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Recent Advances and Future Trends on Plasticity and Impact Mechanics of Ships and Offshore Structures

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Abstract

While in service, ships and offshore structures are likely subjected to various types of extreme and accidental events that essentially involve plasticity and impact issues. Ships and offshore structures are typical examples of thin-walled structures, but their environments in construction and operation are quite unique compared to other types of thin-walled structures. Those include welding induced high temperature causing initial imperfections (e.g., initial distortions, residual stress or softening in the heat-affected zones of welded aluminium structures); abnormal waves/winds/currents; dynamic pressure loads arising from sloshing, slamming or green water; low temperature in Arctic operations; cryogenic conditions resulting from liquefied natural gas cargo; ultra-high pressure in ultra-deep waters; elevated temperature due to fire; blast loads due to explosion; impact loads arising from collision, grounding or dropped objects; age-related degradation such as corrosion, fatigue cracking and local denting damage; and hull girder collapse or sinking. Such events sometimes result in catastrophic consequences that lead to casualties, property damage, and pollution. This paper presents recent advances and future trends with the focus on plasticity and impact mechanics of ships and offshore structures in association with extreme and accidental conditions.

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Keywords: Ships; offshore structures; plasticity; impact mechanics; accidental conditions; extreme conditions

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1. Introduction

Ships and offshore structures usually operate under normal conditions while in service, but they can face various types of extreme and even accidental conditions, resulting in various action effects, as shown in Fig. 1 [1]. The sources of such actions and action effects include (without consideration of any specific order): welding induced high temperature causing initial imperfections (e.g., initial distortions, residual stress or softening in the heat-affected zones of welded aluminum structures); abnormal waves/winds/currents; dynamic pressure loads arising from sloshing, slamming or green water; low temperature in Arctic operations; cryogenic conditions resulting from liquefied natural gas cargo; ultra-high pressure in ultra-deep waters; elevated temperature due to fire; blast loads due to explosion; impact loads arising from collision, grounding or dropped objects; age-related degradation such as corrosion, fatigue cracking and local denting damage; and hull girder collapse or sinking. Such events sometimes result in catastrophic consequences that lead to casualties, property damage, and pollution.

Fig. 1. Extreme and accidental events involved in ships and offshore structures [1].

Plasticity and impact mechanics is certainly a key element of nonlinear structural consequences associated with extreme and accidental events [2]. This paper presents recent advances and future trends with the focus on plasticity and impact mechanics of ships and offshore structures in association with their causative mechanisms and nonlinear structural consequences against extreme and accidental events.

2. Causative mechanism and structural consequences

Various extreme and accidental events exposed to ships and offshore structures while in service cause highly nonlinear problems associated with non-Gaussian, multi-physics, multi-scale, and multi-criteria where plasticity and impact effects are always involved as challenging issues.

2.1. Fabrication related initial imperfections [3-6]

Ships and offshore structures are typically fabricated by flame cutting and welding reaching up to over 1,200 deg. C, and thus they always have initial imperfections in the form of initial distortions and residual stresses, caused by the successive expansion and shrinkage during the heating and cooling. In a welded steel plate, the heat affected zone is formed with a band width, in which the stress is approximately equal to the tensile yield stress because the molten metal can expand freely, as a liquid, whereas after welding it quickly reverts to a solid and the shrinkage that occurs during cooling involves “plastic flow”. The compressive residual stress is developed in the rest of the plating to achieve an equilibrium condition. In the heat affected zone of welded aluminum structures, in contrast to steel structures, a softening phenomenon occurs in which the yield strength within the heat affected zone is reduced relative to that of the base metal. Because such fabrication related initial imperfections may have an effect on the structural properties and load-carrying capacities of structures, they must be dealt with as parameters of influence in structural design and strength assessment.

2.2. Abnormal waves, winds, and currents [4]

Actions arising from environmental phenomena on offshore structures are different from those on trading ships. The nature of offshore structures and their operation are such that waves, winds and current, among others, while waves are the primary source of environmental actions on trading ships at sea where considerations related to specialized operations such as berthing are somewhat different.

The wave parameters for offshore structural designs include heights, periods, and directions with associated probabilities and persistence times. It is important realize that the waves inducing the most severe response in the