AQWA-DRIFT 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.

Century Dynamics Limited
Dynamics House
86, Hurst Road
Horsham, West Sussex
RH12 2DT

Tel: +44 (0)1403 270066
Fax: +44 (0)1403 270099

C O N T E N T S

CHAPTER 1 - INTRODUCTION

1.1 PROGRAM

AQWA-DRIFT is a computer program which simulates the motion of floating structures arbitrarily connected by articulations or mooring lines under the action of wind, wave and current forces. The program has the following two modes of operation:

1. Slow drift mode, in which the structure is subjected to only the second order wave forces, steady wind and current;

2. Wave frequency mode, in which both slow drift and wave frequency forces are included along with steady wind and current.

The program requires a full hydrostatic and hydrodynamic description of each structure. This can either be input as data or transferred directly from the output results of an AQWA-LINE analysis.

1.2 MANUAL

The AQWA-DRIFT Program 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-DRIFT.

The method of data preparation and modelling is fully described and reference is made to the AQWA Reference Manual. The Reference Manual contains information common to one or more programs and a complete guide to the format used for input of data into the AQWA Suite. It is desirable that the AQWA-DRIFT Program Manual and AQWA Reference Manual be available when using the program AQWA-DRIFT.

CHAPTER 2 - PROGRAM DESCRIPTION

AQWA-DRIFT is a time domain program which uses linear hydrodynamic coefficients supplied by AQWA-LINE or an equivalent source of linear hydrodynamic data plus other hydrodynamic and hydrostatic information to simulate the motions of large floating structures.

2.1 PROGRAM CAPABILITY

AQWA-LINE computes the linearised hydrodynamic fluid wave loading on a floating or fixed rigid body using 3-dimensional diffraction/radiation 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 excitation loading which induces motion, is composed of diffraction forces due to the scattering of the incident wave field, and the Froude-Krylov force 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 wavelength. To calculate the hydrodynamic coefficients, the fluid is assumed to be ideal and hence potential flow theory is used. Effects which are attributable to the viscosity of the fluid are taken into account in the calculation of the current loads and other hull forces. 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 a mean position. The mean second order wave drift forces may also be calculated by AQWA-LINE after the first order fluid flow problem has been solved. These are used by AQWA-DRIFT to calculate the slowly varying drift force on each structure. The drift force is calculated at each timestep in the simulation, together with the instantaneous value of all other forces. These are applied to the structure, and the resulting acceleration calculated. From this, the position and velocity are determined at the subsequent timestep. The process is then repeated at the following timestep, and so the time history of the structure motion is constructed. The program can be used to calculate the response of structures to drift forces only, but wave forces can also be added with the restriction that the length of time between calculation of the forces and integration of the structure motions must be decreased to accommodate the more rapid variation in wave force.

2.2 THE COMPUTER PROGRAM

The program AQWA-DRIFT may be used on its own or as an integral part of the AQWA Suite of rigid body response programs using the data base from AQWA-LINE. When AQWA-LINE has been run, a backing file, called the HYDRODYNAMIC DATABASE File, 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 this 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 use of 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 hydrodynamic coefficients and drift forces being input to AQWA-DRIFT for irregular wave simulation.

- 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 operating in irregular waves. The analysis is performed in the frequency domain.
AQWA-NAUT	Used to simulate the real-time motion behaviour of a floating body or bodies operating in regular and irregular waves. Wind and current loads may also be considered and the body motions may be coupled or uncoupled.
AQWA-DRIFT	Used to simulate the real-time motion behaviour of a floating body or bodies operating in irregular waves. The program has particular application to long period wave drift induced motions. Wind and current loading may also be applied to the body.

AQWA-AGS — Used in two modes: model visualisation to draw and check the idealised model of the structure analysed; and graph mode to plot graphs of the results of the analysis of any of the other programs in the AQWA suite.

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-DRIFT. 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

The hydrostatic forces, in common with all forces, are recalculated at each timestep in the displaced position. The forces are determined from the linear stiffness matrix, the defined vertical position of the centre of gravity and the buoyancy force acting on the structure at equilibrium. This is given by

$$\underline{F}_{hys}(t) = \underline{B} + \underline{K} \cdot (\underline{x}_E - \underline{x}(t))$$

where

$\underline{B}$ = the buoyancy force on structure at equilibrium

$\underline{K}$ = the six degree of freedom stiffness matrix at equilibrium position

$\underline{x}_E$ = position of the centre of gravity when the structure is in hydrostatic equilibrium

$\underline{x}(t)$ = the position and orientation of structure at time, t

$\underline{F}_{hys}(t)$ = the hydrostatic force and moment at time, t.

3.1.2 Hydrostatic Equilibrium

The description of all wave forces, and the added mass, dampings and stiffness matrices of a particular structure must be calculated and input at a position of hydrostatic equilibrium, i.e. the net hydrostatic and gravitational forces and moments must be zero. It is the motions about this position that AQWA-DRIFT calculates. For more details of rules governing hydrostatic equilibrium see AQWA-LINE manual.

3.1.3 Hydrostatic Stiffness Matrix

For rigid body motion analysis 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 considering hydrostatic pressure together with the body's mass distribution, the matrix will take the following form:

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

where the various terms in the stiffness matrix are:

$$K33 = A$$

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

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

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

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

$$K46 = -x_{gb}\,vol$$

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

$$K56 = -y_{gb}\,vol$$

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 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}	gives 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.

3.2.1 Morison Forces

Morison forces, which are applicable to small tubular structures or parts of structures, can be included in an AQWA-DRIFT, AQWA-NAUT or AQWA-LIBRIUM analysis by the use of TUBE elements. The forces are calculated at each timestep (AQWA-DRIFT and AQWA-NAUT) or at each iteration (AQWA-LIBRIUM). The force (normal to the tube axis) on a TUBE element is given by:

F(Morison) = F(drag) + F(Froude-Krylov) + F(wave inertia)

(Note that only drag is calculated in AQWA-LIBRIUM)

$$F(drag) = 0.5 * \rho * C_d * V * Mod(V) * D * l$$

where

ρ	=	density of water
C_d	=	user-specified drag coefficient
V	=	relative fluid velocity (normal to tube axis), i.e.
V	=	V(current) + V(waves) - V(tube)
D	=	diameter of the tube
l	=	length of the tube

For AQWA-DRIFT and AQWA-NAUT only,

$$F(Froude\ Krylov) = \rho * vol * a_w$$

where

vol	=	displaced volume of the tube
a_w	=	local wave acceleration (normal to tube axis)

$$F(wave\ inertia) = \rho * vol * C_a(i) * a_w$$

where

$C_a(i)$	=	added mass coefficient in the 3 local directions X (axial), Y and Z (transverse) of the tube i.e.
$C_a(x)$	=	0
$C_a(y), C_a(z)$	=	user-specified coefficient (default value = 1)

3.3 DIFFRACTION/RADIATION WAVE FORCES

The total wave frequency force acting on a structure is the sum of the diffraction forces due to the disturbance of the incident waves by the structure and the Froude-Krylov force due to the 'dynamic pressure' inside the waves. For large floating structures these two components are of comparable magnitude and are calculated for regular waves by AQWA-LINE or similar programs. Details of the calculation can be found in the AQWA-LINE manual.

In AQWA-DRIFT the diffraction force and Froude-Krylov force are added together to form the TOTAL WAVE FORCE which is calculated at each timestep. Section 3.3 describes how the wave spectrum is discretised such that the wave at any time instant is given by

$$A(t) = \mathrm{Re} \sum_{i=1}^{NSPL} a_i * \exp(-\omega_i t + k_i x_p + \phi_i)$$

where

Re	denotes the real part of the complex expression	
ω_i	=	the frequency of each regular wave component in the spectrum
k_i	=	the wave number of frequency ω_i
x_p	=	the distance from the origin of the wave system, perpendicular to the wave direction
a_i	=	the amplitude of the regular wave component
ϕ_i	=	a random phase angle
A(t)	=	the instantaneous wave elevation, at time t

and the sum is over the number of regular wave components in the wave spectrum (NSPL).

Similarly, the total wave force at each timestep is given by the following expression:

$$F_{wt}(t) = \mathrm{Re} \sum_{i=1}^{NSPL} a_i * f_i * \exp(-\omega_i t + k_i x + \phi_i)$$

where

f_i	=	the complex total wave force per unit wave amplitude at frequency ω_i

and again the summation is over all the frequencies forming the spectrum.

3.4 MEAN WAVE DRIFT FORCES

AQWA-DRIFT does not explicitly calculate the mean wave drift force on each structure in a spectrum. The mean drift force is the average effect of the slowly varying wave drift force which is calculated as described in Section 3.5. The program requires the regular mean wave drift force coefficients over a range of frequencies. These are calculated by AQWA-LINE or an equivalent program. The theory of regular wave drift forces is contained in Section 3.4 of the AQWA-LINE manual.

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, i.e. a spectrum, then the total wave drift force acting on the body is characterised by a mean component and a slowly varying wave drift force. The second order wave exciting force can be written as:

$$F_{sv}(t) = \sum_{i=1}^{NSPL} \sum_{j=1}^{NSPL} \left\{ P_{ij}^{-} \cos\left[-\left(w_i - w_j\right)t + \left(\varepsilon i - \varepsilon j\right)\right] + P_{ij}^{+} \cos\left[-\left(w_i + w_j\right)t + \left(\varepsilon_i + \varepsilon_j\right)\right]\right\}$$

$$+ \sum_{i=1}^{NSPL} \sum_{j=1}^{NSPL} \left\{ Q_{ij}^{-} \sin\left[-\left(w_i - w_j\right)t + \left(\varepsilon_i - \varepsilon_j\right)\right] + Q_{ij}^{+} \sin\left[-\left(w_i + w_j\right)t + \left(\varepsilon_i - \varepsilon_j\right)\right]\right\}$$

(3.5.1)

Where P_{ij} and Q_{ij} are the in-phase and out-of-phase components of the time-independent transfer function.

If we neglect the sum frequency calculations, e.g. (3.5.1) can be written as:

$$F_{sv}(t) = \sum_{i=1}^{NSPL} \sum_{j=1}^{NSPL} \left\{ P_{ij}^{-} \cos\left[-\left(w_i - w_j\right)\right]t + \left(\varepsilon_i - \varepsilon_j\right)\right\} +$$

$$+ \sum_{i=1}^{NSPL} \sum_{j=1}^{NSPL} \left\{ Q_{ij}^{-} \sin\left[-\left(w_i - w_j\right)t + \left(\varepsilon_i - \varepsilon_j\right)\right]\right\}$$

(3.5.2)

Newman's approximation [3] implies the following:

1) $P_{ij}^{-} = \dfrac{\left(P_i^{-} + P_j^{-}\right)}{2}$

2) $Q_{ij}^{-} = 0$ (this is all the more valid that waves are short).

Based on the above approximations equation (3.5.2) can be written as:

$$Fsv(t) = \sum_{i=1}^{NSPL} \sum_{j=1}^{NSPL} a_i \cdot a_j \cdot P_{ij} \cdot \cos\left[-\left(w_i - w_j\right)t + \left(\varepsilon_i - \varepsilon_j\right)\right]$$

(3.5.3)

where

w_i, w_j = the frequencies of each pair of wave components
a_i, a_j = amplitudes of the wave components
ε_i, ε_j = random phase angles
NSPL = the number of lines in to which the spectrum is divided

The assumption by Newman is valid for regular wave components closely separated in frequency in deep water. Newman's approximation becomes increasingly inaccurate in shallow water. It has been found that the QTF's (drift force coefficients) can be increased significantly in shallow water. In AQWA there is the option of including the second order incident and diffracted potential and performing difference frequency calculations using the full QTF matrix (as opposed to Newman approximation). If the full difference frequency calculation is performed then the in-phase component (P_{ij}^- in equation 3.5.2) consists of 5 components which can be written as follows:

$$\begin{aligned}
P_{ij}^- = &-\oint_{WL} \frac{1}{4}\rho g \zeta_i \zeta_j \cos(\varepsilon_i - \varepsilon_j)\vec{n}dl && \text{- first order relative wave elevation}\\
&+\iint_{S_0} \frac{1}{4}\rho |\nabla \phi_i||\nabla \phi_j| \vec{n}ds && \text{- pressure drop due to first order velocity}\\
&+\iint_{S_0} \frac{1}{2}\rho \left(X_i \nabla \frac{\partial \phi_j}{\partial t}\right)\vec{n}ds && \text{- pressure due to product of gradient of first order pressure and first order motion}\\
&+\mathrm{M}_s\ R_i\ \ddot{X}g_j && \text{- contribution due to products of first order angular motions and inertia forces}\\
&+\iint_{S_0} \rho \frac{\partial \phi^{(2)}}{\partial t}\vec{n}dS && \text{- contribution due to second order potentials}
\end{aligned}$$

and WL stands for water line along the structure surface.

The out-of-phase component Q_{ij}^- can be calculated similarly to the P_{ij}^-

3.6 INTERACTIVE FLUID LOADING BETWEEN BODIES

The importance of fluid interaction between structures will depend on both body separation distances and the relative sizes of the bodies. All the programs in AQWA can now handle full hydrodynamic interaction, including radiation coupling, for 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. There are some restrictions, the main ones being that hydrodynamic interaction cannot be used with forward speed and shear force, bending moment and splitting force cannot be calculated in the AGS if two or more hydrodynamically interacting structures are modelled.

3.7 STRUCTURAL ARTICULATIONS AND CONSTRAINTS

3.7.1 Articulations

Articulations are modelled in AQWA-DRIFT by specifying a point on a structure about which 0,1,2 or 3 rotational freedoms are constrained (see also Section 4.13).

Mathematically, this corresponds to additional constraint equations in the formulation of the equations of motion. At each articulation, the constraint equation relates the acceleration of a point on one structure to the acceleration of a point on another structure. These equations must be identical for compatibility, i.e.

$$a_{p\,1} = a_{g\,1} + w_1 * r_1 + w_1 * (w_1 * r_1)$$

$$a_{p\,2} = a_{g\,2} + w_2 * r_2 + w_2 * (w_2 * r_2)$$

where

a_{pi} = the translational acceleration of a point on structure i
a_{gi} = the translational acceleration of the CG of structure
w_i = the angular acceleration of structure i
r_i = the vector from the CG to articulation on structure i
$a_{p\,1}$ = $a_{p\,2}$

for each constrained freedom are the constraint equations.

3.7.2 Constraints

Constraints are modelled in AQWA-DRIFT by modifying the equations of motion so that the accelerations in the constrained degrees of freedom are forced to be zero.

3.8 WIND AND CURRENT LOADING

3.8.1 Wind and Current

The wind and current drag are both calculated in a similar manner from a set of user-derived environmental load coefficients, covering a range of heading angles. The input coefficients are defined as

(drag force or moment)/(wind or current velocity) ^{2}

The force is calculated at each timestep by

$$F_j = C_j(\theta) * rv^2$$

where	F_j	=	the force vector for degree of freedom j
	$C_j(\theta)$	=	the value of the wind or current coefficient for wind relative angle of incidence θ
	rv	=	the velocity relative to the slow position of the structure for the current or the velocity relative to the total position of the structure for the apparent wind.

The wind and current velocity in the above expression (rv) is calculated to be the relative velocity between the absolute wind and current velocity and the SLOW velocity of the structure. This is because the time scale of the wind and current flow is much longer than the typical wave periods, so the wind and current flows do not have time to develop in response to the wave frequency variations of position.

According to the above definition, the coefficients are dimensional and the user must conform to a consistent set of units. (For details see Appendix A of the Reference Manual.)

3.8.2 Yaw Rate Drag Force

It is clear that the wind and current loads, when calculated as described in Section 3.8.1, have no dependence on yaw rotational velocity. This contribution is calculated separately and the yaw rate drag moment (F_6) is given as follows:

$$F_6 = YRDC \cdot \sum_{i=L_{\min}}^{L_{\max}} x_i \cdot \left[(cy \cdot cur) - (cy + a_i) \cdot \sqrt{cx^2 + (cy + a_i)^2} \right]$$

where

cx	=	cur $*$ cos (θ)
cy	=	cur $*$ sin (θ)
a_i	=	$x_i \cdot rz$

In the above

cur	=	the magnitude of the relative wind or current
θ	=	the relative angle of incidence
rz	=	the yaw velocity
YRDC	=	the yaw rate drag coefficient
x_i	=	the position along the length of the structure

and the summation is over forty points equally spaced along the length of the structure between Lmin and Lmax.

If the centre of gravity is not at the geometric centre of the structure's projection of the water surface, the yaw rate drag will have a lateral component given by a very similar expression, i.e.

$$F_6 = \mathrm{YRDC} * \sum_{i=L_{min}}^{L_{max}} [(cy * cur) - (cy + a_i) * \sqrt{cx^2 + (cy + a_i)^2}]$$

3.9 THRUSTER FORCES

Up to ten thruster forces may be applied to each body. The magnitude of the thrust vector is constant and the direction of the vector is fixed to and moves with the body. The program calculates the thruster moments from the cross product of the latest position vector of the point of application and the thrust vector.

3.10 MOORING LINES

The types of mooring lines available include both linear and non-linear cables. These can be summarized as follows:

A. Linear Cables

- Linear elastic cables (LINE)
- Winch cables (WINCH)
- Constant force cables (FORC)
- Pulleys (PULY)
- Drum winch cable (LNDW)

B. Non-Linear Cables

- Catenary cables (CATN)
- Steel wire cables (SWIR)
- Non-linear cables described by a POLYNOMINAL of up to fifth order (POLY)
- Composite catenary cables (COMP)
- Intermediate buoys and clump weights (BUOY)

Finally, fixed and floating fenders (FEND) can be defined. These are classified as a type of mooring line and have non-linear properties.

3.10.1 Force of Constant Magnitude and Direction

The constant "FORCE" line acts at the centre of gravity of the body in question. The force magnitude and direction are assumed fixed and DO NOT CHANGE with movement of the body. Thruster forces, which do change direction with the body, are described in Section 3.9.

3.10.2 Constant Tension Winch Line

The "WINCH" line maintains a constant tension provided the distance between the ends of the line is greater than a user specified 'unstretched length'. The direction of the tension depends on the movement of the end points.

3.10.3 Weightless Elastic Hawsers

The elastic hawser tensions are simply given by the extension over the unstretched length and their load/extension characteristics. The load/extension characteristics can either be linear (like a spring) or take the following polynomial form:

$$P(e) = a_1 e + a_2 e^2 + a_3 e^3 + a_4 e^4 + a_5 e^5 \quad (3.10.1)$$

where

P	=	the line tension
e	=	the extension

3.10.4 Heavy Inelastic Catenary Chains

Catenaries in AQWA are considered to be uniform, inelastic, with significant mass and no fluid loading except for buoyancy. As the solution of the catenary equations is well documented (see Reference 1 in Appendix B) the summary of the solution used in AQWA is presented. The equations can be expressed in an axis system whose local X axis is the projection of the vector joining the attachment points on the sea bed and whose z axis is vertical. For catenaries which have zero slope at the contact/attachment point on the sea bed these equations can be written as:

$$L = \frac{T_0}{W} \sinh\left(\frac{Wx}{T_0}\right)$$

$$z = \frac{T_0}{W}\left(\cosh\left(\frac{Wx}{T_0}\right) - 1\right)$$

and $T_e \quad = \quad T_0 + Wz$

where

L	=	Length of the catenary from the attachment point on the structure to the contact point on the sea bed

Given the following notation,

T_e	=	Total tension at the attachment point on the structure
T_0	=	Horizontal tension at the sea bed
W	=	Weight of the line less that of the displaced water per unit length
x	=	Horizontal distance between the attachment point on the structure and the **contact** point on the sea bed
x_r	=	Horizontal distance between the attachment point on the structure and the **anchor** point on the sea bed
z	=	Vertical distance between the attachment point on the structure and the anchor point on the sea bed

The stiffness matrix, (K), relating the force to the translational displacements at the attachment point of the structure, is written as:

$$K = K_{xz} \begin{bmatrix} \dfrac{WL}{T_e - T_0} & 1 & 0 \\ 1 & \dfrac{T_e}{x_r} & 0 \\ 0 & 0 & \dfrac{T_e}{zT_0}\left(x - \dfrac{L\,T_0}{T_e}\right) \end{bmatrix}$$

where

$$K_{xz} = T_0\left(z - \frac{WL^2}{T_e} + \left(x - \frac{LT_0}{T_e}\right) * \frac{WL}{(T_e - T_0)}\right)^{-1}$$

K is rotated about the Z axis until parallel to a reference axis system. The stiffness matrix, K, for each mooring line is defined at the attachment point on the structure, and must be translated to a common reference point and axis system. In the AQWA suite, the centre of gravity is chosen. This translation, as formulated in Section 3.10.3, is applied to any local stiffness matrix and force applied at a point on a structure.

3.10.5 Translation of the Mooring Line Force and Stiffness Matrix

The formulation of a vector translation may be applied directly to a force and displacement in order to translate the stiffness matrix, K, from the point of definition to the centre of gravity. It should be noted however that if the stiffness matrix is defined in a FIXED AXIS SYSTEM, which does **not** rotate with the structure, an additional stiffness term is required This relates the change of moment created by a constant force applied at a point when the structure is rotated.

