The use of self compacting concrete in the rehabilitation of a jetty in Trafaria, Portugal

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Abstract

A 20 years old prestressed concrete girder jetty was moderately affected by corrosion of its reinforcement, clearly showing the effect of chloride penetration and of the micro environments that led to different corrosion rates.

Two technologies were considered for its rehabilitation: cathodic protection and the complete replacement of the concrete cover contaminated with chlorides. The second technology was chosen and the concrete of the cover of the girders was replaced by a high quality self compacting concrete.

The paper describes the inspection and rehabilitation works of the jetty and will also refer the collapse, due to the corrosion of the prestressing cables when subjected only to its dead load, of a prestressed pedestrian bridge, connecting the jetty to a dolphin.

Keywords: Corrosion; Jetty; Repairing

1. Introduction

The Silopor jetty in Trafaria was constructed in 1982 and had a satisfactory performance for 22 years. Nevertheless, the aggressivity of the marine environment of the Tagus estuary and its interaction with the structure led to the corrosion of the passive reinforcement.

This paper presents the deterioration and repairing works that were done on this jetty in 2004 as well as the collapse of a pedestrian beam connecting the jetty to an adjacent dolphin.

2. Description of the Structure

The 254 m long jetty was constructed with a series of 9 concrete blocks founded in the river bed and connected by 8 slab sets with 20.40 m x 19.00 m in plan. This deck supports the live loads of the terminal use and of the three 6500 kN cranes (1200 kN live load and 5300 kN dead weight each).

Fig. 2 shows the layout and the sections of the structure. The jetty is connected to adjacent dolphins by three prestressed pedestrian beams.

The concrete structure of the jetty has the 4 main beams of the deck prestressed.

The materials adopted in construction were:

- Concrete: C 25/30
- Passive steel: A 400 NR
- Prestressing steel: A 1900
- Specified concrete cover: 3.50 cm

Both concrete cover and concrete specifications were not adequate for a requirement of a 50 years service life. In consequence, the contamination of the structure by chlorides and the corrosion of the reinforcement happened after 20 years.

