Chapter 11

VERSION 6S (Second-order module)

This chapter is not completed and will be updated with the release of V6.3S.

WAMIT Version 6.3S designates a program which extends the capabilities of WAMIT Version 6.3 to include the complete analysis of second-order hydrodynamic quantities, as in the previous version of the second-order module, V5.3S. V6.3S has all of the capabilities of V6.3, as described in Chapters 1-10. The extended capabilities of V6.3S include the sum- and difference-frequency components of the second-order forces and moments (Quadratic Transfer Functions, or QTF), the second-order hydrodynamic pressure on the body and in the fluid domain, the second-order wave elevation and the second-order Response Amplitude Operator (RAO), all in the presence of bichromatic and bidirectional waves and one or more structures. The structures can be either freely floating, constrained or fixed.

The list of major updates from V5.3S and V6.1S is as follows.

1. The higher-order method is implemented and the second-order solution can now be evaluated either by the low-order method or higher-order method. All of the geometric input formats described in Chapters 5 and 6 can be used for the second-order solution. When the higher-order method is specified (ILOWHI=1), the second-order solution is represented by B-splines in the same manner as for the linear solution. But the forcing on the body and the free surface are integrated in a piecewise manner as in the low-order method. Using this hybrid approach, the continuous second-order solution is obtained with efficient evaluation of the integral of the forcing.

2. An option for automatic free-surface discretization is implemented. The discretization is made in an optimum manner based on the geometric data in GDF files. This simplifies the use of the second-order extension, particularly for the analysis of multi-body interactions.

3. V6.3S is written in Fortran 90/95. The parameter statements in the earlier versions are removed and arrays are allocated dynamically at runtime.

4. The second-order hydrodynamic pressure can be output at user-specified points in the same manner as the linear pressure.

5. The second-order quadratic pressure force acting along the waterline is output along with the body pressure. This output may be useful when the pressure force is integrated

locally to evaluate the cross-sectional force/moment of structures. The geometric data of the waterline segments are output in the PNL file.

The second-order output may not be available in some situations. They include i) the generalized mode (NEWMDS) option is not allowed, ii) fixed/free modes option is not allowed, iii) walls are not allowed and iv) the zero-thickness structure is not allowed. When the second-order RAO of constrained structures are evaluated, the external constraints may not be accounted fully. More specifically, the quadratic interaction between the external constraints and the linear body motion can not be included as an input to the program.

This Chapter describes the special features in input and output of V6.3S which differ from those of V6.3. It is recommended to review the previous chapters, if users are not familiar with V6.3. In the following, the preparation of input files is explained followed by the description of the output from V6.3S. The description of the theoretical background of the second-order analysis can be found in References [9], [17], [26] and other documents cited therein.

All input files prepared for V6.3 are required in order to run V6.3S. These files are CFG, GDF, POT, FRC, optional FNAMES.WAM and, when ILOWHI=1, optional SPL. The input files to V6.3 can be used without modifications, when only the linear output and mean drift force are required.

To evaluate the second-order output, new parameters must be added to the CFG (or CONFIG.WAM) and FRC files. In addition, one or two new input files must be prepared as instructed below. The extensions of new files are .PT2 (Potential Control file 2) and .FDF (Free surface Data File). The filenames of PT2 and FDF can be specified in the optional FNAMES.WAM in order to avoid interactive input during batch runs.

11.1 THE CONFIGURATION FILE (CFG)

The parameter **I2ND** must be specified to evaluate the second-order output.

I2ND=0: Do not compute the second-order solution (0 is the default value).

I2ND=1: Compute the second-order solution for the sum- and difference-frequencies listed in the PT2 file.

When I2ND=1, the dimension of the **NOOUT** array parameter in the CFG file must be increased from 9 to 16. The last 7 options correspond to second-order output as described in the next section. For example, by setting

NOOUT=1 1 1 1 0 1 1 1 1 1 1 1 0 1 1 1

all linear and second-order outputs would be printed in the OUT file except the linear and the second-order pressure on the body surface (IOPTN(5) and IOPTN(13)).

