Durability of Marine Concrete in Libya – Field Study on Five Seaports

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ABSTRACT

The construction practice of marine concrete structures is of a great concern, considering the severe conditions that this concrete is subjected to. These conditions may lead to the relatively rapid deterioration of concrete of marine structures in case of inappropriate specifications or poor practice. This issue is of more importance in the hot-humid climates such as the case of Libyan Coast, North Africa.

In view of the above, this study is aimed to conduct a detailed survey on five major commercial and industrial seaports along the coast of Libya. The quality of concrete in the surveyed parts was evaluated thoroughly, including visual inspections and conducting several field and laboratory concrete tests.

The study concluded that the concrete structures in all the ports suffer from serious durability problems, especially those related to steel corrosion due to the electro–chemical activity in all tested elements, in addition to high percentage of chloride ions concentrations penetrated through the concrete. Furthermore, it was found that the compressive strength in two of the surveyed ports was below the minimum limits specified in the related specifications.

The study discusses the possible causes that led to this situation, and suggests a series of practical procedures that ensure better design for durable marine concrete with the minimum need to maintenance through its service life.

KEYWORDS

Libya, Marine Concrete, Steel Corrosion, Compressive Strength, Durability.

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1 INTRODUCTION

Marine concrete durability is becoming an increasingly important issue due to growing need for concrete coastal structures in developing countries. Massive quantities of concrete were poured in the Libyan port projects during the last three decades, in order to meet the rapidly growing demand for port facilities due to increase in the oil exports and the country's imports needed for development. Although concrete structures in marine environment are designed to last for a considerable life span with minimum maintenance, natural deterioration of reinforced concrete components in particular can occur in the following forms: alkali aggregate reaction, frost attack, sulphate attack, chloride attack and carbonation. Good quality concrete may eliminate some or all of the factors influencing deterioration, starting from the proper choice of constituent materials and their proportioning, to the workmanship at site in the form of mixing, casting, compacting and curing. The objective of this paper is to present a case study of concrete deterioration of some major marine structures in arid and semi-arid climates of Libya, showing and stressing the importance of drafting and implementing the proper specifications for the works throughout.

2 MARINE CONCRETE DURABILITY

It has been proved in practice that concrete structures can remain serviceable, with little or no maintenance, for 50 years or more in a marine environment. One of the main characteristics influencing the durability of concrete is its permeability. With strong dense aggregate, a suitable low permeability is achieved by having a sufficiently low water/cement ratio, by ensuring complete compaction of the concrete and by using proper curing methods to ensure complete hydration of the cement and crack-free surfaces. The cement content should be sufficient to provide adequate workability with a low w/c ratio so that the concrete can be completely compacted with the means available. Construction and supervision must be such as to ensure a consistently high standard of workmanship [FIP 1985]. The durability of reinforced concrete structures is, in general terms, affected by three parameters under the control of designer: cover, crack widths and concrete quality. The principal factors influencing concrete durability in arid and semi-arid environment are water/cement ratio, reinforcement cover, curing, type of cement and cement content.

3 CONCRETE SPECIFICATIONS OF LIBYAN PORTS

A review of the concrete specifications used in different ports along the Libyan coast is made. The study ports from west to east are Abukammash, Tripoli, Misurata Commercial, Misurata LISCO and Brega Industrial Port (Fig.1). The specifications differ according to the design and construction aspects. Presented below are some of the mostly adopted specifications [Elwefati and Barony 1988].

![Figure 1. Location of the ports on the Libyan coast](image)
3.1 Mixing of Concrete

In addition to the common specifications, admixtures were prohibited in the case of Tripoli port, while for the other ports a reference was made to the minimum cement content, minimum concrete strength, and maximum w/c ratio. These limits, however, varied from one port to another as shown in Table 1.

3.2 Curing

Curing compounds were specified in Tripoli port, while only water curing was allowed in other ports. No reference to any specific curing procedure was made in the other ports.

3.3 Reinforcement Cover

While no reference is made in any of the specifications to the reinforcement cover, the tolerance from what is given in the working drawings was stated.

3.4 Precautions during inclement weather

All specifications considered cases of windy, rainy and cold weather conditions, while no reference to hot weather concreting was made, which was interesting because of the long hot/dry summer season.

3.5 Concrete production

Beside the common specifications for mixing, transporting, placing, compacting and curing of concrete, some of the specifications made no reference to minimum concrete strength, and the requirements for the mix design and quality control. Table 1 shows some of the given concrete specifications as well as the produced concrete characteristic cube strength and the corresponding standard deviation in the investigated port projects.

