CGHYDRO (a boundary element program for the computation of hydrodynamic forces on long floating structures)

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CGHYDRO is a computer program, based on boundary element methods, for the computation of the hydrodynamic forces (added mass, added damping, and exciting wave force), on long floating structures. The 3-dimensional effects are taken into account in the computation. The program can be used for any kind of cross section shape and sea bottom configuration. The boundary element solution produces a small and efficient computer code.

INTRODUCTION

The hydrodynamic forces are a basic factor in modelling the response of floating structures. These forces are: hydrodynamic or added mass, hydrodynamic or added damping, and wave exciting force. Their computation is based on wave diffraction theory.[1,2] For long structures the 3-dimensional sea state is taken into account, and this accounts for the effect of the structure motion on added mass and damping and for the effect of the wave direction on the exciting forces.[3]

The hydrodynamic forces are frequency dependent. For practical applications their evaluation over a wide frequency range is necessary, thus inexpensive solutions are needed. For their computation, finite and boundary element methods can be used. The region under modelling can be considerably large compared to the dimensions of the cross section. The depth and the wave length affect the vertical and horizontal extension of the mesh.

For a finite element solution, the mesh can be very large, and must be readjusted for each wave length in order to maintain the same order of accuracy. Also the mesh has to be extended for a number of wave lengths in the horizontal direction in order to apply accurately the radiation conditions. In a boundary element solution the number of elements is not necessarily large since only the boundary is modelled. The element length of the boundary surface can easily be readjusted for each wave length, and the radiation conditions can be easily treated. Boundary elements result in more elegant and economical solutions.

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PROBLEM DEFINITION – THEORETICAL TREATMENT

The hydrodynamic forces on the structure are the added mass, added damping, and the exciting wave force (Fig. 1). Due to the large dimensions of the structure, compared with the wave length, their derivation is based on the wave diffraction theory.[1-3] The waves are assumed to be of small amplitude and the flow incompressible and irrotational, and linear wave theory is used. The basic governing Laplace's equation and the boundary conditions (free surface, sea bottom and radiation), for the 3-dimensional problem are shown in Fig. 1. The wave velocity potential is considered consisting of five parts, incident waves, potential due to heave, sway and roll motion of the structure and scattered wave potential due to an immovable structure.[1,4] The problem is reduced (Fig. 1) using Fourier techniques into the superposition of 2-dimensional solutions governed by the 2-dimensional Helmholtz equation.[4]

The Hankel's function has been used as a source function to transform the problem into an integral equation problem[4] (Fig. 2). This choice of Green's function satisfies only the field equations. The boundary conditions are introduced with extra boundary integrals. By discretising the boundary into boundary elements,[5] the integral equations are transformed into a set of linear equations (Fig. 2). The solution of these equations gives the unknown potential values along the boundary elements.

The hydrodynamic forces on the structure are obtained by integrating the wave pressure over the underwater structural surface (Fig. 3). The nondimensionalisation of Fig. 4 has been chosen as more appropriate for the final hydrodynamic coefficients.

PROGRAM CAPABILITIES INPUT-OUTPUT

The program computes the hydrodynamic coefficients for any kind of cross section and boundary conditions. Figure 5 shows the two typical cases, when the bottom conditions are taken into account and when the deep water conditions are used. In the case of deep water conditions, the user has to specify only the boundary elements for the cross section and the number of elements for the other regions. For each wave frequency, in order to maintain constant accuracy,[4] the program readjusts the boundary at infinity at a relative distance to the structure specified by the user with the ratio s/(wave-length) (Fig. 5). Automatic

