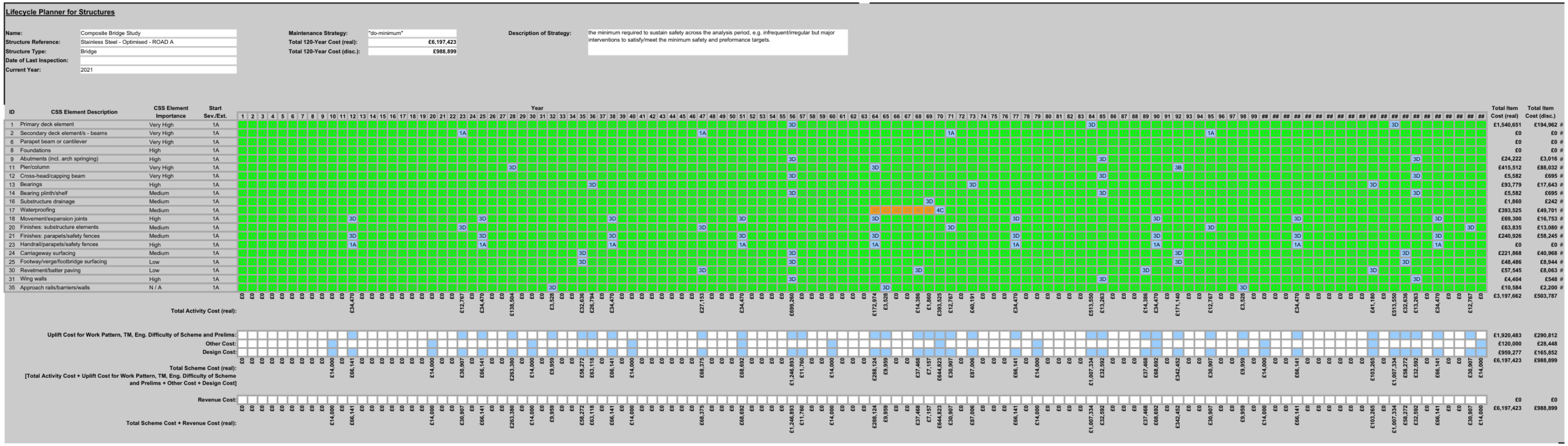


Lifecycle Planner for Structures

Name:	Composite Bridge Study
Structure Reference:	Carbon Steel - Optimised - ROAD A
Structure Type:	Bridge
Date of Last Inspection:	May 2012
Current Year:	2021
Maintenance Strategy:	"do-minimum"
Total 120-Year Cost (real):	£7,537,280
Total 120-Year Cost (disc.):	£1,295,883
Description of Strategy:	the minimum required to sustain safety across the analysis period, e.g. infrequent/irregular but major interventions to satisfy/meet the minimum safety and preformance targets.

ID	CSS Element Description	CSS Element Importance	Start Sev./Ext.	Total Item Cost (real)	Total Item Cost (disc.)
1	Primary deck element	Very High	1A	£1,540,651	£194,962 #
2	Secondary deck element/s - beams	Very High	1A	£0	£0 #
6	Parapet beam or cantilever	Very High	1A	£0	£0 #
8	Foundations	High	1A	£0	£0 #
9	Abutments (incl. arch springing)	High	1A	£24,222	£3,016 #
11	Pier/column	Very High	1A	£415,512	£88,032 #
12	Cross-head/capping beam	Very High	1A	£5,582	£695 #
13	Bearings	High	1A	£93,779	£17,643 #
14	Bearing plinth/shelf	Medium	1A	£5,582	£695 #
16	Substructure drainage	Medium	1A	£1,860	£242 #
17	Waterproofing	Medium	1A	£393,525	£49,701 #
18	Movement/expansion joints	High	1A	£69,300	£16,753 #
19	Finishes: deck elements	Medium	1A	£612,791	£140,606 #
20	Finishes: substructure elements	Medium	1A	£63,835	£13,080 #
21	Finishes: parapets/safety fences	Medium	1A	£240,926	£58,245 #
23	Handrail/parapets/safety fences	High	1A	£0	£0 #
24	Carriageway surfacing	Medium	1A	£221,868	£40,968 #
25	Footway/verge/footbridge surfacing	Low	1A	£48,486	£8,944 #
30	Revetment/batter paving	Low	1A	£57,545	£8,063 #
31	Wing walls	High	1A	£4,404	£548 #
35	Approach rails/barriers/walls	N / A	1A	£10,584	£2,200 #
	Total Activity Cost (real):			£3,810,453	£644,393
	Uplift Cost for Work Pattern, TM, Eng. Difficulty of Scheme and Prelims:			£2,497,801	£423,262
	Other Cost:			£120,000	£28,448
	Design Cost:			£1,109,026	£199,780
	Total Scheme Cost (real): [Total Activity Cost + Uplift Cost for Work Pattern, TM, Eng. Difficulty of Scheme and Prelims + Other Cost + Design Cost]			£7,537,280	£1,295,883
	Revenue Cost:			£0	£0
	Total Scheme Cost + Revenue Cost (real):			£7,537,280	£1,295,883

B.3 Maintenance activities for weathering steel and duplex steel solutions



Lifecycle Planner for Structures

Name:	Composite Bridge Study
Structure Reference:	Stainless Steel - Optimised - ROAD A
Structure Type:	Bridge
Date of Last Inspection:	
Current Year:	2021
Maintenance Strategy:	"do-minimum"
Total 120-Year Cost (real):	£6,197,423
Total 120-Year Cost (disc.):	£988,899
Description of Strategy:	the minimum required to sustain safety across the analysis period, e.g. infrequent/irregular but major interventions to satisfy/meet the minimum safety and preformance targets.

