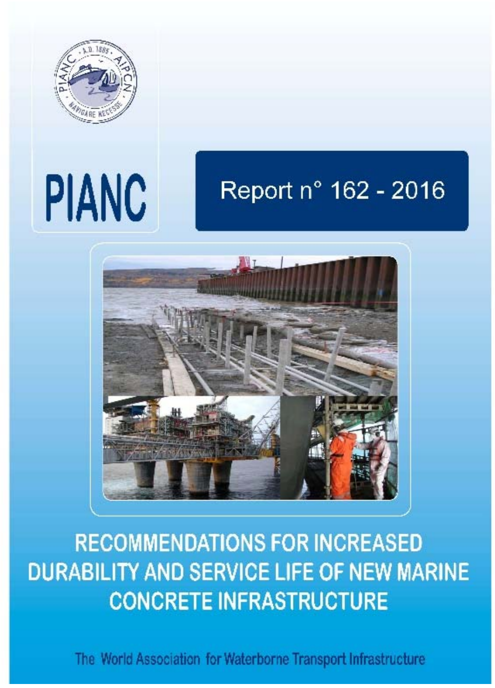
RECOMMENDATIONS FOR INCREASED DURABILITY AND SERVICE LIFE OF NEW MARINE CONCRETE INFRASTRUCTURE



Report of Working Group 162 of the MARITIME NAVIGATION COMMISSION

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In Memory of Odd E Gjørv. Chairman of WG 162

Born 5. februar 1935

Deceased 16. februar 2016, Trondheim

Odd was working on the report when he had a heart attack and sadly did not get to see the finished result.

This proceeding addresses the work done by the PIANC Working Group 162 dedicated to provide recommendations for increased durability and service life of new marine concrete infrastructure.

The durability of concrete structures in the marine environment is not only related to design and materials but also to construction.

As a basis for the durability design and production of new major concrete infrastructure, all minimum requirements in existing concrete codes and standards as well as all established recommendations and guidelines for good construction practice must be strictly followed.

In recent years, many owners of existing concrete infrastructure have experienced a significant and rapidly increasing proportion of their limited construction budgets being spent on repairs and maintenance of the structures, many owners are showing an increasing interest to invest somewhat more at the outset of their new projects in order to obtain a better controlled and enhanced durability of the structures.

A better durability design and quality assurance for new concrete infrastructure can be achieved, and documentation of as-built construction quality and compliance with the durability specification can be obtained.

In the report, some additional recommendations and guidelines to existing concrete standards for durability and service life are provided, the objective of which has been to obtain a better controlled and enhanced durability of new marine concrete infrastructure, beyond what is possible when based only on existing concrete standards. This guidance is given with emphasis upon durability design and quality assurance as well as condition assessment and preventive maintenance during the operational life of the structures.

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Historical background – Definition of the problem

Deterioration and repair of marine concrete infrastructures has merged as a challenge for the owners of structures. In all deteriorating processes, extensive experience demonstrates that steel corrosion is still the most critical and greatest threat to the durability and long-term performance of the structures. Although current standards have been improved in recent years, still an uncontrolled penetration of salt with subsequent steel corrosion can take place on relatively new important marine concrete structures. As soon as the corrosion starts, the owner has a p a cost problem but later on also develops into a more difficult safety problem.

The durability and service life of the structure is dependent upon preventing the initiation of electrochemical corrosion. This is typically done by ensuring a quality concrete (low permeability, free of chlorides, reactive aggregates, high temperatures during curing, etc.), concrete resistant to environmental attack (freeze thaw, alkali-aggregate reaction, sulfate attack, carbonation, chlorides, etc.), and concrete cover. Additional measures can be undertaken to extend the life of a structure, such as sealers, coatings, corrosion resistant materials and cathodic protection systems.

The durability of a structure is dependent upon the system of cementitious materials, aggregates, water, admixtures, and reinforcing.

The durability of concrete structures in the marine environment is not only related to design and materials but also to construction.

Although all minimum durability requirements stated by existing standards must always be followed and fulfilled for new concrete structures, some owners are willing to invest somewhat more in order to obtain an increased and more controlled durability and service life beyond what is possible - more than 100 years - when only based on current standards. New recommendations and guidelines for increased durability, service life and service life modeling of new and important marine concrete infrastructure should be developed.

With the environmental constraints placed on the construction of new facilities in many countries, it may be easier or more economical to extend the service life of an existing structure. Guidance should also be developed for mitigation measures to extend the service life of existing structures.

Objective of the report

This report provides guidance to owners and designers of marine concrete infrastructure worldwide, in order to provide a safe, efficient and cost-effective design and construction of these structures, with emphasis upon:

- Durability design
- Quality assurance and achieved construction quality
- Condition assessment and preventive maintenance

The report of the WG is only to be considered as a guidance in addition to existing standards for concrete durability and service life. It should also be considered as an additional document for improved quality assurance during concrete construction as well as the regular condition assessment and preventive maintenance during operation of the structures.

Agenda of the report

Readers will find after an introduction on the topic and a state of art of the way to address the durability (Chapter 2), two approaches to deals with durability over the codes and standards(Chapter 3).

