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Methods for ultimate limit state assessment of ships and ship-shaped offshore structures: Part I—Unstiffened plates

Jeom Kee Paik*, Bong Ju Kim, Jung Kwan Seo

Department of Naval Architecture and Ocean Engineering, Pusan National University, 30 Jangjeon-Dong, Geumjeong-Gu, Busan 609-735, Republic of Korea

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Abstract

The present paper is Part I of a series of three papers prepared by the authors on the methods useful for ultimate limit state assessment of marine structures, that have been developed in the literature during the last few decades. It is considered that such methods are now mature enough to enter day-by-day design and strength assessment practice. The aims of the three papers are to conduct some benchmark studies of such methods on ultimate limit state assessment of (unstiffened) plates, stiffened panels, and hull girders of ships and ship-shaped offshore structures, using some candidate methods such as ANSYS nonlinear finite element analysis (FEA), DNV PULS, ALPS/ULSAP, ALPS/HULL, and IACS common structural rules (CSR) methods. As an illustrative example, an AFRAMAX-class hypothetical double hull oil tanker structure designed by CSR method is studied. In the present paper (Part I), the ultimate limit state assessment of unstiffened plates under combined biaxial compression and lateral pressure loads is emphasized using ANSYS, DNV PULS, and ALPS/ULSAP methods, and their resulting computations are compared. Part II will deal with methods for the ultimate limit state assessment of stiffened panels under combined biaxial compression and lateral pressure using ANSYS, DNV PULS, and ALPS/ULSAP methods, and Part III will treat methods for the progressive collapse analysis of the hull structure using ANSYS, ALPS/HULL, and IACS CSR methods.

Keywords: Ultimate limit states; Limit state design; Ships; Ship-shaped offshore structures; IACS common structural rules; ANSYS FEA; DNV PULS; ALPS/ULSAP; ALPS/HULL

1. Introduction

It is now well recognized that the limit state approach is a better basis for design and strength assessment of various types of structures than the traditional allowable working stress approach, because it is not possible to determine the true margin of structural safety as long as the limit states remain unknown. While the offshore industry has extensively applied the limit state approach for design, the shipbuilding industry has traditionally utilized classification society guidance based on the allowable working stress approach for design of trading ships.

In recent years, substantial efforts by stakeholders such as International Organization for Standardization (ISO), International Maritime Organization (IMO), and classification societies have been directed to the developments of limit state based standards (ISO, 2006a, b; IMO, 2006), and rules (IACS, 2006a, b).

Although four types of limit states are relevant, namely serviceability limit states (SLS), ultimate limit states (ULS), fatigue limit states (FLS), and accidental limit states (ALS), the present paper is focused on ULS of ships and offshore structures.

During the last few decades, methods useful for ULS assessment of marine structures have been developed in the literature. The aim of the present study is to perform a benchmark study of such methods on ULS assessment of ships and ship-shaped offshore structures, including ANSYS nonlinear finite element analysis (FEA) (ANSYS, 2006), DNV PULS (DNV, 2006), ALPS/ULSAP (2006), ALPS/HULL (2006), and IACS common structural rules

*Corresponding author. Tel.: +82 51 510 2429; fax: +82 51 512 8836.
E-mail address: jeompaik@pusan.ac.kr (J.K. Paik).

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(CSR, IACS, 2006a). As an illustrative example, an AFRAMAX-class hypothetical double hull oil tanker structure designed by CSR method is studied.

To meet the page limit requirement of a single paper, the present study results are subdivided into a series of three papers. The present paper is the first paper (Part I) of the three, dealing with ULS of unstiffened plates surrounded by support members (e.g., transverse floors and longitudinal stiffeners) and subjected to combined biaxial compression and lateral pressure loads. ANSYS FEA, DNV PULS, and ALPS/ULSAP methods are employed for the ULS assessment and their computational results are compared. Two other papers, i.e., Part II (Paik et al., 2007a) and Part III (Paik et al., 2007b), dealing with methods for ULS assessment of stiffened panels (Fig. 1) and hull girders will be presented in separate forms because of page limits.

