SHIP-SHAPED OFFSHORE INSTALLATIONS

Ship-shaped offshore units are some of the more economical systems for the development of offshore oil and gas fields and are often preferred in marginal fields. These systems are especially attractive when developing oil and gas fields in deep- and ultradeep-water areas and locations remote from existing pipeline infrastructures. Recently, the ship-shaped offshore units have also been considered for application to near-shore oil and gas terminals. This book is an ideal text and reference on the technologies for designing, building, and operating ship-shaped offshore units, within inevitable space (and time) requirements. This book includes a range of topics, from the initial contracting strategy to the decommissioning and the removal of the units concerned. Coverage includes both fundamental theory and principles of the individual technologies. This book will be useful to students who are approaching the subject for the first time as well as designers working on the engineering for ship-shaped offshore installations.

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Ship-Shaped Offshore Installations

DESIGN, BUILDING, AND OPERATION

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Today, the need for development of offshore oil and gas resources in increasingly deeper waters is becoming more important because of many reasons associated with the world economy and the related energy resource development constraints and strategies.

Fixed-type offshore platforms, which have been useful for oil and gas developments in relatively shallow waters, are now much less feasible as we move further in developing oil and gas fields in deep- and ultradeep-water areas, now reaching more than 1,000m water depth. Floating-type offshore structures have to be increasingly considered to develop these deep-water areas. In addition to ship-shaped offshore units, at least three other types of floating production systems – semisubmersibles, spars, and tension leg platforms (TLP) – are also available today for that purpose. All of these types of floating systems require storage, pipeline infrastructure, and other associated field structures and systems to transport produced oil and gas to the facilities on shore, but perhaps to varying degrees.

That the use of ship-shaped offshore units remains a very attractive alternative in many cases of field development is attributable to its ability to successfully serve multiple functions, such as production, storage, and offloading, and the capability for oil or gas to be transported to shore via shuttle tankers. Ship-shaped offshore units reduce need for pipeline infrastructure and are functional on a fast-track basis.

Ship-shaped offshore units are now recognized as perhaps one of the most economical of all systems for potential developments of offshore oil and gas and are often the preferred choice in marginal fields. These systems are becoming more attractive for developing oil and gas fields in deep- and ultradeep-water areas and locations remote from the existing pipeline infrastructures. Recently, the ship-shaped offshore units have also begun to be applied to near-shore oil and gas terminals.

Although the use of ship-shaped offshore units has been in existence since the late 1970s, the complexity and size of the units have been gradually increasing, and there are still many issues related to design, building, and operation to be resolved for achieving high integrity in terms of safety, health, environment, and economics/financial expenditures.

Although ship-shaped offshore units are similar to trading tankers in structural geometry, they are different in a variety of ways. Environmental conditions are unique in each case, and structural design concepts must be tailored to a specific location. Trading tankers may avoid rough weather or alter their heading in operation, but ship-shaped offshore units must be continuously located in the same area with
site-specific environments and do not have the ability to periodically dry-dock for the necessary inspection and maintenance. This is an aspect that must be reflected in some fashion in the design and long-term durability and reliability of the units concerned.

To continue further on the subject of differences from trading tankers, one should note that ship-shaped offshore units are likely to be subjected to significant environmental actions even during loading and unloading; however, trading tankers are typically loaded and unloaded at still-water condition in harbor. And, for historical reasons, the design return period of ship-shaped offshore units is typically taken as 100 years, and that of trading tankers is considered to be 20 to 25 years or so.

The application of existing procedures, criteria, and standards to the structural design of ship-shaped offshore units also requires additional thought and discussion. This can be particularly important for the many interface areas between the hull and topsides. Even for the hull part, the shipbuilding industry standards may need to be selectively upgraded to ensure the long life and onsite reliability needed. Similarly, for the topsides part, it is often not straightforward to apply the relatively more economical shipbuilding industry standards, in part perhaps because of differences in the background, experience, and culture of the operating personnel involved. In any event, the complexities of the design are enormous, and there are many interface issues (e.g., those related to the interaction between hull and topsides facilities and related consistency in design information) that need to be identified up front and addressed and managed on a continuous basis.

In such a situation, direct analyses from first principles, advanced engineering, and practices are increasingly desired so that practicing engineers and academic researchers can resolve the issues that remain, reconcile differences in standards and practices, and improve structural and other design procedures and criteria. In the never-ending quest for safe, reliable, yet economical structures and systems effectively designed and constructed, there are often demanding schedules and other constraints and challenges.

Also, many diverse international organizations in the maritime industry such as the International Maritime Organization (IMO), International Organization for Standardization (ISO), International Association of Classification Societies (IACS), and the industry in general are now increasingly applying the limit-state design approach for both trading ships and ship-shaped offshore installations, making related knowledge and training even more relevant. Another emerging and increasingly more important technology consists of risk-based approaches to design, operation, and human and environmental safety, with much of the same accompanying knowledge, training, and familiarization needs.

