

# AQWA-LINE MANUAL

## **PREFACE**

The development of the AQWA suite of programs was carried out by Century Dynamics Limited who are continually improving the capabilities of the programs, as more advanced hydrodynamic calculation techniques become available.

Century Dynamics Limited welcome suggestions from users regarding program development.

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## **CHAPTER 1 - INTRODUCTION**

### **1.1 PROGRAM INTRODUCTION**

AQWA-LINE is a computer program which calculates the linear response of a floating body or bodies in regular waves. The program may be used separately or in association with other programs within the AQWA Suite. The principal analysis technique used within AQWA-LINE is Radiation/Diffraction theory. This type of analysis is usually used on bodies whose characteristic dimensions cause scattering of the incident regular waves. The calculation provides the first and second order wave loadings on a floating or fixed body.

### **1.2 MANUAL INTRODUCTION**

The AQWA-LINE Manual describes the various uses of the program, together with the method of operation. The theory and bounds of application are outlined for the analytical procedures employed within the various parts of AQWA-LINE. When using AQWA-LINE, the user must model the body form and specify a wave environment. The method of data preparation and modelling is fully described and reference is made to the AQWA Reference Manual. This Reference Manual contains a complete guide to the format used for input of data into the AQWA Suite. It is recommended that the AQWA-LINE User Manual and AQWA Reference Manual be available when running the program AQWA-LINE.

## **CHAPTER 2 - PROGRAM DESCRIPTION**

### **2.1 PROGRAM CAPABILITY**

AQWA-LINE computes the linearised hydrodynamic fluid wave loading on a floating or fixed rigid body using 3-dimensional radiation/diffraction theory. The fluid forces are composed of reactive forces and active excitation forces. The reactive fluid loading is due to body motions and may be calculated by investigating the radiated wave field arising from body motions. The active or wave excitation loading which induces motion is composed of diffraction forces due to the scattering of the incident wave field and the Froude-Krylov forces due to the pressure field in the undisturbed incident wave.

The incident wave acting on the body is assumed to be harmonic and of small amplitude compared to its length. The fluid is also assumed to be ideal and hence potential flow theory is used. The hydrostatic fluid forces may also be calculated using AQWA-LINE and these, when combined with the hydrodynamic forces and body mass characteristics, may be used to calculate the small amplitude rigid body response about an equilibrium mean position. The solution technique utilises a distribution of fluid singularities over the mean wetted surface of the body. Since the motion is assumed harmonic, the solution is performed in the frequency domain.

The mean second order wave drift forces may be calculated by AQWA-LINE after the first order fluid flow problem has been solved. For the calculation of the mean second order wave drift forces two options can be used: a far-field solution, where only horizontal forces are calculated, and a near-field solution where forces in all six degrees of freedom are calculated.

Finally, AQWA-LINE can evaluate the full QTF (Quadratic Transfer Function) matrix. The QTFs are a convenient way of expressing the second order forces. Using the QTFs the second order wave exciting forces can be expressed in the frequency domain in terms of force spectra or in the time domain as time histories of second order forces.

## **2.2 THE COMPUTER PROGRAM**

The program AQWA-LINE may be used on its own or as an integral part of the AQWA Suite of rigid body response programs. When AQWA-LINE has been run, a HYDRODYNAMIC DATA BASE is automatically created, which contains full details of the fluid loading acting on the body. Another backing file, called the RESTART FILE, is also created and contains all modelling information relating to the body or bodies being analysed. These two files may be used with subsequent AQWA-LINE runs or with other AQWA programs. The concept of using specific backing files for storage of information has two great advantages which are:

- Ease of communication between AQWA programs so that different types of analyses can be done with the same model of the body or bodies, e.g. AQWA-LINE regular wave results may be input to AQWA-FER for irregular spectral wave analysis.
- Efficiency when using any of the AQWA programs. The restart facility allows the user to progress gradually through the solution of the problem, and an error made at one stage of the analysis does not necessarily mean that all the previous work has been wasted.

The programs within the AQWA Suite are as follows:

|              |   |
|--------------|---|
| AQWA-LIBRIUM | Used to find the equilibrium characteristics of a moored or freely floating body or bodies. Steady state environmental loads may also be considered to act on the body (e.g. wind, wave drift and current).   |
| AQWA-LINE    | Used to calculate the wave loading and response of bodies when exposed to a regular harmonic wave environment. The first order wave forces and second order mean wave drift forces are calculated in the frequency domain.                                  |
| AQWA-FER     | Used to analyse the coupled or uncoupled responses of floating bodies while operating in irregular waves. The analysis is performed in the frequency domain.  |
| AQWA-NAUT    | Used to simulate the real-time motion of a floating body or bodies while operating in regular or irregular waves. Wind and current loads may also be considered. If more than one body is being studied, coupling effects between bodies may be considered. |
| AQWA-DRIFT   | Used to simulate the real-time motion of a floating body or bodies while operating in irregular waves. Wave frequency motions and low period oscillatory drift motions may be considered. Wind and current loading may also be applied to the body.         |

## **CHAPTER 3 - THEORETICAL FORMULATION**

The topic headings in this chapter indicate the main analysis procedures used by the AQWA Suite of programs. However, detailed theory is given here only for those procedures used within AQWA-LINE. The theory of procedures used by other programs within the AQWA Suite is described in detail in the appropriate program user manual. References to these user manuals are given in those sections of this chapter where no detailed theory is presented.



### **3.1 HYDROSTATIC LOADING**

#### **3.1.1 Hydrostatic Forces and Moments**

This is the fluid loading acting on a body when placed in still water. The fluid forces acting on the body are calculated by integrating the hydrostatic pressure over the wetted surface of the body, up to the still water level. Hydrostatic moments are taken about the centre of gravity of the body. The expressions for hydrostatic force and moment at any instant in time are as follows:

$$\bar{\mathbf{F}}_{\text{hys}}(t) = - \int_{\mathbf{S}(t)} \mathbf{P} \, \bar{\mathbf{N}} \, d\mathbf{s} \quad (3.1.1)$$

$$\bar{\mathbf{M}}_{\text{hys}}(t) = - \int_{\mathbf{S}(t)} \mathbf{P} \, (\bar{\mathbf{r}} \times \bar{\mathbf{N}}) \, d\mathbf{S} \quad (3.1.2)$$

where

- $\bar{\mathbf{r}}$  = position vector w.r.t. centre of gravity
- $\mathbf{P}$  = hydrostatic pressure (i.e.  $-\rho g z$ )
- $\bar{\mathbf{N}}$  = the outward normal vector of the body surface
- $\mathbf{S}(t)$  = the wetted surface of the body at an instant in time

### **3.1.2 Hydrostatic Equilibrium**

When dealing with problems in the frequency domain, we are concerned with small-amplitude motions about an EQUILIBRIUM floating position. Thus, the wetted surface of the body becomes time-independent and the hydrostatic forces and moments about this mean position of the body must be computed. This is done using the above equations, but in a prescribed position which is time invariant. Obviously, the prescribed position must be one which allows the body to take up an equilibrium position in the still fluid. The equilibrium position will be dependent on the mass and mass distribution of the body combined with the distribution of hydrostatic pressure and external forces. The distribution of hydrostatic pressure may be described in terms of the total upward buoyant force and the position of the centre of buoyancy. For an equilibrium state to exist, the following static conditions must be true:

#### **Rules for Hydrostatic Equilibrium**

- 1     The weight of the body must equal the total upward force produced by buoyancy and external forces. Lateral force components must also have a resultant force equal to zero. Note that, if the only forces acting on the body are gravity and hydrostatic pressure, then the weight of the body must equal the upward buoyant force.
- 2     The moments acting on the body must sum to zero. If moments are taken about the centre of gravity, then the buoyancy moment and that of all external forces must be zero. Note that, if the only forces acting on the body are gravity and hydrostatic pressure, then the centre of gravity and the centre of buoyancy must be in the same vertical line.

When the prescribed body position is one of equilibrium, we may ascertain if it is a stable position, an unstable position or a neutrally stable position. The cut water-plane properties of the body yield this information via the calculation of the body's metacentre. The metacentric point is defined as the intersection of the body's upward buoyant force with the centre-line of the body, after the body has been rotated by a small amount. The metacentric point will normally be different for rotations about X and Y axes. For more details, see Section 3.12.

### 3.1.3 Hydrostatic Stiffness Matrix

For the analysis of rigid body motion about a mean equilibrium position, we require a hydrostatic stiffness matrix for each body. If the matrix is expressed in terms of motions about the centre of gravity, and hydrostatic pressure is considered together with the body's mass distribution, the matrix will take the form:

$$K_{\text{hys}} = \rho * g * \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & K33 & K34 & K35 & 0 \\ 0 & 0 & K43 & K44 & K45 & K46 \\ 0 & 0 & K53 & K54 & K55 & K56 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

where the various terms in the stiffness matrix are:

$$K33 = A$$

$$K34 = K43 = \int_A y dA + y_{\text{wp}} A$$

$$K35 = K53 = -\int_A x dA - x_{\text{wp}} A$$

$$K44 = \int_A y^2 dA + 2y_{\text{wp}} \int_A y dA + y_{\text{wp}}^2 A + z_{\text{gb}} * \text{vol}$$

$$K45 = K54 = -x_{\text{wp}} * y_{\text{wp}} * A - y_{\text{wp}} \int_A x dA - x_{\text{wp}} \int_A y dA - \int_A xy dA$$

$$K46 = -x_{\text{gb}} * \text{vol}$$

$$K55 = \int_A x^2 dA + 2x_{\text{wp}} \int_A x dA + x_{\text{wp}}^2 A + z_{\text{gb}} * \text{vol}$$

$$K56 = -y_{\text{gb}} * \text{vol}$$

The integrals are with respect to the body's cut water-plane and the total area of the cut water-plane is 'A'. The displaced volume of the fluid is given by 'vol'. The following coordinates are also used:

$x_{wp}$ ,  $y_{wp}$  and  $z_{wp}$  give the origin of the water-plane axes w.r.t. the centre of gravity

$x_{gb}$ ,  $y_{gb}$  and  $z_{gb}$  give the centre of buoyancy w.r.t. the centre of gravity

Note: If the body is in a free-floating equilibrium state, with no external forces acting on it, then the terms K46 and K56 will be equal to zero and the stiffness matrix will be symmetric.

### **3.2 MORISON FORCES AND WAVE LOADING**

Morison forces, which are applicable to small non-diffracting structures or parts of structures, are included in AQWA-LINE and therefore AQWA-LINE can handle mixed models (diffracting and non-diffracting elements). The contribution of the Morison elements is written to the hydrodynamic database. The results printed in the .LIS file will include the effects of ALL elements.

Note that Morison drag forces, which are non-linear, are not calculated in AQWA-LINE.

### 3.3 DIFFRACTION/RADIATION WAVE FORCES

#### 3.3.1 Fundamental Calculations assuming zero forward speed

This section deals with the hydrodynamic fluid loading of diffracting bodies in regular harmonic waves. The fluid is assumed to be ideal and irrotational, which allows potential theory to be used. The other major assumption is that the incident wave acting on the body is of small amplitude when compared to its length (i.e. small slope). The theory may be used to calculate the active wave excitation on FIXED bodies and the reactive wave forces on FLOATING bodies.

In hydrodynamic problems which include a fluid free-surface boundary, it is common practice to define a system of axes with the origin in the free surface of the fluid. For the description of rigid body motions, however, it is more convenient to use the centre of gravity of the body as a dynamic reference point. Let us therefore define two sets of axes systems as shown in Figure 3.1.

|   |  |
|---|--|
| Fixed Reference Axes<br>or Global Axes  | X,Y,Z with origin in the free-surface and Z axis pointing vertically upwards |
| Local System Axes<br>or Body Fixed Axes | x,y,z with origin at the body's centre of gravity                            |

The axes through the centre of gravity will initially be parallel to the global fixed reference axes and it is **assumed that body motions are small**. Therefore, any Eulerian angular displacements coincide with the angular displacements about the fixed reference axes. The following notation is used to denote the rigid body motions:

| Translations            | Rotations               |
|-------------------------|-------------------------|
| $x_1$ = surge (along x) | $x_4$ = roll (about x)  |
| $x_2$ = sway (along y)  | $x_5$ = pitch (about y) |
| $x_3$ = heave (along z) | $x_6$ = yaw (about z)   |

Note: The naming of the various motions assumes that the body is described in the sense that the forward and aft direction is parallel to the X axis. If the body lies parallel to the Y axis, then the rolling of the body will be termed 'pitch' and the pitching 'roll'!

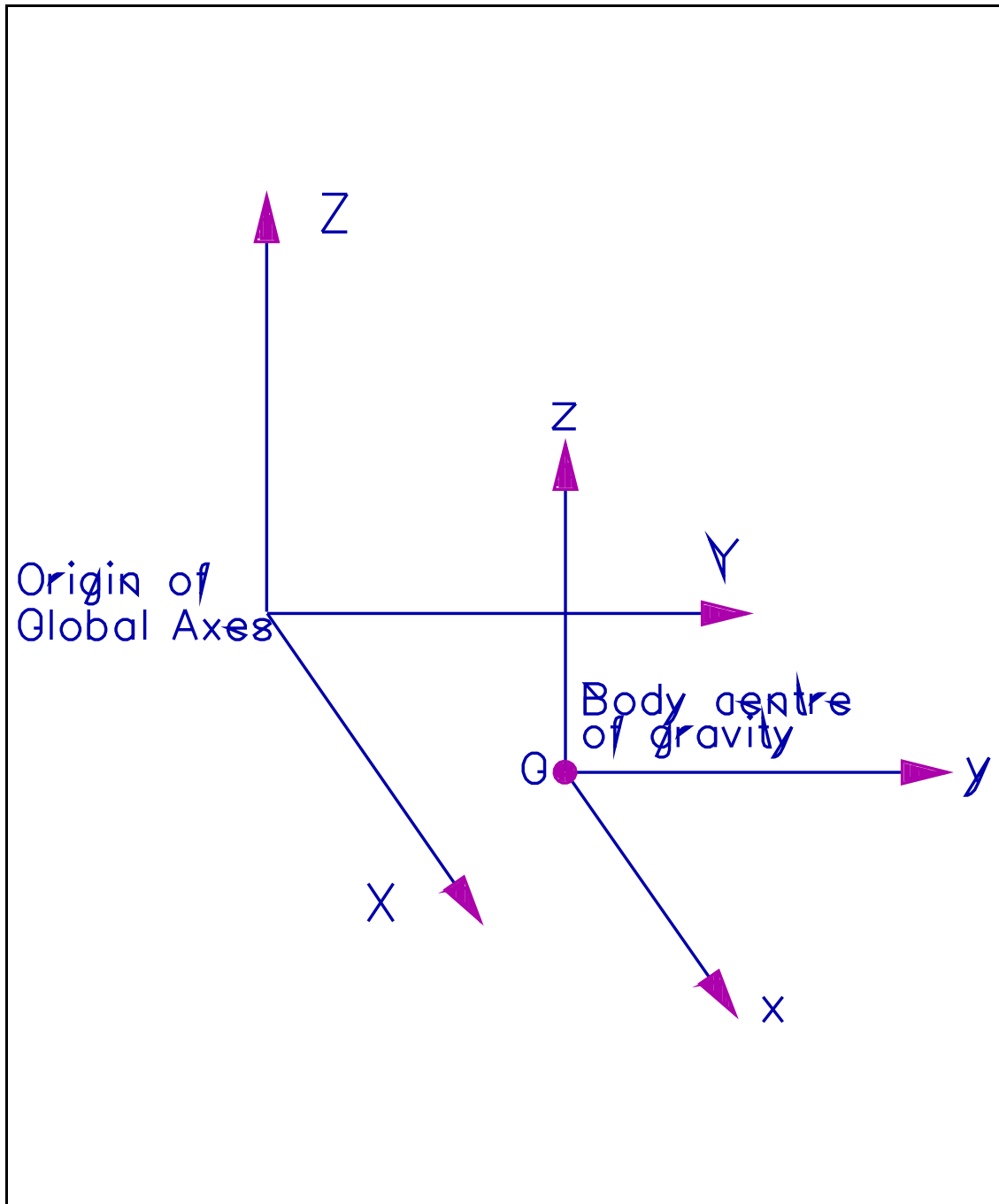


FIGURE 3.1 - AXIS SYSTEMS

Since the theory is first order, the 'Linear Superposition Theorem' may be used to formulate the velocity potential within the fluid domain. Let us define the fluid flow field to be characterised by a velocity potential:

$$Q(X,Y,Z,t) = q(X,Y,Z) e^{-i\omega t} \quad (3.3.1)$$

This complex potential function 'q' may be separated into contributions from the six modes of body motion, the incident wave field and the diffracted or scattered wave field. Effectively, we are considering the problem to be a combination of two separate problems and since the super-position theorem holds, then this is acceptable. The two problems may be viewed as:

1. The problem of a FLOATING body undergoing harmonic oscillations in still water. The body motions will cause the fluid to react on the body and this is the cause of the reactive body forces. Note these reactive forces will then be a function of the motions and are commonly written in terms of ADDED MASS and WAVE DAMPING coefficients.
2. The problem of a FIXED body being subjected to a regular incident wave train. The wave forces acting on the fixed body are considered to be the wave excitation forces. Again it is worth noting that these are usually broken down into two components, these being the FROUDE-KRYLOV and WAVE DIFFRACTION force components.



The potential may therefore be written as:

$$q(X,Y,Z)e^{-i\omega t} = \left[ (q_I + q_d) + \sum_{j=1}^6 q_j \cdot x_j \right] e^{-i\omega t} \quad (3.3.2)$$

where

|          |   |                                       |
|----------|---|---------------------------------------|
| $q_I$    | = | incident wave potential               |
| $q_d$    | = | diffracted wave potential             |
| $q_j$    | = | potential due to j th motion          |
| $x_j$    | = | j th motion (per unit wave amplitude) |
| $\omega$ | = | frequency of incident wave            |

The potential for the undisturbed incident wave field at a point (X,Y,Z) in the fluid domain is known and may be written as:

$$q_I = \frac{-ig \cosh[k(d+Z)] e^{ik(X \cos \theta + Y \sin \theta)} e^{-i\omega t}}{\omega \cosh(kd)} \quad (3.3.3)$$

where

|          |   |  |
|----------|---|--|
| $d$      | = | depth of water                               |
| $k$      | = | wave number (i.e. $2\pi/\text{wavelength}$ ) |
| $\theta$ | = | wave direction (0 degrees along +ve X axis)  |

This incident wave function represents a cosine wave travelling in the positive X direction. The relationship between the wave number 'k' and the angular frequency ' $\omega$ ' is given by:

$$\omega^2 = g k \tanh(kd) \quad (3.3.4)$$

The potential functions are complex but the resultant physical quantities such as fluid pressure and body motions will be obtained by considering the REAL part only. We must solve for the unknown potentials and this is done by using Green's Theorem together with the required boundary conditions on the surfaces which enclose the fluid domain. The potentials are solved at a discrete number of points on the wetted body surface. A similar solution technique to that used in AQWA-LINE is described in Reference 1 (see Appendix B).

When the potentials are known, the hydrodynamic pressure distribution may be calculated by using the linearised Bernoulli's equation.

$$P = -\rho \frac{dq}{dt} \quad (3.3.5)$$

From the pressure distribution, the various fluid forces may be calculated by integrating the pressure over the wetted surface of the body. We have described the fluid forces in terms of reactive and active components. The ACTIVE forces may be written as

$$F_j = -\int_S P n_j dS = -\int_S i\omega \rho (q_I + q_d) n_j dS \quad (3.3.6)$$

where

$$\begin{aligned} F_j &= \text{active force (per unit wave amplitude) in } j \text{ th direction} \\ n_j &= \text{generalised surface normal for } j \text{ th direction} \\ S &= \text{wetted surface of the body in equilibrium} \end{aligned}$$

It has also been noted that the active wave forces may be considered to be made up of two components and these are shown below:

$$F_j = -\int_S i\omega \rho q_I n_j dS \quad -\int_S i\omega \rho q_d n_j dS \quad (3.3.7)$$

Froude-Krylov  
Force

Diffraction  
Force

The REACTIVE forces acting on the body, due to body motions, may be written as:

$$F_{ji} = -\int_S P_i n_j dS = -\int_S i\omega \rho q_i x_i n_j dS \quad (3.3.8)$$

where

$$F_{ji} = \text{reactive force (per unit wave amplitude) in the } j \text{ th direction, due to the } i \text{ th motion}$$

The potential 'q' may be expressed in real and imaginary parts and substituted into equation (3.3.8) to produce the ADDED MASS and WAVE DAMPING coefficients.

Let

$$q_i = q_i^{\text{Re}} + i q_i^{\text{Im}}$$

hence

$$F_{ji} = \omega \rho x_i \int_S q_i^{\text{Im}} n_j dS - i \omega \rho x_i \int_S q_i^{\text{Re}} n_j dS \quad (3.3.9)$$

Since the motion of the body is harmonic, we may express equation (3.3.9) in terms of coefficients which are in phase with body velocity and acceleration.

$$F_{ji} = -A_{ji} \ddot{x}_i - B_{ji} \dot{x}_i \quad (3.3.10)$$

where

$$A_{ji} = \frac{\rho}{\omega} \int_S q_i^{\text{Im}} n_j dS = \text{ADDED MASS coefficient} \quad (3.3.11)$$

$$B_{ji} = \rho \int_S q_i^{\text{Re}} n_j dS = \text{WAVE DAMPING coefficient}$$

Note: If a problem requires the wave loading on a FIXED body, then only the active wave forces are of interest. When the body is FLOATING, both the active and reactive fluid forces must be considered. It is also worth noting that all fluid forces calculated above are a function of the body wetted surface geometry only and are independent of the mass characteristics of the body.

### 3.3.2 Corrections for forward speed

The pulsating source method, as described in 3.3.1, does not account for forward speed in its formulation. Instead, a correction is made to the zero speed solution to account for the forward speed effects (see reference 5). This correction is similar to those used for strip theories, as far as the hydrodynamic coefficients (added mass and damping) is concerned. More specifically, the hydrodynamic coefficients for forward speed are expressed in terms of the zero speed coefficients, the mean forward speed and the frequency of encounter

The frequency of encounter can be given as:

$$\omega_e = \omega + \frac{\omega^2 U}{g} \cos \beta \quad (3.4.11)$$

where

|            |   |
|------------|---|
| $\omega_e$ | the frequency of encounter  |
| $\omega$   | the wave frequency  |
| $U$        | the speed of the vessel   |
| $\beta$    | the heading angle between the vessel and the wave propagation direction |

An example of the corrections used by the pulsating source method when forward speed is present can be given by the calculation of the added mass and damping coefficients in pitch, namely:

$$A_{55}(\omega_e) = A_{55}^0(\omega_e) + \left( \frac{U}{\omega_e} \right)^2 A_{33}^0(\omega_e) \quad (3.4.12)$$

$$B_{55}(\omega_e) = B_{55}^0(\omega_e) + \left( \frac{U}{\omega_e} \right)^2 B_{33}^0(\omega_e)$$

where the zero speed hydrodynamic coefficients are denoted with a superscript 0.

The pulsating source method has been tested over many years against the translating-pulsating method. The translating-pulsating source method, contrary to the pulsating source method, explicitly accounts for forward speed in its formulation. It was found that although, the translating-pulsating source gives benefits in the calculation of individual hydrodynamic coefficients and wave action, the differences in the response calculations are quite small. Particularly, in cases where low to moderate speeds are considered (i.e.  $Fn < 0.3$ ) the differences are very small and the computational effort required for the translating-pulsating source far outweighs that for the pulsating source methods (see reference 6).

In AQWA the use of forward speed with hydrodynamically interacting structures employed is not possible.

### 3.4 THE SECOND ORDER WAVE EXCITING FORCES

#### 3.4.1 Mean Wave Drift Forces (Far Field Solution)

The mean wave drift forces on a floating body in the horizontal plane may be calculated by considering the rate of change of linear and angular momentum within a prescribed fluid domain. This is known as the far field solution. The method is detailed in references 2 and 3 given in Appendix B. The rate of change of linear and angular momentum may be written as:

$$\frac{d\bar{G}}{dt} = -\rho \int_{S+S_f+S_{in}} \left[ \left( \frac{P}{\rho} + gZ \right) \bar{N} + \bar{V} (V_n - U_n) \right] dS \quad (3.4.1)$$

$$\frac{d\bar{H}}{dt} = -\rho \int_{S+S_f+S_{in}} \left[ (\bar{r} * \bar{N}) \left( \frac{P}{\rho} + gZ \right) \bar{N} + (V_n - U_n) (\bar{r} * \bar{V}) \right] dS \quad (3.4.2)$$

where

|           |   |                                      |
|-----------|---|--------------------------------------|
| $\bar{G}$ | = | linear momentum                      |
| $\bar{H}$ | = | angular momentum                     |
| $\bar{V}$ | = | fluid velocity                       |
| $U_n$     | = | normal velocity of surfaces          |
| $V_n$     | = | normal velocity of fluid on surfaces |
| $\bar{r}$ | = | position vector of point on surface  |
| $\bar{N}$ | = | unit normal of surfaces              |
| $\rho$    | = | fluid density                        |
| $P$       | = | fluid pressure                       |

$S$ ,  $S_f$  and  $S_{in}$  are the control surfaces of the fluid domain

|          |   |                                       |
|----------|---|---------------------------------------|
| $S$      | = | body wetted surface                   |
| $S_f$    | = | fluid free surface                    |
| $S_{in}$ | = | large cylindrical surface at infinity |

$X$ ,  $Y$  and  $Z$  are coordinates in fixed axes in water plane

Letting the body have NO FORWARD SPEED and considering the forces and the moments in the HORIZONTAL PLANE, we have:

$$F_x = - \int_{S_{in}} (P n_x + \rho V_x V_n) dS - \frac{dG_x}{dt} \quad (3.4.3)$$

$$F_y = - \int_{S_{in}} (P n_y + \rho V_y V_n) dS - \frac{dG_y}{dt} \quad (3.4.4)$$

$$M_z = - \int_{S_{in}} (\bar{r} * \bar{n})_z P + (\bar{r} * \bar{V})_z V_n dS - \frac{dH_z}{dt} \quad (3.4.5)$$

The next step is to take the time averages of the above equations to obtain the MEAN forces and moments. The last term in the equations is periodic and therefore no net increase of momentum is contributed from one cycle to another. The coordinates are expressed in polar form and substituted into equations (3.4.3),(3.4.4) and (3.4.5). The resulting mean forces and moment are:

$$\bar{F}_x = - \int_{S_{in}} \overline{P \cos \Phi + \rho V_R (V_R \cos \Phi - V_P \sin \Phi) R} d\Phi dz \quad (3.4.6)$$

$$\bar{F}_y = - \int_{S_{in}} \overline{P \sin \Phi + \rho V_R (V_R \sin \Phi - V_P \cos \Phi) R} d\Phi dz \quad (3.4.7)$$

$$\bar{M}_z = - \int_{S_{in}} \overline{\rho V_R V_P R^2} d\Phi dz \quad (3.4.8)$$

where

|                     |   |                           |
|---------------------|---|---------------------------|
| $V_R, V_\Phi$       | = | polar velocity components |
| $\bar{\phantom{x}}$ | = | mean quantity             |
| $P$                 | = | fluid pressure            |

Equations (3.4.6), (3.4.7) and (3.4.8) are exact, since no assumptions of linearity have been made. We now make the assumption that the wave slope is small and retain contributions to the forces and moment which are of second order in the incident wave amplitude. The fluid, being assumed ideal and irrotational, may be characterised by a suitable potential function and the derivatives of this will produce the required velocity terms for the above equations. The potential describing the fluid field needs only to be to a first order as the second order potential makes no contribution to the mean wave drift in the horizontal plane. The first order potential is known from the solution of the linear diffraction/radiation problem and therefore the polar velocities may be obtained as:

$$V_R = \frac{dq}{dR} \quad \text{and} \quad V_\Phi = \frac{1}{R} \frac{dq}{d\Phi} \quad (3.4.9)$$

The pressure is obtained from Bernoulli's equation which is:

$$P = -\rho \frac{dQ}{dt} - \frac{1}{2} \rho |\bar{V}|^2 - \rho gZ \quad (3.4.10)$$

where

$$Q(R, \Phi, Z, t) = q(R, \Phi, Z) e^{-i\omega t} \text{ is the velocity potential}$$

Substituting for the pressure and integrating over the cylindrical control surface at infinity, we may arrive at the final expressions for the mean horizontal drift forces and moment.

The mean wave drift forces and moments in the horizontal plane may therefore be found and are proportional to the incident wave amplitude squared and are a function of wave frequency. It has been shown that the mean wave drift depends on the fluid first order potential solution. This linear potential is dependent on whether the body is FIXED or FLOATING in the fluid. If the body is floating, then the fluid domain will consist of radiation, diffraction and incident wave field components (see Section 3.3). If the body is fixed, then radiated waves due to body motions must not be considered in the description of the fluid domain. It is therefore seen that the mean wave drift will normally be different for a body fixed or floating in a given regular incident wave train.

### 3.4.2 Mean Wave Drift Forces (Near Field Solution)

The mean wave drift forces on a floating body in the horizontal and vertical planes may be calculated based on the method of direct integration of pressure acting on the wetted surface of the body. This is known as the near field solution.

The expression for the evaluation of the 2<sup>nd</sup> order mean wave drift force and moments can be written as follows:

$$F_{strc}^{(2)} = - \oint_{WL} 0.5 \rho g \zeta_r^2 \bar{n} dl + \iint_{S_0} 0.5 \rho |\nabla \phi|^2 \bar{n} dS \\ + \iint_{S_0} \rho \left( X \cdot \nabla \frac{\partial \phi}{\partial t} \right) \bar{n} dS + M_s \cdot R \cdot \ddot{X}g$$

$$M_{strc}^{(2)} = - \oint_{WL} 0.5 \rho g \zeta_r^2 (\bar{x} \times \bar{n}) dl \\ + \iint_{S_0} 0.5 \rho |\nabla \phi|^2 (\bar{x} \times \bar{n}) dS \\ + \iint_{S_0} \rho \left( X \cdot \nabla \frac{\partial \phi}{\partial t} \right) (\bar{x} \times \bar{n}) dS \\ + I_s \cdot R \cdot \ddot{X}g$$

in which WL stands for water line along the structure surface;  $\zeta_r$  is the relative wave surface elevation;  $S_0$  is the structure wetted surface;  $X$  is the motion at structure surface;  $M_s$  is the structure mass;  $R$  is the structure rotation matrix;  $\ddot{X}g$  is the structure CoG acceleration vector.

### 3.4.3 QTF Calculations and Shallow Water Enhancements:

The second order wave exciting force, for the general case of a spectrum consisting of more than one wave train of different frequencies, (see reference 4\*) can be written as:

$$F^{(2)}(t) = \sum_{i=1}^N \sum_{j=1}^N \left\{ P_{ij}^- \cos[-(\omega_i - \omega_j)t + (\varepsilon_i - \varepsilon_j)] + P_{ij}^+ \cos[-(\omega_i + \omega_j)t + (\varepsilon_i + \varepsilon_j)] \right\} \\ + \sum_{i=1}^N \sum_{j=1}^N \left\{ Q_{ij}^- \sin[-(\omega_i - \omega_j)t + (\varepsilon_i - \varepsilon_j)] + Q_{ij}^+ \sin[-(\omega_i + \omega_j)t + (\varepsilon_i + \varepsilon_j)] \right\}$$

where  $P_{ij}$  and  $Q_{ij}$  are the in-phase and out-of-phase components of the time independent transfer function, with



$$\begin{aligned}
 P_{ij}^{(\pm)} = & - \oint_{WL} \frac{1}{4} \rho g \zeta_i \zeta_j \cos(\varepsilon_i \pm \varepsilon_j) \vec{n} dl && \text{Waterline integral} \\
 & + \iint_{S_0} \frac{1}{4} \rho |\nabla \phi_i| |\nabla \phi_j| \vec{n} dS && \text{Bernoulli} \\
 & + \iint_{S_0} \frac{1}{2} \rho \left( X_i \cdot \nabla \frac{\partial \phi_j}{\partial t} \right) \vec{n} dS && \text{Acceleration} \\
 & + M_s \cdot R_i \cdot \ddot{X} g_j && \text{Momentum} \\
 & + \iint_{S_0} \rho \frac{\partial \phi^{(2)}}{\partial t} \cdot \vec{n} \cdot dS && \text{2nd order potential}
 \end{aligned}$$

where

- WL stands for water line along the structure surface;
- $\zeta r$  is the relative wave surface elevation;
- $S_0$  is the structure wetted surface;
- $X$  is the motion at structure surface;
- $M_s$  is the structure mass;
- $R$  is the structure rotation matrix;
- $Xg$  is the structure CoG acceleration vector.

The evaluation of the out-of-phase components ( $Q_{ij}$ ) is similar to that followed for the in-phase components ( $P_{ij}$ ). In AQWA-LINE all the out-of-phase and in-phase components can be evaluated and stored in an ASCII file for further use in a post-processing job.

The second order wave potential does not contribute to the diagonal terms of the QTF matrix, so that it has no effect on the mean wave drift force. However, the second order wave potential contributes to the off-diagonal terms of the QTF. It has been found that in **shallow water** the QTF's (drift force coefficients) can be increased significantly by the second order potential. Therefore, the inclusion of the second order incident and diffracted potential is necessary for the accurate evaluation of the second order wave exciting forces in shallow water. In AQWA this is done using the Pinkster approximation. The time independent QTF's, as evaluated in AQWA-LINE, is a convenient method by means of which it is possible to express the time histories of the second order wave exciting forces in the time domain. In AQWA, this is done in the post-processing program AQWA-DRIFT.

\* Pinkster, J.A (1980), 'Low Frequency Second Order Wave Exciting Forces and Moments'

### 3.5 SLOWLY VARYING WAVE DRIFT FORCES

When a body is positioned in a regular wave train it will experience a mean wave drift force which is time invariant. If the wave environment is composed of more than one wave train then

the total wave drift force acting on the body is characterised by a mean component and a slowly TIME varying wave drift force. The details of these slowly varying drift forces are contained within the AQWA-DRIFT User Manual (Section 3.5).

### **3.6 INTERACTIVE FLUID LOADING BETWEEN BODIES**

The concept of fluid interactive loading between bodies is usually referred to in the context of Radiation/Diffraction Theory (Section 3.3). Essentially we are concerned with the influence of one body's flow field on another's. Obviously the importance of interaction will depend on both body separation distances and the relative sizes of the bodies. All the programs in AQWA can handle full hydrodynamic interaction including radiation coupling between up to 10 structures. This is essential for accurate modelling of vessels which are in close proximity. The hydrodynamic interaction is applicable to all AQWA programs and includes not only the Radiation coupling but the Shielding Effects as well. Two points regarding hydrodynamic interaction should be emphasized:

- The Response Amplitude Operators (RAOs) for each of the hydrodynamically interacting structures will be different from those that would have resulted if each of these structures were on its own. The RAOs are not a physical property of a structure but, as can be seen from the equations of motion, depend on the radiation and diffraction forces. The radiation as well as the diffraction forces change in the case of hydrodynamic interaction and therefore the RAOs of the structures in question will also change.
- When hydrodynamic interaction is employed, special attention is needed when the user moves the structures relatively to each other (using the MSTR card). In AQWA, the RAOs are always evaluated relative to the FIXED REFERENCE AXIS (FRA). That means, if the user defines different positions of one or more hydrodynamically interacting structures in two consecutive AQWA-LINE runs, the results between these two runs will not be comparable.

There are some restrictions with hydrodynamic interaction in AQWA-LINE:

1. Hydrodynamic interaction cannot be used in conjunction with forward speed;
2. Shear force, bending moment and splitting force cannot be calculated in the AGS when two or more hydrodynamically interacting structures are employed.

### **3.7 STRUCTURAL ARTICULATIONS AND CONSTRAINTS**

In AQWA-LINE, there is no facility for structural connections of any type between bodies. For details regarding the theory of this facility, the user must consult the AQWA Reference Manual.

The AQWA-FER, AQWA-NAUT, AQWA-DRIFT and AQWA-LIBRIUM program user manuals may also be consulted.

### **3.8 WIND AND CURRENT LOADING**

Wind or current loading may not be used within AQWA-LINE. For details of wind and current loading, see the AQWA Reference Manual together with the other AQWA program user manuals.

### **3.9 THRUSTER FORCES**

Thruster forces may not be used within AQWA-LINE. For details of thruster forces, see the Aqwa Reference Manual together with the other AQWA program user manuals.

### **3.10 MOORING LINES**

The effect of mooring lines is to contribute to the external forces and stiffness matrix of a structure. This in turn will affect the static equilibrium position and its stability in this position. The stiffness matrix about an equilibrium position may be used within AQWA-LINE and details of the theory involved may be found in the AQWA Reference Manual and in the AQWA-LIBRIUM User Manual.

It is generally assumed that the mooring lines do not significantly affect the vessel first order motions. If they do, then the mooring stiffness must be input (to be added to the hydrostatic stiffness) to ensure that the wave forces and motions are correct.

### **3.11 WAVE SPECTRA**

AQWA-LINE performs no spectral analysis calculations and therefore no wave spectra need be input. Other AQWA programs allow the user to specify mathematical spectra or to define their own spectra by reading in a table of spectral density vs frequency. The mathematical spectra can assume **either** the Pierson-Moskowitz form for fully developed sea **or** the JONSWAP form for developing sea. More than one set of parameters have been used to define these spectra. For details of the particular sets used by the AQWA Suite, refer to the AQWA Reference Manual.

### **3.12 STABILITY ANALYSIS**

When running AQWA-LINE, it is important to ensure that the body position prescribed for motion analysis is a **stable floating equilibrium position**. The calculations required to assess

**hydrostatic stability** are performed within AQWA-LINE. When additional stiffness due to mooring lines is input as a supplement to the hydrostatic stiffness (e.g. from AQWA-LIBRIUM) then additional features must be considered.

### **3.12.1 Free Floating Hydrostatic Stability**

The hydrostatic equilibrium position will be dependent on the mass and mass distribution of the body, combined with the distribution of hydrostatic pressure forces. The distribution of hydrostatic pressure may be described in terms of the total upward buoyant force and the position of the centre of buoyancy. For an equilibrium state to exist, the following static conditions must be true:

#### **Rules for Hydrostatic Equilibrium**

(Note that this is with **no external forces** acting on the body)

1. The weight of the body must equal the total upward force produced by buoyancy.
2. The moments acting on the body must sum to zero. For this to be true, the centre of gravity and the centre of buoyancy must be in a vertical line.

When the prescribed body position is one of equilibrium, we may ascertain if it is a stable position, an unstable position or a neutrally stable position. The cut water-plane properties of the body yield this information via the calculation of the body's metacentre. The metacentric point is defined as the intersection of the body's upward buoyant force with the centre-line of the body after the body has been rotated by a small amount. The stability criteria used for a free floating body is the GM (i.e. METACENTRIC HEIGHT). Thus when the body's weight equals the weight of fluid displaced and the centre of gravity and centre of buoyancy are in the same vertical line, then the user must check the metacentric heights so that the sign of the hydrostatic restoration can be assessed.

#### **Metacentric Height (GM) as a Stability Criterion**

when  $GM > 0$  the body is STABLE

when  $GM < 0$  the body is UNSTABLE

when  $GM = 0$  the body is NEUTRALLY STABLE

Note: The metacentric heights, both in the longitudinal and transverse directions, may be used to generate the X and Y rotational stiffness terms in the overall hydrostatic stiffness matrix (see AQWA Reference Manual). The final hydrostatic stiffness matrix should be SYMMETRIC for a body in equilibrium.

### 3.12.2 Moored Floating Stability

AQWA-LINE does not perform any stability calculations with the inclusion of mooring lines. Mooring lines may be input via a supplement to the hydrostatic stiffness or a total stiffness matrix may be input which contains the effects of mooring and hydrostatic pressure. These stiffness matrices may be obtained from AQWA-LIBRIUM. This program also checks to see if the moored system is in a stable equilibrium position. This is done by calculation of the stiffness eigenvalues.

## 3.13 FREQUENCY DOMAIN SOLUTION

AQWA-LINE solves a set of linear algebraic equations to obtain the harmonic response of the body to regular waves. These response characteristics are commonly referred to as RESPONSE AMPLITUDE OPERATORS (RAOs) and are proportional to wave amplitude.