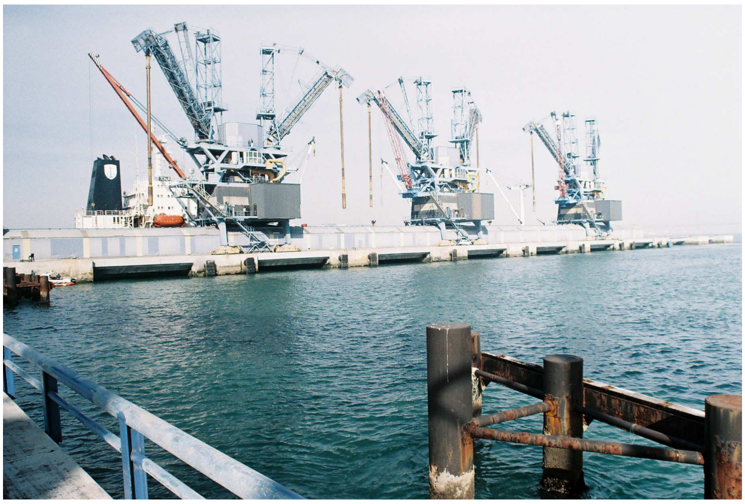

Fig. 1 View of the jetty

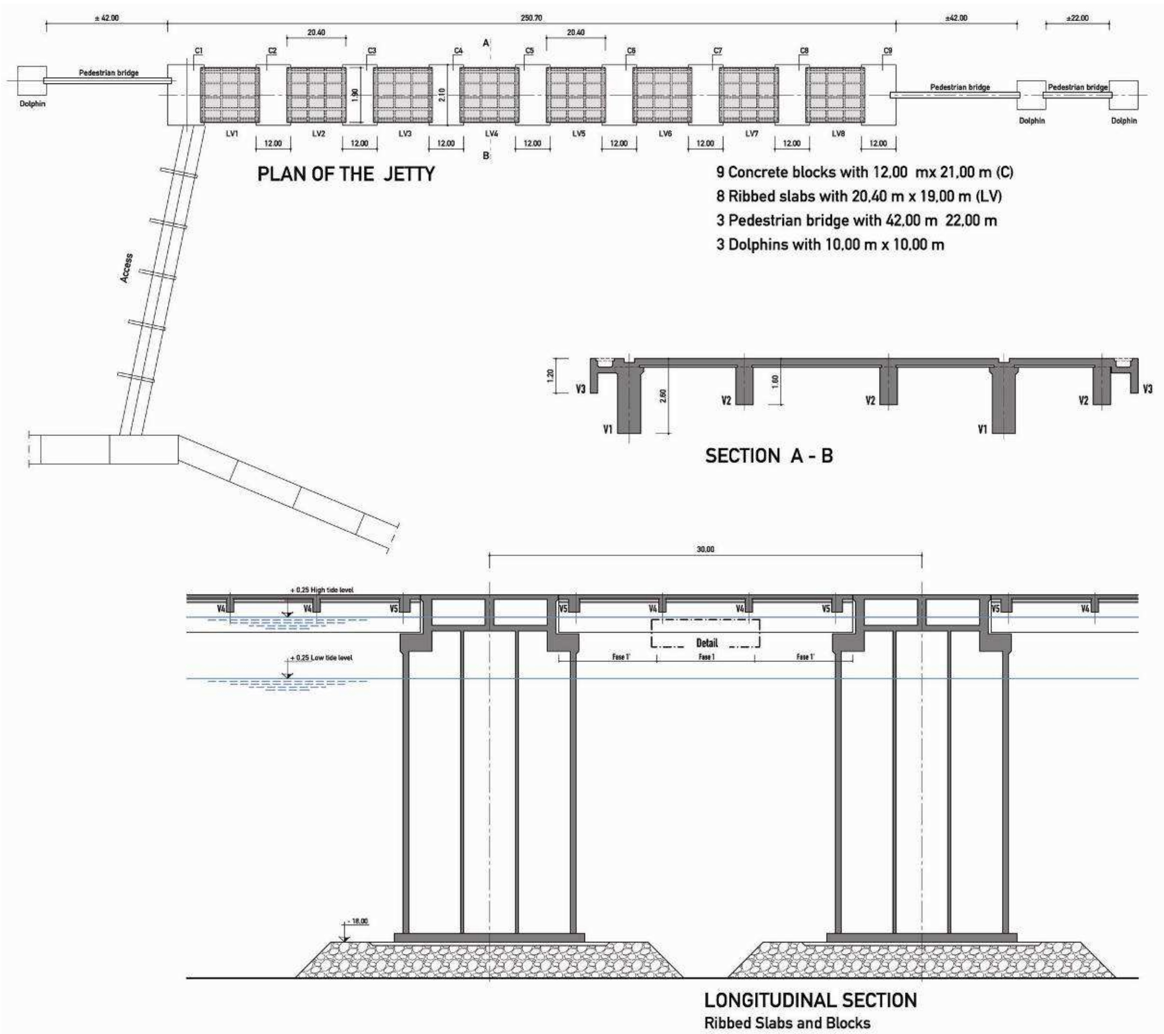

Fig. 2 Layout and sections of the structure

3. Structure Deterioration. Inspection and Tests

3.1 Visual Inspection

Fig. 3 Deterioration levels in 2004

It is interesting to point out the following observations:

- The reinforcement corrosion and the spalling in the main beams are much smaller than in the other beams. The high tide generally reaches the bottom of the main beams saturating them (and so the corrosion rate is reduced).
- In the secondary beams the corrosion is concentrated in the bottom face and corners. The concentration of reinforcement near the bottom of these simply supported beams increased the effects of expansion forces due to corrosion. These bottom faces are subjected to the "splash" zone and the high tide never reaches their level.
- The pre cast slab used to concrete the slab shows a generalised delamination.

  This bottom slab face is subjected to very aggressive conditions. In winter the splash of the waves reaches its surface. In summer the evaporation, due to high temperatures, leads to the condensation of salted water and the consequent absorption of chlorides by concrete.
- The pedestrian beams were too slender. Delamination of concrete exposed the prestressed ducts and so its replacement was planned. Some days prior to their replacement, one of these beams collapsed into the river bed, subjected only to its dead weight and without any accidental effect.

