# Rationale for using Stainless Steel Reinforcement in the UK Construction Industry

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## 1.0 Introduction

It is now established that in environments that result in the exposure of concrete reinforced with plain carbon steels to environments that allow transport of chlorides to the reinforcement can result in serious corrosion. The source of chlorides is, now, mainly from exposure to road de-icing salts on in the splash and atmospheric zones of marine structures. The traditional approach to improving the durability of reinforced concrete structures, as given in design codes and standards, has been through changes to the concrete specification; in terms of mix design and/or cover requirements. While this approach can improve the performance it is not an inherently durable solution to the problem of chloride-induced corrosion. Therefore there remains a risk that within the design, or intended life, of a structure it will need to be maintained. This maintenance is, more often than not, difficult, disruptive and expensive.

In the last 5 years there has been an increasing interest in alternative approaches to durability that do result in inherently durable structures, at least in respect of corrosion. One option is to use materials that are inherently durable in the probable service environment. A seemingly obvious option for use as reinforcement is stainless steel but the use of these materials has been hindered by the perception that the use of stainless steel would be prohibitively expensive. In part this perception has been due to a lack of authorative guidance on the appropriate use of stainless steel.

This paper outlines the approach developed in the UK in relation to the cost effective use of stainless steel reinforcement. In particular the approach has been developed for use on highway structures, such as bridges but the basic approach can, with minor modifications, be adapted for other types of structures in similar environments. The technical case for the use of stainless steel is not considered in detail in this paper as this has been reported elsewhere[1,2]. Rather it outlines the methodology of approach to using stainless steel that reduces the premium, on initial cost, that results from the use of stainless steel.

## 2.0 Historical

The first known use of stainless steel reinforcement was on the Progresso Pier in the Gulf of Mexico in @1940. The structure used the equivalent of modern grade 1.4301 steel to reinforce the arches of the pier, there are no significant reported uses of stainless steel as reinforcement for the next 40 years.

However, in the early 1970's when it became apparent that chloride could cause serious corrosion problems for reinforcement the Building Research Establishment (BRE) commenced a programme of research into the use of different materials for reinforcement. This work continued for over 20 years and although the excellent performance of stainless steel was reported in the literature[3,4,5] it was not adopted by design codes and standards in any meaningful manner.

This did not prevent the occasional use of stainless steel reinforcement on structures considered to be at risk of corrosion or where very long design lives were required. In 1998 the Concrete Society published a technical report[6] on the use of stainless steel reinforcement. This report went a considerable way to providing a case for using stainless steel and also provided a good list of uses in the UK. However, the document fell some way short of providing definitive guidance on key issues relating to the use of stainless steel; in particular when to use stainless steel and when to use particular grades of stainless steel.

The UK Highways Agency, responsible for the design, maintenance and refurbishment of the UK motorway and trunk road system initiated their own research programme on the possible uses of stainless steel in highway structures. This work was undertaken between 1998 and 2000 by Arup Research & Development and took, as it's starting point the Concrete Society report.

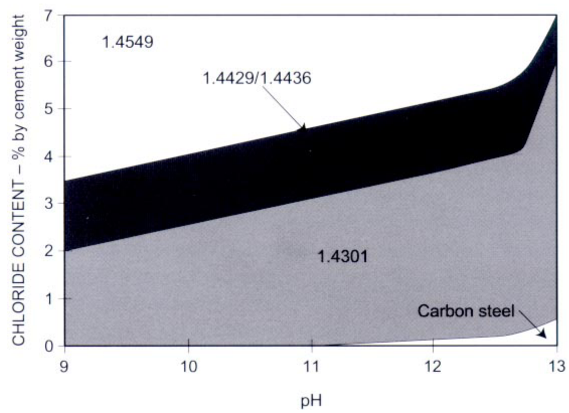



Figure 5. Corrosion resistance measured as a function of pH and chloride content

Reviewing this report it became very clear from the uses reported that there was, apparently, no rational basis for the use of stainless steel in respect of where to use a given grade or indeed when to use stainless steel at all. In terms of selecting an appropriate material grade the only explanation that could be offered was that in most cases this was based on the grade that would be used for atmospheric exposure, taking no account of any beneficial effects of the concrete surrounding the reinforcement. It was also apparent from the report that where stainless steel had been used the opportunity had not been taken to amend other design for durability rules relevant to carbon steel but not stainless steel and that in many cases stainless steel had been used more widely than was necessary on particular structures.