### 3.13.1 Wave Frequency Motions

The set of linear equations with frequency dependent coefficients are obtained as:

$$M(s)\ddot{X} + M(a)\ddot{X} + C\dot{X} + K(s)X = F \quad (3.13.1)$$

where

|          |   |  |
|----------|---|--|
| $M(s)$   | = | Structural mass matrix                                       |
| $M(a)$   | = | Hydrodynamic added mass matrix                               |
| $C$      | = | System linear damping matrix                                 |
| $K(s)$   | = | Total system stiffness matrix                                |
| $F$      | = | External wave forces on the system (per unit wave amplitude) |
| $X$      | = | Response motions (or RAOs)                                   |
| $\omega$ | = | Frequency of regular incident wave                           |

Writing  $X=X_0 e^{i\omega t}$  and  $F=F_0 e^{i\omega t}$  where  $\omega$  is the frequency of wave forcing, then the solution of equation (3.13.1) will have the form:

$$X_0 = H F_0 \quad (3.13.2)$$

where

$$H = (K(s) - M \omega^2 + i C \omega)^{-1} \quad (3.13.3)$$

$H$  is termed the transfer function or 'modal receptance' which relates input forces to output response. (Note  $M$  is the sum of structural and added mass.) The added mass, linear wave damping and wave forces are all FREQUENCY DEPENDENT.

AQWA-LINE can calculate the RAOs at any point of the structure given the RAOs at the structure's centre of gravity and the vector from the centre of gravity to the position of interest. Then the RAOs of a point P,  $X_p$ , may be found using the following relationship.

$$X_p = T * X_g \quad (3.13.4)$$

where

$$\begin{array}{ll} X_g & = \text{RAOs at the centre of gravity} \\ T & = \text{translation matrix between the centre of gravity and the point P} \end{array}$$

### **3.13.2 Drift Frequency Motions**

The theory above describes the first order or wave frequency calculations, where the frequency of structural response is the same as the forcing frequency, and the response of a structure to a pair of waves of different frequency is simply the sum of the response to each individual wave. The calculation of structural response to second order wave forcing (drift forces) is more complex. The theory of second order wave loading is explained in detail in the literature (e.g. Reference 4 in Appendix B). A condensed version of the theory is given in the AQWA-FER Manual.

## **3.14 TIME HISTORY SOLUTION IN IRREGULAR WAVES**

Only used within AQWA-DRIFT and AQWA-NAUT (see AQWA-DRIFT and AQWA-NAUT Manuals).

## **3.15 TIME HISTORY SOLUTION IN REGULAR WAVES**

Only used within AQWA-NAUT (see AQWA-NAUT Manual).

### **3.16 LIMITATIONS OF THEORETICAL APPLICATIONS**

The main theoretical limitations of AQWA-LINE should be clearly understood by the user and they are listed below:

1. The theory at present relates to a body or bodies which have zero or small forward speed.
2. If first order rigid body motions are required, then the mean body position must be one of static equilibrium.
3. The motions are to a first order and hence must be of small amplitude.
4. The incident regular wave train must be of small amplitude compared to its length (i.e. small slope).
5. The fluid is assumed inviscid and the fluid flow irrotational.
6. Any body motions are harmonic.
7. The forces and moments on a fixed body require only the diffraction problem to be solved.
8. No viscous roll damping is included within the analysis.

## **CHAPTER 4 - MODELLING TECHNIQUES**

This chapter relates the theory in the previous chapter to the general form of the input data required for the AQWA Suite. The sections are closely associated with the sections in the program input format. All modelling techniques related to the calculations within AQWA-LINE are presented. This may produce duplication where the calculations are performed by other programs in the suite. Other modelling techniques which are indirectly related are included to preserve subject integrity. These are indicated accordingly.

Where modelling techniques are only associated with other programs in the AQWA Suite, the information may be found in the appropriate sections of the respective manuals (the section numbers below correspond to those in the other manuals as a convenient cross reference).



## **4.1 INTRODUCTION**

The model of a floating body requires different techniques depending on the type of problem that the user wishes to solve. An approximate model may be acceptable in one analysis or even omitted altogether in another.

In general, there are only TWO DIFFERENCES in the modelling technique required for each program:

1. The first is in the description of the body's surface geometry, the model's mass distribution being common. The description of body geometry being by one or more pressure plates, etc. The elements describe the body surface and thus the hydrostatic and hydrodynamic characteristics of the model.
2. The second is in the description of the environment, where mooring lines, regular and irregular waves, wind and current are not accepted by all programs.

When using AQWA-DRIFT and AQWA-FER, we do not require a hydrostatic or hydrodynamic model, but only the hydrostatic stiffness matrix, hydrodynamic loading coefficients and wave forces, which are the RESULTS of calculations utilising models involving geometric surface definitions. Thus, when AQWA- LINE is run, all these parameters are transferred automatically to backing files for future use with other AQWA programs.

The differences in the hydrostatic and hydrodynamic models, which are associated with the body geometry, for AQWA-LINE/NAUT/LIBRIUM may be summarised in the form of simple restrictions, as follows:

|   |   |  |
|---|---|--|
| Hydrostatic model<br>(AQWA-LINE/LIBRIUM/NAUT) | - | Pressure plates and tubes. No restrictions   |
| Hydrodynamic model<br>(AQWA-LINE)             | - | Pressures plates and tubes. Restricted in geometry and proximity to each other and to the boundaries |
| Hydrodynamic model<br>(AQWA-NAUT)             | - | Pressure plates and tubes. Restricted only by size (as a function of wavelength)                     |

In practice, this means that there is a hydrodynamic model for AQWA-LINE, to which other elements are added for AQWA-LIBRIUM/NAUT. If the user wishes, a more approximate model may be defined, with fewer elements, when restrictions allow.

## **4.2 MODELLING REQUIREMENTS FOR AQWA-LINE**

### **4.2.1 When used as an Independent Program**

AQWA-LINE requires the following categories of physical modelling:

1. Body mass characteristics and surface geometry
2. Global static environmental parameters
3. Analysis equilibrium position
4. Wave environmental parameters

These categories are described in the following sections.

### **4.2.2 Following an AQWA-LINE Run**

After an AQWA-LINE run or series of runs have been completed, then it may be required to utilise the diffraction/radiation results for other types of analysis. This is why a HYDRO-DYNAMIC DATABASE file and RESTART file are set up automatically by AQWA-LINE. These files may be used by other AQWA programs to obtain information relating to body characteristics or fluid loading. Consider the following examples of use.

1. Irregular Wave Motions

Use AQWA-LINE to generate fluid loading details and then use AQWA-FER for spectral analysis for statistical prediction of body motions.

2. Coupled Body Analysis

Again use AQWA-LINE to obtain fluid loading and then use AQWA-FER to apply coupling constraints between bodies for overall body motions in the frequency domain.

3. Regular and Irregular Wave Motion in Time Domain

Obtain Diffraction/Radiation forces from AQWA-LINE and then use these within the time history programs AQWA-NAUT or AQWA-DRIFT.

4. Second Order Slowly Varying Wave Drift

Obtain mean wave drift coefficients or/and full QTFs from AQWA-LINE and use them to calculate the time varying wave drift forces within AQWA-DRIFT.

### **4.3 DEFINITION OF STRUCTURE AND POSITION**

Full details may be found in AQWA Reference Manual

Two sets of axes are used in AQWA-LINE and these are shown in Figure 3.1. They are the FRA (Fixed Reference Axes) and the LSA (Local System Axes). Full details of the axes systems used in the AQWA Suite are given in the AQWA Reference Manual. In AQWA-LINE, body motions and fluid forces are with respect to the centre of gravity of the particular body (see Section 3.3 and Figure 3.1).

The AQWA suite employs a single common sign convention with the axes defined as in the AQWA Reference Manual.

Translations of a structure in the X, Y and Z direction are termed SURGE, SWAY and HEAVE and are positive in the positive direction of their respective associated axes. The rotational freedoms termed ROLL, PITCH and YAW are positive in a clockwise direction when looking along the coordinate axes from the origin.

When running AQWA-LINE, it is important to note that the structure may **only be moved vertically** from its definition position for the diffraction/radiation analysis (i.e. only the draught may be altered). This restriction is imposed to ensure that the axes in which the hydrodynamic coefficients are defined are parallel to the FRA. Therefore, if the user cannot achieve the correct position for the diffraction/radiation analysis by altering only the draught of the structure then **the definition position is not valid**.

## **4.4 STRUCTURAL GEOMETRY AND MASS DISTRIBUTION**

When AQWA-LINE is used to study the small amplitude response of a body to regular waves, it is required to define the body's geometrical form and mass distribution characteristics. The calculation of fluid forces requires the integration of pressures over the WETTED SURFACE of the body. Therefore, the wetted body surface must be suitably modelled. Within AQWA-LINE, the wetted surface is a MEAN EQUILIBRIUM surface which is held constant. This section describes how the body surface and mass distribution are modelled via the use of a discrete element technique.

### **4.4.1 Coordinates**

In the modelling process, any point on the structure is located by referring to the X, Y and Z coordinate of a point in the FRA, which is termed a NODE. The model of structure geometry and mass distribution consists of a specification of one or more ELEMENTS (see also Sections 4.1, 4.4.2) whose position is that of a node or nodes. Each node has a NODE NUMBER, which is chosen by the user to be associated with each coordinate point. Nodes do not themselves contribute to the model, but may be thought of as a table of numbers and associated coordinate points which are used as reference points for other modelling facilities (e.g. definition of elements, identification of critical motion points, mooring positions, etc).

Note that nodes are also used to define the position of other points not necessarily on the structure, e.g. the attachment points of each end of a mooring line.

### **4.4.2 Elements and Element Properties**

To describe the mean geometrical wetted surface of the body, together with the body's mass distribution, use is made of the variety of modelling elements available within the AQWA suite (see AQWA Reference Manual). Within AQWA-LINE the following types of elements can be used:

|              |   |  |
|--------------|---|--|
| PMAS Element | - | Point Mass Element, describing mass properties             |
| PBOY Element | - | Point Buoyancy Element, which gives vertical buoyant force |
| TPPL Element | - | Triangular Pressure Plate Element, transmits pressure      |
| QPPL Element | - | Quadrilateral Pressure Plate Element, transmits pressure   |
| TUBE Element | - | Morison Tube Element                                       |
| STUB Element | - | Tube of non-circular cross section                         |
| DISC Element | - | Circular Disc element                                      |
| FPNT Element | - | Point Element, for output of wave pressure                 |

Each of the above elements has physical properties associated with it, together with the number of nodes required to define the position of the element. The physical properties associated with each type of element are described in terms of MATERIAL and GEOMETRY GROUPS and the information contained within these groupings is shown in Table 4.1.

| Element Type | Number of nodes | Physical Element Properties by Group      |                                       | Type of Fluid Loading        |
|--------------|-----------------|---|---------------------------------------|------------------------------|
|              |                 | MATERIAL GROUP                            | GEOMETRY GROUP                        |                              |
| PMAS         | 1               | contains the mass given to the element    | given mass inertia properties         | none                         |
| PBOY         | 1               | contains mass of fluid displacement       | none                                  | hydrostatic                  |
| TPPL         | 3               | none                                      | none                                  | hydrodynamic and hydrostatic |
| QPPL         | 4               | none                                      | none                                  | hydrodynamic and hydrostatic |
| TUBE         | 2               | contains the density given to the element | geometric and hydrodynamic properties | hydrodynamic and hydrostatic |
| STUB         | 3               | contains the density given to the element | geometric and hydrodynamic properties | hydrodynamic and hydrostatic |
| DISC         | 2               | none                                      | geometric and hydrodynamic properties | hydrodynamic                 |
| FPNT         | 1               | none                                      | none                                  | none                         |

TABLE 4.1 - PROPERTIES OF ELEMENTS

Thus, the mass of the body and its inertial characteristics may be modelled by using a single PMAS element (or a series of such elements). The mean wetted surface is modelled using the pressure plates. ALL pressure plate elements transmit hydrostatic pressure but, within AQWA-LINE, only elements defined as DIFFRACTION PLATE elements transmit **hydrodynamic diffraction /radiation pressure**. Also, the distribution of diffraction plate elements **must obey certain rules** (see Section 4.4.3).

A diffraction plate element is identified by a DIFF label, when inputting the element (see AQWA Reference Manual for Deck 2 input).

The TUBE element is a tubular element with uniform circular cross section with constant wall thickness (Morison Type element). Forces on a TUBE element are: added mass, drag force, Froude-Krylov force, hydrostatic force and weight. Note that drag force is not included in AQWA-LNE.

Slender tube (STUB) elements differ from TUBE elements in the following respects:

1. STUB elements permit tubes of non-circular cross section to be modelled, by allowing the tube properties (diameter, drag coefficient, added mass coefficient) to be specified in two directions at right angles.
2. Longer lengths of tube can be input, as the program automatically subdivides STUB elements into sections of shorter length - for integration purposes.
3. An improved (second order) version of Morison's equation is used to calculate the drag and inertia forces on STUB elements. This is particularly useful in the study of dropped objects.
4. STUB elements should, however, only be employed if the (mean) diameter is small compared with the length.

#### **4.4.3 Rules for Distribution of Diffraction Plate Elements**

The RULES for the distribution of diffraction pressure plate elements over the wetted body surface fall into two categories. These may be classified as rules relating to theoretical considerations and rules relating to numerical computational considerations. The hydrodynamic diffraction/ radiation fluid forces are calculated by using a discrete distribution of fluid SOURCES over the wetted surface of the body (see Section 3.3). These sources are positioned at the centres of the user defined diffraction pressure plate elements. The following rules relate generally to placement and sizing of plate elements which in turn reflects on the distribution of sources.

##### **(A) RULES due to Theoretical Considerations**

1. The plate elements, which automatically generate sources, **MUST COVER** the entire mean wetted surface of the body or bodies. The body mean wetted surface is that part of the body which is in contact with the fluid when the body is in an equilibrium or steady state position. This wetted surface must be between the fluid free-surface and the sea-bed.
2. The plates, and hence sources, should be **CONCENTRATED** on those parts of the body which are likely to experience high fluid flow (e.g. the bow section or aft end section of a ship).
3. Plate characteristic dimensions should be **LESS THAN 1/7th OF THE INCIDENT WAVE LENGTH**. Therefore, the longest side of the plate element should satisfy this criterion.
4. Plate element side dimensions should be **LESS THAN** the local radius of curvature of the surface body part being modelled. This condition cannot be satisfied at sharp corners and these are effectively rounded off (e.g. knuckles on a ships hull).
5. Diffracting plates modelling the body surface **MUST NOT CUT** the free surface of the fluid. Plates below the free surface are allowed by AQWA to be denoted as non-diffracting.
6. Plate element **NORMALS MUST** point outwards from the body surface into the fluid domain. Plate orientations should be checked (using AQWA Graphical Supervisor (AGS)) as AQWA-LINE cannot detect incorrectly placed plates.
7. If the clearance between the body and the sea-bed is large, and using the wave property of exponential decay with depth, parts of the body at a depth greater than approximately  $\frac{1}{2}$  the wave length may be ignored in the diffraction/radiation calculation. Note that, when employing this economy tactic, the hydrostatic calculation **MUST** still be performed over the entire wetted body surface, unless the hydrostatic stiffness matrix is input directly by the user. This hydrostatic information may be acquired from AQWA-LIBRIUM or from other sources (e.g. curves of form).

**(B) RULES due to Numerical Computational Considerations**

1. Element sizes should vary GRADUALLY over the wetted body surface (e.g. larger elements may be used in the parallel mid-body of a ship and gradually decrease in size as the bow or stern is reached).
2. Elements should have an aspect ratio of GREATER THAN 1/3. The nearer this is to unity, the better. The aspect ratio of a plate element is defined as follows:

$$\text{Aspect ratio} = \frac{\text{area}}{\text{length}^2} * C$$

where

$$\begin{aligned} \text{Area} &= \text{area of plate element} \\ \text{length} &= \text{longest side of plate element} \end{aligned}$$

C is a multiplier which has the value:

$$C = \frac{4}{n * \tan(90 - 360 / (2 * n))}$$

$$n = \text{the number of element sides}$$

3. Element centres, and thus sources, should be at LEAST one element equivalent radius (facet radius) apart. An equivalent radius for any geometrical form of element may be deduced by equating the actual area to that of a circular element of equal area,

$$r_e = \sqrt{\text{area} / \pi}$$

4. The centre of a diffraction plate must be greater than a certain distance below the fluid free-surface when the body is in the ANALYSIS POSITION. Therefore the VERTICAL coordinate of the centre of area (i.e. the source) must satisfy the following criteria:

$$(1) \quad ZS > 0.000273 * (\text{water depth})$$

and

$$(2) \quad ZS > 0.0000132 * (\text{wave length})$$

where

$$ZS = \text{Z coordinate of the source in the analysis position (i.e. distance of the source below the still water surface)}$$



5. The centre of a diffraction plate should also be MORE THAN a certain distance from the SEA-BED. Obviously, this will depend on the draught of the body and the prescribed water depth. The minimum distance permitted is one half of the element characteristic radius (see Rule 3 above).
6. Adjacent diffraction plate elements should have an area ratio of more than 1/3, e.g. the Adjacent Area Ratio is the MINIMUM of the following:

$$i \text{ th area} / j \text{ th area} \quad \text{AND} \quad j \text{ th area} / i \text{ th area}$$

where

|                 |                 |                     |
|-----------------|-----------------|---------------------|
| i th<br>element | j th<br>element | 2 adjacent elements |
|-----------------|-----------------|---------------------|

Note: Adjacent elements are defined as elements that have common sides.

7. Discretisation of the body should not lead to any gaps in the coverage of the wetted surface and any gaps found (using AQWA-AGS) should be eliminated.
8. The maximum number of elements that may be explicitly defined (on all structures) is 6000. The number of plate elements defined relates only to that part of the body being explicitly modelled. Therefore if NF plates are used to model half the body, then two times NF plates will effectively be used for the whole body (effectively four times NF, if using four fold symmetry).

Thus the maximum TOTAL number of elements that may be defined (including all structures) is 24000 if they are all plate elements.

For example a model could have:

|                                   |      |                          |         |      |
|-----------------------------------|------|--------------------------|---------|------|
| Tubes                             | 100  | not affected by symmetry | Total = | 1 00 |
| PMAS                              | 1    | not affected by symmetry | Total = | 1    |
| Non-diffracting                   | 2000 | with 2-fold symmetry     | Total = | 4000 |
| Diffracting                       | 3899 | with 2-fold symmetry     | Total = | 7798 |
|                                   |      |                          |         |      |
| Total explicitly defined elements | =    |                          | 6000    |      |
| Total elements in analysis        | =    |                          | 11899   |      |

9. Try and use the symmetry properties of a body surface to the full. **The use of symmetry may only be applied to plate elements.**

#### **4.5 MORISON TUBE ELEMENTS**

TUBE elements are defined by specifying end nodes, diameter, wall thickness and end cut lengths (over which the forces are ignored). Each tube element may have a different drag and added mass coefficient associated with it. Drag coefficients can be defined as functions of Reynolds Number.

Full consideration is given to current variation over the tube length and to partial submersion of members. Drag on TUBE elements is not calculated in AQWA-LINE because this is a non-linear (velocity<sup>2</sup>) force.

Added mass is evaluated on all submerged or partially submerged tubes but, if the user wishes to suppress these calculations, the drag and added mass coefficients on any or all tubes of a given structure may be set to zero.

## **4.6 STATIC ENVIRONMENT**

### **4.6.1 Global Environmental Parameters**

The global or static environmental parameters are those which often remain constant or static throughout an analysis and comprise the following:

|                              |   |
|------------------------------|---|
| Acceleration due to Gravity: | Used to calculate all forces and various dimensionless variables throughout the program suite   |
| Density of Water:            | Used to calculate fluid forces and various dimensionless variables throughout the program suite   |
| Water Depth:                 | <p>A fundamental parameter for the calculations in AQWA-LINE/NAUT</p> <p>Used also by AQWA-DRIFT/FER, through the wave number, to calculate phase relationships for various parameters</p> <p>Used in AQWA-LIBRIUM to calculate the clearance from the sea bed only</p> |

## **4.7 LINEAR STIFFNESS**

### **4.7.1 Hydrostatic Stiffness**

The hydrostatic stiffness matrix is calculated in AQWA-LINE and then transferred automatically via backing file to the other programs in the suite, when they are used as a post-processor to AQWA-LINE. For details of the hydrostatic stiffness matrix, see Section 3.1.3.

The hydrostatic stiffness matrix may also be input directly into AQWA-LINE if known from other sources. Note that, although this matrix is termed 'linear hydrostatic', a matrix may be input which includes other linear stiffness terms. However, the user is advised to consider other linear stiffness terms as ADDITIONAL stiffness, to be modelled separately as described in the following section.

### **4.7.2 Additional Linear Stiffness**

The additional linear stiffness is so called to distinguish between the linear hydrostatic stiffness calculated by AQWA-LINE (or from any other source) and linear stiffness terms from any other mechanism or for parametric studies.

Although all terms in the additional linear stiffness can be included in the hydrostatic stiffness matrix, the user is advised to model the two separately. The most common reasons for an additional stiffness model are as follows:

- when modelling the effect of mooring lines (such a stiffness matrix may be obtained from AQWA-LIBRIUM).
- when the modelling facilities for a particular mechanism are not available in the AQWA Suite.
- when the user wishes to investigate the sensitivity of the analysis to changes in the linear stiffness matrix.
- when the hydrostatic stiffness matrix is incomplete.

**Note:** This facility does not REPLACE but complements the stiffness due to hydrostatic pressure. Also note that, when mooring lines or any other mechanism significantly change the wave frequency response of a body (e.g. tension leg platforms), then the overall system stiffness must include an additional linear mooring stiffness, so that AQWA-LINE can calculate the correct drift forces, these being a function of body response.

## **4.8 WAVE FREQUENCIES AND DIRECTIONS**

The wave frequencies and directions are those at which the wave forces and hydrodynamic coefficients are to be calculated or are defined. The reactive hydrodynamic coefficients are a function of wave frequency whereas the wave excitation forces are a function of frequency and direction.

There are only TWO CRITERIA regarding the specification of values for the frequencies and directions and these relate to subsequent use of AQWA-LINE results with other AQWA programs. These criteria may be summarised as follows:

1. The extreme values must be chosen to adequately define the hydrodynamic coefficients at those frequencies where wave energy in the sea spectra is significant and ALL possible directions of subsequent response analysis (see AQWA-FER Manual). If geometric symmetry has been specified (see Section 4.3.3), only those directions for the defined quadrants are required.
2. Sufficient values of wave frequency and direction are used to adequately describe the variation of hydrodynamic coefficients and wave forces, so that interpolation procedures may be undertaken.

Clearly, if either of these criteria is violated, approximate results will be obtained. Where possible, the program will indicate this. However, this should not be relied on, as anticipation of the intentions of the user is not usually possible.

## **4.9 HYDRODYNAMIC COEFFICIENTS AND WAVE FORCES**

The wave loading coefficients are calculated by AQWA-LINE and transferred automatically to backing file for use with other AQWA programs. The hydrodynamic components are calculated as follows:

- M(a) Hydrodynamic added mass matrix
- C(r) Radiation damping matrix
- F(d) Harmonic wave diffraction force/moment components
- F(k) Harmonic wave Froude-Krylov force/moment components
- F(m) Mean second order wave drift forces

The added mass and damping are frequency dependent and the external forces vary with both frequency and direction (see previous section for details of the frequencies and directions).

Note: If the hydrodynamic information above is known for a particular number of frequencies and directions, then these may be directly defined in AQWA-LINE, so that the amount of diffraction/radiation calculation is decreased. It is important that the information input is complete, in the sense that it compares directly with any subsequent AQWA-LINE runs. (i.e. the directionality of the defined input corresponds with those directions to be used in subsequent AQWA-LINE calculations).

#### **4.10 WIND AND CURRENT LOADING COEFFICIENTS**

No wind or current loading coefficients are required in AQWA-LINE (see AQWA-LIBRIUM/DRIFT/NAUT manuals).

#### **4.11 THRUSTER FORCES**

Thruster forces are not used in AQWA-LINE (see AQWA-LIBRIUM/DRIFT/NAUT manuals).

#### **4.12 CONSTRAINTS OF STRUCTURE MOTIONS**

This facility is used within AQWA-LINE to obtain the second order mean drift forces on a fixed body. When this is required, all six degrees of freedom are constrained.

#### **4.13 STRUCTURAL ARTICULATIONS**

These are not used in AQWA-LINE (see AQWA-DRIFT/NAUT/FER/LIBRIUM manuals).

#### **4.14 WAVE SPECTRA, WIND AND CURRENT SPECIFICATION**

These are not required by AQWA-LINE (see AQWA-FER/DRIFT/LIBRIUM manuals).

#### **4.15 MOORING LINES**

The effects of mooring lines can only be included within AQWA-LINE by specifying a linear mooring stiffness matrix to complement the hydrostatic stiffness matrix (see Section 4.7.2). The mooring stiffness matrix about the equilibrium moored floating position may be calculated using AQWA-LIBRIUM (see AQWA-LIBRIUM manual).

#### **4.16 ITERATION PARAMETERS FOR SOLUTION OF EQUILIBRIUM (AQWA-LIBRIUM ONLY)**

These are not applicable to AQWA-LINE (see AQWA-LIBRIUM manual).

#### **4.17 TIME HISTORY INTEGRATION IN IRREGULAR WAVES (AQWA-DRIFT and AQWA-NAUT)**

This is not applicable to AQWA-LINE (see AQWA-DRIFT and NAUT manuals).

#### **4.18 TIME HISTORY INTEGRATION IN REGULAR AND IRREGULAR WAVES**

This is not applicable to AQWA-LINE (see AQWA-NAUT manual).

#### **4.19 SPECIFICATION OF OUTPUT REQUIREMENTS**

See options list in Appendix A and AQWA Reference Manual.



## **CHAPTER 5 - ANALYSIS PROCEDURE**

This chapter assumes that the user is familiar with the physics of the analysis and how one is expected to model the structure in its environment. It also deals with the methodology associated with running the program and links the modelling requirements of the previous chapter with the stages of analysis necessary to solve a given type of problem.

This involves classification of the types of problem and details of the required program runs. The stages within each program run are identified together with the options used.

## **5.1 TYPES OF ANALYSIS**

The types of problem listed below are those which may be solved using AQWA-LINE as an INDEPENDENT PROGRAM. However, AQWA-LINE may be used to provide the wave diffraction/radiation loading required when using other AQWA programs to solve a far wider range of problems (see AQWA-FER/NAUT/DRIFT/LIBRIUM user manuals).

- calculation of hydrostatic loads and small angle static stability properties.
- calculation of wave diffraction/radiation loads acting on a fixed or floating body, including the mean wave drift forces.
- calculation of natural frequencies for moored or free-floating body.
- calculation of wave frequency RAOs for free-floating uncoupled bodies.
- calculation of wave frequency RAOs for moored uncoupled bodies.

Note that the calculation of free-floating RAOs and free-floating natural frequencies is considered an integral part of the data checking process, which is automatically carried out and printed.

## **5.2 RESTART STAGES**

All programs in the AQWA Suite have a facility for gradual progression through any given analysis. This is obtained by structuring each program into a number of distinct analysis stages, called RESTART STAGES (see AQWA Reference Manual). These are common to all programs in the AQWA Suite and the user may sequentially run any number (there are six stages). Since the restart stages are common to all programs, this allows the user to run more than one program within any analysis (e.g. the user may run the first three stages of AQWA-LINE and then run the last two stages of AQWA-FER, to complete a specific type of analysis).

Use of the RESTART PROCESS, via a program restart option (see Appendix A), implies that information is available on a backing file from a previous program run, and not through the normal card image input file. The required backing files, called restart files, are created automatically when a program is run. This process is also used to transfer information from one program to another program, so that data input is minimised.

The program stages are:

|         |   |  |
|---------|---|--|
| Stage 1 | - | Geometric Definition and Static Environment            |
| Stage 2 | - | Input of the Diffraction/Radiation Analysis Parameters |
| Stage 3 | - | The Diffraction/Radiation Analysis                     |
| Stage 4 | - | Input of the Analysis Environment                      |
| Stage 5 | - | Motion Analysis  |
| Stage 6 | - | Graphical Display of Model and Results                 |

Note that the graphics program, AQWA-AGS, allows the visualisation of the geometric model, together with parameters, at any stage in the analysis. (N.B. Stages 2 to 5 are not required to visualise the body data input in Stage 1.) **This only applies to AQWA-AGS**, as all other programs must progress from one stage to another with NO stages omitted.

### **5.3 STAGES OF ANALYSIS**

A typical analysis using AQWA-LINE requires the following stages:

1. Select a consistent set of units.
2. Identify the geometric and material data for the body or bodies.
3. Specify one or more point masses to represent the mass and mass inertia for each of the structures.
4. If the body is floating, then the equilibrium position must be known. This may be obtained from AQWA-LIBRIUM or from the body's hydrostatic curves of form. If the vessel is moored, then the resulting stiffness effect may also be included in the analysis (see Section 4.7.2 and AQWA-LIBRIUM manual).
5. Identify and specify the range of wave frequencies and directions at which the diffraction/radiation analysis parameters are required.
6. Specify the water depth and the density of the water.
7. Calculate the co-ordinates of the node points for each element used in modelling the body.
8. Code up the above information in a suitable manner acceptable to AQWA-LINE (see AQWA Reference Manual and Chapter 6 of this manual). The use of the graphics program AQWA-AGS is most useful when doing this.
9. Perform a DATA run (i.e. use the DATA program option) which will provide checks on the model input and the modelling technique employed. Note that the DATA option performs Stages 1 and 2 of the analysis and is therefore equivalent to a restart 1 to 2. It is also most useful to use the PPEL option on the first run, as this gives detailed properties of all elements used and facilitates comprehensive checking. Note that the data run will create a restart file containing all information regarding the structural details of the body input.
10. After a successful DATA run the diffraction/radiation calculations are undertaken. This is the kernel of the AQWA-LINE program and a restart Stage 3 of the analysis performs this task. The hydrodynamic loads will be calculated together with the RAOs. Note that the hydrodynamic DATABASE will now contain all the relevant wave loading information for each wave frequency and direction.
11. View results using the graphics program AQWA-AGS.

- 12.\* If more wave frequencies are required, to supplement the previous number specified, then the user may specify additional frequencies for analysis, but the total number of wave frequencies that may be held in the restart file at any one time is 50. Any additional frequencies may be joined to the previous results by re-running Stage 3 of the analysis with the required additional frequencies indicated (see Section 2.6 of AQWA Reference Manual).
13. Following the diffraction/radiation analysis, all hydrodynamic wave loads will have been calculated, together with the RAOs for the bodies. The user may then perform various other calculations within restart Stages 4 and 5, using AQWA-LINE, for example, changes in mass distribution and scaling may be undertaken (see Chapter 6).
14. Use of AQWA-LINE results within other programs in the AQWA Suite.

If spectral analysis for irregular sea-states is required, then the program AQWA-FER may be used, in conjunction with the restart file created by the previous AQWA-LINE program run.

If a time history analysis involving regular or irregular waves is required, then the program AQWA-NAUT may be used. This program can also utilise the AQWA-LINE restart file, if the structural model is acceptable. If the model of the body has to be altered in any way, then the hydrodynamic database is used to supply the revised restart file with the relevant diffraction wave loads for the frequencies and directions previously defined.

If an irregular wave time history analysis is required, which involves slowly varying drift motion, then the AQWA-LINE restart file may again be used in association with AQWA-DRIFT.

- \* It is suggested this part of an AQWA-LINE analysis is ignored by the new user. Therefore, the new user is advised to choose the wave frequencies carefully and should any additional frequencies be required, it is best to run a new AQWA-LINE analysis with all frequencies.

## **CHAPTER 6 - DATA REQUIREMENT AND PREPARATION**

This chapter describes the form in which data is expected by the program and is intended as a list of the data **requirements** and general format for each type of analysis that may be performed when running AQWA-LINE. The detailed format for data preparation may be found in the AQWA Reference Manual.

The data is divided into units of related information called **decks**. Each deck is composed of a deck identifier and a number of data input strings written in card image format. Full details of deck structuring are given in the AQWA Reference Manual.

A summary of all possible data that may be input is listed, together with a summary for various forms of analysis. In this latter case, a **typical** input data summary is given, where the more unusual facilities have been omitted.

## **6.0 ADMINISTRATION CONTROL ( DECK 0) PRELIMINARY DECK**

This deck is always required when performing AQWA program analysis runs. The information input relates directly to the administration of the job being done and the control of the AQWA program being used.

Program control has the following functions:

- identification of the program to be used within the AQWA suite
- the type of program analysis to be performed (i.e. if choice exists)
- the analysis stage to be performed (i.e. restart stages)

Administration of the analysis being performed:

- user title identification given to the analysis
- choice of output required from program run (i.e. program options)

The above information is input to the program through the following cards contained in Deck 0:

- |              |   |  |
|--------------|---|--|
| JOB card     | - | This contains information stating the program to be used, the type of program analysis to be undertaken, and the user identifier for the run in question.  |
| TITLE card   | - | This lets the user prescribe a title for the run.  |
| OPTIONS card | - | Various program options are available within the AQWA suite, some of which are common to all programs, others of which are for use with specific programs. The options for AQWA-LINE control the type of output required from the program and the restart stages of analysis to be performed (see Appendices A and B). |
| RESTART card | - | If the restart option is used, then the start and finish stages of analysis must be prescribed via the restart card.   |

For complete details of the above card formats, see the AQWA Reference Manual. For a list of options for use within AQWA-LINE, see Appendix A.

One option commonly used is the DATA option and it is worth noting its purpose. The DATA option performs Stages 1 and 2 of an AQWA-LINE analysis. This means that all information relating to the body and the regular wave environment is read in, allowing all data checking to be performed. After the user is satisfied with the acceptance of data, then a diffraction analysis can be undertaken by restarting the program at Stage 3 and progressing as necessary.

Another important program option involves the Mean Wave Drift forces. If these are not required, then the AQWA-LINE program option NODR may be used to inform AQWA-LINE not to perform the calculation.

## **6.1 STAGE 1 (DECKS 1 TO 5) GEOMETRIC DEFINITION AND STATIC ENVIRONMENT**

Input to Stage 1 of the analysis is only necessary if the restart stage at which the analysis begins is 1 (see Chapter 5 for details). If the restart stage is greater than 1, there is NO INPUT for Stage 1 of the analysis, as all definitions of body geometry and static environment are to be read in from the restart backing file created by previous AQWA-LINE runs.

### **6.1.1 Description of Physical Parameters Input**

The data input in Decks 1 to 5 relates to the description of each body and the environment, which normally remains unchanged throughout the analysis. This normally includes the following parameters:

- the coordinates of any node point on or surrounding the structure, referenced by any other deck
- an element distribution describing the body mass characteristics, together with the hydrostatic and hydrodynamic surface geometries (see AQWA Reference Manual for the range of elements that may be used in AQWA-LINE)
- a table of material values associated with elements used in the body description (i.e. mass or density values)
- a table of geometrical values associated with elements used in the body description (i.e. inertial properties, tube diameter and thickness)
- the depth and density of the water and acceleration due to gravity

### **6.1.2 Description of General Format**

The input format for Decks 1 to 5 is designed to provide checking on the data for the average user and the program outputs a suitable message to inform the user if the instructions for data preparation have been misinterpreted or are unusual. When running data for the first time it is recommended that the PRCE option is used (see Appendix A), as the data input in these decks is output automatically in order that the user may check the interpretation before proceeding to the next stage of the analysis.



### **6.1.3 Data Input Summary for Decks 1 to 5**

|        |   |  |
|--------|---|--|
| Deck 1 | - | Coordinates of node points                       |
|        | - | Node numbers                                     |
| Deck 2 | - | Elements used to model body's wetted surface     |
|        | - | Elements used to model mass distribution of body |
| Deck 3 | - | Table of element material properties             |
| Deck 4 | - | Table of element geometrical properties          |
| Deck 5 | - | Static environmental parameters                  |

The above information is required before an AQWA-LINE diffraction/radiation calculation can be performed. The information contained within Decks 1 to 5 must be input into AQWA-LINE and the AQWA Reference Manual gives details of the format for these input data decks.

## 6.2 STAGE 2 (DECKS 6 TO 8) THE DIFFRACTION/RADIATION ANALYSIS PARAMETERS

### 6.2.1 Description of Physical Parameters Input

The data input in these decks relates to the equation of motion of a diffracting body or bodies in regular waves for a range of frequencies and directions. (Note that the structural mass is input in Decks 1 to 5.) For a specified range of frequencies and directions the equation of motion can be written (to first order) as:

$$M(s)\ddot{x} + M(a)\ddot{x} + C(r)\dot{x} + K x = F(d) + F(k)$$

Then the parameters in the equation of motion are:

- K - The Linear Stiffness Matrix, with associated values of
- The Buoyancy Force at Equilibrium
- Global Z Coordinate of the Centre of Gravity at Equilibrium

and, for each frequency,

- M(a) - Added Mass Matrix
- C(r) - Radiation Damping Matrix

and, for each frequency and each direction,

- x - Motion Responses (i.e. Response Amplitude Operators or RAOs)
- F(d) - Wave Diffraction Forces
- F(k) - Wave Froude Krylov Forces

All the above parameters may be input explicitly into the program through Decks 6 to 8 (in which case no radiation/diffraction analysis would be required). It is more usual, however, to specify simply the body's position via vertical placement of the centre of gravity with respect to the water surface, and inform AQWA-LINE of the frequencies and directions at which the diffraction/radiation calculations are to be performed (i.e. for wave forces, added mass, etc).

### 6.2.2 Description of General Format

The input format and restrictions in these decks are designed to provide maximum cross checking on the data input when the more advanced facilities are used. This ensures that the program is able to output a suitable message to inform the user that the instructions for data preparation have been misinterpreted. In any event, the interpretation of the data input in Decks 6 to 8 is output automatically in order that the user may check this before proceeding to the next stage of the analysis.

It is important to recognise the different function of the specification of the frequencies and directions when using AQWA-LINE. The program AQWA- LINE is used to CALCULATE or DEFINE the hydrodynamic diffraction/radiation analysis parameters. Other programs REQUIRE these hydrodynamic parameters to perform an analysis, i.e.

- For AQWA-LINE, the range of frequencies and directions specified are those at which the hydrodynamic parameters are to be CALCULATED (N.B. one may also define the hydrodynamic parameters).
- For AQWA-LIBRIUM/FER/DRIFT/NAUT, parameters are read from backing file automatically or may be input manually. In the latter case, the range of frequencies and directions specified are those at which the parameters are to be INPUT within these decks.

### **6.2.3 Total Data Input Summary for Decks 6 to 8**

- |        |   |
|--------|---|
| Deck 6 | <ul style="list-style-type: none"><li>- A range of frequencies</li><li>- A range of directions</li><li>- Details relating to alterations of the results of a previous run</li></ul>   |
| Deck 7 | <ul style="list-style-type: none"><li>- Linear hydrostatic stiffness matrix</li><li>- Additional stiffness matrix</li><li>- The buoyancy force at equilibrium (usually not required)</li><li>- Global Z coordinate of the centre of gravity at equilibrium</li><li>- Added mass matrix</li><li>- Additional mass matrix (usually not required)</li><li>- Radiation damping matrix</li><li>- Additional linear damping matrix (usually not required)</li><li>- Diffraction forces</li><li>- Froude Krylov forces</li><li>- Motion responses (or RAOs. For checking only)</li></ul> |
| Deck 8 | <ul style="list-style-type: none"><li>- Second Order Mean Wave Drift Forces</li></ul>   |

Usually, not all the data items above are required for any particular analysis, in which case the user simply omits the items which are not applicable. The following sections show the required data input for the available modes of analysis.

#### **6.2.4 Input for AQWA-LINE using Results of a Previous AQWA-LINE Run**

If there are no changes to the results from a previous AQWA-LINE run, all the data is read automatically from the backing file and this stage is completely omitted. In this case, these decks are not required at all and must be removed from the card image data deck. The analysis is re-started at the beginning of Stage 4.

Deck 6 to 8 - No Input Required

#### **6.2.5 Input for AQWA-LINE for Complete Hydrodynamic Calculation**

If it is required to perform the diffraction/radiation hydrodynamic calculations for a complete range of frequencies and directions then only these need be input, together with any additional linear stiffness terms (e.g. mooring stiffness about the equilibrium position).

Typical input data required for different cases are as follows:

a) for a run for a range of frequencies and directions

Deck 6 - A range of frequencies  
- A range of directions

Deck 7 - No input required code NONE for the deck header

Deck 8 - No input required code NONE for the deck header

b) for a run involving an additional linear stiffness

Deck 6 - A range of frequencies  
- A range of directions

Deck 7 - Additional linear stiffness matrix

Deck 8 - No input required code NONE for the deck header

Details of the card image format are given in the AQWA Reference Manual.