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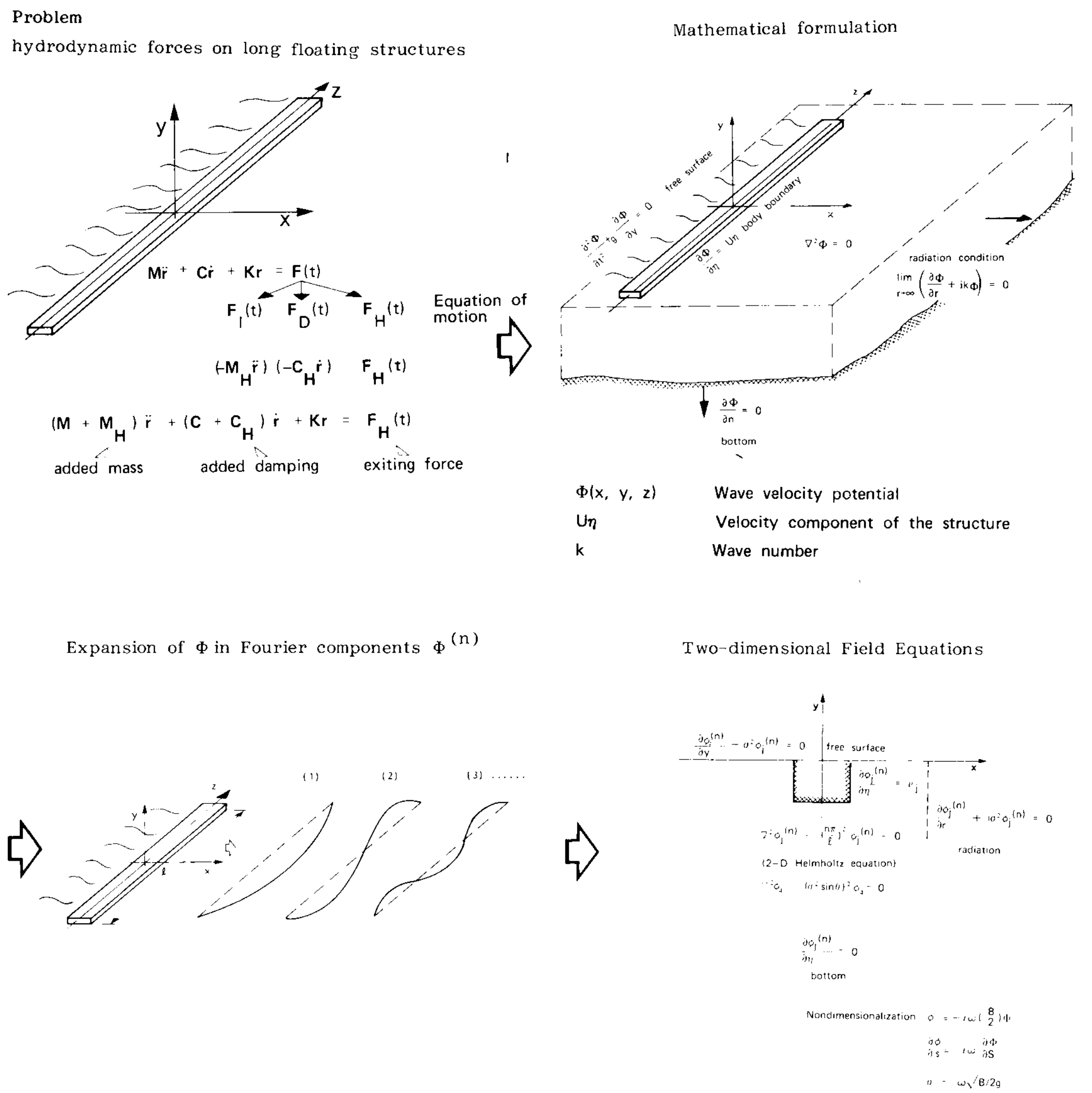

Figure 1. Problem formulation

mesh generation for the cases of rectangular cross section is possible. The amount of input data is very small and can be prepared in about 5 to 10 min.

The output includes:

(1) Printout with all the information about the geometry of the region and the element dimensions.
(2) Tables with the coefficients a_{ij}, b_{ij} and f_i of Fig. 3 for each wave frequency.
(3) Tables with the normalised hydrodynamic coefficients β_i, ξ_i and δ_i of Fig. 4 for each wave frequency.
(4) Plot of the region and the subdivision in boundary elements.
(5) Plots on the hydrodynamic coefficients versus wave frequency.

In the case of the hydrodynamic force coefficients, the tables and graphs include all the specified wave directions.

SOFTWARE

The program is written in FORTRAN-IV. It is a dynamic code allocating storage in the blank COMMON as it is required during the execution. It uses the minimum necessary memory size. The reading and writing operations from low-speed storage have been reduced to a minimum possible. The maximum possible amount of data is kept in core. A memory size of $4(n+2)n$ words, where n is the number of boundary elements, is enough for the program blank COMMON needs. For commonly encountered cases, 60-80 boundary elements is sufficient for good results. This corresponds to a blank COMMON of 15000 to 27000 words. The program execution time depends on the number of boundary elements, the required output values and plots, and the number of wave frequencies. Typical execution time in a CDC 6600 for a common case is around 1 CPU second per wave frequency.

