AQWA™-LIBRIUM MANUAL

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CHAPTER 1 - INTRODUCTION

1.1 PROGRAM INTRODUCTION

AQWA-LIBRIUM is a computer program which finds the static equilibrium configuration of a floating system, calculates the mooring loads and examines the static and/or dynamic stability about this position. The program has the following three modes of operation:

1. Find STATIC equilibrium position, report mooring loads and investigate the static stability characteristics.

2. Given static equilibrium position, investigate the slow DYNAMIC stability characteristics.

3. Find static equilibrium position, report mooring loads and investigate both STATIC and slow DYNAMIC stability characteristics.

The static equilibrium configuration will form the basis of dynamic analyses of floating systems.

1.2 MANUAL INTRODUCTION

The AQWA-LIBRIUM 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-LIBRIUM. When using AQWA-LIBRIUM, the user may either model the component body forms or provide their hydrostatic stiffness properties and specify a mooring configuration and environmental conditions.

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-LIBRIUM User Manual and AQWA Reference Manual be available when running the program AQWA-LIBRIUM.

CHAPTER 2 - PROGRAM DESCRIPTION

AQWA-LIBRIUM gives the equilibrium configuration and the stability properties, both static and dynamic, of a system of one or more floating bodies under the influence of mooring lines, steady wind, current, thrusters and wave drifting forces.

2.1 PROGRAM CAPABILITIES

The program can accommodate up to ten bodies, twenty sea spectra and one hundred mooring lines. The mooring lines may be grouped together in **not** more than 25 combinations. The program loops over the mooring combinations and sea spectra with the latter being the inner loop. A mooring line can be modelled as a linear or non-linear elastic weightless hawser, a force with constant magnitude and direction, a constant winch force or a uniform catenary chain. The sea spectra may take the Pierson-Moskowitz or JONSWAP form or numerical values supplied by the user.

The equilibrium position of each of the bodies is described by six coordinates, three translational and three rotational. The static stability of the complete system is assessed through an eigenvalue analysis of the global stiffness matrix at equilibrium. The global stiffness matrix is non-linear and comprises of hydrostatic pressures, mooring tensions and 'stiffness' due to the variation in wind, current and wave drifting forces and moments with heading.

The slow dynamic stability of the system is assessed through an eigenvalue analysis of the equations of small perturbations from the equilibrium position in the horizontal plane (i.e. surge, sway and yaw **only**). In addition to the wind, current, mooring, thruster and steady drift forces, the analysis also accounts for the mass moment of inertia, added mass and damping of the bodies at 'drift frequencies'.

Given an initial guess of the equilibrium configuration, AQWA-LIBRIUM moves the bodies in steps towards the final position via a series of finite displacements. The displacements in each step are determined by summing the residual forces and moments acting on the bodies and forming the stiffness matrix of the system at its latest position. **Only** time invariant forces and moments are permitted in the analysis. Once equilibrium is reached, the program reports all the mooring forces, the local mooring stiffness matrices, the global stiffness matrix, and examines the stability of the system.

The equilibrium configuration determined by AQWA-LIBRIUM may be used as a starting point for analyses carried out by other modules in the AQWA suite (e.g. AQWA-DRIFT, AQWA-FER and AQWA-LINE), and of course as input to the dynamic stability part of AQWA-LIBRIUM.

2.2 THE COMPUTER PROGRAM

The program AQWA-LIBRIUM may be used on its own or as an integral part of the AQWA SUITE of rigid body response programs. When AQWA-LIBRIUM has been run, a data base is automatically created which contains full details of the forces acting on the body. Another backing file, called the RESTART FILE, is also created and this contains all modelling information relating to the body or bodies being analysed. These two files may be used with subsequent AQWA-LIBRIUM runs. 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 slow drift coefficients being input to AQWA-LIBRIUM for a slow dynamic stability analysis.

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

The programs within the AQWA SUITE are as follows:

AQWA-LIBRIUM Used to find the equilibrium characteristics of a moored or freely floating body or bodies. Steady state environmental loads may also be considered to act on the body (e.g. wind, wave drift and current).

AQWA-LINE Used to calculate the wave loading and response of bodies when exposed to a regular harmonic wave environment. The first order wave forces and second order mean wave drift forces are calculated in the frequency domain.

AQWA-FER Used to analyse the coupled or uncoupled response of floating bodies operating in irregular waves. The analysis is performed in the frequency domain.

AQWA-NAUT Used to simulate the real-time motion behaviour of a floating body or bodies operating in regular waves. Wind and current loads may also be considered, and the body motions may be coupled or uncoupled.

AQWA-DRIFT Used to simulate the real-time motion behaviour of a floating body or bodies operating in irregular waves. The program has particular application to long period wave drift induced motions. Wind and current loading may also be applied to the body.

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

CHAPTER 3 - THEORETICAL FORMULATION

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

3.1 HYDROSTATIC LOADING

AQWA-LIBRIUM calculates the hydrostatic forces and moments directly from the integral of hydrostatic pressure on all the elements which make up the submerged part of the body. The cut waterplane area together with the locations of the centre of buoyancy and the centre of gravity of the body determine the hydrostatic stiffness matrix. As each body is moved towards equilibrium, the hydrostatics are recalculated based on the new submerged volume.

In AQWA-LIBRIUM, the hydrostatic forces and stiffnesses acting on each body are specified with respect to a set of axes whose origin is located at, and move with, the **centre of gravity** of the body, while the axes remain parallel to the **fixed reference axes** (see Section 4.3) at all times. The hydrostatic stiffness matrix is as follows:

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

whe
re the various terms in the hydrostatic stiffness matrix (K_{hys}) are:

$$K33 = A$$

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

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

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

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

$$K46 = -x_{gb}.vol$$

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

$$K56 = -y_{gb} . vol$$

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

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

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

Note that K_{46} and K_{56} will be zero and the stiffness matrix symmetric if the centre of buoyancy and the centre of gravity are located on the same vertical line. For a freely floating body in EQUILIBRIUM, this is automatically the case (however before equilibrium is reached, the matrix will not be symmetric). In general, if the body is in EQUILIBRIUM under the influence of mooring lines the centre of buoyancy and the centre of gravity will not be located on the same vertical line. Hence the hydrostatic stiffness matrix can be asymmetric while the global system stiffness matrix will still be symmetric.

There are instances where the detailed geometry of the bodies is not available or not required. The user may input directly a buoyancy force and a stiffness matrix which will be assumed constant throughout the analysis.

3.2 MORISON FORCES

These forces are only determined for tubular members of a structure. The full Morison equation for the fluid forces acting on a unit length of such a structural member is

$$dF = 0.5\rho . C_d D(u_f - u_s)|u_f - u_s| + \rho . AC_m \dot{u}_f - \rho A(C_m - 1)\dot{u}_s \qquad (3.2.1)$$

(Drag Force) (Inertia Force)

where

C_d	=	drag coefficient
D	=	characteristic drag diameter
u_f	=	fluid velocity
u_s	=	structure velocity
C_m	=	inertia coefficient
A	=	area of cross section
ρ	=	fluid density

Note that all accelerations are zero in AQWA-LIBRIUM.

Full account is taken of fluid velocity variation over the tube length.

The force arising from components of velocity in line with the tube axis is assumed to be zero and forces acting on the tube end discs are ignored.

