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A global approximation to the Green function for diffraction radiation of water waves

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Abstract

The Green function of the theory of diffraction radiation of time-harmonic (regular) waves by an offshore structure, or a ship at low speed, in deep water is considered. The Green function G and its gradient ∇G are expressed in the usual manner as the sum of three components that correspond to the fundamental free-space singularity, a non-oscillatory local flow, and waves. Simple approximations that only involve elementary continuous functions (algebraic, exponential, logarithmic) of real arguments are given for the local flow components in G and ∇G. These approximations are global approximations valid within the entire flow region, rather than within complementary contiguous regions as can be found in the literature. The analysis of the errors associated with the approximations to the local flow components given in the study shows that the approximations are sufficiently accurate for practical purposes. These global approximations provide a particularly simple and highly efficient way of numerically evaluating the Green function and its gradient for diffraction radiation of time-harmonic waves in deep water.

Keywords: regular water waves, diffraction radiation, Green function, local flow, global approximation

1. Introduction

Diffraction radiation of time-harmonic water waves by an offshore structure within the classical framework of linear potential flow theory and the Green function method is routinely used to predict added-mass and wave-damping coefficients, motions, and wave loads. Wave diffraction radiation by a ship that advances in ambient waves at low forward speed is also often analyzed using the zero-speed Green function at the encounter frequency. This Green function, which represents the velocity potential due to a pulsating source at a singular point under the free surface as is well known, is an essential element of the theory of wave diffraction radiation. Accordingly, the Green function has been studied in a broad literature, e.g. Havelock [1, 2], Thorne [3], Haskind [4], Wehausen [5], Kim [6], Noblesse [7], especially for the simplest case of deep water that is considered here.

The Green function G can be expressed as the sum of the fundamental free-space singularity and a flow component that accounts for free-surface effects. Moreover, this free-surface component is commonly decomposed into a wave component W that represents the waves radiated by the pulsating source, and a non-oscillatory local flow component L. This basic decomposition into a wave component and a local flow component is not unique. Indeed, three alternative decompositions and related single-integral representations of the Green function G are given in Noblesse [7].

Several alternative mathematical representations and approximations of G and ∇G that are well suited for numerical evaluation can be found in the literature. In particular, complementary near-field and far-field asymptotic expansions and Taylor series are given in Noblesse [7], Martin [8] and Telste & Noblesse [9]. Several practical approximate methods for computing G and ∇G have also been given. These alternative methods include polynomial approximations within complementary contiguous flow regions, given in Newman [10, 11], Chen [12, 13], Wang [14] and Zhou et al. [15], and table interpolation associated with function and coordinate transformations, given in Ba et al. [16] and Ponizy et al. [17]. Other useful practical methods can be found in the literature, notably in Peter & Meylan [18], Yao et al. [19], D'elía et al. [20] and Shen et al. [21].

Accuracy and efficiency are essential requirements of methods for numerically evaluating G and ∇G, and these important aspects are considered in the practical approximate methods listed in the foregoing. Indeed, the alternative methods proposed in these studies provide accurate and efficient methods for computing G and ∇G.

Numerical errors associated with potential-flow panel methods stem from several well-known sources, including:

(i) discretization of the wetted hull surface of an offshore structure or a ship; i.e. the number and the type (flat or curved) of panels,

(ii) approximation of the variations (piecewise constant, linear, quadratic, or higher-order) of the densities of the singularity (source, dipole) distributions over a surface panel,

(iii) numerical integration of the Green function and its gradient over a (flat or curved) panel, and

(iv) numerical approximation of the Green function and its gradient.

Moreover, the Green function G (as well as its gradient ∇G) is given by the sum of the fundamental free-space singularity, a wave component W and a non-oscillatory local flow component L, as was already noted. Thus, numerical errors that stem from the approximations of the local flow components in the representations of G and ∇G are only one part among several sources

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