The full 6 ∗6 stiffness matrix (K_g) for each mooring line, relating displacements of the centre of gravity to the change in forces and moments acting on that structure at the centre of gravity, is therefore given by

$$K_g = \begin{bmatrix} I \\ T_a^t \end{bmatrix} \begin{bmatrix} K \end{bmatrix} \begin{bmatrix} I & T_a \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & P_m T_a^t \end{bmatrix}$$

$$K_g = \begin{bmatrix} K & K T_a \\ T_a^t K & T_a^t K T_a \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & P_m T_a^t \end{bmatrix}$$

where

$$T_a = \begin{bmatrix} 0 & z & -y \\ -z & 0 & x \\ y & -x & 0 \end{bmatrix} \qquad P_m = \begin{bmatrix} 0 & Pz & -Py \\ -Pz & 0 & Px \\ Py & -Px & 0 \end{bmatrix}$$

x,y,z	=	Coordinates of the attachment point on the structure relative to the centre of gravity.
Px,Py,Pz	=	The X, Y and Z components of the tension in the mooring line at the attachment point on the structure.

Note The term $P_m.T_a^t$ is NOT symmetric. In general, only a structure in static equilibrium will have a symmetric stiffness matrix. However this also means that if the mooring forces are in equilibrium with all other conservative forces then the TOTAL stiffness matrix will be symmetric.

The force at the centre of gravity (P_g) in terms of the forces at the attachment point (P_a) is given by:

$$P_g = \begin{bmatrix} I \\ T_a^t \end{bmatrix} \begin{bmatrix} P_a \end{bmatrix} = \begin{bmatrix} P_a \\ T_a^t\ P_a \end{bmatrix}$$

3.10.6 Stiffness Matrix for a Mooring Line Joining Two Structures

When two structures are attached by a mooring line, this results in a fully-coupled stiffness matrix, where the displacement of one structure results in a force on the other. This stiffness matrix may be obtained simply by considering that the displacement of the attachment point on one structure is equivalent to a NEGATIVE displacement of the attachment point on the other structure. Using the definitions in the previous section the $12 * 12$ stiffness matrix K_G is given by:

$$K_G = \begin{bmatrix} I \\ T_a^t \\ -I \\ -T_b^t \end{bmatrix} \begin{bmatrix} K \end{bmatrix} \begin{bmatrix} I & T_a & -I & -T_b \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & P_m T_a^t & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & P_n T_b^t \end{bmatrix}$$

where

$$T_b = \begin{bmatrix} 0 & z & -y \\ -z & 0 & x \\ y & -x & 0 \end{bmatrix} \qquad P_n = \begin{bmatrix} 0 & Pz & -Py \\ -Pz & 0 & Px \\ Py & -Px & 0 \end{bmatrix}$$

x,y,z	=	Coordinates of the attachment point on the second structure relative to its centre of gravity
Px,Py,Pz	=	The X, Y and Z components of the tension in the mooring line at the attachment point on the second structure

3.11 WAVE SPECTRA

The method of wave forecasting for irregular seas is achieved within the AQWA suite by the specification of wave spectra. For further details of spectral forms the reader is referred to Appendix E of the AQWA Reference Manual.

Because of the manner in which the drift force is calculated, it is required that the spectrum be defined such that the spectral area between adjacent spectral lines is equal. Thus spectral lines will be close together when the spectral density is large around the spectral peak, and spaced further apart when spectral density is low at either end of the spectrum.

The program does this by calculating the spectral density at a very large number of raster points on the frequency scale, which are equally spaced between the defined spectrum end frequencies. The program uses a default of 5000 raster lines. The raster is then divided into the required number of spectral 'packets' such that the spectral area of each packet is equal. Linear interpolation is used between the raster points to help define the limits of the packets. A spectral line is then placed at the frequency such that the first moment of area of the spectral energy in the packet is zero. This is equivalent to defining the spectral line which represents the packet at the centre of area of the packet.

3.12 STABILITY ANALYSIS

AQWA-DRIFT performs no formal stability analysis. Some physical systems which can be modelled by AQWA-DRIFT may be inherently statically or dynamically unstable. This may be detected by careful inspection of the resulting time histories. Note that dynamic instability is dependent on the initial conditions of the simulation. AQWA-LIBRIUM is designed to investigate the stability of systems and details are in the AQWA-LIBRIUM manual.

3.13 FREQUENCY DOMAIN SOLUTION

AQWA-DRIFT is a time-domain program for analysis of non-linear systems in irregular waves. Linear systems or linearised systems in irregular waves can be analysed in the frequency-domain by AQWA-FER.

3.14 TIME HISTORY SOLUTION IN IRREGULAR WAVES

3.14.1 Time Integration of Equation of Motion

At each timestep in the simulation, the position and velocity are known since they are predicted in the previous timestep. From these, all the position and velocity dependent forces, i.e. damping, mooring force, total wave force, drift force etc. are calculated. These are then summed to find the six total forces and moments for each structure (one for each degree of freedom). The total force is then equated to the product of the total mass (structural and added) and the rigid body accelerations.

The acceleration at the next timestep can thus be determined. It has been found necessary to use an extremely reliable two-stage predictor-corrector integration scheme to predict the position and velocity of the structures at the following time increment. The forces are then recomputed with the new position and velocity and the process is repeated to create, step by step, the time history of motion.

3.14.2 Motions at Drift Frequency

Large floating structures which are moored at sea, because of their large mass and flexible or 'soft' moorings, tend to have natural periods of oscillation in the horizontal degrees of freedom which are of the order of minutes. At these periods there is no first order spectral energy so they are not appreciably excited by first order forces in these degrees of freedom. The structures may of course have heave, roll or pitch resonances within the range of wave excitation but for the moment we shall consider only the motions in the horizontal freedoms, i.e. surge, sway and yaw.

Section 3.5 explains however that in irregular waves there also exists what are termed second order wave forces which oscillate at frequencies which are the difference between pairs of first order wave frequencies. These difference frequencies can be very small. Small frequencies imply large periods which may coincide with the natural period of oscillation of a large floating structure. The result of this excitation at periods close to resonance is large amplification factors in the motions of the structure. These motions are the drift frequency motions.

The equation of motion for the drift frequency motions is:

$$[\, m_s + m_d \,]\, \ddot{x}(t) = F_{sv}(t) + F_c(t) + F_w(t) + F_t(t) + F_h(t) + F_d(t) \qquad (3.14.1)$$

where

$\ddot{x}$	=	the acceleration vector
m_s	=	the structural mass and inertia
m_d	=	the added mass and inertia at drift frequency

$[F_{sv}]$ = the slowly varying drift force

$[F_c]$ = the current forces

$[F_w]$ = the wind forces

$[F_t]$ = the mooring forces

$[F_h]$ = the hydrostatic forces

$[F_d]$ = the damping force

It is assumed that the values of drift added mass/inertia and damping are constant.

3.14.3 Motions at Drift and Wave Frequency

As well as being excited by drift forces, the structure will also be subjected to the first order wave frequency forces. These forces are added to the list of forces in the drift equation of motion in Section 3.14.2. Since the added mass/inertia and damping are not constant over the wave frequency range, these forces are modified to allow for this variation. The total wave frequency force (i.e. diffraction plus Froude-Krylov) in each degree of freedom is calculated by

$$F_{\omega f}(t) = \mathrm{Re} \sum_{j}^{NSPL} \left(a_j * (f_j + (m_d - m_j) * \ddot{x}_j + (c_d - c_j) * \dot{x}_j) * \exp(-\omega_j t + k_j x + \phi_j) \right) \qquad (3.14.2)$$

where

$\ddot{x}_j$	=	$-\omega_j^2\ x_j$
$\dot{x}_j$	=	$i\ \omega_j\ x_j$
i	=	the imaginary quantity $\sqrt{-1}$
m_d	=	the drift added mass
m_j	=	the added mass at frequency j
c_d	=	the drift damping
c_j	=	the damping at frequency j
a_j	=	the amplitude of the regular wave component
x	=	the distance from the origin of the wave system perpendicular to the wave directions
ϕ_j	=	random phase, frequency j
ω_j	=	the j th frequency
k_j	=	the wave number at frequency j
f_j	=	the complex total wave force at frequency j
x_j	=	the complex position at frequency j, i.e. the complex response amplitude operator
$\dot{x}_j$	=	the complex velocity at frequency j

$\ddot{x}_j$ = the complex acceleration at frequency j

and

$x_j = H_j F_j$

$H_j = (K - M_j \omega_j^2 - i C_j \omega_j)^{-1}$

$M_j = m_s + m_a$

where

m_s = structural mass matrix
m_a = hydrodynamic added mass matrix at frequency j
C_j = system linear damping matrix at frequency j
K = total system stiffness matrix
F_j = total wave force at frequency j

Equation 3.14.2 shows how a mass difference correction and a damping difference correction are applied to the total wave force, to correct for the variation of added mass and damping with frequency. This correction involves a 'best estimate' of the wave frequency response at each frequency calculated from the linear equation of motion at that frequency.

The modified total wave force is calculated and added to the sum of all other forces to form the equation motion for drift and wave frequency motions.

$$[\, m_s + m_d \,]\ \ddot{x}(t) = F_{sv}(t) + F_c(t) + F_w(t) + F_t(t) + F_h(t) + F_{wf}(t) \qquad (3.14.3)$$

where all terms are as previously defined.

3.14.4 Slow Drift and Wave Frequency Positions

The total motion of the structure can be thought of as comprising a slow drift motion and a fast wave frequency position. These 'slow' and 'wave frequency' positions added together give the 'total' position.

When only drift wave forces are present, the structure will execute drift oscillations. This motion is termed the slow motion and its position the SLOW POSITION.

When both drift and wave frequency forces are present, the structure will still perform drift oscillations, but these will be accompanied by wave frequency oscillations about the slow position. The oscillation about the SLOW position is called the WAVE FREQUENCY POSITION. The sum of the slow position and the wave frequency position is called the TOTAL position, referred to as simply the POSITION.

3.14.5 Response Amplitude Operator Based Position

The wave frequency response of the structure is determined by AQWA-LINE, and is stored in the form of response amplitude operators at a series of frequencies. A time history of the wave frequency response can be fabricated by combining the response amplitude operators with the wave spectrum. This is done for each degree of freedom as follows:

$$x(t) = \mathrm{Re} \sum_{i=1}^{NSPL} a_i * x_i * \exp(-\omega_i t + k_i x + \phi_i) \qquad (3.14.5)$$

where

Re	=	the real part of the complex expression
x_i	=	the complex response amplitude operator at frequency ω_i
ω_i	=	the frequency of a regular wave component in the spectrum
k_i	=	the wave number of frequency ω_i
x_p	=	the distance from the origin of the wave system perpendicular to the wave direction
a_i	=	the amplitude of the regular wave component, frequency i
ϕ_i	=	a random phase angle, frequency i
$x(t)$	=	the instantaneous displacement at time t

and the sum is over all the regular wave components in the discretised spectrum. This is called the response amplitude operator based position (RAO BASED POSITION) and is used to calculate the initial FAST position to minimise transients (see Section 3.14.7).

A similar expression is used to calculate the RAO BASED VELOCITY, using the fact that

$$\dot{x}_i = i.\ \omega_i\ .x_i$$

where

x	=	the complex position at frequency ω_i
$\dot{x}_i$	=	the complex velocity at frequency ω_i

3.14.6 Filtering of Slow Position from Total Position

In the case where both drift motion and wave frequency motions exist, the current, and wave drift forces are applied to the structure in an axis system which follows the SLOW position. This is done because the flows take a finite time to develop and cannot follow the rapid oscillations due to the wave frequency forces. For example, calculations of current drag, which involve the relative velocity, use the relative velocity between current and SLOW position. The force is then applied in the relative direction between current and yaw of the structure. The same applies to the drift force, but the wind forces are applied using an axis system which follows the total position. The slow position is obtained from the total position by filtering the position through a low pass band filter which separates out the slow and fast oscillations. This is achieved by integrating the following equation at each time step:

$$\ddot{x}_s + 2.c.\omega_f.\dot{x}_s + \omega_f^2.(x_s - x_t) = 0 \qquad (3.14.6)$$

where

$\ddot{x}_s, \dot{x}_s, x_s$	=	the filtered slow acceleration, velocity, and position
x_t	=	the total position
ω_f	=	the filtering frequency
c	=	the filter damping

The filter frequency is chosen by the program to eliminate the wave frequency effects. The damping is set to 20 percent critical. The SLOW position is filtered out of the TOTAL position leaving the WAVE FREQUENCY position. It is clear that for simple cases, the RAO BASED POSITION will be very similar to the WAVE FREQUENCY position. This can often prove a useful check on the wave frequency position in runs where wave frequency forces are added.

3.14.7 Initial Position and Transients

AQWA-DRIFT solves the second order differential equations of motion for each structure, integrating them to form a time-history. For this, the program requires the initial conditions in order to begin the integration. Initial conditions are required for the SLOW position and the TOTAL position. Details of how this is done are can be found in Section 4.15D of the AQWA Reference Manual. As explained there, for simulations including wave frequency forces, it is usual for the user to allow the program to calculate the initial FAST position, which is added to a defined SLOW position to form the TOTAL POSITION. The FAST or RAO based position is calculated as described in Section 3.14.5.

This ensures that the TOTAL initial condition contains a FAST component equal to the steady state solution in response to the wave frequency forces at that instant. By giving the structure an initial SLOW position close to its equilibrium position, transients can be minimised.

3.15 TIME HISTORY SOLUTION IN REGULAR WAVES

Only available within AQWA-NAUT(see AQWA-NAUT manual).

3.16 LIMITATIONS OF THEORETICAL APPLICATIONS

The main theoretical limitations of AQWA-DRIFT should be clearly understood by the user. Since the program uses data calculated by AQWA-LINE, the limitations of the input data must also be understood. Refer to AQWA-LINE manual Section 3.15 for details of the assumptions made. The AQWA-LINE assumptions which affect the analysis, together with the major limitations due to assumptions inherent in AQWA-DRIFT, are listed below:

AQWA-LINE assumptions

1. The theory at present relates to a body or bodies which have zero or small forward speed.

2. The wave frequency motions are to first order and hence must be of small amplitude.

3. The fluid domain is assumed ideal and irrotational in the calculations of the added mass, dampings and wave forces.

4. The second order mean wave drift force is calculated using near-field or far-field solution methods. For more information consult the AQWA-LINE manual.

AQWA-DRIFT assumptions

5. The calculation of the slowly varying drift force is accurate only for low frequencies.

6. The drift forces are calculated in the free floating position of the structure and include components due to the first order wave frequency response of the structure. Should the wave frequency response be appreciably altered by the addition of mooring lines not previously considered, or any other external influence, then the drift forces will clearly be in error.

3.17 THE USE OF CONVOLUTION FOR THE EVALUATION OF THE RADIATION FORCES IN THE TIME-DOMAIN

By default the AQWA time domain programs, NAUT and DRIFT, assume that the radiation forces can be calculated by using the velocity/acceleration RAOs and added mass/damping coefficients at all frequencies to define a set of force RAOs. The radiation force time history can then be derived from the force RAOs and the wave energy packet. This assumption is only valid if the response of the structure at wave frequency is essentially linear, i.e. the structure's motion matches RAOs in frequency, amplitude and phase. Since RAOs are calculated for steady state oscillation under linear forces, the actual structure response, especially when non-linear mooring force is involved or when the motion has not reached a steady state (i.e transient motion) may differ from what is predicted by the RAOs. Consequently the RAO based radiation force calculation may no longer be accurate.

In order to address the above problem, users of AQWA have the option of using the ‘convolution method’ (CONV) in the time-domain programs AQWA-DRIFT and AQWA-NAUT. The convolution of the added mass and damping from the frequency domain to the time domain is a rigorous treatment of the radiation force which uses the actual structure motion instead of RAOs. With this method the radiation force is evaluated separately from the other forces and uses the actual velocity/acceleration of the structure rather than the velocity/acceleration based on the RAOs.

The convolution, as a method of evaluating the radiation forces, can be summarized as follows:

– is more general

– is more accurate for any non linear response

– simplifies the concept of radiation forces

– automatically takes account of non-linear/transient response

– does not require ‘de-coupling’ of low/wave frequency motions.

– automatically calculates interaction between low/wave frequency effects.

With the convolution method, the radiation force is now treated as a totally separate force. Remember that the added mass and damping calculated by AQWA-LINE is only a mechanism for the calculation of the forces created on a structure by moving that structure in still water in simple harmonic motion at a specific frequency. Strictly speaking, the radiation force in the time domain can only be calculated if the response of the structure is infinitely small and at freqencies calculated by AQWA-LINE. In general, the response of a structure will be made up of all frequencies, which implies that the added mass and damping coefficients must be known at all frequencies. For the convolution method to be viable, the maximum frequency range practicable must be calculated by AQWA-LINE. For a tanker this should be from about 0.1 to 1.25 radians/sec or 5-60 second periods. This also implies that a minimum of about 800-1000 elements (total, all quadrants) is required.

It is also fundamental to understand that the frequency dependent added mass and damping coefficients of linear systems are not independent. The added mass from zero to infinity can be calculated totally from the damping by a Fourier transform and inverse (non-symmetric) transform and vice versa. In other words a frequency dependent damping implies the existence of a frequency dependent added mass and vice versa. If user input of frequency dependent added mass and damping is accepted in the future for convolution then it will be required to obey this criterion.

The convolution method as implemented in AQWA-DRIFT and NAUT has 4 distinct stages:

1. Extrapolation of added mass/damping from zero to 'infinity'.

2. The calculation of the time history convolution integral function (CIF).

3. Interpolation of the CIF at an integral number of time steps

4. Calculation of the radiation force at any time by integrating the CIF.

Steps 1 to 3 are performed for each analysis before starting the time history simulation.

The convolution method, as a method of evaluating the radiation as well as the diffraction forces, appears extensively in the literature. Users wishing to study the convolution method in more detail may refer to ref. [6] and [7].

CHAPTER 4 - MODELLING TECHNIQUES

This chapter relates the theory in the previous section 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-DRIFT are presented. This may produce duplication in the user manuals 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

When using AQWA-DRIFT we do not require a description of the full structure surface. Instead the properties of the structure are described numerically. The hydrostatic properties are defined by a stiffness matrix and the hydrodynamic properties are defined by hydrodynamic loading coefficients and wave forces, which are the RESULTS of calculations by programs like AQWA-LINE, which use models involving geometric surface definitions.

When AQWA-LINE is run, all these parameters are transferred automatically to backing files for future use with other AQWA programs.

4.2 MODELLING REQUIREMENTS FOR AQWA-DRIFT

4.2.1 When Used as an Independent Program

AQWA-DRIFT requires the following categories of modelling information:

1. Body mass and inertia characteristics.
2. Wave hydrodynamic and hydrostatic description.
3. Wind and current force coefficient description.
4. Description of mooring configuration.
5. Analysis environment description.
6. Time integration parameters.

These categories will be described in the following sections:

4.2.2 Following an AQWA-LINE Run

After an AQWA-LINE run or a series of runs has been completed, then it may be required to utilise the results in an AQWA-DRIFT analysis. AQWA-LINE automatically produces a HYDRODYNAMICS DATABASE file and a RESTART file. These contain all the information required by AQWA-DRIFT, concerning the structure's mass and inertia properties, the hydrostatic properties and the wave hydrodynamic properties (in the form of a description of the added mass, damping and wave forces, at a series of regular wave frequencies).This information corresponds to categories 1 and 2 of Section 4.2.1 which, if requested, is automatically transferred to the AQWA-DRIFT run, the remaining information being provided by a user-prepared data file.

4.3 DEFINITION OF STRUCTURE AND POSITION

Full details may be found in the Aqwa Reference Manual.

4.3.1 Axis Systems

AQWA-DRIFT uses several axis systems for different purposes.

1. Fixed Reference Axes (FRA)

   The OXY plane of the FRA lies on the free surface and OZ points vertically upwards.

2. Local System Axes (LSA)

   The LSA axis are fixed to the vessel with their origin at the centre of gravity. They coincide with the FRA when the vessel is in its definition position.

3. Slow Axis System (SLA)

   The slow axis system is similar to the LSA in that its origin is located at the centre of gravity, but differs in that it follows only the slow drift motion of the structure.

4.3.2 Conventions

The AQWA suite employs a common sign convention with the axes defined in the previous section.

Translations of a body in the X, Y and Z direction are termed SURGE, SWAY and HEAVE and are positive in the positive direction of their respective axes. Rotations about the X, Y and Z axes (of the FRA) are termed ROLL, PITCH and YAW. The positive sense of these is determined by the right hand screw rule.

4.3.3 The Structural Definition and Analysis Position

In the description of the body geometry and mass distribution, the user may define the structure in any position. There are, however, three **important considerations** when choosing the position in which to define the structure.

e.g. If the structure is a ship or barge, conventional terminology for motion along, and rotation about the longitudinal axis is SURGE and ROLL. However, if the longitudinal axis is defined parallel to the FRA Y-axis then rotational motion about this axis will be termed PITCH, and translational motion along this axis SWAY. Thus, conventional body surge and roll will be termed sway and pitch by the program.

For other structures, e.g. semi-submersibles, this may not be so relevant. The user must take due note of the terms associated with the motions about the axes and is recommended to define all ship/barge shaped structures with the longitudinal axis parallel to the FRA X-axis.