When ILOWHI=0 and I2ND=1, the source formulation must be activated by setting ISOR=1. Execution of the program will be aborted with an appropriate error message, if ISOR=0.

11.2 THE FORCE CONTROL FILE (FRC)

If I2ND=1 in the CFG file, the dimension of the IOPTN array in FRC must be increased from 9 to 16. The last seven elements control the second-order output. (If I2ND=0, only the first 9 elements would be read in the program. The trailing IOPTNs must be on the same line with IOPTN(9). Otherwise the first IOPTN on the next line would be read in by the program as VCG.) As an example, the Alternative Form 1 of Force Control File is shown below.

```
header
IOPTN(1)...IOPTN(9)IOPTN(10)IOPTN(11)IOPTN(12)...IOPTN(16)
VCG
XPRDCT(1,1) XPRDCT(1,2) XPRDCT(1,3)
XPRDCT(2,1) XPRDCT(2,2) XPRDCT(2,3)
XPRDCT(3,1) XPRDCT(3,2) XPRDCT(3,3)
NBETAH
BETAH(1) BETAH(2) ...  BETAH(NBETAH)
NFIELD
XFIELD(1,1) XFIELD(2,1) XFIELD(3,1)
.
.
XFIELD(1,NFIELD) XFIELD(2,NFIELD) XFIELD(3,NFIELD)
```

The definitions of IOPTN(I), for I=1,...,9 are the same as those of V6.3 as listed in Section 3.3. The definitions of IOPTN(I), for I=10,...,16, and the associated numeric output filenames are shown below.

IOPTN(I) = 0 : do not output parameters associated with option I=10,...,15.

IOPTN(I) = 1 : do output parameters associated with option I=10,...,15.

IOPTN(16) can take one of three value 0, 1, or 2:

IOPTN(16) = 0 : do not output the second-order RAO.

IOPTN(16) = 1 : do output the second-order RAO computed using the 'indirect' exciting force.

IOPTN(16) = 2 : do output the second-order RAO computed using the 'direct' exciting force.

Option	Description	File name
10	Quadratic second-order forces	*frc*.10s, *frc*.10d
11	Total second-order forces by indirect method	*frc*.11s, *frc*.11d
12	Total second-order forces by direct method	*frc*.12s, *frc*.12d
13	Second-order hydrodynamic pressure on the body	*frc*.13s, *frc*.13d
14	Second-order hydrodynamic pressure in the fluid	*frc*.14s, *frc*.14d
15	Second-order wave elevation	*frc*.15s, *frc*.15d
16	Second-order response amplitude operator	*frc*.16s, *frc*.16d

The last letters, 's' and 'd', of the numeric filenames signify that the files contain the sum-frequency output and difference-frequency output, respectively.

When IOPTN(13)=1, the second-order hydrodynamic pressure on the body surface is output. If the body is surface piercing, the normalized hydrodynamic pressure force per unit length at the midpoint of the waterline segments is output as well.

When IOPTN(14)=1 or IOPTN(15)=1, the number of field points NFIELD and their Cartesian coordinates XFIELD should be specified in the FRC file. The second-order wave elevations are computed only for the points on the free surface. (A point is defined to be on the free surface if the vertical distance from the free surface, nondimensionalized by ULEN, is less than 10^{-6} in absolute value.)

The total second-order forces of the output Options 11 and 12 are the sum of the two force components. One component is the quadratic force of Option 10 and the other is the second-order potential force. The latter obtained by the 'indirect' method is added to the quadratic force in the output Option 11. In the output Option 12, the second-order potential force is obtained by the 'direct' method. The output options Option 11 and 12 are the same physical forces computed by different approaches and they must converge to each other with finer discretization. The description of these two methods can be found in References [9] and [17].

When two linear wave periods are the same, the difference frequency quadratic force of Option 10 is the same as the mean drift force of Option 9 and Option 8. Since the second-order potential force is trivial in this case, the output Options 11 and 12 are also the same as the mean drift force. The second-order RAO of Option 16 is set to zero in this case. Although the output options 11d, 12d and 16d are trivial, they are included in the corresponding numerical output files. (Note that, in earlier versions of the second-order module, the output was omitted from Options 11d, 12d and 16d, when two periods are identical.)

