Journal of Advances and Scholarly Researches in Allied Education
Vol. 15, Issue No. 7, September-2018, ISSN 2230-7540

Analysis of the Scattering from Targets on Ocean like Rough Surfaces

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Abstratct – Recently the iterative forward backward (FB) method has been proposed to solve the magnetic field integral equation (MFIE) for smooth one dimensional (1-D) rough surface. This method has proved to be very efficient, converging in a small number of iterations. Nevertheless, this solution becomes unstable when some obstacle like a ship or a large breaking wave, is included in the original problem has been presented. The generalized forward backward electric field integral equation (EFIE), which is solved using a hybrid combination of the conventional FB method and the method of moments (MoM), the latter of which is only applied over a small region around the obstacle. The GFB method is shown to provide accurate results numerical results show that different random ocean surface greatly affect the backscatter patterns of ship like target, although the patterns tend to have about the some average level. The purpose of the GFB method introduced here is to provide a numerical tool for studying this class of scattering problems.

Keywords: Rough Surface Scattering, Iterative Methods, Integral Equation, Sea Scattering.

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INTRODUCTION

The electromagnetic scattering from rough surfaces such as ocean like surfaces has been extensively found in the literature. A recent review can be found in a special issue about this topic (Brown, 1998). Most recent advances have been focused on the direct numerical simulation of the scattering problem. Numerical techniques based on integral equation formulations such as the well-known method of moments (MoM) (Harrington, 1993) are apparently some of the have played an increasingly important role. Different methods have been developed in recent years in order to reduce the number of computer operations required to analyze the rough surface scattering problem via the method of moments.

Recently, a new and powerful iterative numerical technique called the forward backward (FB) method has been proposed by Holiday, et.al., [3] [4] for solving the magnetic field integral equation (MFIE), which describes the current induced on a perfect electrically conducting (PEC) surface.

A hybrid approach has been presented in (West, et. al., 1998) where the scattering from water waves of different degrees of breaking is numerically examined by combining the MoM and the geometrical theory of diffraction (GTD). The technique is implemented using impedance-surface boundary conditions to handle scattering media of conductivity such as sea water.

In this paper, we present a generalization of the FB method which allows us to study the scattering from composite surfaces that can include one or more large arbitrarily shaped obstacle on the ocean surface. The new approach, called the generalized forward backward (GFB) method, is based on a combination of the conventional. FB method with the MoM where the MoM is only applied to the region close to the obstacle.

The GFB could be combined with modern integral equation acceleration algorithms such as could reduce the fast multipole method (Burkholder and Kwon, 1996) or the novel spectral acceleration method, which could reduce the computational cost of O(N)

GENERALIZED FORWARD BACKWARD METHOD:

Let us consider now the composite problem depicted in the Fig. 1, where one or more PEC obstacles (like a ship or large rogue breaking wave) are included in the surface contour S. For this kind of problem the conventional FB method does not exhibit convergent behavior, because the presence of the obstacle highly disturbs the propagation process assumed by the conventional FB method. There are strong interactions between the obstacle and the nearby ocean like surface, and within the obstacle itself, all of which may not be taken into account with the conventional formulation involved in the standard FB method.

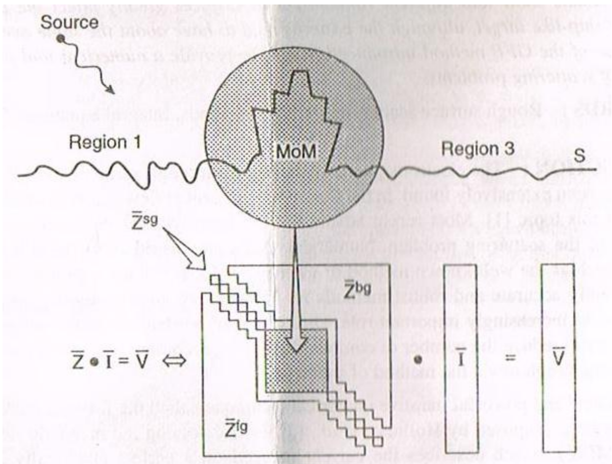

Fig. 1.