3.2 Deterioration Assessment

The concrete cover showed a large scatter, between 17 to 62 mm. The critical chloride content (~ 0.4% of the concrete mass) was reached up to 45 mm inside concrete, so in a significant part of the passive reinforcement corrosion was progressing.

4. The Repairing Works

For the repairing works, two solutions were considered:

- The introduction of a cathodic protection of the whole of the structure and local repairing of the damaged areas;

or

- the replacement of the whole surface of the concrete cover by a new high performance micro-concrete and introduction of an epoxy surface protection. A minimum concrete cover of 50 mm was also specified;

The Client chose the second methodology.

The specifications were the following:

- Micro-concrete
  - Concrete grade: C 35/45 or higher
  - Concrete mix:

    400 kg/m³ > C (cement) > 300 kg/m³)

    water / cement ratio < 0.4

    maximum aggregate size: 10 mm
  - Concrete curing: humid curing for 12 days
  - Concrete performance:

    water penetration: (ISO 7031) $x^{average} < 20$ mm ; $x^{max} < 50$ mm

    permeability coefficient: $K < 1 \times 10^{-12}$ m/s

    chloride penetration: (Tang Luping accelerated test) - $D < 1 \times 10^{-12}$ m²/s

    water absorption: $i = a\sqrt{t}$ $a < 0.1$ mm / $min^{0.5}$

    $x \leq 10$ mm after 4 hours

    porosity: ≤ 14 %

    bond strength (pull out test): ≥ 1 MPa (28 days)
- Surface protection (Interzone 954 epoxy paint)
  - e (dry thickness) ≥ 300 µm
  - Cl^- diffusion coefficient $D < 1 \times 10^{-10}$ cm²/s (EN 838)

The estimated quantities of repairing works were:

beams = 4400 m²

slabs = 490 m²

and the cost estimate was: 1.25×10^6 €

Fig. 4 shows some details of the execution.

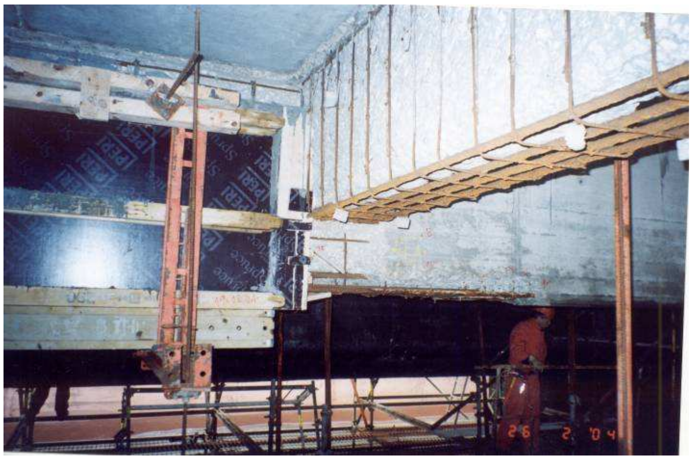

Fig. 4 Details of the execution

The following relevant aspects should be referred:

➢ A self compacting concrete was applied with the following mix (kg per cubic meter of concrete):

L (binder):
- Cement type I, 42.5R = 355
- Fly ash = 117
- Slag = 195

- Sand 1 (4.76 mm) = 320
- Sand 2 (1.19 mm) = 384
- 12.7 mm aggregate = 704
- Admixture 1 - Glenium 26 scc = 18.10
- Admixture 2 - Bettoretard = 2.33
- Water (w) = 188 (w / L = 0.28)

Fig. 5 Self compacting concrete

The concrete control showed the following results:

- Concrete strength at 7 days: 46 to 64 MPa (49.5 to 59.5 MPa if the two extreme results are ignored)

28 days: 71 to 96.5 MPa (74.5 to 89.5 MPa if the two extreme results are ignored)

Water penetration test: 7 mm maximum penetration (ISO 7031)

Water absorption: 2 to 19 mm after 4 hours

Concrete porosity: 12.7 to 15.8 %

Chloride penetration (A ASHTO - ASTMC 1202-91)

879 to 1652 Coulombs 28 days

498 to 879 Coulombs 80 days

The replacement of the concrete cover was done in sequenced phases in order to maintain the reinforcement bonded to the concrete (fig. 4).

