Stainless steel reinforcing bar

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Introduction

The growing interest in stainless steel reinforcing bar, (rebar), has been principally influenced by Highways Authorities in the western world due to the premature failure of carbon steel in reinforced concrete highway bridges. Alarmed at the extent of corrosion damaged structures, and the high cost of repair, their focus over the past decade has been on solutions and materials to provide sustainable construction for the design life of 120 years.

This presentation will briefly outline the role of steel reinforcement in concrete, show the suitability of stainless steel, and outline the advances made over the past decade in standards and guidance documents to assist the civil engineer in designing cost-effective and durable structures using stainless steel.

Concrete construction – the role of reinforcement

Concrete is an excellent building material when in compression. Take for example, the Dome of the Pantheon in Rome that was built in the 2nd century. It has an interior diameter of 43 metres and the height to the oculus is also 43m. Internally the Dome is a perfect hemisphere and has only therefore to transmit compression forces, arising from its 5,000 tonne self weight, to the massive walls that support it.

It has no steel reinforcement. So, sustainable construction can be achieved without the use of reinforcing steel. But few structures today, if any, are the same perfect structural form. Current design standards tend to efficient use of materials which leads to slender structures and a more complex array of forces than simple compression. Concrete is not a good material in tension, but steel is, and that is the principal reason for its deployment. In most concrete structures, the tension forces generated are highest towards the outer surfaces of the structure and steel reinforcement is therefore placed close to the surface with a minimum layer of concrete cover.

Initially, the high pH of new concrete offers a degree of protection to the steel but in time, due to the penetration of carbon dioxide, the pH of the concrete reduces, and the protection to the steel is depleted.

Concrete is a porous material and wet/dry weather cycles permit the capillary action of moisture into the concrete. In coastal areas the prevailing moisture carries chlorides from sea-salts. In appropriate climates, significant volumes of de-icing salts are applied to highways and bridges in winter periods. Water run-off has therefore high concentrates of chloride ion that can penetrate the finest of cracks in the concrete, or through deck joints or junctions such as bearing shelves. On reaching the reinforcing steel, the chloride ion initiates corrosion, and the resulting expansionary forces cause the concrete to crack and spall. The time to repair is frequently less than 20 years.

Many purported solutions to the corrosion problem have been considered. These include coated bar, cathodic protection, increased concrete cover, concrete additives, but none
different materials for their suitability as reinforcement.has been considered the total solution. One major study for the Federal Highways Authorities in the US involved the assessment of 57 (1) The conclusion was that 1.43xx (316) stainless steel was the most suitable material for the design life of highway bridges of 120 years.

It is the cost of repair, however, that has alarmed the highways agencies responsible for the network of roads and bridges that make up the infrastructure. The cost of corrosion world-wide has been estimated to be US$550 billion.

Case studies - The cost of repair

The following examples illustrated the high cost of repair. 1. Thane Bridge over the backwaters of the Arabian Sea near Mumbai, India.

After only ten years of service, a five year life extension cost eight times the original cost of construction.

2. Janek Sethu bridge (over a railway line), India   Built in 1981 at a cost of Rs.9 crore (1 crore = 10 million rupees) a partial repair in 1999 cost 23.5 Rs. Crore.

3. Lidingo River crossing railway bridge, Stockholm, Sweden.   This 1100m long steel and concrete bridge, built in 1971, suffered from corrosion of the carbon steel reinforcement in the tidal zone. The essential repair of the 24 piers cost €1.5 million and took two years to complete. By using stainless steel rebar for the repair the durability has been estimated at 100 years.

4. Midland Link Viaduct, UK.   Built in 1972 at a cost of £28m, evidence of corrosion became apparent after two years of operation. By 1989, £45m had been spent on repair. By 2010 it is estimated that a further £120m will be spent on repair.

It is the infrastructure, however, and highway bridges in particular, where the effect of corrosion has greatest impact. Repairs to bridge structures generally involve lane closures, traffic disruption, traffic queues and delays, and sometimes detours. Motorway lane closures, that are necessary to protect the workforce during the period of repair, are calculated in the UK by the Highways Agency using their QUADRO programme [queues and delays at road works] but can be £10,000/hour depending upon traffic density.

It has been shown by long term tests that it has h

The case for stainless rebar

Austenitic stainless steel is eminently suitable as reinforcement in concrete.

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2. It is produced in a range of diameters from 3 to 50mm, and to strength levels higher than carbon steel.

(3)3. It has been shown in test that there is no adverse galvanic reaction between stainless steel and carbon steel in concrete. 4. When using stainless steel reinforcement, concrete cover can be reduced, not increased as (4)would be necessary with carbon steel. 5. The periodic sealant coating given to concrete, Silane, is eliminated when using stainless steel (4)reinforcement. 6. Requires no ongoing monitoring as would be necessary, for example, with cathodic protection methods.