11.3 THE POTENTIAL CONTROL FILE 2 (PT2)

It is not necessary to prepare the PT2 file, when all of the 2nd-order output options, from 10 to 16, are suppressed.

The PT2 file contains two set of parameters. One specifies mode indices for which the second-order output is calculated. The other specifies period/wave heading pairs for which the second-order output is calculated.

The input data in the Potential Control File 2 (PT2) are listed below:

header
IRAD2(1) IDIF2(1)
MODE2(1,1) MODE2(2,1) MODE2(3,1) MODE2(4,1) MODE2(5,1) MODE2(6,1)
IRAD2(2) IDIF2(2)
MODE2(1,2) MODE2(2,2) MODE2(3,2) MODE2(4,2) MODE2(5,2) MODE2(6,2)
.
.
IRAD2(NBODY) IDIF2(NBODY)
MODE2(1,NBODY) MODE2(2,NBODY) MODE2(3,NBODY) ... MODE2(6,NBODY)
IXSUM IXDIF
NSUMP
IPER(1) JPER(1) NBETA2(1)
IBETA(1,1) JBETA(1,1)
.
IBETA(1,NBETA2(1)) JBETA(1,NBETA2(1))
.
.
.
IPER(NSUMP) JPER(NSUMP) NBETA2(NSUMP)
IBETA(NSUMP,1) JBETA(NSUMP,1)
.
IBETA(NSUMP,NBETA2(NSUMP)) JBETA(NSUMP,NBETA2(NSUMP))
NDIFP
IPER(NSUMP+1) JPER(NSUMP+1) NBETA2(NSUMP+1)
IBETA(NSUMP+1,1) JBETA(NSUMP+1,1)
.
IBETA(NSUMP+1,NBETA2(NSUMP+1)) JBETA(NSUMP+1,NBETA2(NSUMP+1))
.
.
.
IPER(NPER2) JPER(NPER2) NBETA2(NPER2)
IBETA(NPER2,1) JBETA(NPER2,1)
.
IBETA(NPER2,NBETA2(NPER2)) JBETA(NPER2,NBETA2(NPER2))

IRAD2(N) is an index for the computation of the radiation solution of the N-th body at the sum- or difference frequency.

IRAD2(N)=-1 Do not compute the second-order radiation solution.

IRAD2(N)= 0 Compute the second-order radiation solution for the modes specified by MODE2.

IRAD2(N)=1: Compute the second-order radiation solution for all modes.

IDIF2(N) is an index for the computation of the second-order diffraction solution at the sum- or difference- frequency.

IDIF2(N)=-1: Do not compute the second-order diffraction solution.

IDIF2(N)=0: Compute the second-order diffraction solution for the modes specified by MODE2.

IDIF2(N)=1: Compute the second-order diffraction solution for all modes.

MODE2(1∼6) represent the modes for which the second-order radiation and diffraction solutions are to be computed.

IXSUM, IXDIF are indices controlling the selection of periods and wave headings to form pairs.

IXSUM=0: Do not compute the sum-frequency second-order solution.

IXSUM=1: Compute the sum-frequency second-order solution only for selected combinations of the wave periods and headings listed below.

IXSUM=2: Compute the sum-frequency second-order solution for all combinations of the wave periods and headings (PER and BETA) listed in the POT file.

IXDIF=0: Do not compute the difference-frequency second-order solution.

IXDIF=1: Compute the difference-frequency second-order solution only for selected combinations of the wave periods and headings listed in the PT2 file.

IXDIF=2: Compute the difference-frequency second-order solution for all combinations of the wave periods and headings (PER and BETA) listed in the POT file.

When IXSUM=1 or IXDIF=1, the number of combinations and indices of selected periods and headings should be specified in the PT2 file through the following parameters:

NSUMP is the total number of combinations of wave periods for the sum-frequency solution.

NDIFP is the total number of combinations of wave periods for the difference-frequency solution.

