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Stainless steel composite bridge study

– A summary of ARUP reports

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In 2011 and 2012 Outokumpu commissioned Ove Arup & Partners Ltd to investigate in detail the use of stainless steel in composite bridge constructions both as related to the initial cost of building the bridge and to the life cycle cost LCC over a 60-year period. This is a summary report of the two extensive study reports:

- Stainless Steel Composite Bridge – Study Report [1]
- Stainless Steel Composite Bridge – Life Cycle Cost for Maintenance Study [2]

The full reports can be requested through your local Outokumpu sales representative.

Abstract

A comparison of costs of using duplex stainless and carbon steel in a steel-concrete composite bridge has been undertaken. The study considers both the total construction cost and life cycle cost. The study has shown that it is possible to design bridge beams in stainless steel to a cost which is comparable to carbon steel. The savings in reduced maintenance costs over a 60 years service life with a stainless design can be in the range of 30-40% compared to painted carbon steel. For longer service lives, the savings in maintenance cost for a stainless bridge will be even higher.

Introduction

Outokumpu commissioned Arup to investigate the implications of designing steel-concrete composite bridges using stainless steel. Such bridges within the UK and continental Europe commonly use structural steels (e.g. S355 to EN 10025-2) or structural steels with improved corrosion resistance, “weathering steels” (e.g. S355W to EN 10025-5).

Using stainless steel for such bridges provides superior durability characteristics to the structure, such as reduced maintenance costs and the removal of the need for re-painting and without the negative aspects posed by the use of weathering steels. However, there is a perception that the cost of stainless steel for such purposes would be prohibitively high. These studies seek to investigate and challenge this perception by taking advantage of the enhanced mechanical properties of stainless steel as well as its durability.

Bridge Description

A two-span integral bridge, each span 28 m, carrying a two-lane roadway. The reinforced concrete deck acts compositely with four main girders of constant depth.

The bridge carries a 2-lane single carriageway rural road over another road. The carriageway has 1.0 m wide marginal strips and has a 2 m wide footway on either side. A four-girder arrangement has been chosen, and a deck slab thickness of 250 mm has been assumed. The deck cantilevers 1.6 m outside the centerlines of the outer girders.

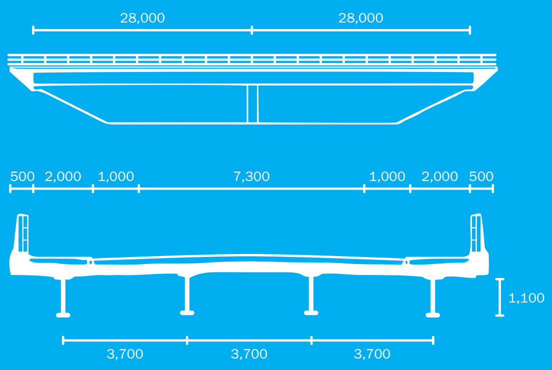

Figure 1 The reference composite highway bridge design [3].

Materials

The following materials have been used as part of the study:

- Carbon steel: S355 to EN 10025-2 (used in reference design)
  Nominal yield stress = 355 N/mm²
- Weathering Steel: S355W to EN 10025-5
  Nominal yield stress = 355 N/mm²
- Duplex stainless steel: EN 1.4462 to EN 10088-2
  Nominal yield stress = 460 N/mm²
- Lean Duplex stainless steel EN 1.4162 to EN 10088-2
  Nominal yield stress = 450 N/mm²

Two different duplex steels were included. Although these two steels have different levels of corrosion resistance they have similar strengths, and consequently from a bridge design perspective give similar results. Lean Duplex (EN 1.4162) is a more cost effective option in less aggressive environments. Guidance on stainless steel material selection for structural applications is given in Eurocode EN 1993-1-4 Annex A.

The stainless design study including an optimized design

A reference design for a steel-concrete composite highway bridge was used as the context for the study. Using this bridge as a basis, the implications of changing the steel type have been investigated. The reference design used was taken from the UK Steel Construction Institute's publication "Composite Highway Bridge Design: Worked Examples" (Publication 357) [3].

Design standards

The design standards used for the study were the relevant Eurocodes [4, 5, 6, 7] covering the design of stainless steel and steel composite bridges. UK national annexes [8, 9, 10, 11] to the Eurocodes have been chosen as these were used in the reference design. The study findings should be representative for countries with differing national annexes.

The design study first considered a simple replacement of S355 carbon steel beams with duplex (and lean duplex) stainless steel beams, utilizing the higher strength of the duplex stainless steel to potentially allow thinner beam web and flanges, but without altering the basic design concept. It was concluded that it is not the material strength of the cross section that primarily governs the design, but the stability/stiffness of the structure as a whole. Therefore, the increased material strength of duplex stainless has only a modest impact. The result of this initial study was that duplex (and lean duplex) stainless steel can offer a weight reduction of 12% compared to the carbon steel reference design, and that weathering steel resulted in a 6% increase due to the necessary corrosion allowance.