2. Candidate methods

For the present benchmark study in terms of ULS assessment of unstiffened plates, the following three methods are employed, namely

- ANSYS nonlinear FEA (ANSYS, 2006);
- DNV PULS (DNV, 2006);
- ALPS/ULSAP (2006).

The ANSYS nonlinear FEA is the most refined method among the candidate methods, and believed to give the most accurate solutions as long as the modeling technique applied is adequate enough in terms of representing actual structural behavior associated with geometrical nonlinearity, material nonlinearity, type and magnitude of initial imperfections, boundary condition, loading condition, mesh size, and so on. For the present benchmark study purpose, the elastic–perfectly plastic material model is applied for all the candidate methods by neglecting strain-hardening effect of material.

Both DNV PULS and ALPS/ULSAP use semi-analytical approaches. While the details of DNV PULS may be found in the documents by DNV (2006), the theory of ALPS/ULSAP developed by the first author (Paik and Thayamballi, 2003, 2007) is described briefly herein.

For ULS assessment of unstiffened plates, membrane stress distribution inside plates is calculated analytically by directly solving the nonlinear governing differential compatibility and equilibrium equations of plates which involve only geometric nonlinearity without plasticity. It is considered that the plates collapse if one of multiple (three) ULS criteria specified is satisfied, where each of ULS criteria is a function of membrane stresses inside the plates, as well as initial imperfections and other parameters of influence.

This approach is quite beneficial because the solutions of the plate governing differential equations are very accurate, as long as the solution method is adequate in terms of the assumed deflection function, boundary condition, and loading condition, among other factors. Further, the types and magnitude of fabrication related initial imperfections in the form of initial deflection and residual stress can be dealt with as parameters of influence, i.e., in an explicit form rather than an implicit form.

For the present benchmark study purpose using the candidate methods, the initial deflection of plating (between support members) and stiffener web are assumed to be the following:

$$w_{\mathrm{opl}} = \frac{b}{200}, \tag{1}$$

where w_{opl} is the maximum plate initial deflection and b the breadth of plating between longitudinal stiffeners.

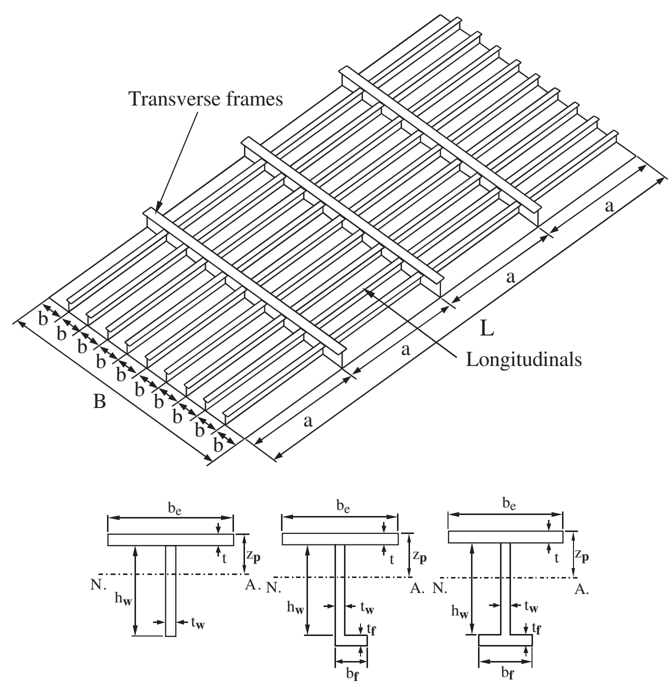

Fig. 1. Nomenclature: A stiffened plate structure considered for ULS assessment by ALPS/ULSAP method (note that the DNV/PULS defnition of stiffener web height is different from the ALPS/ULSAP defnition because the stiffener flange thickness is included in the stiffener web height defined by DNV/PULS).

Table 1
Principal particulars of a hypothetical AFRAMAX size double hull oil tanker

Length O.A.	250.000 m
Length B.P.	239.000 m
Length scantling	236.292 m
Breadth	43.800 m
Depth	21.000 m
Designed draught	13.600 m
Scantling draught	14.900 m
Block coefficient	0.87