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


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A textbook case: Corrosion of the Turcot highway interchange in Montreal [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

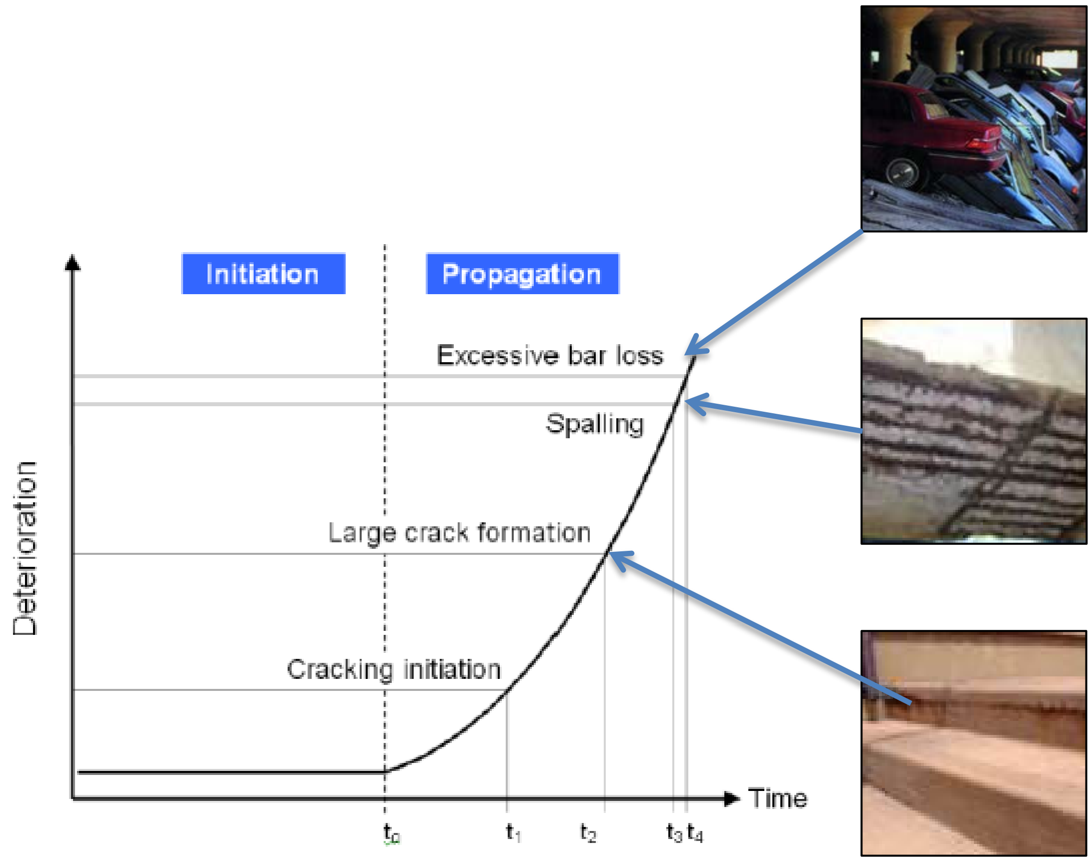
- In spite of constant supervision and repairs, it will have to be removed or partially replaced,
  - Cost estimate so far CAD 3000M.
  - Moreover, CAD 254M will have to be spent to ensure safety until its replacement in 2018
- Lifespan of the structure will be only 50 years!

How reinforced concrete can be damaged by corrosion

Diffusion of corrosive ions (usually chlorides) into concrete:

Steps[3]:

1. Once corrosive ions reach the carbon steel rebar (t0), corrosion begins
2. Corrosion products, which occupy a greater volume than steel, exert an outwards pressure
3. Concrete cracking occurs (t1), opening easy access to chlorides
4. Concrete cover cracks (spalling) (t3), exposing the rebar
5. If unattended corrosion continues until the rebar cannot bear the applied tensile stresses and the structure collapses (t4)



Cracks in concrete accelerate corrosion

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.

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

Proper choice of materials is a good long-term investment

The Progreso Pier (1/3)[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[7,8]

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 2015)

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)[10]

A new construction built over the estuary using 105MT of stainless steel reinforcement in the columns and parapets.