The intention behind writing this book is to develop a textbook and handy resource that sufficiently addresses current practices, recent advances, and emerging trends on core technologies for designing, building, and operating ship-shaped offshore units, within certain inevitable space (and time) requirements. This book covers a wide range of topics, from the initial contracting strategy to the decommissioning and even the removal of the units concerned, but not always to a depth some might have wished for. Although a large number of research papers and references and industry standards useful for specific topics in the areas do exist, we did our best to highlight selected and useful ones among them in the various chapters and appendices.
Preface

We have also tried our utmost to always refer to relevant past work, with proper acknowledgments. It is respectfully requested that any unintentional oversights in this regard be brought to our attention for correction in future editions.

We believe and hope that this book will be very useful for practicing engineers and engineers-in-training and will contribute to their increased awareness and potentially greater use of advanced and sophisticated technologies as well as existing and emerging practices. Because of its coverage of the fundamentals and principles of the individual technologies, this book will also be useful for university students who are approaching both the initial and more intensive studies of advanced engineering for ship-shaped offshore installations. With regard to the scope, emphasis, and other relevant aspects of this book, we encourage all related and pertinent feedback and suggestions for the future; these will be gratefully received.

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Any opinions expressed in this book are strictly those of the authors and not those of the organizations with which the authors are associated or of the individuals and organizations who provided us invaluable assistance during this effort.

Finally, we take this opportunity to thank our wives and families for their unfailing patience and support during the writing of this second book we coauthored: Yun Hee, Myung Hoon, and Yun Jung and Nita and Neil. To them we hereby dedicate this book.

Jeom Kee Paik and Anil Kumar Thayamballi
How to Use This Book

Our intention behind writing this book is to develop a textbook and handy resource that contains current practices, recent advances, and future trends on core technologies essential for ship-shaped offshore installations. We feel that such a book, with an appropriate mixture of academic rigor and practical experience, will be a welcome addition to many bookshelves, including those of university students in key shipbuilding countries worldwide and of interested practitioners. Therefore, in this book we have attempted to cover, within a limited space, a number of pertinent topics ranging from the initial contracting strategy to the decommissioning and removal of the floating units concerned.

Chapter 1 presents an overview of ship-shaped offshore installations, including structural characteristics with general arrangement and midship section drawings of a hypothetical FPSO. Historical overview and selection strategy of various floating offshore systems (e.g., semisubmersibles, spars, tension leg platforms, and ship-shaped offshore units) to develop oil and gas offshore are also discussed.

Chapter 2 addresses the front-end engineering of ship-shaped offshore installations, including the identification and discussion of various important issues that must be resolved successfully during the design and building of such offshore units.

Chapter 3 describes principles and criteria for designing and building ship-shaped offshore units, with the emphasis on limit-state design. Some considerations for safety factor determination are given. This chapter refers to existing classification society rules, recommended practices, regulations, and international standards that will be used for designing and building ship-shaped offshore units in terms of safety, health, the environment, and economics/financial expenditures.

Chapter 4 addresses environmental phenomena and application to design, covering many types of potential environmental actions such as wind, waves, current, swell, ice, snow, temperature, and marine growth. Emerging practices for predicting impact actions arising from tank sloshing, bow slamming, and green water are presented. Some considerations for the design return period of the offshore units are addressed.

Chapter 5 presents current practices and recent advances useful for serviceability limit-state design of ship-shaped offshore units. This chapter describes the fundamentals, calculation methods, and design criteria for elastic deflection limits under quasistatic actions, elastic buckling limits, permanent set deflection limits under impact-pressure actions (arising from tank sloshing, bow slamming, and green water),
intact vessel stability, watertight integrity, weathervaning (heading control), station-keeping, vessel motion exceedance, vibration and noise, mooring line vortex-induced resonance oscillations, and localized corrosion wastage.

Chapter 6 presents emerging practices and recent advances useful for ultimate limit-state design of ship-shaped offshore units. This chapter describes the fundamentals, calculation methods, and design criteria for determining the ultimate strength of plates, stiffened plate structures, entire vessel hulls, and structural systems. Closed-form expressions and progressive collapse analysis methods are presented. Illustrative examples for the ultimate strength calculations of structural components and vessel hulls are shown.

Chapter 7 presents current practices and recent advances useful for fatigue limit-state design of ship-shaped offshore units, with emphasis on the spectral-analysis-based approach. This chapter describes the fundamentals, calculation methods, and practices for fatigue limit-state design. The methods for determining hot spot stresses with finite-element modeling techniques are presented. The selection of relevant S–N curves and the calculations of fatigue damage accumulation are described. The time-variant crack propagation models that are needed for time-variant reliability assessment of aged structures with fatigue cracking are described together with illustrative examples of the calculations to be made.