In order to more fully utilize the higher strength of duplex stainless steel, a second phase of the study was undertaken to consider possible design changes that could be adopted in order to optimize the material usage for duplex stainless steel. The optimized design was within the rules of the design standards, but made some changes to the concepts for the beam geometry and bridge construction methodology. These optimizations were to change the plan bracing design during the construction phase, add additional splice locations and change the cross section of the beams so that they can be designed as "compact". The result of applying these strategies resulted in a total decrease of the weight by 39%.

The total cost of the construction, shown in Figure 2, is a high level budgetary estimate of the total bridge construction costs including all materials, fabrication and installation costs. The optimized lean duplex (EN 1.4162) design resulted in a total construction cost similar to the carbon steel reference design. Although the lean duplex steel (EN 1.4162) has a higher cost per ton than carbon steel the use of a lower weight of duplex stainless steel beams, and the cost of painting of carbon steel results in overall similar construction cost. The optimized design applied on the duplex (EN 1.4462) steel resulted in a total construction cost 6% higher than the reference carbon steel design, but only 2% higher cost than for the weathering steel.

Maintenance cost over 60 years life time

The potential benefit of duplex stainless steel on maintenance costs was assessed using four scenarios:

1. Bridge over a minor road.
2. Bridge over a main road.
3. Bridge over a marine estuary.
4. Bridge over an electrified railway.

For these scenarios the analysis was carried out for the "service life" of the bridge, i.e. operate and maintain. Any cost analysis provided does not include feasibility, design, construction, disposal or salvage costs for the bridge. The "service life" is determined to be 60 years as this is consistent with other economic transport appraisals, although bridge design lives can often be much longer than this. In this analysis duplex (EN 1.4462) and lean duplex (EN 1.4162) stainless steel are considered equal, i.e. that an appropriate material selection has been made for the service environment which results in negligible need for maintenance interventions.

The LoBEG (London Bridge Engineering Group) Lifecycle Planner for Structures was used to determine how the bridge will behave/deteriorate throughout its service. The Planner provides a consistent approach to assess the lifecycle maintenance requirements of a structure and to allow for comparability between different scenarios.

A typical maintenance strategy was adopted where minimum maintenance is carried out to sustain safety of the structure across the analysis period. This means there are infrequent/irregular but major interventions to satisfy safety and performance targets. In addition, nominal inspections have been included to allow for principle inspections and miscellaneous repairs every 10 years. It was assumed that the stainless steel would not require any major interventions over the service life, but that painted carbon steel would require a suitable level of re-painting and repair appropriate to the environment.

The result of the study is that in all cases both grades of stainless steel gave a lower life cycle cost than painted carbon steel. Only direct costs were included in this analysis. The magnitude of the cost saving was related to the degree of difficulty (and hence cost) of access for inspection and repair. This is a combination of engineering difficulty (e.g. electrified railway, working at height, working over water etc) which increase the duration of the inspection, repair work and the associated costs. Figure 3 demonstrates the difference in maintenance cost between painted carbon steel and duplex stainless steel over a 60 year period. Many bridges today are designed with lives up to 120 years, and it can be anticipated that even greater life cycle cost savings will accrue with use of stainless steel over longer life spans.

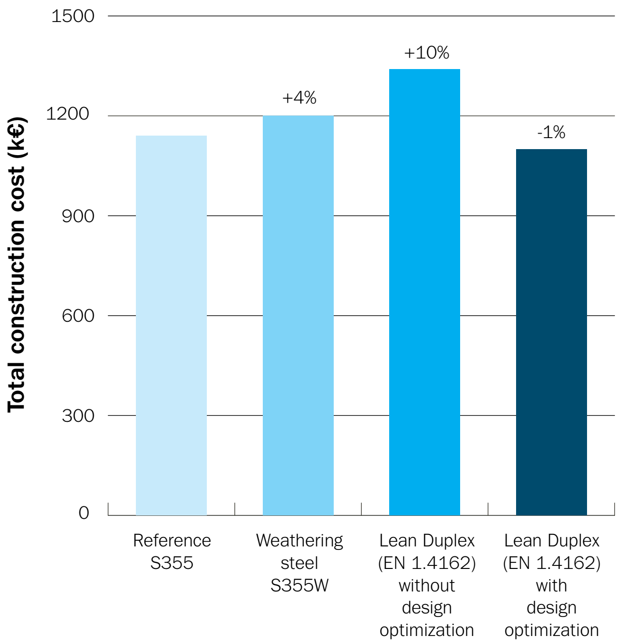

Figure 2 The total construction cost of lean duplex (EN 1.4162) stainless steel compared to the reference designs.