4.4 STRUCTURE GEOMETRY AND MASS DISTRIBUTION

When AQWA-DRIFT is used following an AQWA-LINE run (the normal mode of analysis procedure) the structure geometry and mass distribution are transferred automatically from the backing files produced by AQWA-LINE. This section therefore describes the modelling of the structure geometry and mass distribution when AQWA-DRIFT is used independently (see the AQWA- LINE and AQWA-LIBRIUM manuals when this is not the case).

Note that a hydrostatic or hydrodynamic model as such is not required (see Section 4.2.1), only the hydrostatic stiffness matrix (see Section 3.1.3) and hydrodynamic loading coefficients (see Section 3.3).

4.4.1 Coordinates

Any point on the structure in the modelling process is achieved 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. Each node has a NODE NUMBER, which is chosen by the user to be associated with each coordinate point. Nodes do not contribute themselves to the model but may be thought of as a table of numbers and associated coordinate points which other parts of the model refer to.

Although several coordinates must be defined if several elements are used to define the geometry/mass distribution, normally a single point mass is used, which means that only a single node is defined at the centre of gravity of the structure.

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

4.4.2 Elements and Element Properties

As stated in the previous section, the structural geometry and mass distribution of the model for AQWA-DRIFT, used independently of AQWA-LINE, is achieved by specifying one or more elements, which in total describe the whole structure. The only elements required are POINT MASS elements. A point mass has a position, a value of mass, (e.g. 12 tonnes), and a mass inertia. These in turn are defined by the specification of

- a node number
- a material number
- a geometric group number

The node number (described in the previous section) and the material and geometric group number, are numbers which refer to a table of values of coordinates, masses and structural inertias respectively. Once defined in the table, the numbers may be referred to by any number of elements.

4.5 MORISON ELEMENTS

There are three Morison elements available within AQWA-DRIFT and AQWA-NAUT, namely:

- Tube element (TUBE)
- Slender Tube element (STUB)
- Disc element (DISC)

Tube elements are defined by specifying end nodes, diameter, wall thickness and endcut 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 the variation of local fluid motion over the tube length and to partial submersion of members.

Morison drag and added mass are 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.

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 Morisons 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.

A DISC element (DISC) has no thickness and no mass (users can define a PMAS and attach it to a disc if necessary), but has drag coefficient and added mass coefficient in its normal direction. Therefore, a DISC does not have Froude-Krylov and hydrostatic force. A DISC element has only a drag force and an added mass force.

4.5.1 Reynolds Number Dependent Drag Coefficients

Reynolds number effects on drag can be important at model scale. Drag coefficients are normally considered constant (as is often the case at full scale, i.e. large Reynolds numbers). However, experimental evidence shows that the Reynolds number is not just a simple function of the velocity and diameter for cylinders with arbitrary orientation to the direction of the fluid flow. Considerable improvement in agreement with model tests can be obtained by using a scale factor to obtain a local Reynolds Number and interpolating from classical experimental results,

where

Local Reynolds Number	=	$(U*D/\nu)$ / (scale factor)
U	=	local fluid velocity transverse to the axis of the tube
D	=	tube diameter
ν	=	kinematic viscosity of water

from which drag coefficients can be interpolated from the Wieselberg graph of drag coefficient versus Reynolds number for a smooth cylinder.

Alternatively, a general multiplying factor for drag can be used.

4.5.2 Morison Forces For AQWA-DRIFT with no Wave Frequency Motions

When the wave frequency motions are omitted in an AQWA-DRIFT analysis (i.e. when it has been specified that only drift motions are required), the user has effectively requested that the wave frequency forces on the Morison elements should be omitted, i.e. the forces are to be calculated using only the low frequency motions of structures (including riser and space frame structures).

Although the inertia forces do not usually alter the motions of the main vessel, the drag forces may be significant in contributing to a lightly damped vessel (e.g. in surge).

The user should therefore estimate the additional overall drag-type loading (for input into Deck 10 as 'Hull Drag') or estimate the equivalent linear damping (for input into Deck 7) for the wave spectrum used using the R.M.S wave velocity and Morisons equations for all the Morison elements. If the user is in doubt as to the accuracy of the results, he should run first with no additional damping, and then with the drag/damping described above, to ascertain the sensitivity of the overall motion of the vessel to the forces on the Morison elements.

4.6 STATIC ENVIRONMENT

4.6.1 Global Environmental Parameters

The global or static environmental parameters are those which 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:	Used in AQWA-DRIFT, through the wave number, to calculate phase relationships for various parameters.

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 post-processors to AQWA-LINE. More details may therefore be found in the AQWA-LINE manual in Section 4.7.1.

When AQWA-DRIFT is used independently, the linear hydrostatic stiffness matrix is required as input data. 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. As this stiffness matrix is transferred automatically from backing file when AQWA-DRIFT is used as a post-processor the following notes refer to AQWA-DRIFT when used as an independent program.

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:

- modelling facilities for a particular mechanism are not available in the AQWA suite

- the hydrostatic stiffness matrix is incomplete

- the user wishes to investigate the sensitivity of the analysis to changes in the linear stiffness matrix.

In practice, only in unusual applications will the user find it necessary to consider the modelling of additional linear stiffness.

4.8 WAVE FREQUENCIES AND DIRECTIONS

The wave frequencies and directions are those at which the wave loading, current and wind coefficients are defined and, as they are transferred automatically from backing file when AQWA-DRIFT is used as a post-processor, the following notes refer to AQWA-DRIFT when used as an independent program.

These coefficients, which are required as input data (further details may be found in the following sections) are dependent on frequency and/or direction. A range of frequencies and directions is therefore required as input data, which are those at which the coefficients are defined.

There are only two criteria for the choice of values of the frequency and direction which may be summarised as follows:

1. The extreme values must be chosen to adequately define the coefficients at those frequencies where wave energy in the spectra chosen (see Section 4.14) is significant, and at ALL possible directions of the subsequent response analysis. If geometric symmetry has been specified (see Section 4.3.3 para 2.) only those directions for the defined quadrants are required.

2. Sufficient values are required to adequately describe the variation of these coefficients defined.

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

4.9 WAVE LOADING COEFFICIENTS

The wave loading coefficients are calculated by AQWA-LINE and then transferred automatically from backing file when AQWA-DRIFT is used as a post-processor. Thus the following notes refer to AQWA-DRIFT when used as an independent program. This information falls into five categories. These are:

1. Frequencies and directions at which the regular wave loading has been calculated

2. Added mass and inertia matrices at each frequency

3. Damping coefficient matrices at each frequency

4. Diffraction and Froude Krylov wave forces at each frequency and direction

5. Drift forces at each frequency and direction

It is important that the wave frequency parameters are defined over the range of expected wave excitation frequencies, and that the direction- dependent parameters are defined over the expected RELATIVE angle of incidence.

For wave frequency motion, the added mass and damping matrices are required for the range of frequencies. The diffraction and Froude Krylov forces are required for the range of frequencies AND for the range of directions. AQWA-DRIFT combines the diffraction and Froude-Krylov forces from AQWA-LINE into a resultant total wave force. If the forces are being input manually, the user can input wave forces as either Froude Krylov or diffraction, since the program does not differentiate between the two.

For drift frequency motion, a single added mass and damping matrix are required. These approximate the values of added mass and damping for low frequency motions, which normally include those at drift frequency. The drift forces are calculated by AQWA-DRIFT from the regular wave drift force coefficients, which are defined for the range of frequencies and directions. The added mass varies with frequency of oscillation. As the frequency of oscillation tends to zero, the added mass tends to an asymptotic value. This asymptotic value is a good approximation to the drift added mass. In practice, the added mass of a typically large floating structure, e.g. a 100,000 tonne DWT tanker, is close to its asymptotic value at periods of 25 sec. The longest period wave frequency run should be chosen to provide a suitable value of drift added mass.

4.10 WIND AND CURRENT LOADING COEFFICIENTS

The wind and current loading coefficients are required to model the forces and moments on the structure due to wind and current. These forces are proportional to the square of the relative velocity.

For a simple box shape or similar bluff bodies, these coefficient may be reasonably well approximated by consideration of projected frontal areas and a suitable drag coefficient. For hydrodynamic geometries, e.g. a tanker, net lift forces may also be important. O.C.I.M.F. has published results of model tests on various tankers (see Reference 4).

4.11 THRUSTER FORCES

Thruster forces can be applied on any point of the structure in any direction. Two trusters can produce a moment by acting in parallel directions but not through the same point.

4.12 CONSTRAINTS OF STRUCTURE MOTIONS

The facility of de-activating degrees of freedom is most often used when in the simulation of the drift motion of a structure. Here only the surge, sway and yaw degrees of freedom are of interest, and it is therefore not required that the roll, pitch and heave degrees of freedom be integrated. The position of these non-active freedoms will stay constant and equal to the initial defined value throughout the simulation. It is therefore important to specify these correctly.

Great care must be exercised if the degrees of freedom are de-activated in a structure which is articulated either to another structure or to a fixed point. It is recommended that this should not be done.

4.13 STRUCTURAL ARTICULATIONS

4.13.1 Articulations

Structures in an AQWA-DRIFT analysis can be freely floating, moored or connected to other structures by points of articulation. There are four different types of articulation available. These are as follows:

0	Ball and Socket	Free to rotate in all freedoms
1	Universal	Free to rotate in two freedoms transmitting a moment in the third freedom at right angles to the first two
2	Hinged	Transmitting a moment in two freedoms and free to rotate in the third freedom at right angles the first two
3	Locked	Transmitting a moment in all three freedoms and not free to rotate at all.

4.13.2 Constraints

A constraint can be applied to any degree of freedom. This has the effect of stopping the calculation of forces or moments, and stopping motion in the specified constrained degrees of freedom.

4.14 WAVE SPECTRA, WIND AND CURRENT SPECIFICATION

The user may specify only one spectrum, wind and current speed and their associated directions. For the majority of applications, specification is quite straightforward and no knowledge of the way in which the spectra are used in any program is required. The two rules for specification of the spectrum are as follows:

1. The value of the spectral ordinate at the beginning and end of the frequency range should be small. If the values are not small, only part of the spectrum has effectively been specified.

2. The frequency defining the lower range of the spectrum **must be smaller than the lowest frequency specified in Deck 6**, as the frequency at the lower end of the range is used as both an upper limit to the drift frequencies and a lower limit to the wave frequencies.

4.15 MOORING LINES

4.15.1 Linear/Non-Linear Elastic Hawsers

The line properties are specified by their unstretched lengths, ends nodes on respective bodies and their load/extension characteristics. For linear hawsers, the line stiffness (load per unit extension) is required. For non-linear hawsers, the program permits up to a fifth order polynomial approximation of the elastic property of the following form:

$$P(e) = a_1 e + a_2 e^2 + a_3 e^3 + a_4 e^4 + a_5 e^5 \qquad (4.15.1)$$

where

P = the line tension
e = the extension

The use of a higher order polynomial than necessary could lead to erroneous negative stiffness while a lower order fit could be perfectly adequate (see Figure 4.2). It is always useful to check the polynomial fit prior to its use as input data. Note that the term a_1 is usually a good approximation to the linear stiffness for small extensions.

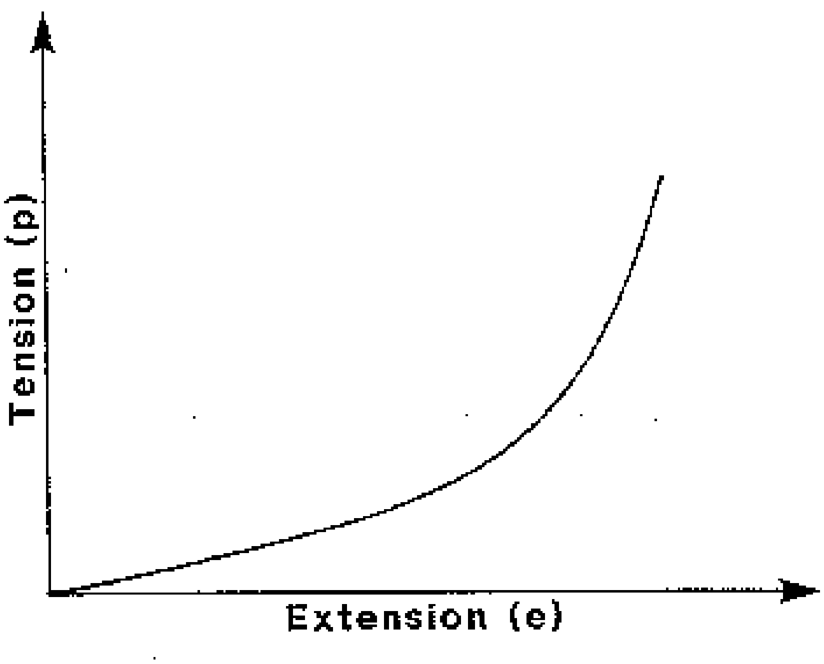

Figure 4.2 - Load/Extension Characteristics

4.15.2 Constant Tension Winch Line

The winch line is characterised by its constant tension, attachment points an 'unstretched length'. The attachment points are specified as nodes and determine the direction of the constant tension. The 'unstretched length' allows the line to go slack when the distance between the end points is less than it. If the user requires constant tension at all times, a zero unstretched length may be input.

4.15.3 'Constant Force' Line

The program allows the user to input a force of constant magnitude and direction. The force is always assumed to act at the centre of gravity of the body. The direction of the force is specified a node on the body and a second node chosen such that the force vector is directed from node 1 to node 2. Once the direction is defined, the program maintains the magnitude and direction despite movement of the body. This facility can be used to input environmental forces where details of the forces (e.g. wind coefficients) are not available.

4.15.4 Catenary line

The catenary model admits uniform, inelastic, heavy catenary lines. Current drag on the line itself is ignored. The line is specified by the end nodes, length, weight in air per unit length and equivalent cross sectional area. The equivalent cross sectional area is numerically equal to the volume of water displaced by a unit length of the chain.

The user may specify maximum and minimum tensions in the line and maximum tension at the anchor. Default values are provided by the program. For length based calculations, the program will adjust the line length if the tension turns out to be outside the range specified (or the default values). If the user wishes to keep constant line length irrespective of the tension, a very large value of maximum allowable tension may be input. In all cases, adequate warning messages will be signalled.

The program evaluates the line tension and stiffness according to close form solution of the catenary equations. The program allows the line to lift off the sea bed (i.e. the tangent to the line at the anchor has non-zero slope) up to the point where the line tension exceeds a user specified/default maximum.

Care must be exercised in the description of the catenary line such that the line is not lying horizontally and the length is sufficient to allow the expected range of movement of its ends. Although the program caters for cases where the catenary line lifts off the sea bed, in practice, most catenary chains are expected to function with a significant length of the line on the sea bed.

The following expression may help the user to check in advance if the catenary is likely to lift off from the sea bed. Just at lift off, T, the tension in the line is approximately related to s, the line length by the simple expression

$$T/W = (s^2 + z^2)/2z \qquad (4.15.2)$$

where

W	=	the 'weight in water' per unit length of the chain
z	=	the vertical distance between the anchor point and the attachment point on the body

By specifying T as given by equation (4.15.2) as the maximum tension, the user can ensure that the line does not 'lift off'.

4.15.5 Steel Wire Cables

The Steel Wire (SWIR) facility allows modelling of the non-linear properties of a new steel wire rope. Although the SWIR cable is classified as a non-linear cable it is possible to model steel wire using linear (LINE) or non-linear (NLIN) lines.

4.15.6 Intermediate Buoys and Clump Weights

The Buoy card (BUOY) defines the properties of intermediate buoys and clump weights. Intermediate buoys cannot be used between structures but only between a structure and the sea bed.

4.15.7 The Pulley Card (PULY)

The PULY facility allows the use of a pulley positioned on a line. A maximum of 2 pulleys is allowed for each pulley set. A PULY card must be proceeded by a LINE card.

4.15.8 The Drum Winch (LNDW)

The LNDW card is used to model a winch or drum winch which winds in or pays out a linear elastic line starting at a user specified time.

4.15.9 Fenders (FEND)

Fixed and floating fenders are available in AQWA. A fixed fender is graphically shown as a sphere in the AGS, or if the axis is defined, a cone whose axis is normal to structure plane to which it is fixed. A floating fender will be shown as a short cylinder. Emphasis has been put on the “realistic” graphical representation of the fender distortion. Fixed and floating fenders in AQWA can be modelled together with conventional mooring lines.

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

Not applicable to AQWA-DRIFT (see AQWA-LIBRIUM manual).

4.17 TIME HISTORY INTEGRATION IN IRREGULAR WAVES

4.17.1 Timestep for Simulation

The timestep for a simulation should be chosen to be a small fraction of the period of variation of the most rapidly varying force or response. A different timestep is applicable if investigating only drift motions, as opposed to drift and wave frequency motions.

Drift motions

In this case only drift motion are being integrated and the timestep should be about one twentieth of the smallest natural period of drift oscillation. A 5 to 10 second timestep is usual for a typical offshore structure.

Drift and wave frequency motions

A suitable timestep in this case will be much shorter, since the response to wave frequency forces is being investigated. A timestep of 0.5 seconds is typical.

Once a timestep has been selected, the program outputs an indication of the expected errors using the chosen timestep. This is explained in Section 7.6 in the description of the output. The program also outputs the error at each timestep in each degree of freedom which is related to the chosen timestep. These errors can always be reduced by shortening the timestep.

4.17.2 Simulation Length and Accuracy Limits

For the time history of motion in an irregular sea to be representative of the structure's motion characteristics in that sea, the time history has to be of sufficient length to allow averaging of maximum and minimum response. Motions simulated over a finite length of time contain some statistical error because the sample may, by chance, contain an unrepresentative number of large or small oscillations. Reference 5 explains that the variance of the mean square value of the slow drift position can be calculated assuming linear mooring stiffness and linear damping. This can provide a useful guide to the expected errors in statistical properties derived from a finite length simulation.

The variance of the mean square value can be calculated form the following:

$$\frac{(4\sigma^4)}{T}\int_0^T 1-\frac{t}{T}\rho^2(t)\ dt \tag{4.17.1}$$

where

σ^2	=	the true mean squared value
$\rho(t)$	=	the auto-correlation function of the process
T	=	the length of the simulation or process

Assuming light damping and linearity in the restoring stiffness and damping, the auto-correlation function is:

$$\rho(t) \quad = \quad \exp(-c\omega\, t^2)\cos(\omega\, t) \qquad (4.17.2)$$

where

ω = natural frequency of oscillation

c = surge damping as a fraction of critical damping

Equation 4.17.1 can thus be evaluated. Since the statistical variation about the mean square value will be approximately Gaussian, the 98 per cent and 68 per cent confidence limits in simulated motion can be deduced and are plotted below.

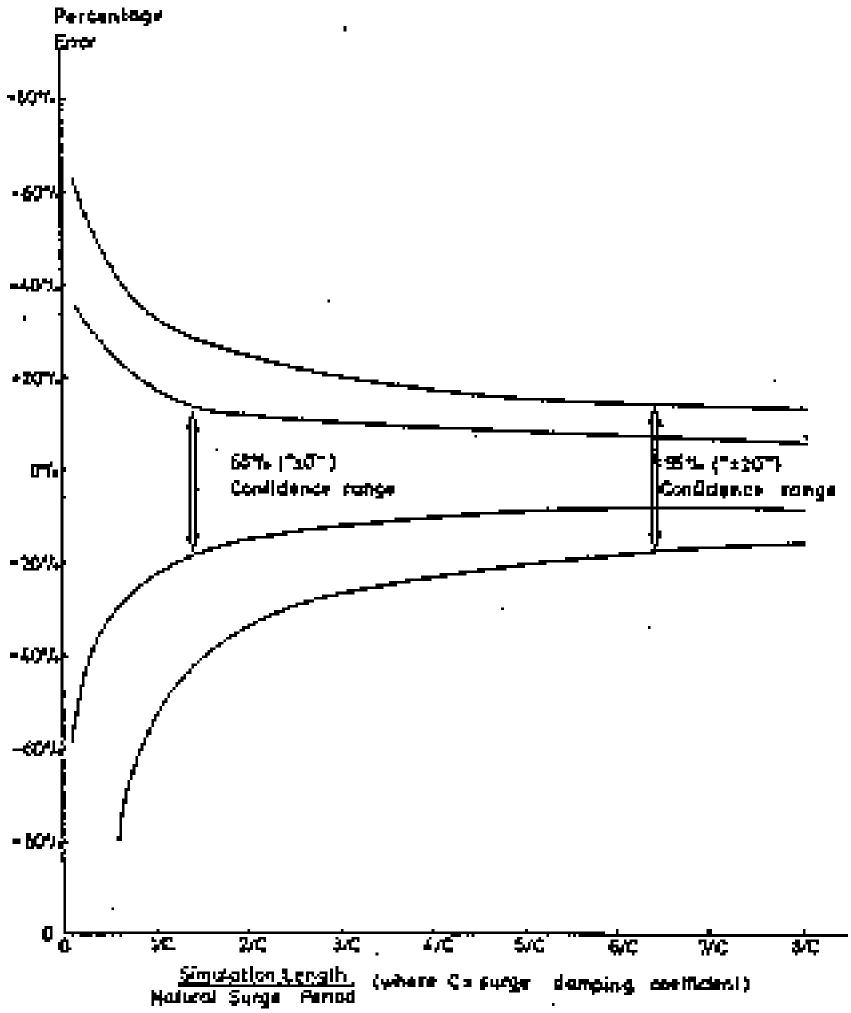

Figure 4.3 - Confidence Limits on Computation of Significant Motion

The graph shows that for a system with 10 percent damping, the length of simulation must be at least 40 times the structures natural period to achieve an estimate of the significant motion correct to +/- 20 per cent.