ID	CSS Element Description	CSS Element Importance	Start Sev./Ext.	Total Item Cost (real)	Total Item Cost (disc.)
1	Primary deck element	Very High	1A	£1,540,651	£194,962 #
2	Secondary deck element/s - beams	Very High	1A	£0	£0 #
6	Parapet beam or cantilever	Very High	1A	£0	£0 #
8	Foundations	High	1A	£0	£0 #
9	Abutments (incl. arch springing)	High	1A	£24,222	£3,016 #
11	Pier/column	Very High	1A	£415,512	£88,032 #
12	Cross-head/capping beam	Very High	1A	£5,582	£695 #
13	Bearings	High	1A	£93,779	£17,643 #
14	Bearing plinth/shelf	Medium	1A	£5,582	£695 #
16	Substructure drainage	Medium	1A	£1,860	£242 #
17	Waterproofing	Medium	1A	£393,525	£49,701 #
18	Movement/expansion joints	High	1A	£69,300	£16,753 #
20	Finishes: substructure elements	Medium	1A	£63,835	£13,080 #
21	Finishes: parapets/safety fences	Medium	1A	£240,926	£58,245 #
23	Handrail/parapets/safety fences	High	1A	£0	£0 #
24	Carriageway surfacing	Medium	1A	£221,868	£40,968 #
25	Footway/verge/footbridge surfacing	Low	1A	£48,486	£8,944 #
30	Revetment/batter paving	Low	1A	£57,545	£8,063 #
31	Wing walls	High	1A	£4,404	£548 #
35	Approach rails/barriers/walls	N / A	1A	£10,584	£2,200 #
	Total Activity Cost (real):			£3,197,662	£503,787
	Uplift Cost for Work Pattern, TM, Eng. Difficulty of Scheme and Prelims:			£1,920,483	£290,812
	Other Cost:			£120,000	£28,448
	Design Cost:			£959,277	£165,852
	Total Scheme Cost (real): [Total Activity Cost + Uplift Cost for Work Pattern, TM, Eng. Difficulty of Scheme and Prelims + Other Cost + Design Cost]			£6,197,423	£988,899
	Revenue Cost:			£0	£0
	Total Scheme Cost + Revenue Cost (real):			£6,197,423	£988,899

Appendix C LOCATION 2 (RAIL)

C.1 Maintenance assumptions

Route Supported	Local Road - B Class	
Annual AV. Daily Traffic	Low (<10,000 vehicles per lande)	
Obstacle Crossed	Railway	
Total Length	62 m	(beams are 56 m in total)
Average Width	14 m	
Average Height	6 m	

					Maintenance Work					Eng Difficulty of maintenance activity							WK. Pattern & T. Management: Work Pattern		WK. Pattern & T. Management: T. Management				
ID	CSS Element Description	Starting Condition (Severity & extent)	Material/Component Type	Exposure to Environment/ Traffic	Action	Quantity	Unit	Rate	Condition After	over water (navigable)	over water (tidal)	over railway	over road	at height	Stats	Others	Type	Duration (days)	Type	Duration (days)	Type	Duration (days)	Eng. Diff.
1	Primary deck element	1A	Insitu Reinforced Concrete	mild																			
2	Secondary deck element/s - beams	1A	Fabricated Steel, Rolled Steel, Steel, or Steel Plate	mild																			
6	Parapet beam or cantilever	1A	Insitu Reinforced Concrete	mild	minor	22.3	m2	367	2B	N	N	N	N	N	N	N	daytime	4	single way controlled	4			N
8	Foundations	1A	Deep Foundation: Piles	mild																			
9	Abutments (incl. arch springing)	1A	Insitu Reinforced Concrete	mild																			
11	Pier/column	1A	Insitu Reinforced Concrete	mild																			
12	Cross-head/capping beam	1A	Insitu Reinforced Concrete	mild																			
13	Bearings	1A	Pot	mild	replace	12	No.	1101	1A	N	N	Electrified	N	5 to 8m	N	N	Weekend/P.Holiday 8hr	3	single way controlled	3			N
14	Bearing plinth/shelf	1A	Insitu Reinforced Concrete	mild																			
16	Substructure drainage	1A	Internal Drainage System	mild	clearing	62	m2	30	1A	N	N	N	N	N	N	N	daytime	3	Hard-shoulder closure	3			
17	Waterproofing	1A	Mastic Asphalt	n/a	replace	825	m2	477	1A	N	N	N	N	N	N	N	daytime	32	Contra-flow	32			
18	Movement/expansion joints	1A	Asphaltic Plug Joint	low	replace	28	m2	275	1A	N	N	N	N	N	N	N	daytime	2	single way controlled	2			N
19	Finishes: deck elements	1A	High Build Epoxy Hydrocarbon Resin Modified Finish	mild	paint	728	m2	90/176	2B/1A	N	N	Electrified	N	5 to 8m	N	N	Weekend/P.Holiday 8hr	20/40	railway possession	20/40			N
20	Finishes: substructure elements	1A	Anti-Graffiti Paint	mild	paint	168	m2	44	1A	N	N	Electrified	N	2 to 5m	N	N	Weekend/P.Holiday 8hr	0.5	railway possessions	0.5			
21	Finishes: parapets/safety fences	1A	Other/Unknown Paint System	severe	paint	360	m2	44	1A	N	N	Electrified	N	5 to 8m	N	N	daytime	5	pedestrian man.	5			N
23	Handrail/parapets/safety fences	1A	Steel	mild	paint	360	m2	0	1A	N	N	N	N	N	N	N	n/a	n/a	n/a	n/a	n/a	n/a	n/a
24	Carriageway surfacing	1A	Asphalt	low	resurf	173/577	m2	154/246	2B/1A	N	N	N	N	N	N	N	daytime	1.5/5	single way controlled	1.5/5			N
25	Footway/verge/footbridge surfacing	1A	Asphalt	mild	resurf	74/248	m2	81/123	2B/1A	N	N	N	N	N	N	N	daytime	0.5/2	pedestrian man.	0.5/2			N
30	Revetment/batter paving	1A	Precast Concrete Blocks - Open Jointed or Interlocking	mild	minor	318	m2	29	2B	N	N	Electrified	N	2 to 5m	N	N	Weekend/P.Holiday 8hr	0.5	railway possessions	0.5			N
31	Wing walls	1A	Insitu Reinforced Concrete	mild																			
35	Approach rails/barriers/walls	1A	Fabricated Steel, Rolled Steel, Steel, or Steel Plate	severe	replace	24	m2	147	1A	N	N	N	N	N	N	N	daytime	2	single way controlled	2			N

General Assumptions

No bracing

Maintenance of services not included but considered for maintenance of bridge elements where applicable

Pot Bearings

Add routine inspection of £15000 every 10 years (extra £5000 assumed as for railway)