### **6.2.6 Input for AQWA-LINE with Results of a Previous AQWA-LINE Run and a Source other than AQWA-LINE**

**The new user is advised to ignore this facility**

If the user wishes to APPEND to or CHANGE the parameters calculated by a previous AQWA-LINE run for the current analysis, this is achieved by simply using the card image input as described below, while also reading the results from a previous AQWA-LINE run.

- |        |   |
|--------|---|
| Deck 6 | - A range of frequencies<br>- A range of directions   |
| Deck 7 | - Added mass matrix<br>- Radiation damping matrix<br>- Diffraction forces<br>- Froude Krylov forces |
| Deck 8 | - Second order mean wave drift forces   |

As the program does not expect a backing file from AQWA-LINE to exist at Stage 2 of the analysis, the ALDB option (see Appendix A) or CPDB card in Deck 6 must be used, to indicate that it exists and must be read. **Using this option means that the Stage 2 data is read twice, once from the hydrodynamic database (.HYD) file, and once from the input data file (Decks 6 to 8).**

To APPEND to the parameters calculated in a previous run, additional frequencies, which differ from those existing, may be input in Deck 6, together with values of the appropriate frequency-dependent parameters, in Decks 7 and 8, at these additional frequencies. Note that as all parameters are defined for a unique range of directions, these directions may not be re-defined.

To CHANGE the parameters calculated in a previous run, these parameters are simply input in Decks 7 and 8 and, depending on the type of input (see individual deck sections in the AQWA Reference Manual), the parameters will be either overwritten with the input values or become the sum of input values and original values.

## **6.3 STAGE 3 (NO INPUT) DIFFRACTION/RADIATION ANALYSIS**

### **6.3.1 Stage 3 in AQWA-LINE**

The Restart Stage 3 in AQWA-LINE is the kernel of the program, in that it is this part of the program which performs the diffraction/radiation calculations and the solution of the oscillatory rigid body motions. Therefore, it is **important** to make sure that the data previously input is correct. **No card image input** is required to perform the Stage 3 diffraction analysis.

Typically, the Stage 3 analysis is performed following a DATA run (via the DATA option). This is very good practice, because it allows the user to check the data comprehensively. Obviously, the user may perform Stages 1 to 3 in one run but this is only recommended when previous successful runs are being repeated for some reason.

Following an AQWA-LINE data run, Stage 3 requires:

- Deck 0 only, with suitable options chosen and a restart card informing the program to start at Stage 3 and finish at a stage which is greater than or equal to 3.

## **6.4 STAGE 4 (DECKS 9 to 18) INPUT OF THE ANALYSIS ENVIRONMENT**

This stage of the AQWA suite is used to INPUT parameters relating to the analysis environment. This encompasses such global influences as sea- spectra, wind and current loading, together with more localised influences, such as element hydrodynamic coefficients and geometrical changes in body characteristics.

Stage 4 allows the user to input the required analysis parameters without instigating any motion analysis and this allows detailed data checking to be undertaken.

### **6.4.1 Description of Parameters Input**

When using AQWA-LINE, only a certain number of Decks between 9 and 18 are used. The decks that may be used for input are as follows.

- Deck 16      The GEOMETRICAL CHANGES deck allows the user to SCALE or CHANGE parameters within the analysis. The parameters which may be scaled or changed are:
- scaling of hydrodynamic results via the characteristic length of the body or bodies previously analysed (N.B. the wave frequency and water depth also are scaled)
  - scaling of the mass of the body or bodies previously analysed (N.B. this is a variation of length scaling because mass is proportional to a characteristic length cubed)
  - the MASS INERTIA characteristics of the body may be changed
  - the CENTRE OF GRAVITY of a body may be changed in the VERTICAL direction
  - specification of a new HYDRODYNAMIC REFERENCE POINT allows the hydrodynamic properties and rigid body motions to be calculated for any point on the body
- Deck 18      Positions of nodes for which RAOs are required

All other decks, which are not used, must have the deck header set equal to NONE (see AQWA Reference Manual).

### **6.4.2 Description of General Format**

It is important to recognise the difference between SCALING and CHANGING parameters. When the term 'scaling' is used, there is no re-resolution of the equations which give the rigid body motions. When the term 'changing' is used, then this means that the parameter is changed within the equations characterising the rigid body motions, and thus a new solution of the equations is required.

When re-starting the program from Stage 4 for post-processing, it is useful to know what structural and environmental information is being stored on the restart and hydrodynamic database files. To obtain a print out of this information, the user simply uses the PRDL program option (see Appendix A).

### **6.4.3 Data Input Summary for Decks 9 to 18**

- Deck 16
- A SCALE FACTOR for the new characteristic body dimension
  - A SCALE FACTOR for the new mass of the body.
  - New MASS INERTIA values for the body, calculated with respect to the centre of gravity
  - A New VERTICAL COORDINATE for the centre of gravity of the body, measured with respect to the body in the original position used for modelling
  - The COORDINATES of the new hydrodynamic reference point, measured with respect to the body in the original position used for modelling
- Deck 18
- Structure and Node numbers of nodes for which RAOs are required

It would be extremely unusual for all the above data to be required for a geometrical changes post-processing analysis. Only those changes required are to be input (see AQWA Reference Manual).



## **6.5 STAGE 5 (NO INPUT) MOTION ANALYSIS**

This stage instigates motion study analysis, using the parameters input throughout Decks 9 to 18 in Stage 4.

Within AQWA-LINE, the first order oscillatory rigid body motions are solved in the Stage 3 analysis (see Section 6.3.1). Therefore, the calculation is **not repeated unless changes** in the body's mass distribution are required (i.e. changes in inertia or centre of gravity via Deck 16 in Stage 4).

### **6.5.1 Input Related to Backing Files and Listing File Output**

The results of all but one AQWA-LINE post-processing analysis for **CHANGE OF geometrical properties** (Deck 16) will be both output to the listing file and stored in the restart and hydrodynamic database backing files. The only exception is the post-processing analysis for the **change of hydrodynamic reference point**, where the results are output to the listing file only (see Section 5.3).

## **6.6 STAGE 6 (NO DECKS) GRAPHICAL DISPLAY**

The AQWA suite has its own graphics program called the AQWA Graphical Supervisor (AGS). This program is used to perform the following tasks:

- Visualisation and checking of the discretised element model used to generate the surface of the body
- Plotting of the body position and motion trajectories to aid physical understanding of the problem
- Tabulation of important parameters within the motion study analysis

For details of the graphics facilities within the AQWA-AGS program, see the AQWA-AGS Users Manual.

### **6.6.1 Input for Display of Model and Results**

The program AQWA-AGS is an interactive graphics program. This means that the program requires instructions or commands from the user while it is running so that it knows what type of picture to plot. The user may request various forms of plots and graphs but before any graphical output can be produced the program must have a structural form to work with.

All information regarding the body characteristics is held within the RESTART file created by previous AQWA suite runs. Therefore the appropriate restart file is simply assigned to AQWA-AGS and this may be interrogated when the user requests a particular type of plot.

When the AQWA suite time-history programs (AQWA-DRIFT/NAUT) are being used, it is convenient to store the time dependent motion trajectories on a results backing file, which may be also assigned to AQWA-AGS for the plotting of time-dependent results (see AQWA-DRIFT/NAUT/AGS User Manuals).

## **CHAPTER 7 - DESCRIPTION OF OUTPUT**

This chapter describes the comprehensive program output provided by AQWA-LINE. The various program stages perform different types of analysis and the output for each stage of analysis is described in detail.

## 7.1 STRUCTURAL DESCRIPTION OF BODY CHARACTERISTICS

### 7.1.1 Properties of All Body Elements

The body's surface geometry and mass characteristics are input to AQWA-LINE through input Decks 1 to 4 (see Section 6.1). These data decks define the following parameters (see AQWA Reference Manual):

- Node numbers and positions
- Elements used to model the body
- Material properties of the various elements
- Geometry group properties of the elements

The information received by AQWA-LINE, to define the body characteristics, is output for checking. The body's resulting centre of mass and inertia matrix are also output. The nodal coordinates are output in the Fixed Reference Axes in the format shown in Figure 7.1.

| * * * * C O O R D I N A T E   D A T A * * * * |      |        |         |       |
|---|------|--------|---------|-------|
| - - - - -                                     |      |        |         |       |
| INPUT   | NODE |        |         |       |
| SEQUENCE                                      | NO.  | X      | Y       | Z     |
| -----   |      |        |         |       |
| 1   | 10   | 0.000  | -25.000 | 0.000 |
| 2   | 11   | 5.833  | -25.000 | 0.000 |
| 3   | 12   | 11.667 | -25.000 | 0.000 |
| 4   | 13   | 17.500 | -25.000 | 0.000 |
| 5   | 14   | 23.333 | -25.000 | 0.000 |
| 6   | 15   | 29.167 | -25.000 | 0.000 |
| 7   | 16   | 35.000 | -25.000 | 0.000 |

**Figure 7.1 - Nodal Coordinate Output**

Following the nodal coordinates, each body's element topology is output. The body topology describes the elements used in the model of the body (see Section 4.4.2). Details of each element are also output, as shown in Figure 7.2. The bodies used each have a specific structure number associated with their output and this appears in the title of the output.

It is also worth noting that the element topology output may be enhanced by more detailed information. This is obtained by using the PPEL program option (i.e. Print Properties of Elements).

| * * * E L E M E N T   T O P O L O G Y   F O R   S T R U C T U R E   1 * * * |         |             |             |             |             |                 |                 |
|---|---------|-------------|-------------|-------------|-------------|-----------------|-----------------|
| -----   |         |             |             |             |             |                 |                 |
| E L E M E N T   |         | N O D E     | N O D E     | N O D E     | N O D E     | M A T E R I A L | G E O M E T R Y |
| N U M B E R   | T Y P E | N U M B E R | N U M B E R | N U M B E R | N U M B E R | N U M B E R     | N U M B E R     |
| -----   |         |             |             |             |             |                 |                 |
| 1   | QPPL    | 10          | 30          | 31          | 11          | 0               | 0               |
| 2   | TPPL    | 150         | 141         | 151         | 0           | 0               | 0               |
| 3   | QPPL    | 11          | 31          | 32          | 12          | 0               | 0               |
| 4   | QPPL    | 17          | 37          | 38          | 18          | 0               | 0               |
| 5   | PMAS    | 9999        | 0           | 0           | 0           | 1               | 1               |

**Figure 7.2 - Element Topology Output**

The body topology output references the material group number which has a mass or density value associated with it. The material group numbers are output as shown in Figure 7.3.

| * * * * M A T E R I A L   P R O P E R T I E S * * * * |               |
|---|---------------|
| -----   |               |
| MATERIAL  |               |
| GROUP   |               |
| NUMBER  | DENSITY/VALUE |
| -----   |               |
| 1   | 7.5594E+07    |
| 2   | 5.7525E+04    |
| 3   | 1.0250E+06    |

**Figure 7.3 - Material Property Output**

The topology output also references the geometry group numbers defined by the user. Each geometry group may have a range of properties associated with it. The number of relevant properties depends on the type of element under consideration. The required geometrical properties for each type of element used in AQWA-LINE are shown in the AQWA Reference Manual. The geometry group numbers and the various parameters within each group are output as shown in Figure 7.4. Here the point mass element contains the full six geometric parameters which are the prescribed inertia values. The localised element drag and added mass coefficients are also printed. (Note that drag is redundant within AQWA-LINE, but may be of importance in other AQWA suite programs e.g. AQWA-NAUT.)

|   |            |            |                                       |             |            |
|---|------------|------------|---------------------------------------|-------------|------------|
| * * * * G E O M E T R I C   P R O P E R T I E S * * * * |            |            |                                       |             |            |
| - - - - -   |            |            |                                       |             |            |
| GEOMETRY  |            |            |                                       |             |            |
| INPUT   | GROUP      | ELEMENT    | G E O M E T R I C   P A R A M E T E R |             |            |
| SEQUENCE  | NO.        | TYPE       | 1                                     | 2           | 3          |
| -----   |            |            |                                       |             |            |
| 1   | 1          | PMAS       | 3.0237E+10                            | 0.0000E+00  | 0.0000E+00 |
| .....(output line continued below).....                 |            |            |                                       |             |            |
|   |            |            | DRAG                                  | ADDED MASS  |            |
| N U M B E R   |            |            | COEFFICIENT                           | COEFFICIENT |            |
| 4   | 5          | 6          | C                                     | C           |            |
|   |            |            | D                                     | M           |            |
| -----   |            |            |                                       |             |            |
| 1.1498E+11  | 0.0000E+00 | 1.1498E+11 | 0.00                                  | 0.00        |            |

**Figure 7.4 - Geometric Property Output**

The program, having accepted the user prescribed element distribution, now outputs the resulting mass and inertia characteristics of the first body being modelled. An example of output is shown in Figure 7.5. The coordinates of the centre of gravity are with respect to the Fixed Reference Axes used in defining the body, and the inertia matrix is about the centre of gravity of the particular body. The types and total number of elements used to model the body are output. The number of elements output is based on the total coverage of the body's wetted surface and not the number input when utilising the program symmetry facilities.

|  |           |            |            |
|--|-----------|------------|------------|
| * * * * * MASS AND INERTIA PROPERTIES OF STRUCTURE 1 * * * * * |           |            |            |
| -----  |           |            |            |
| NUMBER<br>OF<br>ELEMENT TYPE                                   | ELEMENTS  | MASS       | WEIGHT     |
| -----  | -----     | ----       | -----      |
| PMAS   | 1         | 7.5594E+07 | 7.4158E+08 |
| TPPL   | 12        | 0.0000E+00 | 0.0000E+00 |
| QPPL   | 200       | 0.0000E+00 | 0.0000E+00 |
| -----  |           |            |            |
| T O T A L  | 213       | 7.5594E+07 | 7.4158E+08 |
| -----  |           |            |            |
|  | X         | Y          | Z          |
|  | -----     | -----      | -----      |
| CENTRE OF GRAVITY  | 1.100     | 1.175      | 35.000     |
| INERTIA MATRIX   | 3.024E+10 | 0.000E+00  | 0.000E+00  |
|  | 0.000E+00 | 1.150E+11  | 0.000E+00  |
|  | 0.000E+00 | 0.000E+00  | 1.150E+11  |

**Figure 7.5 - Resulting Mass and Inertia**

### **7.1.2 Properties of Diffracting Elements**

The diffracting elements used in AQWA-LINE are very important and their definition should conform to the modelling rules (see Section 4.4.3). To help the user conform to the rules relating to the placement and sizing of the elements, the program outputs a Preliminary Diffraction Modelling Check and a Secondary Diffraction Modelling Check.

An example of the preliminary check list is shown in Figure 7.6. We see that each diffracting element is referenced by the element number which was previously assigned to it in the body topology output (see Section 7.1.1). Complete details of the element are output and this includes the following parameters:

- Node numbers used to define the element (for node number coordinates see nodal coordinate output)
- Equivalent radius of the element (facet radius) (see Section 4.4.3)
- Individual area of the element (facet area)
- Position of the centroid of area (in the Fixed Reference Axes)
- Correction factor of the element which should be as close to unity as possible (see Section 4.4.3)
- The outward body normals of each surface element in three directions
- Aspect ratio of each element (the aspect ratio should be greater than 1/3 for good modelling, as explained in Section 4.4.3)
- Shape Factor of the element (this parameter gives an indication of the overall form or shape of an element and should always be positive and as close to unity as possible. If not, the input details of the element should be checked by the user)
- Minimum Radius Ratio between connecting element centres (this should be greater than unity for a good model)
- Minimum Area Ratio of each element with those elements adjacent to it (this should be greater than 1/3)



```

* * * * PRELIMINARY DIFFRACTION MODELLING CHECK * * * *
-----
* * * * FOR STRUCTURE 1 * * * *
-----

ELEMENT      NODE NUMBERS      FACET      FACET      POSITION OF CENTROID
NUMBER      1      2      3      4      RADIUS      AREA      X      Y      Z
-----

1      10      30      31      11      4.31      58.3      2.92      -25.00      -5.00
2      11      31      32      12      4.31      58.3      8.75      -25.00      -5.00
3      12      32      33      13      4.31      58.3      14.58      -25.00      -5.00
4      13      33      34      14      4.31      58.3      20.42      -25.00      -5.00
5      14      34      35      15      4.31      58.3      26.25      -25.00      -5.00

.....(output line continued below).....

CORRECTION      OUTWARD NORMALS      ASPECT      SHAPE      MINIMUM AREA
FACTOR      X      Y      Z      RATIO      FACTOR      RADIUS      RATIO
-----

0.973      0.000      -1.000      0.000      0.583      1.00      1.35      1.00
0.973      0.000      -1.000      0.000      0.583      1.00      1.35      1.00
0.973      0.000      -1.000      0.000      0.583      1.00      1.35      1.00
0.973      0.000      -1.000      0.000      0.583      1.00      1.35      1.00
0.973      0.000      -1.000      0.000      0.583      1.00      1.35      1.00

```

Figure 7.6 - Preliminary Diffraction Check

The Secondary Diffraction Modelling Check performed by AQWA-LINE relates the diffracting elements to the environmental parameters. The diffracting elements should conform to the modelling rules given in Section 4.4.3 which involve the following:

- Placement of element with respect to the sea-bed and free-surface of the fluid
- Ratio of longest element side to the length of the incident wave form

These criteria are checked in the secondary diffraction checking stage and the form of this output is shown in Figure 7.7. The output is seen to give details of the elements accepted by AQWA-LINE, and those ignored because they do not satisfy the above criteria.

|   |       |
|---|-------|
| * * * * SECONDARY DIFFRACTION MODELLING CHECK * * * * |       |
| -----   |       |
| * * * * FOR STRUCTURE 1 * * * *                       |       |
| -----   |       |
| DEPTH OF LOWEST POINT ON VESSEL . . . . .             | 10.00 |
| SEA BED CLEARANCE OF LOWEST POINT ON VESSEL .         | 40.00 |
| MAX RATIO OF ELEMENT SIDE TO 1/7 WAVELENGTH .         | 1.50  |
| NUMBER OF MORISON POINTS . . . . .                    | 1     |
| NUMBER OF DIFFRACTING ELEMENTS . . . . .              | 53    |
| NUMBER OF DIFFRACTING ELEMENTS IGNORED . . .          | 0     |
| NUMBER OF FIELD POINTS . . . . .                      | 0     |
| NUMBER OF FIELD POINTS IGNORED . . . . .              | 0     |
| TOTAL NUMBER OF DIFFRACTION POINTS . . . . .          | 53    |

**Figure 7.7 - Secondary Diffraction Check**

## 7.2 DESCRIPTION OF ENVIRONMENT

The environmental parameters within AQWA-LINE consist only of fluid depth and density, together with information relating to the regular waves. The static environment is output, as shown in Figure 7.8, and is seen to contain the water depth and density. Note that the gravitational acceleration is also output.

| * * * * G L O B A L   P A R A M E T E R S * * * * |   |          |
|---|---|----------|
| - - - - -   |   |          |
| WATER DEPTH . . . . .                             | = | 50.000   |
| DENSITY OF WATER . . . . .                        | = | 1025.000 |
| ACCELERATION DUE TO GRAVITY . . . . .             | = | 9.810    |

**Figure 7.8 - Static Environment**

The wave environment is now output. AQWA-LINE may have up to 50 wave frequencies/ periods and ten associated wave directions for each body in the analysis. The output summary of wave frequencies and directions is shown, for Structure 1, in Figure 7.9.

The output also shows details of other wave related parameters:

- Wave number ( $2.0 * \pi / \text{wavelength}$ )
- Maximum element size (up to a maximum of  $1/7$  of wavelength)
- Depth ratio (see Section 4.4.3, regarding exponential wave decay)

The final piece of information given in Figure 7.9 relates to the frequency dependent parameters (i.e. added mass, etc). If these parameters have not already been calculated for certain frequencies, then these frequencies are listed as having undefined parameters.

| * * * * WAVE FREQUENCIES/PERIODS AND DIRECTIONS * * * * |                      |           |           |           |           |           |
|---|----------------------|-----------|-----------|-----------|-----------|-----------|
| -----   |                      |           |           |           |           |           |
| STRUCTURE   | VARIABLE             | 1         | 2         | 3         | 4         |           |
| -----   |                      |           |           |           |           |           |
| 1   | DIRECTION (DEGREES)  | 180.00    | 90.00     | 0.00      | 0.00      |           |
|   | FREQUENCY (RADS/SEC) | 0.50265   | 0.52360   | 0.62832   | 0.78540   |           |
|   | FREQUENCY (HERTZ)    | 0.08000   | 0.08333   | 0.10000   | 0.12500   |           |
|   | PERIOD (SECONDS)     | 12.50     | 12.00     | 10.00     | 8.00      |           |
|   | WAVE NUMBER (K)      | 0.02881   | 0.03067   | 0.04153   | 0.06311   |           |
|   | WAVELENGTH (L)       | 218.05    | 204.83    | 151.30    | 99.56     |           |
|   | MAXIMUM ELEMENT SIZE | 31.15     | 29.26     | 21.61     | 14.22     |           |
|   | DEPTH RATIO (D/L)    | 0.23      | 0.24      | 0.33      | 0.50      |           |
|   | DEPTH RATIO (K*D)    | 1.44      | 1.53      | 2.08      | 3.16      |           |
|   | PARAMETERS           |           |           |           |           | UNDEFINED |
| -----   |                      |           |           |           |           |           |
|   |                      | 5         | 6         | 7         | 8         | 9         |
|   |                      | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      |
|   |                      | 0.89760   | 0.00000   | 0.00000   | 0.00000   | 0.00000   |
|   |                      | 0.14286   | 0.00000   | 0.00000   | 0.00000   | 0.00000   |
|   |                      | 7.00      | 0.00      | 0.00      | 0.00      | 0.00      |
|   |                      | 0.08217   | 0.00000   | 0.00000   | 0.00000   | 0.00000   |
|   |                      | 76.46     | 0.00      | 0.00      | 0.00      | 0.00      |
|   |                      | 10.92     | 0.00      | 0.00      | 0.00      | 0.00      |
|   |                      | 0.65      | 0.00      | 0.00      | 0.00      | 0.00      |
|   |                      | 4.11      | 0.00      | 0.00      | 0.00      | 0.00      |
|   |                      | UNDEFINED | UNDEFINED | UNDEFINED | UNDEFINED | UNDEFINED |
| -----   |                      |           |           |           |           |           |

Figure 7.9 - Wave Properties

## **7.3 DESCRIPTION OF FLUID LOADINGS**

The output detailing the various fluid loadings will now be described and this is done by way of the different categories of loading.

### **7.3.1 Hydrostatic Properties**

The hydrostatic fluid loading details output by AQWA-LINE are for the body in the ANALYSIS position (see Section 4.3.3). The hydrostatic output is grouped into the following four categories and these are described below with reference to Figure 7.10.

#### **1. Stiffness Matrix at the Centre of Gravity**

The coordinates of the centre of gravity are output and are with respect to the Fixed Reference Axes, with the body in the prescribed analysis position. The heave, roll and pitch components of the hydrostatic stiffness matrix are given and the matrix is with respect to the centre of gravity of the body.

#### **2. Hydrostatic Displacement Properties**

The AQWA-LINE analysis position is normally one of equilibrium (see Section 3.1.2). The actual and equivalent volumetric displacements are given, together with the coordinates of the centre of buoyancy. These coordinates are again measured with the body in the analysis position and with respect to the Fixed Reference Axes. The completeness of the hull model is checked by considering the normalised force/moment components output.

#### **3. Cut Water Plane Area Properties**

The properties of the cut water plane of the body are output and these include the total area, centre of area and principal second moments of area. The angle PHI output is the angle between the principal cut waterplane axes of the body and the Fixed Reference Axes (Note that the X and Y axes of the FRA are on the free surface).

#### **4. Small Angle Stability Parameters**

The parameters output are in standard naval architectural terms. They include the vertical distance between the centre of gravity and the centre of buoyancy (measured w.r.t. the centre of buoyancy). The metacentres are also output together with the metacentric heights. These allow the restoration per unit degree of rotation to be calculated and output.

```

* * * * HYDROSTATIC PROPERTIES IN THE FREE FLOATING POSITION * * * *
-----
* * * * FOR STRUCTURE 1 * * * *
-----

1. STIFFNESS MATRIX AT THE CENTRE OF GRAVITY
-----

C.O.G      GX=      0.000 GY=      0.000 GZ=      0.000

HEAVE( Z) =      7.541E+07      -1.033E+02      -5.892E+01
ROLL(RX)  =      -1.033E+02      1.205E+10      2.209E+02
PITCH(RY) =      -5.892E+01      2.209E+02      1.377E+11

2. HYDROSTATIC DISPLACEMENT PROPERTIES
-----

ACTUAL VOLUMETRIC DISPLACEMENT . . . . . = 7.375E+04
EQUIVALENT VOLUME OF STRUCTURE . . . . . = 7.375E+04

POSITION OF THE CENTRE OF BUOYANCY      BX =      0.000
                                          BY =      0.000
                                          BZ =     -4.944

AN INCOMPLETE ELEMENT DESCRIPTION OF    FX =      0.000
THE HULL GIVES OUT OF BALANCE FORCES     FY =      0.000
AND MOMENTS. IF THE C.O.B. IS NOT        FZ =      0.000
BELOW THE C.O.G. THIS GIVES OUT OF      MX =      0.000
BALANCE MOMENTS (FORCES ARE DIVIDED     MY =      0.000
BY THE WEIGHT AND ARE W.R.T. AXES       MZ =      0.000
PARALLEL TO THE FIXED REFERENCE AXIS)

3. CUT WATER PLANE AREA PROPERTIES
-----

CUT WATER PLANE AREA . . . . . = 7.500E+03
CENTRE OF FLOATATION I.E. CENTROID      X =      0.000
POSITION IN THE FIXED REFERENCE AXES    Y =      0.000
PRINCIPAL SECOND MOMENTS OF AREA       IXX= 1.563E+06
                                          IYY= 1.406E+07
ANGLE THE PRINCIPAL AXES MAKE WITH      PHI=      0.000
THE FIXED REFERENCE AXIS SYSTEM

4. SMALL ANGLE STABILITY PARAMETERS
-----

DISTANCE BETWEEN C.O.G. AND C.O.B      BG =      4.944
METACENTRIC HEIGHTS WITH RESPECT TO    GMX=      16.243
THE PRINCIPAL AXES OF THE CUT AREA     GMY=     185.735
DISTANCE BETWEEN THE C.O.B. AND THE    BMX=      21.186
METACENTRE (BMX=GMX+BG,BMY=GMY+BG)    BMY=     190.678
RESTORING MOMENT ABOUT THE PRINCIPAL   MX = 2.102E+08
AXES PER DEGREE ROTATION              MY = 2.404E+09

```

Figure 7.10 - Hydrostatic Properties

### 7.3.2 Added Mass and Wave Damping

The added mass and wave damping are functions of wave frequency and are therefore output for all specified values of frequency or period. The added mass and wave damping are expressed in matrix form and Figure 7.11 shows a typical added mass matrix for Structure 1 at a single frequency (wave damping being output in a similar format). Summary tables of variation of added mass and wave damping with wave frequency/period are also output.

|   |            |             |            |             |            |            |
|---|------------|-------------|------------|-------------|------------|------------|
| * * * * HYDRODYNAMIC    PARAMETERS    FOR    STRUCTURE    1 * * * * |            |             |            |             |            |            |
| -----   |            |             |            |             |            |            |
| WAVE PERIOD =    12.500    WAVE FREQUENCY =    0.5027               |            |             |            |             |            |            |
|   |            |             |            |             |            |            |
| ADDED    MASS   |            |             |            |             |            |            |
| -----   |            |             |            |             |            |            |
|   | X          | Y           | Z          | RX          | RY         | RZ         |
|   | -----      |             |            |             |            |            |
| X   | 9.5594E+06 | 0.0000E+00  | 0.0000E+00 | 0.0000E+00  | 5.1529E+08 | 0.0000E+00 |
| Y   | 0.0000E+00 | 4.6946E+07  | 0.0000E+00 | -1.0001E+08 | 0.0000E+00 | 0.0000E+00 |
| Z   | 0.0000E+00 | 0.0000E+00  | 1.3339E+08 | 0.0000E+00  | 0.0000E+00 | 0.0000E+00 |
| RX  | 0.0000E+00 | -1.0001E+08 | 0.0000E+00 | 1.4296E+10  | 0.0000E+00 | 0.0000E+00 |
| RY  | 5.1529E+08 | 0.0000E+00  | 0.0000E+00 | 0.0000E+00  | 2.3278E+11 | 0.0000E+00 |
| RZ  | 0.0000E+00 | 0.0000E+00  | 0.0000E+00 | 0.0000E+00  | 0.0000E+00 | 8.0089E+10 |

**Figure 7.11 - Added Mass Matrix Output**

### 7.3.3 Oscillatory Wave Excitation Forces

The oscillatory wave forces/moments are a function of wave frequency and direction. The wave loading output from AQWA-LINE is therefore presented for all the directions and frequencies specified by the user. The output gives the variation of wave force/moment with frequency for each direction (see Figure 7.12). Output is also given with the wave force/moment varying with direction for each frequency.

## Output Description

The wave forces/moments are output in terms of amplitude and phase, the phase being related to the incident wave form (see Section 4.3.2 and AQWA Reference Manual). The wave forces/moments are divided into their various components and output in terms of the following:

- Froude-Krylov forces/moments
- Diffraction forces/moments
- Total Wave forces/moments

(Figure 7.12 shows only the Froude-Krylov component.)

| * * * * HYDRODYNAMIC PARAMETERS FOR STRUCTURE 1 * * * *   |         |           |          |         |          |         |          |         |  |
|---|---------|-----------|----------|---------|----------|---------|----------|---------|--|
| -----   |         |           |          |         |          |         |          |         |  |
| FROUDE KRYLOV FORCES-VARIATION WITH WAVE PERIOD/FREQUENCY |         |           |          |         |          |         |          |         |  |
| -----   |         |           |          |         |          |         |          |         |  |
| PERIOD  | FREQ    | DIRECTION | X        |         | Y        |         | Z        |         |  |
| (SECS)  | (RAD/S) | (DEGREES) | AMP      | PHASE   | AMP      | PHASE   | AMP      | PHASE   |  |
| -----   |         |           |          |         |          |         |          |         |  |
| 12.50   | 0.503   | 180.00    | 7.54E+06 | 90.00   | 1.21E+00 | -79.95  | 2.26E+07 | 0.00    |  |
| 12.00   | 0.524   |           | 6.75E+06 | 90.00   | 2.36E+00 | -90.60  | 1.85E+07 | 0.00    |  |
| 10.00   | 0.628   |           | 6.08E+05 | 90.00   | 6.77E-01 | -107.19 | 1.04E+05 | 0.00    |  |
| 8.00  | 0.785   |           | 7.41E+06 | -90.00  | 1.27E+00 | 112.93  | 8.64E+06 | -180.00 |  |
| 7.00  | 0.898   |           | 1.36E+06 | -90.00  | 1.28E+00 | 94.29   | 1.90E+05 | -180.00 |  |
| 12.50   | 0.503   | 90.00     | 1.41E+00 | -92.53  | 1.73E+07 | -90.00  | 5.43E+07 | 0.00    |  |
| 12.00   | 0.524   |           | 1.37E+00 | -90.00  | 1.80E+07 | -90.00  | 5.25E+07 | 0.00    |  |
| 10.00   | 0.628   |           | 1.58E+00 | -101.42 | 2.10E+07 | -90.00  | 4.26E+07 | 0.00    |  |
| 8.00  | 0.785   |           | 1.67E+00 | -92.15  | 2.18E+07 | -90.00  | 2.61E+07 | 0.00    |  |
| 7.00  | 0.898   |           | 1.45E+00 | -89.38  | 1.75E+07 | -90.00  | 1.48E+07 | 0.00    |  |
| .....(output line continued below).....                   |         |           |          |         |          |         |          |         |  |
|   |         |           |          |         |          |         |          |         |  |
|   |         |           | RX       |         | RY       |         | RZ       |         |  |
|   |         |           | AMP      | PHASE   | AMP      | PHASE   | AMP      | PHASE   |  |
| -----   |         |           |          |         |          |         |          |         |  |
|   |         |           | 1.81E+01 | 120.91  | 1.90E+09 | 90.00   | 7.29E+01 | 171.28  |  |
|   |         |           | 2.14E+01 | 95.88   | 1.84E+09 | 90.00   | 1.54E+02 | -119.43 |  |
|   |         |           | 1.50E+00 | -2.98   | 1.24E+09 | 90.00   | 9.61E+01 | 171.70  |  |
|   |         |           | 7.11E+00 | 61.58   | 1.45E+08 | -90.00  | 3.76E+01 | -159.58 |  |
|   |         |           | 7.45E+00 | -89.28  | 4.17E+08 | -90.00  | 6.30E+01 | 19.81   |  |
| ....  |         |           | 2.44E+08 | 90.00   | 2.57E+02 | -111.28 | 7.57E+01 | 15.25   |  |
|   |         |           | 2.52E+08 | 90.00   | 2.32E+02 | -58.88  | 7.61E+01 | 9.06    |  |
|   |         |           | 2.85E+08 | 90.00   | 4.18E+02 | -147.76 | 1.29E+02 | 30.27   |  |
|   |         |           | 3.02E+08 | 90.00   | 2.87E+02 | -93.70  | 1.65E+02 | 6.63    |  |
|   |         |           | 2.81E+08 | 90.00   | 1.73E+02 | -96.82  | 1.82E+02 | 14.20   |  |

**Figure 7.12 - Froude Krylov Forces/Moments**



### 7.3.4 Mean Wave Drift Forces

The mean wave drift forces and moment in the horizontal plane (for field solution) or in the horizontal and vertical planes (near field solution) are calculated in the horizontal plane are calculated and output by AQWA-LINE. These are functions of wave period and direction.

The form of output for these wave drift loads is shown in Figure 7.13. It is seen that they are given for each body and for the range of user-specified frequencies.

Mean wave drift forces are proportional to wave amplitude squared and are given for unit wave amplitude.

| * * * * WAVE-DRIFT LOADS FOR UNIT WAVE AMPLITUDE * * * * |               |                     |           |
|--|---------------|---------------------|-----------|
| -----  |               |                     |           |
| * * * * FOR STRUCTURE 1 * * * *                          |               |                     |           |
| -----  |               |                     |           |
| FORCES   | FREQUENCY     | DIRECTION (DEGREES) |           |
| -----  | -----         | -----               |           |
| DUE TO   | (RADIANS/SEC) | 180.0               | 90.0      |
| -----  | -----         | -----               | -----     |
| DRIFT  |               |                     |           |
| ----   |               |                     |           |
| SURGE (X)  |               |                     |           |
|  | 0.503         | -1.27E+03           | 2.92E-02  |
|  | 0.524         | -4.25E+03           | 6.97E-02  |
|  | 0.628         | -9.63E+04           | 5.20E-02  |
|  | 0.785         | -1.81E+05           | -1.71E-02 |
|  | 0.898         | -2.08E+05           | -2.34E-02 |
| SWAY (Y)   |               |                     |           |
|  | 0.503         | -4.63E-04           | 5.93E+04  |
|  | 0.524         | -4.63E-04           | 1.19E+06  |
|  | 0.628         | 1.09E-02            | 6.74E+05  |
|  | 0.785         | 3.66E-02            | 7.77E+05  |
|  | 0.898         | 1.74E-02            | 7.14E+05  |
| YAW (RZ)   |               |                     |           |
|  | 0.503         | -1.02E+00           | -2.27E+00 |
|  | 0.524         | -2.12E+00           | -1.09E+01 |
|  | 0.628         | -1.08E+00           | 9.80E+00  |
|  | 0.785         | 1.80E-02            | -3.58E+00 |
|  | 0.898         | -2.04E+00           | -9.90E+00 |

**Figure 7.13 - Mean Wave Drift Forces/Moments (for field solution)**

## 7.4 BODY NATURAL FREQUENCIES AND RESPONSE AMPLITUDE OPERATORS

### 7.4.1 Natural Frequencies/Periods

AQWA-LINE calculates the uncoupled natural frequency/period for each body at each user specified wave frequency. Added mass variation with wave frequency is taken into consideration.

The damping ratios of the body motions are compared with and expressed as a percentage of critical damping values (see Figure 7.14).

| * * * * NATURAL FREQUENCIES/PERIODS FOR STRUCTURE 1 * * * *                    |           |           |          |           |           |            |          |
|--|-----------|-----------|----------|-----------|-----------|------------|----------|
| -----  |           |           |          |           |           |            |          |
| N.B. THESE NATURAL FREQUENCIES DO *NOT* INCLUDE STIFFNESS DUE TO MOORING LINES |           |           |          |           |           |            |          |
| FREQUENCY                      UNDAMPED NATURAL FREQUENCIES (RAD/SECOND)       |           |           |          |           |           |            |          |
| NUMBER   | (RAD/S)   | SURGE (X) | SWAY (Y) | HEAVE (Z) | ROLL (RX) | PITCH (RY) | YAW (RZ) |
| -----  |           |           |          |           |           |            |          |
| 1  | 0.349     | 0.000     | 0.000    | 0.381     | 0.232     | 0.238      | 0.000    |
| 2  | 0.628     | 0.000     | 0.000    | 0.381     | 0.233     | 0.238      | 0.000    |
|  |           |           |          |           |           |            |          |
| PERIOD                              UNDAMPED NATURAL PERIOD (SECONDS)          |           |           |          |           |           |            |          |
| NUMBER   | (SECONDS) | SURGE (X) | SWAY (Y) | HEAVE (Z) | ROLL (RX) | PITCH (RY) | YAW (RZ) |
| -----  |           |           |          |           |           |            |          |
| 1  | 18.00     | 0.00      | 0.00     | 16.51     | 27.04     | 26.42      | 0.00     |
| 2  | 10.00     | 0.00      | 0.00     | 16.51     | 27.01     | 26.39      | 0.00     |
|  |           |           |          |           |           |            |          |
| FREQUENCY                              APPROXIMATE PERCENTAGE CRITICAL DAMPING |           |           |          |           |           |            |          |
| NUMBER   | (RAD/S)   | SURGE (X) | SWAY (Y) | HEAVE (Z) | ROLL (RX) | PITCH (RY) | YAW (RZ) |
| -----  |           |           |          |           |           |            |          |
| 1  | 0.349     | 0.0       | 0.0      | 4.5       | 0.1       | 0.1        | 0.0      |
| 2  | 0.628     | 0.0       | 0.0      | 0.7       | 0.4       | 0.4        | 0.0      |

**Figure 7.14 - Natural Frequencies/Periods**

### 7.4.2 Response Amplitude Operators

The Response Amplitude Operators (RAOs) are functions of wave frequency and direction. The RAOs output from AQWA-LINE are therefore presented for all the directions and frequencies specified by the user. The output gives the variation of RAOs with frequency for each direction (see Figure 7.15). Output is also given of the variation of RAOs with both frequency and direction.