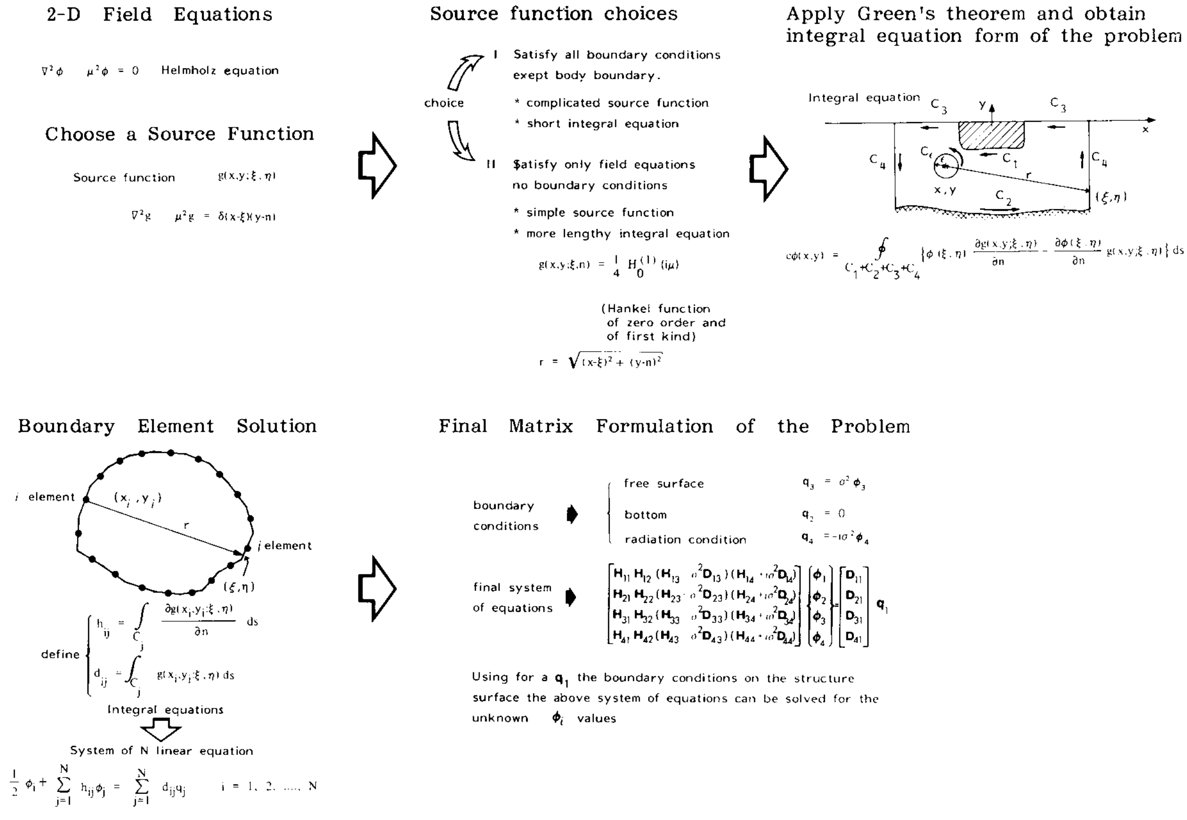

Figure 2. Boundary element solution

Hydrodynamic forces

Hydrodynamic pressure on the structure: $p(X,Y,Z,t) = -\rho_\omega \dfrac{\partial\Phi(X,Y,Z,t)}{\partial t}$

Hydrodynamic forces: $F_i = \int_C p(X,Y,Z,t)\nu_i \, ds$

Introducing: $a_{ij} - ib_{ij} = \int_C \nu_i \phi_j (x,y)\, ds$

Obtain:

Hydrodynamic mass: $[m_H] = \rho_\omega \left(\frac{B}{2}\right)^2 \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$

Hydrodynamic damping: $[c_H] = \rho_\omega \left(\frac{B}{2}\right)^2 \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix}$

Hydrodynamic exciting force: amplitude: $\{f\} = \begin{Bmatrix} f_1 \\ f_2 \\ f_3 \end{Bmatrix}$, phase angle: $\{\bar{f}\} = \begin{Bmatrix} \bar{f}_1 \\ \bar{f}_2 \\ \bar{f}_3 \end{Bmatrix}$

where $f_i = \gamma_\omega \sigma^2 \left(\frac{B}{2}\right)^2 \left(\frac{H}{2}\right) \sqrt{(a_{i0} + a_{i4})^2 + (b_{i0} + b_{i4})^2}$

and $\bar{f}_i = \arctan\left(\dfrac{b_{i0} + b_{i4}}{a_{i0} + a_{i4}}\right) \quad i = 1, 2, 3$

Figure 3. Hydrodynamic forces computation

Nondimensionalization

The coefficients presented below are more important for practical use.