C.2 Maintenance activities for painted carbon steel solutions

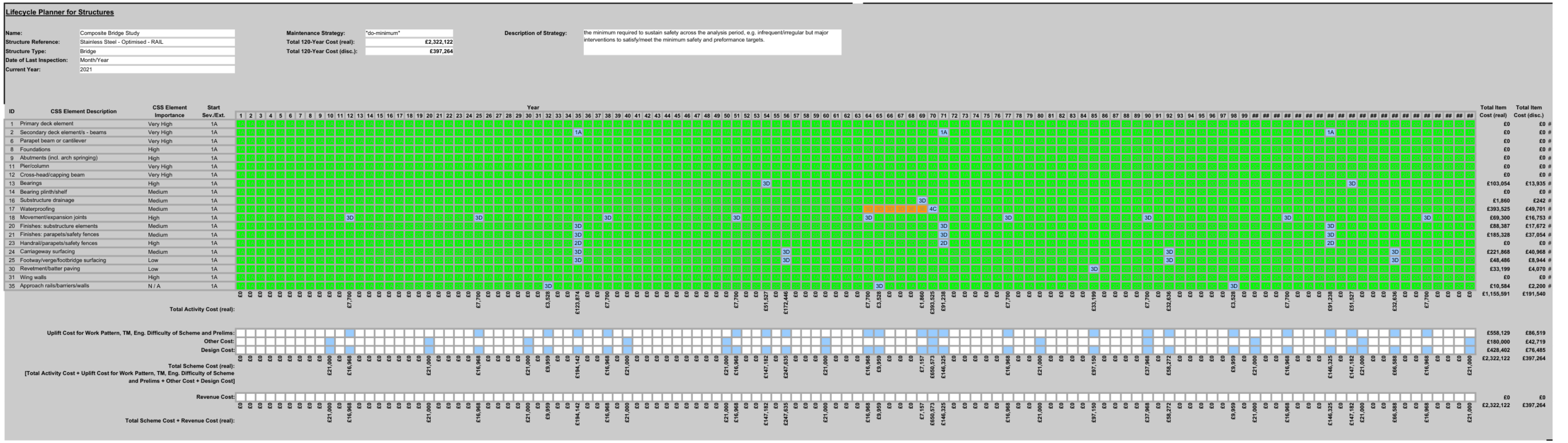
Lifecycle Planner for Structures

Name:	Composite Bridge Study
Structure Reference:	Carbon Steel - Optimised - RAIL
Structure Type:	Bridge
Date of Last Inspection:	Month/Year
Current Year:	2021
Maintenance Strategy:	"do-minimum"
Total 120-Year Cost (real):	£5,994,429
Total 120-Year Cost (disc.):	£1,110,331
Description of Strategy:	the minimum required to sustain safety across the analysis period, e.g. infrequent/irregular but major interventions to satisfy/meet the minimum safety and preformance targets.

ID	CSS Element Description	CSS Element Importance	Start Sev./Ext.	Total Item Cost (real)	Total Item Cost (disc.)
1	Primary deck element	Very High	1A	£0	£0 #
2	Secondary deck element/s - beams	Very High	1A	£0	£0 #
6	Parapet beam or cantilever	Very High	1A	£0	£0 #
8	Foundations	High	1A	£0	£0 #
9	Abutments (incl. arch springing)	High	1A	£0	£0 #
11	Pier/column	Very High	1A	£0	£0 #
12	Cross-head/capping beam	Very High	1A	£0	£0 #
13	Bearings	High	1A	£103,054	£13,935 #
14	Bearing plinth/shelf	Medium	1A	£0	£0 #
16	Substructure drainage	Medium	1A	£1,860	£242 #
17	Waterproofing	Medium	1A	£393,525	£49,701 #
18	Movement/expansion joints	High	1A	£69,300	£16,753 #
19	Finishes: deck elements	Medium	1A	£1,128,769	£218,400 #
20	Finishes: substructure elements	Medium	1A	£88,387	£17,672 #
21	Finishes: parapets/safety fences	Medium	1A	£185,328	£37,054 #
23	Handrail/parapets/safety fences	High	1A	£0	£0 #
24	Carriageway surfacing	Medium	1A	£221,868	£40,968 #
25	Footway/verge/footbridge surfacing	Low	1A	£48,486	£8,944 #
30	Revetment/batter paving	Low	1A	£33,199	£4,070 #
31	Wing walls	High	1A	£0	£0 #
35	Approach rails/barriers/walls	N / A	1A	£10,584	£2,200 #

	Total (real)	Total (disc.)
Total Activity Cost (real):	£2,284,360	£409,941
Uplift Cost for Work Pattern, TM, Eng. Difficulty of Scheme and Prelims:	£2,683,588	£499,323
Other Cost:	£180,000	£42,719
Design Cost:	£846,481	£158,349
Total Scheme Cost (real): [Total Activity Cost + Uplift Cost for Work Pattern, TM, Eng. Difficulty of Scheme and Prelims + Other Cost + Design Cost]	£5,994,429	£1,110,331
Revenue Cost:	£0	£0
Total Scheme Cost + Revenue Cost (real):	£5,994,429	£1,110,331

C.3 Maintenance activities for weathering steel and duplex steel solutions



Lifecycle Planner for Structures

Name:	Composite Bridge Study
Structure Reference:	Stainless Steel - Optimised - RAIL
Structure Type:	Bridge
Date of Last Inspection:	Month/Year
Current Year:	2021
Maintenance Strategy:	"do-minimum"
Total 120-Year Cost (real):	£2,322,122
Total 120-Year Cost (disc.):	£397,264
Description of Strategy:	the minimum required to sustain safety across the analysis period, e.g. infrequent/irregular but major interventions to satisfy/meet the minimum safety and preformance targets.

