AQWA™-FER MANUAL

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CHAPTER 1 - INTRODUCTION

1.1 PROGRAM INTRODUCTION

The determination of the motions of moored floating structures in response to environmental forces (i.e. wind, waves and current) and structure control mechanisms (e.g. bow thrusters) is a complex procedure. It can be achieved using a time domain simulation program (e.g. AQWA-DRIFT) which takes into account system non-linearities, such as mooring line non-linearities, and position dependent environmental loads, as well as any motion control mechanisms. However, time-domain programs are expensive to run, and the large number of possible combinations of environmental conditions (e.g. wind/current strength and direction, type of wave spectrum and wave direction) make a systematic parametric study prohibitively expensive.

The requirement is therefore a simple and inexpensive program that can indicate the structure's response in a number of different environmental states for a number of different mooring configurations. AQWA-FER (Atkins Quantitative Wave Analysis for Frequency-domain Evaluation of Response) is a program which fulfils this requirement.

1.2 MANUAL INTRODUCTION

The AQWA-FER 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-FER. When using AQWA-FER, the user must model the structure and its environment. The method of data preparation and modelling is fully described and reference is made to the AQWA Reference Manual. The Reference Manual contains a complete guide to the format used for input of data into the AQWA Suite. It is necessary that the AQWA-FER User Manual and AQWA Reference Manual be available when running the program AQWA-FER.

CHAPTER 2 - PROGRAM DESCRIPTION

2.1 PROGRAM CAPABILITY

AQWA-FER is a post-processor within the AQWA suite which can also be used as a stand-alone program if the input data is available from other sources. AQWA-FER uses spectral techniques and evaluates the significant response of up to five floating structures coupled by mooring lines in irregular seas.

Since AQWA-FER is a frequency domain program, it does not include system non-linearities in its analysis. However, the program can include both first order (wave frequency) forces and second order (drift frequency) forces. On selection of appropriate analysis options at run time, (see Section 4.0 of the AQWA Reference Manual) the significant motions of any point on any structure may be calculated along with the significant differential motion between any two points within the floating system. The calculation of significant differential motion automatically allows the calculation of the significant tensions in any mooring line be it between two floating structures or between a floating structure and a fixed point.

AQWA-FER may also be used for the much simpler task of calculating the Response Amplitude Operators of a moored or free-floating structure, providing the hydrodynamic data from AQWA-LINE or another linear radiation/ diffraction computer program is available.

Program limitations of AQWA-FER for the analysis of a floating system are as follows:

(a) Significant response of the centre of gravity for each structure up to a maximum of 5 structures.

(b) Significant response of specified positions on any structure or differential motion between any two positions within the floating system, up to a maximum of 35 positions or pairs of positions.

(c) Significant tensions in mooring lines up to a total of 100 mooring lines in 25 different combinations.

2.2 THE COMPUTER PROGRAM

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

- Ease of communication between AQWA programs, so that different types of analyses can be done with the same model of the body or bodies, e.g. AQWA-LINE regular wave results can be input to AQWA-FER for irregular spectral wave analysis.

- Efficiency when using any of the AQWA programs. The Restart facility allows the user to progress gradually through the solution of the problem and an error made at one stage of the analysis does not necessarily mean that all the subsequent work has been wasted.

The programs within the AQWA SUITE are as follows:

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

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

CHAPTER 3 - THEORETICAL FORMULATION

Although it is beyond the scope of this manual to present the full theoretical formulation of the frequency domain solution of floating structures, all theory related to the calculations within AQWA-FER is presented. This may produce duplication where the calculations are performed by other programs in the suite. Other theoretical considerations, indirectly related, are included to preserve subject integrity. These are indicated accordingly.

Where calculations of forces and coefficients for input parameters are calculated only by other programs in the AQWA suite, the theory 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). Users without the other programs in the AQWA suite must consult the literature of the source used to obtain these parameters.

3.1 HYDROSTATIC LOADING

The hydrostatic loading may be found by integrating the still water hydrostatic pressure over the wetted surface area of the structure. The theory may be found in the AQWA-LINE and AQWA-LIBRIUM manuals, the calculations being performed in the corresponding programs (see also Section 4.5 on linear stiffness).

3.2 MORISON FORCES AND WAVE LOADING

Morison forces, which are applicable to small non-diffracting structures or parts of structures, are not included in AQWA-FER. In other words, TUBE elements are not available in AQWA-FER.

3.3 DIFFRACTION/RADIATION WAVE FORCES ON FIXED BODY

The diffraction/radiation wave forces in the AQWA suite are based on the classical Green's function technique and details of the theory may be found in Section 3.3 of the AQWA-LINE manual.

3.4 MEAN WAVE DRIFT FORCES

The mean wave drift forces, which are calculated by AQWA-LINE, are used in the form of steady drift coefficients to calculate drift forces (see AQWA-LINE User 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, then the total wave drift force acting on the body is characterised by a mean component and a slowly TIME VARYING wave drift force. The details of these slowly varying drift forces are contained within the AQWA-DRIFT User Manual (Section 3.5).

3.6 INTERACTIVE FLUID LOADING

Fluid interactive loading between bodies is usually referred to in the context of Radiation/Diffraction Theory (Section 3.3). We are concerned with the influence of one body's flow field on another's. Obviously, the importance of interaction will depend on both body separation distances and the relative sizes of the bodies. At present, fluid interaction between bodies is not available within the AQWA suite.

3.7 STRUCTURAL ARTICULATIONS AND CONSTRAINTS

This facility is now available in AQWA-FER (see AQWA Reference Manual, Section 4.12).

3.8 WIND AND CURRENT LOADING

Although a steady force of wind or current in linear equations of motion have no effect on the frequency domain solution, any non-linear stiffness (e.g. catenaries) will change with the equilibrium position calculated by AQWA-LIBRIUM. This in turn will effect the frequency domain solution of motions and mooring tension. (For more details see AQWA-LIBRIUM manual). The additional effect of wind and current stiffness per se (i.e. rate of change of wind/current force with yaw) is also calculated by AQWA-FER.

3.9 THRUSTER FORCES

Thruster forces only effect the frequency domain solution through a change in non-linear stiffness (if present) due to change in the equilibrium position, which is calculated by AQWA-LIBRIUM (see AQWA-LIBRIUM manual).

3.10 MOORING LINES

The effect of mooring lines is to contribute to the external forces and stiffness matrix of a structure. This in turn will effect the static equilibrium position and its stability in this position (AQWA-LIBRIUM) and solution of the equations of motion (AQWA-FER/DRIFT/NAUT). The user should note that only the external forces and not the stiffness matrix are used within the time-history solution of the equations of motion (AQWA-DRIFT/AQWA-NAUT).

3.10.1 Tension and Stiffness for Mooring Lines with No Mass

The tension in a mooring line whose mass is considered negligible, and thus has no transverse deflection may be expressed in terms of a series of coefficients a_0 , a_1 , a_2 etc and its extension (e) from an unstretched length. The force exerted on a structure by the mooring line (P) may therefore be written:

$$P(e) = a_0 + a_1 e + a_2 e^2 + a_3 e^3 + ...$$

Notice that the constant term may be produced when the unstretched length is continually reset to the actual length (i.e. e = 0). The direction of this force will be given by the vector joining the two attachment points of the mooring line.

The elastic stiffness in the direction of the force is given by:

$$S(e) = \frac{dp(e)}{de} = a_1 + 2a_2 e + 3a_3 e^2 + ...$$

If this elastic stiffness for a given extension is S, and the tension is P, then the $3*3$ stiffness matrix, K, relating the force to the translational displacements at the attachment point of the structure, may be expressed as:

$$\underline{K} = \frac{S}{L}\, \underline{x}\, \underline{x}^t + \left[\underline{I} - \underline{x}\underline{x}^t\right] \frac{P}{L^2}$$

where
$\underline{\ }$	=	a matrix/vector quantity
t	=	the transpose
x	=	the vector joining the attachments point of the cable
I	=	a $3*3$ unit matrix
L	=	the stretched length of the mooring line

Note that K and the direction vector of the force P must be defined in the same axis system. If the axis system chosen has the X, Y or Z axis coincident with direction of P, then the stiffness matrix will be diagonal with S the value of the leading diagonal of the coincident axis and P/L on the other two diagonals, e.g. for the X axis coincident with the line joining to two attachment points of the mooring line.

$$K = \begin{bmatrix} S & 0 & 0 \\ 0 & \frac{P}{L} & 0 \\ 0 & 0 & \frac{P}{L} \end{bmatrix}$$

If a constant tension device is applied on an attachment point, then the elastic stiffness S becomes zero.

Note also that the P/L terms in the equation tend to zero as the mooring line increases in length. This means that, if a mechanism is applied to the attachment point to give a constant direction of the force P, this has the effect of an infinitely long mooring line, i.e. P/L is zero.

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. In the AQWA suite, the centre of gravity is chosen. This translation process is described in Section 3.10.3. Note that this process may be applied to any local stiffness matrix and force applied at any point on a structure.

3.10.2 Tension and Stiffness for Catenaries

Catenaries in AQWA are considered to be uniform, inelastic, with significant mass and with no fluid loading. As the solution of the catenary equations is well documented in the literature, the summary of the solution used in AQWA is presented. The equations are 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, we have the following:

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

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

$$P = T_0 + Wz$$

where

L	=	length of the catenary from the attachment point on the structure to the contact point on the sea bed
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
z	=	vertical distance between the attachment point on the structure and the sea bed

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

$$K = K_{xz}\begin{bmatrix} \frac{WL}{T_e - T_0} & 1 & 0 \\ 1 & \frac{T_e}{x_r} & 0 \\ 0 & 0 & \frac{T_e}{zT_0}\left(x - \frac{LT_0}{T_e}\right) \end{bmatrix}$$

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

where

T_e = Effective total tension at the attachment point on the structure
x_r = Horizontal distance between the attachment point on the structure and the anchor point on the sea bed

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.

3.10.3 Translation of the Mooring Line Force and Stiffness Matrix

Vector translation may be applied directly to a force and displacement in order to translate the point of definition of a stiffness matrix (K) 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 which 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 the **matrix** equation:

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

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

where

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

x,y,z = coordinates of the attachment point on the structure relative to the centre of gravity

Px,Py,Pz = X,Y and Z components of the tensions in the mooring lines at the attachment point on the structure

N.B. The term $P_m\, T_a^t$ is NOT symmetric. In general, only a structure in static equilibrium will have a symmetric stiffness matrix. This means that if the mooring forces are equilibrated with all other conservative forces, then the TOTAL stiffness matrix will be asymmetric.

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

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

3.10.4 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:

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

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	=	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 modelling for irregular seas is achieved within the AQWA suite by the specification of wave spectra. For further details the user is referred to Appendix E of the AQWA Reference Manual.

3.12 STABILITY ANALYSIS

See AQWA-LIBRIUM manual.

3.13 FREQUENCY DOMAIN SOLUTION

3.13.1 Wave Frequency Motions

AQWA-FER has been written to calculate the significant wave-frequency motions, in all degrees of freedom, of moored floating structures, together with the significant tensions in any mooring lines in the floating system. The program employs spectral techniques to perform a linear analysis in the frequency domain. AQWA-FER solves the following equation, for a range of frequencies and directions

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

where

M(s)	=	Structural mass matrix
M(a)	=	Hydrodynamic added mass matrix
C(s)	=	System linear damping matrix
K(s)	=	Total system stiffness matrix
F	=	External wave forces on the system (assumed harmonic)
X	=	Response motions (or RAOs)

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

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

where

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

H is termed the transfer function or 'modal receptance' which relates input forces to output response. (Note M is the sum of structural and added mass).

In spectral form, this may be written:

$$S_{X_iX_i}(\omega) = \sum \left[\mathrm{mod}(H_{ir})\ S^2_{F_rF_r}(\omega) \right] \qquad (3.13.4)$$

where

$S_{X_iX_i}(\omega)$	=	the spectral density of the response
H_{ir}	=	the receptance of the structural system, i.e. the response in freedom i to a harmonic force in freedom r
$S_{F_rF_r}(\omega)$	=	the spectrum of input forces in freedom r

Note: AQWA-FER does not deal with cross-spectral densities. All coupling is through the stiffness matrix. Since significant motion is proportional to the square of the amplitude, the equation takes the relatively simple form of (4), which represents a direct super-position of the effects due to each individual force.

Equation (4) gives the spectrum of response in each degree of freedom. From this we can calculate the amplitude of significant response using:

$$X_{sig} = 2 * \sqrt{A} \qquad (3.13.5)$$

where
A = the area under the response curve

To calculate significant tensions in mooring lines, the same equations apply but with different transfer functions, which relate mooring tensions to external forces.

AQWA-FER calculates the RAOs at a point of the structure using the RAOs at the structure's centre of gravity and the vector from the centre of gravity to the position of interest. The RAOs of a point P, Xp, may then be found using the following relationship:

$$X_p = T * X_g \qquad (3.13.6)$$

where
X_g = the RAOs at the centre of gravity
T = the translation matrix between the centre of gravity and the point P

Once the RAOs at the required point are known, the calculation of the significant motion at the point follows from (5) as before. Since AQWA-FER calculates the significant motions of up to five structures in any position with the phase reference point for the RAOs at the centre of gravity (as output), there is a phase difference due to each structure's position within the wave which is automatically included in the analysis.

This is achieved within AQWA-FER by including this phase difference in each structure's RAOs. The phase is retained until the RAOs are squared to calculate the spectrum of response.

As well as finding the significant response at any specified point on any structure, AQWA-FER will also calculate the relative motion between two positions within the floating system. If a difference between two points is specified, AQWA-FER calculates the RAOs taking into account the phase difference between wave forces due to the position of each structure's centre of gravity in the wave.

3.13.2 Drift Frequency Motions

The theory above describes the first order or wave frequency calculations, where the frequency of structural response is the same as the forcing frequency, and the response of a structure to a pair of waves of different frequency is simply the sum of the response of each individual wave. The calculation of structural response to second order wave forcing (drift forces) is more complex. The theory of second order wave loading is explained in detail in the literature. A condensed version of the theory is as follows:

Given two waves, one of frequency ω_i and one of frequency ω_j , the second order low frequency wave forcing acts at a frequency $(\omega_i - \omega_j)$.

