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TECHNICAL REPORT
TR-NAVFAC ESC-CI-1215

**A NAVY USER'S GUIDE FOR QUALITY
ASSURANCE OF NEW CONCRETE
CONSTRUCTION**

By
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EXECUTIVE SUMMARY

The U.S. Navy has developed and implemented new design and quality assurance procedures, including service life modeling of the concrete materials that is targeted to improve the quality assurance of new marine concrete construction. The approach is delineated in the Uniform Facilities Guide Specification (UFGS) for Marine Concrete and is referred to as the Navy's methodology. This approach allows Naval Facilities Engineering Command (NAVFAC) and others to specify a defined service life for concrete structures in combination with prescriptive criteria. The goal is to allow all parties involved in the design and construction process to have greater confidence that the completed structure will meet service life expectations. The cornerstone of this approach is a validated computer software program that can predict the time for chloride and other ions to contaminate the concrete to a degree that will result in initiation of corrosion and other chemical distress mechanisms when all other necessary conditions are met for a specific environmental condition. The use of the Navy methodology is intended to compliment the fundamental principles of good design and construction to accomplish durable concrete structures and to supplement conventional quality assurance testing of materials. The purpose of this paper is to broaden exposure and to provide guidance on how to implement the methodology correctly and effectively for all users.

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ACRONYMS AND ABBREVIATIONS

| | |
|----------------------|---|
| ACI | American Concrete Institute |
| CCM | Complementary Cementing Material |
| CQC | Contractor Quality Control |
| CRADA | Cooperative Research and Development Agreement |
| ESC | Engineering Service Center |
| FBE | Fusion-bonded Epoxy |
| FEAD | Facilities Engineering and Acquisition Division |
| IDC | Ionic Diffusion Coefficient |
| MTC | Moisture Transport Coefficient |
| NAVFAC | Naval Facilities Engineering Command |
| ROICC | Resident Officer in Charge of Construction |
| SBIR | Small Business Innovative Research |
| SCM | Supplementary Cementitious Material |
| STADIUM [®] | Software for Transport and Degradation in Unsaturated Materials |
| UFGS | Uniform Facilities Guide Specification |
| WBDG | Whole Building Design Guide |

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1.0 INTRODUCTION

The NAVFAC methodology to enhance quality assurance for new concrete construction is a requirement of the Uniform Facilities Guide Specification (UFGS), section 03 31 29, Marine Concrete. It is expected that military construction will incorporate it to achieve more sustainable reinforced concrete structures. The corner stone of the approach employs a validated software program that allows users to predict the service life of the concrete under different types of environmental exposure conditions. Owners and engineers can now have a tool that quantifies the beneficial effects of various chemical compositions provided by specific types and blends of cements, fly ash, silica fume, and blast furnace slag. During construction, concrete samples are taken to test and document the uniformity of the hardened concrete transport properties as delivered to the construction site. This document is provided to users to help transfer the technology to the construction industry. The recommendations set forth are based on Navy research, case studies, review of applicable software programs, and discussions with engineers, suppliers, designers, ASTM International committee members, and experts in the field.

While this user's guide is written as a companion document to the UFGS section 03 31 29, Marine Concrete, it is applicable to all concrete construction to guide the engineers, specifiers, and contractors through the implementation of service life modeling as a tool to enhance quality control and quality assurance. Contract documents prevail in the event of conflict.

2.0 GOAL

A goal of the UFGS section, 03 31 29, Marine Concrete is to delineate the use of quantifiable metrics to evaluate and predict the service life of specific concrete mixtures in a specific marine environment. Doing so will allow the Navy to benefit from a performance-based specifications when used to supplement prescriptive requirements to achieve a specific service life. The development efforts to accomplish this goal have been motivated by the desire to avoid problems associated with premature concrete distress in future military construction by optimizing the material design and strengthening the quality assurance program. In addition, it offers designers a process by which to use greater percentages of complementary cementing materials. For example, Class F fly ash can be used to replace 50% of the portland cement, thus resulting in more durable and sustainable structures.

3.0 PROBLEM

In the design and construction of Navy piers, wharves, and bridges, there has been an implied expectation that the reinforced concrete structure will last a "long time." Without quantifiable metrics to evaluate the predicted service life of a structure, it has been unrealistic to use performance-based specifications or be able to design for a specific service life. The conventional use of prescriptive concrete specifications and tasking the design-build team with Contractor Quality Control (CQC) responsibilities does not offer any direct quantitative information about the potential service life of a given structure exposed to the conditions of a specific environment. Nor can the conventional approach offer assurances that the completed structure will be long lived, even if the contractor meets the requirements set forth in the contract documents.