The RAOs are output in terms of amplitude and phase, the phase being related to the incident wave form. (see Section 4.3.2 and AQWA Reference Manual). All RAOs are given for unit wave amplitude.

| * * * * HYDRODYNAMIC PARAMETERS FOR STRUCTURE 1 * * * * |         |           |         |         |        |         |        |        |  |
|---|---------|-----------|---------|---------|--------|---------|--------|--------|--|
| -----   |         |           |         |         |        |         |        |        |  |
| RAOS-VARIATION WITH WAVE PERIOD/FREQUENCY               |         |           |         |         |        |         |        |        |  |
| -----   |         |           |         |         |        |         |        |        |  |
| PERIOD  | FREQ    | DIRECTION | X       |         | Y      |         | Z      |        |  |
| (SECS)  | (RAD/S) | (DEGREES) | AMP     | PHASE   | AMP    | PHASE   | AMP    | PHASE  |  |
| -----   |         |           |         |         |        |         |        |        |  |
| 18.00   | 0.349   | 0.00      | 0.7050  | 90.30   | 0.0054 | 9.06    | 2.0916 | 12.50  |  |
| 10.00   | 0.628   |           | 0.1969  | 53.44   | 0.0000 | -155.94 | 0.0299 | 105.64 |  |
| 18.00   | 0.349   | 45.00     | 0.5089  | 89.82   | 0.5107 | 88.57   | 2.0932 | 11.52  |  |
| 10.00   | 0.628   |           | 0.1849  | 73.61   | 0.1850 | 73.64   | 0.0328 | 103.52 |  |
| 18.00   | 0.349   | 90.00     | 0.0059  | -170.15 | 0.7066 | 87.96   | 2.0942 | 10.56  |  |
| 10.00   | 0.628   |           | 0.0001  | -69.17  | 0.1969 | 48.85   | 0.0299 | 100.99 |  |
| .....(output line continued below).....                 |         |           |         |         |        |         |        |        |  |
| -----   |         |           |         |         |        |         |        |        |  |
| RX  |         | RY        |         | RZ      |        |         |        |        |  |
| AMP   | PHASE   | AMP       | PHASE   | AMP     | PHASE  |         |        |        |  |
| -----   |         |           |         |         |        |         |        |        |  |
| 0.1602  | -166.46 | 0.2060    | 145.33  | 0.0276  | 89.86  |         |        |        |  |
| 0.0016  | -79.15  | 0.0082    | 155.97  | 0.0072  | 52.69  |         |        |        |  |
| 0.2010  | -141.76 | 0.1814    | 158.61  | 0.0398  | 89.19  |         |        |        |  |
| 0.0161  | 87.23   | 0.0203    | -90.09  | 0.0136  | 72.88  |         |        |        |  |
| 0.2350  | -133.21 | 0.1734    | -170.51 | 0.0276  | 88.43  |         |        |        |  |
| 0.0099  | -41.82  | 0.0014    | -73.62  | 0.0072  | 48.07  |         |        |        |  |

**Figure 7.15 - Response Amplitude Operators**

## **CHAPTER 8 - EXAMPLE OF PROGRAM USE**

In this chapter, an example problem using AQWA-LINE is illustrated. All steps in the analysis procedure are clearly shown, from the problem definition, through the data preparation, to the final diffraction and post-processing analysis run itself. The method used in this chapter can easily be followed by the user and, if so desired, the user can repeat the whole procedure, using the same data as used here, to obtain the same results. In this manner, the new user can quickly obtain confidence in using the program.

## **8.1 BOX STRUCTURE**

### **8.1.1 Problem Definition**

The first example is a rectangular box structure, as shown in Figure 8.1. It is required to obtain the response of the body in regular waves. The range of wave periods of interest is 12 to 18 seconds. Mean wave drift forces are also to be calculated. The analysis is to be performed in S.I. units.

The characteristics of the body are as follows:

|                  |          |             |                            |
|------------------|----------|-------------|----------------------------|
| Length           | =        | 90.0 metres |                            |
| Breadth          | =        | 90.0 metres |                            |
| Depth            | =        | 55.0 metres |                            |
| Draught          | =        | 40.0 metres |                            |
| Mass of the body | =        | 3.321E8 kg  | = 3.321E5 tonnes           |
| Mass inertia     | $I_{xx}$ | =           | 3.6253E11 kgm <sup>2</sup> |
|                  | $I_{yy}$ | =           | 3.4199E11 kgm <sup>2</sup> |
|                  | $I_{zz}$ | =           | 3.5991E11 kgm <sup>2</sup> |

The centre of gravity position vector is (0.0, 0.0, -10.62) measured with respect to the FRA.

The environmental parameters are defined as:

|                 |   |                              |
|-----------------|---|------------------------------|
| Water depth     | = | 250.0 metres                 |
| Water density   | = | 1025.0 kg/metre <sup>3</sup> |
| Wave periods    | = | 12 to 18 seconds             |
| Wave directions | = | 0.0, 45.0 and 90.0 degrees   |

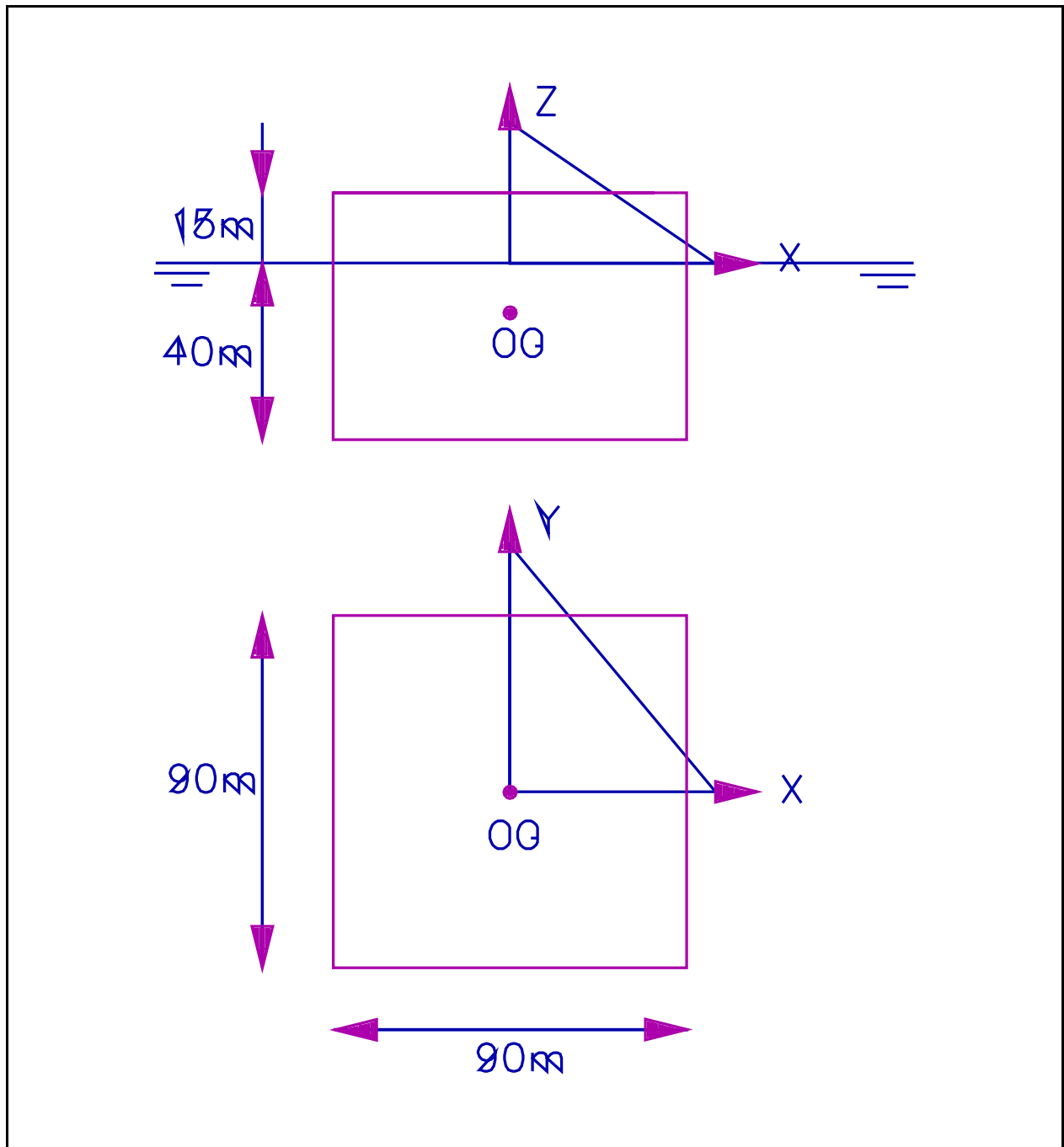


Figure 8.1 - Box Structure

### **8.1.2 Idealisation of Box**

We require to model the following:

1. The mass and inertia properties of the body.
2. The wetted surface of the body when floating in the analysis equilibrium position. The equilibrium position may be obtained from AQWA-LIBRIUM or by other hydrostatic calculations (N.B. the equilibrium may be checked by AQWA-LINE).

Before starting the modelling exercise, the definition position of the body with respect to the Fixed Reference Axes (i.e. FRA) must be chosen. Let the body be defined such that the bottom of the box is 40 metres below the X-Y plane of the FRA and parallel to it. In this example, the DEFINITION position and ANALYSIS position of the body are identical.

### **8.1.3 The Body Surface**

That part of the body surface which will be wetted when the body is in equilibrium is first described. The body has the property of 4-fold symmetry and this may be utilised when modelling the wetted surface of the body. For equilibrium, the mass of the body must equal the mass of water displaced and the centres of gravity and buoyancy must be in the same vertical line, since no external constraining forces are being applied. For the present example, this means that the box floats at an even keel at a draught of 40 metres. Therefore, only one quarter of the box's wetted surface need be described and this is shown in Figure 8.2. In modelling the surface of a body for a diffraction analysis, diffracting plate elements are used. The distribution of these elements should conform to the rules detailed in Section 4.4.3 of this manual and these will now be applied.

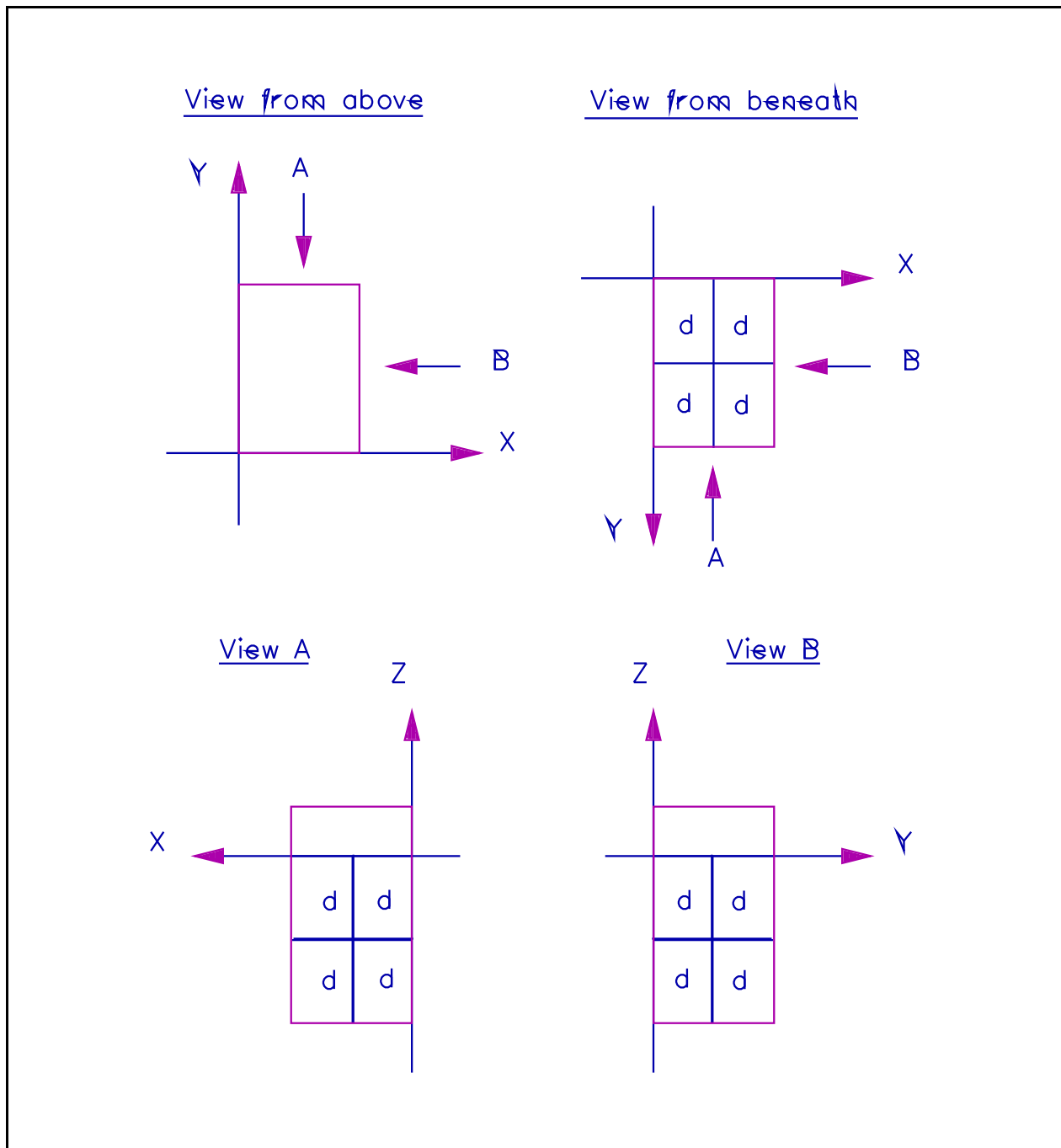
#### Type of Plate Element

Since each of the box surfaces is rectangular and planar, QPPL elements are most suited.

#### Sizing of QPPL Elements

The maximum length that any element may be is first ascertained. The rules state that the maximum length should be 1/7th of the incident wave length. The lowest wave period is 12 seconds and this has a length of approximately 224 metres. Therefore, the maximum element size will be approximately 32 metres.

Based on the above size limitation, 4 QPPL elements are used for each side of the quarter of the box being modelled. The elements will measure 22.5 by 22.5 metres for bottom elements and 20.0 by 22.5 metres for side elements. These dimensions obey the aspect ratio criteria detailed in Section 4.3.3 (i.e. aspect ratio  $> 1/3$ ).



d = diffracting element for AQWA-LINE

Figure 8.2 - Modelling of Body's Wetted Surface



### Placement of QPPL Elements

The placement of the elements should/must obey certain separation rules, which relate to the distances between each adjacent element, the sea-bed and the free-surface of the fluid.

The separation distance between adjacent element centres should be greater than one characteristic radius. Therefore, the characteristic radius of each element size must be calculated.

for the 22.5 \* 22.5 metre bottom element,

$$r_{be} = \sqrt{\text{Area} / \pi} = \sqrt{22.5 * 22.5 / 3.142} = 12.695 \text{ metres}$$

for the 20.0 \* 22.5 metre side element,

$$r_{se} = \sqrt{\text{Area} / \pi} = \sqrt{22.5 * 20.0 / 3.142} = 11.968 \text{ metres}$$

The horizontal separation distance between adjacent side and bottom elements centres is 22.5 metres. The vertical separation distance of side elements is 20.0 metres. The inclined distance between the centres of a bottom and adjacent side element is:

$$\sqrt{10.00^2 * 11.25^2} = 15.052 \text{ metres}$$

The distance between centres of the corner vertical side elements is:

$$\sqrt{11.25^2 * 11.25^2} = 15.910 \text{ metres}$$

Therefore, all separation distances between the element centres are greater than the relevant characteristic element radii.

The bottom elements must also be separated from the sea-bed by a distance greater than one half of a characteristic element radius. This applies when the body is in the analysis position. This is obviously satisfied as the water depth is 250 metres.

The centre of a diffraction plate must also be greater than a certain distance below the fluid free-surface when the body is in the analysis position. Hence the vertical coordinate of each element's centre of area must satisfy the following criteria:

$$(1) \quad ZF > 0.000273 * (\text{water depth}) \quad = \quad 0.6825 \text{ metres}$$

and, for the lowest wave period of 12 seconds,

$$(2) \quad ZF > 0.0000132 * (\text{wavelength})$$

$$ZF > 0.000132 * 224.0 \quad = \quad 0.0296 \text{ metres}$$

where ZF is the Z coordinate of the element nearest the free-surface in the analysis position. In this case, ZF is equal to 10.0 metres and hence satisfies the above criteria.

All the rules regarding separation of element centres are obeyed for the distribution of QPPL diffraction elements shown in Figure 8.2.

Note: All the above hand calculations are performed and output by AQWA-LINE. For the present example, these calculations are easily performed and help explain the criteria for distribution of plate elements. When a problem involves a more complex body form, it is best to run AQWA-LINE with the DATA option operational and let the program check the distribution.

#### **8.1.4 The Body Mass and Inertia**

The mass and inertia characteristics are modelled using a single point mass element (i.e. PMAS), placed at the centre of gravity, which is positioned at X = 0.0, Y = 0.0, Z = -10.62 metres with respect to the FRA. This PMAS element will have the required mass and inertia properties described by the relevant material and geometric group properties as follows:

- Mass input via material group 1 and equal to  $3.321 * 10^8$  kg
- Inertia input via geometry group 1 and set equal to the following:

$$\begin{aligned} I_{xx} &= 3.6253 * 10^{11} \text{ kgm}^2 \\ I_{yy} &= 3.4199 * 10^{11} \text{ kgm}^2 \\ I_{zz} &= 3.5991 * 10^{11} \text{ kgm}^2 \end{aligned}$$

### **8.1.5 Input Preparation for DATA Run**

An AQWA-LINE DATA run is used to perform the following:

- input the node coordinate data
- input the model's element topology with associated material and geometry properties
- input the static environment
- obtain the detailed properties of elements used in each body
- obtain the final mass and inertia properties of each body
- perform the preliminary diffraction modelling checks
- input the wave periods and directions
- input the analysis position of each body
- perform the secondary diffraction modelling checks
- perform hydrostatic calculations for each body

Note that the DATA option is equivalent to a program RESTART which starts at Stage 1 and finishes at Stage 2.

The input decks for the DATA run are shown in Figure 8.3 and the input may be described as follows:

- JOB card provides identifier and program to be used
- TITLE card defines a title header for the run
- OPTIONS card containing the selected options:

|      |   |  |
|------|---|--|
| DATA | - | selects performance of Stages 1 and 2 of the program |
| PPEL | - | requests detailed printout of element properties     |
| PRCE | - | requests an echo printout of the data decks input    |
| END  | - | indicates the end of the options list                |

- Deck 1

Cartesian coordinates of the node points to be used in modelling the body together with the user-selected node number. Note that Deck 1 utilises multiple node generation. Also note that the '500' series input nodes are for mooring line definitions. Mooring lines are not used in AQWA-LINE, but may be used in other AQWA programs (see examples in the AQWA-FER and AQWA-LIBRIUM manuals).

- Deck 2

Elements types used in describing the body, together with definitions of planes of symmetry to be used. Note that the QPPL elements used have been described as diffracting elements (i.e. DIFF identifier). Also note that the FINI card is used to inform the program that no more structures are being input.

- Deck 3

Defines the mass of the body, together with the user-defined material group number (i.e. 1). See reference to Material Group 1 by Element Deck 2 when defining the PMAS element. Note that pressure plate elements have no material properties (i.e. no mass or material density).

- Deck 4

Defines the inertia properties of the body by placing them in Geometry Group 1 and assigning this group to the PMAS element in Deck 2. Again note that pressure plate elements have no geometry group properties.

- Deck 5

This deck is used to input the water depth, the density of the water and the acceleration due to gravity.

- Deck 6

The wave periods are input together with the wave directions. In this case, a range of periods have been selected between 18.0 and 12.0 seconds (note that input is in descending order as periods have been used). The wave directions input are 0, 45 and 90 degrees (i.e. 0 degrees being along the positive X axis and 90 degrees being along the positive Y axis).

- Deck 7

This describes the analysis position for the body via the placement of the Z coordinate of the centre of gravity with respect to the still water surface (i.e. the X-Y plane of the FRA). Additional damping has been added over the period range under consideration. This additional damping is added to the wave or radiation damping calculated by AQWA-LINE.

- Deck 8

This deck has no input and so has a NONE deck header.

```

JOB BOX1  LINE
TITLE
TEST RUN NUMBER 20 (FLOATING BOX 40M DRAUGHT AND 48 FACETS)
OPTIONS PRCE PPEL DATA END
01 COOR
01 1 3 1 45.0 -45.0 0.0 -22.5 0.0 0.0
01 11 3 1 45.0 -45.0 -20.0 -22.5 0.0 0.0
01 21 3 1 45.0 -45.0 -40.0 -22.5 0.0 0.0
01 31 3 1 45.0 -22.5 -40.0 -22.5 0.0 0.0
01 41 3 1 45.0 0.0 -40.0 -22.5 0.0 0.0
01 4 3 10 45.0 -22.5 0.0 0.0 0.0 -20.0
01 5 3 10 45.0 0.0 0.0 0.0 0.0 -20.0
01 101 2 2 45.0 -45.0 15.0 -45.0 0.0 0.0
01 104 2 1 0.0 0.0 15.0 45.0 0.0 0.0
01 501 2 10 45.0 0.0 0.0 101.0 0.0 0.0
01 502 2 10 0.0 45.0 0.0 0.0 101.0 0.0
01 503 2 10 -45.0 0.0 0.0 -101.0 0.0 0.0
01 504 2 10 0.0 -45.0 0.0 0.0 -101.0 0.0
END01 999 0.0 0.0 -10.62
02 ELM1
02SYMX
02SYMY
02QPPL DIFF (4) (1,10) (2,10) (12,10) (11,10)
02QPPL DIFF (4) (2,10) (3,10) (13,10) (12,10)
02QPPL DIFF (2) (1,10) (11,10) (14,10) (4,10)
02QPPL DIFF (2) (4,10) (14,10) (15,10) (5,10)
02QPPL (1) (1,1) (101,1) (103,1) (3,1)
02QPPL (1) (1,1) (5,1) (105,1) (101,1)
02QPPL (1) (101,1) (105,1) (104,1) (103,1)
END02PMAS (1) (999) (1) (1)
03 FINI
03 MATE
END03 1 332.100E6
04 GEOM
END04PMAS 1 3.6253E11 0.0 0.0 3.4199E11 0.0 3.5991E11
05 GLOB
05DPTH 250.0
05DENS 1025.0
END05ACCG 9.806
06 FDR1
06PERD 1 6 18.0 17.0 16.5 16.0 15.0 14.0
06PERD 7 7 12.0
END06DIRN 1 3 0.0 45.0 90.0
07 WFS1
07PERD 1 18.0
07ADMP 4 0.0 0.0 0.0 3.0E+9 0.0 0.0
07ADMP 5 0.0 0.0 0.0 0.0 3.0E+9 0.0
07ADMP 6 0.0 0.0 0.0 0.0 0.0 3.0E+9
07PERD 2 17.0
07ADMP 4 0.0 0.0 0.0 3.0E+9 0.0 0.0
07ADMP 5 0.0 0.0 0.0 0.0 3.0E+9 0.0
07ADMP 6 0.0 0.0 0.0 0.0 0.0 3.0E+9
07PERD 3 16.5
07ADMP 4 0.0 0.0 0.0 3.0E+9 0.0 0.0
07ADMP 5 0.0 0.0 0.0 0.0 3.0E+9 0.0
07ADMP 6 0.0 0.0 0.0 0.0 0.0 3.0E+9
07PERD 4 16.0
07ADMP 4 0.0 0.0 0.0 3.0E+9 0.0 0.0
07ADMP 5 0.0 0.0 0.0 0.0 3.0E+9 0.0
07ADMP 6 0.0 0.0 0.0 0.0 0.0 3.0E+9
07PERD 5 15.0
07ADMP 4 0.0 0.0 0.0 3.0E+9 0.0 0.0
07ADMP 5 0.0 0.0 0.0 0.0 3.0E+9 0.0
07ADMP 6 0.0 0.0 0.0 0.0 0.0 3.0E+9
07PERD 6 14.0
07ADMP 4 0.0 0.0 0.0 3.0E+9 0.0 0.0
07ADMP 5 0.0 0.0 0.0 0.0 3.0E+9 0.0
07ADMP 6 0.0 0.0 0.0 0.0 0.0 3.0E+9
07PERD 7 12.0
07ADMP 4 0.0 0.0 0.0 3.0E+9 0.0 0.0
07ADMP 5 0.0 0.0 0.0 0.0 3.0E+9 0.0
07ADMP 6 0.0 0.0 0.0 0.0 0.0 3.0E+9
END07ZCGE -10.62
08 NONE

```

Figure 8.3 - Input For Data Run on Box Structure

### 8.1.6 Information Supplied by DATA Run

The DATA run produces the following output, shown in Figures 8.4 to 8.17

- Figure 8.4 - AQWA-LINE Header Page (used for identification)
- Figure 8.5 - Card Echo of Input Decks 1 to 5 (due to PRCE option)
- Figure 8.6 - Coordinate Data  
Gives user node number, input sequence number of the node and nodal coordinates for the body in the FRA definition position
- Figure 8.7 - Element Topology  
Gives program administration information relating to all elements used in modelling the body. The information is as follows:
- element type, e.g. QPPL, etc
  - reference number for each element used (supplied by program)
  - node numbers used in forming the element
  - the material and geometry numbers used with each element (N.B. in this problem, only used for the PMAS element)
- Figure 8.8 - Material Properties  
Material Group 1 has been used to model the body's mass
- Figure 8.9 - Geometric Properties  
Geometry Group 1 has been used to model the body's inertia
- Figure 8.10 - Global Parameters  
Global parameters give water depth and density together with acceleration due to gravity.
- Figure 8.11 - Properties of Elements in Detail (due to PPEL option)  
The detailed properties of each element are as follows:
- element number
  - element type/code
  - individual node coordinates used to describe element
  - area/diameter
  - diameter/thickness (diameter for tubes only)
  - free flooding (tubes only)
  - end cuts/width/length
  - the plate width and length together with diagonal length is given
  - mass (only for elements with material properties)
  - submerged volume (tubes only)
  - projected area of plates in 3 orthogonal planes
  - local moments of inertia
  - hydrodynamic coefficients (Morison elements only)

- Figure 8.12 - Mass and Inertia Properties  
Summary of the number and type of elements used to model the COMPLETE body, together with the resultant mass and inertia properties.
- Figure 8.13 - Preliminary Diffraction Modelling Check  
List of all details needed to be calculated in the satisfaction of the distribution rules for diffracting elements. The following are output:
- Element/facet characteristic radius
  - Element/facet area
  - Position vector of centroid of element area
  - Correction factor (see Section 4.4.3)
  - Outward body normals
  - Aspect ratio
  - Shape factor
  - Minimum radius ratio (min separation distance/element radius)
  - Minimum area ratio (min adjacent area/element area)
- Figure 8.14 - Card Echo of Input Decks 6 to 8 ( due to PRCE option)
- Figure 8.15 - Wave Frequencies/Periods and Directions  
Listing of wave particulars and other important parameters which relate to the wave length.
- depth ratio (water depth/wave length or wave number)
  - maximum element size (wave length/7)
  - parameter definition flag, indicating whether the hydrodynamic diffraction parameters have already been calculated or specified
- Figure 8.16 - Secondary Diffraction Modelling Check  
This gives the sea-bed clearance, together with the maximum element to wave length/7 ratio. The number and type of elements accepted and ignored are also given
- Figure 8.17 - Hydrostatic Properties in Free Floating Position  
Full hydrostatic details are listed to allow the user to check that the body is in equilibrium. Note that the small angle stability properties are with respect to the principal cutwater-plane axes.

It is always wise to check that the surface of the model is completely described. This is easily verified by inspecting the out-of-balance force report.

```

AAAAAA  QQQQQQ  WW      WW  AAAAAA      LL      IIII  NN      NN  EEEEEEEE
AAAAAAAA QQQQQQQQ WW      WW  AAAAAAAAA LL      IIII  NNN      NN  EEEEEEEE
AA      AA  QQ      QQ  WW      WW  AA      AA  LL      II      NNNN      NN  EE
AA      AA  QQ      QQ  WW      WW  AA      AA  LL      II      NNNNN      NN  EE
AAAAAAAA QQ      QQ  WW      WW  AAAAAAAAA IIII  LL      II      NN  NNN      NN  EEEEE
AAAAAAAA QQ      QQ  WW  WW  WW  AAAAAAAAA IIII  LL      II      NN      NNN  NN  EEEEE
AA      AA  QQ      QQ  WW  WW  WW  AA      AA  LL      II      NN      NNNNN      EE
AA      AA  QQ  QQ  QQ  WW  WW  WW  AA      AA  LL      II      NN      NNNN      EE
AA      AA  QQQQQQQQ WWWWWWWWWW AA      AA  LLLLLLLL IIII  NN      NNN  EEEEEEEE
AA      AA  QQQQQQ      WWWWWWWW  AA      AA  LLLLLLLL IIII  NN      NN  EEEEEEEE
      QQ

```

THE CONTINUING DEVELOPMENT OF THE AQWA SUITE WAS  
CARRIED OUT BY CENTURY DYNAMICS LIMITED WHO ARE  
CONTINUALLY IMPROVING THE CAPABILITIES OF  
THE HYDRODYNAMIC CALCULATIONS AS MORE ADVANCED  
TECHNIQUES BECOME AVAILABLE. SUGGESTIONS FROM  
USERS REGARDING DEVELOPMENT WILL BE WELCOMED.

CENTURY DYNAMICS LIMITED  
DYNAMICS HOUSE  
86 HURST ROAD  
HORSHAM  
WEST SUSSEX  
RH12 2DT

JOB TITLE : TEST RUN NUMBER 20 (FLOATING BOX 40M DRAUGHT AND 48 FACETS)

Figure 8.4 - AQWA-LINE Header Page



```

DECK 1
-----

01 1 3 1 45.000 -45.000 0.000 -22.500 0.000 0.000
01 11 3 1 45.000 -45.000 -20.000 -22.500 0.000 0.000
01 21 3 1 45.000 -45.000 -40.000 -22.500 0.000 0.000
01 31 3 1 45.000 -22.500 -40.000 -22.500 0.000 0.000
01 41 3 1 45.000 0.000 -40.000 -22.500 0.000 0.000
01 4 3 10 45.000 -22.500 0.000 0.000 0.000 -20.000
01 5 3 10 45.000 0.000 0.000 0.000 0.000 -20.000
01 101 2 2 45.000 -45.000 15.000 -45.000 0.000 0.000
01 104 2 1 0.000 0.000 15.000 45.000 0.000 0.000
01 501 2 10 45.000 0.000 0.000 101.000 0.000 0.000
01 502 2 10 0.000 45.000 0.000 0.000 101.000 0.000
01 503 2 10 -45.000 0.000 0.000 -101.000 0.000 0.000
01 504 2 10 0.000 -45.000 0.000 0.000 -101.000 0.000
END01 999 0 0 0.000 0.000 -10.620 0.000 0.000 0.000

DECK 2
-----

02SYMX 0
02SYMY 0
02QPPL DIFF 0 (4) (1,10) (2,10) (12,10) (11,10)
02QPPL DIFF 0 (4) (2,10) (3,10) (13,10) (12,10)
02QPPL DIFF 0 (2) (1,10) (11,10) (14,10) (4,10)
02QPPL DIFF 0 (2) (4,10) (14,10) (15,10) (5,10)
02QPPL 0 (1) (1,1) (101,1) (103,1) (3,1)
02QPPL 0 (1) (1,1) (5,1) (105,1) (101,1)
02QPPL 0 (1) (101,1) (105,1) (104,1) (103,1)
END02PMAS 0 (1) (999) (1) (1)

DECK 2
-----

DECK 3
-----

END03 1 3.321E+08

DECK 4
-----

END04PMAS 1 3.625E+11 0.000E+00 0.000E+00 3.420E+11 0.000E+00 3.599E+11

DECK 5
-----

05DPTH 250.00 0.00 0.00 0.00 0.00 0.00
05DENS 1025.00 0.00 0.00 0.00 0.00 0.00
END05ACCG 9.81 0.00 0.00 0.00 0.00 0.00

```

**Figure 8.5 - Card Echo of Input Decks 1 to 5**

| * * * * C O O R D I N A T E   D A T A * * * * |      |          |          |         |
|---|------|----------|----------|---------|
| -----   |      |          |          |         |
| INPUT   | NODE |          |          |         |
| SEQUENCE                                      | NO.  | X        | Y        | Z       |
| -----   |      |          |          |         |
| 1   | 1    | 45.000   | -45.000  | 0.000   |
| 2   | 2    | 22.500   | -45.000  | 0.000   |
| 3   | 3    | 0.000    | -45.000  | 0.000   |
| 4   | 11   | 45.000   | -45.000  | -20.000 |
| 5   | 12   | 22.500   | -45.000  | -20.000 |
| 6   | 13   | 0.000    | -45.000  | -20.000 |
| 7   | 21   | 45.000   | -45.000  | -40.000 |
| 8   | 22   | 22.500   | -45.000  | -40.000 |
| 9   | 23   | 0.000    | -45.000  | -40.000 |
| 10  | 31   | 45.000   | -22.500  | -40.000 |
| 11  | 32   | 22.500   | -22.500  | -40.000 |
| 12  | 33   | 0.000    | -22.500  | -40.000 |
| 13  | 41   | 45.000   | 0.000    | -40.000 |
| 14  | 42   | 22.500   | 0.000    | -40.000 |
| 15  | 43   | 0.000    | 0.000    | -40.000 |
| 16  | 4    | 45.000   | -22.500  | 0.000   |
| 17  | 14   | 45.000   | -22.500  | -20.000 |
| 18  | 24   | 45.000   | -22.500  | -40.000 |
| 19  | 5    | 45.000   | 0.000    | 0.000   |
| 20  | 15   | 45.000   | 0.000    | -20.000 |
| 21  | 25   | 45.000   | 0.000    | -40.000 |
| 22  | 101  | 45.000   | -45.000  | 15.000  |
| 23  | 103  | 0.000    | -45.000  | 15.000  |
| 24  | 104  | 0.000    | 0.000    | 15.000  |
| 25  | 105  | 45.000   | 0.000    | 15.000  |
| 26  | 501  | 45.000   | 0.000    | 0.000   |
| 27  | 511  | 146.000  | 0.000    | 0.000   |
| 28  | 502  | 0.000    | 45.000   | 0.000   |
| 29  | 512  | 0.000    | 146.000  | 0.000   |
| 30  | 503  | -45.000  | 0.000    | 0.000   |
| 31  | 513  | -146.000 | 0.000    | 0.000   |
| 32  | 504  | 0.000    | -45.000  | 0.000   |
| 33  | 514  | 0.000    | -146.000 | 0.000   |
| 34  | 999  | 0.000    | 0.000    | -10.620 |

**Figure 8.6 - Coordinate Data**

| * * * * E L E M E N T   T O P O L O G Y   F O R   S T R U C T U R E   1 * * * * |         |             |             |             |             |                 |                 |
|---|---------|-------------|-------------|-------------|-------------|-----------------|-----------------|
| -----   |         |             |             |             |             |                 |                 |
| E L E M E N T   |         | N O D E     | N O D E     | N O D E     | N O D E     | M A T E R I A L | G E O M E T R Y |
| N U M B E R   | T Y P E | N U M B E R | N U M B E R | N U M B E R | N U M B E R | N U M B E R     | N U M B E R     |
| -----   |         |             |             |             |             |                 |                 |
| 1   | QPPL    | 1           | 2           | 12          | 11          | 0               | 0               |
| 2   | QPPL    | 11          | 12          | 22          | 21          | 0               | 0               |
| 3   | QPPL    | 21          | 22          | 32          | 31          | 0               | 0               |
| 4   | QPPL    | 31          | 32          | 42          | 41          | 0               | 0               |
| 5   | QPPL    | 2           | 3           | 13          | 12          | 0               | 0               |
| 6   | QPPL    | 12          | 13          | 23          | 22          | 0               | 0               |
| 7   | QPPL    | 22          | 23          | 33          | 32          | 0               | 0               |
| 8   | QPPL    | 32          | 33          | 43          | 42          | 0               | 0               |
| 9   | QPPL    | 1           | 11          | 14          | 4           | 0               | 0               |
| 10  | QPPL    | 11          | 21          | 24          | 14          | 0               | 0               |
| 11  | QPPL    | 4           | 14          | 15          | 5           | 0               | 0               |
| 12  | QPPL    | 14          | 24          | 25          | 15          | 0               | 0               |
| 13  | QPPL    | 1           | 101         | 103         | 3           | 0               | 0               |
| 14  | QPPL    | 1           | 5           | 105         | 101         | 0               | 0               |
| 15  | QPPL    | 101         | 105         | 104         | 103         | 0               | 0               |
| 16  | PMAS    | 999         | 0           | 0           | 0           | 1               | 1               |

Figure 8.7 -Element Topology

| * * * * M A T E R I A L   P R O P E R T I E S * * * * |               |
|---|---------------|
| -----   |               |
| MATERIAL  |               |
| GROUP   |               |
| NUMBER  | DENSITY/VALUE |
| -----   |               |
| 1   | 3.3210E+08    |

Figure 8.8 - Material Properties

| * * * * G E O M E T R I C   P R O P E R T I E S * * * * |       |         |   |            |            |            |            |            |             |             |
|---|-------|---------|---|------------|------------|------------|------------|------------|-------------|-------------|
| - - - - -   |       |         |   |            |            |            |            |            |             |             |
| GEOMETRY  |       |         |   |            |            |            |            |            | DRAG        | ADDED MASS  |
| INPUT   | GROUP | ELEMENT | G E O M E T R I C   P A R A M E T E R   N U M B E R |            |            |            |            |            | COEFFICIENT | COEFFICIENT |
| SEQUENCE  | NO.   | TYPE    | 1   | 2          | 3          | 4          | 5          | 6          | C<br>D      | C<br>M      |
| -----   |       |         |   |            |            |            |            |            |             |             |
| 1   | 1     | PMAS    | 3.6253E+11  | 0.0000E+00 | 0.0000E+00 | 3.4199E+11 | 0.0000E+00 | 3.5991E+11 | 0.00        | 0.00        |

Figure 8.9 - Geometric Properties

```
      * * * * G L O B A L   P A R A M E T E R S * * * *  
      - - - - -  
  
WATER  DEPTH   . . . . . =    250.000  
  
DENSITY  OF  WATER . . . . . =   1025.000  
  
ACCELERATION  DUE  TO GRAVITY . . . . . =     9.806
```

