DESIGN PRINCIPLES AND CRITERIA FOR SHIPS AND OFFSHORE STRUCTURES

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Keywords: Structural mechanics, serviceability limit states, ultimate limit states, fatigue limit states, accidental limit states, limit states-based design

Contents

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.

2.5. Air and Sea Temperatures

The temperature is a primary design parameter for vessels trading in arctic regions, vessels designed to carry low or high temperature cargos and offshore units under similar conditions including, for example heating associated with heavy crude. Information on sea, air and structural temperatures is important for material selection including fracture toughness considerations, for any application where a structure needs to respond to significant temperature changes and also for the design of various onboard systems.

2.6. Ice and Snow

Depending on the areas of operation, the extent to which snow and ice may accumulate on various parts of the offshore units may need to be estimated. Associated risk mitigation considerations can include the provision of adequate strength and stability, and local heating. Physical removal procedures may also need to be specified based on the maximum permitted accumulations in specific cases.

In some cases, snow accumulations may be more likely than icing; for example on windward-facing non-horizontal parts of the offshore unit. Snow, if it remains, can freeze into ice and hence will need to be usually removed prior to that by blowing or other means.

2.7. Marine Growth

Ships and offshore structures are both likely to become fouled with marine growth to differing degrees. In the case of trading ships or some special types of offshore units such as drill ships, the removal of marine growth is simple once dry-docked, although such growth may increase resistance and powering when underway. For design purposes of offshore structures, a marine growth profile (thickness and roughness as a function of water depth) may be specified as part of the metocean data or in other design basis document. Certain types of coatings are said to help with control of marine growth.

2.8. Sloshing

The accelerations arising from the motions of a ship in a seaway can produce sloshing actions on the structures of partially filled tanks. Resonant motions of liquid cargo in oil tanks may produce significant sloshing actions, and the affected structure in a general case must be adequate to withstand them. This is of particular concern in tanker conversions to FPSOs because it is not always the case that trading tankers being converted were necessarily originally designed for partially filled cargo tanks, unlike their ballast tanks. Cargo tanks of moored ship-shaped offshore structures such as FPSOs are continuously loaded and unloaded, and thus subject to differing internal levels of liquid as part of their normal operation.

2.9. Slamming

Parts of (e.g. bow or stern) ships and offshore structures are likely subjected to near impact pressure actions arising from what is termed slamming. Bow slamming and wave slap impact has been known to cause structural damage (e.g., buckling, tripping) in forecastle plating, bow flare plate and stiffeners. Depending on the hull form, the wave environment and several other factors including forward speed and heading, slamming may need to be investigated for trading ships and also ship-shaped offshore structures in transit or during operation.

At a relatively benign location of ship-shaped offshore units, impact pressure actions may be less serious than those for normal trading tankers. However, bow slamming may be of interest for weather-vaning vessels in harsh environments with the bow pitching downwards in certain cases, such as when the waves approach with heading angles within some 15 to 30 degrees off the bow.

2.10. Green Water

Green water can result from waves overtopping the bow, side or stern structures of trading ships or ship-shaped offshore units; its occurrence depends on various factors including the relative motion between the structure and the waves, the speed, the freeboard and the harshness of the environment.

The occurrence of green water implies by definition that the available freeboard is exceeded. The green water concern on ship-shaped offshore structures can be a significant design issue under harsh environmental conditions, and green water can cause damage to deck houses, deck mounted equipments (e.g., switch room compartments), watertight doors, walkway ladders, cable trays, and others.

2.11. Corrosion

While in service, most efficiently designed structural systems including ships and offshore structures, are invariably subject to age-related deterioration which can potentially cause significant issues in terms of financial expenditures at a minimum and perhaps worse. Indeed, such age-related deterioration has reportedly been involved in some of the known-failures of ships and offshore structures. While the loss of the total system typically causes great concern, maintenance of structures for purposes of increased uptime is generally also costly. It is thus of importance to develop and implement strategies for the proper management and control of such age-related deterioration. These strategies usually involve use of coatings, and cathodic protection in addition to design thickness margins.

2.12. Accidental Flooding

If one or more internal spaces of a vessel are opened to the sea by structural damage, then cargo leakage and/or water ingress can potentially take place until equilibrium is established between these spaces and the sea. Such instances of accidental flooding can cause significant changes in draft, trim and heel of the vessel or floating installation. When such changes subsequently immerse non-watertight portions of the vessel, it needs to be assured by design that some degree of equilibrium is still attainable soon considering progressive flooding; or otherwise the vessel can in the extreme, sink either with or without capsizing.

It is hence required to ensure that ships or offshore units must by design survive any reasonable damage resulting in flooding. For example, the reserve buoyancy and stability in damaged conditions with unintended flooding must be sufficient to withstand, say, the wind heeling moment imposed from any direction on the damaged unit. Also, the structural safety must be sufficient enough to survive resulting applied actions, perhaps with some degree of tolerable structural damage.

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Biographical Sketch

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