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Development of a numerical open-source package for marine hydrodynamics: FinGreen3D

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Abstract: *Offshore/marine renewable energy is witnessing a rapid development nowadays around the world. This calls for a powerful numerical tool, ideally open-source packaged, to accelerate relevant research. The present paper introduces a numerical open-source package that has been recently developed in Research Institute for Applied Mechanics, Kyushu University. The software package aims to compute Green's function of finite water depth encountered in wave-structure interaction. As an essential part of the potential flow theory, computation of free-surface Green's function becomes extremely troublesome and demanding. In the present package, a brand new algorithm is developed basing on a sophisticated region-decomposition strategy. Benchmarks are used for validation of the package, proving the balance of efficiency and accuracy. Furthermore, to show its application, a real-scale floating offshore wind turbine platform is computed as well for its behavior in real sea conditions.*

Keywords: renewable energy; hydrodynamics; potential flow theory; offshore engineering; wind turbine

1. INTRODUCTION

Offshore renewable energy is becoming a promising substitute for the traditional energies recently, which may involve offshore wind, wave, and etc. One of key considerations in the design of offshore renewable energy devices is how to calculate wave loads and motions of the large dimensional structures efficiently. The boundary integral equation method [1, 2] is still the first choice as the unknowns are required merely on the specified boundaries such that the computational burden can be reduced significantly. The boundary integral equation is generally derived via Green's theorem, which could be solved numerically by discretizing the boundaries into a large number of elements. In the formulation of corresponding matrices, Green's function and its derivatives must be evaluated successively and efficiently for each combination of source and field points. The number of evaluations of 'core' function or Green's function increase quadratically with the number of panels/nodes on boundaries, especially for structures with complex geometries. In this context, accuracy and efficiency of computing Green's function is critical to the performance of numerical solver for wave-structure interactions.

2. PACKAGE STRUCTURE

Recently, we developed an algorithm [3, 4] which is based on a satisfactory region-decomposition strategy. The new algorithm has been fully written in Fortran 90 and forms into a software package FinGreen3D. We decided to release this package publicly, in order to meet the daily increasing demands in both academic research and industrial applications.

The package includes a set of subroutines which can be categorized into three levels, i.e., Level_1 (top level), Level_2 (intermediate level) and Level_3 (low level), as shown in Fig. 1.

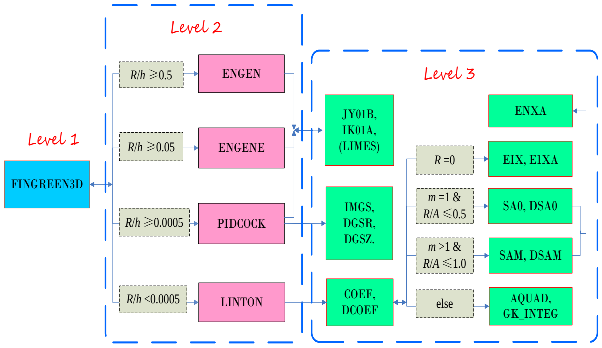


Fig. 1. Multi-level subroutines in the hierarchical code structure.

Major subroutines are listed below:

· FINGREEN3D – A driver subroutine (Level_1), which decomposes the entire parametric domain into four regions and calls the various algorithms accordingly.

· DISPERSION – An intermediate level subroutine (Level_2), which solves the water-wave dispersion equation, using a higher-order iterative procedure based on the method suggested by Newman [5].

· EIGEN – An intermediate level subroutine (Level_2), which calculates Green's function by applying the eigenfunction expansion method in the region $R/h \geqslant 0.5$.

· EIGENE – An intermediate level subroutine (Level_2), which calculates Green's function by applying a combination of the eigenfunction expansion method and the epsilon algorithm in the region $0.05 \leqslant R/h < 0.5$.

· PIDCOCK – An intermediate level subroutine (Level_2), which calculates Green's function applying a combination of Pidcock's expansion method [6] and the epsilon algorithm in the region $0.0005 \leqslant R/h < 0.05$.

· LINTON – An intermediate level subroutine (Level_2), which calculates Green's function by applying Linton's expansion method [7] in the region $R/h < 0.0005$.

· COEF – A lower level subroutine (Level_3), which calculates the expansion coefficients in Linton's expansion method using a combination of special functions, Taylor expansions, and adaptive quadrature methods.

· DCOEF – A lower level subroutine (Level_3), which calculates the derivatives of expansion coefficients with respect to R in Linton's expansion method using a combination of special functions, Taylor expansions, and adaptive quadrature methods.

