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Ultimate Limit State Design of Ship Hulls

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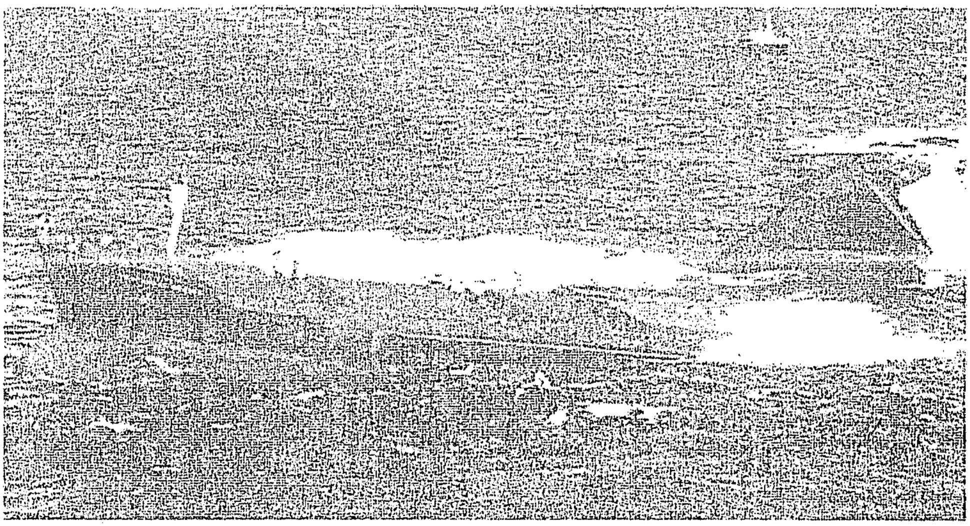

ABSTRACT

This paper is a logical sequel to the authors' last two SNAME annual meeting papers (Paik et al. 2000, 2001) which dealt with the ultimate limit state design of ship plating and stiffened panels. It aims to deal with the advanced ultimate limit state design of ship hulls under vertical bending moments. Traditionally, design criteria and procedures were primarily based on allowable stresses and buckling checks. It is now well recognized that the limit state approach is a better basis for design, because it determines, in a more realistic way, the real safety margin of any economically designed structure. While the limit state design for steel structures uses limit states classified into four types, namely serviceability limit state, ultimate limit state, fatigue limit state and accidental limit state, the present paper is concerned with the ultimate limit state of ship hulls.

In this paper, efficient and accurate methodology for the progressive collapse analysis of ship hulls is presented. The characteristics of progressive collapse behavior of a total of 10 typical merchant ships under vertical bending are then investigated using the analysis method presented. Effects of lateral pressure and horizontal moment on the hull girder ultimate vertical moment are studied. Closed-form ultimate strength formulations for the ultimate strength of ships are developed. Finally, the ultimate limit state design format for ships is addressed.

INTRODUCTION

During the last few decades, the emphasis in structural design has been moving from the allowable stress design to the limit state design, since the latter approach has many more advantages. A limit state is formally defined as a condition for which a particular structural member or an entire structure fails to perform the function that it has been designed for. From the special viewpoint of a structural designer, four types of limit states are considered, namely

- Serviceability limit state (SLS)

H. Paul Cojeen, Member and William S. Peters, Member

[The views expressed here are those of the discussor, and not necessarily those of the U.S. Coast Guard or the Department of Transportation.]

It is usual for discussers to thank the authors for their good work and efforts. These authors led by Prof. Paik, are to be especially commended for the series of exceptional papers (4 to 6 papers) that they have contributed to SNAME over the past several years.

This paper, which culminates a decade of research, provides some very interesting calculation results that deal with the structural safety margin of various ship types. The successful use of progressive collapse analysis for the assessment of structural capacity of a design is particularly encouraging. The calculation results that include the effects of initial imperfections, lateral pressure and horizontal bending moment give us pause, but surely make us reconsider classification society standards, and when taken with the paper of Dr. Payer, seem to point us in a logical direction. The methodology described is very useful because the results of such an analysis can reveal the process of hull girder failure and the associated loads at which various structural components collapse or yield. The idea that the authors suggest to use the ultimate limit state procedure to develop structurally damage tolerant designs is especially noteworthy.

