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Estimation of damping through internally excited roll tests

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ABSTRACT

Roll damping represents a key factor for a proper estimation of the ship behaviour in a seaway. However, due to the typical dominance of viscous effects, accurately estimating roll damping is a challenging task. The most common experimental approach for determining roll damping parameters is based on the analysis of roll decays, although forced and excited roll tests in calm water or in waves have been used as well. This paper proposes a technique for estimating roll damping from internally excited roll tests in calm water. Tests are performed by exciting roll motion through an internal shifting mass. Roll damping parameters can then be determined from the analysis of the obtained roll response curves. The paper describes the experimental technique and a nonlinear mathematical model for representing the system dynamics. A procedure is proposed for determining roll damping coefficients, using, as a basis for the analysis, the developed mathematical model. A case study is reported where damping coefficients are determined for a trawler fishing vessel using the proposed technique. Obtained results are compared with those from standard roll decays analysis. For model validation purposes, the experimental roll response curves are also compared with those simulated through the developed mathematical model.

1. Introduction

From a seakeeping perspective, ship roll damping represents a key factor for a proper estimation of the ship roll behaviour in a seaway. Moreover, from a regulatory, and hence design, perspective roll damping is a major parameter in some stability-related international regulations. This is the case of MSC.1/Circ.1200 (IMO, 2006), which addresses the alternative experimental assessment of the Weather Criterion, and where roll damping may be necessary to determine the regular waves roll-back angle when direct experimentation cannot be carried out. Damping is also fundamental in case of the majority of failure modes addressed by the, still under development, Second Generation Intact Stability Criteria (SGISC) (e.g. IMO, 2016, 2017; Peters et al., 2012). However, due to the typical dominance of viscous effects, accurately determining roll damping is a challenging task.

Roll damping was already considered by Froude (Froude et al., 1955) and, since his seminal contributions, this topic has continued gaining attention over the years. Research studies were and are still focused on different complementary aspects. Large attention has been given to the analytical mathematical modelling of roll damping and to the corresponding analysis of experimental data (e.g. Bulian, 2004; Cardo et al., 1982; Dalzell, 1978; Francescutto and Contento, 1999; Haddara and Bennett, 1989; Park et al., 2017; Roberts, 1985; Spyrou and Thompson, 2000). Nonlinear roll damping prediction at design stage has mostly been based on semi-empirical methods (see, e.g. Himeno, 1981; ITTC, 2011; Ikeda et al., 1978; Kawahara et al., 2012; and see references in the review regarding semi-empirical methods by Falzarano et al., 2015) and on the use of experimental reference data sets (e.g. Blume, 1979). Recently, thanks to the increase of available computational resources and thanks to the improvement of numerical methods, also CFD simulations have started being applied for the estimation of roll damping (see, e.g. Handschel et al., 2012; Hua et al., 2011; Irkal et al., 2016; Ommani et al., 2015; as well as references in the literature review by Bačkalov et al., 2016). While the effort on roll damping modelling and estimation was originally placed into small and medium ship roll angles, more focus is presently given to large angles of roll (Bačkalov et al., 2016). The need to have a proper estimation of roll damping at large rolling amplitudes is linked more to safety rather than to operability. It is therefore understandable that large amplitude roll damping may represent a relevant topic from a regulatory perspective when ship roll motion is directly addressed (IMO, 2006, 2016, 2017; Peters et al., 2012). Current semi-empirical methods, such as the (Simplified) Ikeda's Method (Kawahara et al., 2012), are limited to cargo vessels and specific ranges of hull particulars (Falzarano et al., 2015), although some attempts have

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been made to apply semi-empirical methods to other types of ships such as fishing vessels (Aarsæther et al., 2015; Ali et al., 2004; Kuroda et al., 2003; Míguez González et al., 2013; Paroka and Umeda, 2007). However, such semi-empirical methods have been criticised for lacking accuracy at large roll angles (Bassler, 2013). Hence, as stated in the draft guidelines for direct stability assessment procedures in the framework of SGISC (IMO, 2017), the preferred source of the data to be used for the calibration of roll damping in motion prediction codes should be experimental roll decays or excited roll tests.

In the past, studies have been dedicated to the different experimental procedures which can be followed to gather data for the determination of roll damping. The most typical means for roll damping determination is based on the execution and processing of roll decays. However, excited roll tests may offer advantages with respect to roll decays. In fact, one typical problem associated with roll damping estimation based on roll decays is the difficulty in gathering damping information at large rolling angles. Instead, excited roll tests can allow achieving large rolling oscillation angles by properly modifying the forcing. Different types of roll tests in calm water can be carried out for roll damping estimation, either with free model (excited tests) or with fixed axis (forced tests) (e.g. Blume, 1979; Bertaglia et al., 2004; Handschel and Abdel-Maksoud, 2014; Handschel et al., 2015; Spouge et al., 1986; Wassermann et al., 2016). Moreover, experimental tests in regular beam waves can also be used to identify roll damping through parameter identification techniques (e.g. Bertaglia et al., 2004; Contento et al., 1996; Francescutto and Contento, 1998, 1999; Francescutto et al., 1998; IMO, 2006).