A wave spectrum can be represented by a finite sum of regular waves of different frequencies each with their own wave height. This means that the low frequency drift forces due to such a wave spectrum may be calculated by taking each pair of waves in the wave spectrum in turn and calculating the drift force due to them. If the wave height of an irregular wave train is represented by a finite sum of regular waves, then the wave spectrum, $S(\omega)$, can be thought of as being the sum of small energy packets centred about the frequencies of the component regular waves in the wave height representation, i.e.

$$\text{spectrum} = \sum \left[S(\omega_i) * d\omega_i \right]$$

where

$d\omega_i$ = the frequency difference between two neighbouring spectral lines

ω_i = the value of the wave spectrum at frequency ω_i

Using this representation of the wave spectrum, it can be shown that the drift force at frequency (ω_i - ω_j) in a wave spectrum $S(\omega)$, can be written:

$$F_{ij} = \sum \left[\sum \left[\sqrt{2 * S(\omega_i) * d\omega_i} \; * \; \sqrt{2 * S(\omega_j) * d\omega_j} \; * \; D_{ij} * E_{ij} \right] \right] \qquad (3.13.7)$$

where

$S\omega_i$, $d\omega_i$	=	energy packet in the wave spectrum centred about ω_i
D_{ij}	=	drift force in a pair of unit amplitude waves of frequency ω_i and ω_j
E_{ij}	=	$e^{-i((\omega_i - \omega_j)t - (k_i - k_j)x + \phi_i - \phi_j)}$
k_i , k_j	=	wave numbers corresponding to frequencies ω_i and ω_j
ϕ_i , ϕ_j	=	phases of the two waves

Again it can be shown that the spectrum of drift forces may be written:

$$S_d(u) = 8 * \int (S(\omega_i) * S(\omega_i + u) * D_u^2) \; d\omega_i \qquad (3.13.8)$$

where

$S_d(u)$	=	the value of the drift force spectrum at frequency u
$S(\omega_i)$, $S(\omega_i + u)$	=	the values of the wave spectrum at frequencies ω_i, (ω_i + u)
D(u)	=	the modulus of the drift force coefficient D described above evaluated at frequency u

A similar expression can be derived for the steady drift force which is:

$$F_d = 2 * \int S(\omega_i) * D(\omega_i) \; d\omega \qquad (3.13.9)$$

Relating the motions of the centre of gravity to the forces acting at the centre of gravity (see Section 3.1.1 equation 2) and writing this using suffix notation, we have

$$X_i = H_{ij} * F_j \qquad (3.13.10)$$

where

X_i	=	the motion at the centre of gravity in the i th degree of freedom
H_{ij}	=	the transfer function between a force in the j th degree of freedom and motion in the i th degree of freedom
F_j	=	a force in the j th degree of freedom

From (3.13.8) and (3.13.10) the spectrum of motions can be written:

$$S_{x_i}(u) = 8 * \int (S(\omega_i) * S(\omega_i + u) \; H_{ij} \; D_j^2) \; d\omega \qquad (3.13.11)$$

Similarly, since the motion of any point P, Xp, on a rigid structure can be related to the motion of the structure's centre of gravity by Xp = T $*$ Xg (3.13.6), it follows that the spectrum of motions of any point on a structure may be written:

$$S_{x_i}p(u) = 8 * \int (S(\omega_i) * S(\omega_i + u) \; R_{ij} \; H_{jk} \; D_k^2) \; d\omega \qquad (3.13.12)$$

The values of D_k may be obtained from model tests or full scale data, but it is more usual that D_k is approximated, using a linear diffraction/radiation program (e.g. AQWA-LINE) to calculate the steady drift force coefficients in steady waves. The approximation used in AQWA-FER is:

$$D_k(u) = 0.5 * \left[D_k(\omega_i) + D_k(\omega_i + u) \right] \qquad (3.13.13)$$

Once the spectra of responses have been calculated, it is a simple matter to calculate the significant motion by using the expression shown earlier (equation 3.13.5) i.e.

$$X_{sig} = 2 * \sqrt{A}$$

where

A = the area under the response spectrum

The above theory is for a single body. Multiple body theory is more complex due to the phasing of the wave forces on each body. The spectrum of forces on body 1 is given by expression (3.13.7) with x again set to zero without loss of generality. The spectrum of forces on body 2 must include the phase lag due to its separation from body 1. This means that the spectrum of motions now becomes:

$$S_i(u) = 8 * \int (S(\omega_i) \; S(\omega_i + u) \; R_{ij} \; H_{jk} \; D_k \; e^{i(k_i - k_j)} x_0^2) \;\; d\omega \qquad (3.13.14)$$

where

x_0 = the separation of the two bodies

3.13.3 Integration of Response Spectra

The integration of the response spectra is achieved by a 3-point Gauss-quadrature algorithm using selected frequency intervals based on the natural frequencies of the equations of motion and the peak of the spectrum. The program automatically selects more integration points around the natural frequency of the system where the damping is small.

In order to restrict the number of intervals for integration to a reasonable number, a minimum critical damping is assumed (see Section 3.16).

In general, the user need not be concerned with the details of the integration, but the user must ensure that the damping given is physically realistic.

3.14 TIME HISTORY SOLUTION IN IRREGULAR WAVES (AQWA-DRIFT ONLY)

See AQWA-DRIFT manual.

3.15 TIME HISTORY SOLUTION IN REGULAR WAVES (AQWA-NAUT ONLY)

See AQWA-NAUT manual

3.16 LIMITATIONS OF THEORETICAL APPLICATIONS

There are two limitations on the theory and its implementation in AQWA-FER:

1. The critical damping for the equations of motions at natural frequencies is greater than 0.5 per cent.

2. The peaks of the wave forcing spectrum, both at wave and drift frequency, are not narrower than that of the transfer function of a single degree of freedom system with 10 per cent critical damping.

Although the program will not generally fail if these conditions are violated, inaccuracies in the integration of the response spectrum may result in approximate values for the significant motions and tensions.

CHAPTER 4 - MODELLING TECHNIQUES

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

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

Users formulating data from sources other than programs in the AQWA suite must consult the literature of the source used to obtain these data.

4.1 TYPES OF MODEL AND ANALYSIS

A floating structure requires different modelling depending on the type of problem that the user wishes to solve. An approximate model may be acceptable in one type of analysis or even omitted altogether in another, (e.g. the hydrodynamic model used in AQWA-LINE is not used by AQWA-FER).

In general, there are only two differences in the models required for each program.

1. The first is in the description of the structure geometry (the mass distribution model is common), which is achieved by describing one or more tubes and pressure plates. In total, the elements describe the whole structure and thus define the hydrostatic and hydrodynamic model.

2. The second is in the description of the environment. Mooring lines, wind, current and irregular and regular waves are not accepted by all programs.

AQWA-FER does not require a hydrostatic or hydrodynamic model. Instead, the hydrostatic stiffness matrix and hydrodynamic loading coefficients, which are the RESULTS of previous calculations on these models, are used. For example, when AQWA-LINE has been run, all these parameters are transferred automatically to AQWA-FER from backing files. If AQWA-LINE has not been run previously, the hydrostatic stiffness matrix and wave loading coefficients are required as input data.

For the benefit of those users modelling a structure for more than one program, the differences in the hydrostatic and hydrodynamic models, which are associated with the structure geometry, may be summarised in the form of simple restrictions i.e.

Hydrostatic Model (AQWA-LINE/LIBRIUM/NAUT)	-	Tubes and pressure plates. No restrictions.
Hydrodynamic Model (AQWA-LINE)	-	Pressures plates. Restricted in geometry and proximity to each other and boundaries.
Hydrodynamic Model (AQWA-NAUT)	-	Tubes and pressure plates. Restricted only in size in comparison to the wavelength.

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

N.B. When the user has run AQWA-LINE, the structures and their mass, inertia, hydrostatic, and hydrodynamic properties (excepting wind and current loading, Section 4.10) are contained within a backing file which may be read in automatically by AQWA-FER. Although the hydrostatic and hydrodynamic properties may subsequently be modified, the number of structures and their associated mass and inertia cannot be changed by AQWA-FER.

4.2 MODELLING REQUIREMENTS FOR AQWA-FER

4.2.1 Following an AQWA-LINE Run

As the normal mode of analysis is to run AQWA-LINE and then run AQWA-FER, this section appears before that describing the modelling when AQWA-FER is not used as a post-processor to AQWA-LINE.

Solution of the significant motions and tensions in mooring lines requires the solution of equation (3.13.1). Expanding the damping and stiffness terms, we have:

$$(M(s) + M(a))\, \ddot{X} + (C(h) + C(\omega))\, \dot{X} + (K(h) + K(m) + K(d))\, X = F(t) \qquad (4.2.1)$$

Summarising Section 3.13, the solution of equation (4.2.1) for a harmonic forcing function F(t), together with the calculation of the spectral ordinates for a range of frequencies, will define the response spectrum. The response spectrum may then be integrated to find the significant motions. The tension spectrum is calculated from the motion response spectrum and linear stiffness. The tension spectrum is then integrated to find the significant tensions.

In terms of the equation (4.2.1), parameters which are transferred automatically through a backing files from AQWA-LINE are:

M(s)	=	Structural mass matrix
M(a)	=	Hydrodynamic added mass matrix
C(r)	=	Radiation damping matrix
K(h)	=	Hydrostatic or linear stiffness matrix
F(t)	=	External harmonic forces on the system

The system damping matrix C(s) and system stiffness matrix K(s) in equation (3.13.1) are defined as:

$$C(s) = C(h) + C(w) \qquad (4.2.2)$$

$$K(s) = K(h) + K(m) + K(d) \qquad (4.2.3)$$

where

C(h)	=	Hydrodynamic damping matrix
C(w)	=	Damping due to wind
K(m)	=	Stiffness due to mooring lines
K(d)	=	Hydrodynamic stiffness due to waves, wind and current

1. For Wave Frequency Motions

For wave frequency motions, the hydrodynamic damping matrix C(h) is equal to the radiation damping matrix C(r) and the added mass is that calculated by AQWA-LINE. The terms in (4.2.1) which are required to be defined are:

C(w)	Damping due to wind. If small compared with the radiation damping C(r), this term can be ignored. This is often the case at wave frequency but not normally at drift frequency
K(m)	Stiffness due to mooring lines
K(d)	Hydrodynamic stiffness due to waves, wind and current. These terms which contribute stiffness only to the horizontal freedoms (surge, sway and yaw) can usually be ignored at wave frequency as the response is dominated by the mass inertia forces. However they are very important at drift frequency

Modelling requirements for wave frequency motion are therefore:

A	Wind and current loading coefficients
B	Wave spectrum, wind and current
C	Mooring lines
D*	Equilibrium position for each spectrum and mooring line combination

*Note that both C and D are required in order to calculate K(m), as K(m) is a function of the structure displacement, particularly if the mooring lines are non-linear (see also 4.2.3).

2. For Drift Frequency Motions

At drift frequency, the added mass matrix M(a) and hydrodynamic damping matrix C(h) are NOT the same as the radiation damping and added mass calculated by AQWA-LINE. Therefore, the terms in (4.2.1) which are required to be defined are:

M(a)	Hydrodynamic added mass for low frequency motion
C(h)	Hydrodynamic damping for low frequency motion

Modelling requirements for drift frequency motion are therefore:

A,B,C,D	as in 1. above, **plus**
E	Hydrodynamic added mass and damping matrices for low frequency motion

4.2.2 When used Without a Preceding AQWA-LINE Run

If AQWA-FER is run as an independent program, those parameters normally calculated by AQWA-LINE may be input directly, as AQWA-FER does not assume implicitly that a backing file is available containing these parameters.

The input requirement is therefore those parameters normally calculated by AQWA-LINE (as listed in the previous section) viz.

M(s)	=	Structural mass matrix
M(a)	=	Hydrodynamic added mass matrix
C(r)	=	Radiation damping matrix
K(h)	=	Hydrostatic or linear stiffness matrix
F(t)	=	External harmonic forces on the system

Additional requirements are then the same as if AQWA-LINE had been run previously (see previous section).

4.2.3 Following an AQWA-LINE Run with Modifications to AQWA-LINE Data

The new user is advised to ignore this section

When AQWA-FER is run as a post-processor to AQWA-LINE, any of the parameters calculated by AQWA-LINE may be appended to, modified or overwritten to comply with new model specification WITHOUT recourse to a full rerun of AQWA-LINE.

Additions to data from a previous AQWA-LINE run may be required when using the information from more than one AQWA-LINE run, in order to define the various wave loading coefficients (e.g. added mass, damping, diffraction forces) at all frequencies relating to the integration of the response spectrum. This is achieved simply by concatenating the required AQWA-LINE data into a single file.

The input requirements when using data from several AQWA-LINE runs are the same as those using one data set with the additional information of how to concatenate the files.

It is intended that modifications of the model and/or the wave loading coefficients do not invalidate the calculations performed by AQWA-LINE. It is of fundamental importance to recognise that a change of model specification may invalidate some or all of these calculations. Other changes may mean that the results are only approximate and others may have no effect at all on the validity of the AQWA-LINE results.

Use of AQWA-FER in this mode clearly requires a complete understanding of the complete analysis process and the manner in which the programs achieve this process. This facility should therefore NOT be used without this knowledge.

4.3 DEFINITION OF AXES, CONVENTIONS AND STRUCTURE POSITIONS

Full details may be found in the AQWA Reference Manual.

Two sets of axes are used in AQWA-FER and these are shown in Figure 4.1 They are the FRA (Fixed Reference Axes) and the LSA (Local Axes System). Full details of the axes systems used in the AQWA suite are given in the AQWA Reference Manual. In AQWA-LINE, structure motions and fluid forces are with respect to the centre of gravity of the particular structure (see Section 3.3 and Figure 4.1).

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

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

The direction of wave or wave spectra propagation is defined relative to the positive X-axis of the FRA (Fixed Reference Axes), and is positive in an anticlockwise direction when seen from above, e.g. the heading angle is zero when the propagation is along the positive X-axis, and 90 degrees when along the positive Y-axis of the FRA.

The position of each body is defined by the coordinates of its centre of gravity with respect to the FRA. The orientation of the body is defined by three successive rotations about the OX, OY and OZ axes in the FRA, in that specific order. Within the program, the orientation is defined by the direction cosines of the LSA (local axis system) with respect to the FRA.

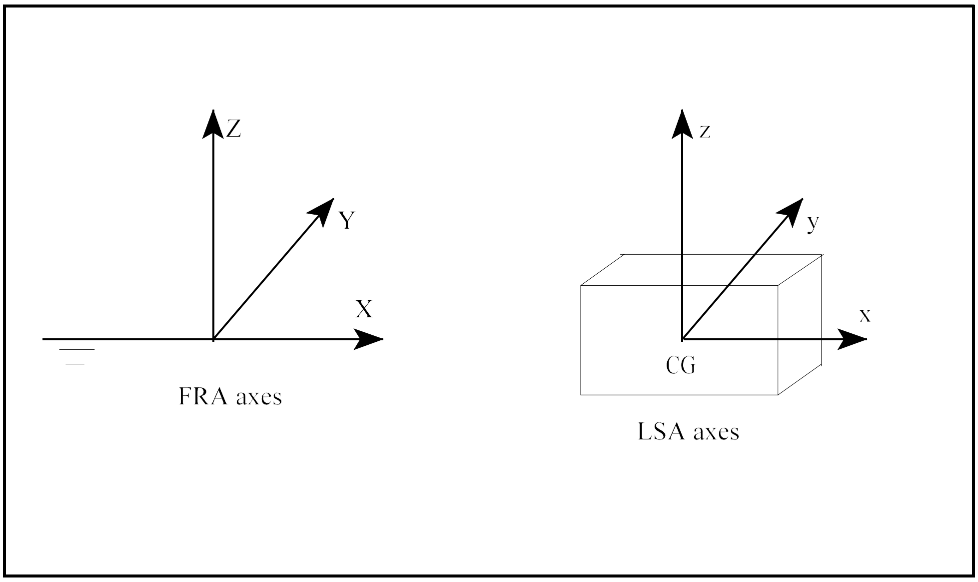

Figure 4.1 - FRA and LSA

4.4 STRUCTURE GEOMETRY AND MASS DISTRIBUTION

When AQWA-FER 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-FER is used independently (see the AQWA-LINE and AQWA-LIBRIUM manuals when this is not the case).