The aim of the HA research was therefore to investigate a possible framework that addressed these points and would result in the publication of definitive guidance on the use of stainless steel reinforcement. The result of this work was the publication of a Departmental Advice Note BA84/02[7] on the use of stainless steel reinforcement for highways structures that is briefly described in the rest of this paper.

| Class of Element | Elements where stainless steel is preferable | Notes |
|---|---|---|
| **A** | All (excluding foundations and piles) | This category only applies to structures where access for maintenance is difficult and disruptive i.e. a major river or rail crossing. Or where routine maintenance such as replacement of waterproofing is disruptive. Such extensive use needs to be justified by a cost benefit analysis including traffic delay costs. |
| **B** | All elements above low water spring tide level to a height of 5 metres above high water spring tide | Consideration should be given to using stainless steel on soffits and edge beams if subject to spray. |
| **C** | Parapet edge beams, bearing shelves on jointed bridges, abutments and intermediate supports adjacent to the carriageway | It is expected that the majority of highway bridges on the trunk road network will fall into this category. |
| **U** | None | All parts of structure are classified as remote from the carriageway or unlikely to be exposed to chlorides, particularly piles and foundations. |
| **E1** | Elements that have suffered widespread chloride induced corrosion. | For most structures the objective is to avoid the risk of having to repeat similar repairs in the future. |
| **E2** | Elements where maintenance is particularly disruptive and difficult. | Elements covered by Categories B & C should also be considered. |

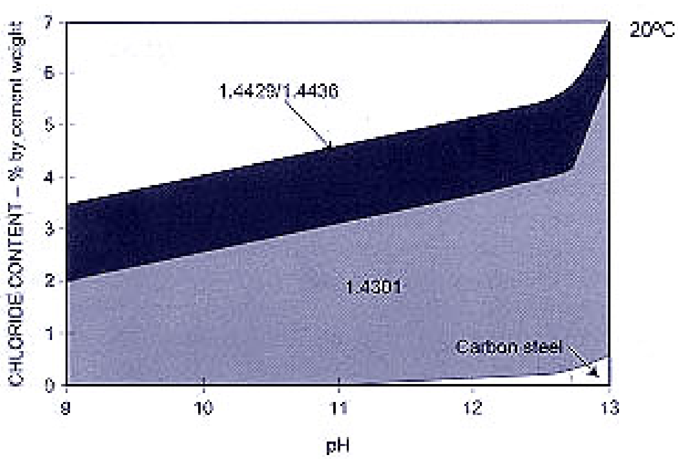
**3.0 Materials Selection**

It is a fact that stainless steels are expensive materials compared to carbon steel reinforcement and that the more highly alloyed the grade the more (significantly) expensive the material will be. It is therefore essential that if cost premiums are to be minimised the most appropriate grade of material should be selected for a given exposure condition. In the case of stainless steels the important parameters that influence the selection of material grade are:

- The possible chloride concentration that may occur within the service life
- The effect of concrete pH on the corrosion resistance of stainless steel.

For highways, and other, structures with design lives in excess of 100 years the possible chloride concentrations are something of an unknown and something that is very difficult to predict with confidence. However, the concentrations that cause problems for carbon steel are reasonably well known and the concentrations that might build up over periods of up to 60 years are known and can be of the order of 5% by weight of cement. However, an uncertainty remains as to what actual levels will be encountered it is therefore necessary that the grade of material selected has sufficient margin to take account of this.