Forces and Moments are calculated with respect to the local tube axis system as shown in Figure 3.1, then transformed to the CG axis system.

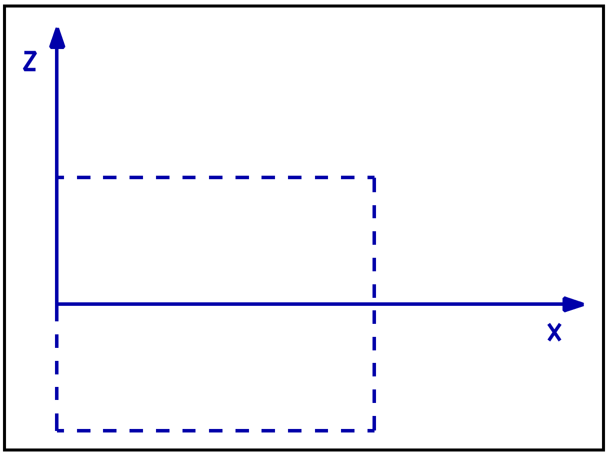

Figure 3.1 - Local Tube Axis System

In general a partially submerged tube which is arbitrarily inclined may have a section which is either completely submerged, partially submerged, or completely out of the water. Each tube element is classified as above and the forces and moments for each section are summed to obtain the total fluid drag load.

For static stability calculations only the tube drag force term is considered since the structure and fluid accelerations are zero.

3.3 DIFFRACTION/RADIATION WAVE FORCES

Not applicable to AQWA-LIBRIUM (see AQWA-LINE Manual).

3.4 MEAN WAVE DRIFT FORCES

This section is applicable **only if** it is considered that the mean wave drift force significantly affects the equilibrium configuration and the mooring loads.

The wave drifting forces and moments are calculated from a set of drift coefficients, D(w), and a wave energy spectrum, S(w). The coefficients are specified over a range of frequencies and directions. The mean wave drift force is given by:

$$\overline{F}_d = 2\int_0^{\infty} S(w)\ D(w)\, dw \qquad (3.4.1)$$

The coefficients for any specific heading angle are obtained through linear interpolation. If required, these coefficients may be supplied by AQWA-LINE. Only the steady component of the drifting forces and moments are computed in the program (see Section 3.4 of AQWA-LINE User Manual for derivation of the wave drift coefficients).

3.5 VARIABLE WAVE DRIFT FORCES

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

3.6 INTERACTIVE FLUID LOADING

Not applicable to AQWA-LIBRIUM (see AQWA-LINE Manual).

3.7 STRUCTURAL ARTICULATIONS AND CONSTRAINTS

It is quite common in the analysis of floating systems to have one or more singular degree of freedom causing failure in the solution of the equations. For the majority of floating systems, the program checks and removes these degrees of freedom such that the global stiffness matrix becomes non-singular and the displacements in the singular coordinates are zero. However, for more complicated systems the user can constrain directly specific degrees of freedom. This is achieved by assigning the relevant d.o.f. to zero displacement. The program will automatically uncouple the singular degrees of freedom from the rest.

3.8 WIND AND CURRENT LOADING

The wind and current drag forces are calculated from a set of user prepared empirical environmental load coefficients covering a range of heading angles. The drag coefficients for any heading are obtained by linear interpolation. The input load coefficients are defined as

$$(\text{drag force or moment}) \;/\; (\text{wind or current velocity})^2$$

According to the above definition, the coefficients are dimensional and the user must conform to a consistent set of units. (For details see Section 2.10 of Reference Manual.)

3.9 THRUSTER FORCES

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

3.10 MOORING LINES

The effect of mooring lines is to contribute to the external forces and stiffness matrix of a structure. This in turn will affect the static equilibrium position and its stability in this position.

AQWA-LIBRIUM allows the user to specify the following:

- a force of constant magnitude and direction
- a constant tension winch line connecting two bodies (or a body and a fixed point)
- linear/non-linear elastic weightless hawsers connecting two bodies (or a body and a fixed point)
- heavy inelastic catenary chains between a body and a sea anchor
- composite elastic catenary chains between a body and a sea anchor

N.B. Current drag on all mooring lines are ignored

Within the program, the tension vector and stiffness matrix of each mooring line are initially evaluated with respect to a set of axes local to the vertical plane containing the line. The detailed method by which the GLOBAL force vector and system stiffness matrix are transformed to the FRA is given in Section 3.10.3.

Force of Constant Magnitude and Direction

The constant "FORCE" line is always assumed to act at the centre of gravity of the body in question. The force magnitude and direction are assumed fixed and DO NOT CHANGE with movement of the body.

Constant Tension Winch Line

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

Weightless Elastic Hawsers

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

$$P(e)=a_1e+a_2e^2+a_3e^3+a_4e^4+a_5e^5 \quad (3.10.1)$$

where

P = line tension
e = extension

For details of the elastic mooring equations, see Section 3.10.1.

Heavy Inelastic Catenary Chains

The submerged weight, length and attachment points of a catenary determine its profile, tension and stiffness. The standard catenary equations are solved for tension by the Newton-Raphson technique. The stiffness is obtained directly through the derivatives of the catenary equations, rather than by the use of numerical differentiation. For details of the catenary equations, see Section 3.10.2.

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 deflection, may be expressed in terms of a series of coefficients and its extension (e) from an unstretched length. The force exerted on a structure by the mooring line (P) may therefore be written as

$$P(e) = a_0 + a_1e + a_2e^2 + a_3e^3 + ...$$

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

$$S(e) = \frac{dP(e)}{de} = a_1 + 2a_2e + 3a_3e^2 + ...$$

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

$$K = S/L \; x \, x^t + (I - x \, x^t) \, p/L^2$$

where

t = transpose
x = vector joining the attachments point of the cable
I = 3∗3 unit matrix
L = 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 the direction of P, then the stiffness matrix will be diagonal with S as the value of the leading diagonal term corresponding to the coincident axis and the other two leading diagonal terms equal to P/L, e.g. for the X axis coincident

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

If a constant tension device (e.g. a winch) is used at 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 used at 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, i.e. the centre of gravity in the AQWA suite. This, as formulated in Section 3.10.3 as the transformation procedure, is applied to any local stiffness matrix and force applied at a 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 no fluid loading. As the solution of the catenary equations is well documented (see reference 1 in Appendix B) the summary of the solution used in AQWA is presented. The equations can be expressed in an axis system whose local X axis is the projection of the vector joining the attachment points on the sea bed and whose z axis is vertical. For catenaries which have zero slope at the contact/attachment point on the sea bed these equations can be written as

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

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

and $P = T_0 + Wz$

where

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

Given the following notation,

T_e = total tension at the attachment point on the structure
T_0 = horizontal tension at the sea bed
W = weight of the line less that of the displaced water per unit length
x = horizontal distance between the attachment point on the structure and the contact point on the sea bed
x_r = horizontal distance between attachment point on the structure and the anchorage
z = vertical distance between 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 written as

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

where

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

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

3.10.3 Translation of the Mooring Line Force and Stiffness Matrix

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

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

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

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

where

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

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

Px,Py,Pz = The X,Y and Z components of the tension in the mooring line at the attachment point on the structure.

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. However this also means that if the mooring forces are in equilibrium with all other conservative forces then the **total** stiffness matrix will be symmetric.

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

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

3.10.4 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

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

where

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

x,y,z = Coordinates of the attachment point on the second structure relative to its centre of gravity.