Note that a hydrostatic or hydrodynamic model is not required, (see Section 4.2.1). Only the hydrostatic stiffness matrix (see Section 4.7) and hydrodynamic loading coefficients are necessary (see Section 4.9).

4.4.1 Coordinates

Any point on the structure is modelled by referring to the X,Y and Z coordinates of a point in the FRA. This point 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 of 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-FER used independently from 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 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

These are not available in AQWA-FER.

4.6 STATIC ENVIRONMENT

4.6.1 Global Environmental Parameters

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

Acceleration due to Gravity:	Used in the calculation of all forces and various dimensionless variables throughout the program suite.
Density of Water:	Used in the calculation of fluid forces and various dimensionless variables throughout the program suite.
Water Depth:	Used to calculate wave properties and clearance from the sea bed.

4.7 LINEAR STIFFNESS

4.7.1 Hydrostatic Stiffness

The hydrostatic stiffness matrix is calculated in AQWA-LINE and 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 be found in the AQWA-LINE manual in the corresponding section.

When AQWA-FER 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. These can 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. As this stiffness matrix is transferred automatically from backing file when AQWA-FER is used as a post-processor, the following notes refer to AQWA-FER 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

N.B. This facility does not REPLACE, but complements, the stiffness due to mooring lines (if present), as AQWA-FER includes the mooring line stiffness in its calculations of the total system 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-FER is used as a post-processor, the following notes refer to AQWA-FER 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 these coefficients are defined.

There are only two criteria for the values of the frequencies and directions 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 of the AQWA Reference Manual) only those directions for the defined quadrants are required.

2. Sufficient values are used to adequately describe the variation of these coefficients over the required frequency and direction range.

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 transferred automatically from backing file when AQWA-FER is used as a post-processor. Thus, the following notes refer to AQWA-FER when used as an independent program.

The terms in the equation of motion which must be modelled (see Section 4.2 and equations 4.2.1/2/3) are:

M(a)	=	Hydrodynamic added mass matrix
C(h)	=	Hydrodynamic damping matrix
F(t)	=	External simple harmonic forces on the system

The external forces may be written as three components i.e.

$$F(t) = F(d) + F(k) + F(2)$$

where

F(d)	=	Diffraction forces
F(k)	=	Froude Krylov forces
F(2)	=	Mean second order wave drift forces

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

The solution of the significant motions (and hence tension) involves the integration of the response spectra over a frequency range from zero to infinity. The wave loading model must therefore represent these wave loading parameters for frequencies ZERO TO INFINITY. In practice this means:

For wave frequency motion - The added mass and damping matrices are required for the range of frequencies and the diffraction and Froude Krylov forces are required at the same range of frequencies and for the range of directions.

For drift frequency motion - A single added mass and damping matrix are required which approximate to 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-FER from the drift coefficients, which are defined for the range of frequencies and directions.

The user is advised always to include the low frequency added mass and damping matrices, even if wave frequency motions only are expected. If drift frequency added mass and damping are not defined, the program will assume default values of zero, which may give rise to very small values on interpolation at the lower frequencies. If any damping values are below a prescribed limit, AQWA-FER will reset these where necessary to continue the analysis with the appropriate warning messages.

If they are unknown, then the added mass values corresponding to those at the lowest frequency known should be used. The damping matrix, however, cannot be approximated in this way, as the hydrodynamic mechanism which produces the damping at low frequency is due NOT ONLY to radiation damping but also to a more complex mechanism, which may depend on several parameters, including the wave spectra.

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 velocity and produce terms for steady forces, stiffness and damping.

In time history simulation (AQWA-DRIFT/NAUT) all these terms are included together by converting the effects of stiffness and damping through the displacement and velocity respectively to give a total force acting on the structure at any time during the simulation.

In the calculation of equilibrium position and stability analysis (by AQWA-LIBRIUM) the effect of the steady forces is to change the equilibrium position, which in turn may change the stiffness of any non-linear mechanism present (e.g. catenaries, hydrostatic stiffness). The effect of wind and current stiffness (i.e. rate of change of wind and current force with yaw) will directly effect both the equilibrium position and stability. The wind and current damping has no effect on the static stability calculations.

In AQWA-FER the change in non-linear stiffness through the change in position must be considered if these changes are significant. The stiffness of the wind and current is calculated by AQWA-FER automatically. Note that this stiffness may be neglected for wave frequency motions but this may give poor results for drift frequency motions.

This stiffness K(a), may be approximated by:

$$K(a12) = \frac{F(wc1) - F(wc2)}{a1 - a2}$$

where

K(a12)	=	the stiffness at a yaw angle of a12
a12	=	(a1+a2)/2
a1	=	angle in radians/sec
a2	=	angle in radians/sec
F(wc1)	=	Wind/current force at a1
F(wc2)	=	Wind/current force at a2
a1-a2	=	A 'small' angle. The expression becomes exact as the angle approaches zero

The effect of wind and current damping on the wave frequency motions is usually small (compared with the radiation damping) but may have a very significant effect on the drift motions.

4.11 THRUSTER FORCES

Thruster forces only effect the frequency domain solution through the change in equilibrium position which, in turn, may change the stiffness of any non-linear mechanism present. The thruster stiffness (i.e. change in thruster force with position) is neglected. This is usually a good approximation for wave frequency motions but if calculations show that this is not a valid approximation for drift frequency motion, the user may model this as an additional stiffness (Section 4.7.2) (see also AQWA-DRIFT/ LIBRIUM/NAUT manuals).

4.12 CONSTRAINTS OF STRUCTURE MOTIONS

Not yet implemented.

4.13 STRUCTURAL ARTICULATIONS

They are not implemented in AQWA-FER (see AQWA-NAUT or AQWA-DRIFT manual).

4.14 WAVE SPECTRA, WIND AND CURRENT SPECIFICATION

The user may specify one or more spectra, wind and current speed and their associated directions. For the majority of applications, specification is straight forward and no knowledge of the way in which the spectra are used in each program is required. The two rules for specification of the spectra are:

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 spectra 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 an upper limit to the drift motions and a lower limit to the wave frequency motions.

4.15 MOORING LINES

4.15.1 Linear/Non-Linear Elastic Hawsers

Mooring line properties are determined by their unstretched lengths, end nodes on respective bodies and their load/extension characteristics. For linear mooring lines, the line stiffness (load per unit extension) is required. For non-linear mooring lines the program permits up to a fifth order polynomial in displacement to approximate the elastic property of the load/extension curve (see also equation 4.15.1 in the AQWA Reference Manual).

$$P(e) = a_0 + a_1 e + a_2 e^2 + a_3 e^3 + a_4 e^4 + a_5 e^5 \tag{4.15.1}$$

where

P	=	the line tension
e	=	the extension
$a_0, a_1, a_2, a_3, a_4, a_5$	=	the coefficients

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

4.15.2 Constant Tension Winch Line

The winch line is characterised by its constant tension, attachment points and an 'unstretched length'. The attachment points are specified by 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 ‘Constanct Force’ Line

The program allows the user to input a force of constant magnitude and direction. The force is assumed to act always at the centre of gravity of the body. The direction of the force is specified by any 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 catenary model gives the user flexibility in its use by allowing for two modes of operation:

LENGTH based	user specifies length, the program determines tension
TENSION based	user specifies tension, the program determines required length

In both cases, the user may specify maximum and minimum tension 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 is outside the range specified (or the default values). If the user wishes to keep constant line length irrespective of the tension, he may input a very large value of maximum allowable tension. In all cases, adequate warning messages will be signalled.

The program evaluates the line tension and stiffness according to closed 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 or default maximum.

The current version of AQWA only admits a horizontal sea bed and catenaries between a body and the sea bed. A catenary joining two bodies is NOT permitted.

Care must be exercised in the description of the catenary line such that the line is not lying horizontally and that 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:

$$\frac{T}{w} = \frac{\left(s^2 + z^2\right)}{2z} \tag{4.15.2}$$

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' from the sea-bed.

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

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

4.17 TIME HISTORY INTEGRATION IN IRREGULAR WAVES (AQWA-DRIFT ONLY)

This is not applicable to AQWA-FER (see AQWA-DRIFT manual).

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

This is not applicable to AQWA-FER (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 physics of the analysis and how one is expected to model the structure in its environment. It also deals with the methodology associated with running the program and links the modelling requirements of the previous chapter with the stages of analysis necessary to solve a given type of problem.

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

5.1 TYPES OF ANALYSIS

The types of problem solutions shown below are based on a type of AQWA-FER analysis and are the same whether AQWA-FER is used independently or as a post-processor to AQWA-LINE.

a. Calculation of wave frequency RAOs for uncoupled moored structures.

b. Calculation of natural frequencies for the moored system of structures for various configurations.

c. Calculation of wave frequency RAOs for coupled moored structures.

d. Calculation of significant motions and tensions for the system due to wave frequency excitation.

e. Calculation of significant motions and tensions for the system due to drift frequency excitation.

f. Calculation of significant motions and tensions for the system due to wave frequency and drift frequency excitation combined.

All the above are controlled by user options and may be requested in any combination.

Note that the calculation of free floating RAOs and free floating natural frequencies is considered an integral part of the data checking process, which is automatically carried out and printed unless the user specifically requests that this should not be included.

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 AQWA Reference Manual Section 2.2).

Use of the restart process implies that information is available on a backing file from a previous AQWA suite 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 :

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 (not yet available) will be able to visualise the geometric model and parameters at any point in the analysis e.g. Stages 2 to 5 are not required to visualise the input data 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-FER independently uses the following Stages (1-7) to replace the calculation and data input in AQWA-LINE.

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 sum of the gravity and hydrostatic forces is 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 preparation (8-14) is required for AQWA-FER 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 equilibrium positions for each spectrum and mooring line combinations.

12. Create a data file.

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 (wave motion/drift motion/both) and re-run with the restart option (restart Stage 5).

CHAPTER 6 - DATA REQUIREMENT AND PREPARATION

This chapter describes the form in which data is expected by the program and is intended as a detailed list of the data requirements and general format for each type of analysis that may be performed when running AQWA-FER. The detailed format may be found in the AQWA Reference Manual. It also uses the concept of the card image deck which is a section of two or more records into which the card image input is divided. It assumes that the user is familiar with this concept, details of which may also be found in the AQWA Reference Manual.

A summary of all possible data that may be input is listed together with a summary for various forms of analysis. In this latter case, an input data summary is given 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 performed 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 (if choice exists)
- the analysis stage to be performed (i.e. restart stages)

Administration of the analysis being performed:

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

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

JOB Card - This contains information stating the program to be used, the type of program analysis to be undertaken and the user identifier for the run in question.

TITLE Card - This lets the user prescribe a title for the run.

OPTIONS Card - Various program options are available within the AQWA suite which are common to all programs while others are for use with specific programs. The options within AQWA-FER 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-FER, 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-FER 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 data then the motion analysis can be undertaken by restarting the program at Stage 5.

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

Input to Stage 1 of the analysis is only necessary if the restart stage at which the analysis begins is Stage 1 (see Chapter 5 for details). If the restart stage is greater than Stage 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 also be 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 of 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 data 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 position or motions are requested by the user specified options
Deck 2	-	Elements used to model 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-FER frequency domain calculation 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 relate, for a range of frequencies and directions, to the equation of motion of a diffracting structure in regular waves, namely:

$$M(s)\ddot{X} + M(a)\ddot{X} + C\dot{X} + KX = F(d) + F(k) + F(2)$$

The parameters in the equation of motion are:

K	=	Linear stiffness matrix with associated values of the buoyancy force at equilibrium and the depth below the still water level 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 (RAOs)
F(d)	=	Diffraction forces
F(k)	=	Froude Krylov forces
F(2)	=	Drift forces

***Note that the drift added mass/damping is input in Stage 4**.

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-FER, these parameters are read from backing file automatically or may be input manually. In the latter case, the range of frequencies and directions specified are those at which these 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
	-	The depth below the still water level 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 (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-FER 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-FER 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. the user wishes to input values from a source other than AQWA-LINE he may do so 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 wave frequency motion only

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 - No input required, enter NONE for the deck header

(b) 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

(c) For a run analysing both 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-FER 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 present analysis, this is 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 ALDF options must be used in the options list (see Appendix A) to indicate that it exists and must be read. **Using this option means that Decks 6 though 8 are read twice, once from the AQWA-line backing file, and once from the card image deck.**

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

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

6.3 STAGE 3 - NO INPUT DATA - DIFFRACTION/RADIATION ANALYSIS

There is no input for Stage 3 in AQWA-FER, as this stage performs the diffraction/radiation analysis, which is either performed in AQWA-LINE or the values have been input by the user from a source other than AQWA-LINE, i.e. when the program is used independently.

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 Stage 1 or 2 (see Chapter 5). If the restart stage is greater than Stage 4 there is NO INPUT for Stage 2 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	If drift motions are required from the analysis, it is mandatory to input the added mass and damping associated with the low frequency motion, which is assumed constant. These coefficients should also be input for wave frequency analysis (see Section 4.9).
Wind and current loading coefficients	These coefficients, which are defined at the directions specified in Deck 6 are associated with the hull forces proportional to the square of the wind and current velocity. They are required even though a steady force has no direct effect on motions. These coefficients contribute indirectly through the stiffness matrix (i.e. rate of change of wind and current force with yaw). Wind damping also has a significant effect on drift motions. Current damping is ignored (see Section 4.10).
Wave spectra, wind and current	The sea state is defined by a wave spectrum together with its wind and current (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).
Equilibrium positions	The position of each structure must be specified for each mooring line and spectrum combination required to be analysed. Note that the automatic transfer of these positions from AQWA-LIBRIUM is not yet available (see Section 4.15 of the AQWA Reference Manual).

