DESIGN PRINCIPLES AND CRITERIA FOR SHIPS AND OFFSHORE STRUCTURES

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**Summary**

This chapter provides a brief introduction to various considerations related to design principles and criteria for ships and offshore structures. The treatment is at a high level, and an associated bibliography is provided for the benefit of those readers interested in pursuing any aspect of the subject matter of this chapter in greater detail.

1. Introduction

In the context of structural design and performance, risk is typically defined as some function of (a) the probability or likelihood that any accident or limit state leads to
severe consequences, such as human injuries, environmental damage, and loss of property or financial expenditure, and (b) the resulting consequences. Wherever there are potential hazards, a risk always exists. To minimize the risk, one may either attempt to reduce the likelihood of occurrence of the undesirable events or hazards concerned, or reduce or mitigate the consequences, or both. What is opted for in the end is typically a product of a cost versus benefit trade off. For structural risk assessment and management, therefore, it is essential to identify the degree of likelihood of a particular risk event and also the related consequences. Identification of either aspect can involve use of structural mechanics and structural analysis.

Risk is affected by structural design and operation. The present chapter addresses design principles and criteria related to structural design of ships and ship shaped offshore structures. Figure 1 illustrates certain structural examples of the types considered. The treatment in the chapter is at a high level, in that given the short length of the treatment, details are generally avoided. Also, to the greatest extent possible, the text aims to impart general principles and practice rather than describe or elaborate on methodologies that may in time change. Technologies for ships and ship-shaped offshore installations are focused on.

The chapter is organized as stated in the contents above. Useful general references for this chapter include Paik and Thayamballi (2003) and (2007); and Hughes and Paik (2010). These and similar (see Bibliography) can be consulted by the interested reader for greater detail.

Figure 1. Ships and offshore structures (Example)

2. Environmental and Operational Demands

Various environmental and operational phenomena occur and contribute to demands on ships and offshore structures during their life cycle. In design, the structure is required to have an adequate margin of safety against any resultant demand from such environmental phenomena in addition to and as part of the functional needs of the structure. A good knowledge of the environmental conditions at the areas where the structures will be installed or operated is necessary in order to appropriately design and assure the required high operational uptimes required for reasons of economy. Such information is also important for specialized weather sensitive operations such as
installation on site, the berthing of supply boats, and for the design of mooring and station-keeping in general.

It is interesting to note that actions arising from environmental and operational phenomena on offshore structures are somewhat different from those on trading vessels. The nature of the offshore structures and their operation are such that winds and currents as well as waves among other factors may induce significant actions and action effects on structures, whereas waves are often the primary source of environmental actions on today’s trading ships at sea; albeit considerations related to specialized operations such as berthing being admittedly somewhat different and imposing additional needs.

2.1. Waves

For both trading ships and ship-shaped offshore structures, wave related factors are a primary design parameter. The factors include heights, periods and directions together with associated probabilities and persistence times. It is important to realize that the waves inducing the most severe response in the global system structure may be different from those resulting in the maximum response in structural components and also that the structural response is wave period dependent in addition to wave amplitude dependent, in floating structures. It is noted also that more frequent waves rather than extreme waves will govern fatigue life although their amplitudes may be smaller compare to the rarer waves.

Wave-induced maximum actions and actions effects may be applied for design by using one of few approaches, for example extreme amplitude design waves, extreme response design waves or the more fundamental wave energy spectra-based methods. An extreme amplitude design wave may be calculated for a specified return period, usually 25 years for trading vessel design and 100 years for ship-shaped offshore structural design of long-term deployment.

It should be also recognized that some maximum actions may develop from a wave or group of waves with a lower amplitude than a higher amplitude wave because of the differing sensitivities of the structural response to the wave frequencies involved. Indeed, several different design wave combinations from various directions and frequencies with crests and troughs at various locations need to be considered for the different types of responses of interest (i.e., maximum roll, maximum vertical hull girder bending moment, etc).

2.2. Winds

Wind can sometimes be a primary metrological oceanographic (metocean) parameter which is important to the design of offshore units, particularly during normal operations. The structure must withstand the forces exerted by the wind, and this depends not only on the structural characteristics such as windage area but also on the speed and direction of the wind. Wind forces over a certain limit will affect the ability to perform certain operations (e.g. lifting).
For offshore structural design for a site, steady extreme wind speeds for specified return periods must be obtained and are specified with averaging times ranging from seconds to hours, for example. The speeds are usually estimated at a standard height of 10m above mean sea level, with standard corrections applied for purposes of obtaining more specific values at other heights.

In addition, the spectra of fluctuating wind gusts are sometimes necessary because wind gusts can excite different types and levels of response depending on frequency. For example, slow-drift horizontal motions of moored structures can be affected by wind gust. Also, wind can lead to phenomena such as vortex shedding, together with associated vibrations in some instances, such as for example on a flare tower.

2.3. Water Depths and Tidal Levels

Water depths and tidal levels are normally lesser parameters for ocean-going trading vessel design, but they can play a more important role for offshore structural design. The overall depth of water at any location can be characterized by a mean depth over a stated period of time, and its variations from the same. Such variations of water depth are due for example to tides and storm surges. The tide related variations are usually regular and predictable in terms of the highest astronomical tide and the lowest astronomical tide.

On the other hand, meteorologically generated storm surges are typically irregular in nature. The effects of tides can approximately be superimposed to the effect of storm surges to estimate the total water levels, which could in some cases be above the highest astronomical tidal level or below the lowest astronomical tidal level.

2.4. Currents

Currents are not generally a strong design parameter for trading vessels, but they, together with waves and swells can affect the orientation of floating offshore installations. Hence directly and indirectly currents in such cases can affect both short-term and long-term loads imposed on the structure and its mooring system. Currents can increase the hull drag forces over and above the values due to the wave system alone. Currents also ultimately affect the station-keeping of the offshore unit and the performance of other station keeping means (e.g., thrusters).

The nature of currents is complex, depending on the local and wide area conditions. A number of current types may be relevant, e.g., oceanic currents, eddy currents, thermal currents, wind driven currents, tidal currents, surge currents and inertial currents. The common ones are usually astronomical tide and storm surge related. But this is by no means a certainty in any specific case or region, and if at all possible specific on-site measurements are preferred to be made before locating an offshore unit at any given site.
Bibliography


API (2001). Recommended practice for planning, designing, and constructing floating production systems, Recommended Practice 2FPS, American Petroleum Institute, March.


Biographical Sketch

Anil Kumar Thayamballi is Senior Staff Consultant and Engineering Advisor with a Marine consultancy group in San Ramon, California. He is a specialist in marine structural design and life-cycle care, with 25 years of broad-ranging experience in ship-shaped structures. He has served on the American Society of Civil Engineers (ASCE) Committee for Fatigue and Fracture Reliability and on the American Petroleum Institute Resource Group RG-4 on Structural Element Behavior. He has served on the ISSC Technical Committee on Design Procedures and Philosophy and has served as its chairman. He has also served as working group chairman for the Tanker structure Cooperative Forum and continues to be involved in the forum activities. He currently serves on the Marine Technology Committee of the SNAME in New York. Dr. Thayamballi is also a member-at-large of the Structural stability Research Council and a member of the Royal Institution of Naval Architects. Dr. Thayamballi is the author or coauthor of more than sixty refereed technical publications and the book Ultimate Limit State Design of Steel-Plated Structures.