4.17.3 Initial Conditions and Start Time

It is important that the simulation should have as small an initial transient at the start as possible, especially if the user requires accurate statistics of the simulations; transients at the start will invalidate the statistics of the run. It is usual when performing a drift motion simulation to position the structure close to the equilibrium position of the structure under the influence of steady forces.

The user may then wish to add in the wave forces over a short segment of the drift run starting just before a peak drift response. This would, for example, indicate how much the wave frequency effects will modify the peak motions and tensions in mooring lines. To do this, the user must pick off the slow position and velocity at some appropriate time in the drift run and then perform another simulation with these slow positions and velocities as the starting conditions. It is very important for the user to remember to give this second simulation a starting time equal to that at which the slow position and velocity occurred, so that the second simulation has exactly the same wave force time history as the first.

4.18 TIME HISTORY INTEGRATION IN REGULAR WAVES (AQWA-NAUT ONLY)

Not applicable to AQWA-DRIFT (see AQWA-NAUT manual).

4.19 SPECIFICATION OF OUTPUT REQUIREMENTS

See options list in Appendix A.

CHAPTER 5 - ANALYSIS PROCEDURE

This chapter assumes that the user is familiar with the theory of the analysis and how to model the structure in its environment. It deals with the method of analysis associated with running the program and links the modelling information in 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 program runs and stages within each program run together with their associated options.

5.1 TYPES OF ANALYSIS

There are several different common types of analysis that the program has been designed to perform. These are the same whether used independently, or as a post-processor to AQWA-LINE, and are as follows

1. Investigation of transient response of coupled moored structures
2. Simulation of drift motions of coupled moored structures
3. Simulation of drift and wave frequency motions of coupled moored structures

In each of these analyses, any chosen variables can be analysed statistically and plotted if required. The different types of analyses and the results that are produced are mainly controlled by program options.

5.2 RESTART STAGES

All programs in the AQWA suite have the facility of running one or more stages of the analysis separately. These stages are referred to in the documentation as RESTART STAGES (see Chapter 2 of the AQWA Reference Manual).

Use of the restart process thus implies that information is available on a backing file from a previous program run and not via the normal card image file. This process is also used to transfer information from one program to another program in the AQWA suite.

These stages are as follows:

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 will allow visualisation of the geometric model and parameters at any point in the analysis, e.g. Stages 2 to 5 are not required to visualise the data input in Stage 1. **This only applies to the graphics**, as all other programs must progress from one stage to another with NO stages omitted. As Stage 3 has no direct calculations in programs other than AQWA-LINE, the programs will 'correct' a request to finish at Stage 2 to one to finish at Stage 3. This remains transparent and requires no action by the user.

5.3 STAGES OF ANALYSIS

An analysis using AQWA-DRIFT independently uses the items 1 to 7 of the following. If the program is being used as a post processor to AQWA-LINE then this information is automatically transferred from AQWA-LINE to AQWA-DRIFT.

1. Select a consistent set of units.

2. Identify the geometric and material data for the body or bodies.

3. List all relevant co-ordinates.

4. Specify one or more point masses to represent the mass and mass inertia of each of the structures.

5. Specify the hydrostatic stiffness together with the position at which the gravity and hydrostatic forces together are zero.

6. Specify the wave diffraction/radiation coefficients and the frequencies and directions at which they are defined for each structure.

7. Specify the wave drift coefficients if drift motions are significant for each structure.

The following items 8 to 14 are required for AQWA-DRIFT used independently or as a post-processor to AQWA-LINE.

8 Determine mooring line properties.

9. Prepare coefficients for wind and current drag for each structure.

10. Specify the wave damping and added mass applicable to low frequency motion for each structure.

11. Specify initial positions for each spectrum and details of the simulation length and timestep length.

12. Create a data file as described in Chapter 6.

13. Perform a DATA run (i.e. with the DATA option switched on) which will provide preliminary checks on the card image data file.

14. After a successful DATA run, select mode of analysis on the first card of the card image input data (drift motion or drift plus wave frequency) and re-run with the restart option.

The usual analysis procedure is to first look at the drift motions of a structure in a drift simulation.

The relative importance of wave frequency effects can then be determined by performing a drift plus wave frequency motion simulation. It is usual to perform this wave frequency simulation starting at some point just before the maximum drift response to see how the peak response is aggravated or reduced by the wave frequency effects. From the output listing of the drift run, it is possible to pick off the structure's position and velocity at some time just before the peak drift motion and use these as the initial conditions for the wave frequency simulation.

CHAPTER 6 - DATA REQUIREMENT AND PREPARATION

This chapter describes the form in which data is expected by the program and it is not intended as a detailed list of the data requirements and general format for each type of analysis that may be performed when running AQWA-DRIFT. The detailed format may be found in the AQWA Reference Manual. The data file is constructed by a series of data decks.

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 used where the more unusual facilities have been omitted.

Most data requirements listed are optional unless specified otherwise and if not input the program defaults are used. These defaults may be found, together with the detailed format description, in the AQWA Reference Manual.

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 is as follows

- 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 which are common to all programs while others are for use with specific programs. The options within AQWA-DRIFT control the type of output required from the program and the restart stages of analysis to be performed (see Appendix A).

RESTART Card - If the restart option is used, then the start and finish stages of the 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-DRIFT, see Appendix A.

One option commonly used is the DATA option and it is worth noting its purpose. The DATA option performs Stages 1 to 4 of an AQWA-DRIFT analysis. This means that all information relating to the analysis is read in allowing all data checking to be performed. After the user is satisfied with the acceptance of data then the analysis can be undertaken by restarting the program at Stage 5 to perform the analysis itself.

6.1 STAGE 1 - DECKS 1 TO 5 - GEOMETRIC DEFINITION AND STATIC ENVIRONMENT

Input for Stage 1 of the analysis is only necessary if the restart stage at which the analysis begins is 1 (see Chapter 5). If the restart stage is greater than 1, there is NO INPUT for Stage 1 of the analysis.

6.1.1 Description Summary of Physical Parameters Input

The data input in these decks relates to the description of each structure and the environment which normally remains unchanged throughout the analysis. This includes any point referenced on or surrounding the structure, the mass inertia, hydrostatic and hydrodynamic model and the (constant) water depth, i.e.

- the coordinates of any point on the structure or its surrounding referenced by any other deck
- point mass element description of the mass distribution
- a table of masses associated with each point mass
- a table of inertias associated with each point mass
- the depth and density of the water and acceleration due to gravity

The data requirements of each program are not the same and may be also dependent on the type of analysis performed. These requirements are listed in detail in the later sections of this chapter.

6.1.2 Description of General Format

The input format these decks is designed to provide checking on the data for the average user, and outputs a suitable message to inform the user if the instructions for data preparation have been misinterpreted or are unusual. When running with a DATA option for the first time it is recommended that the PRCE (PRint Card Echo) option is used (see Appendix A), as the data input in these decks (1-5) is not echoed automatically. The user may then check the results before proceeding to Stage 2 of the analysis.

6.1.3 Data Input Summary for Decks 1 to 5

Deck 1 - The coordinates of points describing elements
- The coordinates of the mooring line attachment points
- The coordinates of any points whose positions or motions are requested by the user specified options

Deck 2 - Elements used to model the mass distribution of body

Deck 3 - A table of masses associated with each point mass

Deck 4 - A table of inertias associated with each point mass

Deck 5 - Static environmental parameters, i.e. the depth and density of the water, and acceleration due to gravity

The above information is required before an AQWA-DRIFT simulation can be performed. The format of the information contained within Decks 1 to 5 may be found in the AQWA Reference Manual.

6.2 STAGE 2 - DECKS 6 TO 8 - THE DIFFRACTION/RADIATION ANALYSIS PARAMETERS

Input to Stage 2 of the analysis is only necessary if the restart stage at which the analysis begins is Stage 1 or 2 (see Chapter 5). If the restart stage is greater than Stage 2, there is NO INPUT for Stage 2 of the analysis.

6.2.1 Description Summary of Physical Parameters Input

The data input in these decks relates to the equation of motion of a diffracting structure or structures in regular waves, for a range of frequencies and directions. (Note that the structural mass is input in Deck 3). For each specified range of frequency and direction,the equation of motion is written as

$$M(s)\, \ddot{x} + M(a)\, \ddot{x} + C\, \dot{x} + K\, x = F(d) + F(f) + F(2)$$

The parameters in the equation of motion are

K - Linear stiffness matrix, with associated values of the buoyancy force at equilibrium, and the global Z coordinate of the centre of gravity at equilibrium

and, for each frequency

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

and, for each frequency and each direction

x - Response Motions (or RAOs)
F(d) - Diffraction Forces
F(f) - Froude Krylov Forces
F(2) - Second Order Drift Forces

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 these decks is output automatically in order that the user may check the results before proceeding to the next stage of the analysis.

For AQWA-DRIFT, parameters are read from a backing file automatically or may be input manually. In the latter case the range of frequencies and directions specified in Deck 6 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 - a range of frequencies
- a range of directions
- details relating to alterations of the results of a previous run

Deck 7 - linear hydrostatic stiffness matrix
- additional stiffness matrix (usually not required)
- the buoyancy force at equilibrium
- global Z coordinate of the centre of gravity at equilibrium
- added mass matrix
- additional mass matrix (usually not required)
- radiation damping matrix
- additional linear damping matrix (usually not required)
- diffraction forces
- Froude Krylov forces
- response motions (or RAOs). For checking only.

Deck 8 - Second Order Drift Forces

It is unusual for all the data above to be required for any particular analysis, in which case the user simply omits the data which is not applicable. The following sections show the required data input for the available modes of analysis.

6.2.4 Input for AQWA-DRIFT using the 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, i.e. these decks are not required at all and must be removed from the card image data deck as the analysis is restarted at the beginning of Stage 4.

Deck 6 to 8 - No Input Required

6.2.5 Input for AQWA-DRIFT with Results from a Source other than AQWA-LINE

Although the parameters calculated by AQWA-LINE can be transferred automatically to other programs in the AQWA suite, this is NOT mandatory. This means that if the backing file produced by an AQWA-LINE run is NOT available, e.g. AQWA-LINE has not been run previously or the user wishes to input values from a source other than AQWA-LINE then data may be input in these decks.

All data appropriate to the analysis (summarised in Section 6.2.3) may then be input in card image format. The exact input will depend on the type of analysis and the particular structure analysed.

Typically, input data required is as follows:

(a) For a run analysing the drift motions only

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

Deck 7 - Linear stiffness matrix

Deck 8 - Second order drift forces

(b) For a run analysing both the wave frequency and drift motions

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

Deck 7 - Linear stiffness matrix
- Added mass matrix
- Radiation damping matrix
- Diffraction forces
- Froude Krylov forces

Deck 8 - Second order drift forces

6.2.6 Input for AQWA-DRIFT with Results from 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 can be achieved by simply using the card image input as described in the previous section, in addition to reading the results from a previous AQWA-LINE run. As the program does not expect a backing file from AQWA-LINE to exist at Stage 2 of the analysis the ALDB option must be used in the options list (see Appendix A) to indicate that it exists and must be read. **Using this option means that the Stage 2 data is read twice, once from the AQWA-LINE backing file, and once from 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 redefined.

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 CARD IMAGE INPUT - DIFFRACTION/RADIATION ANALYSIS

There is no input data for Stage 3, as this is purely a calculation stage, namely, the calculation of the hydrodynamic properties by AQWA-LINE. Note that, if AQWA-DRIFT is being run independently, then the data which would have been calculated by AQWA-LINE must be input by the user (from some other source) in Stage 2.

6.4 Stage 4 - DECKS 9 to 18 - INPUT OF THE ANALYSIS ENVIRONMENT

Input to Stage 4 of the analysis is only necessary if the restart stage at which the analysis begins is less than or equal to 4 (see Chapter 5). If the restart stage is greater than 4, there is NO INPUT for Stage 4 of the analysis.

6.4.1 Description Summary of Parameters Input

The data input in these decks relates to the description of the analysis environment and the structure coefficients associated with the environment.

Low frequency added mass and damping	It is mandatory to input the added mass and damping associated with the low frequency motion. These are assumed constant.
Wind and current loading coefficients	These coefficients, which are defined at directions specified in Deck 6, are associated with the hull forces, which are proportional to the square of the relative wind/current velocity.
Wave spectrum, wind and current	The sea state is defined by a wave spectrum, together with wind and current speed and direction (see Section 4.14).
Mooring lines	The physical characteristics and attachment points of mooring lines, hawsers and tethers may be input if required (see Section 4.15)
Starting position	The initial position of each structure should be specified
Time integration parameters	The timestep to be used throughout the simulation and the number of time steps required is specified. The user also specifies the start time of the simulation.
Morison element parameter	This is either the Local Reynolds Number or a drag scale factor applied to the drag coefficients of Morison elements (already specified in Deck 4).

6.4.2 AQWA-DRIFT Data Input Summary for Decks 9 to 18

Deck 9	-	Low frequency added mass
	-	Low frequency damping
Deck 10	-	Wind loading coefficients for the superstructure
	-	Current loading coefficients for the hull
Deck 11	-	No input required
Deck 12	-	No input required
Deck 13	-	Wind speed and direction for each spectrum
	-	Current speed and direction for each spectrum
	-	Description of the wave spectrum
Deck 14	-	Description of each mooring line combination
Deck 15	-	Initial positions for each structure
Deck 16	-	Number of timesteps, timestep length and start time
Deck 17	-	Morison element parameters
Deck 18	-	Parameters to be analysed statistically and recorded for subsequent plotting

Usually, not all the above data items are required for any particular analysis. In this case, the user simply omits the items which are not applicable. Note also that other data items may not be required, as a consequence of omissions, e.g. current loading coefficients are not required if the current speed is omitted or input as zero.

6.5 STAGE 5 - NO INPUT - Motion Analysis

Stage 5 is the motion analysis stage only and therefore requires no input.

6.6 STAGE 6 - NO DECKS - GRAPHICAL DISPLAY

The AQWA suite has its own graphics program called AQWA-PLANE. 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-PLANE program, see the AQWA-PLANE User Manual.

6.6.1 Input for Display of Model and Results

The program AQWA-PLANE 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 copied over to AQWA-PLANE and this may be interrogated when the user requests a particular type of plot.

The results of all the other programs (AQWA-LINE/DRIFT/FER/LIBRIUM/NAUT) are stored on the GRAPHICS backing file, which is also copied over to AQWA-PLANE for plotting in graphical form.

CHAPTER 7 - DESCRIPTION OF OUTPUT

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

7.1 STRUCTURAL DESCRIPTION OF BODY CHARACTERISTICS

This information is only output when starting at Stage 1, or when the PRDL option is used to echo the information from backing file.

7.1.1 Coordinates and Mass Distribution Elements

Note that the body’s surface geometry is not used in AQWA-DRIFT. Only the mass characteristics are input. These, together with coordinates referenced by later decks, are input in 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-DRIFT to define the mass distribution body characteristics is output for checking, and the body's resultant centre of mass and inertia matrix are also output. The nodal coordinates are output in the Fixed Reference Axes, and the format is 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 point mass's topology is output as shown in Figure 7.2. Each structure element is numbered 1,2,3, etc, in the order which it appears in the output.

It is also worth noting that this 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    NODE      NODE      NODE      NODE    MATERIAL  GEOMETRY

   NUMBER    TYPE  NUMBER    NUMBER    NUMBER    NUMBER    NUMBER    NUMBER
   ---------------------------------------------------------------------------

       1     PMAS    14         0         0         0        11         1
       2     PMAS    11         0         0         0         1         1
       3     PMAS    12         0         0         0         1         2
       4     PMAS    13         0         0         0         2         4
       5     PMAS    10         0         0         0         3         4
```

Figure 7.2 - Element Topology Output

The body topology output references the material group number, which has a mass 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       75593800.000
                       2          57525.000
                       3        1025000.000
                      11          25000.000
```

Figure 7.3 - Material Property Output

The topology output also references the geometry group numbers used by the user. Each geometry group has an inertia tensor associated with it. The geometry group numbers and the inertias specified for each group are output as shown in Figure 7.4. Here the point mass element has a full six geometric parameters which are the prescribed inertia values. It is also seen that the localised element drag and added mass coefficients are also printed. This is in anticipation of the inclusion of other elements which will be implemented in the future.

```
              * * * * 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 point mass description of the structure, now outputs the total resultant 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 body. The types and total number of elements used to model the structure are output.

```
 * * * * * MASS   AND   INERTIA   PROPERTIES   OF   STRUCTURE   1 * * * * *
           ------------------------------------------------------

                               NUMBER
                                 OF
         ELEMENT TYPE         ELEMENTS          MASS                 WEIGHT
         ------------         --------          ----                 ------

              PMAS                5       75593800.000        741575232.000

      ------------------------------------------------------------------

           T O T A L            213       75593800.000        741575232.000
      ------------------------------------------------------------------


                                     X           Y           Z
                               ------------------------------------

   CENTRE OF GAVITY                 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 - Resultant Mass and Inertia

7.2 DESCRIPTION OF ENVIRONMENT

This information is only output when starting at Stage 1, or when the PRDL option is used to echo the information from backing file.

The environmental parameters in AQWA-DRIFT are the fluid depth and density. The static environment is output as shown in Figure 7.6 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 7.6 - Static Environment

The wave environment is now output. AQWA-DRIFT may have up to ten 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 7.7.

The output also shows details of other wave related parameters:

- Wave number, i.e. 2.0*π/(wavelength)
- Maximum element size (applicable to AQWA-LINE/NAUT)
- Depth ratio

The final piece of information given in Figure 7.7 relates to the frequency dependent parameters (i.e. added mass, etc). If these parameters have not already been input 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
---------------------------------------------------------------------
```

Figure 7.7 - Wave Parameters

7.3 DESCRIPTION OF FLUID LOADING

This information is only output when starting at Stage 1 or 2, or when the PRDL option is used to echo the information from backing file from AQWA-LINE.

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

7.3.1 Hydrostatic Stiffness

The hydrostatic stiffness matrix output by AQWA-DRIFT, when printing from backing file, is in the analysis position used in AQWA-LINE for the diffraction/radiation analysis. An example output is shown in Figure 7.8.

```
                    HYDRODYNAMIC PARAMETERS FOR STRUCTURE 1
                    - - - - - - - - - - - - - - - - - - - -

                    AT THE FREE-FLOATING EQUILIBRIUM POSITION
                    ---------------------------------------

               BUOYANCY FORCE . . . . . . . . . . . . =  3.2566E+09

               Z POSITION OF THE CENTRE OF GRAVITY  . = -1.0620E+01

                               STIFFNESS MATRIX
                               ----------------

          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 7.8 - Hydrostatic Stiffness Matrix Output

If used independently, the stiffness matrix output is the sum of the (hydrostatic) stiffness and the additional stiffness input by the user.

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 7.9 shows a typical added mass matrix, for Structure 1, at a single frequency (wave damping being output in a similar fashion). 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 7.9 - Added Mass Matrix Output

7.3.3 Oscillatory Wave Excitation Forces

The wave loading output from AQWA-LINE is presented in tabular form 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 7.10). Output is also given with the wave force/moment varying with direction, for each frequency.

The wave forces/moments are output in terms of amplitude and phase. The phase is related to the incident wave form (see Appendix C of the 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 7.10 shows only the Froude-Krylov component, but the other forces are output in a similar format.

```
               * * * * 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 7.10 - Froude Krylov Forces/Moments

7.3.4 Mean Wave Drift Forces

The mean wave drift forces and moments as a function of wave period and direction are output as shown in Figure 7.11. They are given for each body and for the range of user specified frequencies.

Note that the mean wave drift forces are proportional to wave amplitude squared and are given for unit wave amplitude.

```
* * * * WAVE-DRIFT  LOADS  FOR  UNIT  AMPLITUDE/VELOCITY * * * *
        ------------------------------------------------

        * * * * FOR  STRUCTURE  1 * * * *
                -----------------


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

Figure 7.11 - Mean Wave Drift Forces/Moment

7.4 FREE FLOATING NATURAL FREQUENCIES AND RESPONSE AMPLITUDE OPERATORS

7.4.1 Natural Frequencies/Periods

AQWA-DRIFT calculates the **uncoupled** natural frequency/period, for each structure, at each user specified wave frequency (added mass being a function of wave frequency).