6.4.2 AQWA-FER data input summary for Decks 9 to 18

Deck 9	-	Low frequency added mass
	-	Low frequency damping
Deck 10	-	Wind loading coefficients
	-	Current loading coefficients
Deck 11	-	No input required
Deck 12	-	No input required
Deck 13	-	Wind speed and direction for each wave spectrum
	-	Current speed and direction for each wave spectrum
	-	Description of the wave spectra
Deck 14	-	Description of each mooring line combination
Deck 15	-	Equilibrium positions for each spectrum and mooring line combination required to be analysed
Deck 16	-	No input required
Deck 17	-	No input required
Deck 18	-	Node numbers of those positions for which the significant motions are required

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. Note also that other data 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 DATA - MOTION ANALYSIS

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

6.6 STAGE 6 - NO DECKS - GRAPHICAL DISPLAY

The AQWA suite has its own graphics program, 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 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 program users 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 assigned 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 a results backing file which is assigned to AQWA-PLANE for plotting in graphical form. A list of the parameters which may be plotted will be listed below when this facility becomes available.

CHAPTER 7 - DESCRIPTION OF OUTPUT

This chapter describes the comprehensive program output provided by AQWA-FER. 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 the backing file.

7.1.1 Coordinates and Mass Distribution Elements

Note that the body's surface geometry is not used in AQWA-FER. 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-FER 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 seen in Figure 7.2. Each structure is numbered 1, 2, 3 etc, which corresponds to the order in which they are input, which appears in the title of 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
 ---------------------------------------------------------------------------

      5     PMAS    14         0         0         0        11         1
      5     PMAS    11         0         0         0         1         1
      5     PMAS    12         0         0         0         1         2
      5     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 or density value associated with it. The material group numbers are output as shown in Figure 7.3.

```
                          * * * * M A T E R I A L   P R O P E R T I E S * * * *
                           - - - - - - - - - - - - - - - - - - -



                               MATERIAL
                                GROUP
                                NUMBER   DENSITY/VALUE
                               ----------------------

                                  1         75593800.0
                                  2            57525.0
                                  3          1025000.0
                                 11            25000.0
```

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 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 particular 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 GRAVITY            1.100        1.175       35.000

      INERTIA MATRIX            3.024E+10   0.000E+00   0.000E+00

                                0.000E+00   1.150E+11   0.000E+00

                                0.000E+00   0.000E+00   1.150E+11
```

Figure 7.5 - Resultant Mass and Inertia

7.2 DESCRIPTION OF ENVIRONMENT

The environmental parameters within AQWA-FER consist only of fluid depth and density information relating to the regular waves. The static environment is output as shown in Figure 7.6 and is seen to contain the fluid depth and density. Note that the gravitational acceleration is also output.

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

```
        * * * * 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 - Global Parameters

The wave environment is now to be output and AQWA-FER 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.

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

```
                * * * * WAVE  FREQUENCIES/PERIODS  AND  DIRECTIONS * * * *
                        ------------------------------------------

         STRUCTURE  VARIABLE                1          2          3          4
         ---------------------------------------------------------------------

             1    DIRECTION(DEGREES)      180.00      90.00       0.00       0.00

                  FREQUENCY(RADS/SEC)    0.50265    0.52360    0.62832    0.78540

                  FREQUENCY(HERTZ)       0.08000    0.08333    0.10000    0.12500

                  PERIOD(SECONDS)          12.50      12.00      10.00       8.00
                                                                                    ......
                  WAVE NUMBER(K)         0.02881    0.03067    0.04153    0.06311

                  WAVELENGTH(L)           218.05     204.83     151.30      99.56

                  MAXIMUM ELEMENT SIZE     31.15      29.26      21.61      14.22

                  DEPTH RATIO(D/L)          0.23       0.24       0.33       0.50

                  DEPTH RATIO(K*D)          1.44       1.53       2.08       3.16

                  PARAMETERS                                             UNDEFINED
         ---------------------------------------------------------------------


                       5          6         7          8          9         10
                  ------------------------------------------------------------
                      0.00       0.00      0.00       0.00       0.00       0.00

                   0.89760    0.00000   0.00000    0.00000    0.00000    0.00000

                   0.14286    0.00000   0.00000    0.00000    0.00000    0.00000

                      7.00       0.00      0.00       0.00       0.00       0.00

                   0.08217    0.00000   0.00000    0.00000    0.00000    0.00000
           .....

                     76.46       0.00      0.00       0.00       0.00       0.00

                     10.92       0.00      0.00       0.00       0.00       0.00

                      0.65       0.00      0.00       0.00       0.00       0.00

                      4.11       0.00      0.00       0.00       0.00       0.00

                   UNDEFINED UNDEFINED UNDEFINED UNDEFINED UNDEFINED UNDEFINED
                  ------------------------------------------------------------
```

Figure 7.7 - Wave Parameters

7.3 DESCRIPTION OF FLUID LOADINGS

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

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

7.3.1 Hydrostatic Stiffness

The hydrostatic stiffness matrix output by AQWA-FER when printing from backing file is in the analysis position used in AQWA-LINE for the diffraction/radiation analysis. 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 7.8 shows a typical added mass matrix for body 1 at a single frequency. (Wave damping is 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 7.8 - 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 7.9). 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 Section 4.3.2 and 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 7.9 shows only the Froude-Krylov component)

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

              FROUDE KRYLOV FORCES-VARIATION WITH WAVE PERIOD/FREQUENCY
              ---------------------------------------------------------

  PERIOD FREQ  DIRECTION          X                 Y                 Z
  ------ ----- --------- -----------------------------------------------------
  (SECS)(RAD/S)(DEGREES)    AMP      PHASE    AMP      PHASE    AMP      PHASE
  ----------------------------------------------------------------------------

   12.50 0.503   180.00  7.54E+06   90.00  1.21E+00  -79.95  2.26E+07    0.00
   12.00 0.524           6.75E+06   90.00  2.36E+00  -90.60  1.85E+07    0.00
   10.00 0.628           6.08E+05   90.00  6.77E-01 -107.19  1.04E+05    0.00
    8.00 0.785           7.41E+06  -90.00  1.27E+00  112.93  8.64E+06 -180.00
    7.00 0.898           1.36E+06  -90.00  1.28E+00   94.29  1.90E+05 -180.00

   12.50 0.503    90.00  1.41E+00  -92.53  1.73E+07  -90.00  5.43E+07    0.00
   12.00 0.524           1.37E+00  -90.00  1.80E+07  -90.00  5.25E+07    0.00
   10.00 0.628           1.58E+00 -101.42  2.10E+07  -90.00  4.26E+07    0.00
    8.00 0.785           1.67E+00  -92.15  2.18E+07  -90.00  2.61E+07    0.00
    7.00 0.898           1.45E+00  -89.38  1.75E+07  -90.00  1.48E+07    0.00


                   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 7.9 - Froude Krylov Forces/Moments

7.3.4 Mean Wave Drift Forces

The mean wave drift forces and moments, expressed as functions of wave period and direction, are output as shown in Figure 7.10. It is seen that they are given for each body and for the range of user specified frequencies.

Note that the mean wave drift forces are a function of wave amplitude squared and are given for unit wave amplitude.

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

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



              FORCES   FREQUENCY   DIRECTION (DEGREES)
              ------   ---------   ------------------
              DUE TO (RADIANS/SEC)  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 7.10 - Mean Wave Drift Forces/Moments

7.4 FREE FLOATING NATURAL FREQUENCIES AND RESPONSE AMPLITUDE OPERATORS

7.4.1 Natural Frequencies/Periods

AQWA-FER calculates the **uncoupled** natural frequencies/periods for each body 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 7.11).

```
      * * * * 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 7.11 - Natural Frequencies/Periods

7.4 BODY RESPONSE AMPLITUDE OPERATORS AND NATURAL FREQUENCIES

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 those calculated in AQWA-LINE.

The output gives the variation of RAOs with frequency, for each direction. (see Figure 7.12). 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 is related to the incident wave form (see Section 4.3.2 and the AQWA Reference Manual). All RAOs are given for unit wave amplitude.

N.B. These RAOs, which do **not** include the stiffness due to the mooring lines specified in Deck 14, are labelled as 'R.A.O.S - VARIATION WITH WAVE PERIOD/ FREQUENCY' (see Figure 7.12). 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



              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 7.12 - Response Amplitude Operators

7.5 COUPLED NATURAL FREQUENCIES FOR THE MOORED STRUCTURE

The natural frequencies for the total system of coupled structures is output only for the first spectrum of each mooring line combination, unless the user has specified the PRRP option (PRint Recalculated Parameters) in which case they are printed for all spectra as, in general, the natural frequencies do not vary substantially with different spectra. Note also that the undamped natural frequencies are only output within the wave frequency range, and that the natural frequencies are different for each frequency/period as the added mass and damping are frequency dependent.

Results are output for natural frequencies (see Figures) and also for natural periods (not illustrated).

7.5.1 Undamped Natural Frequencies

The undamped natural frequencies, as previously stated, are for the whole system of structures, including mooring lines, and correspond to a common frequency set (that of Structure 1 is used) and common orientation of the matrices in the equations of motion. As values of the matrices are interpolated for these frequencies and a particular orientation, the values of undamped natural frequencies will, in general, not be the same as those described in Section 7.4.1, even if no mooring lines are present.

The MODE numbers in Figure 7.13 will not always correspond to the freedoms of motion, i.e. modes 1,2,3,4,5,6 will not ALWAYS be surge (X), sway (Y), heave (Z), roll (RX), pitch (RY) and yaw (RZ). However, if the freedoms are largely uncoupled in the equilibrium positions specified, a one to one correspondence would be expected. Zero value for natural frequency means that no natural frequency exists for that mode, e.g. when there is no stiffness.

```
                * * * * UNDAMPED NATURAL FREQUENCIES/PERIODS * * * *
                        ------------------------------------



N.B. THESE NATURAL FREQUENCIES ARE FOR THE FULL STRUCTURAL SYSTEM (THIS INCLUDES MOORING LINES)
THEY ARE CALCULATED AT THE FREQUENCIES OF THE FIRST STRUCTURE. DAMPING GIVEN IS PERCENTAGE CRITICAL



                          SPECTRUM NUMBER  1
                         --------------------

REQUENCY  FREQUENCY     UNDAMPED  NATURAL  FREQUENCIES (RADIANS/SECOND)
NUMBER     (RAD/S)      MODE  1     MODE  2     MODE  3     MODE  4     MODE  5     MODE  6
---------------------------------------------------------------------------------------------
    1        0.524        0.000       0.000       0.634       0.380       0.598       0.000
    2        0.647        0.000       0.000       0.619       0.383       0.635       0.000
    3        0.747        0.000       0.000       0.598       0.389       0.655       0.000
    4        0.847        0.000       0.000       0.567       0.397       0.687       0.000
    5        0.947        0.000       0.000       0.546       0.405       0.699       0.000

    6        1.047        0.000       0.000       0.499       0.412       0.708       0.000
    7        1.147        0.000       0.000       0.488       0.418       0.716       0.000
```

Figure 7.13 - Undamped Natural Frequencies for the Coupled System

7.5.2 Damped Natural Frequencies

The damped natural frequencies, as previously stated, are for the whole system of structures including mooring lines, and correspond to a common frequency set (that of Structure 1 is used) and common orientation of the matrices in the equations of motion. As the damping has been included, these will not be identical to the undamped natural frequencies.

These natural frequencies, although not used per se in the integration of the response spectrum, are derived from the same equations which are used in the integration. The frequencies at which values are given are those at which the spectrum is evaluated. Note that the spacing is finer close to the natural frequencies, thus improving the modelling of the peak in the motion transfer function.

The damped natural frequency for low frequency (drift) motions is unique, as the added mass and damping are not frequency-dependent. This is always frequency number 1 in Figure 7.14. The frequency in the second column, at which the natural frequency is evaluated, is the centre of the low frequency range. Note that in Figure 7.14 frequency number 1 is omitted, as it is taken from an analysis where drift motions are not requested.

The NAT/FREQ numbers in Figure 7.14 do not correspond to any particular freedom, as they are sorted in ascending order. If the user wishes to know which mode of motion corresponds to which natural frequencies, the undamped natural frequencies should be compared with these frequencies. However, if no clear correspondence can be found, the user must refer to the dynamic stability analysis in AQWA-LIBRIUM, where the full eigenvectors of each mode are output. Note that only natural frequencies greater than 0.001745 (period 1 hour) are output.

```
                 * * * * DAMPED NATURAL FREQUENCIES/PERIODS * * * *
                         ----------------------------------


N.B. THESE FREQUENCIES ARE SORTED IN ASCENDING ORDER. DAMPING GIVEN IS PERCENTAGE CRITICAL.



                               SPECTRUM NUMBER  1
                               ------------------
```

FREQUENCY NUMBER	FREQUENCY (RAD/S)	NAT/FREQ 1 FREQ	NAT/FREQ 1 DAMPING	NAT/FREQ 2 FREQ	NAT/FREQ 2 DAMPING	NAT/FREQ 3 FREQ	NAT/FREQ 3 DAMPING
2	0.257	0.4271	1.1	0.8436	1.2	0.9087	1.3
3	0.273	0.4239	1.1	0.8199	1.3	0.8813	1.4
4	0.289	0.4206	1.1	0.7968	1.5	0.8547	2.3
5	0.307	0.4172	1.2	0.7742	2.1	0.8288	3.2
6	0.326	0.4138	1.2	0.7522	2.7	0.8037	4.2
7	0.346	0.4103	1.2	0.7307	3.3	0.7793	5.1
8	0.368	0.4067	1.2	0.7097	3.9	0.7556	6.1
9	0.390	0.4031	1.3	0.6892	4.5	0.7326	7.0
10	0.414	0.3994	1.3	0.6692	5.1	0.7103	8.0
11	0.440	0.3955	1.0	0.6497	5.7	0.6886	9.0
12	0.467	0.3916	1.0	0.6307	6.3	0.6675	10.0
13	0.496	0.3876	1.0	0.6121	7.0	0.6470	11.0
14	0.526	0.3839	1.0	0.5957	7.5	0.6288	11.9
15	0.559	0.3838	1.0	0.5976	7.2	0.6288	11.3
16	0.593	0.3838	1.0	0.5997	6.8	0.6289	10.6
17	0.630	0.3837	1.0	0.6018	6.4	0.6289	9.9
18	0.669	0.3836	1.0	0.6041	6.0	0.6289	9.1
19	0.710	0.3836	2.0	0.6065	5.6	0.6288	8.3
20	0.754	0.3835	2.0	0.6091	5.1	0.6289	7.5
21	0.800	0.3834	2.1	0.6117	4.7	0.6289	6.5
22	0.850	0.3834	2.1	0.6142	4.2	0.6291	5.5
23	0.902	0.3833	2.1	0.6165	3.7	0.6298	4.5
24	0.958	0.3832	2.1	0.6180	3.2	0.6313	3.4
25	1.017	0.3832	2.1	0.6189	2.4	0.6337	2.3
26	1.099	0.3832	0.1	0.6183	3.0	0.6319	3.1

Figure 7.14 - Damped Natural Frequencies for the Coupled System

7.6 PARAMETERS AT THE SPECTRUM INTEGRATION POINTS

Greater insight into the dynamic response of a system of structures may be obtained if more information is available about the system throughout the frequency range. Option controlled output is therefore available for the force spectral density, transfer matrix, response spectrum and RAOs at the frequencies at which AQWA-FER evaluates these functions, in order to integrate the response spectrum to obtain the significant motions and tensions in the mooring lines.

The frequencies at which these parameters are output are calculated by the program and cannot be altered by the user. They are referred to as the Spectral Integration Points (SIP) in this section.

7.6.1 Force Spectral Density Matrix

The force spectral density at the SIP is output for all six degrees of freedom for each structure (only 3 are illustrated). The forces are referenced at the centre of gravity of each structure in a axis system parallel to the Fixed Reference Axis (FRA), and not in the local axis system. The phase is referenced to the origin of the FRA.

Figure 7.15 shows the format of the output when the PRFS (PRint Force Spectrum) option is used. This output is the leading diagonal of the matrix and hence gives no information about the relative phase of the force between freedoms. Figure 7.16 shows the output format, including the cross spectral densities for the coupled system, when the PRCS (PRint Coupled Spectra information) is also used. Only a few frequencies are shown, as several pages of output are normally obtained.

Note that the force spectrum is that appropriate to the direction of the corresponding wave spectrum.

