Supporting presentation for lecturers of Architecture/Civil Engineering

Chapter 07A:
Structural Applications of Stainless Steel Reinforcing Bar

See also: stainlesssteelrebar.org
Wrong choice of materials can lead to big problems
A textbook case: Corrosion of the Turcot highway interchange in Montreal\textsuperscript{1,2}

- A key interchange between Decarie (North-South) and Ville Marie (East-West) highways, built in 1966.
- Over 300,000 vehicles per day
- Made of reinforced concrete, badly corroded today by deicing salts
It will have to be replaced

- In spite of constant supervision and repairs, it will have to be removed or partially replaced,
  - Cost estimate so far CAD 3000M.
  - Moreover, CAD 254M will have to be spent to ensure safety until its replacement in 2018

- Lifespan of the structure will be only 50 years!
How reinforced concrete can be damaged by corrosion
Diffusion of corrosive ions (usually chlorides) into concrete:

Steps:

1. Once corrosive ions reach the carbon steel rebar \((t_0)\), corrosion begins.
2. Corrosion products, which occupy a greater volume than steel, exert an outwards pressure.
3. Concrete cracking occurs \((t_1)\), opening easy access to chlorides.
4. Concrete cover cracks (spalling) \((t_3)\), exposing the rebar.
5. If unattended corrosion continues until the rebar cannot bear the applied tensile stresses and the structure collapses \((t_4)\).
Concrete often exhibits cracks, though which corrosive ions reach quickly the steel.
Here are some causes of crack formation (ref. 4).
Please note that cracks do not take place immediately, and will also occur in concealed areas, where they cannot be repaired.

<table>
<thead>
<tr>
<th>Type of cracking</th>
<th>Form of crack</th>
<th>Primary Cause</th>
<th>Time of Appearance</th>
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</thead>
<tbody>
<tr>
<td>Plastic settlement</td>
<td>Above and aligned with steel reinforcement</td>
<td>Subsidence around rebar; excessive water in the mix</td>
<td>10 minutes to three hours</td>
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<tr>
<td>Plastic shrinkage</td>
<td>Diagonal or random</td>
<td>Excessive early evaporation</td>
<td>30 minutes to six hours</td>
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<tr>
<td>Thermal expansion and contraction</td>
<td>Transverse (example: across the pavement)</td>
<td>Excessive heat generation or temperature gradients</td>
<td>One day to two or three weeks</td>
</tr>
<tr>
<td>Drying shrinkage</td>
<td>Transverse or pattern</td>
<td>Excessive water in the mix; poor joint placement; joints over-spaced</td>
<td>Weeks to months</td>
</tr>
<tr>
<td>Freezing and thawing</td>
<td>Parallel to the concrete surface</td>
<td>Inadequate air entrainment; non-durable coarse aggregate</td>
<td>After one or more winters</td>
</tr>
<tr>
<td>Corrosion of reinforcement</td>
<td>Above reinforcement</td>
<td>Inadequate concrete cover; ingress of moisture or chloride</td>
<td>More than two years</td>
</tr>
<tr>
<td>Alkali-aggregate reaction</td>
<td>Pattern cracks; cracks parallel to joints or edges</td>
<td>Reactive aggregate plus moisture</td>
<td>Typically, over five years, but may be much sooner with highly reactive aggregate</td>
</tr>
<tr>
<td>Sulfate attack</td>
<td>Pattern cracks</td>
<td>External or internal sulfates promoting the formation of ettringite</td>
<td>One to five years</td>
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</table>
Proper choice of materials is a good long-term investment
The Progreso Pier (1/3)\textsuperscript{5,6}

At Progreso, Mexico, a pier was built in 1970.
The marine environment made the carbon steel rebar corrode – the structure failed.
The Progreso Pier (2/3)

The neighbouring pier had been erected in 1937 – 1941 using stainless steel reinforcement.
The Progreso Pier (3/3)

Ever since then, it has been maintenance free and remained in pristine condition.
Major civil engineering structures must last over 100 years now
Haynes Inlet Slough Bridge, Oregon, USA 2004

An unusual arch-hinged bridge with 400 tons of stainless steel reinforcing bar in its deck. The 230m-long link over Haynes Inlet Slough is expected to last 120 maintenance-free years. Although stainless steel costs a lot more than average steel, the bridge life-cycle cost will be greatly reduced.
Hong Kong- Zhuhai- Macau Bridge\(^9\)
(construction began in 2009, to be completed in 2018)

The prestigious Hong Kong- Zhuhai- Macau causeway project is one of the largest bridge projects in the world. The life time requirement is 120 years without maintenance. Therefore stainless steel reinforcement has been specified in the critical areas of the structure, mainly in splash zones. Eventually 15000MT of stainless will be used.
Broadmeadow Bridge, Dublin, Ireland (2003)