The damping values of the body motions are compared with, and expressed as a percentage of, critical damping values (see Figure 7.12).

```
        * * * * NATURAL  FREQUENCIES/PERIODS FOR  STRUCTURE  1 * * * *
                ----------------------------------------------


N.B. THESE NATURAL FREQUENCIES DO *NOT* INCLUDE STIFFNESS DUE TO MOORING LINES.

     FREQUENCY        UNDAMPED  NATURAL  FREQUENCIES (RADIANS/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 7.12 - Natural Frequencies/Periods

7.4.2 Response Amplitude Operators

The Response Amplitude Operators (which are not required to calculate the wave/drift frequency motion) will be output as zero if the user has not specified them in Deck 7, unless the user has used the CRNM option (Calculate RAOs with No Moorings). If they are printed from an AQWA-LINE backing file they will be those calculated by AQWA-LINE.

The output gives the variation of RAOs with frequency, for each direction (see Figure 7.13). Output is also given with the RAOs varying with direction, for each frequency.

The RAOs are output in terms of amplitude and phase, the phase being related to the incident wave form (see Appendix C of the AQWA Reference Manual).

N.B. These RAOs, which do **not** include the effect of mooring lines specified in Deck 14, are labelled as 'R.A.O.S - VARIATION WITH WAVE PERIOD/FREQUENCY' (see Figure 7.13). If the user has used the CRAO option (Calculate RAOs) then the RAOs are appropriate to each structure in turn **with other structures held stationary** and are labelled as 'RECALCULATED R.A.O.S - VARIATION WITH WAVE PERIOD/ FREQUENCY'. This is because, in general, the frequencies and directions for each structure are not the same, and are therefore incompatible with output in this format. RAOs for the fully coupled system are output, for one direction associated with a particular spectrum, and are described in Section 7.6.

```
             * * * * HYDRODYNAMIC  PARAMETERS  FOR  STRUCTURE  1 * * * *
                     -------------------------------------------

                    R.A.O.S-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 7.13 - Response Amplitude Operators

7.5 SPECTRAL LINE PRINTOUT

The program outputs the frequency and the spectral density of each of the discrete spectral lines that form the wave spectrum, in the form shown in Figure 7.14. The printout shows the wave number, frequency, random phase number and spectral density, for each spectral line. By taking four times the square root of the sum of the contributions from each of the raster lines, the program provides an exact indication of the significant wave height (S.W.H.) of the defined spectrum.

4 TIMES SQUARE ROOT OF RASTER AREA (S.W.H.) = 3.902

NUMBER	WAVE NUMBER	FREQUENCY	PHASE	ORDINATES
1	9.8792E-03	0.3090	0.0028	1.1475
2	1.0706E-02	0.3225	47.3536	1.6838
3	1.1357E-02	0.3326	272.0179	2.0824
4	1.1924E-02	0.3411	165.1140	2.3971
5	1.2442E-02	0.3486	191.7962	2.6514
6	1.2928E-02	0.3555	78.8253	2.8589
7	1.3394E-02	0.3620	16.9361	3.0284
8	1.3845E-02	0.3681	244.3913	3.1661
9	1.4287E-02	0.3740	244.5467	3.2766
10	1.4724E-02	0.3797	336.4894	3.3637
45	4.8742E-02	0.6914	234.5467	0.7391
46	5.2786E-02	0.7195	26.1669	0.6187
47	5.7912E-02	0.7536	227.3885	0.5011
48	6.4732E-02	0.7967	318.4946	0.3870
49	7.4474E-02	0.8546	98.1756	0.2777
50	9.0196E-02	0.9405	157.1081	0.1746

Figure 7.14 - Wave Spectral Lines

7.6 TIME HISTORY AND FORCE PRINTOUT

At each requested timestep, the full description of the position of the structure and the magnitude of all relevant forces is printed on the output listing. Figure 7.15 shows a typical example.

The example printout is record number 21 of a simulation, i.e. it is a description of the state of affairs at the twenty first timestep of the run and occurs at a time of 100 seconds.

The printout refers to Structure 1, which has three degrees of freedom active, i.e. surge, heave and pitch. When degrees of freedom are deactivated, there is no printout for that freedom unless there are user requested nodes or tensions being printed in which case the X,Y,Z and any other active freedoms are printed.

The value of each variable is stated in the chosen set of consistent units and are with respect to the Fixed Reference Axis System.

```
JOB TITLE-MODIFIED TEST 20 (FLOATING BOX, 40M DRAUGHT)
-----------------------------------------------------------------------------------------------------------------------------------
                                                                   D E G R E E    O F   F R E E D O M
RECORD NO.  STRUCTURE    POSITION, FORCES
             NUMBER      AND MOMENTS AT              X            Y              Z              RX            RY            RZ

TIME (SECS)          CENTRE OF GRAVITY         SURGE         SWAY          HEAVE           ROLL         PITCH          YAW
-----------------------------------------------------------------------------------------------------------------------------------
RECORD NO.   21
100.00      1   POSITION                      0.3857       0.0000       -16.9777          0.0000      -0.3786       0.0000
                VELOCITY                      0.8794       0.0000         2.3170          0.0000       0.1104       0.0000
                ACCELERATION                  0.0000       0.0000         0.0000          0.0000       0.0000       0.0000
                RAO BASED POSITION           -1.5131       0.0000        -6.3577          0.0000      -0.3786       0.0000
                RAO BASED VELOCITY            0.7749       0.0000         2.3170          0.0000       0.1104       0.0000
                WAVE FREQ POSITION            1.5131       0.0000         6.3577          0.0000       0.3786       0.0000
                WAVE FREQ VELOCITY           -0.7749       0.0000        -2.3170          0.0000      -0.1104       0.0000
                WAVE FREQ ACCEL               0.0000       0.0000         0.0000          0.0000       0.0000       0.0000
                SLOW POSITION                 1.8988       0.0000       -10.6200          0.0000       0.0000       0.0000
                SLOW VELOCITY                 0.1045       0.0000         0.0000          0.0000       0.0000       0.0000
                SLOW ACCEL                    0.0000       0.0000         0.0000          0.0000       0.0000       0.0000
                MOORING                     -9.9028E+05  0.0000E+00    4.4670E+05    -4.0000E+00  -6.2262E+06  -8.5938E-02
                LINEAR DAMPING              -3.0504E+07  2.3105E-01   -4.4610E+07     1.6727E-01   2.7668E+07  -6.0535E-05
                DRIFT                        3.6214E+06  5.2877E-02    0.0000E+00     0.0000E+00   0.0000E+00  -1.2570E+01
                GRAVITY                      0.0000E+00  0.0000E+00   -3.2566E+09     0.0000E+00   0.0000E+00   0.0000E+00
                CURRENT DRAG                -3.2215E+04 -2.7797E-09    0.0000E+00     0.0000E+00   0.0000E+00   0.0000E+00
                HYDROSTATIC                  0.0000E+00  0.0000E+00    3.7742E+09    -8.2009E+02   1.6130E+08   0.0000E+00
                WIND                        -1.4415E+01 -1.2438E-12    0.0000E+00     0.0000E+00   0.0000E+00   0.0000E+00
                THRUSTER                     0.0000E+00  0.0000E+00    0.0000E+00     0.0000E+00   0.0000E+00   0.0000E+00
                YAW DRAG                     0.0000E+00  0.0000E+00    0.0000E+00     0.0000E+00   0.0000E+00   0.0000E+00
                WAVE FREQ FORCE              1.2676E+08  1.3466E+01    1.0230E+08    -1.1802E+02   4.1145E+07   1.3792E+00
                ERROR PER TIMESTEP           0.0000E+00  0.0000E+00    0.0000E+00     0.0000E+00   0.0000E+00   0.0000E+00
                TOTAL REACTION FORCE         0.0000E+00  0.0000E+00    0.0000E+00     0.0000E+00   0.0000E+00   0.0000E+00
                TOTAL FORCE                  9.8852E+07  1.3750E+01    5.7575E+08    -9.4194E+02   2.2389E+08  -1.1277E+01

                TENSION LINE      1          1.2745E+06  3.9454E-03    7.6713E+04     TOTAL TENSION  1.2768E+06
                TENSION LINE      2         -5.5078E+03  1.7629E+06    1.1097E+05     TOTAL TENSION  1.7664E+06
                TENSION LINE      3         -2.2537E+06  6.1715E-03    1.4804E+05     TOTAL TENSION  2.2586E+06
                TENSION LINE      4         -5.5078E+03 -1.7629E+06    1.1097E+05     TOTAL TENSION  1.7664E+06
```

Figure 7.15 - Timestep Printout

The following describes each of the variables:

1. POSITION

   Total position of structure centre of gravity in the Fixed Reference Axis

2. VELOCITY

   Total velocity of structure centre of gravity in the Fixed Reference Axis

3. ACCELERATION

   Total acceleration of structure centre of gravity in the Fixed Reference Axis

4. RAO BASED POSITION

   FAST position of structure centre of gravity calculated by summing the real part of the product of complex response amplitude operator and the wave spectrum for each frequency forming the wave spectrum.

5. RAO BASED VELOCITY

   FAST velocity of structure centre of gravity calculated by summing the real part of the product of complex response amplitude operator of velocity and the wave spectrum for each frequency which forms the wave spectrum.

7. WAVE FREQ POSITION

   Rapidly varying part of total position filtered from POSITION

8. WAVE FREQ VELOCITY

   Rapidly varying part of total velocity filtered from VELOCITY

9. WAVE FREQ ACCEL

   Rapidly varying part of total acceleration filtered from ACCELERATION

10. SLOW POSITION

    Slowly varying part of total position filtered from POSITION

11. SLOW VELOCITY

    Slowly varying part of total velocity filtered from VELOCITY

12. SLOW ACCEL

    Slowly varying part of total acceleration filtered from ACCELERATION

14. MOORING

    The total force and moments on the structure due to all the mooring lines, catenaries and hawsers

17. LINEAR DAMPING

    The total linear damping force

19. DRIFT

    The total second order drift force on structure

21. GRAVITY

    The total gravity force on structure

22. CURRENT DRAG

    The total drag force on structure due to relative current

24. HYDROSTATIC

    The total hydrostatic force on structure

25. WIND

    The total drag force on structure due to relative wind

27. THRUSTER

    The total force on structure due to all applied thruster forces

28. YAW DRAG

    The drag on the structure due to its yaw velocity

29. WAVE FREQ FORCE

    The total diffraction and Froude Krylov force on the structure

30. ERROR PER TIMESTEP

The maximum error in the position for the present timestep

31. TOTAL REACTION FORCE

    The total reaction force due to articulations on each structure

50. TOTAL FORCE

    The sum total of all forces applied to the structure

7.7 STATISTICS PRINTOUT

At the end of the simulation timestep printout, those parameters which have been printed at each timestep are then analysed statistically over the whole length of the simulation. The results are tabulated in the form shown in Figure 7.16.

This example shows the statistics for the position of Structure 1. For each of the active degrees of freedom, the following are calculated.

MEAN VALUE		the sum of all the values divided by the number of timesteps
2 x R.M.S		two times the root mean squared value. This is often termed the significant value
MEAN HIGHEST 1/3 PEAKS	+ -	the mean value of the highest third positive and negative peaks. For simulation of a linear system this should be equal to twice the root mean square. A large difference between this value and the significant value is an indication that the variation of the parameter is not following a normal distribution. A large difference between the values for positive and negative peaks is an indication of skewness or asymmetry of variation.
MAXIMUM PEAKS	+	the three maximum peak values
MINIMUM PEAKS	-	the three minimum peak values

The values of each parameter are sorted into small ranges (or bins) covering the total range of variation. For example, in Figure 7.16, the X or surge position is greater than 3.2 and less or equal to 3.8 for 4 percent of the time.

```
                         STRUCTURE    1  POSITION OF COG
                        ------------------------------

 ----------------------------------------------------------------------
                       SURGE(X)          SWAY(Y)          HEAVE(Z)
 ----------------------------------------------------------------------

   MEAN VALUE             1.5484           0.0000          -10.5363

   2  x R.M.S             2.7670           0.0000            9.2783

   MEAN HIGHEST    +      2.9586           0.0000            9.2706
    1/3 PEAKS      -     -2.2109           0.0000           -9.1744

   MAXIMUM PEAKS   +      4.9162           0.0000           -1.1053
                          4.0976           0.0000           -1.4260
                          2.9995           0.0000           -3.4676

   MINIMUM PEAKS   -     -0.9920           0.0000          -20.3015
                         -0.5930           0.0000          -19.1198
                         -0.5785           0.0000          -16.9777

   -----------       ----------------------------------------------------
   PROBABILITY       RANGE   PER CENT  RANGE   PER CENT  RANGE   PER CENT
   DISTRIBUTION      LIMITS   OCCUR    LIMITS   OCCUR    LIMITS   OCCUR
   -----------       ----------------------------------------------------
                         -1.000            0.000          -24.000
                               10.0              0.0                0.0
                         -0.400            0.000          -21.600
                               11.0              3.0                2.0
                          0.200            0.000          -19.200
                               11.0              1.0                7.0
                          0.800            0.000          -16.800
                               14.0              3.0               11.0
                          1.400            0.000          -14.400
                               14.0              2.0               20.0
                          2.000            0.000          -12.000
                               23.0             14.0               16.0
                          2.600            0.000           -9.600
                                5.0             22.0               20.0
                          3.200            0.000           -7.200
                                4.0             33.0               11.0
                          3.800            0.000           -4.800
                                4.0             22.0                7.0
                          4.400            0.000           -2.400
                                4.0              0.0                6.0
                          5.000            0.000            0.000
```

Figure 7.19 - Statistics Summary

CHAPTER 8 - EXAMPLE OF PROGRAM USE

In this chapter, an example problem using AQWA-DRIFT is illustrated. The problem is one in which AQWA-LINE has been used to perform the analysis Stages 1 to 3. All steps in the subsequent analysis procedure are clearly shown, from the problem definition, through the data preparation, to the final analysis run itself. The method used in this chapter can be easily 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 gain confidence in using the program.

8.1 BOX STRUCTURE

8.1.1 General Discussion

Although, in general concept, the response of a structure in irregular waves is quite straightforward, errors are often encountered due to the failure to perform simple preliminary calculations to estimate the order of magnitude of the expected results. It is clearly not desirable or necessary to repeat the complicated calculations performed by AQWA-DRIFT. However, certain preliminary calculations, which are shown in this example, are ESSENTIAL in order to

- Minimise input data errors
- Minimise mis-interpretation of the input data requirements
- Enable the user to predict and isolate areas of interest in the analysis
- Enable intelligent interpretation of the results of the analysis

8.1.2 Problem Definition

The first example is a rectangular box structure for which the analysis has been run using AQWA-LINE for Stages 1 to 3. This is the simplest and most common form of analysis (AQWA-LINE run of Stages 1 to 3 followed by an AQWA-DRIFT run). It is assumed that the user is familiar with the box structure example in AQWA-LINE. Although the example in the AQWA-LINE manual includes post-processing Stages 4 and 5, this does not affect the AQWA-DRIFT run of Stages 4 and 5 in any way.

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^2	
	I_{yy}	=	3.4199E11 kgm^2	
	I_{zz}	=	3.5991E11 kgm^2	

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^3
Wave periods	=	12 to 18 seconds
Wave directions	=	0.0, 45.0 and 90.0 degrees

The box structure is moored by horizontal soft moorings attached to the mid-sides of the box at the water line, as shown in Figure 8.1

Unstretched length of each mooring line	=	100.0 metres
Stretched length of each mooring line	=	101.0 metres
Extension of each mooring line	=	1.0 metres
Stiffness of each mooring line	=	1.4715E6 N/m
Pre-tension in each mooring line	=	1.4715E6 newtons

It is required to obtain the response of the box in irregular waves for a given sea-state, with particular attention being paid to the hawser tensions. In the first instance, only the drift oscillations of the structure will be investigated. After this has been completed, the effect of the wave frequency forces will be investigated. Note that the analysis is performed using SI units.

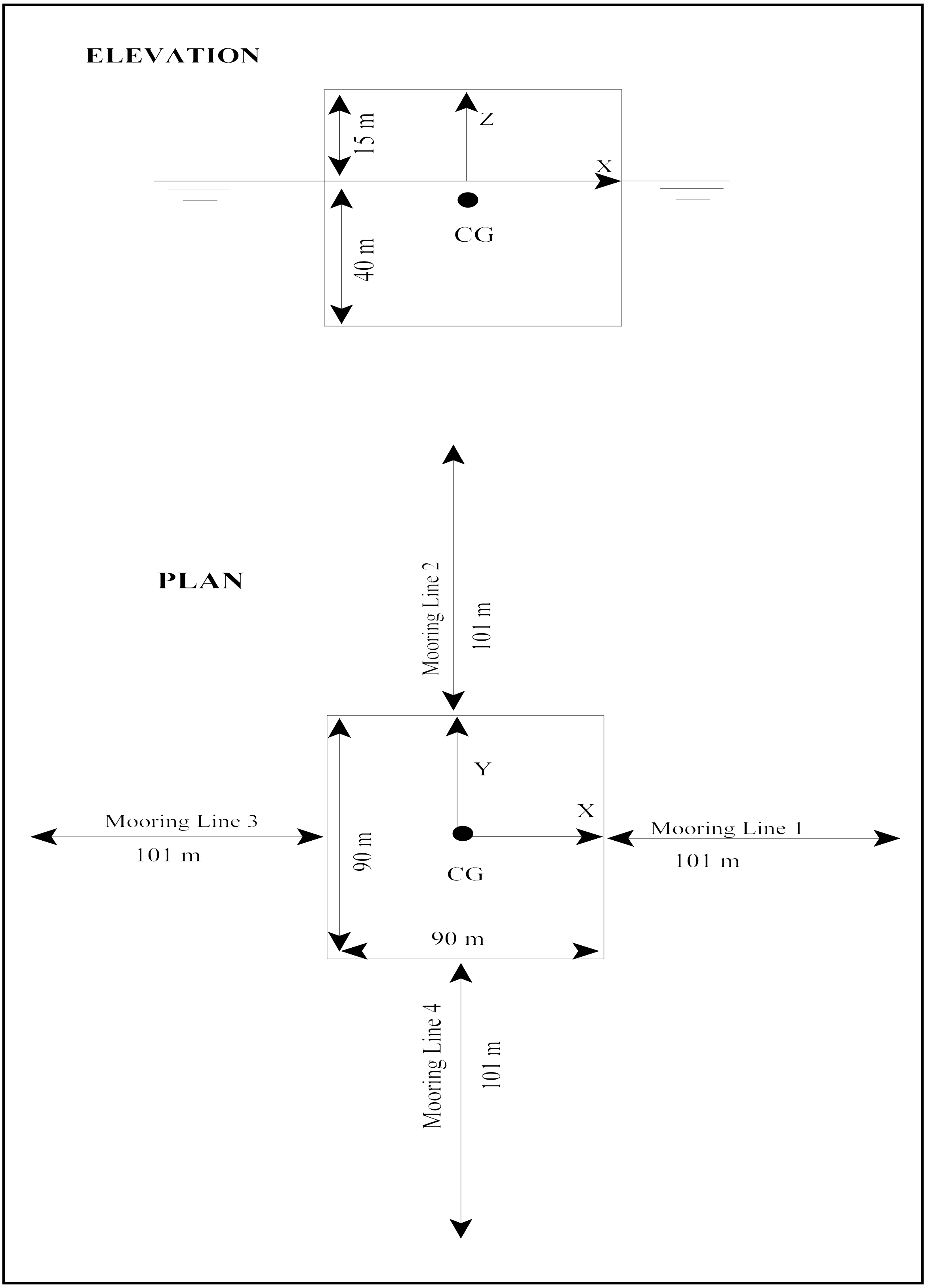

Figure 8.1 - Mooring Lines

8.1.3 Natural Frequencies

It is good practice when using AQWA-DRIFT to perform some short and simple preliminary runs to ensure that the model has been formed correctly before embarking on long simulation runs, where errors in modelling may be more difficult to identify.

The first check is to ensure that the model has the correct natural periods. This is achieved by performing a short run with the structure initially displaced from its still water equilibrium position and allowing it to oscillate at its natural frequency about the equilibrium position. The observed natural periods of the motion can be checked against simple calculations. Since we are restricting the investigation to the structure's drift motion response, only the natural frequencies in the horizontal degrees of freedom (surge, pitch, yaw) need be investigated.

In the horizontal freedoms, AQWA-LINE gives no natural frequencies as the hydrostatic stiffness in these freedoms is zero. With the addition of the four mooring lines in this AQWA-DRIFT analysis, all these freedoms will have stiffness and corresponding natural frequencies.

At a frequency of 0.349 rad/sec (period 18 secs) the surge terms on the leading diagonal of the added mass and stiffness matrices are

Surge added mass inertia = $3.02*10^8$ kg

Surge stiffness = $2.94*10^6$ N/m (2 lines each of $1.47*10^6$)

The natural frequency squared is therefore $2.94*10^8$ /($3.32*10^8$ + $3.02*10^8$) giving a freedom uncoupled natural frequency of 0.0681 rad/sec (natural period 92.2 secs).

At a frequency of 0.349 rad/sec (period 18 secs) the yaw terms on the leading diagonal of the added mass and stiffness matrices are

Yaw added mass inertia = $1.27*10^{11}$ kgm^2

Yaw stiffness = $3.84*10^8$ Nm/rad

The yaw stiffness due to each line is given by

$$K = Td(1+d/L)$$

where

T = tension

d = distance between CG and attachment point

L = line length

Total yaw stiffness = $4 * 1.47*10^6 * 45(1+45/100)$ = $3.84*10^8$ Nm/rad

The natural frequency squared is therefore $3.84*10^8$ /($3.60*10^{11}$ + $1.27*10^{11}$) giving an uncoupled natural frequency of 0.0281 rad/sec (natural period 223.7 secs).

We will see that it is the motions of the structure at these frequencies that will dominate the drift response of the structure.

The added mass at low or drift frequency will not generally be the same as that at the lowest wave frequency, but is sufficiently close for the purpose of the calculations above.

