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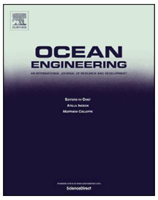

A simplified structural safety assessment of a fin-typed energy saving devices subjected to nonlinear hydrodynamic load

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ABSTRACT

As the demand of environmental restriction and cost reduction increases, a fin-typed structure attached around a propeller has been developed to reduce fuel consumption rate of a vessel by improving the thrust force. Some cracks have been reported in the vicinity of the root of the fin, i.e. the welded line between ESD and hull structure, which is caused by the fluctuating hydrodynamic force induced by the ship motion. As a method of fatigue strength assessment for ship structure, the spectral approach has been widely utilized based on the hydrodynamic loads calculated using the potential theory. However, the nonlinear vertical lift force caused by the vertical motion of the ESD cannot be properly considered in the spectral approach. To take into account the nonlinear effect, computational fluid dynamics (CFD) analysis was adopted for the assessment of hydrodynamic force and the results were approximated by an artificial neural network (Lee et al., 2016). Then, a time series of vertical velocity of energy saving device under irregular wave is converted to time series of lift force and lift moment using the trained neural networks. However, in the previous research, ship speed, heading angle and ESD shape were fixed and their variations could not be reflected in the safety assessment. The proposed neural network is a useful method, but it cannot be directly applied to an actual project due to the absence of information about the artificial neural network itself. This research aims at developing simplified formulas to predict lift force and lift moment instead of the neural network and covering heading angle, ESD shape and ship speed additionally. To investigate the effects of additional variables, a series of CFD analysis is performed and polynomial regression models are employed to examine their relationship with the life force and moment. The established simplified formulas are used for the generation of a time series of lift force and lift moment required in ultimate and fatigue strength assessments. The rainflow counting method is used for the calculation of fatigue damage and the resultant long term distribution is compared with a simplified long term distribution method. The proposed formulas are expected to be used for the same type of ESD with different configuration and ship speed without any further time consuming CFD analysis.

1. Introduction

Due to the growing interest about environmental problem, the demand of the reduction of fuel oil consumption is greater than ever before. Various types of energy saving devices (ESD) have been developed (ABS, 2013; Hooijmans et al., 2010). Among ESDs, a series of fin-typed ESD attached around a propeller has been proposed (Lee et al., 1992). While most researches are focused on the evaluation of energy-saving performance of ESD (Celik and Guner, 2007; Kim et al., 2015), few have studied on the structural safety assessment. The conventional spectral method was used for a calculation of extreme design load and fatigue analysis for ESD. Woo et al. (2013) presented strength and fatigue assessments of duct-type ESD using a linear transfer function. However, it can't reflect the nonlinearity of induced hydrodynamic force.

In order to accurately consider the nonlinearity of the hydrodynamic force acting on ESD, CFD analysis has been used. Up to now, many studies focused on the calculation of lift force and drag force performance of a hydrofoil under steady state flow using CFD analysis. 2D CFD analysis

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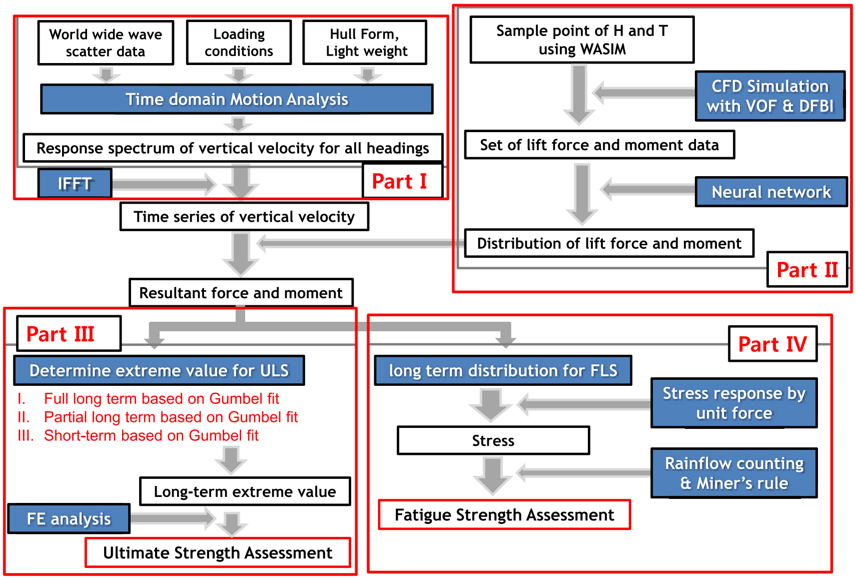

Fig. 1. Whole procedure of Level III method for structural safety assessment of ESD (Lee et al., 2016).