Px,Py,Pz = 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 EQUILIBRIUM AND STABILITY ANALYSIS

3.12.1 Solution of the Equilibrium Position

The FRA system is used for the equilibrium and stability analysis of the floating system. Where force/moment vectors and stiffness matrices are initially evaluated at the LSA (see Section 4.3), the program will transform the vectors/matrices to the FRA prior to the calculation of equilibrium and stability.

Multi-Degree of Freedom Systems

Consider the simple case of a wall-sided ship with mass, M, and cut waterplane area, A. If Zo is an initial guess of the vertical centre of gravity, then dz, the displacement required to move the ship to the equilibrium position, is given by

$$dz = F/K \tag{3.12.1}$$

where

F = (buoyancy when CG is at Z_0) - Mg
K = sea water density $*$ g $*$ A

The analysis of a multi-body system is essentially the same as that of the simple example above except that

1. the system requires NDOF coordinates to describe its position (NDOF = 6 x Number of bodies)
2. the system is fully coupled through the actions of the moorings
3. dz is replaced by a NDOF order vector dX containing the three translations and three rotations of each of the bodies
4. F is replaced by a NDOF order vector containing the sum of the residual forces/moments in each of the coordinates
5. K = { k_{ij} } is now the GLOBAL STIFFNESS MATRIX of the system in the sense that k_{ij} measures the change in the force/moment in the i th coordinate due to a change in displacement in the j th coordinate only.

The Residual Force/Moment Vector

Before equilibrium is reached, a set of unbalanced forces and moments will act on the bodies. The residual forces and moments include hydrostatic pressures, weights of the structures, mooring tensions, wind drag, current drag, thruster forces and steady wave drift forces as described in Sections 3.1 and 3.10.

The Stiffness Matrix

AQWA-LIBRIUM computes all the stiffness contributions directly from analytical expressions for the load/displacement derivatives, rather than through the use of numerical differentiation. This is particularly important in cases such as catenary chains, where the tension can change rapidly with displacement of the end points. If f_i is the force/moment on the structure in the i th coordinate caused by a displacement x_j in the j th coordinate, then

$$k_{ij} = - df_i / dx_j \qquad (3.12.2)$$

Steady wind, current and wave drift forces are **only** functions of the heading angle. Therefore, their stiffness contributions are found only in changes in the 'yaw' coordinate (ie k_{46} ,k_{56}). At present, the effect of changes in global thruster forces or moments with heading has not been implemented.

The Stiffness Matrix is non-linear in general. To move the bodies towards equilibrium requires a number of iterative steps. In each step, the values of the K matrix and the force vector F are re-calculated.

Once the Global System Stiffness Matrix has been formed, the program checks and removes any singular degrees of freedom (see Section 3.7).

Iteration Towards Equilibrium

Let the initial guess of the structure positions and orientations be represented by the vector X^0,

where

X^0	=	$\{ x_1 ,y_1 ,z_1 ,p_1 ,q_1 ,r_1 ,x_2 ,y_2 ...... \}^t$
(x,y,z)	=	coordinates of the CG with respect to the FRA, and
(p,q,r)	=	finite angular rotations which describe the orientation of the bodies.

The superscripts denote the iteration step and the subscripts denote the body number. The displacement required in step 1 is given by

$$dX^1 = K^{-1} (X^0)F(X^0) \qquad (3.12.3)$$

and the new position of the body, X is given by

$$x^1 = x^0 + dX^1 \qquad (3.12.4)$$

The process is repeated until dX is smaller than the user prescribed limit. It is possible to have more than one equilibrium position. For instance, a capsized ship can still float in equilibrium if buoyancy is preserved. Therefore it is important to start off the iteration with an approximation close to the required solution. Also, because of the non- linearities in the system, it is possible to 'overshoot' and miss the intended equilibrium position. Hence, in practice, dX can be scaled by a user defined under-relaxation factor to ensure stability in the iteration scheme.

3.12.2 Static Stability Analysis

The program extracts the eigenvalues of the linearised stiffness matrix at equilibrium by the standard Jacobi successive rotation method. Positive eigenvalues imply stable equilibrium and zero eigenvalues imply neutral stability. If any of the eigenvalues are negative in sign, it means that the body will not return to its equilibrium position after a **small** disturbance in any of the corresponding modes. These eigenvalues are analogous to the meta-centric height, GM, in transverse stability analysis of ships.

3.12.3 Dynamic Stability Analysis

Given the static equilibrium position of the floating system, X_E, the equations of small **horizontal** motions, X, of the system about its equilibrium position can be written as

$$M\ddot{X} = F_W + F_H - F_D - F_M \tag{3.12.5}$$

where

overdot	=	time derivatives
F_W	=	steady wave force
F_H	=	hull drag force
F_D	=	damping force
F_M	=	mooring force

and M, F_W, F_H, F_F and F_M are evaluated at the position $X_E + X$

Expanding, and neglecting terms of second order or higher, this can be written as

$$M\ddot{X} + C\dot{X} = \text{function of } X \tag{3.12.6}$$

These equations of motion can be put into the Hamiltonian form by making the substitution

$$B = \dot{X}$$

$$\text{i.e.} \quad \{B_1,\ B_2, \ldots\} = \{\dot{X}_1,\ \dot{X}_2, \ldots\}$$

such that equation (3.12.5) can be reassembled in the form

$$\dot{A} = S * A \tag{3.12.7}$$

where {A}= {B,B,B ,... X,X,X , ... }^{t}

By letting $A = Be^{Et}$ the eigenvalues, ($E = F + iG$), and eigenvectors of the system given by equation (3.12.7), will give the modes of motion of the system as follows:

1. $F < 0$ STABLE
2. $F > 0$ and $G = 0$ UNSTABLE
3. $F > 0$ and $G \neq 0$ FISHTAILING

Also, the period and damping are given by:

period = 6.28/G

critical damping = (F/G).SQRT$\left(1 + (F/G)^2\right)$

3.13 LIMITATIONS OF THEORETICAL APPLICATIONS

At present AQWA-LIBRIUM only provides stability information which is valid for small displacements about the equilibrium position. The user should be aware of the limitations of extrapolating such data to large displacements from equilibrium.

The program also has no capacity to model internal compartments within a structure, and hence neither internal compartment free-surfaces, nor damage effects on the hydrostatic stiffness, nor small angle stability parameters, are included. These facilities will be included in a later version.

Drag effects on mooring cables are ignored.

CHAPTER 4 - MODELLING TECHNIQUES

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

Where modelling techniques are only associated with other programs in the AQWA suite, the information may be found in the appropriate sections of the respective manuals (the section numbers following 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 this data.

4.1 INTRODUCTION

The model of 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 analysis or even omitted altogether in another.

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

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 the hydrostatic and hydrodynamic model.

The second is in the description of the environment i.e. mooring lines, wind, current, irregular and regular waves. These parameters are not common to all programs.

AQWA-DRIFT and AQWA-FER do not require a hydrostatic or hydrodynamic model but only the hydrostatic stiffness matrix and hydrodynamic loading coefficients, which are the RESULTS of calculations on these models. Thus when AQWA-LINE has been run, all these parameters are transferred automatically from backing files. If AQWA-LINE has not been run previously , the hydrostatic stiffness matrix and wave loading coefficients are required as input data.