Dam repair
Bayonne, France

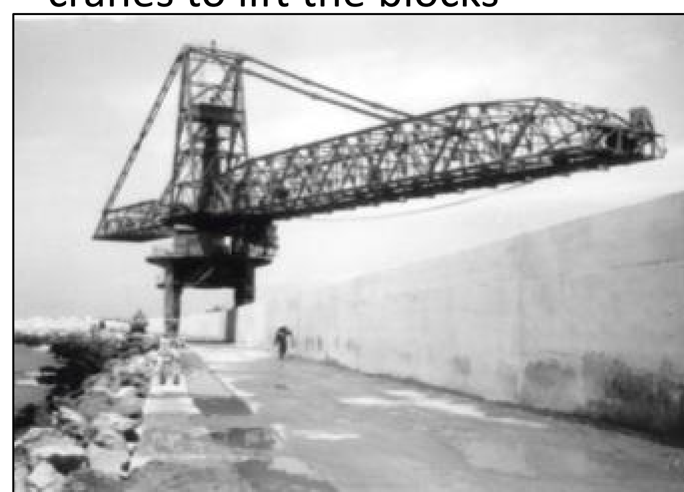
Dam built in the 1960s to protect the entrance to the harbour

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

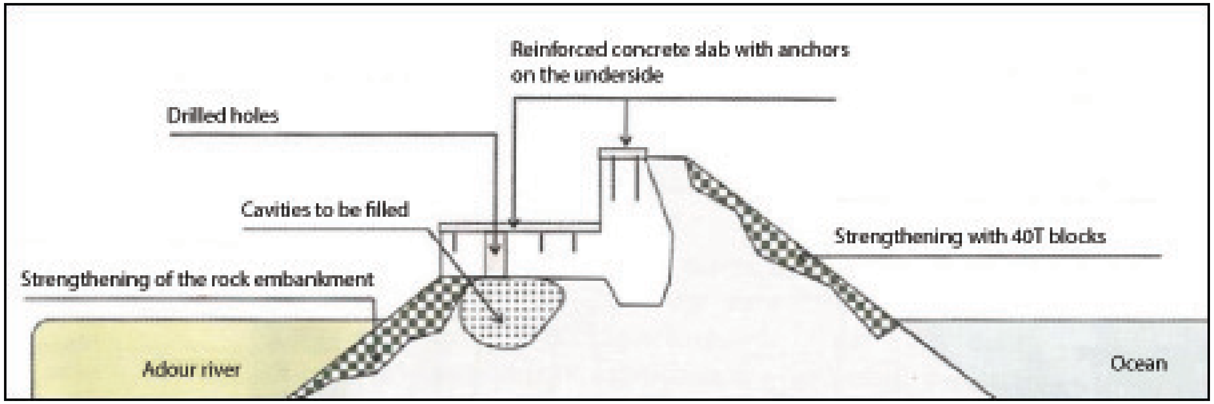
On the river side a 7m wide platform allows the heavy-duty cranes to lift the blocks

Aerial view

Cracks on the deck and wall required repairs



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[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 2800 tonnes of stainless rebar in the reinforced concrete lower part of the towers.

Belt Parkway Bridge, Brooklyn, USA (2004)[14]

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 [15-20]:

- 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[15-20]

	Advantages	Drawbacks
Epoxy coating	Lower initial costs	▪ cannot be bent without cracking ▪ Requires careful handling to avoid damaging it during installation
Galvanizing	Lower initial costs	▪ cannot be bent without cracking ▪ No longer effective when the zinc coating has been corroded
Fiber-reinforced Polymers	Lower initial costs	▪ Cannot be bent without cracking ▪ No heat resistance and poor impact resistance in harsh winters ▪ Lower stiffness than that of steel ▪ Cannot be recycled
STAINLESS STEEL	Low Life Cycle cost: • Design similar to C-steels • Mixed C-steel/stainless reinforcements work well • Easy installation, insensitive to poor worknanship • No maintenance • No life limit • Allows a thinner concrete cover • Better fire resistance • 100% Recycled to premium stainless	▪ Higher initial cost, but no more than a few % when ✓ Stainless is selected for the critical areas ✓ Lean duplex grades are selected

Comparison of stainless rebar with alternative solutions[15-20]

	Advantages	Drawbacks
Cathodic protection	Lower initial costs ? Often used for repairs	▪ Requires careful design for overall protection ▪ Requires careful installation to maintain proper electrical contacts ▪ Requires a permanent source of current (which must be monirored and maintained) or sacrificial anodes that require monitoring & replacement
Membranes/ sealants	Lower initial costs?	▪ Require careful installation (bubbles) ▪ Cannot be installed in any weatehr ▪ Performance over time debatable ▪ Limited to horizontal surfaces

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Thank you