The basis for the selection of material grade uses the work of Pedeferri[8] in Italy, a summary of this is shown in Figure 5.




It can be seen from Figure 1 that the corrosion resistance of stainless steels increases with increasing pH and, more importantly, this resistance is very much greater than for carbon steels.

Experience and evidence from existing structures[9] indicates that the chloride concentrations in concrete vary and that typically these are less than 1% but can increase to the order of 2% in some instances. These levels are well within the limit predicted from Figure 1 for this type of steel. At higher chloride levels 1.4436 type steels could be used with greater confidence.

This data can be used to suggest a sound basis for the selection of stainless steel grades for a given environment. Such a table has been proposed in the BA84/02 and is shown in Table 1.

| 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. | 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<br>1.4436 |
| Specific structural requirements for the use of higher strength reinforcement and suitable for all exposure conditions. | 1.4462<br>1.4429 |

Table 1. Selection of steel grades for different exposure conditions.

The recommendations of this table reflect the corrosion resistance of stainless steel when fully embedded in concrete of normal pH; it is important that this pH is maintained if the corrosion resistance is to be optimised. It will be seen that in most applications the use of a lean alloy grade is acceptable. The table also recommends that in some situations, where higher chloride contents might be encountered, a higher grade of steel should be used and these are discussed in subsequent sections.

**4.0 The selected use of stainless steel reinforcement**

If it is accepted that stainless steel reinforcement is significantly more expensive than ordinary reinforcement it makes sense to develop guidance on using the material only in those areas where there is a significant risk of corrosion. This risk can be identified in terms of:

- Whole structures that are at risk
- Major structural elements that are at risk
- Parts of structural elements that are at risk

In addition structures can also be classified in terms of the consequences of the need for future maintenance and repairs:

- Structures or parts of structures where maintenance is unacceptable
- Structures where maintenance is either severely disruptive or prohibitively expensive
- Structure where maintenance is possible with minimal disruption

Using this type of classification it is possible for individual structures or structural elements to identify the locations where it is appropriate to use stainless steel to be effect. In general terms the BA suggests the approach or classification given in Table 2.

| 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 risk of chloride induced corrosion or where future maintenance is extremely difficult. The BA list bridge decks and exposed columns/piers in a central reserve as examples. |
| Elements of new structures that are | Recommends total replacement with stainless steel above |

| | |
|---|---|
| exposed to seawater or are in seawater splash zones | low water spring time for a height of 5m. Also for edge beams and soffits exposed to spray. |
| Elements of structure adjacent to the carriageway exposed to chlorides from deicing salts | Examples given are bearing shelves below joints, abutment faces and parapet edge beams on most highways structures. |

Table 2. Structures where stainless steel is recommended.

**5.0 Changes to Design for Durability**

The design rules that have been developed for the durability of reinforced concrete reflect the most common reinforcement material that is used, carbon steel, and this is reflected in the approach of most standards and guidance documents. The approach adopted is, broadly, one that aims to improve the quality of concrete as a material and/or increase the protective cover layer over the reinforcement, it is implicit in this approach that durability is achieved by decreasing the permeability of concrete to chloride ion ingress.

When considering the use of corrosion resistant reinforcement there may be scope for reducing the overall cost impact of the reinforcement material by relaxing some of these durability requirements. However, it must be emphasised that in changes to these rules must not lead to a situation in which the overall quality of the concrete surrounding the bars is reduced to such a level that the pH of concrete cannot be maintained. To do so would significantly reduce the corrosion resistance of stainless steel reinforcement. Nonetheless there is scope for some modification to the rules.

The rule changes recommended in BA84/02 are summarised in 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 condition. |
| Design crack width | Allowable crack width increased to 0.3mm |
| Silane treatment (a penetrating, hydrophobic surface treatment) | Not required on elements with stainless steel. |

Table 3. Changes to durability rules where stainless steel reinforcement is used.