The surface protection used was the Interzone 954 epoxy paint. The concrete surfaces are not directly exposed to the sun.

5. The Collapse of a Corroded Prestressed Concrete Pedestrian Bridge

Fig. 6 shows views of the prestressed bridge, before and after the collapse. Fig. 7 shows the main characteristics and dimensions of the bridge.

Fig. 6 Views of the pedestrian bridge

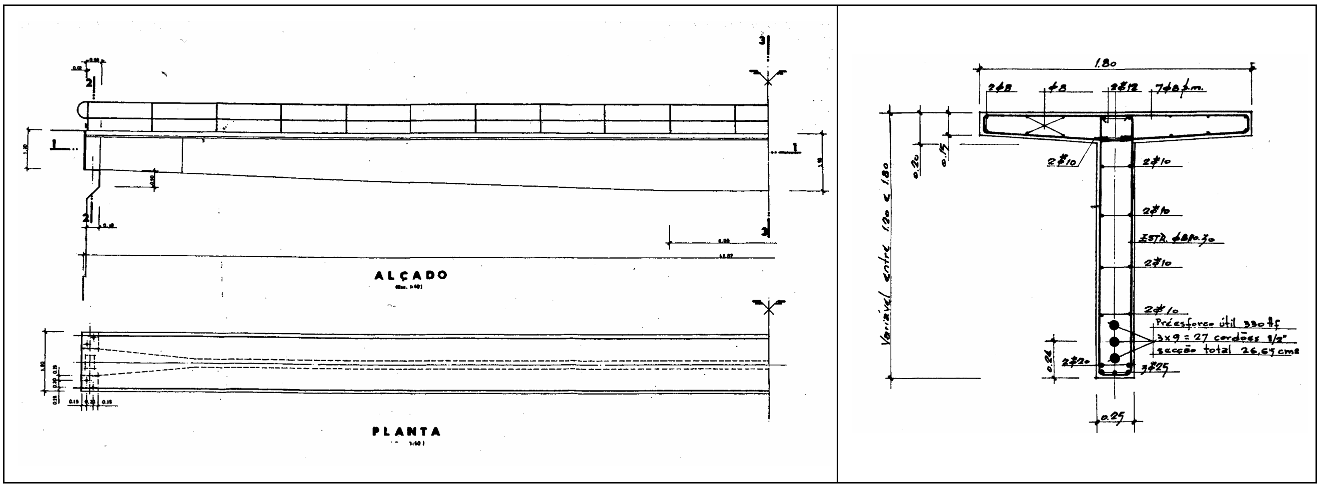

Fig. 7 Dimensions and characteristics of the collapsed bridge

The bending moment due to the dead load was 3970 kNm and the resistant bending moment was 7123 kNm.

The collapse occurred on the 24.02.2004 with the beam subjected only to its dead load. For the collapse to occur a minimum of 2 cables had to rupture, as shown in fig. 8.

