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# Experimental analysis of the effect of frame spacing variation on the ultimate bending moment of box girders

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ABSTRACT

An experimental study is presented of three box girders made of mild steel subjected to pure bending moment, with different spacing between frames. The moment curvature curves are presented, allowing for the analysis of elastic–plastic behaviour until collapse and the evaluation of the ultimate bending moment and post collapse behaviour for each experiment. The residual stress relief during loading and unloading path is also analysed. The effect of the span between transverse frames on the ultimate bending moment of the box girder is studied and thus its dependence on the column slenderness of the panel under compression can be established.

The energy dissipated by internal friction during each load cycle is evaluated and compared with elastic potential energy.



## 1. Introduction

The evaluation of the ultimate capacity of ships under bending moment is a very important issue for the structural design. It is associated with the global failure of the hull and the final result is normally the loss of the ship, its cargo and human lives.

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In the last years several studies have been done on the subject, most of them on the evaluation of the ultimate bending moment of ships made of normal mild steel. The existing calculation methods may be divided into two groups: finite elements methods, and simplified methods. There has been a great activity in this subject and comparisons between the different methods are available in the literature [1,2].

The development of the design of structures under bending has been made on the assumption that the structure can be divided into several simple stiffened plate elements that act independently. The authors have been working on a method based on these assumptions [3], which has been validated against data from a full scale accident [4] where the loading conditions could be well established and compared against some small scale experiments of models representing simplified typical sections of ships [5–8]. The results of these comparisons showed that the method can be used confidently on typical hull configurations and for normal steel.

Changing the span between frames will affect the non-dimensional column's slenderness of those stiffened plate elements leading to different collapse strength despite having the same cross section. The change of frame spacing will induce collapse at different levels of column's slenderness and this suggested a new experimental program, covering the appropriate range of the governing parameters of the plating. In this study the behaviour of three box girders made of the same material with the same configuration but different spans is compared.

## 2. Hull strength evaluation

There are several methods available to evaluate the ultimate moment that a hull may sustain in sagging or hogging. The method of Gordo et al. [3] is able to quantify the overall behaviour of the hull under bending moment and it predicts not only the ultimate bending moment but also the pre and post collapse behaviour. It considers all modes of collapse of the structure and it also includes an algorithm to deal with residual stresses and corrosion.

This method and the software that has been developed to implement it, proved to give good prediction for normal steel ships when compared to the tests and examples that are available in the literature.

In order to provide data for those comparisons a plan of experiments was developed for box girders subjected to pure bending moments. These box girders may reproduce in a simple manner the behaviour of the ship's structure under bending, allowing the identification of the differences of using mild steel or high tensile steel, widening the range of validity of the method and covering the behaviour of panels of high column slenderness.

The typical element of the box girders is a plate with a bar stiffener, which has been proved to be representative of the actual type of structure of ship's hull [9]. In order to obtain information about the carrying capacity of different panel arrangements, like plates reinforced by complex stiffeners, another series of experiments has to be planned due to the geometric limitations for the reproduction of such scantlings at the present scale and limitations on the total loading that one may use in these box girders experiments.

### 2.1. Main parameters of the structural design

The main parameters affecting the structural design of ship hulls subjected to bending moment are the plate and column slenderness, because they affect directly the effectiveness of the panels under compression. These parameters are defined as follows:

- Plate slenderness, $\beta = \frac{b}{t}\sqrt{\frac{\sigma_e}{E}}$
- Column slenderness, $\lambda = \frac{a}{r}\sqrt{\frac{\sigma_e}{E}}$

and they depend directly on the geometry of the structural elements and on the material properties.

The geometric characteristics of interest are the width ($b$) and the span ($a$) of the plate elements, as well as their thickness ($t$) and the radii of gyration ($r$) of the cross section of the stiffener with an