The first of these changes can be significant, as cover for most environments is in excess of 50mm of concrete and in more extreme conditions maybe as high as 75mm. For large structural elements this reduction is therefore significant in its own right and may also have other beneficial effects in reducing the overall size of foundations and the amount of reinforcement needed in the steel. The increase in allowable crack width is also beneficial as in some structural elements it may lead to a reduction in the overall size and quantity of reinforcement that is required and thereby reducing costs.

In addition to the elimination of hydrophobic impregnation materials such as silane it may also be possible to eliminate other costly coatings such as waterproofing. The BA takes a very conservative approach to this change as there is concern in the HA that the omission of such membranes may cause other problems. However, these risks are offset by the use of higher grade stainless steel, 1.4436, and there has been a precedent set for approach that predates the issue of the BA on the Highnam Bridge near Gloucester. Potentially the omission of waterproofing membranes offers a considerable saving in both time and money as these membranes typically cost in the region of £25 to £50m².

**6.0 Recent examples of the use of stainless steel reinforcement**

The following three examples of the use of stainless steel reinforcement each show a benefit of using stainless steel in a particular application. It should be noted that these examples are not intended to be an exhaustive list of the use of stainless steel reinforcement.

**6.1 Highnam Bridge Widening – A48 Gloucester, UK**

It is standard practice on UK highway structures to provide a waterproofing membranes to bridge decks; the use of these materials has greatly reduced the problems that are often associated with corrosion of reinforcement in decks. However, such membranes are expensive and slow to apply particularly on the upgrading or refurbishment of existing structures where only partial road closures are permitted.

On the Highnam Bridge there were particular constraints on lane closures due to the narrow nature of the structure. In practice the refurbishment of the water proofing membrane would have effectively required the closure of the bridge, something that was unacceptable. It was therefore proposed that the new reinforced concrete cross beams were fabricated without reliance on the use of waterproofing membranes and were instead provided with stainless steel reinforcement. The grade of steel used was 1.4436.

The Highnam Bridge predated the issue of the UK HA guidance but it is likely that the conservative specification of stainless steel reinforcement would be followed even now after the publication of the guidance. This is because bridge decks that are subject to road de-icing salts can be exposed to higher levels of chlorides and the consequences of future maintenance are to the deck are far more serious.

This bridge sets an interesting precedent as it is possibly the only modern UK bridge that has been constructed where the waterproofing membrane has been omitted.

### 6.2 Broadmeadow Bridge, Dublin, Eire

This structure carries a new motorway over a tidal estuary to the north of Dublin. The main columns supporting the structure are formed of reinforced concrete and are exposed to tidal fluctuations of brackish (chloride containing waters). The design life of the structure is 120 years and it probable that chloride ingress to the level of the reinforcement would occur within this design life. In addition the estuary itself is environmentally sensitive and the client required a structural solution that would be maintenance free for the whole of the specified design life.

The exposure conditions and the requirement for such long maintenance free life naturally led to the consideration of stainless steel for the reinforcement. At the time of design we were undertaking research for the UK HA and had not developed the guidance document. Our recommendations with respect to the selection of material type and grade therefore adopted a more cautious approach than would perhaps be the case today.

Given the exposure conditions and long life the material grade selected for the main reinforcement (40mm diameter bars) of the columns was grade 1.4436 to BS6744[10]. It is probable that if the structure were designed with current guidance in mind the grade of reinforcement that would be selected would be 1.4403 and that some relaxation of design for durability requirements would be achieved.

### 6.3 Highway structures in Hong Kong

The marine and coastal environment of Hong Kong is one that has caused problems for the durability of steel and reinforced concrete structures. As a consequence of this the Hong Kong utility organisations, such as Highways Department, are now very aware concrete durability issues and expect designers of major infrastructure projects to take these concerns into account during design. Currently most designers approach this problem in a conventional manner by improving the design and specification of concrete or by showing through probabilistic models of concrete mixes that corrosion is unlikely within the life the of the structure.