The dimension NPER2, used in the last arrays in PT2, is the total number of period combinations; NPER2 = NSUMP + NDIFP.

IPER, JPER are indices which identify the 1st-order periods selected from an array PER (1∼ NPER).

NBETA2(I) is the total number of wave-heading pairs for the I-th period combination.

IBETA, JBETA are indices which identify the wave headings selected from an array BETA (1∼NBETA).

11.4 FREE SURFACE DATA FILE (FDF)

It is not necessary to prepare an FDF file if IOPTN(10)=1 but all other second-order output are suppressed.

The FDF file contains all requisite data to perform the integration of the quadratic forcing over the entire free surface exterior to the bodies. The integration is carried out by numerical quadratures over the free surface close to the body. Away from the body, the integration can be performed efficiently using asymptotic approximation of the forcing. For this reason, the free surface is divided into two regions by a 'Partition Circle'. The radius of the partition circle, which will be denoted by R_{part}, should be sufficiently large so that the asymptotic expansion of the forcing is valid outside of this circle.

For better computational efficiency, the region inside R_{part} may be divided into two subregions by an inner circle which is smaller than the partition circle. One subregion is the free surface inside the inner circle and exterior to the bodies. The other is an annular region between the inner and partition circles. The inner region is discretized into quadrilateral panels and the integration is performed piecewise for each panel. The intermediate region may be subdivided into one or more annuli and the integration performed based on the Gauss Chebyshev quadrature in the azimuthal direction and the Gauss Legendre quadrature in the radial direction over each annulus. In the outer region, semi-analytic integration is performed based on the asymptotic approximation of the integrand.

There are two alternative forms for the FDF file. In a simpler form, the free surface panels in the inner region is generated automatically inside the program. In the other form, the user must specify the horizontal coordinates of the panel vertices.

The data in the FDF file should be given relative to the **global** coordinate system.

11.4.1 ALTERNATIVE Form 1 FDF

When this form is used, the discretization of the inner region is carried out automatically inside the program. The data in this form of FDF are

header
PARTR
NPF SCALE
NAL DELR NCIRE NGSP

PARTR is the dimensional radius of the inner circle with the center at the origin of the global coordinate system. PARTR is measured in the same units as the length ULEN.

If PARTR is smaller than 1.25 times the maximum distance from the body surface to the origin of the global coordinate system, the program issues a warning and increases PARTR automatically.

NPF is an integer flag specifying Alternative forms of the FDF file. In Alternative 1 format, NPF must be a **negative** integer.

SCALE is a real number used as a scaling factor of the size of the free surface panels relative to the average length of the waterline panels on the body. For example, if SCALE=1.5, the length scale of free surface panels will be 1.5 times the waterline panels.

The following four input parameters are relevant to the integration on the intermediate region:

NAL is the total number of annuli subdividing the intermediate annular region. When NAL=0, the parameters DELR, NCIRE and NGSP need not be specified.

DELR is the dimensional radial increment of each annulus (in the same units as ULEN).

NCIRE is the integer exponent of 2 such that the total number of nodes is equal to $2^{\text{NCIRE}} + 1$ for the azimuthal integration based on Gauss-Chebyshev quadrature.

NGSP is the number of nodes used for the Gauss-Legendre radial quadrature on each annulus.

The Gauss quadrature over the intermediate region may be more efficient than the integration using quadrilateral panels, especially when the partition circle is large compared to the bodies. However, choosing appropriate values for the parameters NCIRE and NGSP may not be simple. Unlike the piecewise integration using panels, inadequate values of these parameters may produce the result with gross error. It is recommended to check the dependence of the results to these parameters.

11.4.2 ALTERNATIVE Form 2 FDF

The data in this form of FDF should be input in the following form:

```
header
PARTR
NPF NTCL
NAL DELR NCIRE NGSP
VERX(1,1) VERX(2,1) VERX(3,1) VERX(4,1)
VERY(1,1) VERY(2,1) VERY(3,1) VERY(4,1)
.
.
.
VERX(1,NPF) VERX(2,NPF) VERX(3,NPF) VERX(4,NPF)
VERY(1,NPF) VERY(2,NPF) VERY(3,NPF) VERY(4,NPF)
```

PARTR: same as Alternative 1 FDF

NPF is the total number of free surface panels defined by the user.