Although most marine structures do achieve satisfactory service life, a few have suffered from premature concrete deterioration and distress, resulting in loss of service and the need for costly repairs or replacements. One prominent example is the Ford Island Bridge in Pearl Harbor, Hawaii, which, after three years, suffered from severe loss of concrete cover due to seawater attack on some of the pre-stressed concrete piles. In an effort to reduce the risk of premature distress, the quality assurance portion of this approach is designed to identify construction mistakes, thus minimizing required corrective action and allowing potential issues to be corrected during construction.

“There must be recognition on the part of someone in authority that uniform concrete of good quality requires intelligent effort and faithfulness to details all along the line—proper materials, proper design, proper mixing and transporting, and special care in placing and protecting. It must be recognized that, to obtain the desired results, some qualified person must be made responsible for these details, and having been made responsible, must be entrusted with the necessary authority,” (McMiillian, 1929). In U.S. Navy military construction, this responsibility has been assigned to the design-build contractor. The Navy’s Facilities Engineering and Acquisition Division (FEAD) or Resident Officer In Charge of Construction (ROICC) must rely on the building contractor to measure and monitor the quality of the construction. This arrangement of CQC is recognized as having inherent shortcomings. During the past two years, it has been observed that users are unfamiliar with the Navy methodology requirements and have many questions as to why and how to implement it.

4.0 OVERVIEW

The U.S. Navy has developed and implemented an approach related to measuring the quality of hardened concrete mixtures with respect to their potential to achieve structures with a defined service life. This approach is delineated in UFGS, section 03 31 29, Marine Concrete. During preconstruction, the design-bid-build contract team develops an optimized concrete mixture(s) that has the potential of meeting the prescribed service life—a process that includes laboratory tested and mathematically modeled uncracked concrete specimens to predict the time to initiate corrosion in the specific marine environment where the structure will be located. During construction, at specified intervals, concrete cylinders are made from the delivery of the ready-mix or batched precast concrete to validate that the concrete’s transport properties are consistent with the approved mixture.

The methodology is applicable to design-build and design-bid-build contracts. To date, it has been used for the design and construction of several Navy piers and wharfs. It has also been adopted for several public projects including the new locks currently under construction for the Panama Canal, U.S. Embassies, and highway bridge projects, collectively valued at several billion dollars.

5.0 PERFORMANCE-BASED SPECIFICATIONS

Development and implementation of performance-based specifications was first approved by the Office of the Secretary of Defense for implementation in the aviation business sector. NAVFAC ESC’s interest in developing performance-based specifications is shared by other U.S. agencies

including the Federal Highway Administration, National Ready-Mix Concrete Association, and the Precast Concrete Institute. The use of performance-based specifications provides a contract vehicle for innovation, allowing for more durable concrete structures. Use of performance specifications mandates that a clear definition of performance and how to measure and predict service-life be agreed upon by all parties.

6.0 APPROACH

The strategy is to shift construction documents toward performance-based specifications while retaining applicable prescriptive criteria. This allows the U.S. Navy to specify the desired service life of new structures. The use of the Navy methodology is intended to enhance confidence, prior to taking ownership from the builder, that the completed structure is likely to meet the defined service life. The use of performance-based specifications is challenging, as there must be a reliable evaluative technique to predict long-term performance from candidate mixtures prior to construction and similar techniques that will validate the concrete construction. The methods used to accomplish these goals must be agreeable to all parties prior to signing bid documents. The methodology is structured as a three-part process.

7.0 BACKGROUND

NAVFAC ESC initiated an effort in 2002 to collaborate with private industry by awarding two Small Business Innovative Research (SBIR) contracts to develop tools for predictive modeling of marine concrete. One of those companies, SIMCO Technologies, Inc., successfully developed and demonstrated a software program that predicted the movement of ions in and out of marine concrete structures (Burke & Marchand, 2003) (Marchand, Samson, Burke, Tourney, Thaulow, & Sahu, 2003) (Maltais, Marchard, Ouellet, Samson, & Tourney, 2004). The resulting numerical modeling software program is called STADIUM[®] (Software for Transport and Degradation in Unsaturated Materials). SIMCO successfully transitioned the development of STADIUM[®] to an international consortium of public and private partners to advance the software. Under the SBIR agreement, SIMCO has licensed the use of the STADIUM[®] for a fee.