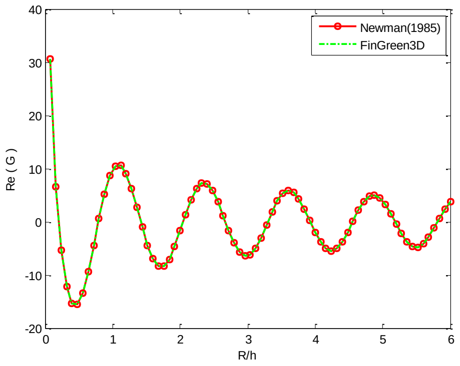
The driver subroutine, FINGREEN3D, is the only Level_1 subroutine, from which all the Level_2 subroutines are called. Level_2 subroutines correspond to the four expansion methods in the corresponding regions, respectively. Level_3 subroutines consist of affiliated subroutines and external subroutines. The affiliated subroutines are called by two Level_2 subroutines, i.e., PIDCOCK and LINTON, used for integrations by the Chebyshev approximation, series expansions or adaptive quadrature algorithms [8]. The majority of external subroutines are from the book of Zhang & Jin [9], used for calculating some special functions, such as exponential integral function, error function, Gamma function, and many kinds of Bessel functions, based on continued fractions. Since so frequently called, the external subroutines of Bessel functions are hereby modified into several derivative versions, in order to make the computation speed accelerated. Another external subroutine is from Mishonov & Penev [10], used for predicting the limit of a series in which first several terms are known through the epsilon algorithm.

3. VALIDATION OF THE PACKAGE

To verify implementations of the released package, a comparison is made with the standard Newman's method [11] using multi-dimensional polynomial approximations.

Comparison results are shown in Fig. 2, for a high pulsating frequency. Both the pulsating point source and the fluid field point are seclected on the free surface in present tests as the free-surface Green function is believed to be more difficult to evaluate when $z+\zeta=0$. As clearly shown in Fig. 2, even under such extremely troublesome conditions, perfect agreements can still be achieved between present results and those using Newman's method.

(a)



(b)

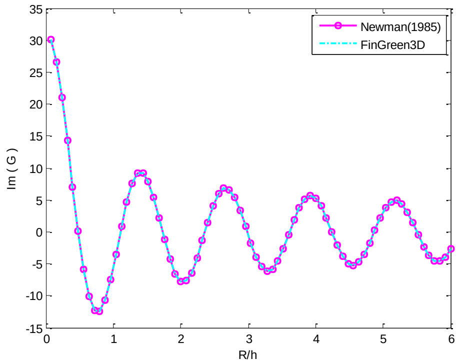


Fig. 2. Values of free-surface Green's function G, as a function of R/h, when the point source and the field point locate at the free surface with a pulsating frequency of $f=1.1145\text{s}^{-1}$: (a) real part of G; (b) imaginary part of G.

Fig. 3 shows variation of the wave term Gw in a wide domain near the point source which is locating on the free-surface, as a function of the distance between field and source point. The horizontal component R and the vertical component z of the distance are both normalized by the water depth h. From either oblique view or contour plot of the function value or derivative values, the fluctuations appear to steepest at the neighborhood of the source point. The fluctuation magnitude decays along both directions, with either increase of the horizontal distance R/h or the vertical distance z/h.

(a)

(b)

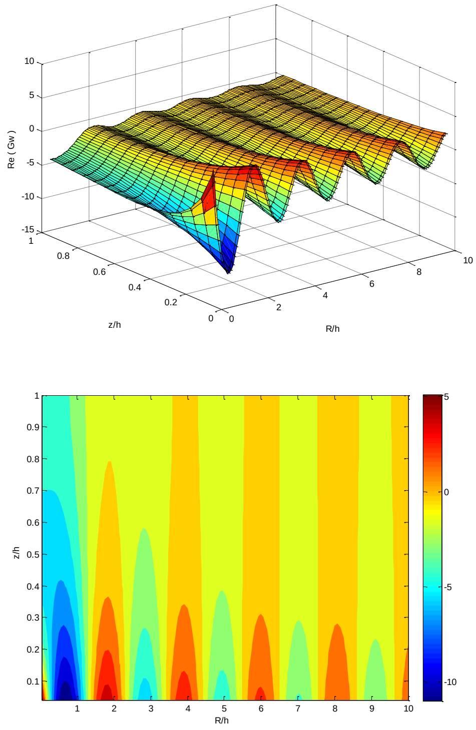


Fig. 3. Real part of the complex harmonic wave term Gw in free-surface Green's function, when a point source locates at the free surface with a pulsating frequency of $f=8.6327\times10^{-1}\text{s}^{-1}$: (a) oblique view, and (b) contour plot.

To analyze how much degree of computation efficiency the package can achieve, the CPU time (unit: μs) of per evaluation of the Green function and its derivatives using FinGreen3D is shown in Fig. 3. The computation is performed on a SONY laptop which has an Intel(R)

Core(TM) i7-2670QM CPU of 2.2 GHz and a 64-bit Windows 7 operating system sequentially on one single thread. The computation costs a total CPU time of 5.9746×10^2s for the 200 input point distances (i.e., 0.2 billion evaluations of the code FinGreen3D have been performed). From Fig. 3, we can easily know that one implementation of the code consumes approximately 2~4 µs.