The differences in the hydrostatic and hydrodynamic models, which are associated with the structure geometry for AQWA-LINE/DRIFT/FER, 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 relative to the wave length.

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, and when restrictions allow, a more approximate model may be defined with less elements to minimise computer costs.

4.2 MODELLING REQUIREMENTS FOR AQWA-LIBRIUM

AQWA-LIBRIUM requires models of the inertia, hydrostatic and hydrodynamic properties of the bodies, the moorings and the environmental loads. Some analyses using AQWA-LIBRIUM might not require all of these models. For example, a static analysis would not require the hydrodynamic model. In general, AQWA programs do not require modelling of **all** aspects of the system for two reasons:

1. The calculations associated with a particular model may have been done previously by one of the AQWA programs, and the results can be transmitted either through backing files or manually as card image input.

2. The mechanics of the system are such that a model is not required.

The models used by AQWA-LIBRIUM follow closely the form used by the rest of the AQWA suite. In most cases, the same model should be applicable to all AQWA programs. However, the user may choose to adopt different models of the same system. A typical example is the modelling of the hydrostatics of a wall-sided pontoon. In AQWA-LIBRIUM, the hydrostatic calculation is not affected by mesh size. Therefore the complete side of a pontoon may be accurately modelled by one flat quadrilateral pressure plate. In AQWA-LINE, the mesh size is governed by the wave length but only the wetted part of the hull requires modelling. Hence the user may choose either to use two different meshes for the two programs or to use a mesh which is acceptable to both. The former will lead to cheaper AQWA-LIBRIUM runs while the latter will save the user from the labour of remodelling. (See Figure 4.1 for an illustration of the differences between an AQWA- LINE and an AQWA-LIBRIUM mesh.)

The general modelling requirements for AQWA-LIBRIUM are:

Analysis	Models
Static	mass, hydrostatics, moorings, current, wind, wave drift, thrusters.
Dynamic	the same as above plus mass distribution (hence inertia), hydrodynamic properties at drift frequency. (Only one wave spectrum can be input.)

The following subsection describes an exception to the above requirements.

4.2.1 Following an AQWA-LINE Run

An AQWA-LINE run is performed before an AQWA-LIBRIUM run ONLY if it is considered that the second order mean wave drift forces in an irregular sea will significantly affect the equilibrium configuration of the system. If this is the case the modelling requirements for AQWA-LIBRIUM will depend on the type of model used by the AQWA-LINE run. If the AQWA- LINE model includes all **non-diffracting** elements (e.g. Morison elements, elements above water line), remodelling of the hydrostatic properties is not required by AQWA-LIBRIUM, unless the user wishes to use a coarser mesh for the AQWA-LIBRIUM run.

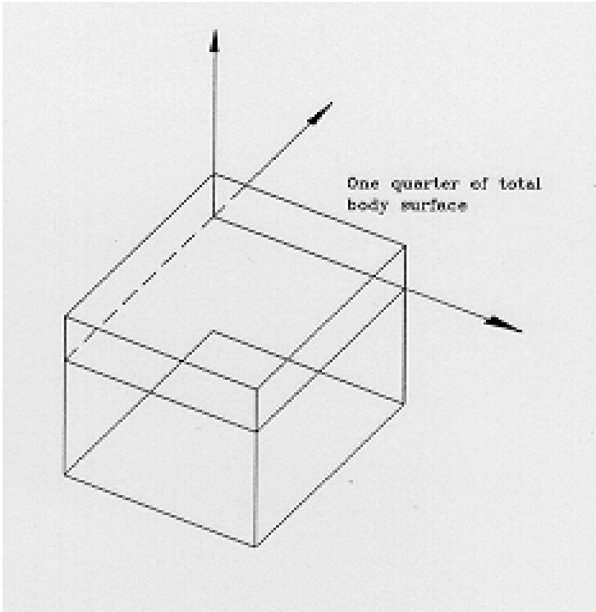

Figure 4.1a - AQWA-LIBRIUM Mesh

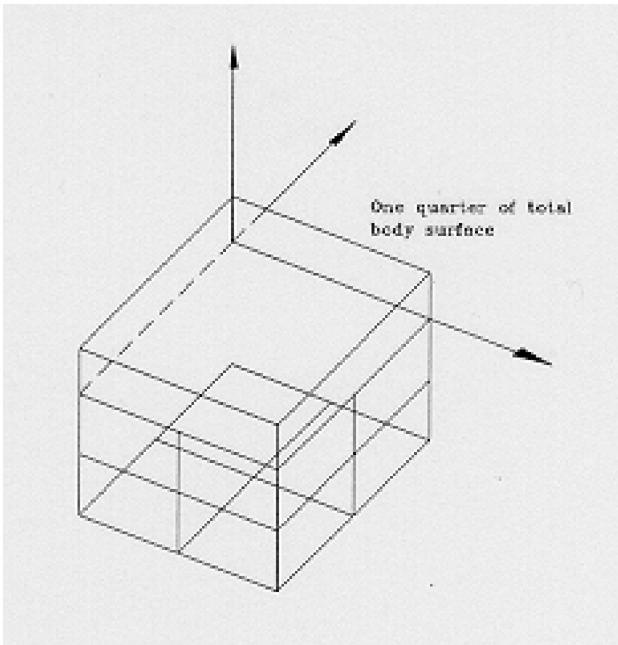

Figure 4.1b - AQWA-LINE Mesh

4.3 DEFINITION OF STRUCTURE AND POSITION

Full details may be found in AQWA Reference Manual.

Two sets of axes are used in AQWA-LIBRIUM and these are shown in Figure 4.2 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, body motions and fluid forces are with respect to the centre of gravity of the particular body (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, 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 that specific order**. Within the program, the orientation is defined by the direction cosines of the BODY FIXED AXES (BFA) with respect to the FRA.

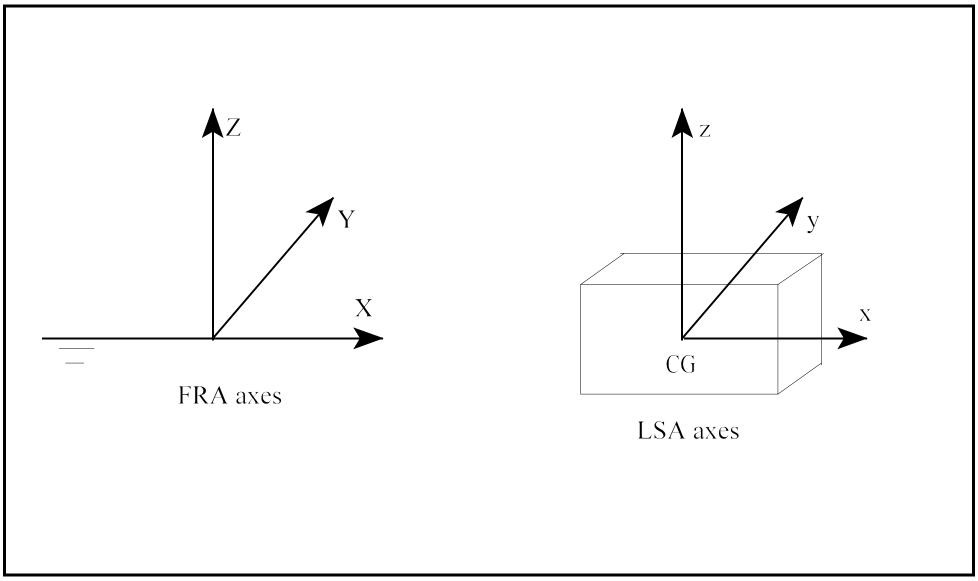

Figure 4.2 - Axes Systems

4.4 STRUCTURE GEOMETRY AND MASS DISTRIBUTION

When AQWA-LIBRIUM is used following an AQWA-LINE run, 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-LIBRIUM is used independently. (See the AQWA-LINE manual when this is not the case.)