8.1.4 Low Frequency Added Mass and Damping

It may be assumed that, at low frequency, the added mass and damping remain constant, as values of drift added mass for the horizontal freedoms tend towards finite values at low frequency. The values often used are those of the lowest wave frequency input in AQWA-LINE. This is normally a good approximation. The values for the vertical freedoms are also used because no motion at low frequency is expected. However, for damping, empirical values may be input based on either the experience of the user or experimental results. For this example, values of added mass and damping at a frequency of 0.349 rad/sec (period 18 secs) will be used. Note that for the evaluation of undamped natural periods, no drift damping is used. This applies to the initial AQWA-DRIFT run.

8.1.5 Hull and Superstructure Loading Coefficients

Data for the hull and superstructure loading coefficients for wind and current in this example are based on the projected area through the centroid in the three directions specified in Deck 6.

Forces due to the current at 0, 90 degree headings in the X and Y directions respectively (for unit velocity) are

Force = 0.5 ∗ Density ∗ Area ∗ Drag coefficient ∗ cos (heading)

= 0.5 ∗ 1025.0 ∗ 40.0 ∗ 90.0 ∗ 1.6 ∗ cos (0) = 2.95E6 Ns^2/m^2

At 45 degrees, in both the X and Y directions, the forces are

= 0.5 ∗ 1025.0 ∗ 40.0 ∗ 127.0 ∗ 1.3 ∗ cos (45) = 2.40E6 Ns^2/m^2

The corresponding moments at the centre of gravity (10.62 metres below the waterline, centre of area at Z = -20.0) are 2.95E6 $*$ 9.38 and 2.40E6 $*$ 9.38

i.e.

At a heading of 0,	Moment	=	2.77E7 (-ve in Y, zero in the X direction)
At a heading of 45,	Moment	=	2.25E7 (-ve in Y, +ve in the X direction)
At a heading of 90,	Moment	=	2.77E7 (zero in Y, +ve in the X direction)

The units for the moment coefficients are Ns^2 /m.

Similarly, the forces on the superstructure due to the wind at 0, 90 degree headings in the X and Y directions respectively (for unit velocity) are:

Force = $0.5 * 1.22 * 15.0 * 90.0 * 1.6 * \cos(0)$ = 1.32E3 Ns^2/m^2

At 45 degrees, in both the X and Y directions, the forces are:

= $0.5 * 1.22 * 15.0 * 127.0 * 1.3 * \cos(45)$ = 1.07E3 Ns^2/m^2

The corresponding moments at the centre of gravity (10.62 metres below the waterline, centre of area at Z = +7.5) are 1.32E3 $*$ 18.12 and 1.07E3 $*$ 18.12

i.e.

At a heading of 0,	Moment	=	2.39E4 (+ve in Y, zero in the X direction)
At a heading of 45,	Moment	=	1.94E4 (+ve in Y, -ve in the X direction)
At a heading of 90,	Moment	=	2.39E4 (zero in Y, -ve in the X direction)

8.1.6 Sea Spectra, Current and Wind

The following spectrum and its associated directions will be used in the drift and wave frequency analyses:

Spectrum Type	Frequency Range (radians/sec)	Significant Wave Height	Zero Crossing Period
Pierson-Moskowitz	0.3 - 1.0	8.0	11.0

Current and wind will not be applied.

8.1.7 Specification of the Mooring Lines

The mooring lines are simple linear elastic hawsers and therefore require one line of input data for each mooring line. Each line contains stiffness, unstretched length, and the structure numbers and node numbers of the two attachments points. For a line joining a structure to a fixed point, the structure number corresponding to the fixed point should be set to zero. The node numbers and their positions, to which the mooring lines are attached, must be input in the coordinate Deck 1. Each mooring line of unstretched length 100 metres has a stiffness of 1.47E6 newtons per metre. Each mooring line is pre-tensioned to 1.47E6 newtons (i.e. extended by 1 metre) to give the structure a significant yaw stiffness.

8.1.8 Start Position for Analysis

If the starting position is offset from the equilibrium position of the structure, there will be a transient response, which will decay to the steady state under the action of the specified damping. Such an offset is necessary to investigate the natural period of the structure. However, it is best to keep this offset small, in order to minimise the influence of the initial transient on the statistics of the complete run.

The equilibrium position given by AQWA-LIBRIUM for the specified spectrum (NB without current, wind and thruster forces) is:

Surge (X)	Sway (Y)	Heave (Z)	Roll(RX)	Pitch (RY)	Yaw (RZ)
0.7425	0.0000	-10.6200	0.0000	-0.0523	0.0000

Only the positions in the horizontal degrees of freedom need be considered.

8.1.9 Time Integration Parameters

The structure's natural periods of oscillation in surge and yaw have been calculated to be 92 and 224 seconds. A suitable timestep therefore is 5 seconds (minimum period/20). To determine the natural period of oscillation, a simulation of about 4 cycles is sufficient. So, for surge oscillations, 80 timesteps are used. For the complete simulation, 800 timesteps are used.

8.1.10 Input Preparation For Natural Frequency Data Run

The AQWA-LINE run (see AQWA-LINE example), has been performed and the following information is contained on the RESTART backing file produced by AQWA-LINE:

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

The input decks for the AQWA-DRIFT DATA run are shown in Figure 8.2 and are described below.

Note that the DATA option is equivalent to a program RESTART which starts at the beginning of Stage 4 and finishes at the end of Stage 2.

-	JOB	card	provides identifier program, and type of analysis to be used
-	TITLE	card	prescribes a title header for the run
-	OPTIONS	card	containing the selected options:
	REST	-	indicates that a restart run is required
	DATA	-	selects performance of up to Stage 4 only
	END	-	indicates the end of the options list
-	RESTART	card	specifies start and finish stages

- Deck 9

  Low frequency or drift added mass (values input are at the lowest wave frequency)
  Zero damping (default) is used for natural frequency calculation
  The value of yaw rate drag is input

- Deck 10

  Wind and current loading coefficients

- Deck 11

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

- Deck 12

  Since only the horizontal degrees of freedom are being used, the heave, roll and pitch freedoms are de-activated

- Deck 13

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

- Deck 14

  Description of each mooring line property and combination

- Deck 15

  The structure is given a surge displacement of 1 metre from the origin of the FRA (the equilibrium position for this run)

- Deck 16

  The time integration parameters

- Deck 17

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

- Deck 18

  Additional output requests concerning the hawser attachment points information at every tenth timestep (default) is required

```
JOB BOX1  DRIF  DRFT
TITLE                NATURAL FREQUENCY DATA RUN
OPTIONS REST DATA END
RESTART   4  4
    91    DRM1
    91YRDP  503  501  3.2800E4
    91ADDM         1  3.0158E8
    91ADDM         2            3.0158E8
 END91ADDM         6                                                  1.269E11
    10    HLD1
    10CUFX    1    3  2.9500E6  2.4000E6  0.0000E0
    10CUFY    1    3  0.0000E0  2.4000E6  2.9500E6
    10WIFX    1    3  1.3200E3  1.0700E3  0.0000E0
 END10WIFY    1    3  0.0000E0  1.0700E3  1.3200E3
    11    NONE
    12    CONS
    12DACF    1    3
    12DACF    1    4
 END12DACF    1    5
    13    NONE
    14    MOOR
    14LINE    1  501    0  511  1.4715E6     100.0
    14LINE    1  502    0  512  1.4715E6     100.0
    14LINE    1  503    0  513  1.4715E6     100.0
 END14LINE    1  504    0  514  1.4715E6     100.0
    15    STRT
 END15POS1                1.0       0.0    -10.62
    16    TINT
 END16TIME        80       5.0       0.0
    17    NONE
    18    PROP
    18PREV   10
    18NODE    1  501
    18NODE    1  502
    18NODE    1  503
 END18NODE    1  504
```

Figure 8.2 - Data File for Natural Frequency Data Run

8.1.11 Output from Natural Frequency Data Run

The DATA run produces the output shown in Figures 8.3 to 8.12, described below.

Figure 8.3 AQWA-DRIFT Header Page used for Identification

Figure 8.4 Card echo (mandatory) for Decks 9 to 18
This is used to check data input

Figure 8.5 Yaw rate drag and Drift Frequency Added mass and Damping
An echo of the data input in Deck 9

Figure 8.6 Wind/Current Loads and Thruster Forces
A tabulation of the data input in Deck 10

The omission of thruster forces is also brought to the users attention

Figure 8.7 Constraints

The table shows X, Y, RZ freedoms active
Articulations are not yet implemented

Figure 8.8 Cable/Mooring Line Configurations

Tabulation of the mooring lines input in Deck 14 (Note that the cable group number is only applicable to non-linear mooring lines)

Figure 8.9 Initial Conditions of the Centre of Gravity
Tabulation of the initial position and velocity input in Deck 15

Figure 8.10 Time Integration Parameters

Details of the simulation length and timestep

The expected errors for the specified timestep are indicated(Note that the error for the expected response period of 92 seconds is about 0.3 per cent)

Figure 8.11 Position of User-Requested Nodes

Tabulation of the nodes and their positions input in Deck 18. (Note that the positions shown are those in the last analysis position input in Deck 15)

```
 AAAAAA    QQQQQQ   WW       WW   AAAAAA        DDDDDDD    RRRRRR    IIII   FFFFFFFF   TTTTTTTT
AAAAAAAA  QQQQQQQQ  WW       WW  AAAAAAAA       DDDDDDDD  RRRRRRRR   IIII   FFFFFFFF  TTTTTTTTTT
AA    AA  QQ    QQ  WW       WW  AA    AA       DD    DD  RR    RR    II    FF            TT
AA    AA  QQ    QQ  WW       WW  AA    AA       DD    DD  RR    RR    II    FF            TT
AAAAAAAA  QQ    QQ  WW       WW  AAAAAAAA  IIII DD    DD  RRRRRRRR    II    FFFFF         TT
AAAAAAAA  QQ    QQ  WW  WW   WW  AAAAAAAA  IIII DD    DD  RRRRRRRR    II    FFFFF         TT
AA    AA  QQ    QQ  WW  WW   WW  AA    AA       DD    DD  RRRRR       II    FF            TT
AA    AA  QQ QQ QQ  WW  WW   WW  AA    AA       DD    DD  RR RRR      II    FF            TT
AA    AA  QQQQQQQQ  WWWWWWWWWW   AA    AA       DDDDDDDD  RR  RRR    IIII   FF           TTTT
AA    AA   QQQQQQ    WWWWWWWW    AA    AA       DDDDDDD   RR   RRR   IIII   FF           TTTT
               QQ
```

```
THE 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 : NATURAL FREQUENCY DATA RUN
```

Figure 8.3 - AQWA-DRIFT Header Page (used for identification)

```
DECK  9
-------

    91YRDP  503  501  3.28E+04  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
    91ADDM    0    1  3.02E+08  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
    91ADDM    0    2  0.00E+00  3.02E+08  0.00E+00  0.00E+00  0.00E+00  0.00E+00
 END91ADDM    0    6  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  1.27E+11

DECK 10.1
-------

    10CUFX    1     3 2.950E+06 2.400E+06 0.000E+00 0.000E+00 0.000E+00 0.000E+00
    10CUFY    1     3 0.000E+00 2.400E+06 2.950E+06 0.000E+00 0.000E+00 0.000E+00
    10WIFX    1     3 1.320E+03 1.070E+03 0.000E+00 0.000E+00 0.000E+00 0.000E+00
 END10WIFY    1     3 0.000E+00 1.070E+03 1.320E+03 0.000E+00 0.000E+00 0.000E+00

DECK 11
-------

DECK 12
-------

    12DACF    1    3    0    0    0    0    0    0    0
    12DACF    1    4    0    0    0    0    0    0    0
 END12DACF    1    5    0    0    0    0    0    0    0

DECK 13
-------


DECK 14
-------

    14LINE    1  501    0  511 1.472E+06 1.000E+02 0.000E+00 0.000E+00 0.000E+00
    14LINE    1  502    0  512 1.472E+06 1.000E+02 0.000E+00 0.000E+00 0.000E+00
    14LINE    1  503    0  513 1.472E+06 1.000E+02 0.000E+00 0.000E+00 0.000E+00
 END14LINE    1  504    0  514 1.472E+06 1.000E+02 0.000E+00 0.000E+00 0.000E+00

DECK 15
-------

 END15POS1               1.000     0.000   -10.620     0.000     0.000     0.000

DECK 16
-------

 END16TIME    0   80     5.000     0.000     0.000     0.000     0.000     0.000

DECK 17
-------

DECK 18
-------

    18PREV   10    0    0    0
    18NODE    1  501    0    0
    18NODE    1  502    0    0
    18NODE    1  503    0    0
 END18NODE    1  504    0    0
```

Figure 8.4 - Card Echo for Decks 9 to 18

```
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
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

YAW-RATE DRAG CONSTANT. . . . . . . . . . . . . = 32800.000
NEGATIVE X COORDINATE OF VESSEL EXTREMITY . . =   -45.000
POSITIVE X COORDINATE OF VESSEL EXTREMITY . . =    45.000
```

ADDED MASS AT DRIFT FREQUENCY

	X	Y	Z	RX	RY	RZ
X	3.0158E+08	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Y	0.0000E+00	3.0158E+08	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Z	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
RX	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
RY	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
RZ	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.2690E+11

DAMPING AT DRIFT FREQUENCY

	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	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
RX	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
RY	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
RZ	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

Figure 8.5 - Drift Frequency Added Mass and Damping

```
                 W I N D / C U R R E N T   L O A D S   F O R   U N I T   A M P L I T U D E / V E L O C I T Y
                 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
                           A N D   T H R U S T E R   F O R C E S   F O R   S T R U C T U R E   1
                           - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


                                                  NO  THRUSTER  FORCES
                                                  --------------------


FORCES   FREQUENCY   DIRECTION(DEGREES) (SURGE=COS SWAY=SIN HEAVE=COS)
                                        (ROLL=SIN PITCH=COS YAW=SIN)
------   ---------   ---------------------------------------------
DUE TO (RADIANS/SEC)   0.0      45.0      90.0
------ ------------- --------------------------

WIND
----
SURGE(X)
                   1.32E+03  1.07E+03  0.00E+00
SWAY(Y)
                   0.00E+00  1.07E+03  1.32E+03
HEAVE(Z)
                   0.00E+00  0.00E+00  0.00E+00
ROLL(RX)
                   0.00E+00  0.00E+00  0.00E+00
PITCH(RY
                   0.00E+00  0.00E+00  0.00E+00
YAW(RZ)
                   0.00E+00  0.00E+00  0.00E+00

CURRENT
-------
SURGE(X)
                   2.95E+06  2.40E+06  0.00E+00
SWAY(Y)
                   0.00E+00  2.40E+06  2.95E+06
HEAVE(Z)
                   0.00E+00  0.00E+00  0.00E+00
ROLL(RX)
                   0.00E+00  0.00E+00  0.00E+00
PITCH(RY
                   0.00E+00  0.00E+00  0.00E+00
YAW(RZ)
                   0.00E+00  0.00E+00  0.00E+00
```

Figure 8.6 - Wind/Current Loads and Thruster Forces

```
                    C O N S T R A I N T S
                    - - - - - - - - - - -


  STRUCTURE                           ACTIVE FREEDOMS TABLE
  NUMBER      X         Y         Z        RX        RY         RZ
----------------------------------------------------------------


      1       X         X                                      X
```

Figure 8.7 - Constraints

C A B L E / M O O R I N G   L I N E   C O N F I G U R A T I O N S

CABLE ATTACHMENTS(STRUCTURE - 0 - IS GROUND)

COMBINATION NUMBER	CABLE NUMBER	CABLE GROUP	CABLE TYPE	ATTACHED TO STRUCTURE	AT NODE NUMBER	LINKED TO STRUCTURE	AT NODE NUMBER	UNSTRETCHED LENGTH	FORCE OR STIFFNESS
1	1	0	LIN ELASTIC	1	501	0	511	100.000	0.147E+07
	2	0	LIN ELASTIC	1	502	0	512	100.000	0.147E+07
	3	0	LIN ELASTIC	1	503	0	513	100.000	0.147E+07
	4	0	LIN ELASTIC	1	504	0	514	100.000	0.147E+07

Figure 8.8 - Cable/Mooring Line Configurations

```
              I N I T I A L   P O S I T I O N   A N D   V E L O C I T Y   O F   T H E
              - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
                              C E N T E R   O F   G R A V I T Y
                              - - - - - - - - - - - - - - - - -

STRUCTURE  PARAMETER         TRANSLATIONS(FRA)                    ROTATIONS(FRA)                  DIRECTION COSINES

 NUMBER                  X            Y            Z             RX           RY           RZ             X       Y       Z
-----------------------------------------------------------------------------------------------------------------------------


   1   POSITION        1.000        0.000      -10.620         0.000        0.000        0.000        1.0000  0.0000  0.0000

                                                                                                      0.0000  1.0000  0.0000

                                                                                                      0.0000  0.0000  1.0000

   1   VELOCITY        0.000        0.000        0.000         0.000        0.000        0.000

-----------------------------------------------------------------------------------------------------------------------------
```

Figure 8.9 - Initial Position of the Centre of Gravity

```
                 T I M E   I N T E G R A T I O N   P A R A M E T E R S
                 - - - - - - - - - - - - - - - - - - - - - - - - - - -

      INTEGRATION SCHEME= TWO-STAGE PREDICTOR-CORRECTOR WITH THIRD ORDER ERRORS
      -------------------------------------------------------------------------

                        STARTING RECORD NUMBER........     1

                        NUMBER OF TIME STEPS..........    80

                        PRESENT TIME STEP.............   5.000

                        PRESENT TIME..................   0.000

    EXPECTED ERRORS FOR INTEGRATION OF SINUSOIDAL MOTION FOR TIME-STEP OF  5.0000
    -----------------------------------------------------------------------------

                 FREQUENCY    PERIOD   AMPLITUDE ERROR  PHASE ERROR

                 (RAD/SEC)  (SECONDS)    (PER CENT)      (DEGREES)
                 --------------------------------------------------

                   0.0200     314.16         0.0             0.2
                   0.0300     209.44         0.0             0.3
                   0.0500     125.66         0.1             0.9
                   0.0700      89.76         0.3             1.8
                   0.1000      62.83         0.9             3.4
                   0.1500      41.89         3.0             6.6
                   0.2000      31.42        10+             10+
                   0.3000      20.94        10+             10+
                   0.5000      12.57        10+             10+
                   0.7000       8.98        10+             10+
                   1.0000       6.28        10+             10+
                   1.5000       4.19        10+             10+
                   2.0000       3.14        10+             10+
                   5.0000       1.26        10+             10+
```

Figure 8.10 - Time Integration Parameters

P O S I T I O N   O F   U S E R - R E Q U E S T E D   N O D E S

STRUCTURE NUMBER	NODE NUMBER		WITH RESPECT TO THE FIXED REFERENCE AXIS X	Y	Z	RELATIVE TO THE CENTRE OF GRAVITY X	Y	Z
1	501	POSITION	46.000	0.000	0.000	45.000	0.000	10.620
1	502	POSITION	1.000	45.000	0.000	0.000	45.000	10.620
1	503	POSITION	-44.000	0.000	0.000	-45.000	0.000	10.620
1	504	POSITION	1.000	-45.000	0.000	0.000	-45.000	10.620

Figure 8.11 - Position of User-Requested Nodes

8.1.12 Natural Frequency Simulation Run

Once the user is satisfied that the data input in Decks 8 to 18 are correct, the full natural frequency simulation can be performed.

As a program restart is being performed, the user must copy over the RESTART 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 18 previously input.

The only data required to be input is in the Preliminary Deck. This contains merely the information to indicate that a Stage 5 analysis is required as shown below in Figure 8.12

```
JOB BOX2  DRIF
TITLE          NATURAL FREQUENCY SIMULATION RUN
OPTIONS REST END
RESTART   5  5
```

Figure 8.12 - Data File for Natural Frequency Simulation Run

Alternatively, it is possible to modify the data file used for the DATA run, by making the two changes of removing the DATA option and changing the RESTART card to run from Stage 4 to Stage 5.

8.1.13 Output from Natural Frequency Run

The program outputs results to two different sources - the listing file and the graphics file.

The listing file contains a full description of the structure at every tenth timestep, as requested. The position, velocity and acceleration, plus all the relevant forces for a drift motion analysis, are printed for each of the active degrees of freedom. Figure 8.13 shows the output for the first two timesteps only.