ID	CSS Element Description	CSS Element Importance	Start Sev./Ext.	Total Item Cost (real)	Total Item Cost (disc.)
1	Primary deck element	Very High	1A	£0	£0 #
2	Secondary deck element/s - beams	Very High	1A	£0	£0 #
6	Parapet beam or cantilever	Very High	1A	£0	£0 #
8	Foundations	High	1A	£0	£0 #
9	Abutments (incl. arch springing)	High	1A	£0	£0 #
11	Pier/column	Very High	1A	£0	£0 #
12	Cross-head/capping beam	Very High	1A	£0	£0 #
13	Bearings	High	1A	£103,054	£13,935 #
14	Bearing plinth/shelf	Medium	1A	£0	£0 #
16	Substructure drainage	Medium	1A	£1,860	£242 #
17	Waterproofing	Medium	1A	£393,525	£49,701 #
18	Movement/expansion joints	High	1A	£69,300	£16,753 #
20	Finishes: substructure elements	Medium	1A	£88,387	£17,672 #
21	Finishes: parapets/safety fences	Medium	1A	£185,328	£37,054 #
23	Handrail/parapets/safety fences	High	1A	£0	£0 #
24	Carriageway surfacing	Medium	1A	£221,868	£40,968 #
25	Footway/verge/footbridge surfacing	Low	1A	£48,486	£8,944 #
30	Revetment/batter paving	Low	1A	£33,199	£4,070 #
31	Wing walls	High	1A	£0	£0 #
35	Approach rails/barriers/walls	N / A	1A	£10,584	£2,200 #
	Total Activity Cost (real):			£1,155,591	£191,540
	Uplift Cost for Work Pattern, TM, Eng. Difficulty of Scheme and Prelims:			£558,129	£86,519
	Other Cost:			£180,000	£42,719
	Design Cost:			£428,402	£76,485
	Total Scheme Cost (real): [Total Activity Cost + Uplift Cost for Work Pattern, TM, Eng. Difficulty of Scheme and Prelims + Other Cost + Design Cost]			£2,322,122	£397,264
	Revenue Cost:			£0	£0
	Total Scheme Cost + Revenue Cost (real):			£2,322,122	£397,264

Appendix D LOCATION 3 (RAIL COAST)

D.1 Maintenance assumptions

Route Supported	Local Road - B Class
Annual AV. Daily Traffic	Low (<10,000 vehicles per lande)
Obstacle Crossed	Railway
Total Length	62 m (beams are 56 m in total)
Average Width	14 m
Average Height	6 m

					Maintenance Work					Eng Difficulty of maintenance activity						
ID	CSS Element Description	Starting Condition (Severity & extent)	Material/Component Type	Exposure to Environment/ Traffic	Action	Quantity	Unit	Rate	Condition After	over water (navigable)	over water (tidal)	over railway	over road	at height	Stats	Others
1	Primary deck element	1A	Insitu Reinforced Concrete	moderate	moderate	207	m2	1468	2B	N	N	Electrified	N	5 to 8m	N	N
2	Secondary deck element/s - beams	1A	Fabricated Steel, Rolled Steel, Steel, or Steel Plate	mild												
6	Parapet beam or cantilever	1A	Insitu Reinforced Concrete	mild	minor	22.3	m2	367	2B	N	N	N	N	N	N	N
8	Foundations	1A	Deep Foundation: Piles	mild												
9	Abutments (incl. arch springing)	1A	Insitu Reinforced Concrete	moderate	minor	72.5	m2	367	2B	N	N	N	N	N	N	N
11	Pier/column	1A	Insitu Reinforced Concrete	severe	moderate	168	m2	1468	2B	N	N	Electrified	N	5 to 8m	N	N
12	Cross-head/capping beam	1A	Insitu Reinforced Concrete	moderate	minor	3	m2	367	2B	N	N	Electrified	N	5 to 8m	N	N
13	Bearings	1A	Pot	moderate	replace	12	No.	1101	1A	N	N	Electrified	N	5 to 8m	N	N
14	Bearing plinth/shelf	1A	Insitu Reinforced Concrete	moderate	minor	3	m2	367	2B	N	N	Electrified	A	5 to 8m	N	N
16	Substructure drainage	1A	Internal Drainage System	mild	clearing	62	m2	30	1A	N	N	N	N	N	N	N
17	Waterproofing	1A	Mastic Asphalt	n/a	replace	825	m2	477	1A	N	N	N	N	N	N	N
18	Movement/expansion joints	1A	Asphaltic Plug Joint	low	replace	28	m2	275	1A	N	N	N	N	N	N	N
19	Finishes: deck elements	1A	High Build Epoxy Hydrocarbon Resin Modified Finish	moderate	paint	728	m2	90/176	2B/1A	N	N	Electrified	N	5 to 8m	N	N
20	Finishes: substructure elements	1A	Anti-Graffiti Paint	moderate	paint	168	m2	44	1A	N	N	Electrified	N	2 to 5m	N	N
21	Finishes: parapets/safety fences	1A	Other/Unknown Paint System	severe	paint	360	m2	44	1A	N	N	Electrified	N	5 to 8m	N	N
23	Handrail/parapets/safety fences	1A	Steel	mild	paint	360	m2	0	1A	N	N	N	N	N	N	N
24	Carriageway surfacing	1A	Asphalt	low	resurf	173/577	m2	154/246	2B/1A	N	N	N	N	N	N	N
25	Footway/verge/footbridge surfacing	1A	Asphalt	mild	resurf	74/248	m2	81/123	2B/1A	N	N	N	N	N	N	N
30	Revetment/batter paving	1A	Precast Concrete Blocks - Open Jointed or Interlocking	moderate	minor	318	m2	29	2B	N	N	Electrified	N	2 to 5m	N	N
31	Wing walls	1A	Insitu Reinforced Concrete	moderate	minor	4	m2	367	2B	N	N	N	N	N	N	N
35	Approach rails/barriers/walls	1A	Fabricated Steel, Rolled Steel, Steel, or Steel Plate	severe	replace	24	m2	147	1A	N	N	N	N	N	N	N

	WK. Pattern & T. Management						
	Work Pattern		T. Management				
ID	Type	Duration (days)	Type	Duration (days)	Type	Duration (days)	Eng. Diff.
1	Weekend/P.Holiday 8hr	37	railway possessions	37			N
2							
6	daytime	4	single way controlled	4			N
8							
9	Weekend/P.Holiday 8hr	2	railway possessions	2			
11	Weekend/P.Holiday 8hr	9	railway possessions	9			
12	Weekend/P.Holiday 8hr	0.5	railway possessions	0.5			
13	Weekend/P.Holiday 8hr	3	railway possessions	3			
14	Weekend/P.Holiday 8hr	0.5	railway possessions	0.5			
16	daytime	3	Hard-shoulder closure	3			
17	daytime	32	Contra-flow	32			
18	daytime	2	single way controlled	2			N
19	Weekend/P.Holiday 8hr	20/40	railway possession	20/40			N
20	Weekend/P.Holiday 8hr	0.5	railway possessions	0.5			
21	daytime	5	pedestrian man.	5			N
23	n/a	n/a	n/a	n/a	n/a	n/a	n/a
24	daytime	1.5/5	single way controlled	1.5/5			N
25	daytime	0.5/2	pedestrian man.	0.5/2			N
30	Weekend/P.Holiday 8hr	0.5	railway possessions	0.5			N
31	Weekend/P.Holiday 8hr	0.5	railway possessions	0.5			
35	daytime	2	single way controlled	2			N