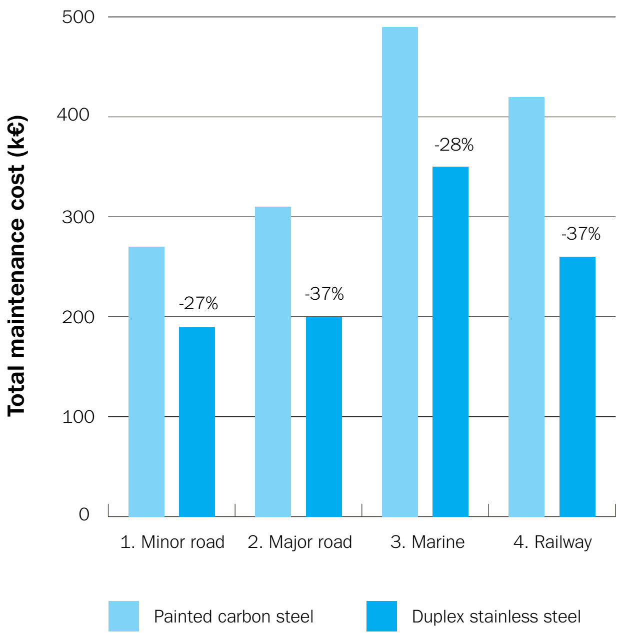

Figure 3 Comparison of the total maintenance cost between painted carbon steel and duplex stainless steel for all four road scenarios.

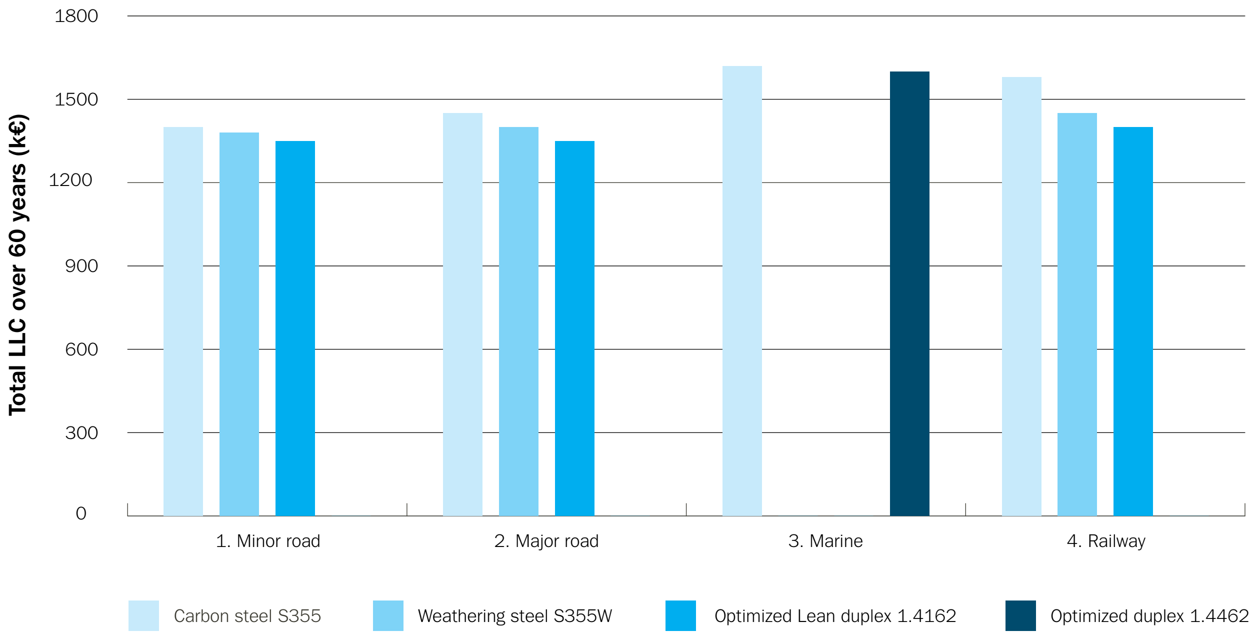

Figure 4 The total construction cost + maintenance cost over 60 years for the carbon steel designs and for the optimized lean duplex (EN 1.4162) and duplex (1.4462) stainless steel design.

Summary of the two ARUP reports

In the original reports, no conclusions were drawn from the summary of the two studies. With the simplification that the maintenance cost for weathering steel is similar to stainless steel the summary graph in Figure 4 is obtained. The weathering steel is not considered for the marine application, as it has a high corrosion rate in marine atmospheres and is usually not used in such locations.

Figure 4 demonstrates the cost competitiveness over the 60-year period of the optimized lean duplex (1.4162) design even further than in Figure 2 where only the construction cost is considered. In the marine scenario the duplex stainless steel 1.4462 is chosen for the comparison due to the more severe corrosion conditions expected.

It can be argued that a similar optimized design as for lean duplex stainless steel can also be applied to S355 carbon steel and weathering steel. This will in most road scenarios still give a cost competitive lean duplex scenario compared to an optimized carbon steel and a slightly higher cost than for the weathering steel design. However, this is not likely to happen since most carbon steel bridge designs use standard beam dimensions, while for stainless steel the designer has the opportunity to optimize the design since they are fabricated specifically for each project. There is also less incentive to optimize carbon steel beams because the material is relatively cheap, such that fabrication and erection costs are dominant.

Conclusions

The study has shown that it is possible to design bridge beams in stainless steel to a cost which is comparable to carbon steel. The savings in reduced maintenance costs over a 60 years service life with a stainless design can be in the range of 30-40% compared to painted carbon steel. For longer service lives, the savings in maintenance cost for a stainless bridge will be even higher.

References

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