Added mass:
- Sway $\beta_2 = \dfrac{\rho_\omega \left(\frac{B}{2}\right)^2 a_{11}}{\rho_\omega A} = \dfrac{\left(\frac{B}{2}\right)^2 a_{11}}{A}$
- Heave $\beta_1 = \dfrac{\rho_\omega \left(\frac{B}{2}\right)^2 a_{22}}{\rho_\omega A} = \dfrac{\left(\frac{B}{2}\right)^2 a_{22}}{A}$
- Roll $\beta_3 = \dfrac{c^2 \rho_\omega \left(\frac{B}{2}\right)^2 a_{11} + \rho_\omega \left(\frac{B}{2}\right)^4 a_{22}}{\rho_\omega I_0} = \dfrac{c^2 \left(\frac{B}{2}\right)^2 a_{11} + \left(\frac{B}{2}\right)^4 a_{33}}{I_0}$

Added percent of critical damping:
- Sway $\zeta_1 = \dfrac{\rho_\omega \left(\frac{B}{2}\right)^2 b_{11}}{2\rho_\omega(1+\beta_1)A} = \dfrac{\left(\frac{B}{2}\right)^2 b_{11}}{2(1+\beta_1)A}$
- Heave $\zeta_2 = \dfrac{\rho_\omega \left(\frac{B}{2}\right)^2 b_{22}}{2\rho_\omega(1+\beta_2)A} = \dfrac{\left(\frac{B}{2}\right)^2 b_{22}}{2(1+\beta_2)A}$
- Roll $\zeta_3 = \dfrac{c^2 \left(\frac{B}{2}\right)^2 b_{11} + \left(\frac{B}{2}\right)^4 b_{33}}{2(1+\beta_3)I}$

Hydrodynamic Exiting force per unit length for unit wave amplitude:
- Sway $\delta_1 = \sigma^2 \sqrt{(a_{10} + a_{14})^2 + (b_{10} + b_{14})^2}$
- Heave $\delta_2 = \sigma^2 \sqrt{(a_{20} + a_{24})^2 + (b_{20} + b_{24})^2}$
- Roll $\delta_3 = \sigma^2 \sqrt{(a_{30} + a_{34})^2 + (b_{30} + b_{34})^2} + \dfrac{c}{\left(\frac{B}{2}\right)} \delta_1$

where:
- A : underwater cross section area
- γ_ω : water specific weight
- g : acceleration of gravity
- B : cross section width
- I_0 : cross section polar moment of inertia
- c : distance from surface to cross section cendroid (positive upwards)
- σ : normalized frequency $\sigma = \omega\sqrt{B/2g}$

Figure 4. Non-dimensionalisation

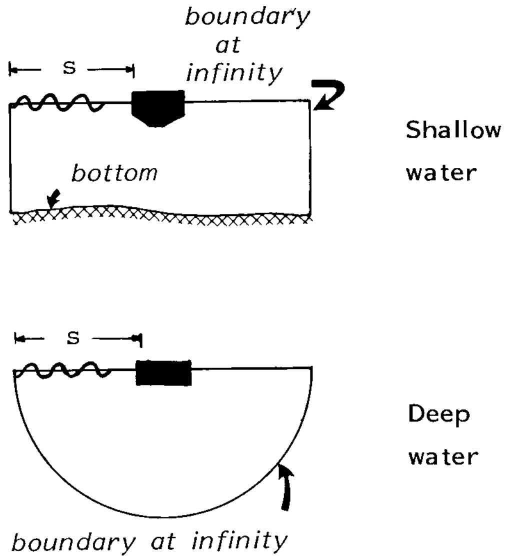

Figure 5. Fluid region considered in the solution

The output of the program is in the form of tables and graphs. For the graphical output a CALCOMP package of plotting routines is required. A version of the program using only standard WRITE FORTRAN statements, also exists with digital plots for regular printers or CRT's. A version of the program for microcomputers is under development.

GENERAL REMARKS

The program is well documented, yet the user manual is very short since the amount of input data is small. References 4, 6 and 7 explain in detail the theoretical aspects of the computational methods and contain a number of examples so the user can become accustomed to the correct use of the results and the nondimensionalisation procedure.

The accuracy of the method is discussed in refs 4 and 6. Results have been compared with values of hydrodynamic forces presented in refs 8 and 9 for the 2-dimensional case. The discrepancies between the results were less than 1% even for a small number of boundary elements.

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