```
                      * * * * FORCE SPECTRAL DENSITY MATRIX * * * *
                              -----------------------------


N.B.  THE LEADING DIAGONAL PRINTED BELOW DOES NOT CONTAIN THE PHASE INFORMATION FOR COUPLED FREEDOMS



                                     SPECTRUM NUMBER  1
                                     ------------------


           FREQUENCY  SPECTRAL     SURGE(X)          SWAY(Y)          HEAVE(Z)
            (RAD/S)   ORDINATE    AMP    PHASE      AMP    PHASE      AMP    PHASE
           ------------------------------------------------------------------------..

            1 0.2577    0.00   2.55E+07    0.0  1.72E+08    0.0  1.70E+08    0.0 ..
            2 0.2875    0.04   2.60E+10    0.0  1.75E+11    0.0  1.73E+11    0.0
            3 0.3173    0.43   8.86E+11    0.0  5.98E+12    0.0  5.91E+12    0.0
            4 0.3316    0.90   2.71E+12    0.0  1.83E+13    0.0  1.80E+13    0.0
            5 0.3506    1.85   8.44E+12    0.0  5.70E+13    0.0  5.63E+13    0.0

            6 0.3697    3.05   1.96E+13    0.0  1.32E+14    0.0  1.31E+14    0.0 ..
            7 0.3767    3.51   2.52E+13    0.0  1.70E+14    0.0  1.68E+14    0.0
            8 0.3814    3.82   2.95E+13    0.0  1.99E+14    0.0  1.97E+14    0.0
            9 0.3862    4.12   3.42E+13    0.0  2.31E+14    0.0  2.28E+14    0.0
           10 0.3880    4.23   3.60E+13    0.0  2.43E+14    0.0  2.40E+14    0.0

           11 0.3891    4.30   3.72E+13    0.0  2.52E+14    0.0  2.48E+14    0.0 ..
           12 0.3903    4.38   3.85E+13    0.0  2.60E+14    0.0  2.57E+14    0.0
           13 0.3909    4.41   3.91E+13    0.0  2.64E+14    0.0  2.61E+14    0.0
           14 0.3916    4.45   3.99E+13    0.0  2.69E+14    0.0  2.66E+14    0.0
           15 0.3922    4.50   4.07E+13    0.0  2.75E+14    0.0  2.71E+14    0.0

           16 0.3937    4.59   4.23E+13    0.0  2.86E+14    0.0  2.82E+14    0.0 ..
           17 0.3979    4.83   4.72E+13    0.0  3.19E+14    0.0  3.15E+14    0.0
           18 0.4022    5.06   5.23E+13    0.0  3.53E+14    0.0  3.49E+14    0.0
           19 0.4045    5.19   5.52E+13    0.0  3.73E+14    0.0  3.68E+14    0.0
           20 0.4081    5.39   6.01E+13    0.0  4.06E+14    0.0  4.00E+14    0.0

           21 0.4117    5.55   6.47E+13    0.0  4.37E+14    0.0  4.32E+14    0.0 ..
           22 0.4130    5.61   6.65E+13    0.0  4.49E+14    0.0  4.43E+14    0.0
           23 0.4139    5.65   6.77E+13    0.0  4.57E+14    0.0  4.51E+14    0.0
           24 0.4148    5.69   6.89E+13    0.0  4.65E+14    0.0  4.60E+14    0.0
           25 0.4153    5.71   6.96E+13    0.0  4.70E+14    0.0  4.64E+14    0.0

           26 0.4160    5.74   7.06E+13    0.0  4.76E+14    0.0  4.70E+14    0.0 ..
```

Figure 7.15 - Force Spectral Density Matrix of the Centre of Gravity

```
                  * * * * FORCE SPECTRAL DENSITY MATRIX * * * *
                          -----------------------------


                               SPECTRUM NUMBER  1
                               ------------------


FREQUENCY  SPECTRAL     SURGE(X)           SWAY(Y)            HEAVE(Z)
 (RAD/S)   ORDINATE    AMP    PHASE       AMP    PHASE       AMP    PHASE
-------------------------------------------------------------------------..

 1 0.2577    0.00   2.55E+07    0.0   6.63E+07   39.2   6.59E+07   76.7
                    6.63E+07   39.2   1.72E+08    0.0   1.71E+08   37.5
                    6.59E+07   76.7   1.71E+08   37.5   1.70E+08    0.0
                    8.51E+07   38.7   2.21E+08   -0.5   2.20E+08  -38.0
                    3.83E+09   -1.6   9.96E+09  -40.8   9.90E+09  -78.3
                    4.27E+09  117.7   1.11E+10   78.6   1.10E+10   41.1 ..

 2 0.2875    0.04   2.60E+10    0.0   6.75E+10   39.2   6.70E+10   76.7
                    6.75E+10   39.2   1.75E+11    0.0   1.74E+11   37.5
                    6.70E+10   76.7   1.74E+11   37.5   1.73E+11    0.0
                    8.66E+10   38.7   2.25E+11   -0.5   2.24E+11  -38.0
                    3.90E+12   -1.6   1.01E+13  -40.8   1.01E+13  -78.3
                    4.35E+12  117.7   1.13E+13   78.6   1.12E+13   41.1

 3 0.3173    0.43   8.86E+11    0.0   2.30E+12   39.2   2.29E+12   76.7 ..
                    2.30E+12   39.2   5.98E+12    0.0   5.95E+12   37.5
                    2.29E+12   76.7   5.95E+12   37.5   5.91E+12    0.0
                    2.96E+12   38.7   7.68E+12   -0.5   7.63E+12  -38.0
                    1.33E+14   -1.6   3.46E+14  -40.8   3.44E+14  -78.3
                    1.48E+14  117.7   3.86E+14   78.6   3.83E+14   41.1

 4 0.3316    0.90   2.71E+12    0.0   7.03E+12   39.2   6.99E+12   76.7 ..
                    7.03E+12   39.2   1.83E+13    0.0   1.82E+13   37.5
                    6.99E+12   76.7   1.82E+13   37.5   1.80E+13    0.0
                    9.03E+12   38.7   2.35E+13   -0.5   2.33E+13  -38.0
                    4.07E+14   -1.6   1.06E+15  -40.8   1.05E+15  -78.3
                    4.53E+14  117.7   1.18E+15   78.6   1.17E+15   41.1
```

Figure 7.16 - Force Spectral Density Matrix for the Coupled System

7.6.2 The Transfer or Receptance Matrix

The transfer or receptance matrix at the SIP is output for all six degrees of freedom for each structure and is in the same format as the force spectral density (Figure 7.15). The reference point is the centre of gravity of each structure in an axis system parallel to the Fixed Reference Axis (FRA), and not in the local axis system. The phase is referenced to the origin of the FRA.

Figure 7.15 shows the output FORMAT when the PRTI (PRint Transfer matrix at spectral Integration points) option is used. This output will be the leading diagonal of the matrix and hence gives no information about the relative phase of the transfer function between freedoms. Figure 7.16 shows the output FORMAT including the phase information for the coupled system when the PRCS (PRint Coupled Spectra information) is also used.

The transfer matrix is independent of the direction of the wave spectrum but will vary with each spectrum, wave and current which effect the stiffness and damping.

7.6.3 The RAOs at Spectrum Integration Points

The response amplitude operators (RAOs) at the SIP are output for all six degrees of freedom for each structure and are in the same format as the force spectral density (Figure 7.15). The reference point is the centre of gravity of each structure in a axis system parallel to the Fixed Reference Axis (FRA), and not in the local axis system. The phase is referenced to the origin of the FRA.

N.B. The force spectrum is that appropriate to the direction of the corresponding wave spectrum.

7.6.4 The Response Spectral Density

The response spectral density at the SIP is output for all six degrees of freedom for each structure (Figure 7.17). The reference point is the centre of gravity of each structure in an axis system parallel to the Fixed Reference Axis (FRA), and not in the local axis system. Phase information is not applicable.

Figure 7.18 shows the format of the output when the PRRS (PRint Response Spectrum) option is used. This output is the leading diagonal of the matrix and hence gives no information about the relative phase of the response spectrum between freedoms. Figure 7.18 shows the output format including the phase information for the coupled system when the PRCS (PRint Coupled Spectra information) is ALSO used.

```
                    * * * * R E S P O N S E   S P E C T R U M  * * * *
                            - - - - - - - - - - - - - - - - -


                                    SPECTRUM NUMBER  1
                                    ------------------
```

FREQUENCY (RAD/S)		SPECTRAL ORDINATE	SURGE(X)	SWAY(Y)	HEAVE(Z)	ROLL(RX)	PITCH(RY)	YAW(RZ)
1	0.2577	0.00	0.000	0.000	0.000	0.000	0.000	0.000
2	0.2875	0.04	0.002	0.008	0.000	0.049	0.000	0.013
3	0.3173	0.43	0.039	0.140	0.006	1.480	0.009	0.240
4	0.3316	0.90	0.098	0.319	0.018	4.737	0.029	0.558
5	0.3506	1.85	0.242	0.688	0.060	18.497	0.100	1.230
6	0.3697	3.05	0.446	1.142	0.151	74.403	0.257	2.047
7	0.3767	3.51	0.529	1.320	0.202	136.874	0.345	2.344
8	0.3814	3.82	0.588	1.454	0.243	224.684	0.418	2.538
9	0.3862	4.12	0.645	1.615	0.289	410.161	0.499	2.711
10	0.3880	4.23	0.666	1.693	0.307	532.667	0.532	2.769
11	0.3891	4.30	0.680	1.760	0.320	649.437	0.555	2.808
12	0.3903	4.38	0.695	1.841	0.333	806.839	0.579	2.846
13	0.3909	4.41	0.701	1.886	0.340	897.575	0.590	2.862
14	0.3916	4.45	0.710	1.951	0.348	1033.038	0.604	2.882
15	0.3922	4.50	0.718	2.028	0.356	1200.376	0.619	2.901
16	0.3937	4.59	0.735	2.253	0.373	1712.177	0.651	2.937
17	0.3979	4.83	0.783	5.202	0.427	8841.487	0.749	2.955
18	0.4022	5.06	0.829	64.330	0.487	145781.641	0.858	4.156
19	0.4045	5.19	0.854	6.718	0.521	11008.864	0.923	3.588
20	0.4081	5.39	0.893	2.989	0.580	2405.925	1.033	3.557
21	0.4117	5.55	0.927	2.399	0.641	1027.723	1.147	3.590
22	0.4130	5.61	0.939	2.310	0.664	811.177	1.191	3.606
23	0.4139	5.65	0.947	2.266	0.681	699.897	1.223	3.618
24	0.4148	5.69	0.955	2.232	0.697	610.132	1.255	3.630
25	0.4153	5.71	0.959	2.217	0.706	569.918	1.272	3.637
26	0.4160	5.74	0.965	2.198	0.720	515.869	1.298	3.647

Figure 7.17 - Response Spectrum for the Centre of Gravity

```
                    * * * * R E S P O N S E   S P E C T R U M  * * * *
                            - - - - - - - - - - - - - - - - -


                                  SPECTRUM NUMBER  1
                                  -----------------


      FREQUENCY  SPECTRAL  SURGE(X) SWAY(Y) HEAVE(Z)  ROLL(RX) PITCH(RY) YAW(RZ)
       (RAD/S)   ORDINATE
      --------------------------------------------------------------------------

       1 0.2577    0.00      0.000    0.000    0.000     0.000    0.000   0.000
                             0.000    0.000    0.000     0.000    0.000   0.000
                             0.000    0.000    0.000     0.000    0.000   0.000
                             0.000    0.000    0.000     0.000    0.000   0.000
                             0.000    0.000    0.000     0.000    0.000   0.000
                             0.000    0.000    0.000     0.000    0.000   0.000

       2 0.2875    0.04      0.002    0.003    0.000     0.000    0.000  -0.002
                             0.003    0.008   -0.001     0.000    0.000   0.000
                             0.000   -0.001    0.000     0.000    0.000   0.000
                             0.000    0.000    0.000     0.001    0.000   0.000
                             0.000    0.000    0.000     0.000    0.000   0.000
                             0.000    0.000    0.000     0.000    0.000   0.000

       3 0.3173    0.43      0.039    0.066   -0.002     0.001    0.000  -0.034
                             0.066    0.140   -0.015    -0.002   -0.001   0.000
                            -0.002   -0.015    0.006     0.001    0.000  -0.001
                             0.001   -0.002    0.001     0.026   -0.001  -0.010
                             0.000   -0.001    0.000    -0.001    0.000   0.000
                            -0.001    0.000   -0.001    -0.010    0.000   0.004

       4 0.3316    0.90      0.098    0.160   -0.005     0.002   -0.001  -0.078
                             0.160    0.319   -0.040    -0.006   -0.001   0.001
                            -0.005   -0.040    0.018     0.005    0.000  -0.002
                             0.002   -0.006    0.005     0.083   -0.002  -0.028
                            -0.001   -0.001    0.000    -0.002    0.001   0.001
                            -0.001    0.001   -0.002    -0.028    0.001   0.010
```

Figure 7.18 - Response Spectrum for the Centre of Gravity

7.7 SIGNIFICANT MOTIONS AND TENSIONS

The significant motions and tensions described in the following sections are given in term of amplitude i.e. significant peak-to-peak motions are twice the values output.

The spectrum numbers are simply the user input sequence and range from 1 to 20 (maximum). Six spectra are illustrated in the figures.

7.7.1 Significant Motions of the Centre of Gravity

Note that these motions (shown in Figure 7.19) are in local axis system, e.g. if a structure is yawed by 30 degrees, then the surge motions given are at 30 degrees to the X-axis of the Fixed Reference Axis system and the sway is at 30 degrees to the Y axis. Similarly, the roll motion referred to is about an axis at an angle of 30 degrees to the X axis of the Fixed Reference Axis system.

Six degrees of freedom are printed on each page of output.

Note that these values must be added to the mean motion to obtain the total motion of the centre of gravity.

