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Hydrodynamic characteristics of ship sections in shallow water with complex bottom geometry

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ABSTRACT

The method of boundary integral equation developed by the authors was applied for computing inertial and damping characteristics of ship sections for the cases of multi-stepped and inclined bottoms. Comparative calculations for three typical ship hull sections were performed and analyzed. The frequency-dependent data computed for these ship sections can be used to assess the bottom geometry's influence onto the ship motions in waves by means of the strip theory. Limiting values of the same characteristics corresponding to the close-to-zero frequency can also be used for estimation of hydrodynamic forces in manoeuvring over shallow and confined waterways.

1. Introduction

Continuous growth of the average size and speed of vessels results in repeated problems related to insufficient water clearances affecting the navigation safety and increasing the operation costs. Often these problems are related to the squat sometimes resulting in undesirable contacts with the ground which requires reduction of the ship's speed deteriorating the waterway's capacity. Practical aspects related to the ship manoeuvrability in restricted waters were discussed by Gray et al. (2003) and by Landsburg et al. (2005). Another undesirable effect is also related to touching the ground as result of ship motions on waves. These motions depend relatively weekly on the ship's speed but mainly on the oncoming waves' amplitude. The remedy here is not to enter the dangerous zone until the sea calms down but idle time means additional losses. Finally, proximity of the seabed can alter the response of the ship to control actions which increases the danger of steering errors sometimes resulting in accidents and even disasters.

It is clear that it is extremely important to predict the ship's behaviour in shallow and confined waters. First, this can help to make reasonable decisions about the channels' dredging. Then, safe levels of the sea state and ship speed can be estimated and prescribed by the port authorities. Creation of adequate mathematical models for ship manoeuvring with due account for the shallow-water effects is also very desirable as if such models are implemented in bridge simulators, navigators, and helmsmen can be better trained and prepared to complicated manoeuvring phenomena.

Although most of the listed problems were dealt with more than once, see Zhao (1986), Kobayashi (1995), and Beukelman and Journée (2001) to name just a few, no one particular method can be still recommended for preferable use. Especially weak is the treatment of the shallow-water seakeeping problem. Beck and Tuck (1972), Andersen (1979), Van Oortmerssen (1976), and Svendsen and Madsen (1981) did some earlier work but the recent literature has not been very prolific in this subject.

As the model's computational efficiency and speed are very important for the envisaged applications, faster though simpler hydrodynamic formulations must be currently preferred. The largest gain can be obtained from using the strip method whenever possible. This method exploits characteristics of the ship hull's strips or sections for which the hydrodynamic problem is two-dimensional and much simpler for solution then the full 3D problem. Huge experience accumulated during decades indicates on the sufficient accuracy of the strip method when applied to slender ships. It is less suitable for catamarans or in other situations when the flow bi-dimensionality is compromised.

Standard hydrodynamic characteristics of the ship sections are those related to their small-amplitude oscillations within a certain frequency interval and this predetermines the problem considered in the present paper. It is also important to bear in mind that low-frequency data corresponding to the horizontal motions can also be useful for manoeuvring problems.

As the natural or even somewhat dredged seabed cannot be always approximated with the horizontal flat rigid surface, it is important that the computational method be able to determine sectional hydrodynamic characteristics in presence of arbitrary rigid boundary. The only evident restriction important for keeping consistency of the strip theory is gentle boundary surface slope along the ship's longitudinal axis.

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Such a method based on earlier publications by Yeung (1973, 1982) was developed by the authors, first, for the deep water case (Sutulo and Guedes Soares, 2004) and, second, for the fluid of finite depth (Sutulo et al., 2009). In the latest publication, the method was applied to the flat-bottom case where it was possible to verify it comparing to some independent results and also the high-contrast depth case was studied. It was found in the latter case that presence of a variable depth seabed affects the contour hydrodynamic characteristics in a non-trivial way and some other bottom configurations approximating natural depth variations could be of interest. In the present article, some additional results related to the case of complicated though schematized bottom geometry: cases of 3, 4, and 8 levels (steps) and of a continuous inclined ramp. The main part of the paper containing plots of added mass and damping coefficients is preceded by a concise description of the theory involved and computational method used which is, however, reduced to the minimum still permitting independent reading of this paper. Also, from the same reasons, shown are some selected results for the flat bottom and single-step case.

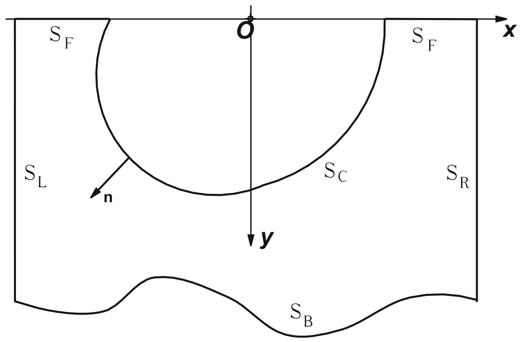

Fig. 1. Contour and computational domain.