General Assumptions

No bracing

Maintenance of services not included but considered for maintenance of bridge elements where applicable

Pot Bearings

Add routine inspection of £15000 every 10 years (extra £5000 assumed as for railway)

D.2 Maintenance activities for painted carbon steel solutions

Lifecycle Planner for Structures

Name:	Composite Bridge Study
Structure Reference:	Carbon Steel - Optimised - RAIL
Structure Type:	Bridge
Date of Last Inspection:	Month/Year
Current Year:	2021

Maintenance Strategy:	"do-minimum"
Total 120-Year Cost (real):	£20,504,858
Total 120-Year Cost (disc.):	£3,501,155

Description of Strategy: the minimum required to sustain safety across the analysis period, e.g. infrequent/irregular but major interventions to satisfy/meet the minimum safety and preformance targets.

ID	CSS Element Description	CSS Element Importance	Start Sev./Ext.	Total Item Cost (real)	Total Item Cost (disc.)
1	Primary deck element	Very High	1A	£3,555,349	£449,912
2	Secondary deck element/s - beams	Very High	1A	£0	£0
6	Parapet beam or cantilever	Very High	1A	£0	£0
8	Foundations	High	1A	£0	£0
9	Abutments (incl. arch springing)	High	1A	£24,222	£3,016
11	Pier/column	Very High	1A	£865,650	£178,066
12	Cross-head/capping beam	Very High	1A	£12,882	£1,604
13	Bearings	High	1A	£154,580	£29,598
14	Bearing plinth/shelf	Medium	1A	£12,882	£1,604
16	Substructure drainage	Medium	1A	£1,860	£242
17	Waterproofing	Medium	1A	£393,525	£49,701
18	Movement/expansion joints	High	1A	£69,300	£16,753
19	Finishes: deck elements	Medium	1A	£1,414,132	£324,476
20	Finishes: substructure elements	Medium	1A	£117,850	£28,624
21	Finishes: parapets/safety fences	Medium	1A	£555,984	£134,411
23	Handrail/parapets/safety fences	High	1A	£0	£0
24	Carriageway surfacing	Medium	1A	£221,868	£40,968
25	Footway/verge/footbridge surfacing	Low	1A	£48,486	£8,944
30	Revetment/batter paving	Low	1A	£132,797	£18,606
31	Wing walls	High	1A	£4,404	£548
35	Approach rails/barriers/walls	N / A	1A	£10,584	£2,200
	Total Activity Cost (real):			£7,596,355	£1,289,274
	Uplift Cost for Work Pattern, TM, Eng. Difficulty of Scheme and Prelims:			£10,200,110	£1,722,569
	Other Cost:			£180,000	£42,719
	Design Cost:			£2,528,393	£446,592
	Total Scheme Cost (real): [Total Activity Cost + Uplift Cost for Work Pattern, TM, Eng. Difficulty of Scheme and Prelims + Other Cost + Design Cost]			£20,504,858	£3,501,155
	Revenue Cost:			£0	£0
	Total Scheme Cost + Revenue Cost (real):			£20,504,858	£3,501,155

D.3 Maintenance activities for weathering steel and duplex steel solutions

Lifecycle Planner for Structures

Name:	Composite Bridge Study	**Maintenance Strategy:**	"do-minimum"
Structure Reference:	Carbon Steel - Optimised - RAIL	**Total 120-Year Cost (real):**	£15,931,136
Structure Type:	Bridge	**Total 120-Year Cost (disc.):**	£2,447,429
Date of Last Inspection:	Month/Year		
Current Year:	2021		

Description of Strategy: the minimum required to sustain safety across the analysis period, e.g. infrequent/irregular but major interventions to satisfy/meet the minimum safety and preformance targets.

ID	CSS Element Description	CSS Element Importance	Start Sev./Ext.	Total Item Cost (real)	Total Item Cost (disc.)
1	Primary deck element	Very High	1A	£3,555,349	£449,912
2	Secondary deck element/s - beams	Very High	1A	£0	£0
6	Parapet beam or cantilever	Very High	1A	£0	£0
8	Foundations	High	1A	£0	£0
9	Abutments (incl. arch springing)	High	1A	£24,222	£3,016
11	Pier/column	Very High	1A	£865,650	£178,066
12	Cross-head/capping beam	Very High	1A	£12,882	£1,604
13	Bearings	High	1A	£154,580	£29,598
14	Bearing plinth/shelf	Medium	1A	£12,882	£1,604
16	Substructure drainage	Medium	1A	£1,860	£242
17	Waterproofing	Medium	1A	£393,525	£49,701
18	Movement/expansion joints	High	1A	£69,300	£16,753
20	Finishes: substructure elements	Medium	1A	£117,850	£28,624
21	Finishes: parapets/safety fences	Medium	1A	£555,984	£134,411
23	Handrail/parapets/safety fences	High	1A	£0	£0
24	Carriageway surfacing	Medium	1A	£221,868	£40,968
25	Footway/verge/footbridge surfacing	Low	1A	£48,486	£8,944
30	Revetment/batter paving	Low	1A	£132,797	£18,606
31	Wing walls	High	1A	£4,404	£548
35	Approach rails/barriers/walls	N / A	1A	£10,584	£2,200
	Total Activity Cost (real):			£6,182,223	£964,798
	Uplift Cost for Work Pattern, TM, Eng. Difficulty of Scheme and Prelims:			£7,577,973	£1,119,377
	Other Cost:			£180,000	£42,719
	Design Cost:			£1,990,941	£320,535
	Total Scheme Cost (real): [Total Activity Cost + Uplift Cost for Work Pattern, TM, Eng. Difficulty of Scheme and Prelims + Other Cost + Design Cost]			£15,931,136	£2,447,429
	Revenue Cost:			£0	£0
	Total Scheme Cost + Revenue Cost (real):			£15,931,136	£2,447,429

Appendix E LOCATION 4 (ESTUARY)

