## Tracking industrial trends

# Bridges, corrosion and lifecycle cost thinking

In his quarterly column, Gary i. Crawford of Mettle Strategic Creativity talks about the costs of corrosion and the modern approaches being adopted to better manage the life and lifecycle costs of bridges and other structures.

Some disciplines seem to find a sense of stability by adhering to the practices and beliefs of the past. For example, it is not uncommon to hear bridge engineers say that no sooner have they erected a bridge that they have to start preventing it from falling down. 'Solace from the inevitability of decay' rather than the 'positive predictability of designed-in lifespan', as it were.

Of course, the main culprit in bridge decay is corrosion of the steel components.

Corrosion converts a refined metal to a more chemically stable form, such as its oxide, hydroxide, or sulphide. It is the gradual destruction of materials by chemical and/or electrochemical reaction with their environment. Rusting, the formation of iron oxides, is a well-known example of electrochemical corrosion. This type of damage typically produces oxides or salts of the original metal and results in the distinctive orange colouration. Corrosion degrades the useful properties of materials and structures including strength, appearance and permeability to liquids and gases.

The primary cause of corrosion of steel bridges is exposure of the steel to atmospheric conditions. This is exacerbated by marine (salt spray) and industrial environments and the only corrosion prevention method for these structures in these environments is a barrier coating.

Until very recently little consideration was given at the design stage to ensure longevity of bridges.

According to the National Cooperative Highway Research Program (*'Bridge Life-Cycle Cost Analysis' – NCHRP Report 483 – 2003*) the United States of America has 614 387 bridges, almost four in ten of which are 50 years or older.

56 007 (9.1%) of the nation's bridges were structurally deficient in 2016 and, on average, there were 188-million trips across these deficient bridges each day. While the number of bridges that are in such poor condition is decreasing, the average age of America's bridges keeps going up and many are approaching the end of their design life.

The most recent estimate puts the cost of the nation's bridge rehabilitation needs at US$123-billion and this is likely to keep increasing.

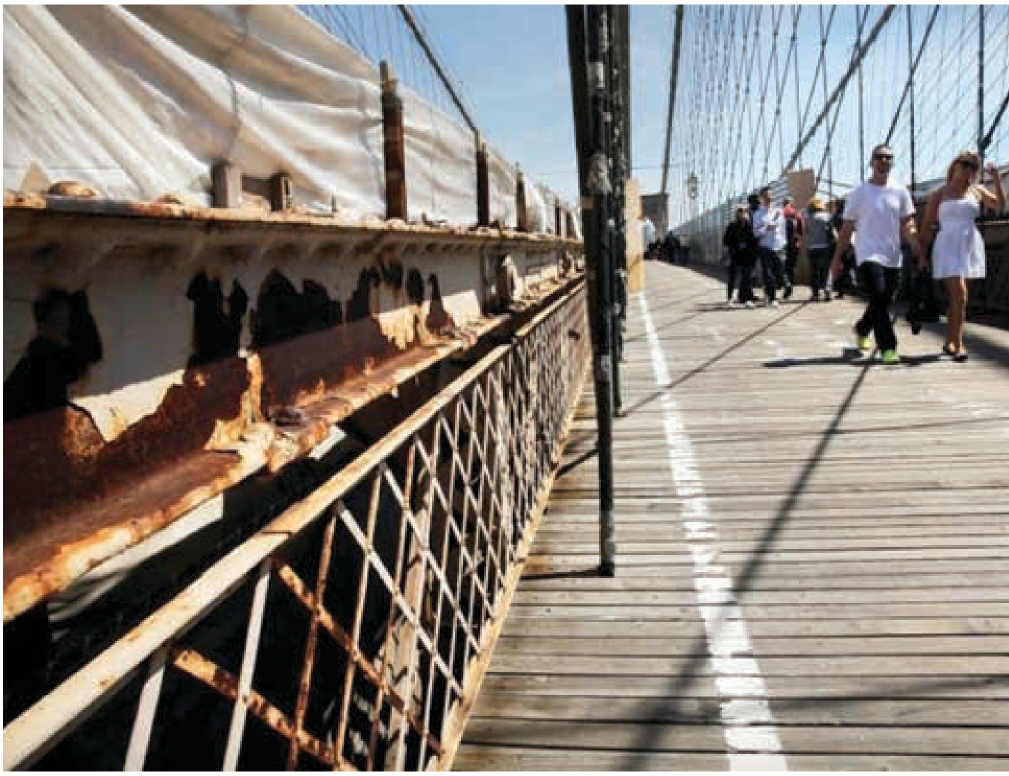
According to the U.S. Department of Commerce Census Bureau, the annual direct cost of corrosion for highway bridges is estimated to be between $6.43- and $10.15-billion, consisting of: $3.79-billion to replace structurally deficient bridges over the next 10 years; $1.07- to $2.93 billion for maintenance and capital cost of concrete bridge decks; $1.07- to $2.93 billion for maintenance and cost of capital for concrete substructures and superstructures (minus decks); and $0.50-billion in maintenance painting costs for steel bridges.