Table 1. Deviations from specifications in some selected Libyan ports

<table>
<thead>
<tr>
<th>Port</th>
<th>W/C Specified</th>
<th>W/C Actual</th>
<th>Cement Content Specified (Kg/m³)</th>
<th>Cement Content Actual (Kg/m³)</th>
<th>Compressive Strength Specified (MPa)</th>
<th>Compressive Strength Characteristic (MPa)</th>
<th>St. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tripoli (TP)</td>
<td>0.5</td>
<td>0.5</td>
<td>-</td>
<td>300</td>
<td>-</td>
<td>33.2</td>
<td>15.7</td>
</tr>
<tr>
<td>Benghazi</td>
<td>0.5</td>
<td>0.48</td>
<td>370</td>
<td>360</td>
<td>37.5</td>
<td>42.7</td>
<td>5.2</td>
</tr>
<tr>
<td>Brega (BIP)</td>
<td>0.5</td>
<td>0.51</td>
<td>370</td>
<td>370</td>
<td>37.5</td>
<td>44.1</td>
<td>7.0</td>
</tr>
<tr>
<td>Misurata (MP)</td>
<td>0.5</td>
<td>0.43</td>
<td>370</td>
<td>380</td>
<td>40</td>
<td>46.2</td>
<td>9.2</td>
</tr>
</tbody>
</table>

4 CASE STUDIES

Arid desert climate prevails as in the case of Brega port, with maximum temperature from 40°C to 45°C during summer, extending up to six months. Winter months, on the other hand, can experience a drop of temperature down to slightly above zero coupled with an increase in humidity up to 75%. Winter months, also, are characterized with some violent storms and modest rainfall with mean annual precipitation of 150 mm all occur during winter. Appreciable fluctuation in both temperature and humidity occurs between day and night all year round.

The semi-arid, also known as semi-Mediterranean climate in other four ports offers relatively more temperate conditions as regard to both temperature and humidity, while sea storms are violent as well. Annual rainfall in the Tripoli area is around 350 mm, while in Misurata commercial and LISCO ports are is around 280 mm, most of which fall during the winter months from December to February.
Hot and generally dry winds called 'Ghibli' are active in summer. This is usually accompanied by dust and sand. The two major types of deterioration inflicted upon the concrete of the above ports are salt weathering and reinforcement corrosion, Fig. 2. Apart from appearance, salt weathering of concrete surfaces is not considered a problem for the structural concrete. Its formation is only limited to the outer few millimeters and was likely to have been caused by the increase in the concentration of salts in the pores of the hardened cement paste during the cycles of wetting and drying. In the following, a brief description of each of the studied ports is presented.

4.1 Abukammash Port

Abukammash port is located about 150 km west of Tripoli, Fig.1. Its main purpose is to import the raw materials needed to run Abukammash petrochemical complex, and to export the products of the complex. The main component is a 1100 m long and 3.5 m wide R.C. Jetty. The structural elements consist of precast slabs, steel trusses, capping beams, 800 mm steel piles and R.C. abutment. The visual inspection and field tests showed that the precast concrete slabs and beams suffer from medium to severe corrosion which led to spalling of concrete cover and considerable losses in the reinforcement and concrete cross-sectional areas.

4.2 Tripoli Port

Tripoli port is considered as one of the oldest ports in the southern coast of the Mediterranean from the point of continuous existence and commercial use. The present major development consists of two rubble mound breakwaters constructed in two stages, the first stage was built during 1973-1977, with a length of 2190 m, and in the second stage, a further 2520 m length was completed during 1976-1980. The main breakwater has suffered from so many distressing effects leading to cross-sectional failure and heavy structural damages. Further investigations recommended a new design and rehabilitation of the breakwater. Repairs and rehabilitation of Tripoli port constitutes a major reconstruction through change in the ruble mound cross-section as well as casting new wave wall on top of the old one. This was required due to the increase of significant wave height ($H_s$) to almost double of its original value [Barony et al. 1987]. The change of $H_s$ from 4.0 m to 7.5 m is currently being considered as design parameter for maritime structures on the Libyan coast.

4.3 Misurata Commercial Port

Misurata commercial port is located about 210 km east of Tripoli, Fig. 1. It consists of two rubble mound breakwaters and berthing and storage facilities. The main breakwater was constructed in the first stage at 1987, with a length of 1200 m for north part, and 1800 m for east part, while the berths were constructed in two stages, the first stage was built at 1978, with a length of 1120 m, and second stage with a length of 1520 m. Corrosion deterioration in the form of cracks of the rubble mound breakwater wall was observed. These are generally following the reinforcement bars. There are also...
signs of an abrasion on the surface of the walls leaving the aggregate exposed. For berths, no signs of serious deterioration were noticed. However, the berths suffered also from differential settlement.