Effect of using stainless steel on Capital Cost

Although the initial cost of stainless steel is considerably higher than carbon steel, increased durability of a structure can be achieved cost-effectively by placing the stainless steel in the elements of the structure at highest risk to corrosion and using carbon steel for the remainder.

Selective substitution, as it has become known, has been accepted by the major highways authorities in the Western World.

The effect on initial capital cost of using this method of construction can be seen in the new Broadmeadow Bridge in the Irish Republic. This 313m long highway bridge over marshland carries the main motorway carriageway across the estuary. Stainless steel reinforcement was used for the starter bars in the deck, to make the connection, in the 12m high supporting columns, and in the safety parapets. The use of stainless steel reinforcement added 8% to the total cost of the reinforcement for the complete project but the increase in total construction cost was only 2.9%. The contractor commented that he was '…delighted to increase the durability for such a small increase as repair in this marshland environment would be very expensive.'

Standards

There are two Standards for stainless steel reinforcing bar: • In the USA: ASTMA955/A955M-03b • In the UK: BS6744:2001.

In addition there are: 1. National Standards & Official Admission DS13080 and DS13082 in Denmark 2. Admissions in Italy by Serviizuo Tecnico Centrale Ministero 3. Admissions by Institut fur Bautechnik in Germany 4. La Norme XPA A35-014 in France 5. SFS-1259 in Finland.

Design Guidance

1. The Design Manual for roads and bridges – Volume 1, Section 3, Part 15, Use of stainless steel reinforcement in highway structures, issued by the UK Highways Agency. This manual classifies bridge structures according to the degree of exposure. It also identifies the elements in the structure where stainless steel should be sited for durability.

2. The use of stainless steel reinforcement in bridges, CD-Rom, issued by the British Stainless Steel Association, contains a cost analysis tool which allows users to recalculate costs for two reference bridges initially designed using carbon steel reinforcement. Drop down menus allow the user to insert (a) the grade of stainless steel (b) the strength of stainless steel, and (c) the cost/tonne of the reinforcement.

Elements of a bridge structure can be analysed individually.

3. T.81 Beton arme D'inox, Le choix de la duree. Issued by idinox and CIMbeton (Centre d'information sur le ciment et ses applications).

4. Guidance on the use of stainless steel in concrete, Technical Report No.51, issued by the Concrete Society, UK.

5. ISSF web site for stainless steel rebar.

Typical Applications

Stainless steel rebar can be used in all reinforced concrete construction. In addition to highway bridges it has been installed in underpasses, sea defence walls, marine docks, Cathedrals, Historic Buildings, and Tower structures. In the case of Dubai Docks, severe corrosion of the epoxy coated rebar after only ten years service, has resulted in the complete sea wall having to be rebuilt using stainless steel rebar.

In London, the extension to the Lord Mayor's famous 700 year old Mansion House has been constructed using stainless steel rebar to match the long life of the existing historic building.

Conclusions

It has been shown that sustainable construction can be achieved for a small increase in capital cost. It has also been shown that the cost associated with premature failure is considerably greater than the initial additional expenditure. The ongoing benefits to future generations, however, in building a highly durable infrastructure, are significant and will result in improved traffic flow, and a major reduction in repair costs.

The Stonecutters Bridge and the Western Corridor Bridge in Hong Kong, currently under construction, contain thousands of tonnes of stainless steel not just for reinforcement, but for cladding of the towers. It is there to provide durability. No maintenance to the exposed tower cladding is intended for the next hundred years.

If these examples of design for sustainability are adopted for all structures, expensive repair can be eliminated.

References

1. David McDonald, Donald Pfeifer, Paul Virmani, *Corrosion resistant reinforcing bars, findings of a 5 year study*. International conference on corrosion and Rehabilitation of Reinforced Concrete Structures, December 1998, Orlando, Florida.

th2. Cox R.N., Oldfield J.W., *The long term durability of austenitic stainless steel in concrete.* Proceedings of the 4 International Symposium on Corrosion of Reinforcement in Concrete Construction, Society of Chemical Industry, 1996, pp 662 – 669.

3. L.Bertolini, M.Gastaldi, M.P.Pedeferri, P.Pedeferri, *Effects of galvanic coupling between carbon steel and stainless steel reinforcement in concrete*, International conference on corrosion and rehabilitation of reinforced concrete structures, Orlando, Florida, December 1998. Proceedings on CD-Rom.

4. The Highways Agency. BA84/02: *Design manual for roads and bridges* – Volume 1, Section 3, Part 15, Use of stainless steel reinforcement in highway structures.