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# Characterisation of Flooding Process of Damaged Ro-Ro Vessel

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## ABSTRACT

**Recent research at the University of Strathclyde culminated in the development of a numerical procedure for assessing the damage survivability of damaged Ro-Ro vessels. Using this as a basis, new survival criteria have been proposed and submitted to IMO for consideration by the international shipping community. This paper presents the results of a fundamental study aimed at enhancing insight into one of the most dominant parameters affecting the survival of a Ro-Ro vessel, the water accumulation on the vehicle deck. The investigation represents an attempt to identify the most important contributing factors to the flooding process by performing a series of experiments using a scaled model of a typical Ro-Ro vessel. The matrix considered involves a range of ship design and environmental parameters in a number of simplified damage scenarios, building up to the more realistic damages in a way that allows for isolation of individual contributions to the water accumulation on the Ro-Ro deck. The results of the experiments, supplemented by and contrasted with results of numerical simulations, are presented and discussed, leading to recommendations for characterising the flooding process for general assessment of damage survivability.**

## INTRODUCTION

The limited understanding of the complex dynamic behaviour of a damaged vessel and the progression of flood water through the ship in a random sea state has, to date, resulted in approaches for assessing the damage survivability of ships that rely mainly on hydrostatic properties with potentially serious consequences concerning the loss of life and property whilst endangering the environment. The tragic accidents of the *Herald of Free Enterprise* and more recently of *Estonia* were the strongest indicators yet of the magnitude of the problem at hand, particularly when water enters the deck of ships with large undivided spaces, such as Ro-Ro vessels. The ship loss could be catastrophic as a result of rapid capsize, rendering evacuation of passengers and crew impractical, with disastrous (unacceptable) consequences. In the wake of these, concerted action to address the water-on-deck problem led to the proposal of new stability requirements, known as the Stockholm Regional Agreement, or more commonly as SOLAS '90+50, pertaining to compliance of existing Ro-Ro vessels with SOLAS '90 requirements whilst accounting for the presence of a maximum 0.5-m height of water on the vehicle deck. In view of the uncertainties in the current state of knowledge concerning the ability of a vessel to survive damage in a given sea state, an alternative route has been allowed which provides a non-prescriptive way of ensuring compliance and, one hopes, enhanced survivability: the *Equivalence* route, by performing model experiments in accordance with the requirements of SOLAS regulation II-1/8. In response to these developments, the shipping industry, slowly but steadily, appears to be favouring the model-experiment route, implicitly demonstrating mistrust towards deterministic regulations which, admittedly, lack solid foundations. An attractive alternative route to tackling the water-on-deck problem in a way that allows for a systematic identification of the most cost-effective and survivability-effective solutions has been introduced by the Ship Stability Research Centre (SSRC) at the University of Strathclyde, by making use of a mathematical/numerical model, developed and validated over the past nine years, describing the dynamic behaviour of a damaged ship in seaway whilst subjected to progressive flooding. During the Joint North West European Project (JNWEP), this model was made the basis for formulating and proposing rational survival criteria to deal with water on deck as part of the probabilistic procedure for assessing damage stability (Vassalos et al., 1996). A relevant paper was submitted to IMO and is being considered by the working group on harmonisation of probabilistic standards. In the developed mathematical model and the ensuing criteria, the process of water accumulation on the Ro-Ro deck as well as the actual amount of water are dominant features. In this respect, an acceptably accurate model of water ingress/egress is a prerequisite to undertaking any investigations on damage survivability. Deriving from the above, this paper attempts to elucidate some of the basic characteristics of the flooding process considering a typical Ro-Ro vessel, by presenting and discussing preliminary results from an extensive experimental programme aimed at enhancing understanding and insight of this complex phenomenon. Firstly, a brief introduction is of the state-of-the-art mathematical model undergoing validation at the SSRC.

## MATHEMATICAL MODEL

To study effectively damage survivability one needs to put together a nonlinear six-degrees-of-freedom seakeeping model that allows the vessel to drift as well as changes in its mass, centre of mass and mean attitude relative to the mean waterplane with time — and the same dependence of environmental excitation and hydrodynamic reaction forces on the changing underwater volume of the vessel must also be catered for; a water ingress model that allows for multiple-compartment flooding in the presence of oscillatory flows in extreme wave conditions and at times of shear flows; and a sloshing model that allows for random inflow and

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