NAVFAC ESC maintains a Cooperative Research and Development Agreement with SIMCO Technologies, Inc. for the ongoing development and technology transfer of STADIUM[®]. The most recent version of STADIUM[®] is Version 2.997. More information regarding the STADIUM[®] software can be obtained from SIMCO Technologies.

A NAVFAC ESC market survey of service life modeling software concluded that STADIUM[®] software is the only program that NAVFAC recognizes as being adequate for service life modeling, therefore a Class Justification and Analysis (J&A) sole source has been signed by NAVFAC Headquarters. A market survey is required as part of the J&A review and documentation to determine if other service life modeling tools meet the Navy's standards for accurate service life modeling.

8.0 FUNDAMENTALS OF GOOD DESIGN

The Navy's methodology is intended to supplement basic principles of good design, not to replace them. Achieving durable concrete structures depends on many factors, some of which include: good design, properly specified concrete cover over the steel reinforcement, use of quality materials, mitigation of alkali silica reaction, limits on drying shrinkage, good workmanship, and an adequate quality control program. An adequately designed reinforced concrete structure from well-constituted and properly consolidated and cured concrete will remain essentially durable as long as the micro-cracks present in the interior do not form an interconnected network of pathways to surface cracks. Adherence to these basic principles is paramount to achieving quality concrete. The use of the Navy methodology is intended to be a tool that compliments the fundamental principles of good design and construction to accomplish durable concrete structures with a defined service life.

9.0 NAVFAC ESC POSITION ON SERVICE LIFE MODELING OF CONCRETE STRUCTURES

Accurate concrete service life modeling is a tool that, when used in combination with other tools and good engineering judgment, enhances the U.S. Navy's ability to build durable concrete structures and to have increased confidence in the remaining service life of existing concrete structures. It is a critical component to the methodology developed by NAVFAC ESC for defining the expected service life of existing and new concrete structures. Technology transfer by the Navy of this approach to the concrete industry is considered a top priority.

Multi-mechanistic service life modeling is applicable for all concrete construction including plain reinforced concrete and pre-stressed or post-tensioned concrete. When applied to plain reinforced concrete structures, current modeling results are only valid when cracks with widths greater than 0.5 millimeter (0.02 inches) (a credit card is typically 0.5 to 0.75 mm thick [.02 to .03 inches) are repaired or sealed. The model accounts for the presence of concrete micro cracking through the measured ion transport properties of concrete samples. Modeling results are valid for all pre-stressed or post-tensioned elements, or concrete elements in compression, as macro-cracks will be closed.

Multi-mechanistic service life modeling is required for U.S. military construction.

Currently the only multi-mechanistic software available and thus deemed acceptable for use on Navy projects is STADIUM[®]. This software is licensed to various engineering firms in the U.S. and Canada. Using environmental exposure conditions specific to a structure's location, which are included in the STADIUM[®] database, and moisture and ion transport properties obtained from concrete samples, the modeling process tracks the movement of several ionic species within the concrete (including the ingress of contaminants) and predicts the chemical deterioration of concrete and onset of steel reinforcement corrosion. This multi-mechanistic model has been validated by NAVFAC ESC and others to more accurately predict performance of concrete compared to software dependent on Fick's second law. Other service life modeling software with capabilities that claim to be equivalent to STADIUM[®] may be submitted to NAVFAC ESC for consideration.

10.0 BENEFITS AND EXPECTATIONS

The average military construction expenditure for US Navy projects that could benefit from the methodology is \$671 million per year for 2012 through 2015. The benefit to each individual project will vary. A conservative estimate of cost avoidance as a result of implementing the methodology for U.S. Navy construction is \$167 million annually. This estimate is based on the expectations that the concrete structure will have a longer life and require fewer repairs and a reduced carbon footprint. Use of this approach by the other military services will have similar benefits.

A service life of 75 years for conventional single-deck pile supported piers, wharves, and bridges can reasonably be accomplished when using this methodology. In the Uniform Facilities Guide Specification, service life is defined as the number of years before major restoration, with minimal maintenance. Major restoration is defined as repairs requiring jack hammering or other destructive means of concrete repair preparation. Recently, NAVFAC ESC completed design documents for a floating double-deck pier with a service life of 100 years (Zueck & Wernli, 2010) (BERGER/ABAM, 2010) (Burke D. F., 2010).