NTCL is the total number of segments on the inner circle

NAL : same as Alternative 1 FDF

DELR: same as Alternative 1 FDF

NCIRE: same as Alternative 1 FDF

NGSP: same as Alternative 1 FDF

VERX(K,I), K=1−4 is the dimensional x coordinate of the K-th vertex of the I-th panel.

VERY(K,I), K=1−4 is the dimensional y coordinate of the K-th vertex of the I-th panel.

For a single body, one quadrant of, half of, or the entire inner region must be discretized according to the symmetry of the problem. Likewise, the number of segments NTCL should be specified over the range of one quadrant, half, or the entire circle depending on the symmetry.

For multiple bodies, the entire inner region must be discretized with respect to the global coordinate system, regardless of the symmetry of the individual bodies. The inner circle must enclose all of the bodies.

When there are multiple waterlines, the distance between each pair of waterlines must be greater than twice the average length of waterline segments. This may require fine discretization of the body near the free surface when the gap between the waterlines are small. In this case, larger value of SCALE must be used in order to avoid fine discretization inside inner circle.

11.4.3 PARTITION CIRCLE AND INNER CIRCLE

As noted above, the radius of the partition circle, R_{part}=PARTR+NAL×DELR, should be sufficiently large so that the asymptotic expansion of the potentials is valid outside of the circle. An appropriate estimation of the radius of the partition circle, R_{part}, is $R_{part} \sim O(h)$ (h=water depth) for shallow water and $R_{part} \sim O(\lambda)$ (λ= longest wavelength involved) for deep water ($h >> \lambda$). The actual constant of proportionality R_{part}/λ may have to be substantially larger than one to achieve accuracy in deep water (see Reference [9] and [12]).

If NAL>0, the radius of the inner circle PARTR should be determined with care. If PARTR is too close to the body, the integration over the intermediate region may not be efficient as intended. The Gauss quadrature converges slowly for the integration of the influence of Rankine sources on the free surface, at nearby points on the body.

If we denote the maximum distance to the body surface from the center of the circle as R_{body}, the following table shows the required number of nodes in the azimuthal integration as PARTR varies. In the table, NCIR=$2^{\mathrm{NCIRE}} + 1$ is the number of nodes of the Gauss-Chebyshev quadrature between $[0, 2\pi]$. The recommended procedure to determine PARTR is i) first to select the parameter NCIRE which would be dependent on the wavelengths of the linear and second-order waves and ii) select R_{part} from the table.

R_{body}/PARTR	NCIRE	NCIR
0.1	3	9
0.4	4	27
0.5	5	33
0.8	6	65
0.9	7	129
0.95	9	257

When field quantities are evaluated on the free surface, such as the second-order wave elevation, similar consideration applys. Thus PARTR should be sufficiently large so that the maximum radial distance to the field points from the origin is substantially less than PARTR. The above table can be used to estimate PARTR after replacing R_{body} with the maximum radial distance to the field points.

11.4.4 RESTRICTION ON VERY LONG WAVES

When $k_i R$, $k_j R$ or $k_2^{\pm} R$ is less than BOUND in the DATA statement of subroutine FARFS.F and RHSFFS.F, the program will continue to run but neglect the integration over the outer region in the total second-order exciting forces. Here R is the partition radius and k_i, k_j and $k_2^{\pm}$ are wavenumbers associated with the frequencies ω_i, ω_j and $\omega_i \pm \omega_j$. This case may be encountered when a very long wavelength is involved in the difference-frequency solution. If this occurs a warning message will appear in the .OUT file. To avoid this condition the user may either increase the partition radius or increase the spread between first-order wave periods.

In V6.3S, BOUND is set to 10^{-3}. The parameter BOUND should be as small as possible, depending on the range of the double-precision floating-point decimal exponent of the computing system. The source code users can modify this value following the guideline that when the exponent is in the range $\pm$ 64 $\times$ n, the recommended value of BOUND is 10^{-n}.