**Figure 8.10 - Global Parameters**

| * * * * P R O P E R T I E S   O F   E L E M E N T S   I N   D E T A I L   -   S T R U C T U R E   1 * * * * |      |             |       |        |                      |            |             |          |            |         |                    |              |                    |            |         |         |            |            |
|---|------|-------------|-------|--------|----------------------|------------|-------------|----------|------------|---------|--------------------|--------------|--------------------|------------|---------|---------|------------|------------|
| ELEMENT   |      | COORDINATES |       |        | GEOMETRIC PROPERTIES |            |             |          |            |         | MOMENTS OF INERTIA |              |                    |            | COEFFS  |         |            |            |
| NO  | CODE | NODE NO     | X     | Y      | Z                    | DIAM/ AREA | THICK- NESS | FREE FLD | ENDCUTS/ 1 | WIDTH 2 | LENGTH             | ELEMENT MASS | SUB VOL/ PROJ AREA | LOCAL AXES |         |         | DRAG C (D) | MASS C (A) |
|   |      |             |       |        |                      |            |             |          |            |         |                    |              |                    | X          | Y       | Z       |            |            |
| 1   | QPPL | 1           | 45.00 | -45.00 | 0.00                 | 450.00     | 0.0000      | NO       | 20.00      | 30.10   | 22.50              | 0.00E+00     | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |
|   |      | 2           | 22.50 | -45.00 | 0.00                 |            |             |          |            |         |                    |              | 4.50E+02           |            |         |         |            |            |
|   |      | 3           | 22.50 | -45.00 | -20.00               |            |             |          |            |         |                    |              | 0.00E+00           |            |         |         |            |            |
|   |      | 4           | 45.00 | -45.00 | -20.00               |            |             |          |            |         |                    |              |                    |            |         |         |            |            |
| 2   | QPPL | 1           | 45.00 | -45.00 | -20.00               | 450.00     | 0.0000      | NO       | 20.00      | 30.10   | 22.50              | 0.00E+00     | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |
|   |      | 2           | 22.50 | -45.00 | -20.00               |            |             |          |            |         |                    |              | 4.50E+02           |            |         |         |            |            |
|   |      | 3           | 22.50 | -45.00 | -40.00               |            |             |          |            |         |                    |              | 0.00E+00           |            |         |         |            |            |
|   |      | 4           | 45.00 | -45.00 | -40.00               |            |             |          |            |         |                    |              |                    |            |         |         |            |            |
| 3   | QPPL | 1           | 45.00 | -45.00 | -40.00               | 506.25     | 0.0000      | NO       | 22.50      | 31.82   | 22.50              | 0.00E+00     | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |
|   |      | 2           | 22.50 | -45.00 | -40.00               |            |             |          |            |         |                    |              | 0.00E+00           |            |         |         |            |            |
|   |      | 3           | 22.50 | -22.50 | -40.00               |            |             |          |            |         |                    |              | 5.06E+02           |            |         |         |            |            |
|   |      | 4           | 45.00 | -22.50 | -40.00               |            |             |          |            |         |                    |              |                    |            |         |         |            |            |
| 4   | QPPL | 1           | 45.00 | -22.50 | -40.00               | 506.25     | 0.0000      | NO       | 22.50      | 31.82   | 22.50              | 0.00E+00     | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |
|   |      | 2           | 22.50 | -22.50 | -40.00               |            |             |          |            |         |                    |              | 0.00E+00           |            |         |         |            |            |
|   |      | 3           | 22.50 | 0.00   | -40.00               |            |             |          |            |         |                    |              | 5.06E+02           |            |         |         |            |            |
|   |      | 4           | 45.00 | 0.00   | -40.00               |            |             |          |            |         |                    |              |                    |            |         |         |            |            |
| 5   | QPPL | 1           | 22.50 | -45.00 | 0.00                 | 450.00     | 0.0000      | NO       | 20.00      | 30.10   | 22.50              | 0.00E+00     | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |
|   |      | 2           | 0.00  | -45.00 | 0.00                 |            |             |          |            |         |                    |              | 4.50E+02           |            |         |         |            |            |
|   |      | 3           | 0.00  | -45.00 | -20.00               |            |             |          |            |         |                    |              | 0.00E+00           |            |         |         |            |            |
|   |      | 4           | 22.50 | -45.00 | -20.00               |            |             |          |            |         |                    |              |                    |            |         |         |            |            |
| 6   | QPPL | 1           | 22.50 | -45.00 | -20.00               | 450.00     | 0.0000      | NO       | 20.00      | 30.10   | 22.50              | 0.00E+00     | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |
|   |      | 2           | 0.00  | -45.00 | -20.00               |            |             |          |            |         |                    |              | 4.50E+02           |            |         |         |            |            |
|   |      | 3           | 0.00  | -45.00 | -40.00               |            |             |          |            |         |                    |              | 0.00E+00           |            |         |         |            |            |
|   |      | 4           | 22.50 | -45.00 | -40.00               |            |             |          |            |         |                    |              |                    |            |         |         |            |            |
| 7   | QPPL | 1           | 22.50 | -45.00 | -40.00               | 506.25     | 0.0000      | NO       | 22.50      | 31.82   | 22.50              | 0.00E+00     | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |
|   |      | 2           | 0.00  | -45.00 | -40.00               |            |             |          |            |         |                    |              | 0.00E+00           |            |         |         |            |            |
|   |      | 3           | 0.00  | -22.50 | -40.00               |            |             |          |            |         |                    |              | 5.06E+02           |            |         |         |            |            |
|   |      | 4           | 22.50 | -22.50 | -40.00               |            |             |          |            |         |                    |              |                    |            |         |         |            |            |
| 8   | QPPL | 1           | 22.50 | -22.50 | -40.00               | 506.25     | 0.0000      | NO       | 22.50      | 31.82   | 22.50              | 0.00E+00     | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |
|   |      | 2           | 0.00  | -22.50 | -40.00               |            |             |          |            |         |                    |              | 0.00E+00           |            |         |         |            |            |
|   |      | 3           | 0.00  | 0.00   | -40.00               |            |             |          |            |         |                    |              | 5.06E+02           |            |         |         |            |            |
|   |      | 4           | 22.50 | 0.00   | -40.00               |            |             |          |            |         |                    |              |                    |            |         |         |            |            |
| 9   | QPPL | 1           | 45.00 | -45.00 | 0.00                 | 450.00     | 0.0000      | NO       | 22.50      | 30.10   | 20.00              | 0.00E+00     | -4.50E+02          | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |
|   |      | 2           | 45.00 | -45.00 | -20.00               |            |             |          |            |         |                    |              | 0.00E+00           |            |         |         |            |            |
|   |      | 3           | 45.00 | -22.50 | -20.00               |            |             |          |            |         |                    |              | 0.00E+00           |            |         |         |            |            |
|   |      | 4           | 45.00 | -22.50 | 0.00                 |            |             |          |            |         |                    |              |                    |            |         |         |            |            |
| 10  | QPPL | 1           | 45.00 | -45.00 | -20.00               | 450.00     | 0.0000      | NO       | 22.50      | 30.10   | 20.00              | 0.00E+00     | -4.50E+02          | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |
|   |      | 2           | 45.00 | -45.00 | -40.00               |            |             |          |            |         |                    |              | 0.00E+00           |            |         |         |            |            |
|   |      | 3           | 45.00 | -22.50 | -40.00               |            |             |          |            |         |                    |              | 0.00E+00           |            |         |         |            |            |
|   |      | 4           | 45.00 | -22.50 | -20.00               |            |             |          |            |         |                    |              |                    |            |         |         |            |            |
| 11  | QPPL | 1           | 45.00 | -22.50 | 0.00                 | 450.00     | 0.0000      | NO       | 22.50      | 30.10   | 20.00              | 0.00E+00     | -4.50E+02          | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |
|   |      | 2           | 45.00 | -22.50 | -20.00               |            |             |          |            |         |                    |              | 0.00E+00           |            |         |         |            |            |
|   |      | 3           | 45.00 | 0.00   | -20.00               |            |             |          |            |         |                    |              | 0.00E+00           |            |         |         |            |            |
|   |      | 4           | 45.00 | 0.00   | 0.00                 |            |             |          |            |         |                    |              |                    |            |         |         |            |            |

Figure 8.11 - Properties of Elements in Detail

| * * * * P R O P E R T I E S   O F   E L E M E N T S   I N   D E T A I L - S T R U C T U R E   1 * * * * |      |             |        |        |                      |            |             |          |            |          |        |                    |                    |            |         |         |                 |       |
|---|------|-------------|--------|--------|----------------------|------------|-------------|----------|------------|----------|--------|--------------------|--------------------|------------|---------|---------|-----------------|-------|
| ELEMENT   |      | COORDINATES |        |        | GEOMETRIC PROPERTIES |            |             |          |            |          |        | MOMENTS OF INERTIA |                    |            |         | COEFS   |                 |       |
| NO  | CODE | NODE NO     | X      | Y      | Z                    | DIAM/ AREA | THICK- NESS | FREE FLD | ENDCUTS/ 1 | WIDTH/ 2 | LENGTH | ELEMENT MASS       | SUB VOL/ PROJ AREA | LOCAL AXES |         |         | DRAG MASS C (D) | C (A) |
|   |      |             |        |        |                      |            |             |          |            |          |        |                    |                    | X          | Y       | Z       |                 |       |
| 12  | QPPL | 1           | 45.00  | -22.50 | -20.00               | 450.00     | 0.0000      | NO       | 22.50      | 30.10    | 20.00  | 0.00E+00           | -4.50E+02          | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00            | 0.00  |
|   |      | 2           | 45.00  | -22.50 | -40.00               |            |             |          |            |          |        |                    | 0.00E+00           |            |         |         |                 |       |
|   |      | 3           | 45.00  | 0.00   | -40.00               |            |             |          |            |          |        |                    | 0.00E+00           |            |         |         |                 |       |
|   |      | 4           | 45.00  | 0.00   | -20.00               |            |             |          |            |          |        |                    |                    |            |         |         |                 |       |
| 13  | QPPL | 1           | 45.00  | -45.00 | 0.00                 | 675.00     | 0.0000      | NO       | 45.00      | 47.43    | 15.00  | 0.00E+00           | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00            | 0.00  |
|   |      | 2           | 45.00  | -45.00 | 15.00                |            |             |          |            |          |        |                    | 6.75E+02           |            |         |         |                 |       |
|   |      | 3           | 0.00   | -45.00 | 15.00                |            |             |          |            |          |        |                    | 0.00E+00           |            |         |         |                 |       |
|   |      | 4           | 0.00   | -45.00 | 0.00                 |            |             |          |            |          |        |                    |                    |            |         |         |                 |       |
| 14  | QPPL | 1           | 45.00  | -45.00 | 0.00                 | 675.00     | 0.0000      | NO       | 15.00      | 47.43    | 45.00  | 0.00E+00           | -6.75E+02          | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00            | 0.00  |
|   |      | 2           | 45.00  | 0.00   | 0.00                 |            |             |          |            |          |        |                    | 0.00E+00           |            |         |         |                 |       |
|   |      | 3           | 45.00  | 0.00   | 15.00                |            |             |          |            |          |        |                    | 0.00E+00           |            |         |         |                 |       |
|   |      | 4           | 45.00  | -45.00 | 15.00                |            |             |          |            |          |        |                    |                    |            |         |         |                 |       |
| 15  | QPPL | 1           | 45.00  | -45.00 | 15.00                | 2025.00    | 0.0000      | NO       | 45.00      | 63.64    | 45.00  | 0.00E+00           | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00            | 0.00  |
|   |      | 2           | 45.00  | 0.00   | 15.00                |            |             |          |            |          |        |                    | 0.00E+00           |            |         |         |                 |       |
|   |      | 3           | 0.00   | 0.00   | 15.00                |            |             |          |            |          |        |                    | -2.03E+03          |            |         |         |                 |       |
|   |      | 4           | 0.00   | -45.00 | 15.00                |            |             |          |            |          |        |                    |                    |            |         |         |                 |       |
| 16  | PMAS | 1           | 0.00   | 0.00   | -10.62               | 0.00       | 0.0000      | NO       | 0.00       | 0.00     | 0.00   | 3.32E+08           | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00            | 0.00  |
| 1   | QPPL | 1           | -45.00 | -45.00 | 0.00                 | 450.00     | 0.0000      | NO       | 20.00      | 30.10    | 22.50  | 0.00E+00           | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00            | 0.00  |
|   |      | 2           | -22.50 | -45.00 | 0.00                 |            |             |          |            |          |        |                    | 4.50E+02           |            |         |         |                 |       |
|   |      | 3           | -22.50 | -45.00 | -20.00               |            |             |          |            |          |        |                    | 0.00E+00           |            |         |         |                 |       |
|   |      | 4           | -45.00 | -45.00 | -20.00               |            |             |          |            |          |        |                    |                    |            |         |         |                 |       |
| 2   | QPPL | 1           | -45.00 | -45.00 | -20.00               | 450.00     | 0.0000      | NO       | 20.00      | 30.10    | 22.50  | 0.00E+00           | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00            | 0.00  |
|   |      | 2           | -22.50 | -45.00 | -20.00               |            |             |          |            |          |        |                    | 4.50E+02           |            |         |         |                 |       |
|   |      | 3           | -22.50 | -45.00 | -40.00               |            |             |          |            |          |        |                    | 0.00E+00           |            |         |         |                 |       |
|   |      | 4           | -45.00 | -45.00 | -40.00               |            |             |          |            |          |        |                    |                    |            |         |         |                 |       |
| 3   | QPPL | 1           | -45.00 | -45.00 | -40.00               | 506.25     | 0.0000      | NO       | 22.50      | 31.82    | 22.50  | 0.00E+00           | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00            | 0.00  |
|   |      | 2           | -22.50 | -45.00 | -40.00               |            |             |          |            |          |        |                    | 0.00E+00           |            |         |         |                 |       |
|   |      | 3           | -22.50 | -22.50 | -40.00               |            |             |          |            |          |        |                    | 5.06E+02           |            |         |         |                 |       |
|   |      | 4           | -45.00 | -22.50 | -40.00               |            |             |          |            |          |        |                    |                    |            |         |         |                 |       |
| 4   | QPPL | 1           | -45.00 | -22.50 | -40.00               | 506.25     | 0.0000      | NO       | 22.50      | 31.82    | 22.50  | 0.00E+00           | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00            | 0.00  |
|   |      | 2           | -22.50 | -22.50 | -40.00               |            |             |          |            |          |        |                    | 0.00E+00           |            |         |         |                 |       |
|   |      | 3           | -22.50 | 0.00   | -40.00               |            |             |          |            |          |        |                    | 5.06E+02           |            |         |         |                 |       |
|   |      | 4           | -45.00 | 0.00   | -40.00               |            |             |          |            |          |        |                    |                    |            |         |         |                 |       |
| 5   | QPPL | 1           | -22.50 | -45.00 | 0.00                 | 450.00     | 0.0000      | NO       | 20.00      | 30.10    | 22.50  | 0.00E+00           | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00            | 0.00  |
|   |      | 2           | 0.00   | -45.00 | 0.00                 |            |             |          |            |          |        |                    | 4.50E+02           |            |         |         |                 |       |
|   |      | 3           | 0.00   | -45.00 | -20.00               |            |             |          |            |          |        |                    | 0.00E+00           |            |         |         |                 |       |
|   |      | 4           | -22.50 | -45.00 | -20.00               |            |             |          |            |          |        |                    |                    |            |         |         |                 |       |
| 6   | QPPL | 1           | -22.50 | -45.00 | -20.00               | 450.00     | 0.0000      | NO       | 20.00      | 30.10    | 22.50  | 0.00E+00           | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00            | 0.00  |
|   |      | 2           | 0.00   | -45.00 | -20.00               |            |             |          |            |          |        |                    | 4.50E+02           |            |         |         |                 |       |
|   |      | 3           | 0.00   | -45.00 | -40.00               |            |             |          |            |          |        |                    | 0.00E+00           |            |         |         |                 |       |
|   |      | 4           | -22.50 | -45.00 | -40.00               |            |             |          |            |          |        |                    |                    |            |         |         |                 |       |

Figure 8.11 - Properties of Elements in Detail (Cont)

| * * * * P R O P E R T I E S   O F   E L E M E N T S   I N   D E T A I L - S T R U C T U R E   1 * * * * |      |             |        |        |                      |            |             |          |            |         |        |                    |                    |            |         |         |            |            |  |
|---|------|-------------|--------|--------|----------------------|------------|-------------|----------|------------|---------|--------|--------------------|--------------------|------------|---------|---------|------------|------------|--|
| ELEMENT   |      | COORDINATES |        |        | GEOMETRIC PROPERTIES |            |             |          |            |         |        | MOMENTS OF INERTIA |                    |            |         | COEFFS  |            |            |  |
| NO  | CODE | NODE NO     | X      | Y      | Z                    | DIAM/ AREA | THICK- NESS | FREE FLD | ENDCUTS/ 1 | WIDTH 2 | LENGTH | ELEMENT MASS       | SUB VOL/ PROJ AREA | LOCAL AXES |         |         | DRAG C (D) | MASS C (A) |  |
| 7   | QPPL | 1           | -22.50 | -45.00 | -40.00               | 506.25     | 0.0000      | NO       | 22.50      | 31.82   | 22.50  | 0.00E+00           | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |  |
|   |      | 2           | 0.00   | -45.00 | -40.00               |            |             |          |            |         |        |                    | 0.00E+00           |            |         |         |            |            |  |
|   |      | 3           | 0.00   | -22.50 | -40.00               |            |             |          |            |         |        |                    | 5.06E+02           |            |         |         |            |            |  |
|   |      | 4           | -22.50 | -22.50 | -40.00               |            |             |          |            |         |        |                    |                    |            |         |         |            |            |  |
| 8   | QPPL | 1           | -22.50 | -22.50 | -40.00               | 506.25     | 0.0000      | NO       | 22.50      | 31.82   | 22.50  | 0.00E+00           | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |  |
|   |      | 2           | 0.00   | -22.50 | -40.00               |            |             |          |            |         |        |                    | 0.00E+00           |            |         |         |            |            |  |
|   |      | 3           | 0.00   | 0.00   | -40.00               |            |             |          |            |         |        |                    | 5.06E+02           |            |         |         |            |            |  |
|   |      | 4           | -22.50 | 0.00   | -40.00               |            |             |          |            |         |        |                    |                    |            |         |         |            |            |  |
| 9   | QPPL | 1           | -45.00 | -45.00 | 0.00                 | 450.00     | 0.0000      | NO       | 22.50      | 30.10   | 20.00  | 0.00E+00           | 4.50E+02           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |  |
|   |      | 2           | -45.00 | -45.00 | -20.00               |            |             |          |            |         |        |                    | 0.00E+00           |            |         |         |            |            |  |
|   |      | 3           | -45.00 | -22.50 | -20.00               |            |             |          |            |         |        |                    | 0.00E+00           |            |         |         |            |            |  |
|   |      | 4           | -45.00 | -22.50 | 0.00                 |            |             |          |            |         |        |                    |                    |            |         |         |            |            |  |
| 10  | QPPL | 1           | -45.00 | -45.00 | -20.00               | 450.00     | 0.0000      | NO       | 22.50      | 30.10   | 20.00  | 0.00E+00           | 4.50E+02           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |  |
|   |      | 2           | -45.00 | -45.00 | -40.00               |            |             |          |            |         |        |                    | 0.00E+00           |            |         |         |            |            |  |
|   |      | 3           | -45.00 | -22.50 | -40.00               |            |             |          |            |         |        |                    | 0.00E+00           |            |         |         |            |            |  |
|   |      | 4           | -45.00 | -22.50 | -20.00               |            |             |          |            |         |        |                    |                    |            |         |         |            |            |  |
| 11  | QPPL | 1           | -45.00 | -22.50 | 0.00                 | 450.00     | 0.0000      | NO       | 22.50      | 30.10   | 20.00  | 0.00E+00           | 4.50E+02           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |  |
|   |      | 2           | -45.00 | -22.50 | -20.00               |            |             |          |            |         |        |                    | 0.00E+00           |            |         |         |            |            |  |
|   |      | 3           | -45.00 | 0.00   | -20.00               |            |             |          |            |         |        |                    | 0.00E+00           |            |         |         |            |            |  |
|   |      | 4           | -45.00 | 0.00   | 0.00                 |            |             |          |            |         |        |                    |                    |            |         |         |            |            |  |
| 12  | QPPL | 1           | -45.00 | -22.50 | -20.00               | 450.00     | 0.0000      | NO       | 22.50      | 30.10   | 20.00  | 0.00E+00           | 4.50E+02           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |  |
|   |      | 2           | -45.00 | -22.50 | -40.00               |            |             |          |            |         |        |                    | 0.00E+00           |            |         |         |            |            |  |
|   |      | 3           | -45.00 | 0.00   | -40.00               |            |             |          |            |         |        |                    | 0.00E+00           |            |         |         |            |            |  |
|   |      | 4           | -45.00 | 0.00   | -20.00               |            |             |          |            |         |        |                    |                    |            |         |         |            |            |  |
| 13  | QPPL | 1           | -45.00 | -45.00 | 0.00                 | 675.00     | 0.0000      | NO       | 45.00      | 47.43   | 15.00  | 0.00E+00           | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |  |
|   |      | 2           | -45.00 | -45.00 | 15.00                |            |             |          |            |         |        |                    | 6.75E+02           |            |         |         |            |            |  |
|   |      | 3           | 0.00   | -45.00 | 15.00                |            |             |          |            |         |        |                    | 0.00E+00           |            |         |         |            |            |  |
|   |      | 4           | 0.00   | -45.00 | 0.00                 |            |             |          |            |         |        |                    |                    |            |         |         |            |            |  |
| 14  | QPPL | 1           | -45.00 | -45.00 | 0.00                 | 675.00     | 0.0000      | NO       | 15.00      | 47.43   | 45.00  | 0.00E+00           | 6.75E+02           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |  |
|   |      | 2           | -45.00 | 0.00   | 0.00                 |            |             |          |            |         |        |                    | 0.00E+00           |            |         |         |            |            |  |
|   |      | 3           | -45.00 | 0.00   | 15.00                |            |             |          |            |         |        |                    | 0.00E+00           |            |         |         |            |            |  |
|   |      | 4           | -45.00 | -45.00 | 15.00                |            |             |          |            |         |        |                    |                    |            |         |         |            |            |  |
| 15  | QPPL | 1           | -45.00 | -45.00 | 15.00                | 2025.00    | 0.0000      | NO       | 45.00      | 63.64   | 45.00  | 0.00E+00           | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |  |
|   |      | 2           | -45.00 | 0.00   | 15.00                |            |             |          |            |         |        |                    | 0.00E+00           |            |         |         |            |            |  |
|   |      | 3           | 0.00   | 0.00   | 15.00                |            |             |          |            |         |        |                    | -2.03E+03          |            |         |         |            |            |  |
|   |      | 4           | 0.00   | -45.00 | 15.00                |            |             |          |            |         |        |                    |                    |            |         |         |            |            |  |
| 1   | QPPL | 1           | 45.00  | 45.00  | 0.00                 | 450.00     | 0.0000      | NO       | 20.00      | 30.10   | 22.50  | 0.00E+00           | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |  |
|   |      | 2           | 22.50  | 45.00  | 0.00                 |            |             |          |            |         |        |                    | -4.50E+02          |            |         |         |            |            |  |
|   |      | 3           | 22.50  | 45.00  | -20.00               |            |             |          |            |         |        |                    | 0.00E+00           |            |         |         |            |            |  |
|   |      | 4           | 45.00  | 45.00  | -20.00               |            |             |          |            |         |        |                    |                    |            |         |         |            |            |  |
| 2   | QPPL | 1           | 45.00  | 45.00  | -20.00               | 450.00     | 0.0000      | NO       | 20.00      | 30.10   | 22.50  | 0.00E+00           | 0.00E+00           | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00       | 0.00       |  |
|   |      | 2           | 22.50  | 45.00  | -20.00               |            |             |          |            |         |        |                    | -4.50E+02          |            |         |         |            |            |  |
|   |      | 3           | 22.50  | 45.00  | -40.00               |            |             |          |            |         |        |                    | 0.00E+00           |            |         |         |            |            |  |
|   |      | 4           | 45.00  | 45.00  | -40.00               |            |             |          |            |         |        |                    |                    |            |         |         |            |            |  |

Figure 8.11 - Properties of Elements in Detail (Cont)



| ***** PROPERTIES OF ELEMENTS IN DETAIL - STRUCTURE 1***** |      |         |             |       |        |                      |             |          |                   |        |                    |                    |                  |         |         |                     |      |      |
|---|------|---------|-------------|-------|--------|----------------------|-------------|----------|-------------------|--------|--------------------|--------------------|------------------|---------|---------|---------------------|------|------|
| ELEMENT   |      |         | COORDINATES |       |        | GEOMETRIC PROPERTIES |             |          |                   |        | MOMENTS OF INERTIA |                    |                  |         |         | COEFFS              |      |      |
| NO  | CODE | NODE NO | X           | Y     | Z      | DIAM/ AREA           | THICK- NESS | FREE FLD | ENDCUTS/WIDTH 1 2 | LENGTH | ELEMENT MASS       | SUB VOL/ PROJ AREA | LOCAL AXES X Y Z |         |         | DRAG MASS C(D) C(A) |      |      |
| 3   | QPPL | 1       | 45.00       | 45.00 | -40.00 | 506.25               | 0.0000      | NO       | 22.50             | 31.82  | 22.50              | 0.00E+00           | 0.00E+00         | 0.0E+00 | 0.0E+00 | 0.0E+00             | 0.00 | 0.00 |
|   |      | 2       | 22.50       | 45.00 | -40.00 |                      |             |          |                   |        |                    | 0.00E+00           |                  |         |         |                     |      |      |
|   |      | 3       | 22.50       | 22.50 | -40.00 |                      |             |          |                   |        |                    | 5.06E+02           |                  |         |         |                     |      |      |
|   |      | 4       | 45.00       | 22.50 | -40.00 |                      |             |          |                   |        |                    |                    |                  |         |         |                     |      |      |
| 4   | QPPL | 1       | 45.00       | 22.50 | -40.00 | 506.25               | 0.0000      | NO       | 22.50             | 31.82  | 22.50              | 0.00E+00           | 0.00E+00         | 0.0E+00 | 0.0E+00 | 0.0E+00             | 0.00 | 0.00 |
|   |      | 2       | 22.50       | 22.50 | -40.00 |                      |             |          |                   |        |                    | 0.00E+00           |                  |         |         |                     |      |      |
|   |      | 3       | 22.50       | 0.00  | -40.00 |                      |             |          |                   |        |                    | 5.06E+02           |                  |         |         |                     |      |      |
|   |      | 4       | 45.00       | 0.00  | -40.00 |                      |             |          |                   |        |                    |                    |                  |         |         |                     |      |      |
| 5   | QPPL | 1       | 22.50       | 45.00 | 0.00   | 450.00               | 0.0000      | NO       | 20.00             | 30.10  | 22.50              | 0.00E+00           | 0.00E+00         | 0.0E+00 | 0.0E+00 | 0.0E+00             | 0.00 | 0.00 |
|   |      | 2       | 0.00        | 45.00 | 0.00   |                      |             |          |                   |        |                    | -4.50E+02          |                  |         |         |                     |      |      |
|   |      | 3       | 0.00        | 45.00 | -20.00 |                      |             |          |                   |        |                    | 0.00E+00           |                  |         |         |                     |      |      |
|   |      | 4       | 22.50       | 45.00 | -20.00 |                      |             |          |                   |        |                    |                    |                  |         |         |                     |      |      |
| 6   | QPPL | 1       | 22.50       | 45.00 | -20.00 | 450.00               | 0.0000      | NO       | 20.00             | 30.10  | 22.50              | 0.00E+00           | 0.00E+00         | 0.0E+00 | 0.0E+00 | 0.0E+00             | 0.00 | 0.00 |
|   |      | 2       | 0.00        | 45.00 | -20.00 |                      |             |          |                   |        |                    | -4.50E+02          |                  |         |         |                     |      |      |
|   |      | 3       | 0.00        | 45.00 | -40.00 |                      |             |          |                   |        |                    | 0.00E+00           |                  |         |         |                     |      |      |
|   |      | 4       | 22.50       | 45.00 | -40.00 |                      |             |          |                   |        |                    |                    |                  |         |         |                     |      |      |
| 7   | QPPL | 1       | 22.50       | 45.00 | -40.00 | 506.25               | 0.0000      | NO       | 22.50             | 31.82  | 22.50              | 0.00E+00           | 0.00E+00         | 0.0E+00 | 0.0E+00 | 0.0E+00             | 0.00 | 0.00 |
|   |      | 2       | 0.00        | 45.00 | -40.00 |                      |             |          |                   |        |                    | 0.00E+00           |                  |         |         |                     |      |      |
|   |      | 3       | 0.00        | 22.50 | -40.00 |                      |             |          |                   |        |                    | 5.06E+02           |                  |         |         |                     |      |      |
|   |      | 4       | 22.50       | 22.50 | -40.00 |                      |             |          |                   |        |                    |                    |                  |         |         |                     |      |      |
| 8   | QPPL | 1       | 22.50       | 22.50 | -40.00 | 506.25               | 0.0000      | NO       | 22.50             | 31.82  | 22.50              | 0.00E+00           | 0.00E+00         | 0.0E+00 | 0.0E+00 | 0.0E+00             | 0.00 | 0.00 |
|   |      | 2       | 0.00        | 22.50 | -40.00 |                      |             |          |                   |        |                    | 0.00E+00           |                  |         |         |                     |      |      |
|   |      | 3       | 0.00        | 0.00  | -40.00 |                      |             |          |                   |        |                    | 5.06E+02           |                  |         |         |                     |      |      |
|   |      | 4       | 22.50       | 0.00  | -40.00 |                      |             |          |                   |        |                    |                    |                  |         |         |                     |      |      |
| 9   | QPPL | 1       | 45.00       | 45.00 | 0.00   | 450.00               | 0.0000      | NO       | 22.50             | 30.10  | 20.00              | 0.00E+00           | -4.50E+02        | 0.0E+00 | 0.0E+00 | 0.0E+00             | 0.00 | 0.00 |
|   |      | 2       | 45.00       | 45.00 | -20.00 |                      |             |          |                   |        |                    | 0.00E+00           |                  |         |         |                     |      |      |
|   |      | 3       | 45.00       | 22.50 | -20.00 |                      |             |          |                   |        |                    | 0.00E+00           |                  |         |         |                     |      |      |
|   |      | 4       | 45.00       | 22.50 | 0.00   |                      |             |          |                   |        |                    |                    |                  |         |         |                     |      |      |
| 10  | QPPL | 1       | 45.00       | 45.00 | -20.00 | 450.00               | 0.0000      | NO       | 22.50             | 30.10  | 20.00              | 0.00E+00           | -4.50E+02        | 0.0E+00 | 0.0E+00 | 0.0E+00             | 0.00 | 0.00 |
|   |      | 2       | 45.00       | 45.00 | -40.00 |                      |             |          |                   |        |                    | 0.00E+00           |                  |         |         |                     |      |      |
|   |      | 3       | 45.00       | 22.50 | -40.00 |                      |             |          |                   |        |                    | 0.00E+00           |                  |         |         |                     |      |      |
|   |      | 4       | 45.00       | 22.50 | -20.00 |                      |             |          |                   |        |                    |                    |                  |         |         |                     |      |      |
| 11  | QPPL | 1       | 45.00       | 22.50 | 0.00   | 450.00               | 0.0000      | NO       | 22.50             | 30.10  | 20.00              | 0.00E+00           | -4.50E+02        | 0.0E+00 | 0.0E+00 | 0.0E+00             | 0.00 | 0.00 |
|   |      | 2       | 45.00       | 22.50 | -20.00 |                      |             |          |                   |        |                    | 0.00E+00           |                  |         |         |                     |      |      |
|   |      | 3       | 45.00       | 0.00  | -20.00 |                      |             |          |                   |        |                    | 0.00E+00           |                  |         |         |                     |      |      |
|   |      | 4       | 45.00       | 0.00  | 0.00   |                      |             |          |                   |        |                    |                    |                  |         |         |                     |      |      |
| 12  | QPPL | 1       | 45.00       | 22.50 | -20.00 | 450.00               | 0.0000      | NO       | 22.50             | 30.10  | 20.00              | 0.00E+00           | -4.50E+02        | 0.0E+00 | 0.0E+00 | 0.0E+00             | 0.00 | 0.00 |
|   |      | 2       | 45.00       | 22.50 | -40.00 |                      |             |          |                   |        |                    | 0.00E+00           |                  |         |         |                     |      |      |
|   |      | 3       | 45.00       | 0.00  | -40.00 |                      |             |          |                   |        |                    | 0.00E+00           |                  |         |         |                     |      |      |
|   |      | 4       | 45.00       | 0.00  | -20.00 |                      |             |          |                   |        |                    |                    |                  |         |         |                     |      |      |
| 13  | QPPL | 1       | 45.00       | 45.00 | 0.00   | 675.00               | 0.0000      | NO       | 45.00             | 47.43  | 15.00              | 0.00E+00           | 0.00E+00         | 0.0E+00 | 0.0E+00 | 0.0E+00             | 0.00 | 0.00 |
|   |      | 2       | 45.00       | 45.00 | 15.00  |                      |             |          |                   |        |                    | -6.75E+02          |                  |         |         |                     |      |      |
|   |      | 3       | 0.00        | 45.00 | 15.00  |                      |             |          |                   |        |                    | 0.00E+00           |                  |         |         |                     |      |      |
|   |      | 4       | 0.00        | 45.00 | 0.00   |                      |             |          |                   |        |                    |                    |                  |         |         |                     |      |      |

Figure 8.11 - Properties of Elements in Detail (Cont)

| * * * * P R O P E R T I E S   O F   E L E M E N T S   I N   D E T A I L - S T R U C T U R E   1 * * * * |      |             |        |       |                      |            |             |          |            |                    |        |              |                    |                  |         |           |                       |
|---|------|-------------|--------|-------|----------------------|------------|-------------|----------|------------|--------------------|--------|--------------|--------------------|------------------|---------|-----------|-----------------------|
| ELEMENT   |      | COORDINATES |        |       | GEOMETRIC PROPERTIES |            |             |          |            | MOMENTS OF INERTIA |        |              |                    | COEFFS           |         |           |                       |
| NO  | CODE | NODE NO     | X      | Y     | Z                    | DIAM/ AREA | THICK- NESS | FREE FLD | ENDCUTS/ 1 | WIDTH 2            | LENGTH | ELEMENT MASS | SUB VOL/ PROJ AREA | LOCAL AXES X Y Z |         |           | DRAG MASS C (D) C (A) |
| 14  | QPPL | 1           | 45.00  | 45.00 | 0.00                 | 675.00     | 0.0000      | NO       | 15.00      | 47.43              | 45.00  | 0.00E+00     | -6.75E+02          | 0.0E+00          | 0.0E+00 | 0.0E+00   | 0.00 0.00             |
|   |      | 2           | 45.00  | 0.00  | 0.00                 |            |             |          |            |                    |        |              | 0.00E+00           |                  |         |           |                       |
|   |      | 3           | 45.00  | 0.00  | 15.00                |            |             |          |            |                    |        |              | 0.00E+00           |                  |         |           |                       |
|   |      | 4           | 45.00  | 45.00 | 15.00                |            |             |          |            |                    |        |              |                    |                  |         |           |                       |
| 15  | QPPL | 1           | 45.00  | 45.00 | 15.00                | 2025.00    | 0.0000      | NO       | 45.00      | 63.64              | 45.00  | 0.00E+00     | 0.00E+00           | 0.0E+00          | 0.0E+00 | 0.00 0.00 |                       |
|   |      | 2           | 45.00  | 0.00  | 15.00                |            |             |          |            |                    |        |              | 0.00E+00           |                  |         |           |                       |
|   |      | 3           | 0.00   | 0.00  | 15.00                |            |             |          |            |                    |        |              | -2.03E+03          |                  |         |           |                       |
|   |      | 4           | 0.00   | 45.00 | 15.00                |            |             |          |            |                    |        |              |                    |                  |         |           |                       |
| 1   | QPPL | 1           | -45.00 | 45.00 | 0.00                 | 450.00     | 0.0000      | NO       | 20.00      | 30.10              | 22.50  | 0.00E+00     | 0.00E+00           | 0.0E+00          | 0.0E+00 | 0.00 0.00 |                       |
|   |      | 2           | -22.50 | 45.00 | 0.00                 |            |             |          |            |                    |        |              | -4.50E+02          |                  |         |           |                       |
|   |      | 3           | -22.50 | 45.00 | -20.00               |            |             |          |            |                    |        |              | 0.00E+00           |                  |         |           |                       |
|   |      | 4           | -45.00 | 45.00 | -20.00               |            |             |          |            |                    |        |              |                    |                  |         |           |                       |
| 2   | QPPL | 1           | -45.00 | 45.00 | -20.00               | 450.00     | 0.0000      | NO       | 20.00      | 30.10              | 22.50  | 0.00E+00     | 0.00E+00           | 0.0E+00          | 0.0E+00 | 0.00 0.00 |                       |
|   |      | 2           | -22.50 | 45.00 | -20.00               |            |             |          |            |                    |        |              | -4.50E+02          |                  |         |           |                       |
|   |      | 3           | -22.50 | 45.00 | -40.00               |            |             |          |            |                    |        |              | 0.00E+00           |                  |         |           |                       |
|   |      | 4           | -45.00 | 45.00 | -40.00               |            |             |          |            |                    |        |              |                    |                  |         |           |                       |
| 3   | QPPL | 1           | -45.00 | 45.00 | -40.00               | 506.25     | 0.0000      | NO       | 22.50      | 31.82              | 22.50  | 0.00E+00     | 0.00E+00           | 0.0E+00          | 0.0E+00 | 0.00 0.00 |                       |
|   |      | 2           | -22.50 | 45.00 | -40.00               |            |             |          |            |                    |        |              | 0.00E+00           |                  |         |           |                       |
|   |      | 3           | -22.50 | 22.50 | -40.00               |            |             |          |            |                    |        |              | 5.06E+02           |                  |         |           |                       |
|   |      | 4           | -45.00 | 22.50 | -40.00               |            |             |          |            |                    |        |              |                    |                  |         |           |                       |
| 4   | QPPL | 1           | -45.00 | 22.50 | -40.00               | 506.25     | 0.0000      | NO       | 22.50      | 31.82              | 22.50  | 0.00E+00     | 0.00E+00           | 0.0E+00          | 0.0E+00 | 0.00 0.00 |                       |
|   |      | 2           | -22.50 | 22.50 | -40.00               |            |             |          |            |                    |        |              | 0.00E+00           |                  |         |           |                       |
|   |      | 3           | -22.50 | 0.00  | -40.00               |            |             |          |            |                    |        |              | 5.06E+02           |                  |         |           |                       |
|   |      | 4           | -45.00 | 0.00  | -40.00               |            |             |          |            |                    |        |              |                    |                  |         |           |                       |
| 5   | QPPL | 1           | -22.50 | 45.00 | 0.00                 | 450.00     | 0.0000      | NO       | 20.00      | 30.10              | 22.50  | 0.00E+00     | 0.00E+00           | 0.0E+00          | 0.0E+00 | 0.00 0.00 |                       |
|   |      | 2           | 0.00   | 45.00 | 0.00                 |            |             |          |            |                    |        |              | -4.50E+02          |                  |         |           |                       |
|   |      | 3           | 0.00   | 45.00 | -20.00               |            |             |          |            |                    |        |              | 0.00E+00           |                  |         |           |                       |
|   |      | 4           | -22.50 | 45.00 | -20.00               |            |             |          |            |                    |        |              |                    |                  |         |           |                       |
| 6   | QPPL | 1           | -22.50 | 45.00 | -20.00               | 450.00     | 0.0000      | NO       | 20.00      | 30.10              | 22.50  | 0.00E+00     | 0.00E+00           | 0.0E+00          | 0.0E+00 | 0.00 0.00 |                       |
|   |      | 2           | 0.00   | 45.00 | -20.00               |            |             |          |            |                    |        |              | -4.50E+02          |                  |         |           |                       |
|   |      | 3           | 0.00   | 45.00 | -40.00               |            |             |          |            |                    |        |              | 0.00E+00           |                  |         |           |                       |
|   |      | 4           | -22.50 | 45.00 | -40.00               |            |             |          |            |                    |        |              | 5.06E+02           |                  |         |           |                       |
| 7   | QPPL | 1           | -22.50 | 45.00 | -40.00               | 506.25     | 0.0000      | NO       | 22.50      | 31.82              | 22.50  | 0.00E+00     | 0.00E+00           | 0.0E+00          | 0.0E+00 | 0.00 0.00 |                       |
|   |      | 2           | 0.00   | 45.00 | -40.00               |            |             |          |            |                    |        |              | 0.00E+00           |                  |         |           |                       |
|   |      | 3           | 0.00   | 22.50 | -40.00               |            |             |          |            |                    |        |              | 5.06E+02           |                  |         |           |                       |
|   |      | 4           | -22.50 | 22.50 | -40.00               |            |             |          |            |                    |        |              |                    |                  |         |           |                       |
| 8   | QPPL | 1           | -22.50 | 22.50 | -40.00               | 506.25     | 0.0000      | NO       | 22.50      | 31.82              | 22.50  | 0.00E+00     | 0.00E+00           | 0.0E+00          | 0.0E+00 | 0.00 0.00 |                       |
|   |      | 2           | 0.00   | 22.50 | -40.00               |            |             |          |            |                    |        |              | 0.00E+00           |                  |         |           |                       |
|   |      | 3           | 0.00   | 0.00  | -40.00               |            |             |          |            |                    |        |              | 5.06E+02           |                  |         |           |                       |
|   |      | 4           | -22.50 | 0.00  | -40.00               |            |             |          |            |                    |        |              |                    |                  |         |           |                       |
| 9   | QPPL | 1           | -45.00 | 45.00 | 0.00                 | 450.00     | 0.0000      | NO       | 22.50      | 30.10              | 20.00  | 0.00E+00     | 4.50E+02           | 0.0E+00          | 0.0E+00 | 0.0E+00   | 0.00 0.00             |
|   |      | 2           | -45.00 | 45.00 | -20.00               |            |             |          |            |                    |        |              | 0.00E+00           |                  |         |           |                       |
|   |      | 3           | -45.00 | 22.50 | -20.00               |            |             |          |            |                    |        |              | 0.00E+00           |                  |         |           |                       |
|   |      | 4           | -45.00 | 22.50 | 0.00                 |            |             |          |            |                    |        |              |                    |                  |         |           |                       |