The UFGS section 03 31 29, Marine Concrete, is available on the web from Whole Building Design Guide (WBDG).

It is expected that the guide specifications will be revised and improved based on lessons learned and input from users.

11.0 SERVICE LIFE MODELING

Training and licenses are provided by SIMCO Technologies, Inc. Currently, there are six certified STADIUM[®] labs, while three other labs are currently in the process of being certified. Currently 10 engineering firms are licensed to use the service-life predicting software.

As of June 2012, the following are STADIUM[®] authorized companies:

- AECOM
- Appledore Marine Engineering
- Construction Testing & Engineering, Inc. (CTE)
- CTL Group
- Lafarge
- RJ Lee Group
- Simpson Gumpertz & Heger
- Siva Corrosion Services, Inc.
- Tourney Consulting Group
- Walter P. Moore

As of June 2012, the following are STADIUM[®] certified laboratories:

- Construction Testing & Engineering, Inc., Escondido, CA
- Construction Testing & Engineering, Inc., Guam
- CTL Group
- Lafarge
- RJ Lee Group
- Tourney Consulting Group

The software predicts the movement of ions in and out of portland cement-based concrete. Contrary to the first generation of chloride penetration models, such as LIFE-365[™], that are based on Fick's second law of diffusion to predict chloride ion movement in saturated concrete using simplifying assumptions for temperature, water movement, and other contributing factors, STADIUM[®] is based on ionic transport modeling in saturated and unsaturated concrete and numerical solutions. The STADIUM[®] model accounts for the complex interactions between the contaminants penetrating the porous network of concrete and the hydrated phases of the cement paste and allows engineers to quantify the effects of various chemical compositions provided by specific types and blends of cements, fly ash, silica fume, and blast furnace slag when used with specific aggregates. Thus, STADIUM[®] model considers the local materials.

The model accounts for temperature and moisture variations and how these environmental exposure conditions influence the rate of contaminant ingress. It is thus possible to provide STADIUM[®] with time-dependent environmental conditions and to simulate the effect of wetting and drying cycles on the chloride penetration rate. The description of the environmental exposures provides a realistic estimate of the extent of chloride ingress, as well as concrete chemical degradations, in a structure during its service life.

Mathematical modeling does not necessarily allow exact quantitative prediction of service life although, they may allow comparison of alternative "approximate solutions" (Vaysburd & Emmons, 2012). Service life modeling using the multi-mechanistic STADIUM[®] model is judged reliable, although one must always use common sense and engineering judgment when analyzing inputs and interpreting the results.

12.0 THREE-PART METHODOLOGY

The methodology is structured as a three-part process.

Part 1: Theoretical Simulations of Candidate Mixtures. Review the materials, mixture design, exposure conditions, and cover expectations to assess the likely performance of the mixture. STADIUM[®] contains a concrete mixture database on which theoretical simulations could be based on. Allow one week to do this.

Part 2: Mixture Durability Evaluation. The concrete producer makes test cylinders from candidate concrete mixes. Lab tests for porosity, migration, and drying are performed at 28 days; at 90 days, migration and porosity tests are repeated. This process takes a minimum of 118 days.

The concrete producer can provide data already available from a past project performed less than 12 months prior to the new project.

The mixture design certification process is led by the design-build team working with the concrete supplier, the certified lab that generates the modeling inputs, and the engineering firm that does the service life modeling. The performance interaction between the concrete, reinforcing steel and potential surface treatments are evaluated simultaneously in the modeling. A durability report, with the test results, is submitted to the client for review and approval. This approach allows teams to be innovative in creating an economical system that will also meet the service life criteria. Once the mixture is approved, concrete production can begin.

Part 3: Quality Assurance During Production. During construction, the same three laboratory tests used for certification of the mixture are required to validate quality (Samson, Marchand, Henocq, & Beausejour, 2008). Each time the concrete is sampled; six cylinders are prepared for testing. The tests are performed after 28 days of curing and take 14 more days to complete. Test results verify if the concrete delivered to the site is being produced uniformly and within the allowable criteria.

The Engineer of Record must specify the frequency of testing during the construction phase. Sufficient testing must be done to maintain confidence that the concrete, as delivered and placed, remains consistent and within specifications.

Test results during concrete production that fall short of the acceptance criteria dictated by service life modeling alert the contractor that something in the production and placement process has drifted out of calibration or that an error has been made. The goal is to track down the problem and correct it as quickly as possible. Unless the concrete producer makes a large error in batching or placing, the chance that sizable section of hardened concrete need to be removed is remote. Removal and replacement is a last resort.