11.4.5 APPROXIMATION WITHOUT FREE SURFACE FORCING

Users can compute the second-order solution without the evaluation of the free surface integral. In light of the large computational effort for the evaluation of this integral, this option provides an efficient way to compute an approximation to the complete second-order solution. However, since the quality of the approximation depends on the problem, this option must be used with discretion. It is not recommended to use this option for the sum-frequency problem where the free-surface forcing is relative important. (Reference [15] provides an example of computational results showing the relative importance of the free-surface integral for a particular structure.)

To use this option, the parameters NPF, NTCL and NAL in the FDF file should be set equal to zero as follows. (PARTR can be any number.)

header

PARTR
0 0
0

11.4.6 HIGHER-ORDER METHOD (ILOWHI=1)

With the low-order option specified (ILOWHI=0), the body and the free surface are represented by quadrilateral panels. The unknown potential on the body surface is assumed constant over each panel. Similarly the linear or quadratic forcing on the body and/or free surface is assumed constant on each panel and the integration of this forcing is performed in a piecewise manner.

With the higher-order option specified (ILOWHI=1), the potential on the body surface is represented by B-splines in both the linear and second-order analyses. In the linear analysis, the forcing on the body surface is assumed continuous and the integration is carried out by Gauss quadrature. In the second-order analysis, however, the integration of the quadratic forcing on the body and the free surface is performed piecewise in the same manner as for ILOWHI=0.

The body surface is virtually discretized into quadrilateral panels by dividing the space between the knot vectors into smaller line segments. The number of line segments, L, is $L = K + 1$, where K is the order of B-spline. If K is the same for all patches, the virtual panels are the same as the low order geometric data in *gdf*_low.GDF which is output by the program, with the parameter ILOWGDF= $K + 1$. These panels can be visualized using a program such as TECPLOT with the input data *gdf*_pan.DAT, by setting IPLTDAT=K+1 in the CFG file.

11.4.7 VISUALIZING FDF

If Alternative Form 1 of FDF is used, the program identifies the panels (virtual panels when ILOWHI=1) on the waterline. Then the free surface panels are generated in a continuous manner starting from the sides of body panels on the waterline by sharing the same vertices. It is advised to arrange the free surface panels in a similar manner near the waterline, when Alternative 2 format is used.

When the Alternative Form 1 of FDF is used, the program outputs the file *fdf*_new.FDF. This is an Alternative Form 2 format of FDF containing the coordinates of the vertices of the free surface panels generated by the program. For both Alternatives of the FDF file, the program output *fdf*_fdf.dat contains the free surface panels in TECPLOT data format. (*fdf* denotes the original filename of Alternative 1 format FDF).

11.5 FNAMES.WAM

When FNAMES.WAM is used to list the input files, the latter should contain the PT2 and FDF file names as well as CFG, GDF, POT, FRC as in the following example:

FNAMES.WAM:
test.cfg
test.gdf
test.pot
test.frc
test.pt2
test.fdf

If all second-order outputs are suppressed, pt2 and fdf can be omitted. If all second-order outputs are suppressed except Option 10, fdf can be omitted.

11.6 DEFINITIONS OF OUTPUT

The non-dimensional definitions of the second-order output from V6.3S are listed in this Section. Note that the second-order outputs satisfy corresponding symmetry relations. For example, the wave excitation Quadratic Transfer Functions (QTF) at the sum- and difference-frequencies satisfy the relations $F^+_{ij} = F^+_{ji}$, and $F^-_{ij} = {F^-_{ji}}^*$, respectively. Here $*$ denotes the complex conjugate. (In the difference-frequency problem, $\omega_i \geq \omega_j$ is assumed. Otherwise, the indices are interchanged automatically within the program.)

1. The second-order wave forces and moments at sum- and difference-frequencies are defined as

$$\bar{F}^+ = \frac{F^+}{\rho g L A_i A_j} \quad \text{and} \quad \bar{F}^- = \frac{F^-}{\rho g L A_i A_j^*}$$

$$\bar{M}^+ = \frac{M^+}{\rho g L^2 A_i A_j} \quad \text{and} \quad \bar{M}^- = \frac{M^-}{\rho g L^2 A_i A_j^*}$$

where L=ULEN is the characteristic body length, and A, g and ρ represent the complex first-order incident-wave amplitude, gravitational acceleration and fluid density, respectively.

