Bending and Compressive Strength of Stiffened Panels with Crack Damage in Longitudinal Stiffeners

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ABSTRACT

This study examines stiffened panels with crack damage in a longitudinal stiffener. The crack is installed near a joint line with a transverse frame. Finite Element analysis (FEA) is performed to clarify the collapse behavior and residual strength of the cracked panels subjected to lateral water pressure and in-plane compression. The influence of the dimensions of the stiffened panel and the number of stiffeners on the collapse behavior is examined. The results indicate that the crack does not affect the bending strength of a thick stiffened panel under lateral pressure, but may reduce the strength of a thin panel. The crack reduces the compressive ultimate strength when the panel has such deep stiffeners that the overall buckling deformation does not increase. In a panel with small stiffeners, the crack constrains the growth of the overall buckling deformation and increases the ultimate strength. Simplified methods are proposed for estimating the reduced strength of the stiffened panel with the crack under in-plane compression. The benefits of the methods are validated through comparison with FEA results.

KEY WORDS: Stiffened panel, crack damage, collapse behavior, bending strength, ultimate strength, finite element analysis, simplified estimation of strength.

INTRODUCTION

The Goal-Based Standards for New Ship Construction (GBS) proposed by the International Maritime Organization (IMO 2010) cites structural design with redundancy as a functional requirement of structural rules. For example, structures should have the redundancy that prevents the overall collapse of a ship even if part of the structural elements has been damaged by cracks. The International Association of Classification Society (IACS 2013) has verified and validated the Harmonized Common Structural Rule for bulk carriers and oil tankers on the basis of the redundancy principle.

Stiffened panels are the main structural components of a ship; thus, it is necessary to examine the collapse behavior and ultimate strength of stiffened panels with crack damage to ensure structural redundancy. Although considerable research has been conducted for cracked panel elements under tensile load, few have examined cracked panels and panel structures under loads other than tension. Paik et al. (2005) performed tensile and compressive tests of unstiffened panels with a crack. Nonlinear finite element analysis (FEA) was performed to examine the residual strength of a cracked panel under compression by changing the panel dimensions and the location and length of the crack (Paik 2009). Brighenti (2005) examined the elastic buckling strength of cracked panels under tension and compression by performing FEA, and discussed the influence of the crack length and orientation. Khedmati et al. (2009) performed FEA for simply supported panels with crack damage and examined the influence of the panel aspect ratio and crack length, location, and orientation on the elastic buckling strength. As research for stiffened panels with crack damage, Margaritis et al. (2012) considered a case where the crack normal to the loading direction was installed at the center of the span between the transverse members. They performed nonlinear FEA for the cracked panels under compression and examined the buckling/plastic collapse behavior.

Most of the damages encountered in actual ship structures are fatigue cracks produced in longitudinal stiffeners. Such cracks get initiated at the welding line between the top flange of the longitudinal stiffener and the vertical stiffener attached to the transverse members, and propagate toward the bottom of the longitudinal stiffener. Because few studies have targeted such realistic crack damage, it is necessary to perform such detailed research to further develop knowledge of the strength and collapse behavior of cracked panels.

This study targets stiffened panels with multiple longitudinal stiffeners subjected to lateral water pressure or in-plane compression in the longitudinal direction, and assumes that one of the stiffeners is cracked near a joint line with a transverse member. Nonlinear FEA is performed to examine the collapse behavior and the residual strength of the cracked panel. The dimensions of the panel and stiffener, the number of stiffeners, and the crack location are varied, and their influence on the residual strength is discussed. Simplified methods are proposed to estimate the reduced strength of the stiffened panel with crack damage under in-plane compression. The benefits of the methods are discussed through comparison with FEA results.

FINITE ELEMENT MODELING AND ANALYSIS PROCEDURE

Finite Element Modeling

This study targets panels stiffened by multiple longitudinal stiffeners, longitudinal girders and transverse frames subjected to lateral water pressure from the panel side or in-plane compression in the longitudinal direction, as shown in Fig. 1. Each load is assumed to act on the panel independently; the combination of both loads is not considered.