4.4.1 Coordinates

Any point on the structure in the modelling process is achieved by referring to the X, Y and Z coordinates of a point in the FRA which is termed a 'NODE'. The model of structure geometry and mass distribution consists of a specification of one or more elements (see also Sections 4.1, 4.4.2), each of whose position is given by one or more nodes. Each node has a **node number**, which is chosen by the user to be associated with each coordinate point. Nodes in themselves do not contribute to the model, but may be thought of as a table of numbers and associated coordinate points to which other parts of the model refer.

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 (see also Section 4.15).

4.4.2 Elements and Element Properties

Each body is modelled by one or more finite elements which could be a combination of tubes, point masses, point buoyancies, and quadrilateral and triangular pressure plates. This facility enables simple modelling of bodies of arbitrary shape. With the exception of plate elements, each element is associated with a set of material and geometric properties which define the structural masses and inertias of the system. When pressure plates are used to simulate the fluid pressure, a point mass with equivalent mass and inertia is needed to model the mass distribution of the body. (The moment of inertia is required for the dynamic runs only.)

The program allows the user to take full advantage of symmetry in specific problems. Up to four fold symmetry is accommodated.

4.5 MORISON ELEMENTS

At present, the only Morison elements available within AQWA-LIBRIUM are tubes. These are defined by specifying end nodes, diameter, wall thickness and endcut lengths (over which the forces are ignored). Each tube element may have a different drag and added mass coefficient associated with it. Drag coefficients can be defined as functions of Reynolds Number.

Full consideration is given to current variation over the tube length, and to partial submersion of members.

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

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

where

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

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

Alternatively, a general multiplying factor for drag can be used. It is the interpolated value multiplied by this factor which is used as the drag coefficient.

Note that for steady state conditions (as in AQWA-LIBRIUM) there are no added mass or slam effects.

4.6 STATIC ENVIRONMENT

4.6.1 Global Environmental Parameters

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

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

4.7 LINEAR STIFFNESS

This section is **only** applicable if the user specifies that the stiffness is to be considered linear, i.e. the stiffness remains linear even for large angle displacement. This is an optional specification (see Appendix A) and means that a linear stiffness matrix is used in the analysis instead of assembling the stiffness from the hydrostatic element description.

4.7.1 Hydrostatic Stiffness

There are some cases where a finite element mesh of a body is neither possible (through lack of detailed geometrical data) nor necessary (e.g. only horizontal planar motion is required, or the movement of the body is likely to be small). In these cases, the user can model the hydrostatic stiffness of that particular body via the LSTF option (Linear Stiffness). The LSTF option requires only user input of buoyancy and hydrostatic stiffness matrix at equilibrium. The program will assume constant buoyancy and stiffness throughout.

4.7.2 Additional Linear Stiffness

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

Although all terms in the additional linear stiffness can be included in the hydrostatic stiffness matrix, the user is advised to model the two separately. The most common applications where an additional stiffness model are useful to have are when

- 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 compliments the stiffness due to mooring lines (if present), as AQWA-LIBRIUM includes the mooring line stiffness in its calculations of the total system stiffness matrix.

In practice, it is only in unusual applications that the user will 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 drift, current and wind coefficients are defined. Since they are transferred automatically from backing file when AQWA-LIBRIUM is used as a post- processor, the following notes refer to AQWA-LIBRIUM when used as an independent program.

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

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

1. The extreme values must be chosen to adequately define the coefficients at those frequencies where wave energy in the spectra chosen (see Section 4.15) is significant, and at **all** possible directions of the subsequent response analysis. If geometric symmetry has been specified (see Section 4.3.3) only those directions for the defined quadrants are required.

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

Clearly, if either of these criteria is violated, erroneous 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 mean wave drift force is calculated from a set of drift coefficients, for a range of headings (either determined from AQWA-LINE or another source), and a wave energy spectrum. Only **horizontal** drift forces/moment are considered.

If wave drift coefficients are calculated by AQWA-LINE, they are transferred automatically from backing file. (See Section 4.9 of the AQWA-LINE Manual for modelling of the wave drift forces.)

If the coefficients are determined from another source, the coefficients have to be specified for a range of frequencies and directions as described in the previous Section. The mean drift force at any frequency within the range is obtained by linear interpolation.

4.10 WIND AND CURRENT LOADING COEFFICIENTS AND THRUSTERS

The wind and current loading coefficients are required to model the forces and moments on the structure due to these environmental effects. These forces are proportional to the square of the velocity and produce terms for steady forces, stiffness and damping.

In the calculation of the equilibrium position and stability analysis, the effect of the steady forces is to change the equilibrium position, and thus the stiffness of any non-linear mechanism present (e.g. catenaries, hydrostatic stiffness). The effect of wind/current stiffness per deg (i.e. rate of change of wind/current force with yaw) will directly affect both the equilibrium position and the stability. The wind/ current damping has no effect on the stability calculations.

The wind/current drag loads can be modelled simply as a force, or in more detail, by specifying the wind/current drag coefficients over a range of wind/ current heading, velocity profile and direction. The drag coefficients at any heading are obtained by linear interpolation.

4.11 THRUSTER FORCES

Up to ten thruster forces may be specified. The point of application of the force vector is defined by a NODE. The magnitude of the vector remains constant and the direction of the vector is fixed in relation to the body fixed axes (BFA).

Note that thruster forces affect 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 is neglected at present but will be included in the next version.

4.12 CURRENT AND WIND VELOCITIES AND DIRECTIONS

The wind and current velocities and associated directions can be included along with the spectral information, as discussed in Section 4.13. In applications where the user is not interested in wave conditions, the data can be input independently, However this data will be **overwritten** if current and wind conditions are specified along with the spectral information. Two types of current velocity can be specified; the first is a uniform velocity distributed over the submerged hull structure and the second is a profiled current velocity varying with both direction, and depth between the sea-bed and water surface. The latter is only utilised in the calculation of drag on Morison elements.

4.13 CONSTRAINTS OF STRUCTURE MOTIONS

It is quite common in the analysis of floating systems to have one or more singular degrees of freedom causing failure in the solution of the equations. For the majority of floating systems, the program checks and removes these degrees of freedom such that the global stiffness matrix, K, becomes non-singular, and the displacements in the singular coordinates are zero. However, for more complicated systems the user can constrain directly specific degrees of freedom. This is achieved by assigning the relevant d.o.f. to a zero displacement.

4.14 WAVE SPECTRA, WIND AND CURRENT SPECIFICATION

The user may specify one or more spectra, wind and current speeds, with associated directions, which may be different for all three. For the majority of applications specification is straightforward and no knowledge of the way in which the spectra are used in each program is required. The only general rule is that 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, this may be the intention of the user however.

Note: Only one spectrum can be defined when using the dynamic stability option.