2.1 The second-order hydrodynamic pressure at sum- and difference-frequencies is defined as

$$\bar{p}^+ = \frac{p^+}{\rho g A_i A_j / L} \quad \text{and} \quad \bar{p}^- = \frac{p^-}{\rho g A_i A_j^* / L}$$

2.2 The second-order hydrodynamic force per unit length acting on the waterline at sum- and difference-frequencies is defined as

$$\bar{f}_w^+ = \frac{f_w^+}{\rho g A_i A_j} \qquad \text{and} \qquad \bar{f}_w^- = \frac{f_w^-}{\rho g A_i A_j^*}$$

3. The second-order wave elevation at sum- and difference-frequencies is defined as

$$\bar{\eta}^+ = \frac{\eta^+}{A_i A_j / L} \qquad \text{and} \qquad \bar{\eta}^- = \frac{\eta^-}{A_i A_j^* / L}$$

4. The second-order response amplitude operator at sum- and difference-frequencies is defined as

$$\bar{\xi}_k^+ = \frac{\xi_k^+}{A_i A_j / L^n} \qquad \text{and} \qquad \bar{\xi}_k^- = \frac{\xi_k^-}{A_i A_j^* / L^n}$$

where $n = 1$ for the translational modes $k = 1, 2, 3$ and $n = 2$ for the rotational modes $k = 4, 5, 6$

11.7 NUMERIC OUTPUT FILES

All requested outputs are listed collectively in the .OUT file and in the numeric output files. The data in the numeric output files are listed as follows:

OPTN.10s, OPTN.11s and OPTN.12s:
PER(i) PER(j) BETA(i) BETA(j) I MOD($\bar{F}_{ij}^+$) PHS($\bar{F}_{ij}^+$) Re($\bar{F}_{ij}^+$) Im($\bar{F}_{ij}^+$)

OPTN.10d, OPTN.11d and OPTN.12d:
PER(i) PER(j) BETA(i) BETA(j) I MOD($\bar{F}_{ij}^-$) PHS($\bar{F}_{ij}^-$) Re($\bar{F}_{ij}^-$) Im($\bar{F}_{ij}^-$)

OPTN.13S:
PER(i) PER(j) BETA(i) BETA(j) M K MOD($\bar{p}^+$) PHS($\bar{p}^+$) Re($\bar{p}^+$) Im($\bar{p}^+$)
(PER(i) PER(j) BETA(i) BETA(j) M K MOD($\bar{f}_w^+$) PHS($\bar{f}_w^+$) Re($\bar{f}_w^+$) Im($\bar{f}_w^+$))

OPTN.13D:
PER(i) PER(j) BETA(i) BETA(j) M K MOD($\bar{p}^-$) PHS($\bar{p}^-$) Re($\bar{p}^-$) Im($\bar{p}^-$)
(PER(i) PER(j) BETA(i) BETA(j) M K (MOD($\bar{f}_w^-$) PHS($\bar{f}_w^-$) Re($\bar{f}_w^-$) Im($\bar{f}_w^-$))

OPTN.14S:
PER(i) PER(j) BETA(i) BETA(j) L MOD($\bar{p}^+$) PHS($\bar{p}^+$) Re($\bar{p}^+$) Im($\bar{p}^+$)

OPTN.14D:
PER(i) PER(j) BETA(i) BETA(j) L MOD($\bar{p}^-$) PHS($\bar{p}^-$) Re($\bar{p}^-$) Im($\bar{p}^-$)

OPTN.15S:
PER(i) PER(j) BETA(i) BETA(j) N MOD($\bar{\eta}^+$) PHS($\bar{\eta}^+$) Re($\bar{\eta}^+$) Im($\bar{\eta}^+$)