Despite experimental tests are the most accepted way to reliably estimate ship roll damping, different alternative approaches still coexist in available international guidelines (e.g. ITTC, 2011; IMO, 2006). Since different experimental approaches are associated with different hydrodynamic scenarios, estimated roll damping may, in principle, differ depending on the used approach. These possible differences have often been neglected, although some studies focusing on this aspect appear to be available in literature (e.g. Bertaglia et al., 2004; Handschel and Abdel-Maksoud, 2014; Handschel et al., 2015; Mathisen and Price, 1985; Wassermann et al., 2016).

Considering the reported background, the scope of the present paper is two-fold. Firstly, the paper presents a methodology to perform and analyse excited roll experiments in calm water, based on the generation of roll excitation through an internally moving mass. Secondly, the paper presents comparisons between roll damping estimated from the proposed excited roll tests and from standard roll decays. The experimental setup used herein for the excitation of roll motion is similar to that used by Bulian et al. (2010) to excite the rotational motion of a free surface tank having a fixed axis. The main advantages of the proposed tests are the full knowledge of the excitation from first-principle mechanics considerations, and the possibility of exciting the model up to large rolling angles.

The paper is organised as follows. Firstly, the proposed methodology is presented. The description of the methodology comprises the description of the experimental setup, the derivation of a 1-DOF mathematical model of roll motion to be used for roll damping assessment, and the description of a procedure for the determination of roll damping coefficients from experimental results. Secondly, a case study is reported. Experimental tests are carried out for a trawler fishing vessel according to the proposed technique. The hull is described, together with the tested loading conditions. Results from excited roll tests are reported, and then corresponding data are analysed to obtain roll damping coefficients according to the proposed procedure. A validation of the mathematical model, using fitted roll damping coefficients, is also reported, both in terms of roll response curves as well as in terms of roll time histories. The case study concludes with a comparison between roll damping estimated in accordance with the proposed procedure, and roll damping estimated from the analysis of roll decays. Details of the roll decays analysis procedure are described in a separate Appendix. Eventually, some concluding remarks are provided.

2. Methodology

This section presents the methodology for the determination of roll damping parameters. The experimental setup is firstly described. Afterwards, the mathematical modelling used for describing the system dynamics is presented. Finally, a methodology for the determination of roll damping coefficients from the obtained experimental data, using the developed mathematical model, is proposed.

2.1. Experimental setup

In the proposed technique, the ship model is freely floating (or at most softly restrained) in calm water and it is excited to roll using an internal shifting mass that moves following a prescribed movement. This type of technique has been referred to in the past as "harmonic excited roll motion (HERM)" technique (Handschel and Abdel-Maksoud, 2014; Handschel et al., 2015; Wassermann et al., 2016). Internally excited roll motion tests have the benefit of potentially allowing the determination of roll damping also at large rolling amplitudes, which are the amplitude ranges typically relevant for ship safety assessment. Obtaining roll damping at large rolling angles through roll decays is, instead, typically difficult (or even impossible), due to the strong natural reduction of roll amplitude in the first oscillation cycles and due to the difficulties associated with the inclining of models at too large initial angles if models are large. Moreover, internally excited roll tests without hard constraints on the model have the benefit of maintaining the natural coupling between roll motion and other relevant motions (particularly sway). This characteristic, instead, is lost when forced tests are carried out with fixed axis, and the correspondingly determined roll damping is therefore affected (see Bačkalov et al., 2016).

The mass in the present experimental techniques moves along a linear guide, and the prescribed motion of the mass, which then generates the internal excitation, is sinusoidal. The guide is fixed to the ship model near its centre of gravity and the movement of the mass is obtained through a controllable electrical engine connected to an encoder, as shown in Fig. 1. The maximum amplitude of the moving mass is directly limited by the overall dimensions of the linear guide. For the case study reported hereinafter, the length of the guide corresponds to 206 *mm*. The moving mass is initially placed at the centre of the guide and it is allowed to move from the centre up to 90 *mm* on each side, which therefore corresponds to the maximum amplitude of transversal motion of the mass ($y_{m,max}$). The oscillation frequency of the moving mass can be varied from 0.1 *rad/s* to 7.0 *rad/s*, corresponding to a range of forcing periods from 0.9 *s* to 62.8 *s*.

Different forcing cases (*FC*) can be generated by different combinations of the moving mass (m_m) and maximum motion amplitude. However, in the present tests, only the moving mass has been changed, keeping always the same maximum amplitude of motion ($y_{m,max} = 90$ *mm*). Each forcing case can be associated with a nominal amplitude of forcing (A_{FC}), which is defined as follows:

$$A_{FC} = m_m g y_{m,max} \tag{1}$$

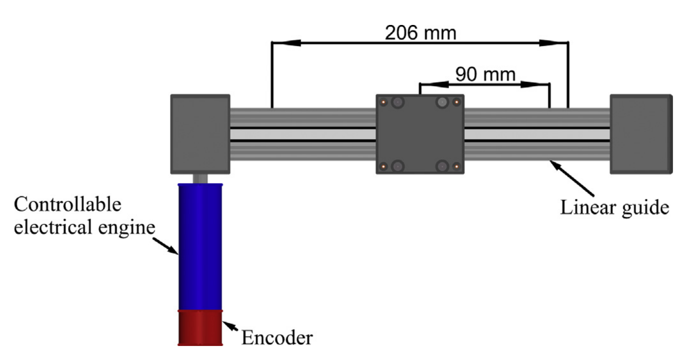

Fig. 1. Details of the linear guide.