Figure 8.11 - Properties of Elements in Detail (Cont)

| * * * * P R O P E R T I E S   O F   E L E M E N T S   I N   D E T A I L - S T R U C T U R E   1 * * * * |      |             |        |       |                      |               |                |             |               |            |                    |                 |                       |            |         |         |           |       |
|---|------|-------------|--------|-------|----------------------|---------------|----------------|-------------|---------------|------------|--------------------|-----------------|-----------------------|------------|---------|---------|-----------|-------|
| -----   |      |             |        |       |                      |               |                |             |               |            |                    |                 |                       |            |         |         |           |       |
| ELEMENT   |      | COORDINATES |        |       | GEOMETRIC PROPERTIES |               |                |             |               |            | MOMENTS OF INERTIA |                 |                       |            | COEFFS  |         |           |       |
| NO  | CODE | NODE        | X      | Y     | Z                    | DIAM/<br>AREA | THICK-<br>NESS | FREE<br>FLD | ENDCUTS/<br>1 | WIDTH<br>2 | LENGTH             | ELEMENT<br>MASS | SUB VOL/<br>PROJ AREA | LOCAL AXES |         |         | DRAG MASS |       |
|   |      | NO          |        |       |                      |               |                |             |               |            |                    |                 |                       | X          | Y       | Z       | C (D)     | C (A) |
| -----   |      |             |        |       |                      |               |                |             |               |            |                    |                 |                       |            |         |         |           |       |
| 10  | QPPL | 1           | -45.00 | 45.00 | -20.00               | 450.00        | 0.0000         | NO          | 22.50         | 30.10      | 20.00              | 0.00E+00        | 4.50E+02              | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00      | 0.00  |
|   |      | 2           | -45.00 | 45.00 | -40.00               |               |                |             |               |            |                    |                 | 0.00E+00              |            |         |         |           |       |
|   |      | 3           | -45.00 | 22.50 | -40.00               |               |                |             |               |            |                    |                 | 0.00E+00              |            |         |         |           |       |
|   |      | 4           | -45.00 | 22.50 | -20.00               |               |                |             |               |            |                    |                 |                       |            |         |         |           |       |
| 11  | QPPL | 1           | -45.00 | 22.50 | 0.00                 | 450.00        | 0.0000         | NO          | 22.50         | 30.10      | 20.00              | 0.00E+00        | 4.50E+02              | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00      | 0.00  |
|   |      | 2           | -45.00 | 22.50 | -20.00               |               |                |             |               |            |                    |                 | 0.00E+00              |            |         |         |           |       |
|   |      | 3           | -45.00 | 0.00  | -20.00               |               |                |             |               |            |                    |                 | 0.00E+00              |            |         |         |           |       |
|   |      | 4           | -45.00 | 0.00  | 0.00                 |               |                |             |               |            |                    |                 |                       |            |         |         |           |       |
| 12  | QPPL | 1           | -45.00 | 22.50 | -20.00               | 450.00        | 0.0000         | NO          | 22.50         | 30.10      | 20.00              | 0.00E+00        | 4.50E+02              | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00      | 0.00  |
|   |      | 2           | -45.00 | 22.50 | -40.00               |               |                |             |               |            |                    |                 | 0.00E+00              |            |         |         |           |       |
|   |      | 3           | -45.00 | 0.00  | -40.00               |               |                |             |               |            |                    |                 | 0.00E+00              |            |         |         |           |       |
|   |      | 4           | -45.00 | 0.00  | -20.00               |               |                |             |               |            |                    |                 |                       |            |         |         |           |       |
| 13  | QPPL | 1           | -45.00 | 45.00 | 0.00                 | 675.00        | 0.0000         | NO          | 45.00         | 47.43      | 15.00              | 0.00E+00        | 0.00E+00              | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00      | 0.00  |
|   |      | 2           | -45.00 | 45.00 | 15.00                |               |                |             |               |            |                    |                 | -6.75E+02             |            |         |         |           |       |
|   |      | 3           | 0.00   | 45.00 | 15.00                |               |                |             |               |            |                    |                 | 0.00E+00              |            |         |         |           |       |
|   |      | 4           | 0.00   | 45.00 | 0.00                 |               |                |             |               |            |                    |                 |                       |            |         |         |           |       |
| 14  | QPPL | 1           | -45.00 | 45.00 | 0.00                 | 675.00        | 0.0000         | NO          | 15.00         | 47.43      | 45.00              | 0.00E+00        | 6.75E+02              | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00      | 0.00  |
|   |      | 2           | -45.00 | 0.00  | 0.00                 |               |                |             |               |            |                    |                 | 0.00E+00              |            |         |         |           |       |
|   |      | 3           | -45.00 | 0.00  | 15.00                |               |                |             |               |            |                    |                 | 0.00E+00              |            |         |         |           |       |
|   |      | 4           | -45.00 | 45.00 | 15.00                |               |                |             |               |            |                    |                 |                       |            |         |         |           |       |
| 15  | QPPL | 1           | -45.00 | 45.00 | 15.00                | 2025.00       | 0.0000         | NO          | 45.00         | 63.64      | 45.00              | 0.00E+00        | 0.00E+00              | 0.0E+00    | 0.0E+00 | 0.0E+00 | 0.00      | 0.00  |
|   |      | 2           | -45.00 | 0.00  | 15.00                |               |                |             |               |            |                    |                 | 0.00E+00              |            |         |         |           |       |
|   |      | 3           | 0.00   | 0.00  | 15.00                |               |                |             |               |            |                    |                 | -2.03E+03             |            |         |         |           |       |
|   |      | 4           | 0.00   | 45.00 | 15.00                |               |                |             |               |            |                    |                 |                       |            |         |         |           |       |

Figure 8.11 - Properties of Elements in Detail (Cont)

```

***** MASS AND INERTIA PROPERTIES OF STRUCTURE 1 *****
-----
      ELEMENT TYPE      NUMBER
                        OF
                        ELEMENTS      MASS      WEIGHT
                        -----
      PMAS              1      3.3210E+08      3.2566E+09
      QPPL              60      0.0000E+00      0.0000E+00
-----
      T O T A L        61      3.3210E+08      3.2566E+09
-----

                        X      Y      Z
                        -----
CENTRE OF GRAVITY      0.000      0.000      -10.620
INERTIA MATRIX
      3.625E+11      0.000E+00      0.000E+00
      0.000E+00      3.420E+11      0.000E+00
      0.000E+00      0.000E+00      3.599E+11

```

Figure 8.12 - Mass and Inertia Properties

| * * * * P R E L I M I N A R Y   D I F F R A C T I O N   M O D E L L I N G   C H E C K * * * *<br>- - - - -<br>* * * * F O R   S T R U C T U R E   1 * * * *<br>- - - - - |    |    |    |    |                 |               |                      |        |        |                      |                 |        |        |                 |                 |                        |               |
|--|----|----|----|----|-----------------|---------------|----------------------|--------|--------|----------------------|-----------------|--------|--------|-----------------|-----------------|------------------------|---------------|
| ELEMENT<br>NUMBER  | 1  | 2  | 3  | 4  | FACET<br>RADIUS | FACET<br>AREA | POSITION OF CENTROID |        |        | CORRECTION<br>FACTOR | OUTWARD NORMALS |        |        | ASPECT<br>RATIO | SHAPE<br>FACTOR | MINIMUM AREA<br>RADIUS | AREA<br>RATIO |
| 1  | 1  | 2  | 12 | 11 | 11.97           | 450.0         | 33.75                | -45.00 | -10.00 | 0.993                | 0.000           | -1.000 | 0.000  | 0.889           | 1.00            | 1.33                   | 1.00          |
| 2  | 11 | 12 | 22 | 21 | 11.97           | 450.0         | 33.75                | -45.00 | -30.00 | 0.993                | 0.000           | -1.000 | 0.000  | 0.889           | 1.00            | 1.26                   | 0.89          |
| 3  | 21 | 22 | 32 | 31 | 12.69           | 506.3         | 33.75                | -33.75 | -40.00 | 0.995                | 0.000           | 0.000  | -1.000 | 1.000           | 1.00            | 1.19                   | 0.89          |
| 4  | 31 | 32 | 42 | 41 | 12.69           | 506.3         | 33.75                | -11.25 | -40.00 | 0.995                | 0.000           | 0.000  | -1.000 | 1.000           | 1.00            | 1.19                   | 0.89          |
| 5  | 2  | 3  | 13 | 12 | 11.97           | 450.0         | 11.25                | -45.00 | -10.00 | 0.993                | 0.000           | -1.000 | 0.000  | 0.889           | 1.00            | 1.67                   | 1.00          |
| 6  | 12 | 13 | 23 | 22 | 11.97           | 450.0         | 11.25                | -45.00 | -30.00 | 0.993                | 0.000           | -1.000 | 0.000  | 0.889           | 1.00            | 1.26                   | 0.89          |
| 7  | 22 | 23 | 33 | 32 | 12.69           | 506.3         | 11.25                | -33.75 | -40.00 | 0.995                | 0.000           | 0.000  | -1.000 | 1.000           | 1.00            | 1.19                   | 0.89          |
| 8  | 32 | 33 | 43 | 42 | 12.69           | 506.3         | 11.25                | -11.25 | -40.00 | 0.995                | 0.000           | 0.000  | -1.000 | 1.000           | 1.00            | 1.77                   | 1.00          |
| 9  | 1  | 11 | 14 | 4  | 11.97           | 450.0         | 45.00                | -33.75 | -10.00 | 0.993                | 1.000           | 0.000  | 0.000  | 0.889           | 1.00            | 1.33                   | 1.00          |
| 10   | 11 | 21 | 24 | 14 | 11.97           | 450.0         | 45.00                | -33.75 | -30.00 | 0.993                | 1.000           | 0.000  | 0.000  | 0.889           | 1.00            | 1.26                   | 0.89          |
| 11   | 4  | 14 | 15 | 5  | 11.97           | 450.0         | 45.00                | -11.25 | -10.00 | 0.993                | 1.000           | 0.000  | 0.000  | 0.889           | 1.00            | 1.67                   | 1.00          |
| 12   | 14 | 24 | 25 | 15 | 11.97           | 450.0         | 45.00                | -11.25 | -30.00 | 0.993                | 1.000           | 0.000  | 0.000  | 0.889           | 1.00            | 1.26                   | 0.89          |

Figure 8.13 - Preliminary Diffraction Modelling Check

```

DECK  6.1
-----

06PERD  1  6  18.0000  17.0000  16.5000  16.0000  15.0000  14.0000
06PERD  7  7  12.0000   0.0000   0.0000   0.0000   0.0000   0.0000
END06DIRN 1  3   0.0000  45.0000  90.0000   0.0000   0.0000   0.0000

DECK  7.1
-----

07PERD  0  1
07ADMP  0  4  0.00E+00  0.00E+00  0.00E+00  3.00E+09  0.00E+00  0.00E+00
07ADMP  0  5  0.00E+00  0.00E+00  0.00E+00  0.00E+00  3.00E+09  0.00E+00
07ADMP  0  6  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  3.00E+09
07PERD  0  2
07ADMP  0  4  0.00E+00  0.00E+00  0.00E+00  3.00E+09  0.00E+00  0.00E+00
07ADMP  0  5  0.00E+00  0.00E+00  0.00E+00  0.00E+00  3.00E+09  0.00E+00
07ADMP  0  6  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  3.00E+09
07PERD  0  3
07ADMP  0  4  0.00E+00  0.00E+00  0.00E+00  3.00E+09  0.00E+00  0.00E+00
07ADMP  0  5  0.00E+00  0.00E+00  0.00E+00  0.00E+00  3.00E+09  0.00E+00
07ADMP  0  6  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  3.00E+09
07PERD  0  4
07ADMP  0  4  0.00E+00  0.00E+00  0.00E+00  3.00E+09  0.00E+00  0.00E+00
07ADMP  0  5  0.00E+00  0.00E+00  0.00E+00  0.00E+00  3.00E+09  0.00E+00
07ADMP  0  6  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  3.00E+09
07PERD  0  5
07ADMP  0  4  0.00E+00  0.00E+00  0.00E+00  3.00E+09  0.00E+00  0.00E+00
07ADMP  0  5  0.00E+00  0.00E+00  0.00E+00  0.00E+00  3.00E+09  0.00E+00
07ADMP  0  6  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  3.00E+09
07PERD  0  6
07ADMP  0  4  0.00E+00  0.00E+00  0.00E+00  3.00E+09  0.00E+00  0.00E+00
07ADMP  0  5  0.00E+00  0.00E+00  0.00E+00  0.00E+00  3.00E+09  0.00E+00
07ADMP  0  6  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  3.00E+09
07PERD  0  7
07ADMP  0  4  0.00E+00  0.00E+00  0.00E+00  3.00E+09  0.00E+00  0.00E+00
07ADMP  0  5  0.00E+00  0.00E+00  0.00E+00  0.00E+00  3.00E+09  0.00E+00
07ADMP  0  6  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  3.00E+09
END07ZCGE 0  0 -1.06E+01  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00

DECK  8.1
-----

```

Figure 8.14 - Card Echo of Input Decks 6 to 8

| * * * * W A V E   F R E Q U E N C I E S   /   P E R I O D S   A N D   D I R E C T I O N S * * * * |                      |           |           |           |           |           |           |           |           |           |           |
|---|----------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| -----   |                      |           |           |           |           |           |           |           |           |           |           |
| STRUCTURE   | VARIABLE             | 1         | 2         | 3         | 4         | 5         | 6         | 7         | 8         | 9         | 10        |
| -----   |                      |           |           |           |           |           |           |           |           |           |           |
| 1   | DIRECTION (DEGREES)  | 0.00      | 45.00     | 90.00     | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      |
|   | FREQUENCY (RADS/SEC) | 0.34907   | 0.36960   | 0.38080   | 0.39270   | 0.41888   | 0.44880   | 0.52360   | 0.00000   | 0.00000   | 0.00000   |
|   | FREQUENCY (HERTZ)    | 0.05556   | 0.05882   | 0.06061   | 0.06250   | 0.06667   | 0.07143   | 0.08333   | 0.00000   | 0.00000   | 0.00000   |
|   | PERIOD (SECONDS)     | 18.00     | 17.00     | 16.50     | 16.00     | 15.00     | 14.00     | 12.00     | 0.00      | 0.00      | 0.00      |
|   | WAVE NUMBER (K)      | 0.01247   | 0.01396   | 0.01481   | 0.01574   | 0.01790   | 0.02054   | 0.02796   | 0.00000   | 0.00000   | 0.00000   |
|   | WAVELENGTH (L)       | 503.68    | 450.19    | 424.38    | 399.23    | 351.06    | 305.87    | 224.74    | 0.00      | 0.00      | 0.00      |
|   | MAXIMUM ELEMENT SIZE | 71.96     | 64.31     | 60.63     | 57.03     | 50.15     | 43.70     | 32.11     | 0.00      | 0.00      | 0.00      |
|   | DEPTH RATIO (D/L)    | 0.50      | 0.56      | 0.59      | 0.63      | 0.71      | 0.82      | 1.11      | 0.00      | 0.00      | 0.00      |
|   | DEPTH RATIO (K*D)    | 3.12      | 3.49      | 3.70      | 3.93      | 4.47      | 5.14      | 6.99      | 0.00      | 0.00      | 0.00      |
|   | PARAMETERS           | UNDEFINED | UNDEFINED | UNDEFINED | UNDEFINED | UNDEFINED | UNDEFINED | UNDEFINED | UNDEFINED | UNDEFINED | UNDEFINED |
| -----   |                      |           |           |           |           |           |           |           |           |           |           |

Figure 8.15 - Wave Frequencies/Periods and Directions

```

      * * * * S E C O N D A R Y   D I F F R A C T I O N   M O D E L L I N G   C H E C K * * * *
      - - - - -
                * * * * F O R   S T R U C T U R E   1 * * * *
                - - - - -

DEPTH OF LOWEST POINT ON VESSEL . . . . . 40.00

SEA BED CLEARANCE OF LOWEST POINT ON VESSEL . 210.00

MAX RATIO OF ELEMENT SIDE TO 1/7 WAVELENGTH . 0.60

NUMBER OF MORISON POINTS . . . . . 4

NUMBER OF DIFFRACTING ELEMENTS . . . . . 12

NUMBER OF DIFFRACTING ELEMENTS IGNORED . . . 0

NUMBER OF FIELD POINTS . . . . . 0

NUMBER OF FIELD POINTS IGNORED . . . . . 0

TOTAL NUMBER OF DIFFRACTION POINTS . . . . . 12

```

Figure 8.16 - Secondary Diffraction Modelling Check



```

* * * * H Y D R O S T A T I C   P R O P E R T I E S   I N   T H E   F R E E   F L O A T I N G   P O S I T I O N * * * *
- - - - -
* * * * F O R   S T R U C T U R E   1 * * * *
- - - - -

1. STIFFNESS MATRIX AT THE CENTRE OF GRAVITY
-----
C.O.G      GX=      0.000 GY=      0.000 GZ=    -10.620
HEAVE( Z)  =      8.141E+07    -7.852E+01    -7.852E+01
ROLL(RX)   =     -7.852E+01     2.441E+10     0.000E+00
PITCH(RY)  =     -7.852E+01     0.000E+00     2.441E+10

2. HYDROSTATIC DISPLACEMENT PROPERTIES
-----
ACTUAL VOLUMETRIC DISPLACEMENT . . . . . = 3.240E+05
EQUIVALENT VOLUME OF STRUCTURE . . . . . = 3.240E+05
POSITION OF THE CENTRE OF BUOYANCY      BX =      0.000
                                          BY =      0.000
                                          BZ =    -20.000

AN INCOMPLETE ELEMENT DESCRIPTION OF    FX =      0.000
THE HULL GIVES OUT OF BALANCE FORCES     FY =      0.000
AND MOMENTS. IF THE C.O.B. IS NOT        FZ =      0.000
BELOW THE C.O.G. THIS GIVES OUT OF       MX =      0.000
BALANCE MOMENTS (FORCES ARE DIVIDED      MY =      0.000
BY THE WEIGHT AND ARE W.R.T. AXES        MZ =      0.000
PARALLEL TO THE FIXED REFERENCE AXES)

3. CUT WATER PLANE AREA PROPERTIES
-----
CUT WATER PLANE AREA . . . . . = 8.100E+03
CENTRE OF FLOATATION, I.E. CENTROID      X =      0.000
POSITION IN THE FIXED REFERENCE AXES     Y =      0.000
PRINCIPAL SECOND MOMENTS OF AREA         IXX=  5.468E+06
                                          IYY=  5.468E+06
ANGLE THE PRINCIPAL AXES MAKE WITH       PHI=      0.000
THE FIXED REFERENCE AXIS SYSTEM

```

Figure 8.17 - Hydrostatic Properties in the Free Floating Position

```
***** HYDROSTATIC PROPERTIES IN THE FREE FLOATING POSITION *****
-----
***** FOR STRUCTURE 1 *****
-----
```

4. SMALL ANGLE STABILITY PARAMETERS  
-----

|  |      |           |
|--|------|-----------|
| DISTANCE BETWEEN C.O.G. AND C.O.B  | BG = | 9.380     |
| METACENTRIC HEIGHTS WITH RESPECT TO<br>THE PRINCIPAL AXES OF THE CUT AREA  | GMX= | 7.495     |
|  | GMY= | 7.495     |
| DISTANCE BETWEEN THE C.O.B. AND THE<br>METACENTRE (BMX=GMX+BG, BMY=GMY+BG) | BMX= | 16.875    |
|  | BMY= | 16.875    |
| RESTORING MOMENT ABOUT THE PRINCIPAL<br>AXES PER DEGREE ROTATION           | MX = | 4.260E+08 |
|  | MY = | 4.260E+08 |

Figure 8.17 - Hydrostatic Properties in the Free Floating Position (Cont)

### 8.1.7 The Diffraction Analysis Run

Once the body model passes all the diffraction checks and is defined in the analysis position, then the diffraction analysis can be run. All wave periods and directions have been previously specified in the DATA run via input through Decks 6 to 8.

The diffraction analysis is performed by a Stage 3 analysis in AQWA-LINE (see Section 6.3.1). Within the present example, it is also necessary to perform a post-processing analysis, this being the transformation of the hydrodynamic forces to axes in the water-plane. This is done by specifying a new hydrodynamic reference point in Deck 16 (i.e. Geometric Changes Deck) and will involve Program Stages 4 to 5.

The diffraction run and post-processing analysis may be performed by two individual program runs or as a single program run encompassing Stages 3 to 5. The second approach is adopted in this example and the data file is shown in Figure 8.18. No data is required for Stage 3 but Stages 4 to 5 require input data via Deck 16. In this example, it is required to find the hydrodynamic forces about a point directly above the centre of gravity and in the water-plane (i.e. 0.0, 0.0, 0.0). The position vector of the new hydrodynamic reference point is input with the body in the definition position. All other decks have deck headers set equal to NONE.

As a program restart is being performed, the user must copy over the restart (.RES) file created by the previous program DATA run. The restart file is used to supply the program with the information contained within Decks 1 to 8, previously input. A hydrodynamic database (.HYD) file will be output, containing the resulting hydrodynamic parameters. The same information will also be output to the restart file.

|           |   |     |     |     |     |
|-----------|---|-----|-----|-----|-----|
| JOB BOX1  | LINE  |     |     |     |     |
| TITLE     | TEST RUN NUMBER 21 (FLOATING BOX 40M DRAUGHT AND 48 FACETS) |     |     |     |     |
| OPTIONS   | REST  | END |     |     |     |
| RESTART   | 3   | 5   |     |     |     |
| 09        | NONE  |     |     |     |     |
| 10        | NONE  |     |     |     |     |
| 11        | NONE  |     |     |     |     |
| 12        | NONE  |     |     |     |     |
| 13        | NONE  |     |     |     |     |
| 14        | NONE  |     |     |     |     |
| 15        | NONE  |     |     |     |     |
| 16        | GMCH  |     |     |     |     |
| END16REFP | 1   | 0   | 0.0 | 0.0 | 0.0 |
| 17        | NONE  |     |     |     |     |
| 18        | NONE  |     |     |     |     |
| 19        | NONE  |     |     |     |     |
| 20        | NONE  |     |     |     |     |

**Figure 8.18 - Data Input for Stages 3 to 5 in Box Example**

### **8.1.8 Output From Diffraction and Post-Processing Run**

Consider first the output relating to the diffraction stage of the analysis (i.e. Stage 3). This contains the following information which is shown in Figures 8.19 to 8.31

- Figure 8.19 - Natural Frequencies/Periods - (undamped) for each degree of freedom. (Note that the stiffness does not EXPLICITLY include stiffness due to moorings, although an equivalent stiffness may be input by the user as 'additional stiffness'). The user should also note that the so-called undamped natural frequency changes with wave frequency, as the added mass is frequency-dependent.
- Figure 8.20 - Stiffness Matrix (N.B. independent of frequency).
- Figure 8.21 - Added Mass and Damping Matrices - for each period/frequency specified.
- Figure 8.22 - Variation of Added Mass and Damping with Frequency.
- Figure 8.23 - Variation of Wave Diffraction Forces with Frequency.
- Figure 8.24 - Variation of Froude-Krylov Forces with Frequency.
- Figure 8.25 - Variation of Total Wave Forces with Frequency. (The total force is the sum of the above forces).
- Figure 8.26 - Variation of Response Amplitude Operators with Frequency.
- Figure 8.27 - Variation of Wave Diffraction Forces with Direction.
- Figure 8.28 - Variation of Froude-Krylov Forces with Direction.
- Figure 8.29 - Variation of Total Wave Forces with Direction.
- Figure 8.30 - Variation of Response Amplitude Operators with Direction.

Note that all the above output is for unit wave amplitude. Since this is a linear analysis, all the above properties are proportional to wave amplitude.

- Figure 8.31 - Wave Drift Loads for Each Frequency and Direction - for unit wave amplitude. These mean wave drift forces are proportional to wave amplitude squared. At present, only the horizontal wave forces and yaw moment are calculated.

|   |           |  |          |           |           |            |          |
|---|-----------|--|----------|-----------|-----------|------------|----------|
| * * * * N A T U R A L   F R E Q U E N C I E S /   P E R I O D S   F O R   S T R U C T U R E   1 * * * * |           |  |          |           |           |            |          |
| N.B. THESE NATURAL FREQUENCIES DO *NOT* INCLUDE STIFFNESS DUE TO MOORING LINES.                         |           |  |          |           |           |            |          |
| FREQUENCY   | FREQUENCY | UNDAMPED NATURAL FREQUENCIES (RADIAN/SECOND) |          |           |           |            |          |
| NUMBER  | (RAD/S)   | SURGE (X)                                    | SWAY (Y) | HEAVE (Z) | ROLL (RX) | PITCH (RY) | YAW (RZ) |
| 1   | 0.349     | 0.000  | 0.000    | 0.380     | 0.232     | 0.238      | 0.000    |
| 2   | 0.370     | 0.000  | 0.000    | 0.382     | 0.232     | 0.238      | 0.000    |
| 3   | 0.381     | 0.000  | 0.000    | 0.382     | 0.232     | 0.238      | 0.000    |
| 4   | 0.393     | 0.000  | 0.000    | 0.383     | 0.232     | 0.238      | 0.000    |
| 5   | 0.419     | 0.000  | 0.000    | 0.384     | 0.232     | 0.238      | 0.000    |
| 6   | 0.449     | 0.000  | 0.000    | 0.384     | 0.232     | 0.238      | 0.000    |
| 7   | 0.524     | 0.000  | 0.000    | 0.383     | 0.232     | 0.238      | 0.000    |
| PERIOD  | PERIOD    | UNDAMPED NATURAL PERIOD (SECONDS)            |          |           |           |            |          |
| NUMBER  | (SECONDS) | SURGE (X)                                    | SWAY (Y) | HEAVE (Z) | ROLL (RX) | PITCH (RY) | YAW (RZ) |
| 1   | 18.00     | 0.00   | 0.00     | 16.52     | 27.03     | 26.41      | 0.00     |
| 2   | 17.00     | 0.00   | 0.00     | 16.46     | 27.03     | 26.41      | 0.00     |
| 3   | 16.50     | 0.00   | 0.00     | 16.43     | 27.03     | 26.41      | 0.00     |
| 4   | 16.00     | 0.00   | 0.00     | 16.41     | 27.04     | 26.41      | 0.00     |
| 5   | 15.00     | 0.00   | 0.00     | 16.38     | 27.04     | 26.42      | 0.00     |
| 6   | 14.00     | 0.00   | 0.00     | 16.37     | 27.04     | 26.42      | 0.00     |
| 7   | 12.00     | 0.00   | 0.00     | 16.42     | 27.03     | 26.40      | 0.00     |
| FREQUENCY   | FREQUENCY | APPROXIMATE PERCENTAGE CRITICAL DAMPING      |          |           |           |            |          |
| NUMBER  | (RAD/S)   | SURGE (X)                                    | SWAY (Y) | HEAVE (Z) | ROLL (RX) | PITCH (RY) | YAW (RZ) |
| 1   | 0.349     | 0.0  | 0.0      | 4.5       | 1.4       | 1.5        | 0.0      |
| 2   | 0.370     | 0.0  | 0.0      | 4.3       | 1.4       | 1.5        | 0.0      |
| 3   | 0.381     | 0.0  | 0.0      | 4.2       | 1.5       | 1.5        | 0.0      |
| 4   | 0.393     | 0.0  | 0.0      | 4.0       | 1.5       | 1.5        | 0.0      |
| 5   | 0.419     | 0.0  | 0.0      | 3.5       | 1.5       | 1.6        | 0.0      |
| 6   | 0.449     | 0.0  | 0.0      | 3.0       | 1.6       | 1.6        | 0.0      |
| 7   | 0.524     | 0.0  | 0.0      | 1.8       | 1.7       | 1.8        | 0.0      |

Figure 8.19 - Natural Frequencies and Periods

|  |            |            |             |             |             |            |
|--|------------|------------|-------------|-------------|-------------|------------|
| * * * * H Y D R O D Y N A M I C   P A R A M E T E R S   F O R   S T R U C T U R E   1 * * * *<br>- - - - - |            |            |             |             |             |            |
| AT THE FREE-FLOATING EQUILIBRIUM POSITION<br>-----   |            |            |             |             |             |            |
| BUOYANCY FORCE . . . . . = 3.2566E+09  |            |            |             |             |             |            |
| Z POSITION OF THE CENTRE OF GRAVITY . = -1.0620E+01  |            |            |             |             |             |            |
| STIFFNESS MATRIX<br>-----  |            |            |             |             |             |            |
|  | X          | Y          | Z           | RX          | RY          | RZ         |
|  | -----      |            |             |             |             |            |
| X  | 0.0000E+00 | 0.0000E+00 | 0.0000E+00  | 0.0000E+00  | 0.0000E+00  | 0.0000E+00 |
| Y  | 0.0000E+00 | 0.0000E+00 | 0.0000E+00  | 0.0000E+00  | 0.0000E+00  | 0.0000E+00 |
| Z  | 0.0000E+00 | 0.0000E+00 | 8.1414E+07  | -7.8525E+01 | -7.8525E+01 | 0.0000E+00 |
| RX   | 0.0000E+00 | 0.0000E+00 | -7.8525E+01 | 2.4408E+10  | 0.0000E+00  | 9.4230E+02 |
| RY   | 0.0000E+00 | 0.0000E+00 | -7.8525E+01 | 0.0000E+00  | 2.4408E+10  | 2.6698E+03 |
| RZ   | 0.0000E+00 | 0.0000E+00 | 0.0000E+00  | 0.0000E+00  | 0.0000E+00  | 0.0000E+00 |

Figure 8.20 - Stiffness Matrix

```

* * * * H Y D R O D Y N A M I C   P A R A M E T E R S   F O R   S T R U C T U R E   1 * * * *
- - - - -
          WAVE PERIOD =  18.000 WAVE FREQUENCY =  0.3491

          ADDED  MASS
          -----

          X          Y          Z          RX          RY          RZ
          -----
X      3.0158E+08      0.0000E+00      0.0000E+00      0.0000E+00     -1.1166E+09      0.0000E+00
Y      0.0000E+00      3.0158E+08      0.0000E+00      1.1166E+09      0.0000E+00      0.0000E+00
Z      0.0000E+00      0.0000E+00      2.3050E+08      0.0000E+00      0.0000E+00      0.0000E+00
RX      0.0000E+00      1.1166E+09      0.0000E+00      8.9184E+10      0.0000E+00      0.0000E+00
RY     -1.1166E+09      0.0000E+00      0.0000E+00      0.0000E+00      8.9184E+10      0.0000E+00
RZ      0.0000E+00      0.0000E+00      0.0000E+00      0.0000E+00      0.0000E+00      1.2691E+11

          DAMPING
          -----

          X          Y          Z          RX          RY          RZ
          -----
X      3.4758E+07      0.0000E+00      0.0000E+00      0.0000E+00     -3.1498E+07      0.0000E+00
Y      0.0000E+00      3.4758E+07      0.0000E+00      3.1498E+07      0.0000E+00      0.0000E+00
Z      0.0000E+00      0.0000E+00      1.9253E+07      0.0000E+00      0.0000E+00      0.0000E+00
RX      0.0000E+00      3.1498E+07      0.0000E+00      3.0156E+09      0.0000E+00      0.0000E+00
RY     -3.1498E+07      0.0000E+00      0.0000E+00      0.0000E+00      3.0156E+09      0.0000E+00
RZ      0.0000E+00      0.0000E+00      0.0000E+00      0.0000E+00      0.0000E+00      3.0002E+09

```

Figure 8.21 - Added Mass and Damping Matrices

```

* * * * H Y D R O D Y N A M I C   P A R A M E T E R S   F O R   S T R U C T U R E   1 * * * *
-----
WAVE PERIOD =  17.000 WAVE FREQUENCY =  0.3696

      ADDED  MASS
      -----

```

|    | X           | Y          | Z          | RX         | RY          | RZ         |
|----|-------------|------------|------------|------------|-------------|------------|
| X  | 2.9746E+08  | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | -1.1396E+09 | 0.0000E+00 |
| Y  | 0.0000E+00  | 2.9746E+08 | 0.0000E+00 | 1.1396E+09 | 0.0000E+00  | 0.0000E+00 |
| Z  | 0.0000E+00  | 0.0000E+00 | 2.2658E+08 | 0.0000E+00 | 0.0000E+00  | 0.0000E+00 |
| RX | 0.0000E+00  | 1.1396E+09 | 0.0000E+00 | 8.9303E+10 | 0.0000E+00  | 0.0000E+00 |
| RY | -1.1396E+09 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 8.9303E+10  | 0.0000E+00 |
| RZ | 0.0000E+00  | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00  | 1.2760E+11 |

```

      DAMPING
      -----

```

|    | X           | Y          | Z          | RX         | RY          | RZ         |
|----|-------------|------------|------------|------------|-------------|------------|
| X  | 4.6862E+07  | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | -5.2857E+07 | 0.0000E+00 |
| Y  | 0.0000E+00  | 4.6862E+07 | 0.0000E+00 | 5.2857E+07 | 0.0000E+00  | 0.0000E+00 |
| Z  | 0.0000E+00  | 0.0000E+00 | 1.8338E+07 | 0.0000E+00 | 0.0000E+00  | 0.0000E+00 |
| RX | 0.0000E+00  | 5.2857E+07 | 0.0000E+00 | 3.0431E+09 | 0.0000E+00  | 0.0000E+00 |
| RY | -5.2857E+07 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 3.0431E+09  | 0.0000E+00 |
| RZ | 0.0000E+00  | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00  | 3.0005E+09 |

Figure 8.21 - Added Mass and Damping Matrices (Cont)



```

* * * * H Y D R O D Y N A M I C   P A R A M E T E R S   F O R   S T R U C T U R E   1 * * * *
-----
          WAVE PERIOD =  16.500 WAVE FREQUENCY =  0.3808

          ADDED  MASS
          -----
                X          Y          Z          RX          RY          RZ
          -----
X      2.9227E+08      0.0000E+00      0.0000E+00      0.0000E+00     -1.1478E+09      0.0000E+00
Y      0.0000E+00      2.9227E+08      0.0000E+00      1.1478E+09      0.0000E+00      0.0000E+00
Z      0.0000E+00      0.0000E+00      2.2478E+08      0.0000E+00      0.0000E+00      0.0000E+00
RX      0.0000E+00      1.1478E+09      0.0000E+00      8.9345E+10      0.0000E+00      0.0000E+00
RY     -1.1478E+09      0.0000E+00      0.0000E+00      0.0000E+00      8.9345E+10      0.0000E+00
RZ      0.0000E+00      0.0000E+00      0.0000E+00      0.0000E+00      0.0000E+00      1.2814E+11

          DAMPING
          -----
                X          Y          Z          RX          RY          RZ
          -----
X      5.3989E+07      0.0000E+00      0.0000E+00      0.0000E+00     -6.7332E+07      0.0000E+00
Y      0.0000E+00      5.3989E+07      0.0000E+00      6.7332E+07      0.0000E+00      0.0000E+00
Z      0.0000E+00      0.0000E+00      1.7699E+07      0.0000E+00      0.0000E+00      0.0000E+00
RX      0.0000E+00      6.7332E+07      0.0000E+00      3.0654E+09      0.0000E+00      0.0000E+00
RY     -6.7332E+07      0.0000E+00      0.0000E+00      0.0000E+00      3.0654E+09      0.0000E+00
RZ      0.0000E+00      0.0000E+00      0.0000E+00      0.0000E+00      0.0000E+00      3.0009E+09

```

Figure 8.21 - Added Mass and Damping Matrices (Cont)

```

* * * * H Y D R O D Y N A M I C   P A R A M E T E R S   F O R   S T R U C T U R E   1 * * * *
-----
WAVE PERIOD = 16.000 WAVE FREQUENCY = 0.3927

      ADDED MASS
      -----

```

|    | X           | Y          | Z          | RX         | RY          | RZ         |
|----|-------------|------------|------------|------------|-------------|------------|
| X  | 2.8426E+08  | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | -1.1516E+09 | 0.0000E+00 |
| Y  | 0.0000E+00  | 2.8426E+08 | 0.0000E+00 | 1.1516E+09 | 0.0000E+00  | 0.0000E+00 |
| Z  | 0.0000E+00  | 0.0000E+00 | 2.2318E+08 | 0.0000E+00 | 0.0000E+00  | 0.0000E+00 |
| RX | 0.0000E+00  | 1.1516E+09 | 0.0000E+00 | 8.9369E+10 | 0.0000E+00  | 0.0000E+00 |
| RY | -1.1516E+09 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 8.9369E+10  | 0.0000E+00 |
| RZ | 0.0000E+00  | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00  | 1.2850E+11 |

```

      DAMPING
      -----

```

|    | X           | Y          | Z          | RX         | RY          | RZ         |
|----|-------------|------------|------------|------------|-------------|------------|
| X  | 6.1707E+07  | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | -8.4896E+07 | 0.0000E+00 |
| Y  | 0.0000E+00  | 6.1707E+07 | 0.0000E+00 | 8.4896E+07 | 0.0000E+00  | 0.0000E+00 |
| Z  | 0.0000E+00  | 0.0000E+00 | 1.6928E+07 | 0.0000E+00 | 0.0000E+00  | 0.0000E+00 |
| RX | 0.0000E+00  | 8.4896E+07 | 0.0000E+00 | 3.0957E+09 | 0.0000E+00  | 0.0000E+00 |
| RY | -8.4896E+07 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 3.0957E+09  | 0.0000E+00 |
| RZ | 0.0000E+00  | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00  | 3.0015E+09 |

Figure 8.21 - Added Mass and Damping Matrices (Cont)

```

* * * * H Y D R O D Y N A M I C   P A R A M E T E R S   F O R   S T R U C T U R E   1 * * * *
-----
WAVE PERIOD = 15.000 WAVE FREQUENCY = 0.4189

      ADDED MASS
      -----

```

|    | X           | Y          | Z          | RX         | RY          | RZ         |
|----|-------------|------------|------------|------------|-------------|------------|
| X  | 2.5904E+08  | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | -1.1378E+09 | 0.0000E+00 |
| Y  | 0.0000E+00  | 2.5904E+08 | 0.0000E+00 | 1.1378E+09 | 0.0000E+00  | 0.0000E+00 |
| Z  | 0.0000E+00  | 0.0000E+00 | 2.2129E+08 | 0.0000E+00 | 0.0000E+00  | 0.0000E+00 |
| RX | 0.0000E+00  | 1.1378E+09 | 0.0000E+00 | 8.9492E+10 | 0.0000E+00  | 0.0000E+00 |
| RY | -1.1378E+09 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 8.9492E+10  | 0.0000E+00 |
| RZ | 0.0000E+00  | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00  | 1.2996E+11 |

```

      DAMPING
      -----

```

|    | X           | Y          | Z          | RX         | RY          | RZ         |
|----|-------------|------------|------------|------------|-------------|------------|
| X  | 7.8023E+07  | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | -1.2756E+08 | 0.0000E+00 |
| Y  | 0.0000E+00  | 7.8023E+07 | 0.0000E+00 | 1.2756E+08 | 0.0000E+00  | 0.0000E+00 |
| Z  | 0.0000E+00  | 0.0000E+00 | 1.5051E+07 | 0.0000E+00 | 0.0000E+00  | 0.0000E+00 |
| RX | 0.0000E+00  | 1.2756E+08 | 0.0000E+00 | 3.1841E+09 | 0.0000E+00  | 0.0000E+00 |
| RY | -1.2756E+08 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 3.1841E+09  | 0.0000E+00 |
| RZ | 0.0000E+00  | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00  | 3.0048E+09 |

Figure 8.21 - Added Mass and Damping Matrices (Cont)

```

* * * * H Y D R O D Y N A M I C   P A R A M E T E R S   F O R   S T R U C T U R E   1 * * * *
-----
WAVE PERIOD =  14.000 WAVE FREQUENCY =  0.4488

      ADDED  MASS
      -----

```

|    | X           | Y          | Z          | RX         | RY          | RZ         |
|----|-------------|------------|------------|------------|-------------|------------|
| X  | 2.2167E+08  | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | -1.0859E+09 | 0.0000E+00 |
| Y  | 0.0000E+00  | 2.2167E+08 | 0.0000E+00 | 1.0859E+09 | 0.0000E+00  | 0.0000E+00 |
| Z  | 0.0000E+00  | 0.0000E+00 | 2.2060E+08 | 0.0000E+00 | 0.0000E+00  | 0.0000E+00 |
| RX | 0.0000E+00  | 1.0859E+09 | 0.0000E+00 | 8.9462E+10 | 0.0000E+00  | 0.0000E+00 |
| RY | -1.0859E+09 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 8.9462E+10  | 0.0000E+00 |
| RZ | 0.0000E+00  | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00  | 1.3169E+11 |

```

      DAMPING
      -----

```

|    | X           | Y          | Z          | RX         | RY          | RZ         |
|----|-------------|------------|------------|------------|-------------|------------|
| X  | 9.3312E+07  | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | -1.7839E+08 | 0.0000E+00 |
| Y  | 0.0000E+00  | 9.3312E+07 | 0.0000E+00 | 1.7839E+08 | 0.0000E+00  | 0.0000E+00 |
| Z  | 0.0000E+00  | 0.0000E+00 | 1.2737E+07 | 0.0000E+00 | 0.0000E+00  | 0.0000E+00 |
| RX | 0.0000E+00  | 1.7839E+08 | 0.0000E+00 | 3.3150E+09 | 0.0000E+00  | 0.0000E+00 |
| RY | -1.7839E+08 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 3.3150E+09  | 0.0000E+00 |
| RZ | 0.0000E+00  | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00  | 3.0159E+09 |