It is very difficult to see what the structure is doing by inspection of the listing file. Plotting the results, however, shows very clearly how the structure is behaving. Figure 8.14 shows the plot of the surge oscillations. From this it is easily recognised that the structure is responding in surge at the predicted period of 92 secs.

```
JOB TITLE-TEST RUN NUMBER 20 (FLOATING BOX 40M DRAUGHT AND 48 FACETS)
-----------------------------------------------------------------------------------------------------------------------------
                                                          D E G R E E   O F   F R E E D O M
RECORD NO.  STRUCTURE    POSITION, FORCES
             NUMBER      AND MOMENTS AT              X            Y            Z              RZ
TIME (SECS)             CENTRE OF GRAVITY         SURGE         SWAY        HEAVE            YAW
-----------------------------------------------------------------------------------------------------------------------------
RECORD NO.    1
     0.00      1     POSITION                    1.0000       0.0000     -10.6200         0.0000
                     VELOCITY                    0.0000       0.0000       0.0000         0.0000
                     ACCELERATION                0.0000       0.0000       0.0000         0.0000
                     MOORING                  -2.9723E+06   0.0000E+00   0.0000E+00     0.0000E+00
                     LINEAR DAMPING            0.0000E+00   0.0000E+00   0.0000E+00     0.0000E+00
                     DRIFT                     0.0000E+00   0.0000E+00   0.0000E+00     0.0000E+00
                     GRAVITY                   0.0000E+00   0.0000E+00  -3.2566E+09     0.0000E+00
                     CURRENT DRAG              0.0000E+00   0.0000E+00   0.0000E+00     0.0000E+00
                     HYDROSTATIC               0.0000E+00   0.0000E+00   3.2566E+09     0.0000E+00
                     WIND                      0.0000E+00   0.0000E+00   0.0000E+00     0.0000E+00
                     THRUSTER                  0.0000E+00   0.0000E+00   0.0000E+00     0.0000E+00
                     YAW DRAG                  0.0000E+00   0.0000E+00   0.0000E+00     0.0000E+00
                     ERROR PER TIMESTEP        0.0000E+00   0.0000E+00   0.0000E+00     0.0000E+00
                     TOTAL REACTION FORCE      0.0000E+00   0.0000E+00   0.0000E+00     0.0000E+00
                     TOTAL FORCE              -2.9723E+06   0.0000E+00   5.1200E+02     0.0000E+00
                     POSITION NODE    26       4.6000E+01   0.0000E+00   0.0000E+00
                     POSITION NODE    28       1.0000E+00   4.5000E+01   0.0000E+00
                     POSITION NODE    30      -4.4000E+01   0.0000E+00   0.0000E+00
                     POSITION NODE    32       1.0000E+00  -4.5000E+01   0.0000E+00
```

Figure 8.13 - Output Listing

```
JOB TITLE-TEST RUN NUMBER 20 (FLOATING BOX 40M DRAUGHT AND 48 FACETS)
-------------------------------------------------------------------------------------------------------------------------------
                                                           D E G R E E   O F   F R E E D O M
RECORD NO.  STRUCTURE    POSITION,FORCES
             NUMBER      AND MOMENTS AT               X             Y             Z              RZ
TIME (SECS)             CENTRE OF GRAVITY           SURGE         SWAY        HEAVE            YAW
-------------------------------------------------------------------------------------------------------------------------------
RECORD NO.   11
    50.00      1     POSITION                   -0.9535       0.0000     -10.6200         0.0000
                     VELOCITY                    0.0177       0.0000       0.0000         0.0000
                     ACCELERATION                0.0045       0.0000       0.0000         0.0000
                     MOORING                   2.8340E+06   0.0000E+00   0.0000E+00     0.0000E+00
                     LINEAR DAMPING            0.0000E+00   0.0000E+00   0.0000E+00     0.0000E+00
                     DRIFT                     0.0000E+00   0.0000E+00   0.0000E+00     0.0000E+00
                     GRAVITY                   0.0000E+00   0.0000E+00  -3.2566E+09     0.0000E+00
                     CURRENT DRAG             -9.2690E+02   0.0000E+00   0.0000E+00     0.0000E+00
                     HYDROSTATIC               0.0000E+00   0.0000E+00   3.2566E+09     0.0000E+00
                     WIND                     -4.1475E-01   0.0000E+00   0.0000E+00     0.0000E+00
                     THRUSTER                  0.0000E+00   0.0000E+00   0.0000E+00     0.0000E+00
                     YAW DRAG                  0.0000E+00   0.0000E+00   0.0000E+00     0.0000E+00
                     ERROR PER TIMESTEP        5.0618E-04   0.0000E+00   0.0000E+00     0.0000E+00
                     TOTAL REACTION FORCE      0.0000E+00   0.0000E+00   0.0000E+00     0.0000E+00
                     TOTAL FORCE               2.8331E+06   0.0000E+00   5.1200E+02     0.0000E+00
                     POSITION NODE    26       4.4047E+01   0.0000E+00   0.0000E+00
                     POSITION NODE    28      -9.5349E-01   4.5000E+01   0.0000E+00
                     POSITION NODE    30      -4.5953E+01   0.0000E+00   0.0000E+00
                     POSITION NODE    32      -9.5349E-01  -4.5000E+01   0.0000E+00
```

Figure 8.13 - Output Listing (continued)

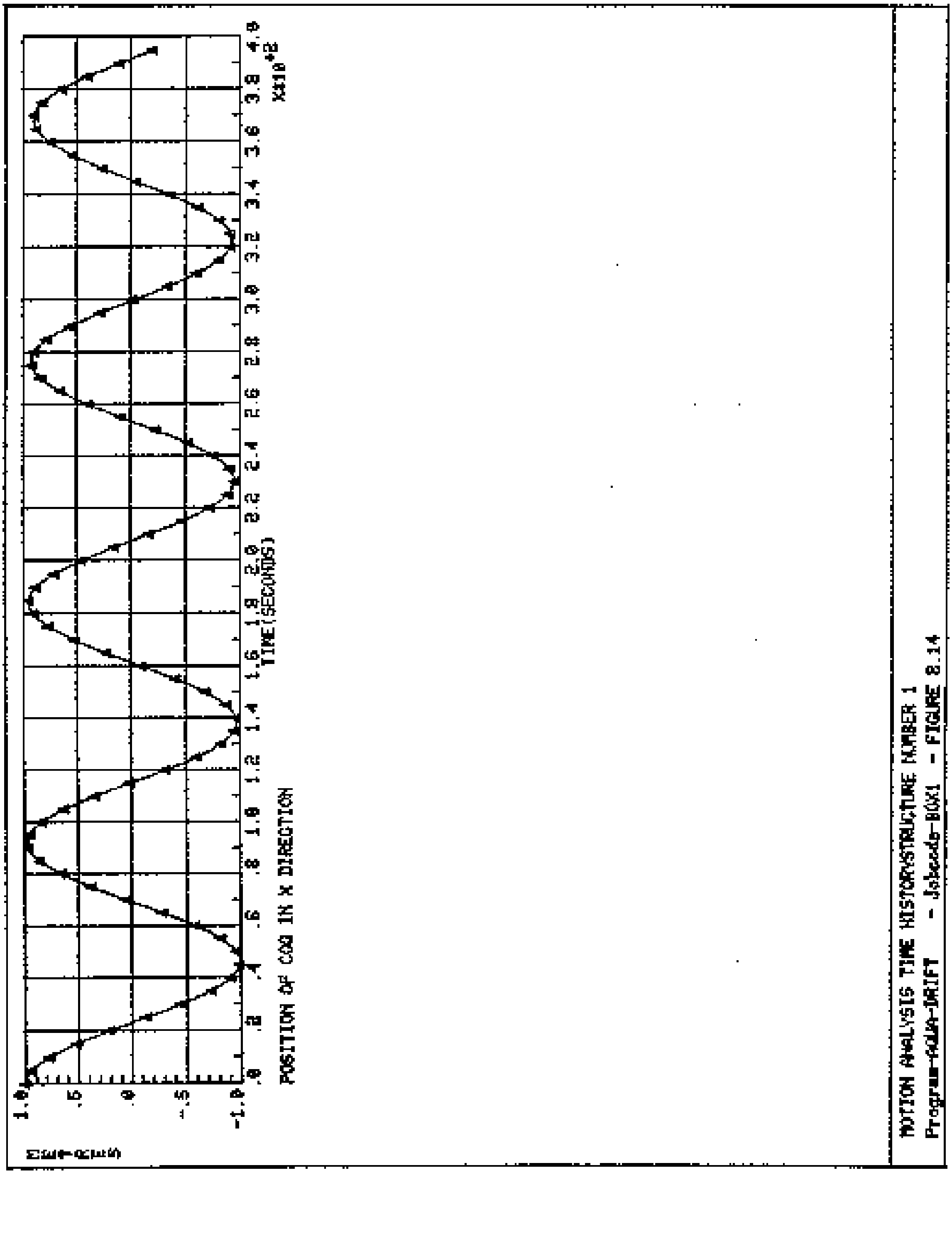

Figure 8.14 - Transient Surge Oscillation

8.1.14 Input Preparation for Drift Motion Data Run

For the full drift motion simulation in the irregular sea, several additions to the data file for the preliminary run are required. These are as follows:

- Deck 9

The drift damping, which was not required for the natural frequency run must be input for each active degree of freedom

- Deck 13

The required spectrum and its direction are input here

- Deck 15

The expected mean position from AQWA-LIBRIUM is about 0.7 metres in surge

- Deck 16

The simulation length is 4000 seconds (800 steps of 5 seconds)

- Deck 18

Output details at every eightieth timestep are requested (to avoid excessive printout)

The hawser tensions are requested as additional output

```
JOB BOX1  DRIF  DRFT
TITLE               DRIFT MOTION DATA RUN
OPTIONS REST DATA END
RESTART   4  4
    91    DRM1
    91YRDP  503  501  3.2800E4
    91ADDM         1  3.0158E8
    91ADDM         2            3.0158E8
    91ADDM         6                                                1.269E11
    91DAMP         1  3.4758E7
    91DAMP         2            3.4758E7
 END91DAMP         6                                                3.0002E9
    10    HLD1
    10CUFX    1    3  2.9500E6  2.4000E6  0.0000E0
    10CUFY    1    3  0.0000E0  2.4000E6  2.9500E6
    10WIFX    1    3  1.3200E3  1.0700E3  0.0000E0
 END10WIFY    1    3  0.0000E0  1.0700E3  1.3200E3
    11    NONE
    12    CONS
    12DACF    1    3
    12DACF    1    4
 END12DACF    1    5
    13    SPEC
    13SPDN                 0.0
 END13PSMZ                 0.3       1.0       8.0      11.0
    14    MOOR
    14LINE    1  501    0  511  1.4715E6     100.0
    14LINE    1  502    0  512  1.4715E6     100.0
    14LINE    1  503    0  513  1.4715E6     100.0
 END14LINE    1  504    0  514  1.4715E6     100.0
    15    STRT
 END15POS1                 0.7       0.0    -10.62
    16    TINT
 END16TIME       800       5.0       0.0
    17    NONE
    18    PROP
    18PREV   80
 END18PTEN    1
```

Figure 8.15 - Data File For Drift Motion Data Run

8.1.15 Drift Motion Simulation Run

When the data run has been completed successfully without error, the full drift motion simulation analysis can be performed.

The data file required to run the simulation is as follows:

```
JOB BOX1  DRIF  DRFT
TITLE               DRIFT MOTION SIMULATION RUN
OPTIONS REST END
RESTART   5  5
```

Figure 8.16 - Data File For Drift Motion Simulation Run

8.1.16 Output from Drift Motion Simulation Run

The results, once again, consist of an output listing file which contains a description of positions and all forces at every twentieth timestep, as requested in Deck 18 of the data file, with statistics calculated at the end of the simulation for all printed parameters. The plotting file is also created from which all time histories can be plotted.

In this example, we are interested in the surge motions of the structure and the resulting tensions in the hawsers.

Figure 8.17 shows the time history of surge motion and Figure 8.18 is an extract from the output listing, which describes the statistics of the structure's position. Figure 8.19 shows the time histories of tension in hawsers 1, 3 and 4.

Figure 8.17 shows that the structure is oscillating about a surge displacement of about 0.7 metres, but there is a high degree of asymmetry in the surge motions. Figure 8.19 shows that, for long periods of time, hawser 1 has no tension i.e. it is slack. It is this slackening of the hawser that produces the asymmetry in the surge motions. Inspection of Figure 8.18, which describes the statistics of the surge motion, shows this asymmetry clearly.

The peak surge displacement of 3.242 metres occurs at about 3825 seconds and the maximum hawser tension in hawsers 3 and 4 occur at the same time.

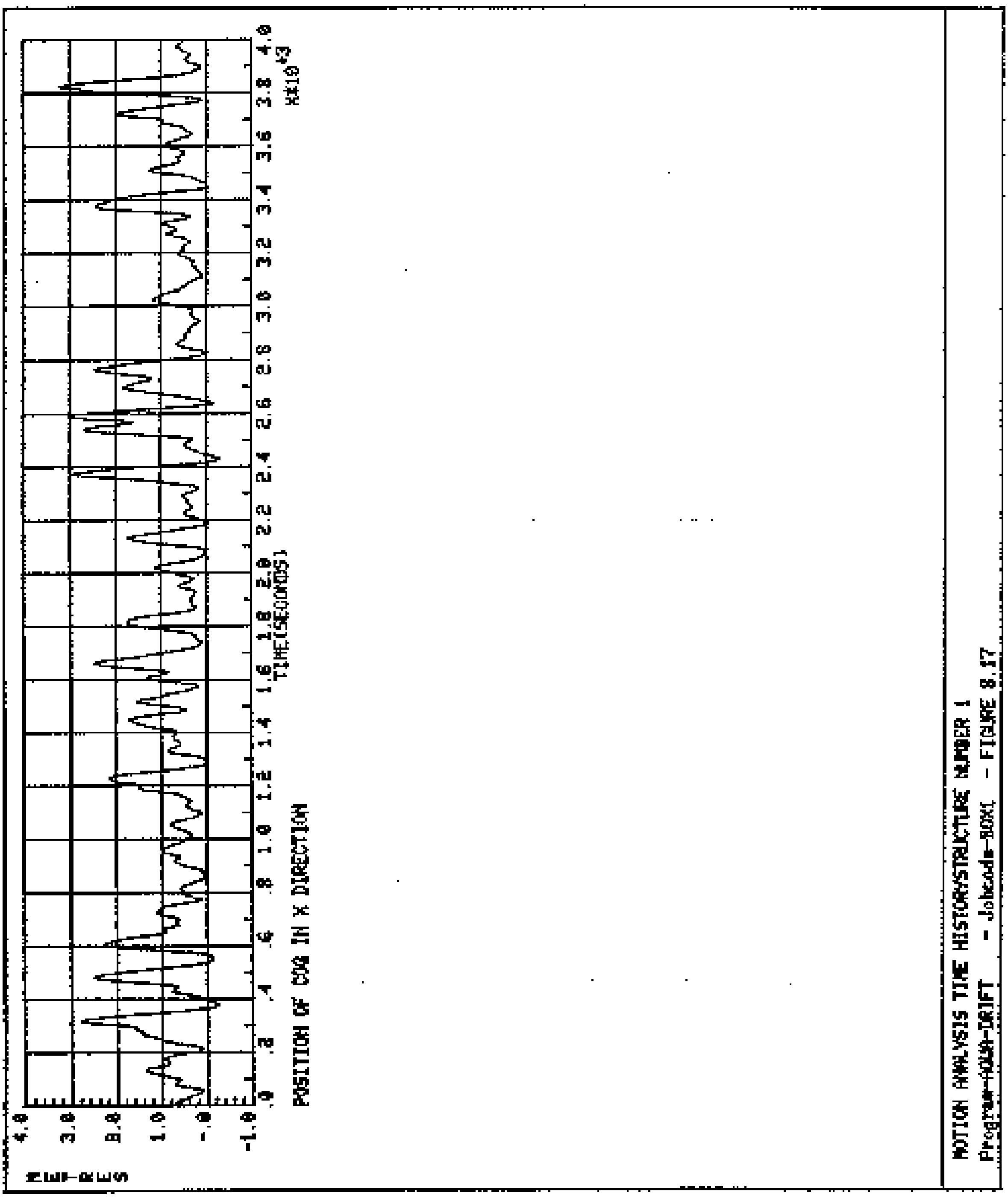

Figure 8.17 - Time History of Surge

```
                              S T A T I S T I C S   R E S U L T S
                               STRUCTURE    1  POSITION OF COG
----------------------------------------------------------------------------------------------------------------------------------
                        SURGE(X)           SWAY(Y)           YAW(RZ)
----------------------------------------------------------------------------------------------------------------------------------
 MEAN VALUE               0.8536             0.0000            0.0000

 2  x R.M.S               1.3874             0.0000            0.0000

 MEAN HIGHEST    +        1.3787             0.0000            0.0000
  1/3 PEAKS      -       -0.8230             0.0000            0.0000

 MAXIMUMUM PEAKS +        3.2419             0.0000            0.0000
                          3.0530             0.0000            0.0000
                          2.9607             0.0000            0.0000

 MINIMUMUM PEAKS -       -0.2635             0.0000            0.0000
                         -0.2353             0.0000            0.0000
                         -0.1340             0.0000            0.0000
 -----------       ---------------------------------------------------------------------------------------------------------------
 PROBABILITY       RANGE   PER CENT  RANGE   PER CENT  RANGE   PER CENT
 DISTIBUTION       LIMITS   OCCUR    LIMITS   OCCUR    LIMITS   OCCUR
 -----------       ---------------------------------------------------------------------------------------------------------------
                   -1.000            0.000             0.000
                             0.0               11.1               1.6
                   -0.500            0.000             0.000
                             3.0               23.4               4.5
                    0.000            0.000             0.000
                            35.1               14.5              13.4
                    0.500            0.000             0.000
                            31.3               11.5              19.0
                    1.000            0.000             0.000
                            12.4               16.0              20.0
                    1.500            0.000             0.000
                             8.9               11.6              19.6
                    2.000            0.000             0.000
                             6.3                5.6              12.1
                    2.500            0.000             0.000
                             2.5                4.0               7.5
                    3.000            0.000             0.000
                             0.6                2.3               1.5
                    3.500            0.000             0.000
                             0.0                0.0               0.8
                    4.000            0.000             0.000
```

Figure 8.18 - Statistics of Structure Position

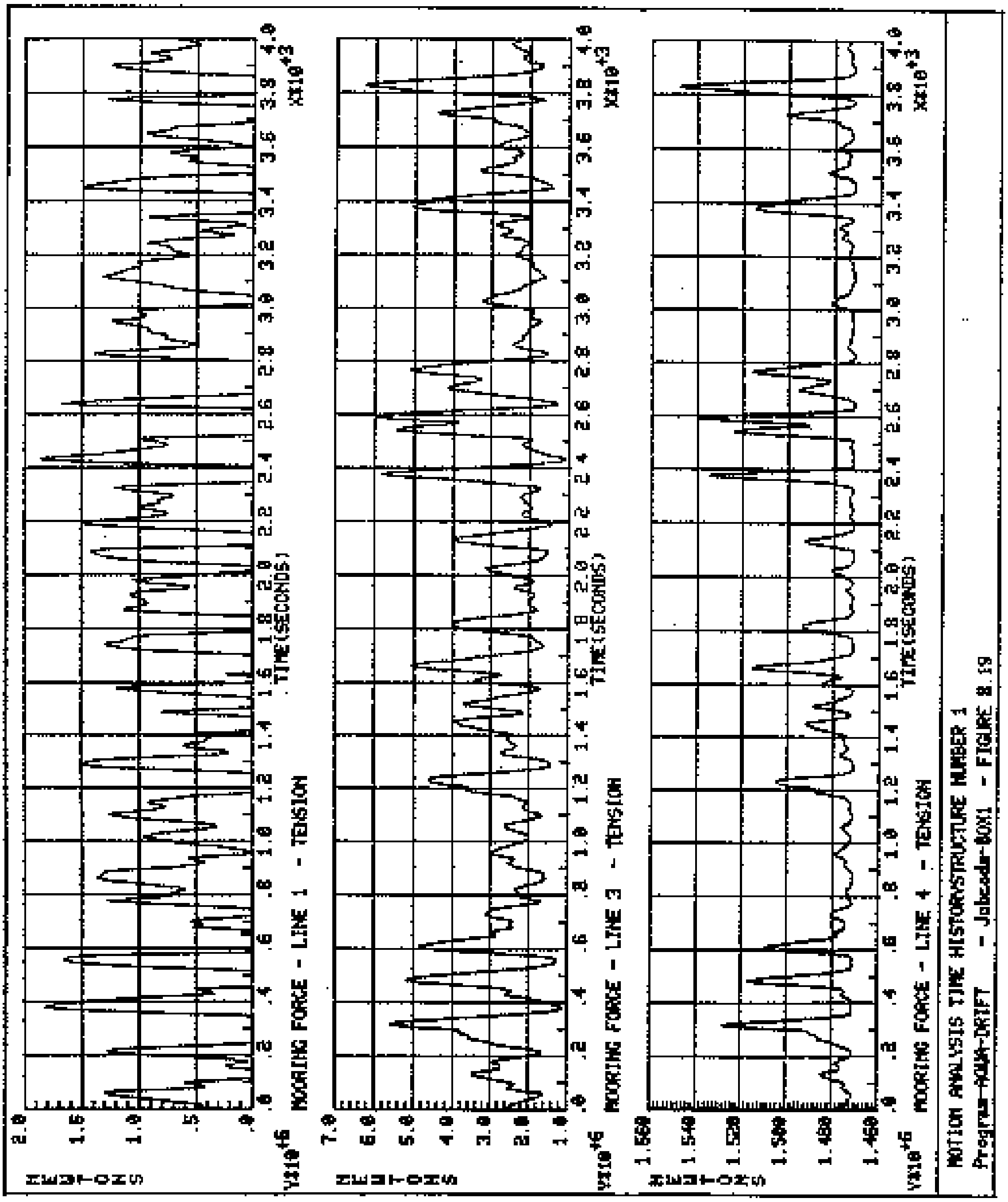

Figure 8.19 - Time History of Tension in Hawsers 1, 3 And 4

8.1.17 Input for Drift/Wave Frequency Simulation Run

Now that the user has an indication of the drift motions of the structure, the effect of adding in wave frequency forces can be investigated. Since this requires a much shorter timestep, it is usual to perform a simulation which includes wave frequency forces only over a short segment of the drift time history. In this example, the wave frequency simulation will start at 3800 secs and end at 3900 seconds; a range which spans the instant of maximum surge displacement in the drift time history. Inspection of the output listing from the drift run yields the slow position and velocity at time 3800 seconds as shown below:

```
                                            X             Y             RZ
                                          SURGE          SWAY           YAW
RECORD NO.  761
  3800.00        POSITION                1.8988        0.0000        0.0000
                 VELOCITY                0.1045        0.0000        0.0000
                 ACCELERATION           -0.0088        0.0000        0.0000
```