OPTN.15D:
PER(i) PER(j) BETA(i) BETA(j) M MOD($\bar{\eta}^-$) PHS($\bar{\eta}^-$) Re($\bar{\eta}^-$) Im($\bar{\eta}^-$)

OPTN.16S:
PER(i) PER(j) BETA(i) BETA(j) I MOD($\bar{\xi}^+$) PHS($\bar{\xi}^+$) Re($\bar{\xi}^+$) Im($\bar{\xi}^+$)

OPTN.16D:
PER(i) PER(j) BETA(i) BETA(j) I MOD($\bar{\xi}^-$) PHS($\bar{\xi}^-$) Re($\bar{\xi}^-$) Im($\bar{\xi}^-$)

Here I is mode index, M indicates the quadrant or half when the body has two or one planes of symmetry, K is the index of the panels on the body, L is the index of the field points.

The numeric output files optn.13s and optn.13d contain the second-order hydrodynamic pressure on the body surface. The points where the pressure is calculated are specified in *gdf*.PNL (see Section 4.9 for the contents in PNL file). If Option 5 is specified, the linear pressure is output for the same set of points.

For the surface-piercing bodies, the second-order pressure force acting on the waterline is of interest. This will be referred to as the waterline pressure force and denoted by $f_w^\pm$. When IPNLBPT=0, $f_w^\pm$ is output to optn.13s and optn.13d for the surface-piercing bodies. $f_w^\pm$ is appended after the output of the pressure($p^\pm$) on the body surface.

The PNL file is also extended accordingly and contains the Cartesian coordinates, the length of waterline segments and normal vector corresponding to the points where $f_w^\pm$ is calculated. The new additional parameters in the PNL file are shown below.

gdf.PNL: M K XCT YCT ZCT LENGTH n_x n_y n_z $(\mathbf{r}\times\mathbf{n})_x$ $(\mathbf{r}\times\mathbf{n})_y$ $(\mathbf{r}\times\mathbf{n})_z$
where LENGTH is the length of the waterline segments. The definitions of other parameters are the same as those in Section 4.9.

Only the hydrodynamic pressure is output for Option 13 (also Option 5). It would be straightforward to calculate the static pressure, however, using available output from the program. The second-order quadratic hydrostatic pressure, $\bar{P}_{sq}^\pm$ normalized in a same manner as the hydrodynamic pressure, can be calculated from the following expression.

$$\bar{P}_{sq}^\pm = \frac{1}{4}[(\xi_{4_i}\xi_{6_j}^\pm + \xi_{4_j}^\pm\xi_{6_i})x + (\xi_{5_i}\xi_{6_j}^\pm + \xi_{5_j}^\pm\xi_{6_i})y - (\xi_{4_i}\xi_{4_j}^\pm + \xi_{6_i}\xi_{6_j}^\pm)z]$$

where ξ_k is the linear RAO output in optn.4. The subscripts 4,5,6 correspond to the roll, pitch and yaw modes, respectively. ξ^- denotes the complex conjugate of $\xi = \xi^+$. The subscripts $_i$ and $_j$ denote the indices of the periods of the linear incident-wave pair. The normalized position vector of the points on the body surface (x, y and z) can be obtained from the data in the PNL file. Note that the position vector in PNL must be normalized by ULEN(1) and converted into each body coordinate system before using in the above expression.

The hydrostatic pressure due to the second-order RAO can be calculated from the following expression where $\xi^{\pm}$ is the second-order RAO output optn.16s and optn.16d.

$$\bar{P}_{sp}^{\pm} = \xi_3^{\pm} + \xi_4^{\pm} \times y - \xi_5^{\pm} \times x$$

The linear static pressure can be calculated from the above expression after replacing the second-order RAO with the linear RAO.

The body motion is taken into account in the evaluation of $f_w^{\pm}$ and it includes the effects of both hydrodynamic and static pressure.

11.8 INSTALLATION OF V6.3S-PC Executable

V6.3S-PC Executable can be installed following the same procedure for the installation of V6.3PC Executable as described in Chapter 2. An additional set of standard Test Runs for the second-order analysis is provided in the directory TESTRUNS_2ND.