2. Formulation of problem and solution method

It is supposed that defined is a two-dimensional domain *G* filled with a non-viscous incompressible fluid and bounded with the piecewise smooth boundary consisting of the smooth contour

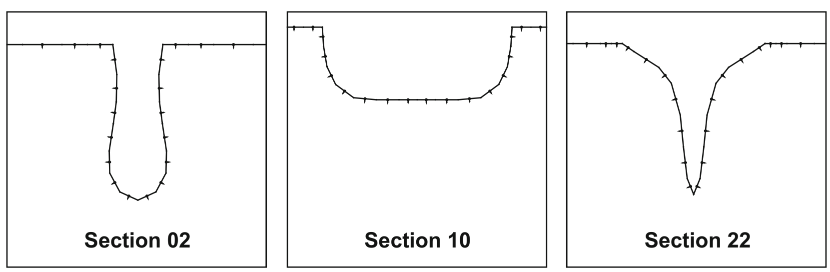

Fig. 2. Ship sections from container ship S-175 (not to the same scale).

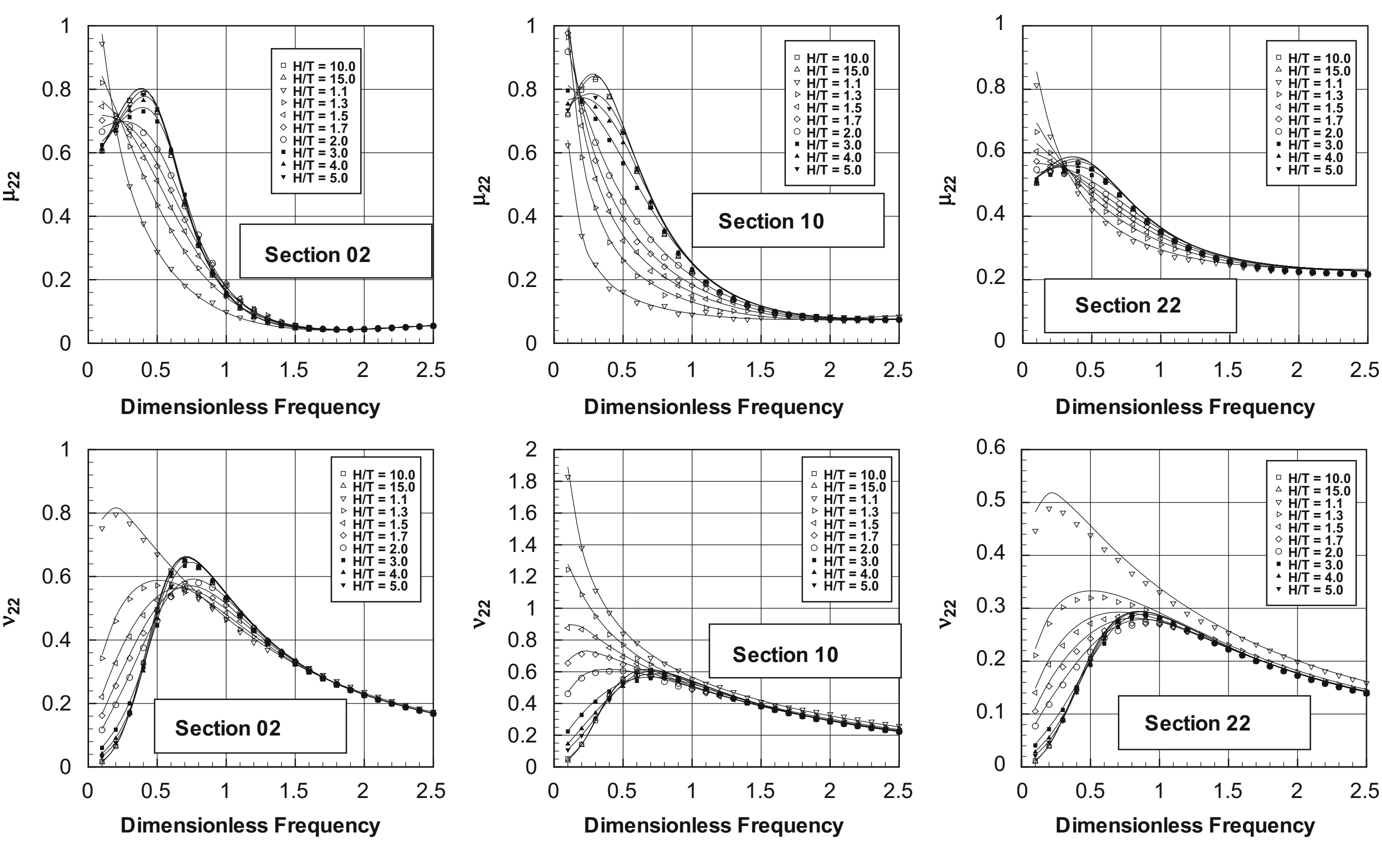

Fig. 3. Inertial and damping dimensionless coefficients in sway for flat seabed.