4.15 MOORING LINES

4.15.1 Linear/Non-Linear Elastic Hawsers

The line properties are specified by their unstretched lengths, ends nodes on respective bodies and their load/extension characteristics. For linear hawsers, the line stiffness (load per unit extension) is required. For non-linear hawsers the program permits up to a fifth order polynomial approximation of the elastic property of the following form (see Section 3.10.1).

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

where

P = line tension
e = extension

The use of a higher order polynomial than necessary could lead to erroneous negative stiffness while a lower order fit could be perfectly adequate (see Figure 4.3). It is always useful to check the polynomial fit prior to its use as input data. Note, for small extensions, the term a_1 is usually a good approximation to the linear stiffness.

4.15.2 Constant Tension Winch Line

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

4.15.3 ‘Constant Force’ Line

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

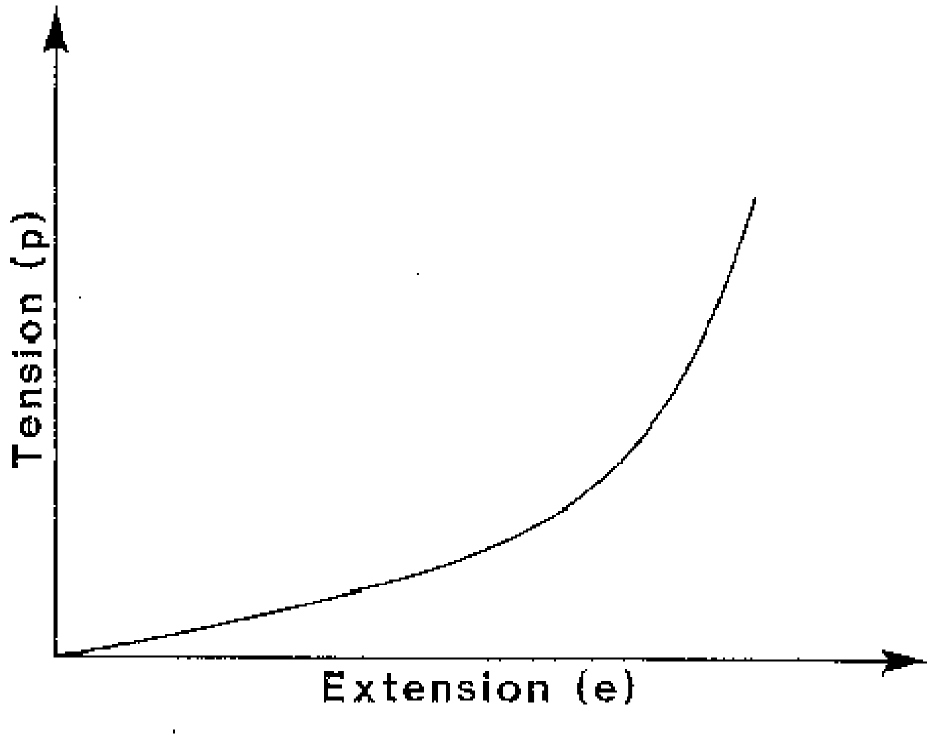

Figure 4.3 - Load/Extension Characteristics

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, program determines tension.
- TENSION based; user specifies tension, 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 turns out to be outside the range specified (or the default values). If the user wishes to keep constant line length irrespective of the tension, a very large value of maximum allowable tension may be input. In all cases, adequate warning messages will be signalled.

The program evaluates the line tension and stiffness as a 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/default maximum.

The current version of AQWA only admits a horizontal sea bed, and catenary between a body and the sea bed. Catenaries joining two bodies are **not** permitted.

Care must be exercised in the description of a 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 the case where the catenary lines lift off the sea bed, in practice, most catenary chains are expected to function with a significant length of the line on the sea bed.

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

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

where

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

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

4.16 ITERATION PARAMETERS FOR SOLUTION OF EQUILIBRIUM

4.16.1 Iteration Limits

A well conditioned system coupled with a good initial guess should require a small number of iteration steps. As a safeguard against modelling errors, the user may limit the number of iteration steps in the first run. Examination of the output should indicate whether the procedures are converging to a solution or otherwise. The default is a maximum of 100 steps.

Note that the more accurate the initial estimate of the equilibrium position, the less iterations will be required to find equilibrium. Users should exercise caution in placing the structures in the fluid since the iteration step is determined using the hydrostatic stiffness (which may be not be defined if the structure is either submerged or emerged).

4.16.2 Iteration Step Size

Due to the non-linearities in the system, it is quite possible to 'overshoot' and miss the intended equilibrium configuration. Hence, the program will restrict the movement of each body according to a user specified or default iteration step size. The step size for each body is characterised by three translations and three rotations. The program will scale the movement of all the bodies by a constant factor such that none of the displacements (total of 6 x number of bodies) exceeds its corresponding step size. In other words, equation 3.12.4 is modified such that

$$x^{n+1} = x^n + C\, dX^{n+1} \qquad (4.16.1)$$

where

C = $\mathrm{Max}\,(dS_1 / dX_1 , dS_2 / dX_2 \,.....\,)$

dS = $\{ dS_1 , dS_2 \,...\, \}$ is the iteration step size

4.16.3 Convergence Limits

The equilibrium configuration is assumed to be found if the movements of each body, as a result of the action of residual forces and moments, are smaller than the default or user specified limits. The limits are specified in terms of the translations and the finite angular rotations of each body.

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

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

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

Not applicable to AQWA-LIBRIUM (see AQWA-NAUT Manual).

4.19 SPECIFICATION OF OUTPUT REQUIREMENTS

See options list (Appendix A).

CHAPTER 5 - ANALYSIS PROCEDURE

This chapter assumes that the user is familiar with the analysis procedure and how to model the structure in its environment. It deals with the methodology of analysis associated with running the program, and links the modelling information in the previous chapter with the stages of analysis necessary to solve a given type of problem. This involves classification of the types of problem, details of the program runs, and stages within each program run, together with their associated options.

5.1 TYPES OF ANALYSIS

Classification of the types of problem (listed below) based on the function of the analysis, is the same whether the program is used independently, or as a post-processor to AQWA-LINE, and is as follows:

- Calculation of the static equilibrium positions for a floating system of one or more bodies. Determination of the hydrostatic loads and the small angle static stability characteristics of the individual freely floating structures, and the mooring loads within the system when in equilibrium.

- Calculation of the slow dynamic stability characteristics (in the horizontal plane) of the system about a given static equilibrium position.

All the above are controlled by the job card and may be requested in any combination.

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, Chapter 2).

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

The stages are as follows:

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

Note that the graphics program, AQWA-PLANE, permits visualisation of the geometric model and parameters at **any** point in the analysis, e.g. Stages 2 to 5 are not required to visualise the 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

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

1. Select a consistent set of units.

2. Assemble geometric and material data for all the structures.

3. Specify one or more point masses to represent the mass and mass inertia of each of the structures. (In the case of tubes, structural mass may be input through the geometric properties.)

4. Calculate the coordinates of the node points for each of the mooring attachments and the elements used in the modelling of the body.

5. Specify the water depth and the density of the water.

6. Specify frequencies and directions and the corresponding drift force coefficients for each structure if equilibrium is required in a sea state.

7. For dynamic stability analysis, specify the drift added mass and damping matrices for each structure.

The following preparation is required for AQWA-LIBRIUM, whether used independently, or as a post processor to AQWA-LINE:

8. Prepare thruster forces, and coefficients for wind and current drag, for each structure.

9. Specify the wave spectra, and the current and wind velocities. (Only one spectrum can be input when using the dynamic stability option.)