```
          * * * * SIGNIFICANT MOTIONS OF CENTRE OF GRAVITY * * * *
                  ----------------------------------------

                  * * * * IN LOCAL VESSEL AXIS SYSTEM * * * *
                          ---------------------------

                          HAWSER COMBINATION NUMBER   1
                          -----------------------------

STRUCTURE SPECTRUM   SURGE      SWAY      HEAVE      ROLL     PITCH      YAW
 NUMBER    NUMBER  AMPLITUDE AMPLITUDE AMPLITUDE(DEGREES)(DEGREES)(DEGREES)
---------------------------------------------------------------------------
     1         1     0.040     0.145     0.593    0.342    0.026    0.267

               2     0.033     0.159     0.961    0.375    0.267    0.088

               3     0.056     0.176     0.961    0.335    0.267    0.288

               4     0.013     0.173     0.686    0.745    0.937    0.237

               5     0.025     0.139     0.681    0.955    0.262    0.872

               6     0.112     0.119     0.976    0.955    0.894    0.278

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

Figure 7.19 - Significant Motions of Centre of Gravity

7.7.2 Significant Motions of Specified Points

The significant motions of specified points are given in the Fixed Reference Axis system, i.e. if a node at the centre of gravity is a specified point, then the motions of this point will not, in general, be the same as the motions of the centre of gravity, output as in Figure 7.19.

In the line labelled NODE NUMBERS (Figure 7.20), when two node numbers are given (viz. 4 and 2), then this denotes that there were two node numbers specified by the user in Deck 18 and refers to the differential motion between the two points.

Up to 3 nodes are printed (9 motions) on each page of output (only two are illustrated).

Note that these values must be added to the mean motion to obtain the total motion of a point.

```
            * * * * SIGNIFICANT MOTIONS OF SPECIFIED POSITIONS * * * *
                    ------------------------------------------

                          MOORING COMBINATION NUMBER  1
                          -----------------------------

                          (MOTIONS GIVEN ARE AMPLITUDE)
                          -----------------------------

     ------------------------------------------------------------------
            INPUT SEQUENCE -          1                     2
     ------------------------------------------------------------------
     SPECTRUM NODE NUMBERS -          9                   4 AND 2
     ------------------------------------------------------------------ .....
      NUMBER  FREEDOM TYPE -    X      Y      Z       X      Y      Z
     ------------------------------------------------------------------ .....

         1                    0.146  0.032  0.455   0.146  0.052  0.555 .....

         2                    0.203  0.162  0.414   0.243  0.134  0.444

         3                    0.263  0.126  0.231   0.225  0.126  0.251

         4                    0.263  0.171  0.451   0.256  0.141  0.441

         5                    0.263  0.127  0.461   0.242  0.147  0.423

         6                    0.493  0.082  0.411   0.436  0.022  0.411

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

Figure 7.20 - Significant Motions of Specified Positions

7.7.3 Significant Tensions in Mooring Lines

In the lines labelled FROM NODE and TO NODE (Figure 7.21), two node numbers are given. These nodes are at the attachment points of each end of a mooring line. The number in brackets refers to the structure number which, if zero, signifies that the node is not connected to a structure but is fixed and therefore has no motion.

Up to 10 tensions are printed on each page of output (only 4 are illustrated).

N.B. These values must be added to the mean tension to obtain the maximum tension of a mooring line.

```
            * * * * SIGNIFICANT TENSIONS IN THE MOORING LINES * * * *
                    -----------------------------------------

                         MOORING COMBINATION NUMBER  1
                         -----------------------------

                        (TENSIONS GIVEN ARE AMPLITUDE)
                        ------------------------------


        ----------------------------------------------------------------
        MOORING LINE NUMBER       1          2          3          4
        ----------------------------------------------------------------
      SPECTRUM FROM NODE -    1( 1)     1( 1)     1( 1)     1( 1)
     ---------------------------------------------------------------- .....
         NUMBER    TO NODE -     1( 2)      2( 0)      3( 0)      3( 0)
        ---------------------------------------------------------------- .....

            1               9.6269E+05 9.0299E+05 9.0495E+05 9.0495E+05 .....

            2               8.6394E+05 8.9394E+05 8.9669E+05 8.9609E+05

            3               7.3456E+05 8.2453E+05 8.2637E+05 7.7459E+05

            4               7.9644E+05 7.2456E+05 7.3774E+05 7.7839E+05

            5               7.4654E+05 7.6394E+05 6.7237E+05 7.4509E+05

            6               6.9456E+05 7.6224E+05 5.7234E+05 8.3459E+05

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

Figure 7.21 - Significant Tensions in the Mooring Lines

CHAPTER 8 - EXAMPLE OF PROGRAM USE

In this chapter, an example problem using AQWA-FER 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 obtain 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-FER. However, certain preliminary calculations, which are shown in this example, are ESSENTIAL in order to:

- Minimise input data errors
- Minimise misinterpretation 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

The Significant Response Amplitude (SGA) of a structure is given by:

Response = 2 $*$ sqrt (Area Under the Response Spectrum)

In turn, the values of the response spectrum are given by the product of the force spectral density and the transfer function.

The magnitude of the force spectral density is governed by the wave forces per unit wave height, calculated by a diffraction/radiation analysis, and the spectrum input. Assuming that the frequencies chosen, at which to calculate the wave loading coefficients, adequately describe their variation with frequency/period, and the wave spectrum together with the current and wind is known, then the force spectrum is straight forward and preliminary calculations may only involve checking the peak value of the spectrum.

However, the form of the transfer function is governed by the natural frequencies and corresponding damping of the system, and should be checked wherever possible. Preliminary calculations will also show whether drift motions are important and may also avoid the necessity to perform a complete analysis. Particular attention should therefore be paid to Section 8.1.3.

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. The is the simplest and most common form of analysis, i.e. an AQWA-LINE run of Stages 1 to 3 followed by several AQWA-FER runs. 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-FER 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 may be 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	=	1.471E6 N/m
Pre-tension in each mooring line	=	1.471E6 newtons

It is required to obtain the response of the box in irregular waves for three given sea states. Both wave frequency and drift frequency motions are of interest. Note that the analysis is performed using SI units.

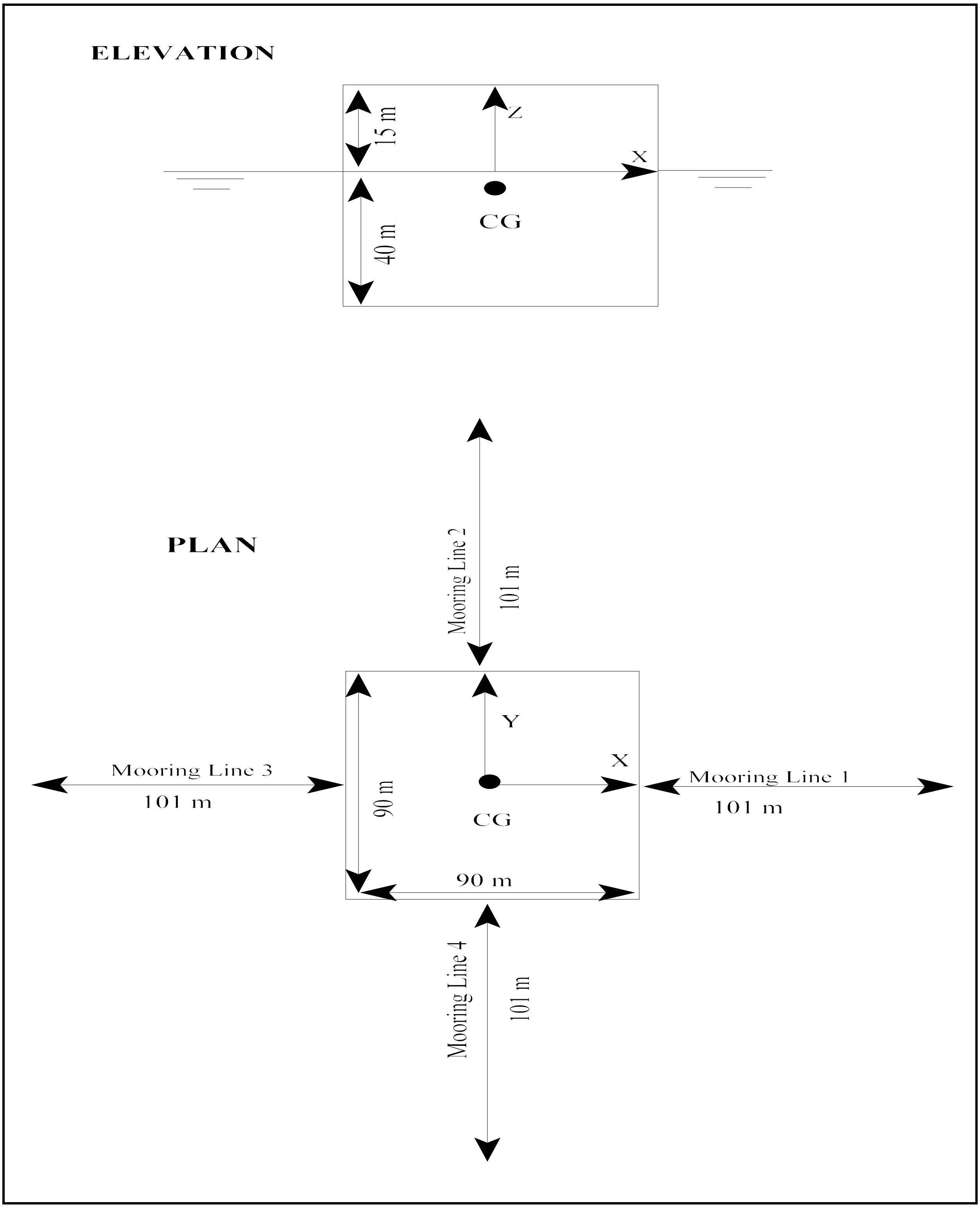

Figure 8.1 - Mooring Lines

8.1.3 Natural Frequencies

The first stage of preparing the data for AQWA-FER is always to inspect the natural frequencies of the structure to find where in the frequency range responses are likely to be significant.

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

Heave added mass = $2.30 * 10^8$ kg
Heave stiffness = $8.14 * 10^7$ N/m

The natural frequency squared is therefore $8.14 * 10^7 / (3.32 * 10^8 + 2.30 * 10^8)$ giving an uncoupled natural frequency as 0.380 radians/sec (natural period 16.5 seconds). This is the same as that output by AQWA-LINE as the heave freedom is not coupled with any other freedom due to the four-fold symmetry of the structure, which only has surge-pitch and sway-roll coupling. For a structure with only two-fold symmetry, sway-yaw and heave-pitch are normally coupled as well as surge-heave and roll-yaw. As the added variation is small, this is a good estimate of the natural frequency of 0.382 which is shown by AQWA-LINE. Note that the natural frequency is only meaningful when the values of added mass and damping are used at that natural frequency i.e. when the natural frequency and the frequency at which it is calculated are the same.

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

Pitch added mass inertia = $8.92 * 10^{10}$ kgm^2
Pitch stiffness = $2.44 * 10^{10}$ Nm/rad (neglecting the mooring lines)

The natural frequency squared is therefore $2.44 * 10^{10} / (3.42 * 10^{11} + 8.92 * 10^{10})$ giving an uncoupled natural frequency of 0.238 rad/sec (natural period 26.4 secs). This is the same as that output by AQWA-LINE, as the pitch freedom is only lightly coupled with surge. Little response at this frequency would be expected as there is little energy in most sea states at this frequency.

This means that all freedoms are essentially uncoupled and each freedom may be treated for checking purposes as a single degree of freedom system to a good approximation.

In the horizontal freedoms (surge, sway and yaw) 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-FER 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 $1.472*10^6$)

The natural frequency squared is therefore $2.94 * 10^6 / (3.32 * 10^8 + 3.02 * 10^8)$ 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:

$$K = T\, d\, (1+d/L)$$

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 224 secs).

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

At these frequencies of 0.0681 and 0.0281 rad/sec, drift motions may be significant and are therefore requested to be output by AQWA-FER.

8.1.4 Low Frequency Added Mass and Damping

It may be assumed that, at low frequency, the added mass and damping remain constant, because values of drift added mass for the horizontal freedoms asymptote to 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 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.

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 3 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

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

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

The corresponding moments at the centre of gravity (10.62 metres below the waterline, centre of area at Z = +7.5) are 1.32E3∗18.1 and 1.07E3∗18.1, 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 three wave spectra and their associated directions were used in this example:

	Spectrum Type	Frequency Range (radians/sec)	Significant Wave Height	Zero Crossing Period
Spectrum 1	Pierson-Moskowitz	0.30 - 1.00	4.0m	11.0 sec
Spectrum 2	Pierson-Moskowitz	0.30 - 1.00	6.0m	11.0 sec
Spectrum 3	Pierson-Moskowitz	0.30 - 1.00	8.0m	11.0 sec

The wind and current speeds and directions were the same for each spectrum as follows:

Wind speed	=	15.0 m/s
Wind direction	=	0.0 degrees
Current speed	=	0.8 m/s
Current direction	=	0.0 degrees

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 the 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 coordinate Deck 1. Each mooring line of unstretched length 100 metres has a stiffness of 1.471E6 newtons per metre.

Each mooring line is pretensioned to 1.471E6 newtons (i.e. extended by 1 metre) to give the structure a significant yaw stiffness.

8.1.8 Equilibrium Position for Analysis

The equilibrium positions used to position the structure for each analysis are normally obtained from AQWA-LIBRIUM. In simple cases, the equilibrium positions may be calculated manually. Note that the equilibrium position only affects the significant motions indirectly through the change in any in non-linear systems. Equilibrium positions given by AQWA-LIBRIUM for the three spectra chosen were as follows:

	Surge (X)	Sway (Y)	Heave (Z)	Roll (RX)	Pitch (RY)	Yaw (RZ)
Spectrum 1	0.0603	0.1773	-10.620	0.0125	0.0103	0.0000
Spectrum 2	0.3622	0.3018	-10.620	0.0213	-0.0110	0.0000
Spectrum 3	0.7695	0.0000	-10.620	0.0000	-0.0397	0.0000

8.1.9 Input Preparation For 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-FER DATA run are shown in Figure 8.2 and the input may be described as follows:

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

-	JOB	card	provides identifier program, and type of analysis to be used
-	TITLE	card	prescribes a title header for the run
-	OPTIONS	card	contains 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	contains the start and finish stages

Note that the current run, which starts at the beginning of Stage 4 and finishes at the end of Stage 4, is equivalent to running with the DATA option.