Additional strategies through protective measures and material are addressed (chapter 4) before to focus on quality assurance and achieved construction quality feedbacks (Chapter 5)

Report contains also assessment methods and preventive maintenance and repairs technics (Chapter 6)

CHAPTER 1: INTRODUCTION

CHAPTER 2: DURABILITY AND SERVICE LIFE

2.1 DETERIORATING PROCESSES

2.2 CODES AND PRACTICE

2.3 QUALITY INSURANCE AND ACHIEVED CONSTRUCTION QUALITY

2.4 CONDITION ASSESSMENT AND PREVENTIVE MAINTENANCE

2.5 LIFE CYCLE COSTING (LCC)

2.6 LIFE CYCLE ASSESSMENT (LCA)

CHAPTER 3: DURABILITY DESIGN

3.1 PROBABILITY APPROACH

3.2 PERFORMANCE BASED APPROACH

CHAPTER 4: ADDITIONAL STRATEGIES AND PROTECTIVE MEASURES

4.1 GENERAL

4.2 STAINLESS STEEL REINFORCEMENT

4.3 NON METALLIC REINFORCEMENT

Overview of the durability subject

With all the recent standards requirements focusing on concrete mix and design, the observed durability problems on marine concrete structures can be ascribed to lack of proper quality assurance during concrete construction and poorly achieved construction quality.

Upon completion of new concrete structures, the achieved construction quality typically shows a high scatter and variability, and during the operation of the structures, any weaknesses and deficiencies will soon be revealed whatever durability specifications and materials have been applied. To a certain extent, a probability approach to the durability design can accommodate the high scatter and variability of quality. However, a numerical approach alone is insufficient for ensuring the durability; greater control and improvements in durability also require the specification of performance-based durability requirements which can be verified and controlled during concrete construction in order to practically achieve quality assurance.

As a basis for the durability design and production of new major concrete infrastructure, all minimum requirements in existing concrete codes and standards as well as all established recommendations and guidelines for good construction practice must be strictly followed.

For concrete structures in the marine environment, many different deterioration processes can affect the durability. The mains processes had been summarize, typically the corrosion of steel by chloride or carbonatation ingress thought the concrete cover or in cracks. Environmental context (freeze-thaw process) and intrinsic concrete phenomena (alkali silica reaction of delayed ettringite formation) may be involved in the deterioration process.

Codes and standards address all minimum requirements according the durability specifications but primarily based on prescriptive requirements to composition of the concrete mixture such as upper levels for water/binder ratio and minimum levels for binder content.

Although a low water/binder ratio also reflects a high density and low permeability of the concrete providing both a high resistance to chloride ingress and good durability, extensive investigations demonstrate that selecting a proper binder system may be much more important for obtaining a high resistance to chloride ingress. As a result, the old and very simple terms "water/cement ratio" or "water/binder ratio" for characterizing and specifying concrete quality have successively lost their meaning. As a consequence, there is need for performance-based definitions and specifications for concrete quality; in particular this is true for characterizing and specifying concrete durability (Bjegović et al., 2014).

It is well established that many durability problems for concrete structures in the marine environment can be ascribed to lack of proper quality assurance during concrete construction and poorly achieved construction quality. In order to accommodate the potential high scatter and variability of quality, a probability approach to the durability design as briefly outlined and discussed in Chapter 3 can be applied. However, since none of the models for such design take into account the effect of cracks or other defects also typically occurring during concrete construction, some additional strategies and protective measures can be considered (Chapter 4).

With the probability approach to the durability design described in Chapter 3, however, performance-based requirements both to concrete quality and concrete cover are Figure 3.1. The DURACON Model as a basis for durability design, quality assurance and operation of new major concrete infrastructure in marine environments (PIANC Norway/NAHE, 2009). established which later on provide a basis for quality assurance and documentation of achieved construction quality (Chapter 5). A performance-based durability design without any probability calculations can also be applied as that described in Chapter 3.

Documentation of achieved construction quality and compliance with the durability specification should be very important for the owner since such documentation may have implications both for the obtained durability and expected service life of the structure. Experience from recent years has shown that where such documentation has been required, it has typically clarified the responsibility of the contractor for the quality of the construction process.

Despite the best compliance to the achieved construction quality both from specification and construction quality assurance, a service manual for regular monitoring and control of the real chloride ingress taking place during the operation of the structure should be required (Chapter 6). It is such a service manual that helps provide the ultimate basis for obtaining a controlled and enhanced service life of the concrete structure in its environment.

In chapter 4, additional strategies and prospective measures are addressing. Whatever approach to the durability design taken, they all have some limitations, since none of them takes into account the effects of cracks or other defects that also typically occur during the production of concrete structures. Therefore, for all new marine concrete infrastructure where high durability and service life are of special importance, additional strategies and protective measures such as those outlined in the following should also be considered.

The report address folowing options:

- Stainless steel reinforcement
- Non metallic reinforcement
- Concrete surface protection
- Concrete hydrophobation
- Protective Skin Systems
- Cathodic prevention systems
- Corrosion inhibitors
- Structural shape
- Prefabricated Structural Elements

For most operational concrete structures, maintenance and repairs are mostly reactive, and the need to take appropriate repair or preventive measures is only identified at an advanced stage of deterioration. Although general condition assessment and preventive maintenance are already part of the established Life Cycle Managment systems for structures, additional regular control of the chloride ingress during operation of marine concrete structures is very important. The general basis for this is briefly outlined and discussed in the chapter 6, and a brief outline of current repair experience is also included.