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DEDICATION

This third book by the author is dedicated with pride to the following people that had the greatest contribution in shaping his professional life.

- *His professor and Ph.D. thesis adviser, Dr. William L. Wainwright who gave him the first lessons in writing a technical paper which became the first publication by the author.*
- *His first supervisor, Mr. William A. Tam, then Director of Marine Research, who had faith in the author's ability and gave him an opportunity to work on hydrodynamic related subjects.*
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PREFACE

The offshore industry has matured over the years through innovation, initiatives and experience. The industry has advanced a long way to its present stage from its first installation of an exploration structure in coastal waters of the Gulf of Mexico in the 1940's. The early structures were fixed to the ocean floor and looked much like the electrical transmission towers common on land. Today the shape, size and type of offshore structures vary depending on the required applications. Offshore structures are abundant in all parts of the world. In addition to structures fixed at their base, moored floating structures and vertically tethered structures have been installed for exploration, production, storage and offshore processing of crude oil. While offshore exploration has been relatively trouble free, there have been a few catastrophic failures. Therefore, design of these structures for accident-free operation under anticipated conditions is vital for the continued success and growth of the offshore industry. One of the means of verifying the design of a structure is the testing of scale model of the structure in a simulated ocean environment during its design phase.

Model testing has been performed through the history of mankind. Systematic hydraulic scale model testing goes back to the nineteenth century. However, even today modeling is partly an art as well as a science. In modeling, certain laws of similarity are followed. Several text books are available that deal with these similarity laws. In many cases, these laws can not all be satisfied in a model test. In these cases, it is necessary to selectively distort some of these scaling laws to perform the model tests. Although this distortion is somewhat of a compromise, valid modeling results can still be expected.

While the technical literature dealing with offshore structures discusses model testing, a comprehensive book in this area discussing design, construction, instrumentation, testing and analysis of physical model is lacking. It is desirable that a single text contain the theoretical and practical aspects of physical modeling. Such a book should be valuable to engineers dealing with the design, construction, installation and operation of offshore structures. This requirement inspired me to write this book on modeling. This book provides reasonably detailed coverage of the technology of model testing. As such, it has applications throughout the entire field of engineering, reaching far beyond its focus on offshore structures. It should be equally appealing to engineers and scientists involved with the design and construction of unique structures.

The Introduction discusses the general need for model testing. A brief history of testing has been given in this section. Some of the general structural areas where model testing has been required have also been mentioned. Chapter 2 describes the modeling laws. It begins with the general requirements for similarity. A general discussion of the famous Buckingham pi theorem and an application of the pi theorem has been included. A few specific examples of modeling are discussed here including structural modeling, testing in uniform flows and modeling distortion. These are considered unique cases that

may be applicable to an offshore structure. In hydraulic testing, however, Froude model law is discussed in detail in this section. A few textbooks that deal with the similarity laws and model testing have been discussed and referenced here. The methods of model construction are considered in Chapter 3. The physical requirements of the model necessary for scale testing are explained. Generally, the construction technique varies based on these requirements. For example, the fixed structures are generally used in the measurement of loads and stresses imposed by the environment. In this case, the dynamic properties of the structure are not a concern. This, however, is not true for compliant or floating structures. The compliant structure, in addition, must satisfy additional scaling laws. The static and dynamic properties that must be satisfied by these structures are discussed in detail. The techniques used in verifying these properties before testing can take place are illustrated.