Chapter 8 addresses emerging practices and recent advances useful for accidental limit-state design. This chapter describes the fundamentals, calculation methods, and practices for determining accidental actions and the consequences of damaged vessel stability due to collision, dropped objects, fire, gas explosion, progressive hull collapse due to structural damage, and accidental flooding. Closed-form expressions and numerical simulation methods are presented. Illustrative examples for analyzing the consequences of the accidental events are shown.

Chapter 9 presents an overview of the considerations and practices for designing and building topsides, cargo export, and mooring facilities. Several illustrations of FPSO systems and the structural response analyses of the interaction between vessel hull and topsides modules are presented. The importance of various interface-management issues is emphasized.

Chapter 10 presents corrosion assessment and management for ship-shaped offshore structures. Starting with pertinent corrosion mechanisms, useful mechanical and phenomenological models for predicting corrosion wastage are presented. Corrective or protective design and operational measures, such as corrosion margin addition, coating, cathodic protection, ballast water deoxygenation, and inhibitors, are described. The effect of corrosion wastage on the ultimate limit state of structural components and vessel hulls is addressed with illustrative examples of the calculations. Methods for predicting the coating durability are also presented in this chapter.

Chapter 11 presents current practices and recent advances for inspection and maintenance of ship-shaped offshore structures. Emerging practices for condition assessment of trading tankers, which may be useful for offshore units, are reviewed. Risk-based inspection and maintenance procedures are presented. The effects of age-related deterioration, such as corrosion and fatigue cracking, on the time-variant ultimate strength reliability of ship-shaped offshore units are addressed. Some
considerations for repair strategies based on quantitative reliability and risk-based methodologies are provided.

Chapter 12 presents current practices for conversion and decommissioning. Although this book is focused on the core technologies for designing and building new-build units, the conversion strategies are also important because a large number of ship-shaped offshore units worldwide are tanker conversions. Today, the world community requires all of us to pay appropriate attention to the decommissioning and disposal of the used offshore units by meeting strict international and regional regulations and standards and also by proactive planning and anticipatory design. This chapter provides an overview of the current practices and the important issues related to decommissioning as well.

Chapter 13 presents emerging practices and recent advances for risk assessment and management. It is highly desirable today to apply risk-assessment methods to designing, building, and operating various types of structural systems, including ship-shaped offshore units. This chapter describes the fundamentals and salient details of selected risk-assessment methods, together with extensive references. Specific areas of the application of risk-assessment methods to the design and operation of ship-shaped offshore units are noted and discussed.

The appendices provide useful data necessary for design of ship-shaped offshore units. Important terminologies used in the book are defined. Scale definitions of wind, wave, and swell are presented. Representative data of sea states at various ocean regions, an important part of wave action predictions of ship-shaped offshore units as well as trading tankers, are provided. Selected data on annual sea-state occurrences in the North Atlantic and North Pacific are presented. Illustrative characteristics of 100-year return period storms and of extremes of environmental phenomena in various regions are provided. Scaling laws for both hydrodynamics and structural mechanics model testing are given. Wind-tunnel testing requirements are addressed. Selected industry standards, guidelines, and recommended practices useful for ship-shaped offshore installations are listed.

The methods and practices presented in this book cover all core technologies that are essential to better understand designing, building, and operating ship-shaped offshore installations in some fashion. We certainly hope that this book, with its advanced methodologies as well as emerging practices together with the list of carefully selected references, is seen and received as a handy resource and also that it meets the needs of practicing engineers and engineers-in-training to a good degree. This book should also be well suited as a textbook for university students in the fields of naval architecture and offshore civil, architectural, and mechanical engineering.

When this book is used as a textbook for undergraduate university students during a 45-hour single-semester class, the fundamentals and some current practices in all chapters should be studied. For postgraduate students, who may be approaching the topics in depth, the detailed methodologies presented in some selected chapters should be studied. For instance, those who are more likely to be interested in structural mechanics and limit-state design may begin with Chapter 1, “Overview of Ship-Shaped Offshore Installations” and focus on Chapters 5 through 8. Of course, it will also be a good idea for graduate-course students in a higher level to concentrate on and further explore any specific chapter, for example, Chapter 6, “Ultimate
Limit-State Design.” Related theoretical and numerical calculations using the closed-form expressions and/or computer programs, where available, can be used.

We hope that future revisions of this book will be made more useful and even more attractive to a wide spectrum of its readers and users; therefore, pertinent feedback and suggestions are encouraged, both by the publisher and the authors, and will be fully considered for future editions.