If necessary, concrete cores can be extracted from the structure to measure the transport properties and predict the service life of the concrete as placed. For those areas adversely affected by substandard concrete, new STADIUM[®] simulations can be helpful to evaluate the effectiveness of different remediation strategies. Mitigation efforts to restore the service life of these areas shall be approved by the Contracting Officer prior to proceeding.

As an example, during the Kilo Wharf Extension in Guam, it was found that the 28-day old concrete samples from the caisson (fabricated off-site in Japan) were not in compliance. The contractor was asked to submit a second set of samples that were 56 days old. These samples, with extended curing, were found to be satisfactory and were judged acceptable. In another case, unexpected results were found to be the result of the temperature of the steam curing drifting out of calibration—a problem that was easily fixed. In neither of these situations was it necessary to replace or repair any of the concrete and the project continued on schedule with confidence.

13.0 APPLICATIONS OF THE METHODOLOGY

The methodology affects the design-build process via several applications, as summarized in Table 13-1.

Table 13-1. List of Applications for Concrete Durability Modeling

| Application | Type of Tool | Remarks |
|--------------------------------|---------------------------|--|
| Planning | Strategic Tool | Prequalifying major construction materials/methods |
| Design | Concrete Design Tool | Aligning predicted service-life options/owner economic expectations |
| Bidding | Estimation Tool | Selection or prequalifying potential durability systems |
| Design/Build | Optimizing Tool | Selection or prequalifying testing/analysis |
| Contract Selection | Selection/Evaluation Tool | Review and evaluate bid proposals |
| Final Material Selection | Optimizing Tool | Selection or prequalifying testing/analysis |
| Construction Quality Assurance | Quality Assurance Tool | Field quality assurance can be monitored with periodic materials testing and/or model simulations |
| Maintenance Budgets | Operational Tool | Periodic review of concrete durability condition will provide insight to the best maintenance programs to match financial expectations |
| Rehabilitation | Restoration Tool | The current condition of a concrete structure can be evaluated and the best repair scheme applied to address degradation root causes and meet financial requirements and budgeting |

14.0 STADIUM® LAB

Testing of concrete cylinders must be done in a certified STADIUM® laboratory to determine specific characteristics that are used for service life modeling. These tests include:

1. ASTM C642 Standard Test Method for Density, Absorption, and Voids in Hardened Concrete.
2. STADIUM® Ionic Diffusion Coefficient (IDC) Migration Test. A modified version of ASTM C1202 Standard Test Method for Electrical Indication of Concrete's Ability to

Resist Chloride Ion Penetration. The analysis of the migration test results provides the intrinsic diffusion coefficient of each ionic species. The test consists of accelerating the ions under an external potential and measures the electrical current across the sample over a 14-day period. The measured currents are analyzed to provide the diffusion coefficients. See Figure 14-1.

3. STADIUM[®] Moisture Transport Coefficient (MTC) Drying Test. A modified version of ASTM C1585 Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes. The test consists in recording the mass loss of concrete samples in a control room. Then the data is used for analysis and evaluation of the moisture transport properties. See Figure 14-2.

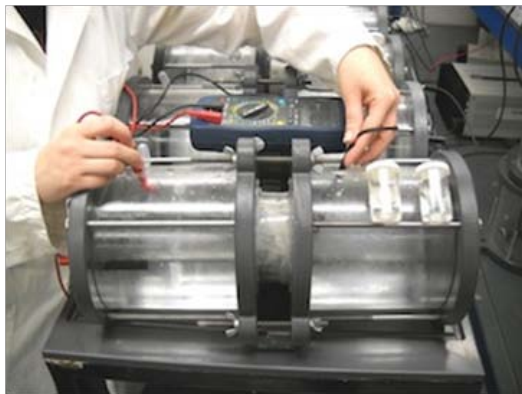


Figure 14-1. Ionic Diffusion Coefficient (IDC) Migration Test (Photo by SIMCO)



Figure 14-2. Moisture Transport Coefficient Drying Test (Photo by Tourney Consulting)

Once the testing is complete, the collected raw data from ionic diffusion and moisture transport coefficient tests are analyzed using STADIUM[®] LAB, these values are used as input for the service-life simulations.