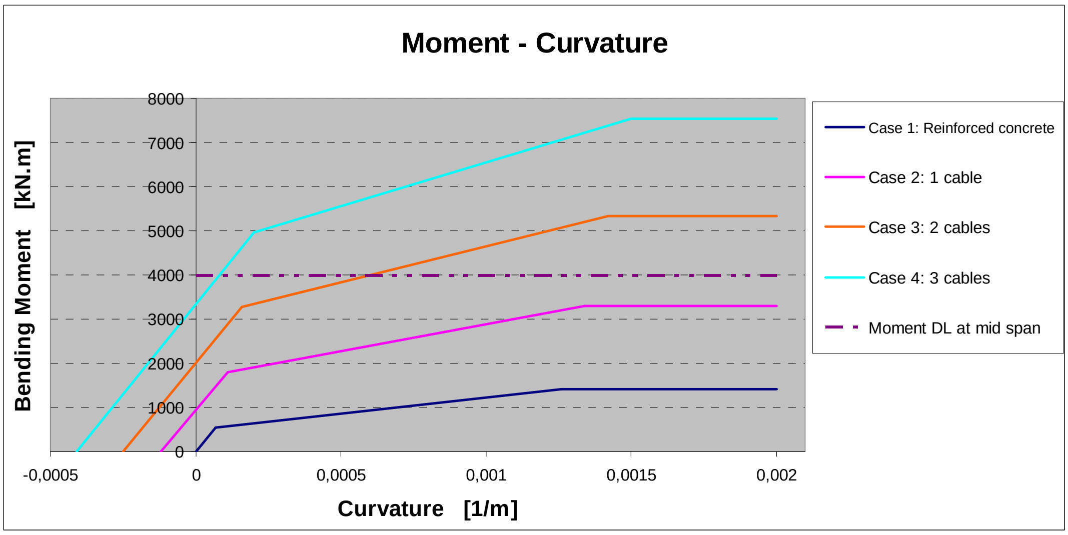

Fig. 8 Moment-curvature relations - assessment of collapse

The underwater inspection showed that the collapse was due to the failure of the mid span in flexure. The inspection of the other two pedestrian bridges showed that the cement grout inside the duct was already contaminated by chlorides.

This example shows the difficulties in assessing the risks of collapse and the sensitivity to severe effects of corrosion. An isostatic prestressed concrete structure, subjected to an aggressive environment, as the marine one, presents a high risk of collapse and thus robustness criteria such as multiple corrosion protection systems should be applied.

The degree of prestressing was high and thus safety mainly relied in the prestressing cable resistance. A high amount of non active reinforcement is important for the robustness of such structures.

Fig. 9 shows the old and the new pedestrian bridge of this jetty and fig. 10 shows the jetty after rehabilitation.

Fig. 9 The old and the new pedestrian bridge

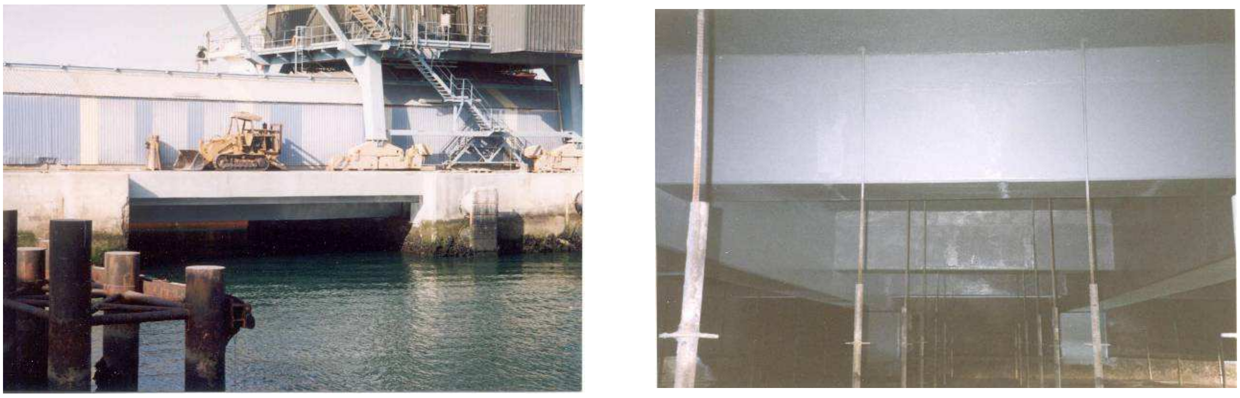

Fig. 10 Views of the jetty after rehabilitation

6. Conclusions

The marine environment is very aggressive to reinforced concrete structures. Prestressed concrete isostatic structures are very sensitive to the effects of steel corrosion which can lead to the collapse of the structure.

The use of self compacting concrete is of particular interest for the repairing of the structures, enabling an easy placing and compaction of a high performance concrete.