

# THE USE OF STAINLESS STEEL REINFORCEMENT IN BRIDGES



**BSSA**

Special BSSA Report - April 2003

## INTRODUCTION

This Special Report provides a summary of a report prepared by Arup Research & Development (AR&D) as part of a group project organised by the British Stainless Steel Association (BSSA) and sponsored by Acerinox, Arcelor (Ugine Savoie), Arminox, AvestaPolarit, Cogne, The Nickel Development Institute (NiDI) and Valbruna.

The report updates an original commissioned by AvestaPolarit (then Avesta Sheffield). BSSA and the sponsors acknowledge their appreciation to AvestaPolarit for making the original report available as a contribution to the current project.

The aims of the current work were:

- To distil the findings of the original work into a form suitable for public dissemination.
- To update the original project report to take account of developments in the use of stainless steel reinforcement since the original work was undertaken. Particularly the issue of the updated standard for stainless steel reinforcement BS6744:2001 and Highways Agency advice note BA84/2002.
- To develop and publish a cost model to evaluate the costs associated with using stainless steel using current market prices.

This report addresses the first of these objectives.

## CORROSION OF REINFORCEMENT IN CONCRETE

It is now recognised that under certain conditions of exposure reinforced concrete may not be as durable a material as is often expected. This is particularly so in atmospheric exposure where contamination of the concrete with chlorides may occur, such as in marine/coastal situations or for structures that can be contaminated with road de-icing salts. Under these conditions transport of chloride through the cover zone of the concrete can lead to corrosion of the reinforcement well within the intended design life of the structure. The resulting corrosion can result in difficult and expensive repairs to the structure.

A number of approaches have been developed to address this problem, both in terms of design of new structures and remedial works for existing structures affected by corrosion. However, most of these approaches tend to rely, to varying degrees, on modifying the concrete surrounding the reinforcement as

opposed to selecting a reinforcement material that is inherently corrosion resistant in the given environment. To a considerable extent the lack of use of corrosion resistant reinforcement to deal with this corrosion risk has been due to the perceived initial cost of using such reinforcement; particularly stainless steel.

However, structure owners are now increasingly aware of the costs and liability associated with assessing the extent of corrosion and carrying out remedial works particularly on highway structures. This awareness has led to a renewed interest in the use of stainless steel reinforcement to minimise the risk of corrosion of concrete structures exposed to road de-icing salts.

## TRACK RECORD AND USES OF STAINLESS STEEL REINFORCEMENT

The use of stainless steel reinforcement is not new and dates back to the late 1930's and a comprehensive list of examples of use can be found in the Concrete Society, Technical Report 51<sup>1</sup>.

In addition to this track record a considerable volume of academic and practical research has been undertaken throughout Europe over the last 30 years; much of this research is summarised in a European Federation of Corrosion publication<sup>2</sup>. Arguably the most important research programmes that are of relevance are those undertaken in Italy by Pedefferri<sup>3</sup> and co-workers and in the UK at the Building Research Establishment (BRE)<sup>4</sup>.



*Progresso Pier, Mexico, built in 1944, an early example of the use of stainless steel reinforcement  
Photo courtesy of NiDI ( [www.nidi.org.uk](http://www.nidi.org.uk) )*

The Italian work has provided a detailed understanding of the corrosion resistance of stainless steel in high pH, high chloride environments. The work showed that the commonly used grades

of stainless steel (1.4301 and 1.4401) retain passivity and corrosion resistance at pH values typical of concrete and chloride levels much higher than those typically encountered in civil engineering structures. The resistance to corrosion of various stainless is shown in figure 1.

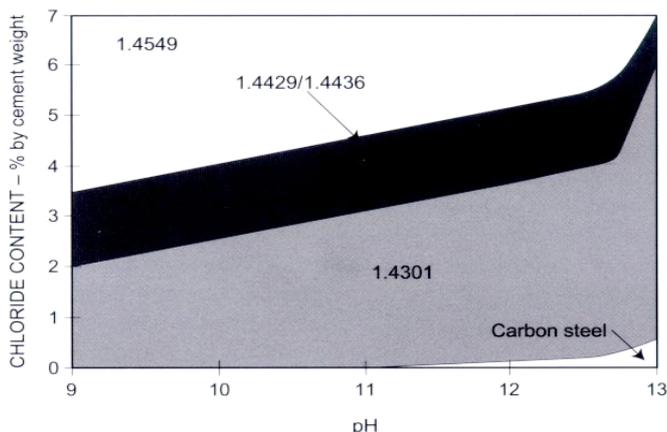


Figure 1. Corrosion resistance measured as a function of pH and chloride content <sup>5</sup>