4.4 Misurata Industrial Port (LISCO)

This port has been established to serve the Libyan iron and steel company (LISCO) to receive ships carrying raw materials. It is located about 5 km east of Misurata Commercial Port. The first stage was built during 1983-1995 consisting of rubble mound breakwater with a length of 1650 m, and berth structure is distinguished by 12 modules, each module has a dimension of 32 m×36 m separated from each other by expansion joints. On each module there are 25 prefabricated transverse beams and 24 prefabricated longitudinal beams. A major type of deterioration, observed at 1993, is the spalling of concrete at soffits of the beams and spalling of concrete at 15 cm height along the sides of the beams. Cracking and cover delamination of some of breakwater walls observed. These deteriorations have been caused by the corrosion of the reinforcement.

4.5 Brega Industrial Port

Brega Industrial Port is located in the gulf of Sirte, Fig. 1, about 800 km east of Tripoli and 250 km west of Benghazi. The port development consists of the main breakwater and berthing facilities which was carried out as an extension of an old oil terminal. The breakwater starts at the shore as rubble mound type then changes to caisson type. The superstructure consists of a roadway slab supported by cross beams and short columns. The north side of the slab rests on a wave wall. This port represents a classical example for concrete deterioration, where the main detrimental factors combined together causing rapid and severe deterioration of concrete within few years of the port service life. In fact, deterioration of concrete was reported early in 1979, only one year after completion of construction which was carried out between 1974 -1978. SRPC was specified and used throughout the port except for a small part of the roadway slabs for which BFSC was used.

The extent of damage inflicted upon the different concrete elements varied widely. The caissons, prefabricated in much better conditions than other components of the project, suffered almost no damage. The cast-in-situ cover slabs were however badly damaged. Elements exposed to direct sunlight and cycles of wetting and drying, such as the super structure of the caisson breakwater, the jetties, and urea berth were badly deteriorated also. Protected surfaces of some of the above elements were less deteriorated. Due to the fact that most of the concrete elements of Brega Industrial Port showed high chloride contamination levels well beyond the rebars, it was suggested that repairs for these elements would be difficult and expensive to undertake and yet questionable as regard to their effectiveness in the long run [Elwefati and Barony 1988].

5 INSPECTION, TESTING AND ANALYSES

Based on the findings of the visual inspection, a field and laboratory testing program was implemented at locations representing the elements subject of this investigation.

5.1 Field Testing Works of R.C. Elements (Corrosion Assessment)

These works comprise a number of the R.C. elements, covering the structural elements. The tests listed below aim to provide information to evaluate the general status of corrosion deterioration.

5.1.1 Rebar Location and Cover Thickness Measurements


5.1.2 Half-Cell Potential Measurements


5.1.3 Core Extraction

Thirty one Concrete cores were extracted from a number of the ports structural elements.
5.1.4 Depth of Carbonation
Measured by the classical method of phenolphthalein spraying immediately after extraction.

5.1.5 Dust Extractions
A drill pit of 12 mm was used for dust extractions every 25 mm up to 75 mm, i.e. behind rebars.

5.2 Laboratory Tests

5.2.1 Compressive Strength Testing
All cores were capped with sulphur compound. Core preparation and consequent testing were undertaken with reference to BS 1881: Part 120, 1983 [British Standard Institution 1983].

5.2.2 Chloride Analyses
The objective of this test was to evaluate the chloride penetration profile of concrete to verify possible chloride attack, the dominant factor influencing R.C. corrosion deterioration. Chloride analysis was performed on concrete dust and core samples according to the recommendations of BS 1881: Part 124:1988 [British Standard Institution 1988]. The result of this analysis is useful in assessing the status of concrete durability for both visually defective and sound concrete. Results are also essential in the process of choosing the suitable type of repair scheme.

6 DISCUSSION OF RESULTS

Table 2 shows samples of the conducted tests. Based on the obtained results from the field & lab tests and analyses, the following remarks and discussions are presented.

6.1 Compressive Strength
Table 2 summarizes the average values of compressive strength for the cores taken from the investigated ports, and the specification requirements. It is clear from this table that the compressive strength of Tripoli and Brega ports didn't meet the specification requirements. The results indicate also the inconsistency of concrete strengths possibly due to inconsistent concrete practice.