Figure 8.21 - Added Mass and Damping Matrices (Cont)

```

* * * * H Y D R O D Y N A M I C   P A R A M E T E R S   F O R   S T R U C T U R E   1 * * * *
- - - - -
WAVE PERIOD = 12.000 WAVE FREQUENCY = 0.5236

      ADDED MASS
      - - - - -
      X          Y          Z          RX          RY          RZ
      - - - - -
X      1.3084E+08      0.0000E+00      0.0000E+00      0.0000E+00      -8.7338E+08      0.0000E+00
Y      0.0000E+00      1.3084E+08      0.0000E+00      8.7338E+08      0.0000E+00      0.0000E+00
Z      0.0000E+00      0.0000E+00      2.2385E+08      0.0000E+00      0.0000E+00      0.0000E+00
RX      0.0000E+00      8.7338E+08      0.0000E+00      8.9068E+10      0.0000E+00      0.0000E+00
RY     -8.7338E+08      0.0000E+00      0.0000E+00      0.0000E+00      8.9068E+10      0.0000E+00
RZ      0.0000E+00      0.0000E+00      0.0000E+00      0.0000E+00      0.0000E+00      1.3823E+11

      DAMPING
      - - - - -
      X          Y          Z          RX          RY          RZ
      - - - - -
X      1.0958E+08      0.0000E+00      0.0000E+00      0.0000E+00      -2.7331E+08      0.0000E+00
Y      0.0000E+00      1.0958E+08      0.0000E+00      2.7331E+08      0.0000E+00      0.0000E+00
Z      0.0000E+00      0.0000E+00      7.4671E+06      0.0000E+00      0.0000E+00      0.0000E+00
RX      0.0000E+00      2.7331E+08      0.0000E+00      3.6675E+09      0.0000E+00      0.0000E+00
RY     -2.7331E+08      0.0000E+00      0.0000E+00      0.0000E+00      3.6676E+09      0.0000E+00
RZ      0.0000E+00      0.0000E+00      0.0000E+00      0.0000E+00      0.0000E+00      3.2185E+09

```

Figure 8.21 - Added Mass and Damping Matrices (Cont)

| * * * * H Y D R O D Y N A M I C   P A R A M E T E R S   F O R   S T R U C T U R E   1 * * * * |          |          |          |          |          |          |          |           |          |          |          |          |   |
|---|----------|----------|----------|----------|----------|----------|----------|-----------|----------|----------|----------|----------|---|
| -----   |          |          |          |          |          |          |          |           |          |          |          |          |   |
| ADDED MASS-VARIATION WITH WAVE PERIOD/FREQUENCY   |          |          |          |          |          |          |          |           |          |          |          |          |   |
| -----   |          |          |          |          |          |          |          |           |          |          |          |          |   |
| PERIOD FREQ   | M        | M        | M        | M        | M        | M        | M        | M         | M        | M        | M        | M        | M |
| (SECS) (RAD/S)  | 11       | 22       | 33       | 44       | 55       | 66       | 13       | 15        | 24       | 26       | 35       | 46       |   |
| -----   |          |          |          |          |          |          |          |           |          |          |          |          |   |
| 18.00 0.349   | 3.02E+08 | 3.02E+08 | 2.30E+08 | 8.92E+10 | 8.92E+10 | 1.27E+11 | 0.00E+00 | -1.12E+09 | 1.12E+09 | 0.00E+00 | 0.00E+00 | 0.00E+00 |   |
| 17.00 0.370   | 2.97E+08 | 2.97E+08 | 2.27E+08 | 8.93E+10 | 8.93E+10 | 1.28E+11 | 0.00E+00 | -1.14E+09 | 1.14E+09 | 0.00E+00 | 0.00E+00 | 0.00E+00 |   |
| 16.50 0.381   | 2.92E+08 | 2.92E+08 | 2.25E+08 | 8.93E+10 | 8.93E+10 | 1.28E+11 | 0.00E+00 | -1.15E+09 | 1.15E+09 | 0.00E+00 | 0.00E+00 | 0.00E+00 |   |
| 16.00 0.393   | 2.84E+08 | 2.84E+08 | 2.23E+08 | 8.94E+10 | 8.94E+10 | 1.28E+11 | 0.00E+00 | -1.15E+09 | 1.15E+09 | 0.00E+00 | 0.00E+00 | 0.00E+00 |   |
| 15.00 0.419   | 2.59E+08 | 2.59E+08 | 2.21E+08 | 8.95E+10 | 8.95E+10 | 1.30E+11 | 0.00E+00 | -1.14E+09 | 1.14E+09 | 0.00E+00 | 0.00E+00 | 0.00E+00 |   |
| 14.00 0.449   | 2.22E+08 | 2.22E+08 | 2.21E+08 | 8.95E+10 | 8.95E+10 | 1.32E+11 | 0.00E+00 | -1.09E+09 | 1.09E+09 | 0.00E+00 | 0.00E+00 | 0.00E+00 |   |
| 12.00 0.524   | 1.31E+08 | 1.31E+08 | 2.24E+08 | 8.91E+10 | 8.91E+10 | 1.38E+11 | 0.00E+00 | -8.73E+08 | 8.73E+08 | 0.00E+00 | 0.00E+00 | 0.00E+00 |   |
| -----   |          |          |          |          |          |          |          |           |          |          |          |          |   |
| DAMPING-VARIATION WITH WAVE PERIOD/FREQUENCY  |          |          |          |          |          |          |          |           |          |          |          |          |   |
| -----   |          |          |          |          |          |          |          |           |          |          |          |          |   |
| PERIOD FREQ   | C        | C        | C        | C        | C        | C        | C        | C         | C        | C        | C        | C        | C |
| (SECS) (RAD/S)  | 11       | 22       | 33       | 44       | 55       | 66       | 13       | 15        | 24       | 26       | 35       | 46       |   |
| -----   |          |          |          |          |          |          |          |           |          |          |          |          |   |
| 18.00 0.349   | 3.48E+07 | 3.48E+07 | 1.93E+07 | 3.02E+09 | 3.02E+09 | 3.00E+09 | 0.00E+00 | -3.15E+07 | 3.15E+07 | 0.00E+00 | 0.00E+00 | 0.00E+00 |   |
| 17.00 0.370   | 4.69E+07 | 4.69E+07 | 1.83E+07 | 3.04E+09 | 3.04E+09 | 3.00E+09 | 0.00E+00 | -5.29E+07 | 5.29E+07 | 0.00E+00 | 0.00E+00 | 0.00E+00 |   |
| 16.50 0.381   | 5.40E+07 | 5.40E+07 | 1.77E+07 | 3.07E+09 | 3.07E+09 | 3.00E+09 | 0.00E+00 | -6.73E+07 | 6.73E+07 | 0.00E+00 | 0.00E+00 | 0.00E+00 |   |
| 16.00 0.393   | 6.17E+07 | 6.17E+07 | 1.69E+07 | 3.10E+09 | 3.10E+09 | 3.00E+09 | 0.00E+00 | -8.49E+07 | 8.49E+07 | 0.00E+00 | 0.00E+00 | 0.00E+00 |   |
| 15.00 0.419   | 7.80E+07 | 7.80E+07 | 1.51E+07 | 3.18E+09 | 3.18E+09 | 3.00E+09 | 0.00E+00 | -1.28E+08 | 1.28E+08 | 0.00E+00 | 0.00E+00 | 0.00E+00 |   |
| 14.00 0.449   | 9.33E+07 | 9.33E+07 | 1.27E+07 | 3.31E+09 | 3.31E+09 | 3.02E+09 | 0.00E+00 | -1.78E+08 | 1.78E+08 | 0.00E+00 | 0.00E+00 | 0.00E+00 |   |
| 12.00 0.524   | 1.10E+08 | 1.10E+08 | 7.47E+06 | 3.67E+09 | 3.67E+09 | 3.22E+09 | 0.00E+00 | -2.73E+08 | 2.73E+08 | 0.00E+00 | 0.00E+00 | 0.00E+00 |   |

Figure 8.22 - Variation of Added Mass and Damping with Frequency

| * * * * H Y D R O D Y N A M I C   P A R A M E T E R S   F O R   S T R U C T U R E   1 * * * * *               |         |           |          |        |          |        |          |         |          |        |          |       |          |         |
|---|---------|-----------|----------|--------|----------|--------|----------|---------|----------|--------|----------|-------|----------|---------|
| - - - - -   |         |           |          |        |          |        |          |         |          |        |          |       |          |         |
| D I F F R A C T I O N   F O R C E S - V A R I A T I O N   W I T H   W A V E   P E R I O D / F R E Q U E N C Y |         |           |          |        |          |        |          |         |          |        |          |       |          |         |
| -----   |         |           |          |        |          |        |          |         |          |        |          |       |          |         |
| PERIOD  | FREQ    | DIRECTION | X        |        | Y        |        | Z        |         | RX       |        | RY       |       | RZ       |         |
| (SECS)  | (RAD/S) | (DEGREES) | AMP      | PHASE  | AMP      | PHASE  | AMP      | PHASE   | AMP      | PHASE  | AMP      | PHASE | AMP      | PHASE   |
| -----   |         |           |          |        |          |        |          |         |          |        |          |       |          |         |
| 18.00   | 0.349   | 0.00      | 2.52E+07 | -72.23 | 0.00E+00 | 0.00   | 1.96E+07 | -154.64 | 0.00E+00 | 0.00   | 1.46E+08 | 90.88 | 0.00E+00 | 0.00    |
| 17.00   | 0.370   |           | 2.66E+07 | -67.54 | 0.00E+00 | 0.00   | 2.00E+07 | -153.72 | 0.00E+00 | 0.00   | 1.63E+08 | 91.89 | 0.00E+00 | 0.00    |
| 16.50   | 0.381   |           | 2.71E+07 | -64.82 | 0.00E+00 | 0.00   | 2.01E+07 | -153.26 | 0.00E+00 | 0.00   | 1.72E+08 | 92.51 | 0.00E+00 | 0.00    |
| 16.00   | 0.393   |           | 2.73E+07 | -61.85 | 0.00E+00 | 0.00   | 2.01E+07 | -152.83 | 0.00E+00 | 0.00   | 1.81E+08 | 93.20 | 0.00E+00 | 0.00    |
| 15.00   | 0.419   |           | 2.67E+07 | -55.24 | 0.00E+00 | 0.00   | 1.99E+07 | -152.00 | 0.00E+00 | 0.00   | 1.97E+08 | 94.70 | 0.00E+00 | 0.00    |
| 14.00   | 0.449   |           | 2.42E+07 | -47.99 | 0.00E+00 | 0.00   | 1.92E+07 | -151.28 | 0.00E+00 | 0.00   | 2.09E+08 | 96.02 | 0.00E+00 | 0.00    |
| 12.00   | 0.524   |           | 1.17E+07 | -33.93 | 0.00E+00 | 0.00   | 1.58E+07 | -150.55 | 0.00E+00 | 0.00   | 2.09E+08 | 95.35 | 0.00E+00 | 0.00    |
|   |         |           |          |        |          |        |          |         |          |        |          |       |          |         |
| 18.00   | 0.349   | 45.00     | 1.86E+07 | -72.52 | 1.86E+07 | -72.52 | 1.96E+07 | -154.63 | 1.06E+08 | -89.12 | 1.06E+08 | 90.88 | 9.38E+00 | -170.89 |
| 17.00   | 0.370   |           | 1.99E+07 | -68.01 | 1.99E+07 | -68.01 | 2.00E+07 | -153.70 | 1.20E+08 | -88.11 | 1.20E+08 | 91.89 | 9.25E+00 | -178.07 |
| 16.50   | 0.381   |           | 2.05E+07 | -65.42 | 2.05E+07 | -65.42 | 2.01E+07 | -153.24 | 1.27E+08 | -87.48 | 1.27E+08 | 92.52 | 8.60E+00 | -167.27 |
| 16.00   | 0.393   |           | 2.09E+07 | -62.61 | 2.09E+07 | -62.61 | 2.02E+07 | -152.81 | 1.34E+08 | -86.78 | 1.34E+08 | 93.22 | 7.28E+00 | -13.76  |
| 15.00   | 0.419   |           | 2.11E+07 | -56.51 | 2.11E+07 | -56.51 | 1.99E+07 | -151.96 | 1.48E+08 | -85.21 | 1.48E+08 | 94.79 | 8.49E+00 | -171.12 |
| 14.00   | 0.449   |           | 2.02E+07 | -50.20 | 2.02E+07 | -50.20 | 1.93E+07 | -151.20 | 1.60E+08 | -83.71 | 1.60E+08 | 96.29 | 9.45E+00 | -176.25 |
| 12.00   | 0.524   |           | 1.43E+07 | -41.53 | 1.43E+07 | -41.53 | 1.60E+07 | -150.30 | 1.72E+08 | -82.55 | 1.72E+08 | 97.45 | 1.08E+01 | -39.09  |
|   |         |           |          |        |          |        |          |         |          |        |          |       |          |         |
| 18.00   | 0.349   | 90.00     | 2.10E+00 | -72.62 | 2.52E+07 | -72.23 | 1.96E+07 | -154.64 | 1.46E+08 | -89.12 | 1.23E+01 | 90.85 | 3.37E+00 | -180.00 |
| 17.00   | 0.370   |           | 2.20E+00 | -68.80 | 2.66E+07 | -67.54 | 2.00E+07 | -153.72 | 1.63E+08 | -88.11 | 1.38E+01 | 91.74 | 2.40E+00 | -180.00 |
| 16.50   | 0.381   |           | 2.29E+00 | -66.20 | 2.71E+07 | -64.82 | 2.01E+07 | -153.26 | 1.72E+08 | -87.49 | 1.47E+01 | 92.35 | 4.59E-01 | -180.00 |
| 16.00   | 0.393   |           | 2.35E+00 | -63.67 | 2.73E+07 | -61.85 | 2.01E+07 | -152.83 | 1.81E+08 | -86.80 | 1.39E+01 | 93.38 | 1.13E+00 | 0.00    |
| 15.00   | 0.419   |           | 2.33E+00 | -59.23 | 2.67E+07 | -55.24 | 1.99E+07 | -152.00 | 1.97E+08 | -85.30 | 1.99E+01 | 93.66 | 2.46E+00 | -179.99 |
| 14.00   | 0.449   |           | 2.29E+00 | -54.73 | 2.42E+07 | -47.99 | 1.92E+07 | -151.28 | 2.09E+08 | -83.98 | 2.15E+01 | 94.84 | 1.94E+00 | -179.98 |
| 12.00   | 0.524   |           | 2.19E+00 | -41.38 | 1.17E+07 | -33.93 | 1.58E+07 | -150.55 | 2.09E+08 | -84.65 | 2.02E+01 | 99.75 | 1.38E+01 | -179.83 |

Figure 8.23 - Variation of Wave Diffraction Forces with Frequency

| * * * * H Y D R O D Y N A M I C   P A R A M E T E R S   F O R   S T R U C T U R E   1 * * * * |         |           |          |         |          |        |          |       |          |        |          |         |          |         |
|---|---------|-----------|----------|---------|----------|--------|----------|-------|----------|--------|----------|---------|----------|---------|
| -----   |         |           |          |         |          |        |          |       |          |        |          |         |          |         |
| FROUDE KRYLOV FORCES-VARIATION WITH WAVE PERIOD/FREQUENCY                                     |         |           |          |         |          |        |          |       |          |        |          |         |          |         |
| -----   |         |           |          |         |          |        |          |       |          |        |          |         |          |         |
| PERIOD  | FREQ    | DIRECTION | X        |         | Y        |        | Z        |       | RX       |        | RY       |         | RZ       |         |
| (SECS)  | (RAD/S) | (DEGREES) | AMP      | PHASE   | AMP      | PHASE  | AMP      | PHASE | AMP      | PHASE  | AMP      | PHASE   | AMP      | PHASE   |
| -----   |         |           |          |         |          |        |          |       |          |        |          |         |          |         |
| 18.00   | 0.349   | 0.00      | 3.03E+07 | -90.00  | 1.25E+00 | -1.43  | 4.72E+07 | 0.00  | 2.80E+01 | 178.98 | 1.34E+08 | -90.00  | 6.00E+00 | 180.00  |
| 17.00   | 0.370   |           | 3.25E+07 | -90.00  | 2.04E+00 | 11.48  | 4.38E+07 | 0.00  | 5.01E+01 | 176.00 | 1.39E+08 | -90.00  | 1.81E+01 | -6.34   |
| 16.50   | 0.381   |           | 3.36E+07 | -90.00  | 1.51E+00 | -7.13  | 4.20E+07 | 0.00  | 6.00E+01 | 178.09 | 1.41E+08 | -90.00  | 1.79E+01 | -26.57  |
| 16.00   | 0.393   |           | 3.48E+07 | -90.00  | 4.00E+00 | 0.00   | 4.01E+07 | 0.00  | 1.81E+01 | 173.66 | 1.42E+08 | -90.00  | 4.62E+01 | -72.35  |
| 15.00   | 0.419   |           | 3.71E+07 | -90.00  | 5.25E+00 | 0.00   | 3.59E+07 | 0.00  | 5.22E+01 | 174.51 | 1.44E+08 | -90.00  | 3.41E+01 | -86.63  |
| 14.00   | 0.449   |           | 3.91E+07 | -90.00  | 1.75E+00 | 0.00   | 3.12E+07 | 0.00  | 1.64E+01 | 167.66 | 1.44E+08 | -90.00  | 8.54E+00 | -69.44  |
| 12.00   | 0.524   |           | 4.09E+07 | -90.00  | 1.13E+00 | 3.18   | 2.05E+07 | 0.00  | 8.00E+00 | 0.00   | 1.38E+08 | -90.00  | 3.41E+01 | -84.96  |
|   |         |           |          |         |          |        |          |       |          |        |          |         |          |         |
| 18.00   | 0.349   | 45.00     | 2.15E+07 | -90.00  | 2.15E+07 | -90.00 | 4.72E+07 | 0.00  | 9.16E+07 | 90.00  | 9.16E+07 | -90.00  | 4.50E+01 | -143.13 |
| 17.00   | 0.370   |           | 2.30E+07 | -90.00  | 2.30E+07 | -90.00 | 4.39E+07 | 0.00  | 9.36E+07 | 90.00  | 9.36E+07 | -90.00  | 5.21E+01 | -176.70 |
| 16.50   | 0.381   |           | 2.38E+07 | -90.00  | 2.38E+07 | -90.00 | 4.20E+07 | 0.00  | 9.44E+07 | 90.00  | 9.44E+07 | -90.00  | 2.42E+01 | -24.44  |
| 16.00   | 0.393   |           | 2.47E+07 | -90.00  | 2.47E+07 | -90.00 | 4.01E+07 | 0.00  | 9.44E+07 | 90.00  | 9.44E+07 | -90.00  | 3.26E+01 | 10.62   |
| 15.00   | 0.419   |           | 2.63E+07 | -90.00  | 2.63E+07 | -90.00 | 3.59E+07 | 0.00  | 9.41E+07 | 90.00  | 9.41E+07 | -90.00  | 3.94E+01 | -120.47 |
| 14.00   | 0.449   |           | 2.78E+07 | -90.00  | 2.78E+07 | -90.00 | 3.13E+07 | 0.00  | 9.16E+07 | 90.00  | 9.16E+07 | -90.00  | 6.33E+01 | -31.43  |
| 12.00   | 0.524   |           | 2.94E+07 | -90.00  | 2.94E+07 | -90.00 | 2.06E+07 | 0.00  | 7.80E+07 | 90.00  | 7.80E+07 | -90.00  | 2.20E+01 | -90.00  |
|   |         |           |          |         |          |        |          |       |          |        |          |         |          |         |
| 18.00   | 0.349   | 90.00     | 3.73E+00 | -127.16 | 3.03E+07 | -90.00 | 4.72E+07 | 0.00  | 1.34E+08 | 90.00  | 1.50E+01 | -90.00  | 8.02E+00 | -176.42 |
| 17.00   | 0.370   |           | 3.27E+00 | -117.30 | 3.25E+07 | -90.00 | 4.38E+07 | 0.00  | 1.39E+08 | 90.00  | 1.65E+01 | -75.96  | 1.53E+01 | -141.63 |
| 16.50   | 0.381   |           | 2.86E+00 | -100.08 | 3.36E+07 | -90.00 | 4.20E+07 | 0.00  | 1.41E+08 | 90.00  | 4.17E+01 | -149.74 | 2.41E+01 | -48.37  |
| 16.00   | 0.393   |           | 3.45E+00 | -125.42 | 3.48E+07 | -90.00 | 4.01E+07 | 0.00  | 1.42E+08 | 90.00  | 2.00E+01 | -53.13  | 3.12E+01 | -125.22 |
| 15.00   | 0.419   |           | 3.48E+00 | -111.04 | 3.71E+07 | -90.00 | 3.59E+07 | 0.00  | 1.44E+08 | 90.00  | 3.83E+01 | -33.27  | 3.49E+01 | -76.76  |
| 14.00   | 0.449   |           | 3.09E+00 | -104.04 | 3.91E+07 | -90.00 | 3.12E+07 | 0.00  | 1.44E+08 | 90.00  | 1.53E+01 | -58.39  | 2.05E+01 | -133.03 |
| 12.00   | 0.524   |           | 3.40E+00 | -102.76 | 4.09E+07 | -90.00 | 2.05E+07 | 0.00  | 1.38E+08 | 90.00  | 2.13E+01 | -138.81 | 3.39E+01 | -135.00 |

Figure 8.24 - Variation of Froude-krylov Forces with Frequency



| * * * * H Y D R O D Y N A M I C   P A R A M E T E R S   F O R   S T R U C T U R E   1 * * * * |         |           |          |         |          |        |          |        |          |        |          |         |          |         |
|---|---------|-----------|----------|---------|----------|--------|----------|--------|----------|--------|----------|---------|----------|---------|
| - - - - -   |         |           |          |         |          |        |          |        |          |        |          |         |          |         |
| TOTAL FORCES-VARIATION WITH WAVE PERIOD/FREQUENCY   |         |           |          |         |          |        |          |        |          |        |          |         |          |         |
| -----   |         |           |          |         |          |        |          |        |          |        |          |         |          |         |
| PERIOD  | FREQ    | DIRECTION | X        |         | Y        |        | Z        |        | RX       |        | RY       |         | RZ       |         |
| (SECS)  | (RAD/S) | (DEGREES) | AMP      | PHASE   | AMP      | PHASE  | AMP      | PHASE  | AMP      | PHASE  | AMP      | PHASE   | AMP      | PHASE   |
| -----   |         |           |          |         |          |        |          |        |          |        |          |         |          |         |
| 18.00   | 0.349   | 0.00      | 5.48E+07 | -81.94  | 1.25E+00 | -1.43  | 3.07E+07 | -15.86 | 2.80E+01 | 178.98 | 1.15E+07 | 101.29  | 6.00E+00 | 180.00  |
| 17.00   | 0.370   |           | 5.80E+07 | -79.91  | 2.04E+00 | 11.48  | 2.74E+07 | -18.82 | 5.01E+01 | 176.00 | 2.47E+07 | 102.52  | 1.81E+01 | -6.34   |
| 16.50   | 0.381   |           | 5.93E+07 | -78.79  | 1.51E+00 | -7.13  | 2.57E+07 | -20.54 | 6.00E+01 | 178.09 | 3.17E+07 | 103.70  | 1.79E+01 | -26.57  |
| 16.00   | 0.393   |           | 6.03E+07 | -77.65  | 4.00E+00 | 0.00   | 2.40E+07 | -22.52 | 1.81E+01 | 173.66 | 3.98E+07 | 104.64  | 4.62E+01 | -72.35  |
| 15.00   | 0.419   |           | 6.10E+07 | -75.52  | 5.25E+00 | 0.00   | 2.06E+07 | -27.01 | 5.22E+01 | 174.51 | 5.48E+07 | 107.14  | 3.41E+01 | -86.63  |
| 14.00   | 0.449   |           | 5.94E+07 | -74.16  | 1.75E+00 | 0.00   | 1.71E+07 | -32.68 | 1.64E+01 | 167.66 | 6.73E+07 | 109.03  | 8.54E+00 | -69.44  |
| 12.00   | 0.524   |           | 4.84E+07 | -78.42  | 1.13E+00 | 3.18   | 1.03E+07 | -49.22 | 8.00E+00 | 0.00   | 7.31E+07 | 105.46  | 3.41E+01 | -84.96  |
|   |         |           |          |         |          |        |          |        |          |        |          |         |          |         |
| 18.00   | 0.349   | 45.00     | 3.96E+07 | -81.89  | 3.96E+07 | -81.89 | 3.07E+07 | -15.88 | 1.47E+07 | -83.63 | 1.47E+07 | 96.37   | 5.35E+01 | -147.81 |
| 17.00   | 0.370   |           | 4.22E+07 | -79.81  | 4.22E+07 | -79.81 | 2.74E+07 | -18.85 | 2.63E+07 | -81.38 | 2.63E+07 | 98.62   | 6.13E+01 | -176.90 |
| 16.50   | 0.381   |           | 4.33E+07 | -78.66  | 4.33E+07 | -78.66 | 2.57E+07 | -20.57 | 3.26E+07 | -80.19 | 3.26E+07 | 99.81   | 1.81E+01 | -41.14  |
| 16.00   | 0.393   |           | 4.43E+07 | -77.46  | 4.43E+07 | -77.46 | 2.40E+07 | -22.57 | 4.00E+07 | -79.18 | 4.00E+07 | 100.82  | 3.93E+01 | 6.23    |
| 15.00   | 0.419   |           | 4.55E+07 | -75.15  | 4.55E+07 | -75.15 | 2.06E+07 | -27.09 | 5.50E+07 | -77.00 | 5.50E+07 | 103.00  | 4.53E+01 | -128.80 |
| 14.00   | 0.449   |           | 4.52E+07 | -73.40  | 4.52E+07 | -73.40 | 1.71E+07 | -32.81 | 7.00E+07 | -75.45 | 7.00E+07 | 104.55  | 5.58E+01 | -37.03  |
| 12.00   | 0.524   |           | 4.04E+07 | -74.57  | 4.04E+07 | -74.57 | 1.04E+07 | -49.63 | 9.50E+07 | -76.45 | 9.50E+07 | 103.55  | 3.00E+01 | -73.77  |
|   |         |           |          |         |          |        |          |        |          |        |          |         |          |         |
| 18.00   | 0.349   | 90.00     | 5.23E+00 | -108.09 | 5.48E+07 | -81.94 | 3.07E+07 | -15.86 | 1.15E+07 | -78.71 | 2.73E+00 | -93.84  | 1.14E+01 | -177.48 |
| 17.00   | 0.370   |           | 5.00E+00 | -98.11  | 5.80E+07 | -79.91 | 2.74E+07 | -18.82 | 2.47E+07 | -77.48 | 4.18E+00 | -31.11  | 1.73E+01 | -146.59 |
| 16.50   | 0.381   |           | 4.92E+00 | -85.07  | 5.93E+07 | -78.79 | 2.57E+07 | -20.54 | 3.17E+07 | -76.30 | 3.71E+01 | -170.25 | 2.38E+01 | -49.19  |
| 16.00   | 0.393   |           | 5.01E+00 | -101.01 | 6.03E+07 | -77.65 | 2.40E+07 | -22.52 | 3.98E+07 | -75.36 | 1.14E+01 | -10.97  | 3.06E+01 | -123.49 |
| 15.00   | 0.419   |           | 5.25E+00 | -90.63  | 6.10E+07 | -75.52 | 2.06E+07 | -27.01 | 5.48E+07 | -72.86 | 3.08E+01 | -2.10   | 3.44E+01 | -80.74  |
| 14.00   | 0.449   |           | 4.90E+00 | -83.29  | 5.94E+07 | -74.16 | 1.71E+07 | -32.68 | 6.73E+07 | -70.97 | 1.04E+01 | 53.62   | 2.19E+01 | -136.73 |
| 12.00   | 0.524   |           | 4.85E+00 | -79.34  | 4.84E+07 | -78.42 | 1.03E+07 | -49.22 | 7.31E+07 | -74.54 | 2.03E+01 | 163.13  | 4.48E+01 | -147.57 |

Figure 8.25 - Variation of Total Wave Forces with Frequency

| * * * * H Y D R O D Y N A M I C   P A R A M E T E R S   F O R   S T R U C T U R E   1 * * * * |         |           |        |       |        |        |        |        |        |         |        |         |        |         |  |
|---|---------|-----------|--------|-------|--------|--------|--------|--------|--------|---------|--------|---------|--------|---------|--|
| -----   |         |           |        |       |        |        |        |        |        |         |        |         |        |         |  |
| RAOS-VARIATION WITH WAVE PERIOD/FREQUENCY   |         |           |        |       |        |        |        |        |        |         |        |         |        |         |  |
| -----   |         |           |        |       |        |        |        |        |        |         |        |         |        |         |  |
| PERIOD  | FREQ    | DIRECTION | X      |       | Y      |        | Z      |        | RX     |         | RY     |         | RZ     |         |  |
| (SECS)  | (RAD/S) | (DEGREES) | AMP    | PHASE | AMP    | PHASE  | AMP    | PHASE  | AMP    | PHASE   | AMP    | PHASE   | AMP    | PHASE   |  |
| -----   |         |           |        |       |        |        |        |        |        |         |        |         |        |         |  |
| 18.00   | 0.349   | 0.00      | 0.7063 | 89.11 | 0.0000 | 153.29 | 2.1131 | 11.72  | 0.0000 | -167.39 | 0.1731 | 90.57   | 0.0000 | -1.01   |  |
| 17.00   | 0.370   |           | 0.6649 | 88.70 | 0.0000 | 157.66 | 3.2316 | 34.24  | 0.0000 | -138.68 | 0.1325 | 91.93   | 0.0000 | 172.71  |  |
| 16.50   | 0.381   |           | 0.6420 | 88.42 | 0.0000 | 122.80 | 3.8001 | 63.85  | 0.0000 | -105.89 | 0.1152 | 92.73   | 0.0000 | 152.51  |  |
| 16.00   | 0.393   |           | 0.6176 | 88.06 | 0.0000 | 154.14 | 3.0466 | 99.87  | 0.0000 | -75.93  | 0.0981 | 93.75   | 0.0000 | 106.75  |  |
| 15.00   | 0.419   |           | 0.5630 | 87.02 | 0.0000 | 160.79 | 1.2160 | 131.09 | 0.0000 | -33.14  | 0.0692 | 95.97   | 0.0000 | 92.53   |  |
| 14.00   | 0.449   |           | 0.4998 | 85.31 | 0.0000 | 157.85 | 0.5606 | 136.50 | 0.0000 | -34.53  | 0.0453 | 99.13   | 0.0000 | 109.77  |  |
| 12.00   | 0.524   |           | 0.3482 | 77.32 | 0.0000 | 157.84 | 0.1443 | 127.63 | 0.0000 | -83.35  | 0.0149 | 115.21  | 0.0000 | 94.34   |  |
|   |         |           |        |       |        |        |        |        |        |         |        |         |        |         |  |
| 18.00   | 0.349   | 45.00     | 0.5103 | 89.17 | 0.5100 | 89.17  | 2.1135 | 11.71  | 0.1026 | -88.87  | 0.1118 | 90.95   | 0.0000 | 31.17   |  |
| 17.00   | 0.370   |           | 0.4835 | 88.81 | 0.4833 | 88.81  | 3.2326 | 34.21  | 0.0761 | -87.18  | 0.0823 | 92.68   | 0.0000 | 2.14    |  |
| 16.50   | 0.381   |           | 0.4689 | 88.56 | 0.4687 | 88.56  | 3.8017 | 63.81  | 0.0645 | -86.07  | 0.0696 | 93.81   | 0.0000 | 137.93  |  |
| 16.00   | 0.393   |           | 0.4534 | 88.25 | 0.4533 | 88.25  | 3.0483 | 99.82  | 0.0530 | -84.51  | 0.0570 | 95.38   | 0.0000 | -174.66 |  |
| 15.00   | 0.419   |           | 0.4192 | 87.39 | 0.4191 | 87.39  | 1.2174 | 131.01 | 0.0330 | -80.10  | 0.0354 | 99.80   | 0.0000 | 50.37   |  |
| 14.00   | 0.449   |           | 0.3803 | 86.06 | 0.3803 | 86.06  | 0.5620 | 136.37 | 0.0161 | -69.08  | 0.0172 | 110.85  | 0.0000 | 142.19  |  |
| 12.00   | 0.524   |           | 0.2895 | 81.12 | 0.2895 | 81.12  | 0.1462 | 127.22 | 0.0111 | 64.44   | 0.0118 | -115.61 | 0.0000 | 105.52  |  |
|   |         |           |        |       |        |        |        |        |        |         |        |         |        |         |  |
| 18.00   | 0.349   | 90.00     | 0.0000 | 71.05 | 0.7059 | 89.11  | 2.1131 | 11.72  | 0.1589 | -89.25  | 0.0000 | -174.08 | 0.0000 | 1.51    |  |
| 17.00   | 0.370   |           | 0.0000 | 81.34 | 0.6646 | 88.70  | 3.2316 | 34.24  | 0.1225 | -87.93  | 0.0000 | -149.91 | 0.0000 | 32.46   |  |
| 16.50   | 0.381   |           | 0.0000 | 87.89 | 0.6417 | 88.42  | 3.8001 | 63.85  | 0.1068 | -87.15  | 0.0000 | -112.35 | 0.0000 | 129.88  |  |
| 16.00   | 0.393   |           | 0.0000 | 58.31 | 0.6174 | 88.06  | 3.0466 | 99.87  | 0.0912 | -86.13  | 0.0000 | -83.46  | 0.0000 | 55.61   |  |
| 15.00   | 0.419   |           | 0.0000 | 69.73 | 0.5628 | 87.02  | 1.2160 | 131.09 | 0.0647 | -83.93  | 0.0000 | -63.26  | 0.0000 | 98.42   |  |
| 14.00   | 0.449   |           | 0.0000 | 74.78 | 0.4997 | 85.30  | 0.5606 | 136.50 | 0.0425 | -80.80  | 0.0000 | -50.97  | 0.0000 | 42.49   |  |
| 12.00   | 0.524   |           | 0.0000 | 75.49 | 0.3482 | 77.32  | 0.1443 | 127.63 | 0.0140 | -64.73  | 0.0000 | -14.37  | 0.0000 | 31.72   |  |

Figure 8.26 - Variation of Response Amplitude Operators with Frequency

| * * * * H Y D R O D Y N A M I C   P A R A M E T E R S   F O R   S T R U C T U R E   1 * * * * |         |           |          |        |          |        |          |         |          |        |          |       |          |         |
|---|---------|-----------|----------|--------|----------|--------|----------|---------|----------|--------|----------|-------|----------|---------|
| -----   |         |           |          |        |          |        |          |         |          |        |          |       |          |         |
| DIFFRACTION FORCES-VARIATION WITH WAVE DIRECTION  |         |           |          |        |          |        |          |         |          |        |          |       |          |         |
| -----   |         |           |          |        |          |        |          |         |          |        |          |       |          |         |
| PERIOD  | FREQ    | DIRECTION | X        |        | Y        |        | Z        |         | RX       |        | RY       |       | RZ       |         |
| (SECS)  | (RAD/S) | (DEGREES) | AMP      | PHASE  | AMP      | PHASE  | AMP      | PHASE   | AMP      | PHASE  | AMP      | PHASE | AMP      | PHASE   |
| -----   |         |           |          |        |          |        |          |         |          |        |          |       |          |         |
| 18.00   | 0.349   | 0.00      | 2.52E+07 | -72.23 | 0.00E+00 | 0.00   | 1.96E+07 | -154.64 | 0.00E+00 | 0.00   | 1.46E+08 | 90.88 | 0.00E+00 | 0.00    |
|   |         | 45.00     | 1.86E+07 | -72.52 | 1.86E+07 | -72.52 | 1.96E+07 | -154.63 | 1.06E+08 | -89.12 | 1.06E+08 | 90.88 | 9.38E+00 | -170.89 |
|   |         | 90.00     | 2.10E+00 | -72.62 | 2.52E+07 | -72.23 | 1.96E+07 | -154.64 | 1.46E+08 | -89.12 | 1.23E+01 | 90.85 | 3.37E+00 | -180.00 |
| 17.00   | 0.370   | 0.00      | 2.66E+07 | -67.54 | 0.00E+00 | 0.00   | 2.00E+07 | -153.72 | 0.00E+00 | 0.00   | 1.63E+08 | 91.89 | 0.00E+00 | 0.00    |
|   |         | 45.00     | 1.99E+07 | -68.01 | 1.99E+07 | -68.01 | 2.00E+07 | -153.70 | 1.20E+08 | -88.11 | 1.20E+08 | 91.89 | 9.25E+00 | -178.07 |
|   |         | 90.00     | 2.20E+00 | -68.80 | 2.66E+07 | -67.54 | 2.00E+07 | -153.72 | 1.63E+08 | -88.11 | 1.38E+01 | 91.74 | 2.40E+00 | -180.00 |
| 16.50   | 0.381   | 0.00      | 2.71E+07 | -64.82 | 0.00E+00 | 0.00   | 2.01E+07 | -153.26 | 0.00E+00 | 0.00   | 1.72E+08 | 92.51 | 0.00E+00 | 0.00    |
|   |         | 45.00     | 2.05E+07 | -65.42 | 2.05E+07 | -65.42 | 2.01E+07 | -153.24 | 1.27E+08 | -87.48 | 1.27E+08 | 92.52 | 8.60E+00 | -167.27 |
|   |         | 90.00     | 2.29E+00 | -66.20 | 2.71E+07 | -64.82 | 2.01E+07 | -153.26 | 1.72E+08 | -87.49 | 1.47E+01 | 92.35 | 4.59E-01 | -180.00 |
| 16.00   | 0.393   | 0.00      | 2.73E+07 | -61.85 | 0.00E+00 | 0.00   | 2.01E+07 | -152.83 | 0.00E+00 | 0.00   | 1.81E+08 | 93.20 | 0.00E+00 | 0.00    |
|   |         | 45.00     | 2.09E+07 | -62.61 | 2.09E+07 | -62.61 | 2.02E+07 | -152.81 | 1.34E+08 | -86.78 | 1.34E+08 | 93.22 | 7.28E+00 | -13.76  |
|   |         | 90.00     | 2.35E+00 | -63.67 | 2.73E+07 | -61.85 | 2.01E+07 | -152.83 | 1.81E+08 | -86.80 | 1.39E+01 | 93.38 | 1.13E+00 | 0.00    |
| 15.00   | 0.419   | 0.00      | 2.67E+07 | -55.24 | 0.00E+00 | 0.00   | 1.99E+07 | -152.00 | 0.00E+00 | 0.00   | 1.97E+08 | 94.70 | 0.00E+00 | 0.00    |
|   |         | 45.00     | 2.11E+07 | -56.51 | 2.11E+07 | -56.51 | 1.99E+07 | -151.96 | 1.48E+08 | -85.21 | 1.48E+08 | 94.79 | 8.49E+00 | -171.12 |
|   |         | 90.00     | 2.33E+00 | -59.23 | 2.67E+07 | -55.24 | 1.99E+07 | -152.00 | 1.97E+08 | -85.30 | 1.99E+01 | 93.66 | 2.46E+00 | -179.99 |
| 14.00   | 0.449   | 0.00      | 2.42E+07 | -47.99 | 0.00E+00 | 0.00   | 1.92E+07 | -151.28 | 0.00E+00 | 0.00   | 2.09E+08 | 96.02 | 0.00E+00 | 0.00    |
|   |         | 45.00     | 2.02E+07 | -50.20 | 2.02E+07 | -50.20 | 1.93E+07 | -151.20 | 1.60E+08 | -83.71 | 1.60E+08 | 96.29 | 9.45E+00 | -176.25 |
|   |         | 90.00     | 2.29E+00 | -54.73 | 2.42E+07 | -47.99 | 1.92E+07 | -151.28 | 2.09E+08 | -83.98 | 2.15E+01 | 94.84 | 1.94E+00 | -179.98 |
| 12.00   | 0.524   | 0.00      | 1.17E+07 | -33.93 | 0.00E+00 | 0.00   | 1.58E+07 | -150.55 | 0.00E+00 | 0.00   | 2.09E+08 | 95.35 | 0.00E+00 | 0.00    |
|   |         | 45.00     | 1.43E+07 | -41.53 | 1.43E+07 | -41.53 | 1.60E+07 | -150.30 | 1.72E+08 | -82.55 | 1.72E+08 | 97.45 | 1.08E+01 | -39.09  |
|   |         | 90.00     | 2.19E+00 | -41.38 | 1.17E+07 | -33.93 | 1.58E+07 | -150.55 | 2.09E+08 | -84.65 | 2.02E+01 | 99.75 | 1.38E+01 | -179.83 |