We want to compliment the authors for their courage to present the calculation results in Table 2 that show the safety measure calculation results for ten different ships. We believe that these show a number of interesting trends that should be explored. In particular, when we look at the computed results, we will assume that the ratio of ultimate vertical moment (M_u) to the total bending moment (M_t) is an acceptable expression of the safety margin incorporated into the design. We believe that the results shown that containerships, FPSOs and the shuttle tanker seem to have a greater margin than double-hull tankers and the bulk carriers. Given the similarity of the hull configuration, we are interested to learn why the results shown for the shuttle tanker are so different than that shown for the double-hull tankers.

The results for the double-hull tankers in the sagging condition and for the bulk carriers in the hogging condition cause us to ask some very basic questions. The results presented take into account an "average amount of imperfections," but what happens to these results when greater imperfections are considered? How would some minor contact damage or higher plate panel deflection effect the results? Further, it is unclear to what degree the effects of lateral pressure and horizontal moment have been included. The results from the paper suggest that these factors contribute to degrade the ultimate hull girder strength.

While keeping that in mind, it may be difficult to consider the presented results, calculated without any structural damage, as indicating that there is sufficient safety margin for these vessels when they may operate with some increased imperfections or damage. The authors pointed out the likelihood of the sinking of a bulk carrier when a forward hold may be flooded, even partially. We think that the results presented here suggest that these types of ships, especially with the losses that continue to be recorded, need to be built with a greater margin of the ratio of M_u to M_t. We believe that, for these ship types, there is ample experience which shows that the level of maintenance is inferior and thus if the more correct level of "imperfections" were used in your model then these ship types would have an even smaller margin of the ratio of M_u to M_t as compared to other ship types.

Simply stated, we believe that some serious consideration should be given to reviewing the IACS unified requirements for hull girder strength. We feel that the design method presented here can assist with that reassessment.

Philippe Rigo, Member

We congratulate the authors for their interesting paper that is the conclusion of several valuable papers published by the same authors.

At the opposite to the previous papers that provided sophisticated formulations to better assess failure modes, this paper concerns a revised practical methodology which is definitively design oriented. Instead of proposing advanced and complex numerical approaches, the authors propose a simple and reliable method that can be easily implemented by classification societies, shipyards and design offices.

The previous Paik-Mansour (1995) method has major shortcomings to consider a single reference panel (element) for each major component (deck, side shell, bottom and double bottom). It is also difficult to use when several steel grades are used. In addition, it is only suitable for merchant ships having a flat bottom and vertical side shells. It was difficult to use for frigates and slender ships.

With this paper and the revised closed-form ultimate strength bending moment formulation, the former shortcomings do not remain anymore. The method seems now ready to be applied to any ship hull. Nevertheless users must keep in mind the method assumptions:

a. the collapse is assumed to occur between two web frames that are assumed to fail after the considered ultimate bending moment;
b. the vertical distribution of the longitudinal strain is assumed linear and is it obviously not the case for multi-deck ships like passenger vessels having large side/deck openings;
c. the ultimate stage (stress distribution) is assumed (see Fig. 17);
d. ...

Concerning this last assumption, have the authors experienced ships for which the assumed ultimate stress distribution is not valid? In order to avoid this assumption a standard progressive collapse seems in some cases more suitable and it does not require more computer time.

Positions of the neutral axis at the assumed ultimate limit states (sagging and hogging) are given, respectively, by equations (3a) and (4a). To use these equations, it is necessary to compute the element stress using equation (2) and before each element axial strain using equation (1). Obviously equation (1) requires knowledge of the neutral axis, which is obtained by equation (3). It seems that an iterative procedure must be used.

Do you update the stress in the elastic regions (2 and 3) using the new position (g_u) of the neutral axis?

Could the authors give information about their recommended procedure?

E. Steen, T. K. Østvold, E. Byklum, and S. Valsgård, Visitors, Det Norske Veritas

The authors address a very important issue which is directly related to the safety of ships against total loss and failure. The subject has been on the agenda for some decades and it deserves continuous attention as the assessment of the safety margins against ship hull girder collapse is of utmost importance.

The authors approach to the problem is to use a progressive hull girder model applying a coarse ISUM element mod-