**Development of a Digital Twin System for Performance Assessment of Marine Engineering Materials and Facilities**

**1. Research background**

Chinese marine engineering industry has achieved great progress since the implementation of the national maritime strategy, *Towards Deep Blue*. Guangdong Province has proposed to actively develop the marine structural engineering industry in *the 13th five-year plan* for the development of emerging industries. This development was setback somewhat by severe structural material failures under complicated marine environment, especially in the South China Sea. It is therefore urgent to establish an intelligent performance-assessment and protection system of the service integrity of materials in key marine engineering facilities, so as to provide technical assurance for their safe operation and service life extension.

The rapid development of information technology in recent years makes the application of digital twin system in industries readily feasible. The *digital twin system for* *engineering materials performance assessment* (hereinafter referred to as “the *DiTSEMPA*”) proposed in this project will construct the digital simulation model for failure processes that establish the mapping (digital twin) between simulation and physical engineering materials and equipment by extracting physical models from huge amount of material service performance data, which is generated from various lab experiments under multiscale, multi-variable coupling and critical conditions, and from data mining and artificial intelligence processing. Taking advantage of the iteration of on-site and real-time monitoring data, *DiTSEMPA* will be able to improve the prediction accuracy for the performance evaluation of structural materials. At present there is a lack of performance data for engineering materials under complicated marine service conditions and uncertainty on the materials failure mechanism, which is further exacerbated by the inadequacy of on-site monitoring techniques and large-scale test facilities, which are vitally required for verification and optimization of *DiTSEMPA*.

Thus, our project plans to employ the *National Major Science and Technology Infrastructure* managed by the lead project team, including the in-house test facilities for large/full scale engineering materials under complicated service conditions, the software and hardware platforms for simulation and safety assessment. By using a representative marine engineering equipment as the research object, service performance data of equipment materials under multifield coupling environment will be acquired from microstructure-component-equipment multi-dimensional testing and simulation, and by building relevant monitoring systems and data applications. The failure mechanisms and the influence of environmental factors will be extracted for modeling. The objective is to develop the methodology and related technology of *DiTSEMPA* for engineering materials performance evaluation and life prediction, to deliver a technical solution for this problem which is internationally known as one of the frontier challenges.

**2. Scientific issues**

For the development of the digital twin system, we need to reveal the cross-scale association and the time evolution models in the service performance of marine engineering materials under multi-field and multi-factor coupling environment, and



clarify the key scientific issues in “size domain”, “environmental domain” and “time domain” as well as their interactive coupling effects.

* **Scientific issues in size domain** **— size effect**

Current experimental data of marine steel accumulated in the laboratory are acquired with the small coupon-level samples, but due to the non-uniformity of the composition and microstructure in the component ( for example, inclusion phase, segregation, defects, etc.), welded joints in facilities, the different metal connection and crevice configuration in fastening and moving parts and so on these data are non-representative of the actual structure. For most cases, such coupon-level data are not useful to reliably predict the service performance of actual structure and facility. Furthermore, the essential connection among material composition, microstructure, environmental factors and service performance needs to be uncovered and the correlations between microscopic and macroscopic properties of marine materials, between coupon-sized samples and large structural components, as well as between materials and components need to be established.

* **Scientific issues in environmental domain — environmental coupling effect**

Different parts of a large marine facility can experience marine atmosphere zone (subject to salt fog environment, aging and thermal and UV radiation of sunlight), spray zone, tidal zone, full-immersion zone, sea mud zone respectively, whose service performances are also affected by structural load, fabrication residual stress, wind load, surge load and other mechanical factors. Moreover, the working state of surface coating and the cathodic protection system also plays an important role in the service performance of the marine structure as well. Thus, to solve scientific issues in environmental domain, it is essential to uncover the complex nonlinear coupling mechanisms and underlying laws governing above-mentioned multi-field and multi-factor environmental effects on service behavior of marine engineering material.

* **Scientific issues in time domain — time effect**

Focusing on the remaining life prediction and evaluation requirements of life extension of marine structures, it is necessary to grasp the time-dependent nonlinear evolution characteristics of service performance of materials in complex and mechano-chemical coupled environments. The key is to develop the laboratory (accelerated) evaluation method and verify its equivalence with the actual on-site service data, so as to construct a time-dependent evolution model of service performance. This model lays a solid foundation for deriving long-term service behavior using short-time service data.

**3. Research Objectives and Activities**

**3.1** **research objects**

There are a great variety of marine engineering materials and facilities who serve under complicated environments. In order to efficiently construct the *digital twin system for engineering materials performance evaluation*, a specific and representative marine engineering facility needs to be selected as the research objects.