10. Determine mooring line combinations and properties.

11. Specify an initial estimate of the equilibrium positions of each structure for each spectrum and mooring line combinations.

12. Code up the above information in a suitable manner acceptable to AQWA-LIBRIUM. (See AQWA Reference Manual and Chapter 6 of this manual.) The use of the graphics program AQWA-PLANE is most useful when doing this.

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 (static/dynamic/both), and re-run with the restart option.

CHAPTER 6 - DATA REQUIREMENT AND PREPARATION

This chapter describes the form in which data is expected by the program, and is not intended as a detailed list of the data requirements. Rather it describes the general format for each type of analysis that may be performed when running AQWA-LIBRIUM. The detailed format may be found in the Reference Manual. It also uses the concept of the card image deck which is a section of two or more records, between 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 Reference Manual.

A summary of the possible data that may be input is listed together with a summary for various forms of analysis. In the latter case a typical 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 done and the control of the AQWA program being used.

Program Control has the following functions:

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

Administration of the analysis being performed is as follows:

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

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

JOB Card	- This contains information stating the program to be used, the type of program analysis to be undertaken, and the user identifier for the run in question.
TITLE Card	- This lets the user prescribe a title for the run.
OPTIONS Card	- Various program options are available within the AQWA suite which are common to all programs, while others are for use with specific programs. The options within AQWA-LIBRIUM 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-LIBRIUM, 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-LIBRIUM analysis. This means that all information relating to the analysis is read, allowing all data checking to be performed. After the user is satisfied with the acceptance of data, then the equilibrium analysis can be undertaken by restarting the program at Stage 5 to perform the analysis itself.

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

Input for Stage 1 of the analysis is only necessary if the restart stage at which the analysis begins is 1 (see Chapter 5 for details). If the restart stage is greater than 1 there should be **no data 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 surroundings referenced by any other deck
- element description of the structure mass and geometry using plate, point mass, point buoyancy and tube elements (see Appendix A of the AQWA Reference Manual for details)
- a table of material values associated with each element
- a table of geometric values associated with each element
- the depth and density of the water, and acceleration due to gravity

The data requirement for each program in the AQWA suite is not the same and may also be dependent on the type of analysis to be 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 of 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 the program for the first time it is recommended that the PRCE option (see Appendix A) is used. This causes the data input in these decks to be output automatically in order that the user may check the program's interpretation of the data before proceeding to the next stage of the analysis.

6.1.3 Data Input Summary for Decks 1 to 5

Deck 1	-	The coordinates of points describing the 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	-	Element description of the mass properties
	-	Element description of the hydrostatic model
	-	Element description of the hydrodynamic model
Deck 3	-	A table of material values associated with each element
Deck 4	-	A table of geometric values associated with each element
Deck 5	-	Static environmental parameters, i.e. the depth and density of the water, and the acceleration due to gravity

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

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

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

6.2.1 Description Summary of Physical Parameters Input

The data input in these decks relates to the equation of motion for a diffracting structure or structures, in monochromatic waves. The latter are defined for a range of frequencies and directions. (Note that the structural mass is input in Decks 1 to 5.) For a specified range of frequencies and directions the equation of motion can be written as

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

The parameters in the equation of motion are

K - Linear Stiffness Matrix

with associated values of

- The Buoyancy Force at Equilibrium
- The Global Z coordinate of the Centre of Gravity at Equilibrium

and, for each frequency

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

and, for each frequency and each direction

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

Of these parameters, only the linear stiffness matrix (with the associated values of the buoyancy force) and the second order drift forces are applicable to a static analysis using AQWA-LIBRIUM. For dynamic stability, the added mass and damping matrices for low frequency motion is also required.

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 if 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.

It is important to recognise the different function of the specification of the frequencies and directions when using AQWA-LINE, which **calculates** the diffraction/radiation analysis parameters, than when using other programs to perform an analysis using these parameters. Thus

- for AQWA-LINE, the range of frequencies and directions specified are those at which the parameters are to be **calculated**.

- for AQWA-LIBRIUM parameters are read from backing file automatically or may be input manually. In the latter case, the range of frequencies and directions specified are those at which the parameters are to be input within these decks.

Note: Although not directly applicable to AQWA-LIBRIUM, if all the diffraction/radiation parameters are either read from an AQWA-LINE backing file or input within Deck 7, a natural frequency analysis can be carried out using the same card image file with the appropriate JOB card. The user is referred to the AQWA-FER Manual for further details.

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 Global Z coordinate of the centre of gravity at equilibrium
- Added mass matrix
- Additional mass matrix (usually not required)
- Radiation damping matrix
- Additional linear damping matrix (usually not required)
- Diffraction forces
- Froude Krylov forces
- Response motions (or RAOs - for checking only)

Deck 8
- Second Order Drift Forces

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

6.2.4 Input for AQWA-LIBRIUM 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. Thus 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-LIBRIUM with Results from Source other than AQWA-LINE

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

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

The input data required is:

Case	Deck 6	Deck 7	Deck 8
No Drift, Hydrostatic Model	None	None	None
No Drift, No Hydrostatic Model	None	Linear Hydrostatic Stiffness Matrix	None
Drift, Hydrostatic Model	Range of frequencies and directions	None	Second Order Drift Forces
Drift, No Hydrostatic Model	Range of frequencies and directions	Linear Hydrostatic Stiffness Matrix	Second Order Drift Forces

Note that a hydrostatic model may consist of TUBE, TPPL or QPPL elements.

6.2.6 Input for AQWA-LIBRIUM with Results from a Previous AQWA-LINE Run and a Source other than AQWA-LINE

The new user is advised to ignore this facility

If the user wishes to APPEND to or CHANGE the parameters calculated by a previous AQWA-LINE run for the current analysis, this can be achieved by 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 database (.HYD) file from AQWA-LINE to exist at Stage 2 of the analysis, the ALDB option must be used in the options list (see Section 6.0) to indicate that it exists and must be read. **Using this option means that the Stage 2 data is input twice, once from the 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 must not be redefined.

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

6.3 STAGE 3 - NO CARD IMAGE INPUT - DIFFRACTION/RADIATION ANALYSIS

6.3.1 Stage 3 in AQWA-LIBRIUM

There is no input for Stage 3 in AQWA-LIBRIUM, as this stage corresponds to the Diffraction/Radiation analysis which has either been performed in AQWA-LINE, or the values from which 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 17 - INPUT OF THE ANALYSIS ENVIRONMENT

Input for Stage 4 of the analysis is only necessary if the restart stage at which the analysis begins is 1 or 2 (see Chapter 5). If the restart stage is greater than 4, there is **no input** for Stage 4 of the analysis.

6.4.1 Description of Physical Parameters Input

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

- Low frequency added mass and damping

If the dynamic equilibrium in a specified sea condition is required from the analysis, it is mandatory to input the added mass and damping (which are assumed constant) associated with the low frequency motion.

- Wind and current loading coefficients and thruster forces

These coefficients, which are defined at directions specified in Deck 6, are associated with the hull forces, and are proportional to the square of the wind /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/current force with yaw). Wind damping also has a significant effect on drift motions. Current damping is ignored (see Section 4.10). The thruster forces are maintained at both constant magnitude and direction to the specified structure.