Lifecycle analysis estimates indirect costs to the user due to traffic delays and lost productivity at more than 10 times the direct cost of corrosion. In addition, it was estimated that employing 'best maintenance practices' versus 'average practices' may save 46% of the annual corrosion cost of a black steel rebar bridge deck, or $2 000 per bridge per year.

The National Cooperative Highway Research Program of 2003 was the first serious attempt to introduce lifecycle costing to the world of bridge design and maintenance. Until then, bridge repair and maintenance costs were seemingly worn as 'badges of courage' ... with costs 'proudly' communicated. For example, the George Washington Bridge, crossing the Hudson River in New York was completed in 1931 at a cost of $75-million and maintenance to date exceeded US$1-billion.

A common rule of thumb is that maintenance costs about 4.0% of the initial construction cost per year. For a structure as old as the George Washington Bridge, that's a lot of 4.0%'s, even though some attempts were made to build in longevity.

In 2005, the *New York Times* reported that



*The repair of the Brooklyn Bridge in Manhattan, originally scheduled for completion in 2005, took until 2016 to complete and total costs of fixes and improvements rose more than US$600-million.*

repairs to the Brooklyn Bridge were $100-million over budget and the completion date had been pushed back yet again due to major cracks and holes discovered during the five years of work. Engineers discovered more than 3 000 new structural 'flags' on the city's most famous span, which increased the costs of repairs and improvements from $508-million to more than $600-million.

The 1 595-foot span was originally set to fully reopen in 2006, but actually took until 2016.

Thankfully, since the publication of the NCHRP's *'Bridge Life-Cycle Cost Analysis'*, sanity seems to have begun to prevail, with lifecycle costing entering the world of bridges and other major structural designs.

Changes in environmental protection regulations have brought about a transformation in the approach to corrosion protection. Until the late-1970s, virtually all steel bridges were protected from corrosion by multiple thin coats of lead- and chromate-containing alkyd paints applied directly over mill scale on the formed steel. Maintenance painting for prevention of corrosion was rare and primarily practiced on larger bridge structures. Since the majority of the steel bridges in the interstate highway system were constructed between 1950 and 1980, most of these structures were originally painted in this manner. Therefore, a large percentage of the steel bridges are protected from corrosion by a coating system that is now beyond its useful service life.

Moreover, the paint system most commonly used contains chromium and lead, which are no longer acceptable because of the effect they have on humans and the environment. Bridge engineers of today have a choice between replacing the lead-based paints with a different coating or painting over the deteriorating areas. Removal of lead-based paint incurs high costs associated with the requirements to contain all the hazardous waste and debris.

Developments include improved and environmentally safe coating systems and methodologies to optimise the use of these systems, such as 'zone' painting, which involves adjusting coating types and maintenance schedules based on the aggressiveness of the environment within different zones on a bridge.

*In its '2017 Infrastructure Report Card', the American Society of Civil Engineers brought some common sense to the table: "New technologies and materials are helping engineers build bridges that last longer. New materials such as high performance steel, ultra-high performance concrete, and composites are being used to add durability and longer life to bridges."*

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The stainless steel family of alloys has an important role to play in structures. Of the most widely used Austenitic grades 1.4301 (304) and 1.4401 (316), containing about 17-18% chromium and 8-11% nickel, 304 is suitable for rural, urban and light industrial use, whereas the more highly alloyed 316 performs well in hostile marine environments.

Load-bearing applications have led to a demand for 'lean' duplex grades in which the mechanical and corrosion properties of the duplex grades are combined with a leanly alloyed composition. Grade 1.4162 (LDX2101) is ideal for applications in construction with a proof strength in the range of 450 to 530 N/mm$^2$.

Stainless steel is also becoming the material of choice for concrete reinforcement. It has a high resistance to corrosion particularly in chloride bearing concrete (from de-icing salts or seacoast exposure). Significant reductions in maintenance and repair will result in applications where the structure is subject to adverse corrosion.

An article, published in the May 1995 issue of *'Concrete International'*, concludes that both "field and laboratory data have shown that stainless steel rebar is capable of maintaining excellent corrosion resistance in severe chloride environments," and that "the chloride tolerance for stainless steel was shown to be significantly greater than that of mild steel." This article also concludes that the "use of stainless steel is warranted when guaranteed long-term corrosion resistance is required."

As the International Stainless Steel Forum states: "Material selection is a decisive factor for the durability of infrastructural buildings and installations. It is the key to maximum availability and low lifecycle cost."

Other rehabilitation methodologies designed to extend the service life of concrete bridges include: cathodic protection, electrochemical chloride removal, overlays, and sealers. Although each of these methods has been shown to be successful, continuing developments are necessary to improve effectiveness and increase the life extension they offer.

It does appear that bridge engineers 'have seen the light' when it comes to designing for structural life expectancy. Hopefully, other engineers will follow suit and not design structures with in-built 'time bombs.'

The message is clear. Design engineers should consider the costs across a structure's entire lifecycle to make smart design and material decisions. ❑