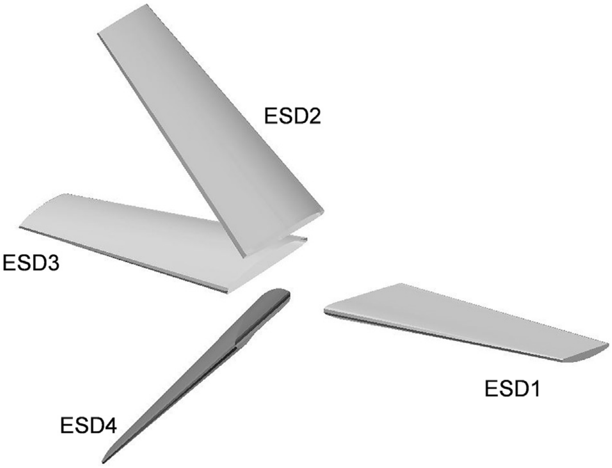

Fig. 2. Energy saving device.

was used to compute the lift coefficient and drag coefficient (Hutchison et al., 2010; Kinnas et al., 2012). The 3D effect was estimated by comparing the 2D and 3D CFD analysis results (Nowruzi et al., 2017; Spentoz et al., 2004). However, in case of ESD, hydrofoils are attached on hull structure and the effect of hull form is necessary to be taken into account in the calculation of the hydrodynamic force of vertically oscillating hydrofoils in addition to the 3D effect of ESD itself. The hydrodynamic force on ESD is found to be affected not only by the three dimensional shape of ESD but also by the ship hull (Lee and Jang, 2014). Therefore, a 3D CFD analysis for entire hull should be performed to obtain the hydrodynamic forces acting on ESD.

In an extreme environmental condition, a large ship motion, particularly heave and pitch motion can induce large nonlinear lift force and lift moment on ESD. Therefore, some cracks at the root of hydrofoil-type device have been reported continuously. As an effort of safety assessment of ESD, Lee et al. (2016) proposed a new procedure taking into account the nonlinearity of hydrodynamic loads. This procedure which is called as Level III method consists of four main parts as shown in Fig. 1: a sea-keeping analysis (Part I), a CFD analysis and an artificial neural network training (Part II), a long-term analysis and an ultimate strength assessment (Part III) and a fatigue strength assessment using rain-flow counting method (Part IV). The artificial neural network explained in this procedure is trained for CFD results for a specific shape of ESD and one ship speed. For a different ESD configuration and different ship speeds, a series of CFD analysis should be newly carried out and a new neural network model needs to be constructed. In order for a neural network to include the additional shape parameters and the ship speed, the number of CFD simulations required for generating sampling points drastically increases due to the increased dimension of input variables.

For this reason, it is necessary to establish an efficient way to cover those additional variables. Moreover, an explicit formula to predict the lifting force and moment would be preferred to the neural network for a direct use in a real project. This research aims at providing simplified formulas to predict lift force and lift moment acting on ESD instead of the neural network to be trained for CFD analysis results. The effect of each additional parameter is reflected into its respective adjustment factor based on the assumption that the coupling effect with other variables are not significant. A few steps to derive the simplified formula are described in Section 2 and Section 3. This simplified formula can be used for the generation of a time series data of lift force and lift moment required in Ultimate Limit Strength assessment (ULS) and Fatigue Limit Strength assessment (FLS) instead of the artificial neural network proposed by Lee et al. (2016) as shown in Fig. 1. This method is named Level II method and the artificial neural network in Level III method is replaced by the proposed simplified formula.

Furthermore, this research also suggests a Level I method that can be used for ULS and FLS based on a simplified long term distribution generated using the proposed simplified formula. It doesn't require to generate times series of lift force and moment for all sea states in the wave scatter diagram. Therefore, Level I method can be regarded as the simplest method even if its accuracy deteriorates compared to Level II and Leve III methods. The detailed explanation about Level II and Level I methods are explained in Section 4.

2. An overall approach to derive a simplified formula

All variables affecting the lift force and moment need to be included in a simplified formula. However, the number of required sample points drastically increases with the number of considered variables. The dimension of design space can be reduced by assuming some parameters constant. The slope angle of ESD blade is set zero in a conservative way because its vertically projected area becomes the largest at zero slop angle.

The following six variables are expected to have substantial influence