A new construction built over the estuary using 105MT of stainless steel reinforcement in the columns and parapets.
Dam repair
Bayonne, France

Dam built in the 1960s to protect the entrance to the harbour

The ocean side is higher and protected by 40T blocks which must be replaced as the storms wear them

On the river side a 7m wide platform allows the heavy-duty cranes to lift the blocks

Cracks on the deck and wall required repairs

Aerial view
Section through the sea wall

Sea wall repair
Bayonne, France
Platform and sea wall have been reinforced with lean duplex stainless steel (EN 1.4362)¹¹

Sea wall repair under way
Early 2014 gale over the dam
Stonecutters Bridge Hong Kong\textsuperscript{12,13}

The world’s second longest spanning cable-stayed bridge, with a main span of 1,018m. The towers are 298m tall with 1,600 tonnes of structural stainless steel in the cable-stay anchorage zone and 2,800 tonnes of stainless rebar in the reinforced concrete lower part of the towers.
To assure long-term (100 years) durability and resistance to the corrosive attack of the area’s marine environment and road salt, the bridge units and parapet barriers were reinforced with stainless steel grade 2205 rebar.
When should stainless steel rebar be considered:

- In corrosive environments:
  - Sea water and even more in hot climates
    - Bridges
    - Piers
    - Docks
    - Anchors for lampposts, railings, ....
    - Sea walls
    - ....
  - Deicing salts
    - Bridges
    - Traffic overpasses and interchanges
    - Parking garages
- Waste water treatment tanks
- Desalination plants
- In structures with a very long life
  - Repairs of historic structures
  - Nuclear waste storage
- In unknown environments in which
  - Inspection is impossible,
  - Repairs are almost impossible or very expensive
Comparison of stainless rebar with alternative solutions

<table>
<thead>
<tr>
<th></th>
<th>Advantages</th>
<th>Drawbacks</th>
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<tbody>
<tr>
<td>Epoxy coating</td>
<td>Lower initial costs</td>
<td>▪ cannot be bent without cracking</td>
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<td></td>
<td></td>
<td>▪ Requires careful handling to avoid damaging it during installation</td>
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<tr>
<td>Galvanizing</td>
<td>Lower initial costs</td>
<td>▪ cannot be bent without cracking</td>
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<td></td>
<td></td>
<td>▪ No longer effective when the zinc coating has been corroded</td>
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<tr>
<td>Fiber-reinforced Polymers</td>
<td>Lower initial costs</td>
<td>▪ Cannot be bent without cracking</td>
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<td></td>
<td></td>
<td>▪ No heat resistance and poor impact resistance in harsh winters</td>
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<td></td>
<td></td>
<td>▪ Lower stiffness than that of steel</td>
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<td></td>
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<td>▪ Cannot be recycled</td>
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<td>STAINLESS STEEL</td>
<td>Low Life Cycle cost:</td>
<td>▪ Higher initial cost, but no more than a few % when</td>
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<td></td>
<td>• Design similar to C-steels</td>
<td>✓ Stainless is selected for the critical areas</td>
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<tr>
<td></td>
<td>• Mixed C-steel/stainless reinforcements</td>
<td>✓ Lean duplex grades are selected</td>
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<tr>
<td></td>
<td>work well</td>
<td></td>
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<td></td>
<td>• Easy installation, insensitive to poor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>workmanship</td>
<td></td>
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<tr>
<td></td>
<td>• No maintenance</td>
<td></td>
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<td></td>
<td>• No life limit</td>
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<tr>
<td></td>
<td>• Allows a thinner concrete cover</td>
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<td></td>
<td>• Better fire resistance</td>
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<td></td>
<td>• 100% Recycled to premium stainless</td>
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<td><strong>Cathodic protection</strong></td>
<td>- Requires careful design for overall protection</td>
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<td>- Requires careful installation to maintain proper electrical contacts</td>
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<td>- Requires a permanent source of current (which must be monitored and maintained) or sacrificial anodes that require monitoring &amp; replacement</td>
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<td>Lower initial costs?</td>
<td>- Require careful installation (bubbles)</td>
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<td>Often used for repairs</td>
<td>- Cannot be installed in any weather</td>
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<td>- Performance over time debatable</td>
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<td>- Limited to horizontal surfaces</td>
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<td><strong>Membranes/sealants</strong></td>
<td></td>
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<tr>
<td>Lower initial costs?</td>
<td></td>
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</tbody>
</table>
References

7. https://www.roadsbridges.com/willing-bend-0 (oregon)
8. http://structurae.net/structures/data/index.cfm?id=s0011506 (oregon)
11. Courtesy Ugitech SA
19. http://www.sintef.no/upload/Byggforsk/Publikasjoner/Prrapp%20405.pdf (general)
Thank you

Test your knowledge of stainless steel here:
https://www.surveymonkey.com/r/3BVK2X6