Figure 8.20 shows the data file for the drift/wave frequency simulation. Several changes to the data deck used for the drift analysis need to be made for the wave frequency simulation. These are as follows:

- JOB CARD

  The analysis type for a run in which wave frequency forces is added must be indicated by WFRQ

- Deck 9

  Since the simulation will have all six degrees of freedom active, the full mass and damping matrices must be input

- Deck 12

  Since the simulation will have all six degrees of freedom active, no freedoms are de-activated

- Deck 15

  The slow position and velocity obtained from the drift run are input

- Deck 16

  The timestep is set to 1.0 second (typical for wave frequency response)

  The total number of timesteps is 100, as explained above

  The simulation starts at time 3800 seconds (this is when the slow position and velocity in Deck 15 occurred and ensures that the structure is subjected to the same force time history as before)

- Deck 18

  Hawser tensions are the only additional information required Information is printed every tenth timestep

```
JOB BOX1  DRIF  WFRQ
TITLE               DRIFT/WAVE FREQUENCY SIMULATION RUN
OPTIONS REST END
RESTART   4  5
    91    DRM1
    91YRDP  503  501  3.2800E4
    91ADDM         1  3.0158E8  0.0000E0  0.0000E0  0.0000E0 -1.1166E9  0.0000E0
    91ADDM         2  0.0000E0  3.0158E8  0.0000E0  1.1166E9  0.0000E0  0.0000E0
    91ADDM         3  0.0000E0  0.0000E0  2.3050E8  0.0000E0  0.0000E0  0.0000E0
    91ADDM         4  0.0000E0  1.1166E9  0.0000E0  8.918E10  0.0000E0  0.0000E0
    91ADDM         5 -1.1166E9  0.0000E0  0.0000E0  0.0000E0  8.918E10  0.0000E0
    91ADDM         6  0.0000E0  0.0000E0  0.0000E0  0.0000E0  0.0000E0  1.269E11
    91DAMP         1  3.4758E7  0.0000E0  0.0000E0  0.0000E0 -3.1498E7  0.0000E0
    91DAMP         2  0.0000E0  3.4758E7  0.0000E0  3.1498E7  0.0000E0  0.0000E0
    91DAMP         3  0.0000E0  0.0000E0  1.9253E7  0.0000E0  0.0000E0  0.0000E0
    91DAMP         4  0.0000E0  3.1498E7  0.0000E0  3.0156E9  0.0000E0  0.0000E0
    91DAMP         5 -3.1498E7  0.0000E0  0.0000E0  0.0000E0  3.0156E9  0.0000E0
 END91DAMP         6  0.0000E0  0.0000E0  0.0000E0  0.0000E0  0.0000E0  3.0002E9
    10    HLD1
    10CUFX    1    3  2.9500E6  2.4000E6  0.0000E0
    10CUFY    1    3  0.0000E0  2.4000E6  2.9500E6
    10WIFX    1    3  1.3200E3  1.0700E3  0.0000E0
 END10WIFY    1    3  0.0000E0  1.0700E3  1.3200E3
    11    NONE
    12    NONE
    13    SPEC
    13SPDN                 0.0
 END13PSMZ                 0.3       1.0       8.0      11.0
    14    MOOR
    14LINE    1  501    0  511  1.4715E6     100.0
    14LINE    1  502    0  512  1.4715E6     100.0
    14LINE    1  503    0  513  1.4715E6     100.0
 END14LINE    1  504    0  514  1.4715E6     100.0
    15    STRT
    15SLP1              1.8988    0.0000    -10.62
 END15SLV1              0.1045    0.0000
    16    TINT
 END16TIME       100       1.0    3800.0
    17    NONE
    18    PROP
    18PREV   10
 END18PTEN    1
```

Figure 8.20 - Data File for Drift/Wave Frequency Simulation Run

8.1.18 Output from Drift/Wave Frequency Simulation Run

Figure 8.21 shows the resulting time history of surge motion. The slow and fast components of this total motion are shown also. From these plots, it is clear that the wave frequency motion is of comparable magnitude to the drift motion in this case, increasing the maximum surge displacement from 3.24m to about 4.8m in the short interval simulated. The increase in line tensions due to the addition of wave frequency forces on the line tensions is shown in Figure 8.22.

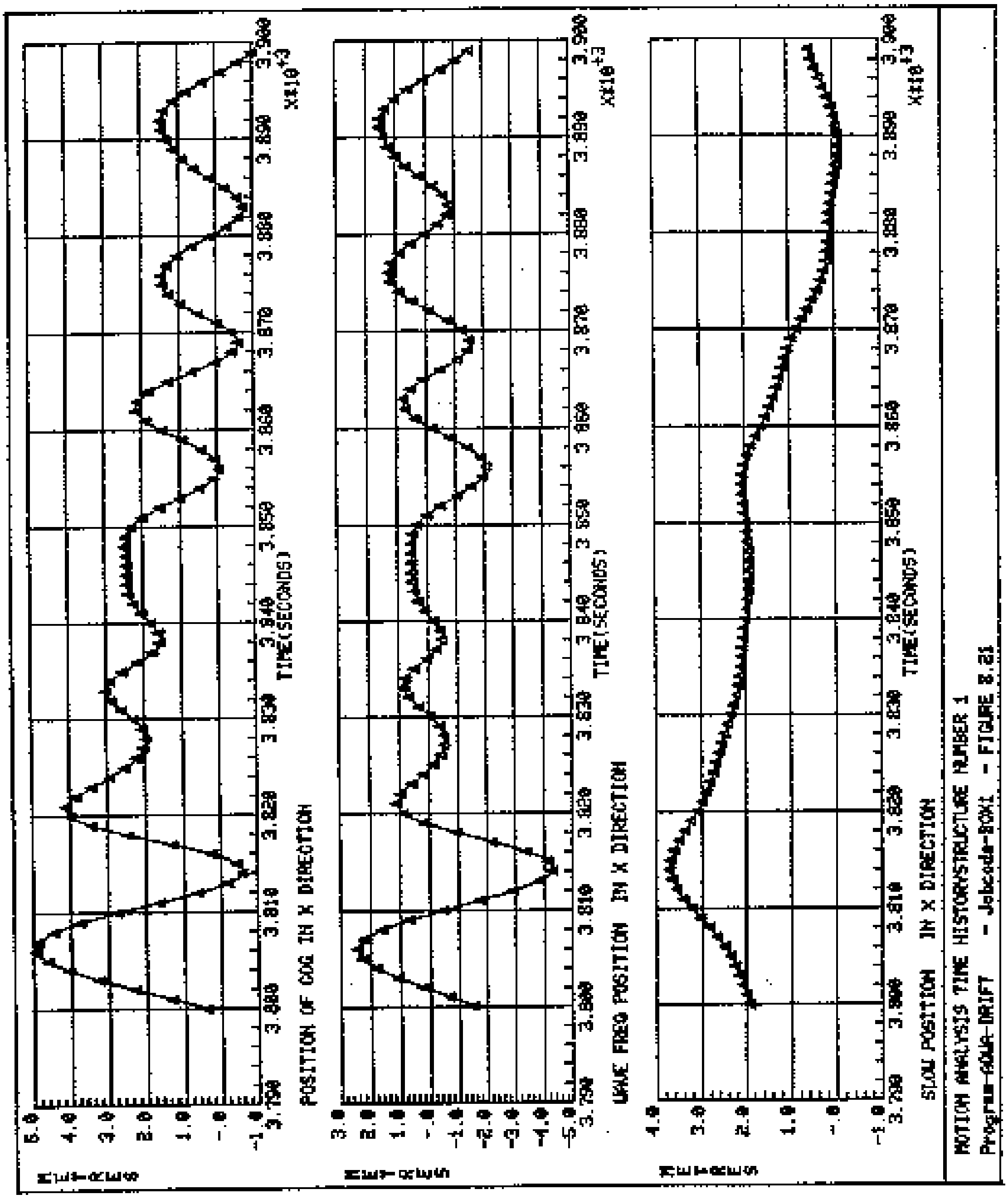

Figure 8.21 -Time Histories of Total Surge Motion and Fast and Slow Components

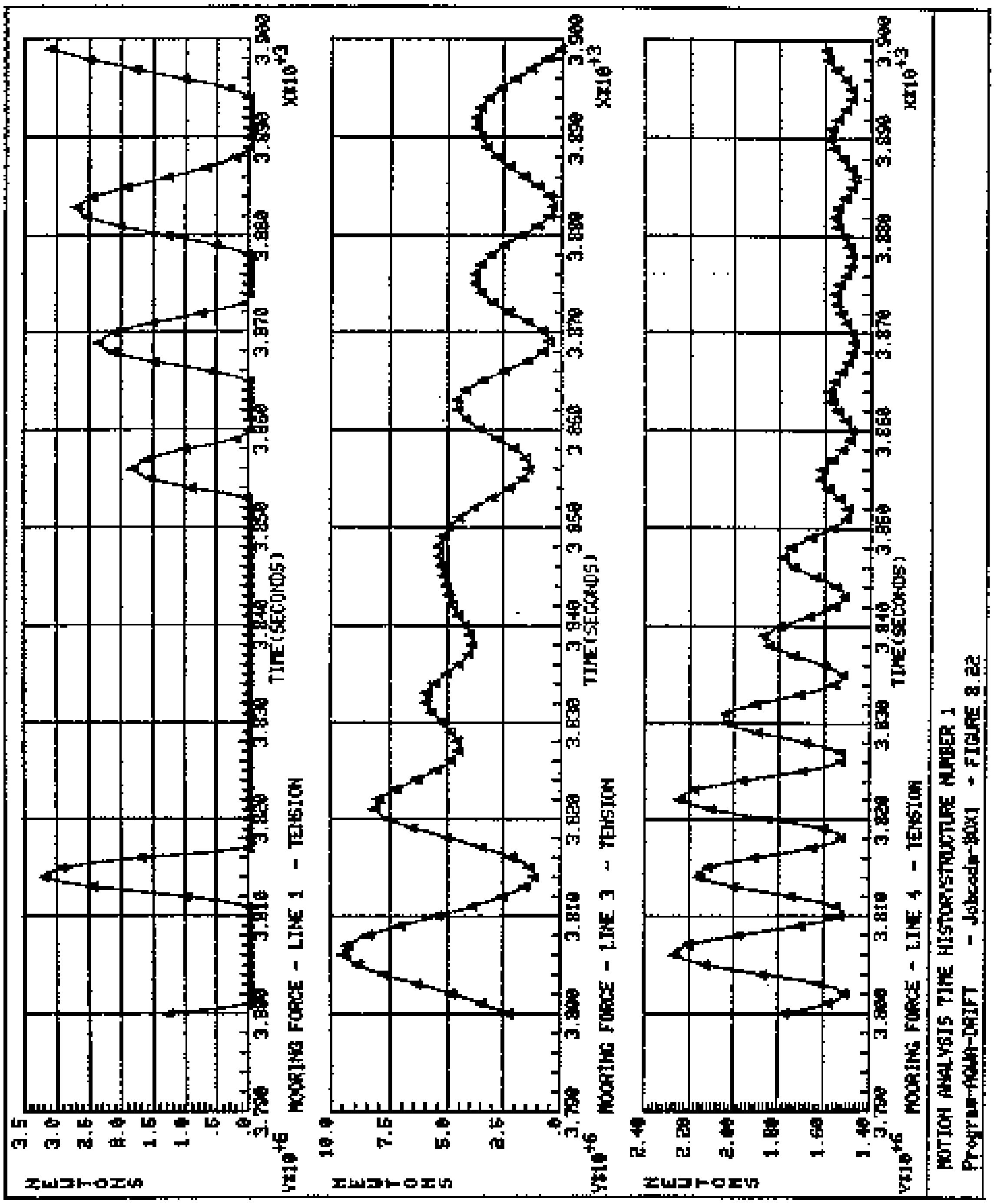

Figure 8.22 - Time History of Tension in Hawsers 1, 3 and 4

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 machine:

- PC (MS-DOS) -

9.1 Running AQWA-DRIFT on the PC

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

- MS-DOS PC -

9.1.1 File Naming Convention for AQWA Files

The user must adopt the following convention of naming the files to be used by the AQWA programs.

Every file name consists of three parts:

- the file prefix — a two character lower case string used to identify a particular AQWA program. The file prefixes are as follows:

Program	Prefix
AQWA-**L**INE	a**l**
AQWA-LI**B**RIUM	a**b**
AQWA-**F**ER	a**f**
AQWA-**D**RIFT	a**d**
AQWA-**N**AUT	a**n**
AQWA-**P**LANE	a**p**
AQWA-**W**AVE	a**w**

- the run identifer — a short name (up to six characters) to identify a particular run. It is suggested that lower case names be used. All the filenames associated with the run will contain the same run identifier in their names.

- the file extension — a three character lower case string to identify the type of the AQWA file (restart file, hydrodynamics file, etc.). The file extension is separated from the rest of the filename by a '.' character.

Example

The filename 'alvlcc.dat' consists of:

the prefix	al	(short for AQWA-LINE)
the run identifer	vlcc	(e.g. name of vessel)
the extension	**.**dat	(input data file)

9.1.2 AQWA File Organisation

Every run of an AQWA program involves the use of a number of specially named input, output and backing files. The following files are used by AQWA-DRIFT:

(**.res**) file - **restart** file - backing file

The restart file is used to store all information relating to the structures being analysed. This information can easily be retrieved on the next run of the analysis sequence, so the input data for the next run can be considerably simplified. This file is an unformatted binary file.

(**.hyd**) file - **hydrodynamics database** file - backing file

This file is used by AQWA-DRIFT and contains a subset of the restart file. It is read only if the ALDB option is used.

(**.pos**) file - **positions** file - backing file

This file contains the structure positions, for each timestep. It is used by AQWA-PLANE to plot trajectories.

(**.plt**) file - **graphics** file - backing file

This file is created and contains positions, velocities, accelerations and all force acting on the structure at every timestep of the simulation. It is used by AQWA-PLANE to produce time history plots.

(**.dat**) file - **input data** file

The input data file contains all the AQWA format data decks needed for the current stage of analysis (Information from previous stages of analysis may be supplied from the restart file.) The input data file is the only readable input file used in the AQWA suite. It is a normal ASCII text file.

(**.lis**) file - **output data** file - listing file

The output data file receives the main results from a program run. It is a normal ASCII text file. Note that this file contains Fortran carriage control characters - a '1' character in the first column to designate the top of a new page. This file can be printed on a LaserJet III with the APRINT command utility. See the PC User Guide for more information on printer control.

9.1.3 Program Size Requirements

The AQWA programs require an absolute minimum of 4Mb of RAM memory. However, 8Mb (or more) is recommended.

9.1.4 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\UTILS programs can be run from any directory provided the C:\AQWA is included in the PATH statement.

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

AQWA55A DRIFT RUNID

Note: There should be spaces between **AQWA**, the program name (ie **DRIFT**), 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-DRIFT, 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 BOXM

COPY ALBOXM.RES ADBOXM.RES

AQWA55A DRIFT BOXM

APPENDIX A - AQWA-DRIFT PROGRAM OPTIONS

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

LIST OF OPTIONS FOR USE IN AQWA-DRIFT

ALDB - READ AQWA-LINE DATABASE

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.

CONV - CONVOLUTION

Instructs AQWA DRIFT or NAUT to use convolution method in radiation force calculation. This is a more rigorous approach to the radiation force calculation in time domain and will enhance the capability of handling non-linear response of structures.

Requests calculation of the full QTF matrix. From version 5.3j onward this option is needed to obtain this.

CRNM - CALCULATE RAOs WITH NO MOORINGS

This option may be used with AQWA-LINE but is more useful with the program AQWA-FER. This option investigates 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

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 minium 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.

FQTF - USE FULL QTF MATRIX

This option specifies that the full matrix of difference frequency QTFs is to be used when calculating slowly varying drift forces.

LAAR - LOCAL ARTICULATION AXIS SYSTEM FOR ARTICULATION REACTION FORCE OUTPUT (LAA)

This option is used to output articulation reaction force in the local articulation axis system. This means that the moments in unconstrained freedoms, e.g. the hinge axis, will always be zero within roundoff.

LSAR - LOCAL STRUCTURAL AXIS SYSTEM (LSA) FOR ARTICULATION REACTION FORCE OUTPUT

This option is used to output articulation reaction force in the local structural axis system. This means that the direction of the output reaction force will follow the structure.

MCNV - CALCULATE C.I.F. USING ADDED MASS AND DAMPING

From version 5.3K onward the default method for calculation of the Convolution Integral Function uses the radiation damping only. This option forces the program to use the previous method based on both added mass **AND** damping.

MRAO - CALCULATE MOTIONS USING RAO's ONLY

This option instructs AQWA DRIFT to calculate motions using RAOs only. These may be defined by the user in Deck 7. Note that this option suppresses all motion except that defined by the RAOs. In particular current, wind, drift forces, moorings etc. have no effect on the motions of the structure.

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

This option switches off printing of the banner page in the *.LIS file.

NOCP - NO CURRENT PHASE SHIFT

This option switches off the wave phase shift due to a current speed. This is only applicable to versions 5.0C and onwards.

NODL - NO DATA LIST

This option switches off all extended data output in the *.LIS file.

NOST - NO STATISTICS

This option stops the automatic calculation of statistics at the end of each simulation run. Statistical processing can be lengthy for long simulations. This option can be used to reduce processing time if statistics are not required.

NOWD - NO AUTOMATIC WAVE DRIFT DAMPING CALCULATION

This option stops the automatic calculation of wave drift damping for a floating structure in AQWA DRIFT. When this option is used, the wave drift damping should be defined in deck 9. Otherwise the program will do the calculation. Please note that the wave drift damping calculated by the program is only for the floating structure defined in AQWA LINE, damping from risers, etc is not included. The NYWD option stops calculation of wave drift damping for yaw motion only.

NYWD - NO YAW WAVE DRIFT DAMPING

This option suppresses the calculation of wave drift for yaw motion. To prevent the calculation of ALL wave drift damping use the NOWD option.

RDDB - READ DATABASE

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 RDDB 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 of the AQWA program manual). 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 Chapter 2).

SDRG - USE SLOW VELOCITY FOR HULL DRAG CALCULATION

This option is used if users wish to use the slow velocity (drift frequency velocity) for the hull drag calculation, instead of the total velocity (drift frequency velocity + wave frequency velocity) which is the default since version 5.0C.

TRAN - TRANSIENT ANALYSIS

This option switches off the slow axis system and stops printout of harmonic analysis at the end of a simulation run. This option should not in general be used. It is only provided as a workaround for DRIFT analysis for both drift and wave frequency motions if it diverges in the time integration.

TRAO - TRANSIENT RAO MOTION

When this option is used AQWA-DRIFT will recalculate the forces based on the RAOs, which can be input by the user in Deck 7. This allows RAOs obtained from (e.g.) Tank tests to be used with the CONV option in transient analyses. If the RAOs are not modified this option has little effect.

PBIS - PRINT FORCE COMPONENTS AT EACH ITERATION STEP

Prints out positions and forces on each structure at each timestep. The scope of the printout can be controlled by selections in Deck 18.

PPEL - PRINT PROPERTIES OF EACH ELEMENT

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

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

APPENDIX B - REFERENCES

1. A Simulation Model For the Dynamic Behaviour of Tankers Moored to Single Point Moorings - B. Molin, G. Bureau, Int. Symposium of Ocean Engineering, (1980)

2. The Influence of Slowly Varying Wave Forces on Mooring Systems - A.E. Loken and O.A. Olsen, OTC 3626 (1979)

3. Second Order Slowly Varying Forces on Vessels in Irregular Waves - J.N. Newman, Int. Symp. on the Dynamics of Marine Vehicles and Structures in Waves, University College London, (1974).

4. Prediction of Wind and Current Forces on VLCCs - Oil Companies International Marine Forum.

5. Experience in Analysis of SPM Systems - R.C.T. Rainey, D.G.F. Cash and S.G. Withee - OTC 4346 (1982).

6. A Validation of Speed and Frequency Dependence in Seakeeping, Bailey, P.A., Hudson, D.A., Price, W.G. and Temarel, P - Proc. Intl. Shipbuilding Conf. St Petersburg, 1998.

7. The Fifth Annual Fairey Lecture: on the Linear Representation of Fluid Forces and Movements in Unsteady Flow, Bishop, RED, Burcher, R.K., and Price, W.G, Journal of Sound and Vibration, 29 (1): 113-128, 1973