15.0 OTHER CONSIDERATIONS

Service life modeling predicts the time it takes chloride ions to reach the depth of the steel reinforcing at a level of contamination of 500 ppm for an uncracked section of concrete, as well as other deterioration mechanisms. Eventually, chlorides will reach the steel reinforcement; however, the amount of time it then takes for the steel to corrode (and cause cracking and spalling) is unknown. Generally, the time for visible damage to occur will be longer in cold climates versus sub-tropical sites. Typically, the candidate concrete mixtures should be designed to resist chloride ion contamination to the level of 500 ppm at 60 years, and then the designer assumes an additional 15 years before significant damage might occur, thus achieving a design that has the potential to deliver a 75-year service life.

Plain steel rebar and pre-stressing strands with specified concrete cover of 75 mm (3.0 inches) should normally be specified according to applicable codes. The predictive service life should consider the steel placement tolerances as specified in ACI 117. Predictive service life modeling is used to confirm that the candidate mixture, type of steel, and concrete cover will yield the required service life for the particular structural element under consideration. Within the STADIUM[®] program, users may select from three exposure options (submerged zone, tidal zone, and marine atmospheric). The results of the software runs will provide the design team with the predicted service life for each unique configuration modeled.

For predicting the service life of the concrete, the design shall meet the owner's design life without relying on a barrier coating to the steel rebar, chemical corrosion inhibitors, or passive cathodic protection for additional life extension. The use of these supplemental corrosion protection methods is entirely acceptable, but it is difficult to justify a specific life extension from either without conclusive research data. Their use is considered a form of “insurance” or “belt and suspenders” and may in fact extend the service life of the structure.

The value of the service life modeling tool to predict the performance-life of concrete structure is, in part, a function of the quality of the input data. Specific input data regarding the environment is one important component. The software is preloaded with typical values for seawater composition, air temperature, water temperature, and humidity for general Navy locations such as Bangor, Washington; Norfolk, Virginia; and Guam. However, it is recommended that local data regarding the chemical composition of the seawater and temperature for the site be measured, as these parameters can have an effect on the calculated rate of deterioration of the concrete and thus, the predicted service life.

The accuracy of the results are enhanced when the design team can sample, during the design phase, aged concrete from an existing structure in the vicinity of the proposed construction site. Concrete core samples from an aged structure provide data about long-term ingress of chemical species, as well as how the cement paste and local aggregates respond to the specific marine conditions.

STADIUM[®] does not predict some concrete properties and degradation mechanisms such as drying shrinkage cracks and alkali silica reaction. These critical properties are addressed in prescriptive language in the Uniform Facilities Guide Specification and must not be overlooked just because the candidate concrete mixture may exhibit excellent transport properties related to service life modeling.

It is essential that the prescriptive tests for shrinkage be accomplished per ASTM C157 as modified by ACI 364 3R. The maximum allowable concrete drying shrinkage for marine concrete in the U.S. Navy is 0.05%. A concrete mixture that meets the service life requirements using STADIUM[®] but fails the shrinkage tests is not acceptable for construction. Constructing a reinforced concrete structure with excessive crack widths will allow for the rapid ingress of seawater and oxygen, which shorten the service-life. Although mixtures containing condensed silica fume offer benefits of high early strength, greater ultimate strength, and greater impermeability, they are also more prone to excessive cracking. This can also be true for some concrete mixtures containing large amounts of portland cement and blast furnace slag. Before the

owner accepts the completed structure, all cracks transverse to the steel rebar in excess of 0.5 millimeters (0.02 inches) should be sealed.

The use of Class F fly ash and blast furnace slag typically show positive improvements to reduce permeability. NAVFAC ESC encourages its use as a partial replacement to ordinary portland cement with fly ash replacing up to 50% of portland cement, which is called high-volume fly ash concrete (Burke D. F., 2012).

When granulated slag, coal fly ash, and natural pozzolans are used as cementing materials for replacement of portland cement in a concrete mixture, and if by doing so, the sustainability, durability, and the initial cost of the concrete mixture show considerable improvement then it is improper to call these materials Supplementary Cementitious Materials (SCM). As the concrete industry moves forward and takes better advantage of this proven technology, it is appropriate to introduce the term Complementary Cementing Material (CCM) to describe these mixtures. When lesser amounts of these materials are used to produce concrete mixtures that do not show these benefits then the term SCM remains applicable.