The work of the BRE was a series of exposure trials that commenced in the early 1970's and ran for over 20 years. Samples of concrete with various different types of reinforcement (including a range of stainless steels) cast in, were exposed at a range of UK sites that would be expected to cause corrosion of carbon steel reinforcement: these included coastal and marine locations. At various intervals over the 20 year period the concrete samples were recovered and broken open to allow inspection of the bars: no corrosion on any of the stainless steel samples was reported.

In more recent times the UK the Highways Agency (HA), the organisation responsible for the UK trunk road system of motorways and other primary routes, has undertaken research into the use of stainless steel and this has resulted in the publication of definitive guidance for use on UK highway structures<sup>6</sup>. This guidance is important for a number of reasons:

- It is the first authoritative guidance on the use of stainless steels from a public organisation in Europe.
- For the first time guidance exists that provides a rational methodology for the selection and use of stainless steel reinforcement.
- The guidance aims to use stainless steel only for those structures, or parts of structures, that are at significant risk of corrosion.
- Although the guidance is aimed at UK highway structures the approach given can be easily used or adapted to other applications.

The guidance document BA84/02 provides detailed guidance that is referred to in the HA design standard BA57/01 (and related advice note BA57/01) and is based on the 2001 revision of BS6744<sup>7</sup>.

## BA84/02 – KEY COMPONENTS

The research that led to the publication of BA84/02 indicated two key areas that were barriers to the wider use of stainless steel because of the impact these factors could have on cost. These were:

- A lack of guidance on the selection of an appropriate material grade of stainless steel for a given situation.
- Lack of guidance on assessing corrosion risk and therefore where the use of stainless was appropriate.

In addition the research also showed that the benefit of high concrete pH on the stability of the passive film on stainless steel in concrete was not taken advantage of in terms of amending design for durability rules developed for carbon steel reinforcement.

These three issues are addressed succinctly in the BA either by description or in the form of default tables.

In assessing the risk of corrosion and where stainless steel should be used the BA provides a number of options depending on the severity of exposure or difficulty of future maintenance. The emphasis of this section is to target stainless steel in those areas that are, historically, known to be at a high risk of chloride induced corrosion. This is dealt with in Section 3 of the BA and summarised in Table 1, although it should be noted that this table is not included in the BA.

Situation	Notes
Total substitution of stainless steel for major components	The BA recommends that this approach is limited to structures or elements where there is a high element of chloride induced corrosion or where future maintenance is extremely difficult. The BA lists bridge decks and exposed columns/piers in a central reserve as examples
Element of new structures that are exposed to seawater or are in seawater splash zones	Recommends total replacement with stainless steel above low water spring tide at a height of 5m. Also for edge beams and soffits exposed to spray.
Elements of structure adjacent to the carriageway exposed to chlorides from de-icing salts	Examples given are bearing shelves below joints, abutment faces and parapet edge beams on most highway structures.

Table 1. Summary of the use of stainless steel reinforcement given in BA84/02

Having defined areas that are at risk of chloride induced corrosion the BA then provides a means of selecting a grade of stainless steel for the application being considered. This is shown in Table 2.

Exposure Condition	Material Grade
Stainless steel embedded in concrete with normal exposure to chlorides in soffits, edge beams, diaphragm walls, joints and substructures.	1.4301
As above but where design for durability requirements are relaxed in accordance with Table 3.7.	1.4301
As above but where additional relaxation of design for durability is required for specific reasons on a given structure or component i.e. where waterproofing integrity cannot be guaranteed over the whole life of the structure.	1.4436
Direct exposure to chlorides and chloride bearing waters for example dowel bars, holding down bolts and other components protruding from the concrete.	1.4429 1.4436
Specific structural requirements for the use of higher strength reinforcement and suitable for all exposure conditions.	1.4462 1.4429

Table 2. Selection of material Grade for given exposure condition

Finally the BA recommends changes to Design for Durability rules developed for carbon steel, Table 3.

Design condition	Relaxation
Cover	Cover for durability can be relaxed to 30mm where stainless steel is used irrespective of the concrete quality or exposure conditions.
Design crack width	Allowable crack width increase to 0.3mm
Silane treatment	Not required on elements with stainless steel.