Figure 8.27 - Variation of Wave Diffraction Forces with Direction

| * * * * H Y D R O D Y N A M I C   P A R A M E T E R S   F O R   S T R U C T U R E   1 * * * * |                 |                        |          |         |          |        |          |       |          |        |          |         |          |         |
|---|-----------------|------------------------|----------|---------|----------|--------|----------|-------|----------|--------|----------|---------|----------|---------|
| -----   |                 |                        |          |         |          |        |          |       |          |        |          |         |          |         |
| FROUDE KRYLOV FORCES-VARIATION WITH WAVE DIRECTION  |                 |                        |          |         |          |        |          |       |          |        |          |         |          |         |
| -----   |                 |                        |          |         |          |        |          |       |          |        |          |         |          |         |
| PERIOD<br>(SECS)  | FREQ<br>(RAD/S) | DIRECTION<br>(DEGREES) | X        |         | Y        |        | Z        |       | RX       |        | RY       |         | RZ       |         |
|   |                 |                        | AMP      | PHASE   | AMP      | PHASE  | AMP      | PHASE | AMP      | PHASE  | AMP      | PHASE   | AMP      | PHASE   |
| 18.00   | 0.349           | 0.00                   | 3.03E+07 | -90.00  | 1.25E+00 | -1.43  | 4.72E+07 | 0.00  | 2.80E+01 | 178.98 | 1.34E+08 | -90.00  | 6.00E+00 | 180.00  |
|   |                 | 45.00                  | 2.15E+07 | -90.00  | 2.15E+07 | -90.00 | 4.72E+07 | 0.00  | 9.16E+07 | 90.00  | 9.16E+07 | -90.00  | 4.50E+01 | -143.13 |
|   |                 | 90.00                  | 3.73E+00 | -127.16 | 3.03E+07 | -90.00 | 4.72E+07 | 0.00  | 1.34E+08 | 90.00  | 1.50E+01 | -90.00  | 8.02E+00 | -176.42 |
| 17.00   | 0.370           | 0.00                   | 3.25E+07 | -90.00  | 2.04E+00 | 11.48  | 4.38E+07 | 0.00  | 5.01E+01 | 176.00 | 1.39E+08 | -90.00  | 1.81E+01 | -6.34   |
|   |                 | 45.00                  | 2.30E+07 | -90.00  | 2.30E+07 | -90.00 | 4.39E+07 | 0.00  | 9.36E+07 | 90.00  | 9.36E+07 | -90.00  | 5.21E+01 | -176.70 |
|   |                 | 90.00                  | 3.27E+00 | -117.30 | 3.25E+07 | -90.00 | 4.38E+07 | 0.00  | 1.39E+08 | 90.00  | 1.65E+01 | -75.96  | 1.53E+01 | -141.63 |
| 16.50   | 0.381           | 0.00                   | 3.36E+07 | -90.00  | 1.51E+00 | -7.13  | 4.20E+07 | 0.00  | 6.00E+01 | 178.09 | 1.41E+08 | -90.00  | 1.79E+01 | -26.57  |
|   |                 | 45.00                  | 2.38E+07 | -90.00  | 2.38E+07 | -90.00 | 4.20E+07 | 0.00  | 9.44E+07 | 90.00  | 9.44E+07 | -90.00  | 2.42E+01 | -24.44  |
|   |                 | 90.00                  | 2.86E+00 | -100.08 | 3.36E+07 | -90.00 | 4.20E+07 | 0.00  | 1.41E+08 | 90.00  | 4.17E+01 | -149.74 | 2.41E+01 | -48.37  |
| 16.00   | 0.393           | 0.00                   | 3.48E+07 | -90.00  | 4.00E+00 | 0.00   | 4.01E+07 | 0.00  | 1.81E+01 | 173.66 | 1.42E+08 | -90.00  | 4.62E+01 | -72.35  |
|   |                 | 45.00                  | 2.47E+07 | -90.00  | 2.47E+07 | -90.00 | 4.01E+07 | 0.00  | 9.44E+07 | 90.00  | 9.44E+07 | -90.00  | 3.26E+01 | 10.62   |
|   |                 | 90.00                  | 3.45E+00 | -125.42 | 3.48E+07 | -90.00 | 4.01E+07 | 0.00  | 1.42E+08 | 90.00  | 2.00E+01 | -53.13  | 3.12E+01 | -125.22 |
| 15.00   | 0.419           | 0.00                   | 3.71E+07 | -90.00  | 5.25E+00 | 0.00   | 3.59E+07 | 0.00  | 5.22E+01 | 174.51 | 1.44E+08 | -90.00  | 3.41E+01 | -86.63  |
|   |                 | 45.00                  | 2.63E+07 | -90.00  | 2.63E+07 | -90.00 | 3.59E+07 | 0.00  | 9.41E+07 | 90.00  | 9.41E+07 | -90.00  | 3.94E+01 | -120.47 |
|   |                 | 90.00                  | 3.48E+00 | -111.04 | 3.71E+07 | -90.00 | 3.59E+07 | 0.00  | 1.44E+08 | 90.00  | 3.83E+01 | -33.27  | 3.49E+01 | -76.76  |
| 14.00   | 0.449           | 0.00                   | 3.91E+07 | -90.00  | 1.75E+00 | 0.00   | 3.12E+07 | 0.00  | 1.64E+01 | 167.66 | 1.44E+08 | -90.00  | 8.54E+00 | -69.44  |
|   |                 | 45.00                  | 2.78E+07 | -90.00  | 2.78E+07 | -90.00 | 3.13E+07 | 0.00  | 9.16E+07 | 90.00  | 9.16E+07 | -90.00  | 6.33E+01 | -31.43  |
|   |                 | 90.00                  | 3.09E+00 | -104.04 | 3.91E+07 | -90.00 | 3.12E+07 | 0.00  | 1.44E+08 | 90.00  | 1.53E+01 | -58.39  | 2.05E+01 | -133.03 |
| 12.00   | 0.524           | 0.00                   | 4.09E+07 | -90.00  | 1.13E+00 | 3.18   | 2.05E+07 | 0.00  | 8.00E+00 | 0.00   | 1.38E+08 | -90.00  | 3.41E+01 | -84.96  |
|   |                 | 45.00                  | 2.94E+07 | -90.00  | 2.94E+07 | -90.00 | 2.06E+07 | 0.00  | 7.80E+07 | 90.00  | 7.80E+07 | -90.00  | 2.20E+01 | -90.00  |
|   |                 | 90.00                  | 3.40E+00 | -102.76 | 4.09E+07 | -90.00 | 2.05E+07 | 0.00  | 1.38E+08 | 90.00  | 2.13E+01 | -138.81 | 3.39E+01 | -135.00 |

Figure 8.28 - Variation of Froude-krylov Forces with Direction

| * * * * H Y D R O D Y N A M I C   P A R A M E T E R S   F O R   S T R U C T U R E   1 * * * * |                 |                        |  |         |          |        |          |        |          |        |          |         |          |         |
|---|-----------------|------------------------|--|---------|----------|--------|----------|--------|----------|--------|----------|---------|----------|---------|
|   |                 |                        | TOTAL FORCES-VARIATION WITH WAVE DIRECTION |         |          |        |          |        |          |        |          |         |          |         |
| PERIOD<br>(SECS)  | FREQ<br>(RAD/S) | DIRECTION<br>(DEGREES) | X  |         | Y        |        | Z        |        | RX       |        | RY       |         | RZ       |         |
|   |                 |                        | AMP  | PHASE   | AMP      | PHASE  | AMP      | PHASE  | AMP      | PHASE  | AMP      | PHASE   | AMP      | PHASE   |
| 18.00   | 0.349           | 0.00                   | 5.48E+07                                   | -81.94  | 1.25E+00 | -1.43  | 3.07E+07 | -15.86 | 2.80E+01 | 178.98 | 1.15E+07 | 101.29  | 6.00E+00 | 180.00  |
|   |                 | 45.00                  | 3.96E+07                                   | -81.89  | 3.96E+07 | -81.89 | 3.07E+07 | -15.88 | 1.47E+07 | -83.63 | 1.47E+07 | 96.37   | 5.35E+01 | -147.81 |
|   |                 | 90.00                  | 5.23E+00                                   | -108.09 | 5.48E+07 | -81.94 | 3.07E+07 | -15.86 | 1.15E+07 | -78.71 | 2.73E+00 | -93.84  | 1.14E+01 | -177.48 |
| 17.00   | 0.370           | 0.00                   | 5.80E+07                                   | -79.91  | 2.04E+00 | 11.48  | 2.74E+07 | -18.82 | 5.01E+01 | 176.00 | 2.47E+07 | 102.52  | 1.81E+01 | -6.34   |
|   |                 | 45.00                  | 4.22E+07                                   | -79.81  | 4.22E+07 | -79.81 | 2.74E+07 | -18.85 | 2.63E+07 | -81.38 | 2.63E+07 | 98.62   | 6.13E+01 | -176.90 |
|   |                 | 90.00                  | 5.00E+00                                   | -98.11  | 5.80E+07 | -79.91 | 2.74E+07 | -18.82 | 2.47E+07 | -77.48 | 4.18E+00 | -31.11  | 1.73E+01 | -146.59 |
| 16.50   | 0.381           | 0.00                   | 5.93E+07                                   | -78.79  | 1.51E+00 | -7.13  | 2.57E+07 | -20.54 | 6.00E+01 | 178.09 | 3.17E+07 | 103.70  | 1.79E+01 | -26.57  |
|   |                 | 45.00                  | 4.33E+07                                   | -78.66  | 4.33E+07 | -78.66 | 2.57E+07 | -20.57 | 3.26E+07 | -80.19 | 3.26E+07 | 99.81   | 1.81E+01 | -41.14  |
|   |                 | 90.00                  | 4.92E+00                                   | -85.07  | 5.93E+07 | -78.79 | 2.57E+07 | -20.54 | 3.17E+07 | -76.30 | 3.71E+01 | -170.25 | 2.38E+01 | -49.19  |
| 16.00   | 0.393           | 0.00                   | 6.03E+07                                   | -77.65  | 4.00E+00 | 0.00   | 2.40E+07 | -22.52 | 1.81E+01 | 173.66 | 3.98E+07 | 104.64  | 4.62E+01 | -72.35  |
|   |                 | 45.00                  | 4.43E+07                                   | -77.46  | 4.43E+07 | -77.46 | 2.40E+07 | -22.57 | 4.00E+07 | -79.18 | 4.00E+07 | 100.82  | 3.93E+01 | 6.23    |
|   |                 | 90.00                  | 5.01E+00                                   | -101.01 | 6.03E+07 | -77.65 | 2.40E+07 | -22.52 | 3.98E+07 | -75.36 | 1.14E+01 | -10.97  | 3.06E+01 | -123.49 |
| 15.00   | 0.419           | 0.00                   | 6.10E+07                                   | -75.52  | 5.25E+00 | 0.00   | 2.06E+07 | -27.01 | 5.22E+01 | 174.51 | 5.48E+07 | 107.14  | 3.41E+01 | -86.63  |
|   |                 | 45.00                  | 4.55E+07                                   | -75.15  | 4.55E+07 | -75.15 | 2.06E+07 | -27.09 | 5.50E+07 | -77.00 | 5.50E+07 | 103.00  | 4.53E+01 | -128.80 |
|   |                 | 90.00                  | 5.25E+00                                   | -90.63  | 6.10E+07 | -75.52 | 2.06E+07 | -27.01 | 5.48E+07 | -72.86 | 3.08E+01 | -2.10   | 3.44E+01 | -80.74  |
| 14.00   | 0.449           | 0.00                   | 5.94E+07                                   | -74.16  | 1.75E+00 | 0.00   | 1.71E+07 | -32.68 | 1.64E+01 | 167.66 | 6.73E+07 | 109.03  | 8.54E+00 | -69.44  |
|   |                 | 45.00                  | 4.52E+07                                   | -73.40  | 4.52E+07 | -73.40 | 1.71E+07 | -32.81 | 7.00E+07 | -75.45 | 7.00E+07 | 104.55  | 5.58E+01 | -37.03  |
|   |                 | 90.00                  | 4.90E+00                                   | -83.29  | 5.94E+07 | -74.16 | 1.71E+07 | -32.68 | 6.73E+07 | -70.97 | 1.04E+01 | 53.62   | 2.19E+01 | -136.73 |
| 12.00   | 0.524           | 0.00                   | 4.84E+07                                   | -78.42  | 1.13E+00 | 3.18   | 1.03E+07 | -49.22 | 8.00E+00 | 0.00   | 7.31E+07 | 105.46  | 3.41E+01 | -84.96  |
|   |                 | 45.00                  | 4.04E+07                                   | -74.57  | 4.04E+07 | -74.57 | 1.04E+07 | -49.63 | 9.50E+07 | -76.45 | 9.50E+07 | 103.55  | 3.00E+01 | -73.77  |
|   |                 | 90.00                  | 4.85E+00                                   | -79.34  | 4.84E+07 | -78.42 | 1.03E+07 | -49.22 | 7.31E+07 | -74.54 | 2.03E+01 | 163.13  | 4.48E+01 | -147.57 |

Figure 8.29 - Variation of Total Wave Forces with Direction

| * * * * H Y D R O D Y N A M I C   P A R A M E T E R S   F O R   S T R U C T U R E   1 * * * * |         |           |        |       |        |        |        |        |        |         |        |         |        |         |
|---|---------|-----------|--------|-------|--------|--------|--------|--------|--------|---------|--------|---------|--------|---------|
| -----   |         |           |        |       |        |        |        |        |        |         |        |         |        |         |
| RAOS-VARIATION WITH WAVE DIRECTION  |         |           |        |       |        |        |        |        |        |         |        |         |        |         |
| -----   |         |           |        |       |        |        |        |        |        |         |        |         |        |         |
| PERIOD  | FREQ    | DIRECTION | X      |       | Y      |        | Z      |        | RX     |         | RY     |         | RZ     |         |
| (SECS)  | (RAD/S) | (DEGREES) | AMP    | PHASE | AMP    | PHASE  | AMP    | PHASE  | AMP    | PHASE   | AMP    | PHASE   | AMP    | PHASE   |
| -----   |         |           |        |       |        |        |        |        |        |         |        |         |        |         |
| 18.00   | 0.349   | 0.00      | 0.7063 | 89.11 | 0.0000 | 153.29 | 2.1131 | 11.72  | 0.0000 | -167.39 | 0.1731 | 90.57   | 0.0000 | -1.01   |
|   |         | 45.00     | 0.5103 | 89.17 | 0.5100 | 89.17  | 2.1135 | 11.71  | 0.1026 | -88.87  | 0.1118 | 90.95   | 0.0000 | 31.17   |
|   |         | 90.00     | 0.0000 | 71.05 | 0.7059 | 89.11  | 2.1131 | 11.72  | 0.1589 | -89.25  | 0.0000 | -174.08 | 0.0000 | 1.51    |
| 17.00   | 0.370   | 0.00      | 0.6649 | 88.70 | 0.0000 | 157.66 | 3.2316 | 34.24  | 0.0000 | -138.68 | 0.1325 | 91.93   | 0.0000 | 172.71  |
|   |         | 45.00     | 0.4835 | 88.81 | 0.4833 | 88.81  | 3.2326 | 34.21  | 0.0761 | -87.18  | 0.0823 | 92.68   | 0.0000 | 2.14    |
|   |         | 90.00     | 0.0000 | 81.34 | 0.6646 | 88.70  | 3.2316 | 34.24  | 0.1225 | -87.93  | 0.0000 | -149.91 | 0.0000 | 32.46   |
| 16.50   | 0.381   | 0.00      | 0.6420 | 88.42 | 0.0000 | 122.80 | 3.8001 | 63.85  | 0.0000 | -105.89 | 0.1152 | 92.73   | 0.0000 | 152.51  |
|   |         | 45.00     | 0.4689 | 88.56 | 0.4687 | 88.56  | 3.8017 | 63.81  | 0.0645 | -86.07  | 0.0696 | 93.81   | 0.0000 | 137.93  |
|   |         | 90.00     | 0.0000 | 87.89 | 0.6417 | 88.42  | 3.8001 | 63.85  | 0.1068 | -87.15  | 0.0000 | -112.35 | 0.0000 | 129.88  |
| 16.00   | 0.393   | 0.00      | 0.6176 | 88.06 | 0.0000 | 154.14 | 3.0466 | 99.87  | 0.0000 | -75.93  | 0.0981 | 93.75   | 0.0000 | 106.75  |
|   |         | 45.00     | 0.4534 | 88.25 | 0.4533 | 88.25  | 3.0483 | 99.82  | 0.0530 | -84.51  | 0.0570 | 95.38   | 0.0000 | -174.66 |
|   |         | 90.00     | 0.0000 | 58.31 | 0.6174 | 88.06  | 3.0466 | 99.87  | 0.0912 | -86.13  | 0.0000 | -83.46  | 0.0000 | 55.61   |
| 15.00   | 0.419   | 0.00      | 0.5630 | 87.02 | 0.0000 | 160.79 | 1.2160 | 131.09 | 0.0000 | -33.14  | 0.0692 | 95.97   | 0.0000 | 92.53   |
|   |         | 45.00     | 0.4192 | 87.39 | 0.4191 | 87.39  | 1.2174 | 131.01 | 0.0330 | -80.10  | 0.0354 | 99.80   | 0.0000 | 50.37   |
|   |         | 90.00     | 0.0000 | 69.73 | 0.5628 | 87.02  | 1.2160 | 131.09 | 0.0647 | -83.93  | 0.0000 | -63.26  | 0.0000 | 98.42   |
| 14.00   | 0.449   | 0.00      | 0.4998 | 85.31 | 0.0000 | 157.85 | 0.5606 | 136.50 | 0.0000 | -34.53  | 0.0453 | 99.13   | 0.0000 | 109.77  |
|   |         | 45.00     | 0.3803 | 86.06 | 0.3803 | 86.06  | 0.5620 | 136.37 | 0.0161 | -69.08  | 0.0172 | 110.85  | 0.0000 | 142.19  |
|   |         | 90.00     | 0.0000 | 74.78 | 0.4997 | 85.30  | 0.5606 | 136.50 | 0.0425 | -80.80  | 0.0000 | -50.97  | 0.0000 | 42.49   |
| 12.00   | 0.524   | 0.00      | 0.3482 | 77.32 | 0.0000 | 157.84 | 0.1443 | 127.63 | 0.0000 | -83.35  | 0.0149 | 115.21  | 0.0000 | 94.34   |
|   |         | 45.00     | 0.2895 | 81.12 | 0.2895 | 81.12  | 0.1462 | 127.22 | 0.0111 | 64.44   | 0.0118 | -115.61 | 0.0000 | 105.52  |
|   |         | 90.00     | 0.0000 | 75.49 | 0.3482 | 77.32  | 0.1443 | 127.63 | 0.0140 | -64.73  | 0.0000 | -14.37  | 0.0000 | 31.72   |

Figure 8.30 - Variation of Response Amplitude Operators with Direction

| * * * * W A V E - D R I F T   L O A D S   F O R   U N I T   W A V E   A M P L I T U D E * * * * |               |                     |          |           |
|---|---------------|---------------------|----------|-----------|
| * * * * F O R   S T R U C T U R E   1 * * * *   |               |                     |          |           |
| FORCES  | FREQUENCY     | DIRECTION (DEGREES) |          |           |
| DUE TO  | (RADIANS/SEC) | 0.0                 | 45.0     | 90.0      |
| DRIFT   |               |                     |          |           |
| SURGE (X)   |               |                     |          |           |
|   | 0.349         | 4.02E+04            | 2.79E+04 | 2.07E-03  |
|   | 0.370         | 2.48E+05            | 1.74E+05 | -3.78E-03 |
|   | 0.381         | 5.69E+05            | 4.01E+05 | -2.09E-02 |
|   | 0.393         | 6.19E+05            | 4.36E+05 | 1.04E-02  |
|   | 0.419         | 3.03E+05            | 2.10E+05 | -2.98E-02 |
|   | 0.449         | 2.25E+05            | 1.46E+05 | -3.75E-02 |
|   | 0.524         | 3.46E+05            | 1.42E+05 | -4.71E-02 |
| SWAY (Y)  |               |                     |          |           |
|   | 0.349         | -2.32E-03           | 2.79E+04 | 4.02E+04  |
|   | 0.370         | -2.22E-03           | 1.74E+05 | 2.48E+05  |
|   | 0.381         | -3.40E-02           | 4.01E+05 | 5.69E+05  |
|   | 0.393         | -5.51E-03           | 4.36E+05 | 6.19E+05  |
|   | 0.419         | -3.23E-03           | 2.10E+05 | 3.03E+05  |
|   | 0.449         | -6.53E-03           | 1.46E+05 | 2.25E+05  |
|   | 0.524         | -1.09E-02           | 1.42E+05 | 3.46E+05  |
| HEAVE (Z)   |               |                     |          |           |
|   | 0.349         | 0.00E+00            | 0.00E+00 | 0.00E+00  |
|   | 0.370         | 0.00E+00            | 0.00E+00 | 0.00E+00  |
|   | 0.381         | 0.00E+00            | 0.00E+00 | 0.00E+00  |
|   | 0.393         | 0.00E+00            | 0.00E+00 | 0.00E+00  |
|   | 0.419         | 0.00E+00            | 0.00E+00 | 0.00E+00  |
|   | 0.449         | 0.00E+00            | 0.00E+00 | 0.00E+00  |
|   | 0.524         | 0.00E+00            | 0.00E+00 | 0.00E+00  |
| ROLL (RX)   |               |                     |          |           |
|   | 0.349         | 0.00E+00            | 0.00E+00 | 0.00E+00  |
|   | 0.370         | 0.00E+00            | 0.00E+00 | 0.00E+00  |
|   | 0.381         | 0.00E+00            | 0.00E+00 | 0.00E+00  |
|   | 0.393         | 0.00E+00            | 0.00E+00 | 0.00E+00  |
|   | 0.419         | 0.00E+00            | 0.00E+00 | 0.00E+00  |
|   | 0.449         | 0.00E+00            | 0.00E+00 | 0.00E+00  |
|   | 0.524         | 0.00E+00            | 0.00E+00 | 0.00E+00  |

Figure 8.31 - Wave Drift Loads for Each Frequency and Direction

|   |               |                     |           |           |
|---|---------------|---------------------|-----------|-----------|
| * * * * W A V E - D R I F T   L O A D S   F O R   U N I T   W A V E   A M P L I T U D E * * * * |               |                     |           |           |
| - - - - -   |               |                     |           |           |
| * * * * F O R   S T R U C T U R E   1 * * * *   |               |                     |           |           |
| - - - - -   |               |                     |           |           |
| FORCES  | FREQUENCY     | DIRECTION (DEGREES) |           |           |
| -----   |               |                     |           |           |
| DUE TO  | (RADIANS/SEC) | 0.0                 | 45.0      | 90.0      |
| -----   |               |                     |           |           |
| D R I F T   |               |                     |           |           |
| -----   |               |                     |           |           |
| PITCH (RY)  |               |                     |           |           |
|   | 0.349         | 0.00E+00            | 0.00E+00  | 0.00E+00  |
|   | 0.370         | 0.00E+00            | 0.00E+00  | 0.00E+00  |
|   | 0.381         | 0.00E+00            | 0.00E+00  | 0.00E+00  |
|   | 0.393         | 0.00E+00            | 0.00E+00  | 0.00E+00  |
|   | 0.419         | 0.00E+00            | 0.00E+00  | 0.00E+00  |
|   | 0.449         | 0.00E+00            | 0.00E+00  | 0.00E+00  |
|   | 0.524         | 0.00E+00            | 0.00E+00  | 0.00E+00  |
| YAW (RZ)  |               |                     |           |           |
|   | 0.349         | -6.57E-02           | 1.38E+03  | 7.35E-01  |
|   | 0.370         | 1.70E+00            | 7.16E+02  | 4.12E-01  |
|   | 0.381         | -1.73E+00           | 4.92E+02  | -1.69E+00 |
|   | 0.393         | -1.75E+00           | 2.96E+02  | -1.30E+00 |
|   | 0.419         | 7.48E-01            | 8.84E+01  | 1.10E+00  |
|   | 0.449         | -6.03E-01           | 4.34E+00  | 6.70E-01  |
|   | 0.524         | -1.48E-01           | -4.01E+01 | 3.45E+00  |

Figure 8.31 - Wave Drift Loads for Each Frequency and Direction (Cont)



### 8.1.8 Output from Diffraction and Post-Processing Run (continued)

Consider now the output from the post-processing run involving Stages 4 and 5. A considerable amount of the information output is similar to that produced in Figures 8.19 to 8.31, the main difference being that the dynamic reference point has now changed to that input in Deck 16. As Deck 16 may also be used to scale or re-calculate RAOs, the user is informed of the most up-to-date values of body mass, inertia and centre of gravity.

The changes to be made to the body properties are output as shown in Figure 8.32. This is followed by output giving the actual body properties following the instigation of the changes deck (see Figure 8.33). The user should note that all subsequent results relate directly to the latest body information output.

The transformation vector between the new hydrodynamic reference point and the centre of gravity of the body is also output. It should be remembered that, although the transformed stiffness matrix is now with respect to the new hydrodynamic reference point, the actual centre of gravity remains unchanged (see Figure 8.33).

| * * * * ( C H A N G E   O F )   S T R U C T U R E   C H A R A C T E R I S T I C S * * * *            |                     |           |           |           |           |                       |
|--|---------------------|-----------|-----------|-----------|-----------|-----------------------|
| - - - - -  |                     |           |           |           |           |                       |
| STRUCTURE<br>NUMBER  | 1                   | 2         | 3         | 4         | 5         | 6                     |
| -----  |                     |           |           |           |           |                       |
| N.B. THE COORDINATES BELOW ARE OUTPUT IN THE FRA WITH THE STRUCTURE IN ORIGINAL DESCRIPTIVE POSITION |                     |           |           |           |           |                       |
| 1  | LENGTH, BEAM, DRAFT | UNKNOWN   |           |           |           |                       |
|  | STRUCTURAL MASS     | 3.321E+08 |           |           |           |                       |
|  | STRUCTURAL INERTIA  | 3.625E+11 | 0.000E+00 | 0.000E+00 | 3.420E+11 | 0.000E+00   3.599E+11 |
|  | ORIG COG POSITION   | 0.000     | 0.000     | -10.620   |           |                       |
|  | HYDRO REF PT AT COG | 0.000     | 0.000     | -10.620   |           |                       |
|  | NEW VALUE           | 0.000     | 0.000     | 0.000     |           |                       |

**Figure 8.32 - Changes Made to Structure Characteristics**

```

* * * * M A S S   A N D   I N E R T I A   P R O P E R T I E S   O F   S T R U C T U R E   1 * * * *
- - - - -

* * * * I N C O R P O R A T I N G   G E O M E T R I C   S C A L I N G   O R   C H A N G E S * * * *
- - - - -

      MASS OF BODY      3.3210E+08
      -----

                X                Y                Z
      -----
COG DEFINED POSITION      0.000      0.000      -10.620
DEFINED REF POINT      0.000      0.000      0.000
INERTIA MATRIX      3.625E+11      0.000E+00      0.000E+00
                   0.000E+00      3.420E+11      0.000E+00
                   0.000E+00      0.000E+00      3.599E+11

* * * * A L L   F O L L O W I N G   O U T P U T   R E L A T E S   T O   T H E   A B O V E * * * *
- - - - -

```

**Figure 8.33 - Scaled or Redefined Mass and Inertia Characteristics**

## **CHAPTER 9 - RUNNING THE PROGRAM**

To run a program in the AQWA suite, it is necessary to have details of the computer system on which the program is loaded. This chapter has sections which are **DEPENDENT ON THE COMPUTER SYSTEM** and therefore it lists commands specific to a particular system. It also contains a general description of the most common approach used in running the program.

The following sections describe the use of the program on the following machines:

- PC (MS-DOS)
- SUN (Open Windows)
- VAX (VMS)

## **9.1 RUNNING AQWA-LINE ON THE PC**

This chapter is written for the following systems and is NOT applicable to any others.

### **- MS-DOS PC -**

#### **9.1.1 Assigning the INPUT/OUTPUT Files**

Every run of an AQWA program involves the use of a number of specially named input, output and backing files. On the PC, the file types are identified by the file extension.

The following files are used by AQWA-LINE:

Input files

- **(.DAT) FILE - INPUT DATA FILE**  
ASCII file for model definition and analysis parameters.

Output files.

- **(.QTF) File**  
ASCII file for input of user-defined QTF data
- **(.RES) FILE - RESTART FILE**  
Binary file containing the model definition/analysis, parameters and the hydrodynamic results calculated in AQWA LINE. Can be used for further AQWA analysis or structure visualisation etc in AGS.
- **(.HYD) FILE - HYDRODYNAMICS DATABASE FILE**  
Binary file containing the hydrodynamic results calculated in AQWA LINE. It contains a subset of the restart file. Can be used for further AQWA analysis.
- **(.LIS) FILE - OUTPUT DATA FILE**  
ASCII file containing model definition/analysis parameters and the analysis results.
- **(.MES) FILE - MESSAGES FILE**  
ASCII file containing messages issued during an AQWA LINE analysis.
- **(.PLT) FILE - PLOT FILE**

Binary file containing AQWA LINE analysis results. Used by AGS for plotting graphs.

- **(.POT) FILE - POTENTIALS FILE**

Binary file containing velocity potentials. Used by AGS or AQWA WAVE for element pressure calculation. This file is only created by AQWA LINE when LDOP option is on.

- **(.USS) FILE - SOURCE STRENGTHS**

Binary file containing source strengths. Used by AGS for wave surface contours calculation. Also used by AQWA WAVE for Morison force calculation. This file is only created by AQWA LINE when LDOP option is on.

- **(.PAG) FILE - PRESSURE GRID FILE**

Binary file containing the pressure grid. It is created by the AGS when a .USS file has been used.

- **(.PAC) FILE - PRESSURES AT CENTROIDS FILE**

Binary file containing pressures at element centroids. Used by AGS for postprocessing involving pressures.

- **(.VAC) FILE - VELOCITIES AT CENTROIDS FILE**

Binary file containing fluid velocities at element centroids. Used by the AGS for wave contour plotting

- **(.QTF) FILE - QUADRATIC TRANSFER FUNCTIONS**

Binary file containing fully populated matrix of QUADRATIC TRANSFER FUNCTIONS. It is only created in AQWA LINE if both AQTF and CQTF options are on.

- **(.SO8) FILE - SCRATCH FILE**

This file is used as a work backing file. The user can ignore the existence of this file, which is automatically deleted at the end of a complete run. It may be deleted by the user if a run has not terminated normally.

- **(.SO9) FILE - SCRATCH FILE**

This file is used as a work backing file. The user can ignore the existence of this file, which is automatically deleted at the end of a complete run. It may be deleted by the user if a run has not terminated normally.

- **(.SO10) FILE - SCRATCH FILE**

This file is used as a work backing file. The user can ignore the existence of this file, which is automatically deleted at the end of a complete run. It may be deleted by the user if a run has not terminated normally.

(.S03) FILE - SCRATCH FILE

This file is used as a work backing file or for database editing

(.S04) FILE - SCRATCH FILE

This file is used as a work backing file or for database editing

### **9.1.2 Program Size Requirements**

Not applicable for the PC.

### **9.1.3 Run Commands**

When AQWA is installed on a PC an icon is placed on the desktop. The program is usually run by dragging and dropping an AL\*.DAT file onto this icon.

However a batch command file is also provided for running all the AQWA programs. This file should be located in directory C:\AQWA\UTILS and is named 'AQWAnnn.BAT', where nnn is the version no. for example 55a. AQWA programs can be run from any directory provided the C:\AQWA\UTILS is included in the PATH statement.

To run AQWA-LINE version 5.5A, simply type:

**AQWA55A   LINE   RUNID**

Note: There should be spaces between **AQWA**, the program name (ie **LINE**), and **RUNID** where RUNID is the run identifier

If the run identifier is omitted, the program will prompt for a run identifier, which should be entered without any leading or embedded spaces. This name identifies the data files for the analysis and is also used to name files created by the run.

If the run identifier is (say) TEST, AQWA-LINE will expect and create files with names of the form ALTEST.EXT, where EXT is the file extension. The user must therefore put the input data into a file named ALTEST.DAT.

For AQWA-LINE, the restart and positions files produced by one run will normally need to be copied across to new names for the next run in the sequence.

To illustrate how to run an analysis sequence, the commands needed to run the manual example are given below:

**AQWA55A   LINE   BOX1**

**COPY   ALBOX1.RES   ALBOX2.RES**

**AQWA55A   LINE   BOX2**

## **APPENDIX A - AQWA-LINE PROGRAM OPTIONS LIST**

The options listed below may be used when running the program AQWA-LINE. They should appear on the options card, which is the card following the job identification card in the administration Deck 0 (see Section 6.0).

Appendix A1 lists options which affect the administration of the analysis and the calculations carried out.

Appendix A2 lists options which affect the printing of results.



**A1 ADMINISTRATION AND CALCULATION OPTIONS FOR AQWA LINE****ALDB - READ AQWA-LINE DATABASE**

(LBDFN) Read the hydrodynamics database from the **hydrodynamics** (.HYD) file created by a previous AQWA-LINE run. This option is used:

- (i) If the user wishes to modify the hydrodynamic data calculated in a previous AQWA-LINE run, or add/modify nodes and non-diffracting elements, without having to re-run the AQWA-LINE radiation/diffraction analysis.
- (ii) If the user is setting up an analysis with several structures, and wishes to pick up the hydrodynamic data for one or more structures, calculated in a previous AQWA-LINE run.

Note: Very often, there is data for only one structure in the hydrodynamics file, in which case the data is associated with Structure 1 in the new run. The RDDB option may also be used if the hydrodynamics file contains more than one structure, provided that all the structures appear, in the same order, in the new run.

**AQTF - ASCII OUTPUT OF FULL QTF MATRIX**

(L) The AQTF run-time option for AQWA-LINE will output an ASCII file AL\*.QTF containing the full matrix of QTF coefficients. The format of the file is detailed in Appendix B1 of the AQWA Reference Manual.

**CQTF - CALCULATION OF FULL QTF MATRIX**

(L) The CQTF run-time option for AQWA-LINE requests calculation of the full QTF matrix. From version 5.3J onward this option does not give printed output; the AQTF option is needed to obtain this.

**CRNM - CALCULATE RAOs WITH NO MOORINGS**

(BDFLN) This option may be used with AQWA-LINE but is more useful with the program AQWA-FER. This option instigates the calculation of RAOs using the values of added mass, wave damping, stiffness and wave forcing specified by the user. The RAOs are then written into the database.

**DATA - DATA CHECK ONLY**

(BDFLN) This option is used to check the data input to the program and provides a means by

which the user may check all input data whilst incurring minimum cost of the program run. This option is equivalent to performing the analysis up to the end of the second stage in AQWA-LINE, and up to the end of Stage 4 in AQWA-DRIFT/FER/LIBRIUM/NAUT. If the data proved to be correct, then the program would be restarted at next stage of the analysis by using the RESTART option.

END                    -            This is used to indicate the end of the option list.

GOON                -            IGNORING MODELLING RULE VIOLATIONS

(L) This is to let the analysis go on in spite of the modelling rule violations. Most of the modelling errors will be turned into warnings by this OPTION. Users are advised not to use this option unless the violations are minor and difficult to correct.

LDOP                -            LOAD OUTPUT

(L) This option is used to create two files, AL\*.POT and AL\*.USS, containing potential and source strength for each wetted element. These two files will be needed for transferring loads for stress analysis.

NOBL                -            NO BLURB. DO NOT PRINT .LIS BANNER PAGE

(BDFLW)            This option switches off printing of the banner page in the \*.LIS file.

NODR                -            NO DRIFT CALCULATIONS

(L) This option flags the program not to perform the Mean Wave Drift Force calculations.

NOFP                -            NO FREE WAVE ELEVATION OUTPUT AT FIELD POINTS

(L) This is to switch off the output of field point wave elevation in the LIS file.

NPPP                -            NO PRESSURE POST-PROCESSING

(L) This option tells the program that there will be no pressure post-processing and therefore the connectivity warnings can be omitted.

NQTF - NEAR FIELD SOLUTION FOR MEAN DRIFT FORCE  
CALCULATION.

(L) This option invokes AQWA LINE to use the near field solution in the calculation of mean drift force. By default the far field solution is used which only calculates the mean drift force in three horizontal degrees of freedom (i.e. surge, sway and yaw). The far field solution is also unable to consider the hydrodynamic interaction between structures.

NRNM - CALCULATES NODAL RAOs WITH NO MOORINGS

(L) This option is used to output in AQWA-LINE run RAOs at particular nodes defined in Deck 18. The run stages should be from 1 to 5.

PFIX - PARTIALLY FIXED MODEL

(L) This option is used to define elements of group number 999 as an adjacent fixed structure. It allows the free floating structure and the fixed structure to be defined in the same ELM\*.deck. Interactions between the two are fully taken into account, while the forces on the two structures are calculated separately.

PLFS - PLOT FREE SURFACE. (This option is no longer necessary in  
version 5.2C and later versions)

(L) This option is used in conjunction with field point cards FPNT in Deck 2 to output free surface elevation at specified field points.

RDDDB - READ DATABASE

(LBDFN) Read the hydrodynamics database from the restart (.RES) file created by a previous AQWA-LINE run.

This option is used if the user wishes to modify the hydrodynamic data calculated in a previous AQWA-LINE run, without having to re-run the AQWA-LINE radiation/diffraction analysis.

Note: Normally, this would be done using the option ALDB (see above). The RDDDB option is only needed if the hydrodynamics file from the previous AQWA-LINE run has been accidentally deleted.

Note that, as the model definition has to be read from the restart file before the hydrodynamics can be read, there is no possibility to change the model definition, when using this option (use ALDB instead).

REST                    -                    RESTART

This option is used when the program is being restarted at any stage greater than the first (see Section 5.2). A restart card must follow the options list when the restart option is used. This card indicates the stage at which the program is to continue and the stage at which the program is to stop (see AQWA Reference Manual).

**A2 PRINTING OPTIONS FOR AQWA-LINE**

**PRDL - Print Data List from Backing File**

When a restart is performed, by default, the expanded data list is NOT output for the previous stages, which have already been performed. This option requests that the expanded data list for ALL decks for previous stages be printed. This option is normally used to confirm that the correct backing files have been assigned for a particular analysis.

**NODL - No Data List**

The user may also switch off ALL output of expanded data by using the NODL option. Note that output involving calculations, e.g. calculation of the mass and inertia of the structure, will still be output.

**PPEL - PRINT PROPERTIES of Each Element**

(BDFLN) This option allows the user to output complete details of each element used in the body modelling. All important details of the body elements are output together with the resultant properties of the bodies. It is only applicable when running Stage 1 of the analysis.

**PRCE - PRINT CARD ECHO FOR DECKS 1 TO 5**

(BDFLN) This option informs the program to output the input received by the program in reading Decks 1 to 5. This is the body modelling.

**PRPR - PRINT PRESSURES**

(L) This option is used to output the total hydrostatic and hydrodynamic fluid pressures at each plate in an AQWA-LINE model.

**PRPT - PRINT POTENTIALS**

(L) This option is used to output the modified and unmodified values of the potential at the diffraction element centres and at the field points. This information may be used to define the fluid flow about the body.

**PRSS - PRINT SOURCE STRENGTHS**

(L) Informs AQWA-LINE to output the singularity strengths for both the modified and unmodified values, the modified strengths being a linear combination of the unmodified values. The actual relationship is a function of the number of body symmetries being utilised.

**APPENDIX B - REFERENCES**

- Reference 1 - Hydrodynamic Loading of Large Offshore Structures : Three-Dimensional Distribution Methods, C.J. Garrison. - Numerical Methods in Offshore Engineering (Wiley 1978)
- Reference 2 - The Drift Force and Moment on Ships in Waves, J.N. Newman. - Journal of Ship Research (1967)
- Reference 3 - Motions of Large Structures in Waves at Zero Froude Number, O.M. Faltinsen and F.C. Michelsen - Symposium on the Dynamics of Marine Vehicles and Structures in Waves (1974)
- Reference 4 - Mean and Low Frequency Wave Drifting Forces on Floating Structures, J.A. Pinkster - Ocean Engineering (1979)
- Reference 5 - Ship Motions and Sea Loads, Salvensen, N., Tuck, E.O. and Faltinsen, O. (1970)
- Reference 6 - A Three Dimensional Ship Motion Theory - Comparison between Theoretical Predictions and Experimental Data of the Hydrodynamic Coefficients with Forward Speed, Inglis and Price, R.B. and Price, W.G (1981)