16.0 SUMMARY OF NAVY PROJECTS

The following projects have used, or are currently using, this methodology:

- Modular Hybrid Pier Test Structure, San Diego, CA
- Kilo Wharf, Guam
- Pier 31, Groton, CT
- Pier 5, Norfolk, VA
- Fuel Pier D, Craney Island, Norfolk, VA
- Wharves Uniform and Tango, Guam
- Pier 12, Naval Station, San Diego, CA

The methodology and tools used for new construction have also been used to predict the remaining service life of numerous existing Navy structures.

17.0 SUMMARY

Various aspects of the U.S. Navy's methodology for quality control and quality assurance of new reinforced concrete construction are presented here to broaden exposure and provide guidance on how to use the methodology correctly and effectively. The development of this unique approach has been motivated by the desire to avoid problems associated with premature concrete distress by optimizing the material design and performing specific laboratory tests as part of the quality assurance program. When used with good engineering judgment this methodology is a tool that can reduce the number of future structures that suffer from premature distress. The methodology

is currently a part of the design-bid-build documents for Pier 12 in Naval Station in San Diego, Fuel Pier D in Norfolk, VA, and other public and private construction. The revision of the Uniform Facilities Guide Specification, section 03 31 29, Marine Concrete was a significant step to implement in general construction, as a scientific methodology that quantifies the service life of new U.S. military construction. This paper is offered to help owners and users to better understand how to use the Navy's methodology.

18.0 QUESTIONS AND ANSWERS

Q1 The market survey is clear and well written but my key concern is that it is limited to a survey of literature and does not appear to include a posting/publicizing to see if there is any other source.

A1 The market survey is the most recent of three survey efforts to identify software and service life modeling processes suitable for Navy use. The first survey was conducted in 2002 included a public solicitation to identify vendors (Burke D. F., 2002). Since that time, ESC has been fully engaged in the development, application, evaluation, and promotion of service life modeling as a tool to enhance owner confidence in concrete construction. In 2009 ACI task group on service life modeling meet at ESC to discuss the attributes of software programs, which is referenced in the J&A. In addition ESC participates on various national and international committees, attends conferences, and presents papers worldwide on this topic (Burke D. F., 2010) (Maltais, Marchard, Ouellet, Samson, & Tourney, 2004) (Marchand, Samson, Burke, Tourney, Thaulow, & Sahu, 2003) (Burke D. F., 2002)(Burke D. F., 2008).

Q2 I see that NIST was contacted but what about Army COE, DOT, AT&T/Verizon, and others who may lay underwater cables in concrete. Have we contacted those entities and others?

A2 Over the last ten years, all applicable government agencies and private companies have been contacted about this topic. The Corp of Engineers has lost most of their technical capability in concrete and have always deferred to the Navy regarding marine concrete. NIST was the first government agency to work on a program on this topic and they have opted out of their development efforts due to the success of STADIUM[®] to fill this technology gap. ESC Oceans Department has a long and comprehensive history concerning laying underwater cables, some of which are in concrete. Commercial telecom companies have not yet shown an interest in predicting long-term service life of concrete in marine environments with respect to modeling tools. There is no direct relationship between STADIUM[®]/waterfront concrete and concrete associated with underwater/waterfront cables systems.

Q3 It looks as if we have a good list of salient characteristics/criteria in the guide specs and I wonder why we cannot use those instead. Why are they insufficient? Particularly where it indicates the goal is to develop and implement performance based specifications, perhaps requiring reliability to X point and let the building contractors choose the product.

A3 The list of salient characteristics is accurate and 100% sufficient to delineate the needs of the Navy for MILCON. If NAVFAC were to include this list of characteristics in the bid documents, it would imply to the bidding community that more than one vendor has the capability to meet the Navy's need. Since there is only one vendor, the bidders would be wasting

time submitting candidate software programs to the Navy Contracting Officer who does not have the technical expertise to evaluate the software programs. Use of performance based specifications mandates that a clear definition of performance and how to measure and predict service life be agreed upon by all parties. The UFGS, section 03 31 29, Marine Concrete defines the criteria and the tools to measure the candidate concrete mixture(s) for MILCON as well as the concrete as delivered to the construction site. The contractor is encouraged to choose a concrete mixture that meets the service life but is not free to choose an alternate methodology or software to measure the predicted performance of that mixture.

Q4 It also appears that we have a Cooperative Research and Development Agreement (CRADA) with STADIUM, which could appear to show favoritism toward this contract product.

A4 NAVFAC ESC is open to establishing a CRADA with others who show an interest and ability. However, none has been identified or expressed an interest.