E.1 Maintenance assumptions

Route Supported	Local Road - B Class	
Annual AV. Daily Traffic	Low (<10,000 vehicles per lande)	
Obstacle Crossed	Estuary - Tidal	
Total Length	62 m	(beams are 56 m in total)
Average Width	14 m	
Average Height	6 m	

Maintenance Work

ID	CSS Element Description	Starting Condition (Severity & extent)	Material/Component Type	Exposure to Environment/ Traffic	Action	Quantity	Unit	Rate	Condition After
1	Primary deck element	1A	Insitu Reinforced Concrete	moderate	moderate	207	m2	1468	2B
2	Secondary deck element/s - beams	1A	Fabricated Steel, Rolled Steel, Steel, or Steel Plate	mild					
6	Parapet beam or cantilever	1A	Insitu Reinforced Concrete	severe	minor	22.3	m2	367	2B
8	Foundations	1A	Deep Foundation: Piles	moderate					
9	Abutments (incl. arch springing)	1A	Insitu Reinforced Concrete	moderate	minor	22	m2	367	2B
11	Pier/column	1A	Insitu Reinforced Concrete	severe	moderate	50.4	m2	1468	2B
12	Cross-head/capping beam	1A	Insitu Reinforced Concrete	moderate	minor	3	m2	367	2B
13	Bearings	1A	Pot	moderate	replace	12	No.	1101	1A
14	Bearing plinth/shelf	1A	Insitu Reinforced Concrete	moderate	minor	3	m2	367	2B
16	Substructure drainage	1A	Internal Drainage System	mild	cleaning	62	m2	30	1A
17	Waterproofing	1A	Mastic Asphalt	n/a	replace	825	m2	477	1A
18	Movement/expansion joints	1A	Asphaltic Plug Joint	low	replace	28	m2	275	1A
19	Finishes: deck elements	1A	High Build Epoxy Hydrocarbon Resin Modified Finish	moderate	paint	728	m2	90/176	2B/1A
21	Finishes: parapets/safety fences	1A	Other/Unknown Paint System	severe	paint	360	m2	44	1A
23	Handrail/parapets/safety fences	1A	Steel	mild	paint	360	m2	0	1A
24	Carriageway surfacing	1A	Asphalt	low	resurf	173/577	m2	154/246	2B/1A
25	Footway/verge/footbridge surfacing	1A	Asphalt	mild	resurf	74/248	m2	81/123	2B/1A
26	Invert/river bed	1A	Insitu Reinforced Concrete	severe	scour prot	1	No.	14682	2B
28	Fenders/cutwaters/collision protection	1A	Gabion Mesh Mattresses	severe	moderate	1	No.	22020	2B
30	Revetment/batter paving	1A	Precast Concrete Blocks - Open Jointed or Interlocking	severe	other	1	No.	58720	1A
31	Wing walls	1A	Insitu Reinforced Concrete	moderate	minor	4	m2	367	2B
35	Approach rails/barriers/walls	1A	Fabricated Steel, Rolled Steel, Steel, or Steel Plate	severe	replace	24	m2	147	1A

Eng Difficulty of maintenance activity / WK. Pattern & T. Management

ID	over water (navigable)	over water (tidal)	over railway	over road	at height	Stats	Others	Work Pattern Type	Duration (days)	T. Management Type	Duration (days)	Type	Duration (days)	Eng. Diff.
1	N	N	N	N	N	N	N	daytime	37	single way controlled	37			other
2														
6	N	N	N	N	N	N	N	daytime	4	single way controlled	4			N
8														
9	N	N	N	N	N	N	N	daytime	2	NA	22			
11	Y	Tidal	N	N	2 to 5m	N	N	daytime	9	single way controlled	9			other
12	Y	Tidal	N	N	5 to 8m	N	N	daytime	0.5	single way controlled	0.5	single way controlled	1	other
13	Y	Tidal	N	N	5 to 8m	N	N	daytime	3	single way controlled	3	single way controlled	5	other
14	Y	Tidal	N	N	5 to 8m	N	N	daytime	0.5	single way controlled	0.5	single way controlled	1	other
16	N	N	N	N	N	N	N	daytime	3	Hard-shoulder closure	3			
17	N	N	N	N	N	N	N	daytime	32	Contra-flow	32			
18	N	N	N	N	N	N	N	daytime	2	single way controlled	2			N
19	Y	Tidal	N	N	5 to 8m	N	N	daytime	20/40	single way controlled	20/40			other
21	N	Tidal	N	N	5 to 8m	N	N	daytime	5	pedestrian man.	5			
23	N	N	N	N	N	N	N	n/a	n/a	n/a	n/a			N
24	N	N	N	N	N	N	N	daytime	1.5/5	single way controlled	1.5/5	n/a	n/a	n/a
25	N	N	N	N	N	N	N	daytime	0.5/2	pedestrian man.	0.5/2			N
26	Y	Tidal	N	N	N	N	N	daytime	10	single way controlled	10			other
28	Y	Tidal	N	N	N	N	N	daytime	10	single way controlled	10			other
30	Y	Tidal	N	N	N	N	N	daytime	10	single way controlled	10			other
31	N	N	N	N	N	N	N	daytime	0.5	NA				
35	N	N	N	N	N	N	N	daytime	2	single way controlled	2			N

General Assumptions

No bracing

Maintenance of services not included but considered for maintenance of bridge elements where applicable

Pot Bearings

Add routine inspection of £15000 every 10 years (extra £5000 assumed as for estuary)