Table 3. Relaxations of carbon steel design for durability requirement.

Note: The changes given in the above table are those acceptable to the UK HA; where the HA are not part of the project it may be possible to relax these requirements further.

## DESIGN EXAMPLES

Two design examples have been assessed using two bridges, typical of modern UK designs, previously designed by Ove Arup & Partners. These were redesigned replacing carbon steel with grade 1.4301 stainless steel as indicated in Table 3, using two

different strength grades of stainless steel reinforcement (500Nmm<sup>2</sup> and 650N/mm<sup>2</sup>). The redesign also took account of the beneficial effects of relaxing the design for durability requirements for carbon steel as recommended in BA84/02

The redesign allowed compilation of a series of Bills of Quantities for each option studied from which the reinforcement and bridge cost could be estimated and compared to the reference design (all carbon steel reinforcement).

The provision of stainless steel in specific locations according to the HA guidelines resulted in percentage cost increases. The amount of this increase is dependent on the relative percentages of reinforcement in the particular bridge and the assumed cost of the reinforcement. For bridge 1, the percentage increase ranged from 1.7% to 11% and for bridge 2 from 1.4% to 11%.



Highnam Bridge A48 Reinforcing cage, 1998  
Photo courtesy of SBS Stainless Bbar Sales

In the original work carried out for AvestaSheffield cost estimates were prepared for the various options of using stainless steel. It was recognised that this price range was conservative and probably did not reflect the price available in a competitive market.

The current project has modified and developed the original cost calculation model to enable the user to input any given value for the cost of stainless steel and then recalculate the overall cost for structural elements and the overall construction cost. This tool can therefore be used to take account the variability of:

- Cost in stainless steel reinforcement over time.
- Cost between different material grades.
- Cost between ranges of bar sizes.
- Cost between straight, bent and fixed bars.

The model should therefore provide a more commercially representative method of assessing the cost of using stainless steel reinforcement. The default values for the cost of stainless used within the model are based on those published in section 2.2 of BA84/02 as £1680 per tonne for bar diameters up to 20mm and £2350 per tonne for bars greater than 25mm diameter for grade

1.4301. These default values were applicable in September 2000.

**The cost model and a copy of the full report and analysis are available on a CD-Rom from the British Stainless Steel Association.**



*Old Post Office Bridge, Cheriton, Hampshire, 2001  
Photo courtesy of Arminox UK*

## CONCLUSIONS

The publication of a revised edition of BS6744 in 2001, followed by the publication of the new Highways Agency Advice Note BA84/02 on the use of stainless steel reflect the increased interest in the potential use of stainless steel in UK construction.

The adoption of the recommendations in these documents, particularly BA84/02, regarding the selection and use of the stainless steel reinforcement will result in the cost effective use of this type of reinforcement. The cost impact of using stainless steel reinforcement can be assessed, for two typical bridge designs, using the cost model developed as part of this project work.

Although this report and the cost model relate to specifically to the use of stainless steel reinforcement in bridges and related civil engineering structures the same basic approach to the use of stainless steel reinforcement can be used on other forms of structure unrelated to highways work.

## REFERENCES

- 1) THE CONCRETE SOCIETY, *Guidance on the use of stainless steel reinforcement*, Technical Report No. 51, 1998.
- 2) Ed. J MIETZ, R POLDER & B ELSENER, *Corrosion Reinforcement in Concrete (EFC 31)*, The Institute of Materials 2000
- 3) PEDEFERRI, P. *Stainless steels in concrete*, Proceedings of COSTS21 Workshop, Paris, 20-21 April 1998.
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- 5) PEDEFERRI, P, *et al*, *Behaviour of stainless steels in concrete*. Repair and rehabilitation of reinforced structures: the state of the art. Ed: Silva Arya, W.F. *et al*. American Society of Civil Engineers 1998
- 6) THE HIGHWAYS AUTHORITY, *Use of Stainless Steel*

*Reinforcement in Highway Structures*, BA 84/02: Design Manual for Roads and Bridges, Volume 1, Section 3, Part 15, HMSO 2002

- 7) BRITISH STANDARDS INSTITUTION, BS 6744:2001 *Stainless steel bars for the reinforcement of and use in concrete – Requirements and test methods*, BSI 2001



*Broadmeadow Bridge, Dublin, 2001  
Picture courtesy of Ove Arup & Partners*

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