The GFB method consists of a generalization of the conventional FB approach which enhances the scope of application of the previous method to composite scattering problems as the one depicted in Fig. 1. The GFB formulation will be presented for a simple problem consisting of a sea surface containing only one obstacle (Fig. 1) The current is expressed as the sum of forward and backward contributions.

$$I = I^{f} + I^{b} \qquad \ldots(1)$$

but now the impedance matrix is split in a different way

$$Z = Z^{fg} + Z^{sg} + Z^{bg} \qquad \ldots(2)$$

Where the Z^{sg} matrix is the diagonal part of Z with an additional block including the impendence submatrix corresponding to the ship and nearby sea region; while Z^{fg} and Z^{bg} are, respectively, the lower triangular part and the upper triangular part of Z but excluding the matrix Z^{sg}, as illustrated. With this decomposition, matrix Z^{sg} contains both the self (diagonal) terms and the interaction of the whole obstacle and nearby sea region together. Then, the original system is transferred in a similar way as in the conventional FB method, yielding the following matrix equation :

$$Z^{sg},\ I^{f} = V - Z^{fg}, (\,I^{f} + I^{b}\,) \qquad \ldots(3)$$

$$Z^{sg},\ I^{b} = - Z^{bg}, (\,I^{f} + I^{b}\,) \qquad \ldots(4)$$

Which can be iteratively solved for I, and I, as

$$(Z^{sg}, + Z^{fg})\ .\ I^{f},^{(i)} = V - Z^{fg}\ .\ I^{b}\ .^{(i-1)} \qquad \ldots(5)$$

$$(Z^{sg}, + Z^{bg})\ .\ I^{b},^{(i)} = - Z^{bg}\ .\ I^{f}\ .^{(i)} \qquad \ldots(6)$$

starting with

$$I^{b},^{(0)} = 0 \text{ in } (5).$$

The solution of differs from other solutions because neither Z^{sg}, + Z^{sg} nor Z^{sg}, + Z^{sg} are triangular matrices. Nevertheless, the equation can also easily solved by combining forward or backward substitution together with the direct factorization of the square block of Z^{sg} whose dimension depends only on number of current elements in Regions 2, namely the slip and nearby sea.

MATHEMATICAL SOLUTION :

A description of the procedure used to solve is presented. It must be pointed out that neither Z + Z are triangular matrices, nevertheless, these equations can be easily solved by combining forward or backward substitution together with the direct factorization of a square block submatrix whose dimension is just the extent of the MoM region. We explain only the resolution of which concerns the matrix Z^{sg} + Z^{fg}. Equation can be solved in a similar manner.

Equation (5) has the general form

$$A\ .\ x = b \qquad \ldots(7)$$

where A = $Z^{sg} + Z^{fg}$. x = $I^{f,(i)}$ and b = V – Z^{fg} . $I^{b},^{(i-1)}$. A is a "quasi" lower triangular matrix. In order to solve these equation is an efficient way, the matrices A, x, and b of (7) are subdivided into blocks. Thus (7) can expressed in terms of the blocks as follows :-

$$A^{s}_{11} + A^{f}_{11})\ .\ x_1 = b_1 \qquad \ldots(8)$$

$$A_{21}\ .\ x_1 + A_{22}\ .\ x_2 = b_2 \qquad \ldots(9)$$

$$A_{31},\ x_1 + A_{32}\ .\ x_2 + (A^{s}_{33} + A_{33}f)\ .\ x_3 = b_3 \qquad \ldots(10)$$

The solution is then obtained as follows :

(1) Eq. (8) is a lower triangular matrix, so x1 can be easily obtained by forward substitution.

(2) Once x_1 has been calculated, x_2 can be obtained from (9) by the direct solution of

$$A_{22}\ .\ x_2 = (b_2 - A_{21}\ .\ x_1) \qquad \ldots(11)$$

LU decomposition may be used so that A_{22} needs to be factorized only once for a given Region 2 geometry. The factorized matrix may then be saved for subsequent iterations and for other excitations.

3) Finally, once x_1 and x_2 have been calculated, x3 can be obtained from (10) again by forward substitution from

$$(A^s_{33} + A^f_{33}) . x_3 = b_3 - A_{31} . x_1 - A_{32} . x_2. \qquad ...(12)$$

because

$$A^s_{33} + A^f_{33}$$

is a lower triangular matrix.

CONCLUSION :

In this paper, we have presented a new computational algorithm, the GFB method, that enhances the scope of application of the conventional FB method to composite 2-D scattering problems consisting of a randomly varying smooth ocean-like surface with abrupt target obstacles present like ships, rogue waves, etc. the new approach has been shown to provide very accurate results and maintains the same fast convergence and $O(N^2)$ computational cost associated with the conventional FB solution. The numerical results show that different random ocean surfaces greatly affect the backscatter patterns of a ship-like target although the patterns tend to have about the same average level. The purpose of the GFB method introduced here is to provide a numerical tool for studying this class of scattering problems.

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