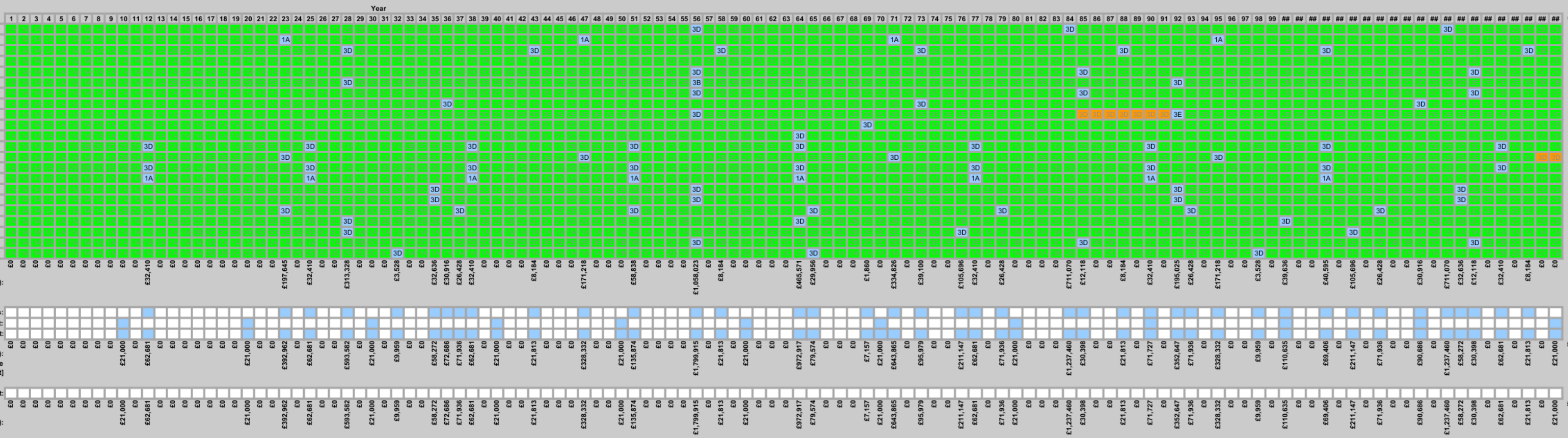
E.2 Maintenance activities for painted carbon steel solutions

Lifecycle Planner for Structures

Name:	Composite Bridge Study
Structure Reference:	Carbon Steel - Optimised - ESTUARY
Structure Type:	Bridge
Date of Last Inspection:	
Current Year:	2021

Maintenance Strategy:	"do-minimum"
Total 120-Year Cost (real):	£10,118,152
Total 120-Year Cost (disc.):	£1,800,779

Description of Strategy: the minimum required to sustain safety across the analysis period, e.g. infrequent/irregular but major interventions to satisfy/meet the minimum safety and preformance targets.



ID	CSS Element Description	CSS Element Importance	Start Sev./Ext.	Total Item Cost (real)	Total Item Cost (disc.)
1	Primary deck element	Very High	1A	£2,133,210	£269,947 #
2	Secondary deck element/s - beams	Very High	1A	£0	£0 #
6	Parapet beam or cantilever	Very High	1A	£57,289	£10,262 #
8	Foundations	High	1A	£0	£0 #
9	Abutments (incl. arch springing)	High	1A	£24,222	£3,016 #
11	Pier/column	Very High	1A	£479,437	£108,005 #
12	Cross-head/capping beam	Very High	1A	£7,729	£962 #
13	Bearings	High	1A	£92,748	£17,809 #
14	Bearing plinth/shelf	Medium	1A	£5,153	£758 #
16	Substructure drainage	Medium	1A	£1,860	£242 #
17	Waterproofing	Medium	1A	£393,525	£59,346 #
18	Movement/expansion joints	High	1A	£69,300	£16,753 #
19	Finishes: deck elements	Medium	1A	£848,479	£194,685 #
21	Finishes: parapets/safety fences	Medium	1A	£222,394	£53,764 #
23	Handrail/parapets/safety fences	High	1A	£0	£0 #
24	Carriageway surfacing	Medium	1A	£221,868	£40,968 #
25	Footway/verge/footbridge surfacing	Low	1A	£48,486	£8,944 #
26	Invert/river bed	Medium	1A	£184,993	£38,852 #
28	Fenders/cutwaters/collision protection	Medium	1A	£118,908	£24,460 #
30	Revetment/batter paving	Low	1A	£317,088	£64,430 #
31	Wing walls	High	1A	£4,404	£548 #
35	Approach rails/barriers/walls	N / A	1A	£10,584	£2,200 #
	Total Activity Cost (real):			£5,241,676	£915,952
	Uplift Cost for Work Pattern, TM, Eng. Difficulty of Scheme and Prelims:			£3,300,931	£581,382
	Other Cost:			£180,000	£42,719
	Design Cost:			£1,395,545	£260,726
	Total Scheme Cost (real): [Total Activity Cost + Uplift Cost for Work Pattern, TM, Eng. Difficulty of Scheme and Prelims + Other Cost + Design Cost]			£10,118,152	£1,800,779
	Revenue Cost:			£0	£0
	Total Scheme Cost + Revenue Cost (real):			£10,118,152	£1,800,779

E.3 Maintenance activities for weathering steel and duplex steel solutions

Lifecycle Planner for Structures

Name:	Composite Bridge Study
Structure Reference:	Stainless Steel - Optimised - ESTUARY
Structure Type:	Bridge
Date of Last Inspection:	
Current Year:	2021
Maintenance Strategy:	"do-minimum"
Total 120-Year Cost (real):	£8,517,419
Total 120-Year Cost (disc.):	£1,432,083
Description of Strategy:	the minimum required to sustain safety across the analysis period, e.g. infrequent/irregular but major interventions to satisfy/meet the minimum safety and preformance targets.