- Deck 9

  Low frequency or drift added mass and damping (values of these at the lowest wave frequency are used)

- Deck 10

  Wind and current loading coefficients

- Deck 11

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

- Deck 12

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

- Deck 13

  Description of the wave spectra
  Wind speed and direction for the spectra
  Current speed and direction for the spectra

- Deck 14

  Description of each mooring line property and combination

- Deck 15

  The equilibrium positions of the structure for each analysis

- Deck 16

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

- Deck 17

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

- Deck 18

  Additional output requests concerning the hawser attachment points

```
JOB BOX2  FER
TITLE                    TEST RUN NUMBER 20 (FLOATING BOX 40M DRAUGHT AND 48 FACETS)
OPTIONS REST END
RESTART   4  4
    91    DRM1
    91ADDM                3.0158E8  0.0000E0  0.0000E0  0.0000E0 -1.1166E9  0.0000E0
    91ADDM                0.0000E0  3.0158E8  0.0000E0  1.1166E9  0.0000E0  0.0000E0
    91ADDM                0.0000E0  0.0000E0  2.3050E8  0.0000E0  0.0000E0  0.0000E0
    91ADDM                0.0000E0  1.1166E9  0.0000E0  8.918E10  0.0000E0  0.0000E0
    91ADDM               -1.1166E9  0.0000E0  0.0000E0  0.0000E0  8.918E10  0.0000E0
    91ADDM                0.0000E0  0.0000E0  0.0000E0  0.0000E0  0.0000E0  1.269E11
    91DAMP                3.4758E7  0.0000E0  0.0000E0  0.0000E0 -3.1498E7  0.0000E0
    91DAMP                0.0000E0  3.4758E7  0.0000E0  3.1498E7  0.0000E0  0.0000E0
    91DAMP                0.0000E0  0.0000E0  1.9253E7  0.0000E0  0.0000E0  0.0000E0
    91DAMP                0.0000E0  3.1498E7  0.0000E0  3.0156E9  0.0000E0  0.0000E0
    91DAMP               -3.1498E7  0.0000E0  0.0000E0  0.0000E0  3.0156E9  0.0000E0
 END91DAMP                0.0000E0  0.0000E0  0.0000E0  0.0000E0  0.0000E0  3.0004E9
    10    HLD1
    10CUFX    1     3     2.9500E6  2.4000E6  0.0000E0
    10CUFY    1     3     0.0000E0  2.4000E6  2.9500E0
    10CURX    1     3     0.0000E0  2.2500E7  2.7700E7
    10CURY    1     3    -2.7700E7 -2.2500E7  0.0000E0
    10WIFX    1     3     1.3200E3  1.0700E3  0.0000E0
    10WIFY    1     3     0.0000E0  1.0700E3  1.3200E3
    10WIRX    1     3     0.0000E4 -1.9400E4 -2.3900E4
 END10WIRX    1     3     2.3900E4  1.9400E4  0.0000E4
    11    NONE
    12    NONE
    13    SPEC
    13CURR                     0.8       0.0
    13WIND                    15.0       0.0
    13SPDN                    90.0
    13PSMZ                     0.3       1.0       4.0      11.0
    13SPDN                    45.0
    13PSMZ                     0.3       1.0       6.0      11.0
    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
   15POS1    1     1      0.0603    0.1773  -10.6200    0.0125    0.0103    0.0000
   15POS1    2     1      0.3622    0.3018  -10.6200    0.0213   -0.0110    0.0000
END15POS1    3     1      0.7695    0.0000  -10.6200    0.0000   -0.0397    0.0000
   16    NONE
   17    NONE
   18    PROP
   18NODE    1   501
   18NODE    1   502
   18NODE    1   503
END18NODE    1   504
```

Figure 8.2 - Input for Data Run on Box Structure

8.1.10 Information Supplied by Data Run

The DATA run produces the following form of output and is shown in Figures 8.3 to 8.11.

Figure 8.3 AQWA-FER 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 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 user's attention

Figure 8.7 Constraints
In the present version of AQWA-FER, all freedoms are active and cannot be constrained, so the table shows all freedoms to be active

Articulations are not yet implemented

Figure 8.8 Formulated Spectra
The wave spectrum and current and wind conditions input in Deck 13 are tabulated showing also the number of spectral lines by default (the number of rasters is not at present applicable to an AQWA-FER analysis)

Figure 8.9 Cable/Mooring Line Configurations
Tabulation of the mooring lines in put in Deck 14 (Note that the cable group number is only applicable to non-linear mooring lines)

Figure 8.10 Initial Equilibrium Positions of the Centre of Gravity
Tabulation of the equilibrium position input in Deck 15

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)

```
JOB BOXM  FER

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

OPTIONS REST END

RESTART   4  4




               AAAAAA    QQQQQQ   WW       WW   AAAAAA         FFFFFFFF  EEEEEEEE   RRRRRR
              AAAAAAAA  QQQQQQQQ  WW       WW  AAAAAAAA        FFFFFFFF  EEEEEEEE  RRRRRRRR
              AA    AA  QQ    QQ  WW       WW  AA    AA        FF        EE        RR    RR
              AA    AA  QQ    QQ  WW       WW  AA    AA        FF        EE        RR    RR
              AAAAAAAA  QQ    QQ  WW       WW  AAAAAAAA  IIII  FFFFF     EEEEE     RRRRRRRR
              AAAAAAAA  QQ    QQ  WW   WW  WW  AAAAAAAA  IIII  FFFFF     EEEEE     RRRRRRRR
              AA    AA  QQ    QQ  WW   WW  WW  AA    AA        FF        EE        RRRRR
              AA    AA  QQ QQ QQ  WW   WW  WW  AA    AA        FF        EE        RR RRR
              AA    AA  QQQQQQQQ  WWWWWWWWWW  AA    AA        FF        EEEEEEEE  RR  RRR
              AA    AA   QQQQQQ    WWWWWWWW   AA    AA        FF        EEEEEEEE  RR   RRR
                            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 : TEST RUN NUMBER 20 (FLOATING BOX 40M DRAUGHT AND 48 FACETS)
```

Figure 8.3 - AQWA-FER Header Page Used for Identification

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

    91ADDM    0     2  0.00E+00  3.02E+08  0.00E+00  1.12E+09  0.00E+00  0.00E+00
    91ADDM    0     3  0.00E+00  0.00E+00  2.31E+08  0.00E+00  0.00E+00  0.00E+00
    91ADDM    0     4  0.00E+00  1.12E+09  0.00E+00  8.92E+10  0.00E+00  0.00E+00
    91ADDM    0     5 -1.12E+09  0.00E+00  0.00E+00  0.00E+00  8.92E+10  0.00E+00
    91ADDM    0     6  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  1.27E+11
    91DAMP    0     1  3.48E+07  0.00E+00  0.00E+00  0.00E+00 -3.15E+07  0.00E+00
    91DAMP    0     2  0.00E+00  3.48E+07  0.00E+00  3.15E+07  0.00E+00  0.00E+00
    91DAMP    0     3  0.00E+00  0.00E+00  1.93E+07  0.00E+00  0.00E+00  0.00E+00
    91DAMP    0     4  0.00E+00  3.15E+07  0.00E+00  3.02E+09  0.00E+00  0.00E+00
    91DAMP    0     5 -3.15E+07  0.00E+00  0.00E+00  0.00E+00  3.02E+09  0.00E+00
 END91DAMP    0     6  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  3.00E+09

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
    10CURX    1     3 0.000E+00 2.250E+07 2.770E+07 0.000E+00 0.000E+00 0.000E+00
    10CURY    1     3-2.770E+07-2.250E+07 0.000E+00 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
    10WIFY    1     3 0.000E+00 1.070E+03 1.320E+03 0.000E+00 0.000E+00 0.000E+00
    10WIRX    1     3 0.000E+00-1.940E+04-2.390E+04 0.000E+00 0.000E+00 0.000E+00
 END10WIRY    1     3 2.390E+04 1.940E+04 0.000E+00 0.000E+00 0.000E+00 0.000E+00

DECK 11
-------

DECK 12
-------

DECK 13
-------

    13CURR    0    0     0.800     0.000     0.000     0.000     0.000     0.000
    13WIND    0    0    15.000     0.000     0.000     0.000     0.000     0.000
    13SPDN    0    0    90.000     0.000     0.000     0.000     0.000     0.000
    13PSMZ    0    0     0.300     1.000     4.000    11.000     0.000     0.000
    13SPDN    0    0    45.000     0.000     0.000     0.000     0.000     0.000
    13PSMZ    0    0     0.300     1.000     6.000    11.000     0.000     0.000
    13SPDN    0    0     0.000     0.000     0.000     0.000     0.000     0.000
 END13PSMZ    0    0     0.300     1.000     8.000    11.000     0.000     0.000

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
-------

    15POS1    1    1     0.060     0.177   -10.620     0.013     0.010     0.000
    15POS1    2    1     0.362     0.302   -10.620     0.021    -0.011     0.000
 END15POS1    3    1     0.770     0.000   -10.620     0.000    -0.040     0.000

DECK 16
-------
DECK 17
-------
DECK 18
-------

    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 10

H Y D R O D Y N A M I C   P A R A M E T E R S   F O R   S T R U C T U R E   1

ADDED MASS AT DRIFT FREQUENCY

	X	Y	Z	RX	RY	RZ
X	3.0158E+08	0.0000E+00	0.0000E+00	0.0000E+00	-1.1166E+09	0.0000E+00
Y	0.0000E+00	3.0158E+08	0.0000E+00	1.1166E+09	0.0000E+00	0.0000E+00
Z	0.0000E+00	0.0000E+00	2.3050E+08	0.0000E+00	0.0000E+00	0.0000E+00
RX	0.0000E+00	1.1166E+09	0.0000E+00	8.9180E+10	0.0000E+00	0.0000E+00
RY	-1.1166E+09	0.0000E+00	0.0000E+00	0.0000E+00	8.9180E+10	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	3.4758E+07	0.0000E+00	0.0000E+00	0.0000E+00	-3.1498E+07	0.0000E+00
Y	0.0000E+00	3.4758E+07	0.0000E+00	3.1498E+07	0.0000E+00	0.0000E+00
Z	0.0000E+00	0.0000E+00	1.9253E+07	0.0000E+00	0.0000E+00	0.0000E+00
RX	0.0000E+00	3.1498E+07	0.0000E+00	3.0156E+09	0.0000E+00	0.0000E+00
RY	-3.1498E+07	0.0000E+00	0.0000E+00	0.0000E+00	3.0156E+09	0.0000E+00
RZ	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	3.0004E+09

Figure 8.5 - Drift 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)
  ------   ---------   --------------------------
  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 -1.94E+04 -2.39E+04

  PITCH(RY)          2.39E+04  1.94E+04  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  2.25E+07  2.77E+07

  PITCH(RY)         -2.77E+07 -2.25E+07  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        X        X        X
```

Figure 8.7 - Constraints

F O R M U L A T E D   S P E C T R A

SPECTRUM NUMBER	SPECTRUM TYPE	NUMBER OF LINES	NUMBER OF RASTERS	LOWER FREQUENCY (RAD/SEC)	UPPER FREQUENCY (RAD/SEC))	PARAMETERS 1	PARAMETERS 2	PARAMETERS 3	SPECTRAL DIRECTION (DEGREES)	CURRENT SPEED	CURRENT DIRECTION (DEGREES)	WIND SPEED	WIND DIRECTION (DEGREES)
1	PIERSON-M	50	5000	0.3000	1.0000	4.0000	11.0000	0.0000	90.0	0.800	0.0	15.0	0.0
2	PIERSON-M	50	5000	0.3000	1.0000	6.0000	11.0000	0.0000	45.0	0.800	0.0	15.0	0.0
3	PIERSON-M	50	5000	0.3000	1.0000	8.0000	11.0000	0.0000	0.0	0.800	0.0	15.0	0.0

Figure 8.8 - Formulated Spectra

```
                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 CABLE  CABLE       CABLE    ATTACHED TO  AT NODE  LINKED TO   AT NODE  UNSTRETCHED  FORCE OR
                                                                     +
  NUMBER    NUMBER GROUP       TYPE     STRUCT/ELEM  NUMBER   STRUCTURE   NUMBER     LENGTH     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 8.9 - Cable/Mooring Line Configurations

I N I T I A L   E Q U I L I B R I U M   P O S I T I O N S   O F   T H E

C E N T R E   O F   G R A V I T Y

HAWS. COMB NUMBER	STRUCTURE NUMBER	SPECTRUM NUMBER	TRANSLATIONAL POSITION(FRA) X	Y	Z	ROTATION ABOUT AXES(FRA) RX	RY	RZ
1	1	1	0.060	0.177	-10.620	0.013	0.010	0.000
		2	0.362	0.302	-10.620	0.021	-0.011	0.000
		3	0.770	0.000	-10.620	0.000	-0.040	0.000

Figure 8.10 - Initial Equilibrium Positions of the Centre of Gravity

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 AXES X	Y	Z	RELATIVE TO THE CENTRE OF GRAVITY X	Y	Z
1	501	POSITION	45.762	0.000	0.031	44.993	0.000	10.651
1	502	POSITION	0.762	45.000	0.000	-0.007	45.000	10.620
1	503	POSITION	-44.238	0.000	-0.031	-45.007	0.000	10.589
1	504	POSITION	0.762	-45.000	0.000	-0.007	-45.000	10.620

Figure 8.11 - Position of User-Requested Nodes

8.1.11 The Motion Analysis Run

Once the user is satisfied that the data input in Decks 8 to 18 are correct, the motion analysis stage can then be performed.

As a program restart is being performed, the user must stream the RESTART and EQUILIBRIUM POSITION files 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, except for the equilibrium positions which are contained in the EQUILIBRIUM POSITION FILE.

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

```
JOB BOX2  FER
TITLE                  MOTION ANALYSIS (FLOATING BOX 40M DRAUGHT AND 48 FACETS)
OPTIONS REST END
RESTART   5  5
```

Figure 8.12 - Data Input for Stage 5 in Box Example

8.1.12 Output from the Motion Analysis Run

The output relating to the motion analysis stage (i.e. Stage 5) contains the following information, which is shown in Figures 8.13 to 8.17.

Figure 8.13 - Undamped Natural Frequencies/Periods

These are given only at the values of frequency input in Deck 6 of the AQWA-LINE data file. The natural frequencies for the vertical freedoms are very similar to those output by AQWA-LINE. This is because:

- The box is input in the same orientation as the analysis position in AQWA-LINE
- No other structures are coupled to the box. The mooring line stiffness is small compared to the hydrostatic stiffness

As the stiffness in the horizontal freedoms is now non-zero, natural frequencies are also given for these freedoms.

Note also that in this example modes 1 to 6 correspond directly to the translational followed by rotation X,Y,Z freedoms.