6.2 Rebars Corrosion Rates
a. The results of half cell potential test were in conformity with the findings of visual inspection, where it indicated a high activity of electro-chemical corrosion reactions in all tested elements when compared to the limits of ASTM C876 [American Society for Testing and Materials 1985]. The readings exceeded -300 m.v. in most of the elements.

b. The results of chemical analysis of dust samples revealed that the chloride contents in the concretes of all ports exceeded the limits of chloride content by mass of concrete specified in concrete society technical report no. 26 [Concrete Society 1994]. This was a clear indication of chloride attack extension to beyond steel rebars.

6.3 Carbonation
Slight carbonation was recorded in all tested specimens, 10 to 20 mm carbonation depth in all ports except Misurata Commercial Port in which the concrete showed even less carbonation of only 2 to 5 mm. Keeping in mind that the concrete cover in all tested elements ranged from 50 to 140 mm, which is higher than the measured values of carbonation, led to the conclusion that carbonation was not a reason for the high levels of rebar corrosion.
Table 2. Summary of test results.

<table>
<thead>
<tr>
<th>Port</th>
<th>Element</th>
<th>Specimen</th>
<th>Concrete Cover (mm)</th>
<th>Half-cell Potential (mv)</th>
<th>Equivalent Concrete Strength (MPa)</th>
<th>Carbonation Depth (mm)</th>
<th>Chloride content Weight/weight of concrete (%)</th>
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<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td>AB-3</td>
<td>25</td>
<td>200-312</td>
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<td>S3</td>
<td>50</td>
<td>109-199</td>
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<td></td>
<td>S7</td>
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<td>128-280</td>
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<td></td>
<td>S50</td>
<td>70</td>
<td>195-321</td>
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<td>Pre-cast Slabs</td>
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<td>195-321</td>
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<td>WT1</td>
<td>65 365-447</td>
<td>29</td>
<td></td>
<td>20</td>
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<td>65 453-663</td>
<td>29</td>
<td>10</td>
<td>0.95</td>
<td>0.86</td>
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<tr>
<td></td>
<td>WT4</td>
<td>65 417-501</td>
<td>42</td>
<td>10</td>
<td>0.38</td>
<td>0.29</td>
<td>0.20</td>
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<tr>
<td></td>
<td>WT5</td>
<td>65 445-605</td>
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<td>10</td>
<td>1.39</td>
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<tr>
<td></td>
<td>WT6</td>
<td>65 406-515</td>
<td>21</td>
<td>20</td>
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<td>0.31</td>
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<tr>
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<td>WT7</td>
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<tr>
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<td>WM1</td>
<td>50 297-465</td>
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<td>0.42</td>
<td>0.41</td>
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<td></td>
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<td>15</td>
<td>0.46</td>
<td>0.41</td>
<td>0.32</td>
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<tr>
<td></td>
<td>W70</td>
<td>100 344-421</td>
<td>56</td>
<td>15</td>
<td>0.38</td>
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<td>100 340-471</td>
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<td>15</td>
<td>0.30</td>
<td>0.27</td>
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<tr>
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<td>0.38</td>
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<td>10</td>
<td>0.63</td>
<td>0.59</td>
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</tr>
</tbody>
</table>

7 CONCLUSIONS

There are many reasons for deterioration of the concrete of the investigated ports. The main causes are related to using inappropriate materials, poor practice and inadequate project specifications, which led to chloride attack to most of the elements and hence, corrosion of reinforcement bars. For example, reviewing the documents and field investigation led to the following:

a. Project specifications were mainly prepared by consulting firms from north Europe based on their experience of the concreting in cold and mild climate of Europe, instead of the hot/humid environment of the Libyan coast.

b. Continuous change of sources and types of constituent materials led to non-homogenous concrete.

c. High porosity of concrete in spite of the relatively high compressive strength.

d. Insufficient concrete cover and poor control of w/c which reached 0.7 in some cases.

e. Insufficient curing and using sulphate resistant cement which is not suitable for corrosive environments.

f. Absence of surface protection to rebars or concrete surfaces.

8 RECOMMENDATIONS

In view of the findings of the study, some practical recommendations can be taken in consideration regarding construction of marine concrete in similar hot/humid climates. Here are some of the most important recommendations:

a. Preparing a local standard for marine concrete depending on local environmental conditions of the Libyan coast.
b. Lowering w/c to less than 0.4 using superplasticizers.
c. Using blended cements such as blast furnace slag cements.
d. Proper practice, particularly, a special care must be given to compaction and curing.
e. Cement content should be 400kg/m$^3$ at least.
f. Using carbon fibers instead of steel reinforcement if possible.
g. Avoiding thin sections and horizontal surfaces.
h. Providing protective coatings to steel rebars and concrete surfaces.

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REFERENCES