However, the limits of this approach are now being realised and there is an increasing incidence of tender specifications requiring the designer to make provisions for secondary methods of corrosion control, such as cathodic protection, in the original design and construction of highway structures.

On two current major infrastructure projects, which cannot be named in this paper, Arup are actively advocating a fundamentally different approach to durability that does not rely on the accepted methods of achieving durability. This approach is based on the use of conventional concrete mixes and stainless steel reinforcement for the outer layers of the bars. This approach is essentially based on that given in the UK HA guidance document. Initial discussions with client organisations has proved positive and it to be hoped that one, or both, of these major projects will commit to the use of stainless steel reinforcement and therefore set an acceptable precedent for it's use in Hong Kong.

## 7.0 Conclusions

The recognition that reinforced concrete structures may not be, in some instances, as durable as intended has led to much research into methods and means of improving the durability. It is only relatively recently that serious consideration has been given to the use of corrosion resistant reinforcement as a means of preventing corrosion of reinforcement. Of the available materials for use in this application, the most well established are stainless steels and these steels can easily be adopted for use with current design standards and rules.

The UK Highways Agency has developed a standardised and rational approach to the use of stainless steel reinforcement for use on bridges. This approaches takes account of the exposure risk of structures, or structural, elements and selects appropriate types and grades of material to address this risk. At the same time the guidance developed allows designers to offset potentially cost increases arising from the use of stainless steel by relaxing other rules developed for design for durability.

The approach given in the HA guidance can be easily adapted to cover other types of structure (such as car parks and marine structures) and could also form the basis for more general rules for use outside the UK.

Work for the BSSA has researched the use of stainless steel reinforcement in accordance with the HA rules and this work has shown that the resultant cost is actually a relatively small proportion of the overall initial construction costs.

The situation in the UK is now one in which there is no longer a technical barrier to the use of stainless steel and the development of this market. However, there remains a challenge for the steel producers and suppliers to develop this market to ensure all in the supply chain are aware of the developments and to make a case for stainless steel.

This paper was presented at ISSF-7 in Berlin, 2003-05-12.

## 8.0 Rebar discussion (summary)

The guest speaker, Graham Gedge from Arup, challenged the stainless steel industry to step up its joint marketing efforts for stainless steel rebar. "The concrete boys have been doing this for 30 years – you have a lot of catching up to do!"

FACTS FOR A COORDINATED APPROACH TO THE MARKET:

**The market**
There is definitely a market for stainless steel rebar. A few examples: USA: 30% of the road bridges are in bad shape (0,5 million bridges!). Germany: 80.000 road bridges need to be repaired.
But, the target must be: only those parts of the structures where the corrosion resistance is needed. Not 100% stainless!

**Preconditions**:
Local/regional design codes and standards
Please learn from the British example
(High strength thinner gauge rebar is interesting, but a bit complicated, since bending resistance easily becomes a limiting factor)

**Costs**:
The general perception that stainless steel is too expensive must be corrected. This is only true, if 100% of the rebar is made of stainless (=> appr 30% higher initial construction costs) Selective use brings this down to 0-15%, depending on how much and where it is used. In most cases selective use will result in increases of the order of 5%.

**Other selling points**:
a) Public sector projects – example motorways
A smooth traffic is very dear to people. Politicians will listen very carefully to suggestions regarding how to avoid "constant" closing down of motorway lanes for repair work. Stainless Steel offers the solution: max 15 vs 120 years lifetime!

b) Private sector projects – example bridges
Waterproofing membranes or silane treatment are often required to increase bridge durability. Both of these are costly and applied towards the end of bridge projects. They also imply regular future repair work. Stainless Steel offers quicker bridge erection and a maintenance free future

*ISSF recommends its long products members to coordinate regional/national promotional approaches, aimed at both public and private rebar users*

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