The testing of offshore structures requires specialized facilities. Many of the small facilities that exist at the universities and other educational institutions are used as teaching tools in discussing the needs and methods of model testing. However, many larger commercial facilities are in existence in various parts of the world. Many of these facilities are described in detail in Chapter 4 including their capabilities and limitations. This section will be useful to a design engineer in choosing a suitable facility for his particular test requirements. The important components of these testing facilities, such as the wave generators, the current generators, the towing carriages and beaches are described. The most important feature of these testing facilities is the wave generation capability. A few theories of wave generation and beach reflection are presented for those interested in designing wavemakers. These facilities are used in duplicating the ocean environment. The modeling of the ocean environment is the subject of Chapter 5. Simulation of various types of waves, such as random two-dimensional and three-dimensional waves, wave groups, and higher harmonic waves, are discussed in detail. The wind and current generation and co-generation of current and waves are also explained in this section. Another important requirement of any model testing is the measurement of the responses of a structure model. This includes the inputs to structures from external sources and the corresponding outputs. In hydraulic testing, this measurement is further complicated by the presence of fluids. Various types of measuring instruments and measuring techniques are introduced in Chapter 6. Design methods of a few specialized instruments are described and methods of the waterproofing these instruments are discussed. The calibration procedure for special instruments is shown. Typical calibration curves of a few of these are also included. The important considerations in the recording of data output from these instruments are given here.

The actual modeling of various offshore structures is described in Chapters 7-9. Various areas covered in these chapters are outlined in the following:

FIXED STRUCTURES

Gravity Platform
Storage Structures
Piled Jackets
Subsea Pipelines

OFFSHORE OPERATIONS

Transport of Jackets
Towing of Structures
Launching of Structures
Submergence of Structures
Pipelaying

FLOATING STRUCTURES

Buoys
Single Point Moorings
Moored Tankers
Tension Leg Platforms
Compliant Structures
Semisubmersibles

Chapter 7 deals with the fixed structures. The methods of installing load measuring devices on fixed structures and associated problems are described in detail. Various examples are included. Actual recorded data are given to illustrate the validity as well as inadequacies of the techniques. Offshore operations include special techniques in delivering the completed structure to the offshore sites. These require launching, transportation, submergence and installation of these structures. These various stages are generally model tested to insure a proper installation procedure and to identify potential unforeseen problems. This is the subject of Chapter 8. Chapter 9 covers the area of seakeeping tests. These tests include floating structures moored to the ocean floor by mooring lines, articulated columns, vertically tethered structures, e.g., tension leg platforms and compliant structures. Special care is needed to insure proper duplication of model response without introduction of additional effects through setup. Example cases are discussed and illustrated.

In all these tests, data are recorded by the various instruments installed on the model. These data require special routines to reduce raw recorded data to a usable form for application in a design and analysis. Special care is taken to avoid spurious data entering into the test data. The data analysis techniques that may be used in reducing test results are described in Chapter 10. Examples are taken from specific tests to illustrate these techniques.

It should be noted here that the dimensional units in describing quantities in the book are somewhat mixed. This reflects the slow transition in this country from the English to the metric system. Wherever possible dual units have been provided. In general metric system has been followed. However, with conversion factor noted, some examples have been left in the English units. It is hoped that readers will have appreciation for both systems in following the material in the book.

A list of symbols has been included at the end of the book. Attempt has been made to maintain consistency throughout the book. A few variables have been used with dual meanings in two different parts of the book with little confusion. Some local variables have not been included in the list to limit its size. They have been defined locally where they appear. Subscripts and superscripts have been defined in the list. A list of all the abbreviations appearing in the book has also been included for convenience.

As is evident from its contents, this book should be a valuable addition to the library of all offshore engineers and naval architects whether they are involved in the research, design, construction or offshore operations. All hydraulic and ocean engineering curriculums in universities offer a course in modeling. This book should be a very appropriate reference for such a course. It is written such that it may be used as a text for a junior or senior level course in a four year engineering curriculum. Since the book deals with many subjects in modeling that go beyond the specifics for offshore structures, it should be found useful by all engineers and scientists interested in structural or hydraulic testing. Finally, it should also be valuable as a reference to many model testing facilities as a complement to their expertise in the area.

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OFFSHORE STRUCTURE MODELING

"I contend that unless the reliability of small scale experiments is emphatically disproved, it is useless to spend vast sums of money on full scale trials which after all may be misdirected unless the ground is thoroughly cleared beforehand by an exhaustive investigation on a small scale."

William Froude, 1886