Q5 In my view the market survey document does seem to explain why we need this reliability data and validation. It does not seem to me that the 12 items used for the SBIR are the same as salient characteristics though. Therefore, what are our minimum needs (i.e. what are the salient characteristics?)

A5 Any vendor who wishes to submit a software product that claims to be equivalent must meet the same criteria as established in the SBIR. The Navy should not downgrade our expectations for performance when we are dealing with mission critical structures demanding substantial capital improvement funds.

Q6 Legal has some concerns in regards to data rights. Based on SIBR do we already own the rights?

A6 The legal agreement established in the SBIR contract between the government and the vendor states that the intellectual property rights belong to the vendor. In addition, it was agreed that NAVFAC ESC may use the software free of charge for research but not for day-to-day project design. If the intellectual property rights had not been granted to the vendor, the vendor would not have been motivated to develop the software. The SBIR contract paid for about 20% of the development costs for STADIUM[®], the remaining funds came from other public and private sources.

Q7 Concerns with the value noted in the J&A. Based on current award of P-990 this amount seems extremely low. What is included in the amount proposed in the draft J&A?

A7 The cost to accomplish enhanced quality assurance using UFGS 03 31 29 includes two phases. The first phase includes service life modeling using STADIUM[®] of the candidate concrete mixtures prior to construction; this effort requires the J&A. The cost of phase I is relatively small and constant regardless of the size of the MILCON. The second phase entails sampling and testing of the production concrete at specified intervals. The test results from slump, compressive strength, and ion diffusion document the uniform properties of the fresh and hardened concrete during the production phase. The Engineer of Record specifies the intervals

for sampling and ion diffusion testing. MILCON projects with a lot of concrete and frequent sampling will cost more than smaller projects.

Q8 The UFGS requires that samples be taken for each 76.5 cubic meters (100 cubic yards), or fraction thereof. Please advise if there is an allowance in this requirement for large pours. Our concern is the rigid sampling criteria, if our concrete pour exceeds 76.5 cubic meters (100 cubic yards). Would a second set of cylinders be required if we poured 85.63 cubic meters (112 cubic yards) in a day (for example)?

A8 The UFGS is a guideline. The Navy and the Engineer of Record can adjust the frequency of testing as best suits the particulars of each project.

Q9 It is our understanding that providing epoxy coating (or galvanized bar) increases the corrosion threshold and propagation time by as much as 10 years in some cases. Can rebar coating be considered in the service life of the marine concrete and/or play a factor in acceptance if there is a deviation between the trial batching and production sampling results?

A9 If the quality assurance testing of the concrete samples during construction indicates adverse variations, then the Navy-Contractor team members needs to make an assessment of how severe the non-compliance is and how the process can be adjusted to restore the quality of the concrete. For concrete already placed that has properties less than expected, the benefits of using either galvanized or fusion-bonded coatings will certainly tend to mitigate the concern. However, the benefits of both are very subjective in terms of defining how many extra years of service either will contribute. The use of either galvanized rebar or FBE rebar are considered to be an “insurance policy” if something goes poorly during construction then these supplemental corrosion systems will enhance our confidence that the structure will last longer. How much longer is not known.

Q10 Are there instances when one should and should not specify the use of STADIUM®?

A10 The new methodology for enhanced quality control requires extra effort and time to perform laboratory tests on the candidate mixture(s) and then more testing of the concrete as placed. This approach yields a final product that provides the owner with confidence in the concrete’s long-term durability. Obviously, these benefits come at a cost. Currently, the use of STADIUM® is essential for all major MILCON projects of \$5 million or greater. The costs to conduct the material tests and service-life modeling are likely to drop in the future as users become familiar with the processes and a database is developed from the results of each completed project. In time, these costs will be further reduced as the boundary conditions for various Navy sites are defined thus allowing its use on projects of lesser cost. However, project cost is not the only consideration of when one should use this three-step method. For example, a project of essential mission importance should employ STADIUM® even if the total cost is low. In contrast, a facility with a short service-life requirement, such as 20 to 30 years, may exclude the use of STADIUM® as common concrete mixtures and curing methods are likely to achieve this modest expectation for service-life. STADIUM® is most applicable for projects where the service life goals push beyond conventional performance and where periodic concrete repairs will adversely affect the facility to support the Navy mission. Finally, the Engineer of Record shall specify the frequency of sampling and testing during the construction phase. For example,

the concrete for a new Bachelor Officers Quarters with a 40-year service life should be tested just once, whereas a new pier should be tested many times during its construction.

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