The development of offshore wind power industry is entering an accelerated status in China, and Guangdong province plans to build 23 offshore wind farms with a total installed capacity of 66.85 million kilowatts by 2030. At present, most sites for wind power construction are located in the intertidal zone, where the service environment is more demanding than the offshore platform, as the alternation of wetting and drying is more frequent on the steel surface and the effect of surge and spray more severe. The coupling effect of the unique wind load and the harsh corrosive environment makes the failure forms of offshore wind power materials and facilities more complex and diverse. At the meantime, the construction of remote inspection on service status and real-time management system for risk assessment and maintaining decision are desperately needed with the development of the Chinese offshore wind power gradually reaching toward the far sea. However, due to the short operating life of offshore wind farms in China, a system that assesses the service performance and life of materials has not been generated for the lack of data of service performance of materials and accumulation of failure mechanism, comparing with other marine engineering facilities.

Therefore, in view of urgent industrial demand, and shortage of service performance data, our project takes offshore wind facility as the research object in implementing the key scientific tasks. The present project will aim at constructing the digital twin system for material service performance evaluation for offshore wind facility, and demonstrating its key functionalities.

**3.2 Research Activities**

**1) Methods of accelerated testing for offshore wind power materials under multi-field and multi-factor coupling conditions**

This project takes typical metallic materials (such as structural steels), joints (welded joint and connection sections), key equipment and coating systems of offshore wind power as research objects. Accelerated multiscale experimental evaluation methods for material/component/facility will be developed by collecting and analyzing multifield and multifactor test results produced using a spectrum of corrosion conditions which consist of marine atmosphere and seawater, under mechanical loading typical of wind and sea wave operational stresses. Data generation and accumulation as well as their subsequent analyses of service performance for typical materials, structures and facilities under complex environmental and loading conditions simulating the actual working conditions will enable determination of the failure mechanism and the influences of various factors involved.

**2) Multi-scale modeling and simulation of service performance of offshore wind power materials**

Based on the mechanistic model of offshore wind power facility service performance under multi-factor coupling conditions, the multi-scale digital modeling and simulation of the service behavior of offshore wind power facility will be carried out in this task. The multi-scale correlation of material/structure environmental damage behavior can be realized by the cross-scale transfer of key parameters among different scales, regional nesting and other methods. The simulation models and their parameters can be modified by comparing and validating of simulation results with the multi-scale experimental data, produced in the previous task, to support further analysis of the failure mechanism of materials and facilities. Meanwhile, the corresponding mechanistic model and data association can be used as the basis of physical information fusion to support the construction of the *DiTSEMPA* for offshore wind power.

**3) Development of real-time monitoring technology for the offshore wind power facility**

Based on the operational characteristics of offshore wind power facility, a monitoring sensor technology for environmental condition sensing of marine environment and a corrosion monitoring sensor based on multi-electrode technology will be developed. On the basis of the Internet-of-Things technology, the real-time monitoring system and related hardware will also be developed to acquire the data of stress and strain levels of key components of offshore wind power components. Data for the working status of the cathodic protection and other protection systems can also be integrated, to support health monitoring of the offshore wind power facility. Optimization of maintaining strategy for key components can also be developed using the sensed data as well the models from the previous task.

**4) Development of digital twin prototype system for service performance of the offshore wind power facility**

Multi-source data fusion method and key technologies for integrity monitoring and life prediction of key materials are expected to be achieved on the basis of multiscale experimental evaluation data, numerical simulation data on service performance, and collection of related failure cases. The *DiTSEMPA* prototype of microstructure-component-subsystem will be built especially for the key components, with functions to perform rigorous ranking of local environmental conditions, and to carry out risk level classification of the monitored components. This *DiTSEMPA* system will initially have the ability of failure probability analysis and life prediction for marine wind power materials and facilities, and it can be further expanded to apply for other marine structures.

**5) Technical integration and verification of the intelligent system for assessing the service performance of offshore wind power** **facility**

The integration of the *DiTSEMPA* prototype and the online monitoring system established in the present project, with the existing monitoring and operation system of the offshore wind power facility will be carried out in this task. The relevant data, models, methods and tools provided by the *DiTSEMPA* will be used to achieve the safety evaluation of the offshore wind power facility. After completing the on-site demonstration of the *DiTSEMPA* for offshore wind power facility, the failure probability and life prediction model can be iteratively optimized basing on the on-site real-time monitoring data. Finally, a real-time intelligent *DiTSEMPA* with functions of service status monitoring, operational safety evaluation, risk warning and life prediction will be established.