ID	CSS Element Description	CSS Element Importance	Start Sev./Ext.	Year (activities)	Total Item Cost (real)	Total Item Cost (disc.)
1	Primary deck element	Very High	1A	56: 3D; 84: 3D; 112: 3D	£2,133,210	£269,947 #
2	Secondary deck element/s - beams	Very High	1A	23: 1A; 47: 1A; 71: 1A; 95: 1A	£0	£0 #
6	Parapet beam or cantilever	Very High	1A	28: 3D; 43: 3D; 58: 3D; 73: 3D; 88: 3D; 103: 3D; 118: 3D	£57,289	£10,262 #
8	Foundations	High	1A		£0	£0 #
9	Abutments (incl. arch springing)	High	1A	56: 3D; 85: 3D; 114: 3D	£24,222	£3,016 #
11	Pier/column	Very High	1A	28: 3D; 56: 3B; 92: 3D	£479,437	£108,005 #
12	Cross-head/capping beam	Very High	1A	56: 3D; 85: 3D; 114: 3D	£7,729	£962 #
13	Bearings	High	1A	36: 3D; 73: 3D; 110: 3D	£92,748	£17,809 #
14	Bearing plinth/shelf	Medium	1A	56: 3D; 92: 3D	£5,153	£758 #
16	Substructure drainage	Medium	1A	69: 3D	£1,860	£242 #
17	Waterproofing	Medium	1A	64: 3D	£393,525	£59,346 #
18	Movement/expansion joints	High	1A	12: 3D; 25: 3D; 38: 3D; 51: 3D; 64: 3D; 77: 3D; 90: 3D; 103: 3D; 116: 3D	£69,300	£16,753 #
21	Finishes: parapets/safety fences	Medium	1A	12: 3D; 25: 3D; 38: 3D; 51: 3D; 64: 3D; 77: 3D; 90: 3D; 103: 3D; 116: 3D	£222,394	£53,764 #
23	Handrail/parapets/safety fences	High	1A	12: 1A; 25: 1A; 38: 1A; 51: 1A; 64: 1A; 77: 1A; 90: 1A; 103: 1A	£0	£0 #
24	Carriageway surfacing	Medium	1A	35: 3D; 56: 3D; 92: 3D; 113: 3D	£221,868	£40,968 #
25	Footway/verge/footbridge surfacing	Low	1A	35: 3D; 56: 3D; 92: 3D; 113: 3D	£48,486	£8,944 #
26	Invert/river bed	Medium	1A	23: 3D; 37: 3D; 51: 3D; 65: 3D; 79: 3D; 93: 3D; 107: 3D	£184,993	£38,852 #
28	Fenders/cutwaters/collision protection	Medium	1A	28: 3D; 64: 3D; 100: 3D	£118,908	£24,460 #
30	Revetment/batter paving	Low	1A	28: 3D; 76: 3D; 105: 3D	£317,088	£64,430 #
31	Wing walls	High	1A	56: 3D; 85: 3D; 114: 3D	£4,404	£548 #
35	Approach rails/barriers/walls	N / A	1A	32: 3D; 65: 3D; 98: 3D	£10,584	£2,200 #

Year	Total Activity Cost (real)	Total Scheme Cost (real)	Total Scheme Cost + Revenue Cost (real)
1	£0	£0	£0
2	£0	£0	£0
3	£0	£0	£0
4	£0	£0	£0
5	£0	£0	£0
6	£0	£0	£0
7	£0	£0	£0
8	£0	£0	£0
9	£0	£0	£0
10	£0	£21,000	£21,000
11	£0	£0	£0
12	£32,410	£62,681	£62,681
13	£0	£0	£0
14	£0	£0	£0
15	£0	£0	£0
16	£0	£0	£0
17	£0	£0	£0
18	£0	£0	£0
19	£0	£0	£0
20	£0	£21,000	£21,000
21	£0	£0	£0
22	£0	£0	£0
23	£26,428	£71,936	£71,936
24	£0	£0	£0
25	£32,410	£62,681	£62,681
26	£0	£0	£0
27	£0	£0	£0
28	£313,328	£593,582	£593,582
29	£0	£0	£0
30	£0	£21,000	£21,000
31	£0	£0	£0
32	£3,528	£9,959	£9,959
33	£0	£0	£0
34	£0	£0	£0
35	£32,636	£58,272	£58,272
36	£30,916	£72,686	£72,686
37	£26,428	£71,936	£71,936
38	£32,410	£62,681	£62,681
39	£0	£0	£0
40	£0	£21,000	£21,000
41	£0	£0	£0
42	£0	£0	£0
43	£8,184	£21,813	£21,813
44	£0	£0	£0
45	£0	£0	£0
46	£0	£0	£0
47	£0	£0	£0
48	£0	£0	£0
49	£0	£0	£0
50	£0	£21,000	£21,000
51	£58,838	£135,874	£135,874
52	£0	£0	£0
53	£0	£0	£0
54	£0	£0	£0
55	£0	£0	£0
56	£1,058,023	£1,799,915	£1,799,915
57	£0	£0	£0
58	£8,184	£21,813	£21,813
59	£0	£0	£0
60	£0	£21,000	£21,000
61	£0	£0	£0
62	£0	£0	£0
63	£0	£0	£0
64	£465,571	£972,917	£972,917
65	£29,956	£79,574	£79,574
66	£0	£0	£0
67	£0	£0	£0
68	£0	£0	£0
69	£1,860	£7,157	£7,157
70	£0	£21,000	£21,000
71	£0	£0	£0
72	£0	£0	£0
73	£39,100	£95,979	£95,979
74	£0	£0	£0
75	£0	£0	£0
76	£105,696	£211,147	£211,147
77	£32,410	£62,681	£62,681
78	£0	£0	£0
79	£26,428	£71,936	£71,936
80	£0	£21,000	£21,000
81	£0	£0	£0
82	£0	£0	£0
83	£0	£0	£0
84	£711,070	£1,237,460	£1,237,460
85	£12,118	£30,398	£30,398
86	£0	£0	£0
87	£0	£0	£0
88	£8,184	£21,813	£21,813
89	£0	£0	£0
90	£32,410	£71,727	£71,727
91	£0	£0	£0
92	£195,025	£352,647	£352,647
93	£26,428	£71,936	£71,936
94	£0	£0	£0
95	£0	£0	£0
96	£0	£0	£0
97	£0	£0	£0
98	£3,528	£9,959	£9,959
99	£0	£0	£0
100	£39,636	£110,635	£110,635
101	£0	£0	£0
102	£0	£0	£0
103	£40,595	£90,228	£90,228
104	£0	£0	£0
105	£105,696	£211,147	£211,147
106	£0	£0	£0
107	£26,428	£71,936	£71,936
108	£0	£0	£0
109	£0	£0	£0
110	£30,916	£90,686	£90,686
111	£0	£0	£0
112	£711,070	£1,237,460	£1,237,460
113	£32,636	£58,272	£58,272
114	£12,118	£30,398	£30,398
115	£0	£0	£0
116	£32,410	£62,681	£62,681
117	£0	£0	£0
118	£8,184	£21,813	£21,813
119	£0	£0	£0
120	£0	£21,000	£21,000

Cost item	Total (real)	Total (disc.)
Total Activity Cost (real):	£4,393,197	£721,267
Uplift Cost for Work Pattern, TM, Eng. Difficulty of Scheme and Prelims:	£2,754,108	£454,222
Other Cost:	£180,000	£42,719
Design Cost:	£1,190,114	£213,876
Total Scheme Cost (real): [Total Activity Cost + Uplift Cost for Work Pattern, TM, Eng. Difficulty of Scheme and Prelims + Other Cost + Design Cost]	£8,517,419	£1,432,083
Revenue Cost:	£0	£0
Total Scheme Cost + Revenue Cost (real):	£8,517,419	£1,432,083