Figure 8.14 - Damped Natural Frequencies/Periods

These are given at the mid-range of the drift frequency (defined by the 0.3 start frequency of the spectrum input in Deck 13) and at the wave frequency spectrum integration points, which are chosen by AQWA-FER to give an accurate discretisation of the transfer function and spectrum.

These frequencies are sorted in ascending order, as the order of output from an eigenvalue solution of the equations of motions for a coupled system of equations is somewhat arbitrary, and in general not related to the order of the freedoms input.

Note that the high damping in the surge and sway freedoms reduces the values of the natural frequencies more as the frequency increases and eventually eliminates them. This phenomenon is, however, of academic interest, as the natural frequency itself is in the drift frequency range.

Figure 8.15 - Significant Motions of Centre of Gravity

These motions are given in the local vessel axis system.

Figure 8.16 - Significant Motions of Specified Positions

These motions are given in the Fixed Reference Axis System.

Figure 8.17 - Significant Tensions in the Mooring Lines

U N D A M P E D   N A T U R A L   F R E Q U E N C I E S / P E R I O D S

N.B. THESE NATURAL FREQUENCIES ARE FOR THE FULL STRUCTURAL SYSTEM (THIS INCLUDES MOORING LINES)
THEY ARE CALCULATED AT THE FREQUENCIES OF THE FIRST STRUCTURE

SPECTRUM NUMBER 1

FREQUENCY NUMBER	FREQUENCY (RAD/S)	UNDAMPED NATURAL FREQUENCIES(RADIANS/SECOND) MODE 1	MODE 2	MODE 3	MODE 4	MODE 5	MODE 6
1	0.349	0.068	0.068	0.381	0.236	0.242	0.028
2	0.370	0.068	0.068	0.382	0.236	0.242	0.028
3	0.381	0.068	0.068	0.382	0.236	0.242	0.028
4	0.393	0.069	0.069	0.383	0.236	0.242	0.028
5	0.419	0.070	0.070	0.384	0.236	0.242	0.028
6	0.449	0.073	0.073	0.384	0.236	0.242	0.028
7	0.524	0.079	0.079	0.383	0.236	0.242	0.028

PERIOD NUMBER	PERIOD (SECONDS)	UNDAMPED NATURAL PERIOD(SECONDS) MODE 1	MODE 2	MODE 3	MODE 4	MODE 5	MODE 6
1	18.00	92.66	92.62	16.51	26.60	25.98	224.68
2	17.00	92.37	92.33	16.45	26.60	25.98	224.84
3	16.50	91.99	91.95	16.43	26.60	25.98	224.96
4	16.00	91.41	91.37	16.40	26.59	25.98	225.04
5	15.00	89.53	89.49	16.38	26.59	25.98	225.38
6	14.00	86.66	86.63	16.37	26.59	25.98	225.76
7	12.00	79.25	79.22	16.41	26.59	25.98	227.24

Figure 8.13 - Undamped Natural Frequencies/Periods

D A M P E D   N A T U R A L   F R E Q U E N C I E S / P E R I O D S

N.B. THESE FREQUENCIES ARE SORTED IN ASCENDING ORDER. DAMPING GIVEN IS PERCENTAGE CRITICAL

SPECTRUM NUMBER 1

FREQUENCY NUMBER	FREQUENCY (RAD/S)	NAT/FREQ 1 FREQ	NAT/FREQ 1 DAMPING	NAT/FREQ 2 FREQ	NAT/FREQ 2 DAMPING	NAT/FREQ 3 FREQ	NAT/FREQ 3 DAMPING	NAT/FREQ 4 FREQ	NAT/FREQ 4 DAMPING	NAT/FREQ 5 FREQ	NAT/FREQ 5 DAMPING	NAT/FREQ 6 FREQ	NAT/FREQ 6 DAMPING
1	0.150	0.0279	11.0	0.0621	40.3	0.0621	40.2	0.2362	1.5	0.2417	1.5	0.3802	4.5
2	0.310	0.0279	11.0	0.0621	40.3	0.0621	40.2	0.2362	1.5	0.2417	1.5	0.3802	4.5
3	0.329	0.0279	11.0	0.0621	40.3	0.0621	40.2	0.2362	1.5	0.2417	1.5	0.3802	4.5
4	0.350	0.0279	11.0	0.0618	41.2	0.0618	41.1	0.2362	1.5	0.2417	1.5	0.3802	4.5
5	0.373	0.0279	11.0	0.0560	56.9	0.0560	56.9	0.2362	1.5	0.2417	1.5	0.3817	4.3
6	0.397	0.0278	11.0	0.0451	75.6	0.0451	75.6	0.2362	1.5	0.2418	1.5	0.3828	3.9
7	0.422	0.0199	95.9	0.0200	95.9	0.0278	11.0	0.2362	1.5	0.2418	1.5	0.3835	3.5
8	0.449	0.0277	11.0	0.2362	1.5	0.2418	1.5	0.3838	3.0				
9	0.477	0.0277	11.2	0.2362	1.4	0.2418	1.5	0.3834	2.5				
10	0.508	0.0276	11.5	0.2362	1.4	0.2418	1.5	0.3830	2.0				
11	0.762	0.0275	11.7	0.2362	1.4	0.2418	1.5	0.3828	1.8				

PERIOD NUMBER	PERIOD (SECONDS)	NAT/PERIOD 1 PERIOD	NAT/PERIOD 1 DAMPING	NAT/PERIOD 2 PERIOD	NAT/PERIOD 2 DAMPING	NAT/PERIOD 3 PERIOD	NAT/PERIOD 3 DAMPING	NAT/PERIOD 4 PERIOD	NAT/PERIOD 4 DAMPING	NAT/PERIOD 5 PERIOD	NAT/PERIOD 5 DAMPING	NAT/PERIOD 6 PERIOD	NAT/PERIOD 6 DAMPING
1	41.89	225.40	11.0	101.23	40.3	101.21	40.2	26.60	1.5	25.99	1.5	16.53	4.5
2	20.30	225.40	11.0	101.23	40.3	101.21	40.2	26.60	1.5	25.99	1.5	16.53	4.5
3	19.08	225.40	11.0	101.23	40.3	101.21	40.2	26.60	1.5	25.99	1.5	16.53	4.5
4	17.93	225.41	11.0	101.65	41.2	101.63	41.1	26.60	1.5	25.99	1.5	16.52	4.5
5	16.86	225.59	11.0	112.18	56.9	112.14	56.9	26.60	1.5	25.99	1.5	16.46	4.3
6	15.85	225.81	11.0	139.30	75.6	139.19	75.6	26.60	1.5	25.99	1.5	16.41	3.9
7	14.89	316.09	95.9	314.42	95.9	226.14	11.0	26.60	1.5	25.99	1.5	16.38	3.5
8	14.00	226.50	11.0	26.60	1.5	25.99	1.5	16.37	3.0				
9	13.16	227.15	11.2	26.60	1.4	25.99	1.5	16.39	2.5				
10	12.37	227.83	11.5	26.60	1.4	25.99	1.5	16.41	2.0				
11	8.25	228.18	11.7	26.60	1.4	25.99	1.5	16.42	1.8				

Figure 8.14 - Damped Natural Frequencies

```
S I G N I F I C A N T   M O T I O N S   O F   C E N T R E   O F   G R A V I T Y
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
              I N   L O C A L   V E S S E L   A X I S   S Y S T E M
              - - - - - - - - - - - - - - - - - - - - - - - - - - -

                         HAWSER COMBINATION NUMBER   1
                         -----------------------------
```

STRUCTURE NUMBER	SPECTRUM NUMBER	SURGE AMPLITUDE	SWAY AMPLITUDE	HEAVE AMPLITUDE	ROLL (DEGREES)	PITCH (DEGREES)	YAW (DEGREES)
1	1	0.000	0.974	2.856	0.185	0.000	0.001
	2	1.128	1.127	4.287	0.179	0.193	0.001
	3	2.236	0.000	5.715	0.000	0.431	0.000

Figure 8.15 - Significant Motions of the Centre of Gravity

S I G N I F I C A N T   M O T I O N S   O F   S P E C I F I E D   P O S I T I O N S

MOORING COMBINATION NUMBER 1

(MOTIONS GIVEN ARE AMPLITUDE)

INPUT SEQUENCE -	1			2			3		
SPECTRUM NODE NUMBERS -	501			502			503		
NUMBER FREEDOM TYPE -	X	Y	Z	X	Y	Z	X	Y	Z
1	0.000	1.001	2.856	0.000	1.001	2.780	0.000	1.001	2.856
2	1.151	1.148	4.209	1.151	1.148	4.215	1.151	1.148	4.369
3	2.279	0.000	5.545	2.279	0.000	5.715	2.279	0.000	5.899

S I G N I F I C A N T   M O T I O N S   O F   S P E C I F I E D   P O S I T I O N S

MOORING COMBINATION NUMBER 1

(MOTIONS GIVEN ARE AMPLITUDE)

INPUT SEQUENCE -	4			5			6		
SPECTRUM NODE NUMBERS -	504								
NUMBER FREEDOM TYPE -	X	Y	Z	X	Y	Z	X	Y	Z
1	0.000	1.001	2.938						
2	1.151	1.148	4.363						
3	2.279	0.000	5.715						

Figure 8.16 - Significant Motions of Specified Positions

```
                 S I G N I F I C A N T   T E N S I O N S   I N   T H E   M O O R I N G   L I N E S
                 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

                                        MOORING COMBINATION NUMBER  1
                                        -----------------------------
                                (TENSIONS GIVEN ARE AMPLITUDE.UNITS - FORCE)

------------------------------------------------------------------------------------------------------------------------------------
 MOORING LINE NUMBER      1          2          3          4          5          6          7          8          9          10
------------------------------------------------------------------------------------------------------------------------------------
SPECTRUM FROM NODE -   501( 1)    502( 1)    503( 1)    504( 1)
------------------------------------------------------------------------------------------------------------------------------------
 NUMBER    TO NODE -   511( 0)    512( 0)    513( 0)    514( 0)
------------------------------------------------------------------------------------------------------------------------------------

    1                4.1443E+04 1.4733E+06 4.6907E+04 1.4736E+06

    2                1.6888E+06 1.6837E+06 1.7005E+06 1.6971E+06

    3                3.3526E+06 9.3384E+04 3.3554E+06 9.3384E+04

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

Figure 8.17 - Significant Tensions in the Mooring Lines

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-FER 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-FER:

(**.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-FER 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.

(**.trc**) file - **diagnostics** file

This file contains progress diagnostics (if any) from the program run. This is a normal ASCII text file.

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

A batch command file is provided for running all the AQWA programs. This file should be located in directory c:\aqwa and is named aqwa.bat. AQWA programs can be run from any directory provided the c:\aqwa directory is included in the PATH statement.

To run AQWA-FER, simply type:

aqwa fer runid

where **runid** is the run identifier.

(Note the space between **aqwa** and the program name).

The run identifier identifies the data files for the analysis and is also used to name files created by the run (see above). If the run identifier is not understood, the program will prompt for a new run identifier, which should be entered without any leading or embedded spaces.

For AQWA-FER, 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:

aqwa line boxm

copy alboxm.res afboxm.res

aqwa fer boxm

APPENDIX A - AQWA-FER PROGRAM OPTIONS LIST

The options listed below may be used when running the program AQWA-FER. 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-FER

REST - RESTART Option

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

DATA - DATA Option

This option is used to check the data input to the program. This option is equivalent to performing the first two stages of the program analysis (see Sections 6.1 and 6.2). If the data proved to be correct, then the program would be restarted at Stage 3 of the AQWA-LINE analysis by using the RESTART option.

CRNM - CALCULATE RAOs WITH NO MOORINGS

This option instigates the calculation of RAOs for a body using the values of Added Mass, Wave Damping, Stiffness and Wave forcing specified by the user but does NOT include the stiffness from mooring lines. These RAOs may then be used to compare with those WITH mooring lines to ascertain the effect of the mooring lines on the response. The RAOs are then written into the database.

PPEL - PRINT PROPERTIES of Each Element on Each Structure

This option allows the user to output the 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 used when running AQWA-FER as an independent program and, until further elements are available, is of limited usefulness.

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, 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.

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).

PRDL - PRINT DATA LIST FROM RESTART FILE

This option reads the data contained within the restart backing file and outputs it to the user. Typically, all body modelling information is output together with environmental wave loading details.

CRAO - Calculate RAOs

Informs AQWA-FER to calculate and output the RAOs for each structure INCLUDING the mooring lines but assuming each body is independently moving. These may be used to assess the effect of the coupling of the complete system, by comparing these RAOs with those for the fully coupled system (see OPTION PRRI). This is done for the first spectrum of each mooring line combination only unless the PRRP option is used.

PRRP - PRINT RECALCULATED PARAMETERS

Informs AQWA-FER to print certain parameters where they are recalculated FOR EACH SPECTRUM. At present, this applies to the:

(i) Calculation of RAOs (CRAO option)
(ii) Undamped and damped natural frequencies (output by default for the first spectrum automatically)

PRRI - PRINT RAOS AT SPECTRA INTEGRATION POINTS

This option is used to output the FULLY COUPLED RAOs which are used to calculate the response spectrum. The peak values will not generally be contained in the output, as this is not necessary for accurate integration of the response spectra, which is achieved in AQWA-FER within one percent. However, the peak value will never exceed the values output by more than 80 percent, provided the damping exceeds one half percent critical at low frequencies and one and a half percent critical at wave frequency.

Note that these RAOs are calculated for the direction of the corresponding spectra in the **fixed reference axis system.**

PRTI - PRINT TRANSFER MATRIX AT SPECTRA INTEGRATION POINT

This option is used to output the transfer matrix at the integration points of the response spectra for the FULLY COUPLED system of the equations of motion. By default, this option only outputs the leading diagonal of this matrix, which therefore omits the information relating to the phase between the freedoms the structures. DO NOT use this option if the information is not required, as the computing costs are substantially increased during integration of the wave frequency motions.

The complete matrix may be output by using the PRCS option in addition to this option.

PRFS - PRINT FORCE SPECTRAL DENSITY MATRIX AT SPECTRA INTEGRATION POINTS

This option is used to output the wave force spectra for both drift and wave frequency, at the integration points of the response spectra, for the direction the corresponding spectra. By default, this option only outputs the leading diagonal of this matrix, which therefore omits the information relating to the phase between the freedoms the structures.

The complete matrix may be output by using the PRCS option in addition to this option.

N.B. The forces are in the **fixed reference axis system**.

PRRS - PRINT RESPONSE SPECTRUM AT SPECTRA INTEGRATION POINTS

This option is used to output the RESPONSE SPECTRUM at the integration points of the response spectra for the FULLY COUPLED system of the equations of motion. By default, this option only output the leading diagonal of this matrix, which therefore omits the information relating to the phase between the freedoms the structures.

The complete matrix may be output by using the PRCS option in addition to this option.

N.B. The response is in the **fixed reference axis system**.

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 data and the static environment (see Section 6.1).

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