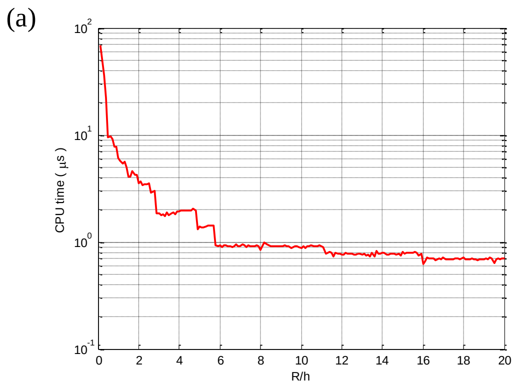


Fig. 4. Computation time for per implementation of FinGreen3D, as a function of normalised point distance *R*/*h* (right). The figure is obtained based on averaged CPU time of 1 million evaluations of FinGreen3D for each input point distance *R*/*h*.

4. APPLICATION IN OFFSHORE RENEWABLE ENERGY

FinGreen3D is dedicated to the continous development of innovative design of offshore renewable devices. Hereby we show a typical example platform which is specifically designed for supporting three wind turbines in Kyushu University at the second development stage. The side length is 120 m, and the submerged volume is 4860 m^3. The wind turbines are designed to operate in water depth of 50 m. In our numerical computation, the hull surface is meshed by 5736 constant panels in the panel solver.

Fig. 5 shows contour plots of the scattered free surface elevation in the vicinity of the platform with different incident wave angles and wave frequencies. It can be obseарved that in the case of large wavelength, the incident wave can almost easily pass through the floating ‘obstacle’. While the wavelength is much more comparable to the physical dimension of the platform, the diffraction becomes more apparent. The free surface elevation varies sharply along the incident wave direction, until the uppermost column in this direction. As the waves go far away from the structure, the amplitude of elevation decreases, which agrees with our knowledge in common practice.

5. CONCLUSION

We present a well-structured software package for evaluation of free-surface Green function in finite depth which is widely considered as the essential part but changlenging to deal with in the analysis of wave-structure interactions. The package structure and its interface have been clearly illustrated so as to make it well understandable by the readers/users. The accuracy and efficiency of present package have been confirmed by extensive validations. This package - FinGreen3D is distributed publicly and can freely be downloaded from CPC Program Library, Queen’s University, Belfast, N. Ireland. It is hoped that the publication of present package would promote the relevant researches in the fields of offshore/marine renewable energy and ocean engineering.

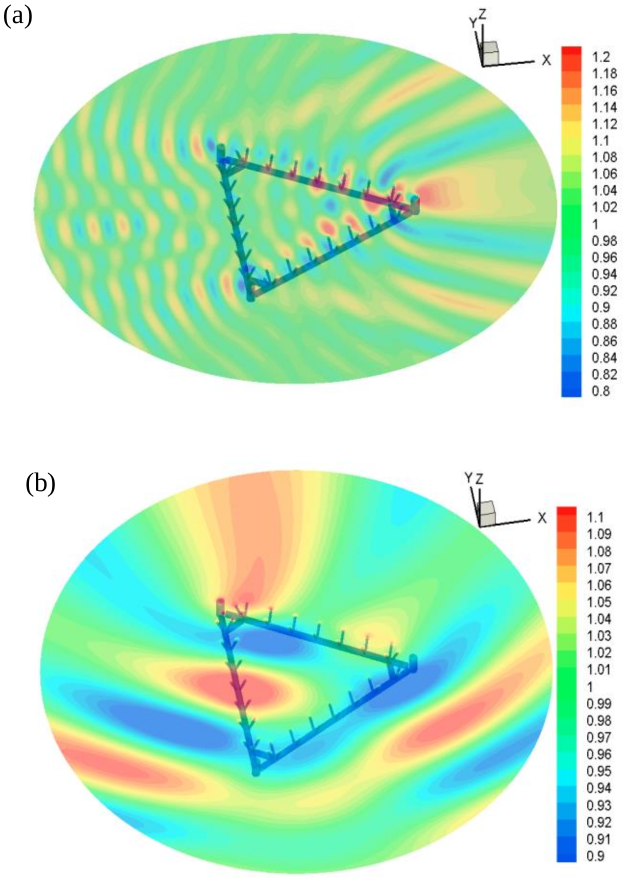


Fig. 5 Contour plot of free surface elevation (normalized by the incident wave amplitude) in the following conditions: (a) α=0°, kL=20.78; (b) α=90°, kL=5.16. The upper column shows the free-surface elevation for a high frequency incident wave, while the bottom column shows the free-surface elevation for a low frequency incident wave.

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