- Degrees of freedom to be deactivated

Degrees of freedom can be deactivated by specifying the structure and freedom. This sets the relevant d.o.f. to zero displacement.

- Wave spectra, wind and current

The sea state is defined by a wave spectrum together with its wind and current (see Section 4.14). However if a sea state is not specified, wind and current conditions can be input independently. Note only one spectrum can be used when the dynamic stability option is active.

- Mooring lines

The physical characteristics and attachment points of mooring lines, hawsers and tethers may be input if required (see Section 4.15).

- Initial estimate of equilibrium positions

The initial estimate of the equilibrium position of each structure can be specified for each mooring line and spectrum combination required to be analysed.

- Limits of the iterations to be used in the equilibrium analysis

The maximum, number of iterations, iteration step, and error, considered acceptable, can be specified by the user. Otherwise the default values will be used.

- Morison element parameters

These are either the Local Reynolds Number, or the drag scale factor, as applied to the drag coefficients of Morison elements (already specified in Deck 4) within that structure.

6.4.2 AQWA-LIBRIUM Data Input Summary for Decks 9 to 17.

Deck 9 - Low frequency added mass
- Low frequency damping

Deck 10 - Wind loading coefficients for the superstructure
- Current loading coefficients for the hull

Deck 11 - Wind and current speed and direction when no sea state is specified. Profiled current data for Morison elements

Deck 12 - Degrees of freedom of structures which are to be deactivated

Deck 13 - Wind speed and direction for each spectrum
- Current speed and direction for each spectrum
- Description of the wave spectra

Deck 14 - Description of each mooring line property
- Description of mooring layout for each combination

Deck 15 - Initial estimates of the equilibrium positions for each spectrum and mooring line combination required to be analysed

Deck 16 - Iteration and convergence limits

Deck 17 - Morison element parameters

6.5 STAGE 5 - NO INPUT - EQUILIBRIUM ANALYSIS

This stage performs the search for equilibrium and therefore requires NO INPUT.

6.6 STAGE 6 - NO DECKS - GRAPHICAL DISPLAY

The AQWA suite has its own graphics program called AQWA-PLANE. This program is used to perform the following tasks.

- Visualisation and checking of the discretised element model used to generate the surface of the body

- Plotting of the body position and motion trajectories to aid physical understanding of the problem

- Tabulation of important parameters within the motion study analysis

For details of the graphics facilities within the AQWA-PLANE program, see the AQWA PLANE User Manual.

6.6.1 Input for Display of Model and Results

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

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

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

CHAPTER 7 - DESCRIPTION OF OUTPUT

This chapter describes the comprehensive program output provided by AQWA-LIBRIUM.

The various program stages perform different types of analyses and the output for each stage of the 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 the PRDL option is used to print this information from backing file.

7.1.1 Properties of All Body Elements

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

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

The information received by AQWA-LIBRIUM to define the 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 FRA 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 body's element topology is output. The body topology describes the elements used in the model of the body (see Section 4.4.2). Details of each element are also output as seen in Figure 7.2. The bodies used each have a specific structure number associated with their output, and this appears in the title of the output.

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

```
* * * E L E M E N T   T O P O L O G Y   F O R   S T R U C T U R E  1 * * *
      - - - - - - -   - - - - - - - -   - - -   - - - - - - - - - -

 E L E M E N T    NODE      NODE      NODE      NODE    MATERIAL  GEOMETRY

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

     1     QPPL    10        30        31        11         0         0
     2     TPPL   150       141       151         0         0         0
     3     QPPL    11        31        32        12         0         0
     4     QPPL    17        37        38        18         0         0
     5     PMAS  9999         0         0         0         1         1
```

Figure 7.2 - Element Topology Output

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

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



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

              1        75593800.000
              2           57525.000
              3         1025000.000
```

Figure 7.3 - Material Property Output

The topology output also references the Geometry Group numbers used by the user. Each Geometry Group may have a range of properties associated with it. The number of relevant properties depends on the type of element under consideration. The Geometry Group numbers and the various parameters within 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. The localised element Drag and Added Mass coefficients are also printed.

```
        * * * * G E O M E T R I C   P R O P E R T I E S * * * *
                ---------   ----------

              GEOMETRY
   INPUT      GROUP    ELEMENT  G E O M E T R I C   P A R A M E T E R
 SEQUENCE      NO.      TYPE        1           2           3
 ---------------------------------------------------------------------
      1         1       PMAS      3.0237E+10  0.0000E+00  0.0000E+00  ....


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


                                         DRAG        ADDED MASS
      N U M B E R                    COEFFICIENT     COEFFICIENT
         4           5           6           C             C
                                              D             M
      ----------------------------------------------------------------
 ....  1.1498E+11  0.0000E+00  1.1498E+11   0.00          0.00
```

Figure 7.4 - Geometric Property Output

The program, having accepted the user prescribed element distribution, now outputs the 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 FRA used in defining the body, and the inertia matrix is about the centre of gravity of the particular body. The types and total number of elements used to model the body are output. The number of elements output is based on the total coverage of the body's wetted surface and not the number input when utilising the program symmetry facilities.

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


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

               PMAS             1      75593800.000        741575232.000

               TPPL            12             0.000                0.000

               QPPL           200             0.000                0.000
         ------------------------------------------------------------------

            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

This information is output only if the program is starting at Stage 1 or the PRDL option is used to print this information from backing file.

The environmental parameters within AQWA-LIBRIUM consist only of the fluid, depth, and density and the gravitational acceleration. The static environment is output as shown in Figure 7.6 and is seen to contain these values.

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

WATER  DEPTH  . . . . . . . . . . . . . . . . . =    50.000

DENSITY  OF  WATER  . . . . . . . . . . . . . . = 1025.000

ACCELERATION  DUE  TO GRAVITY . . . . . . . . . =     9.810
```

Figure 7.6 - Static Environment

Following the static environment data, the wave environment is output and AQWA-LIBRIUM 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. Drift Forces). If these parameters have not already been input for certain frequencies, then these frequencies are listed as having undefined parameters.

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

STRUCTURE  VARIABLE                 1         2         3         4
---------------------------------------------------------------------
     1   DIRECTION(DEGREES)      180.00     90.00      0.00      0.00

         FREQUENCY(RADS/SEC)    0.50265   0.52360   0.62832   0.78540

         FREQUENCY(HERTZ)       0.08000   0.08333   0.10000   0.12500

         PERIOD(SECONDS)          12.50     12.00     10.00      8.00

         WAVE NUMBER(K)         0.02881   0.03067   0.04153   0.06311
                                                                     ......
         WAVELENGTH(L)           218.05    204.83    151.30     99.56

         MAXIMUM ELEMENT SIZE     31.15     29.26     21.61     14.22

         DEPTH RATIO(D/L)          0.23      0.24      0.33      0.50

         DEPTH RATIO(K*D)          1.44      1.53      2.08      3.16

         PARAMETERS                                          UNDEFINED
---------------------------------------------------------------------
```

Figure 7.7 - Wave Particulars

7.3 DESCRIPTION OF FLUID LOADING

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

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

7.3.1 Hydrostatic Stiffness

The hydrostatic stiffness matrix output by AQWA-LIBRIUM (as shown in Figure 7.8) 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.

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

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

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

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


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

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

   X  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00

   Y  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00

   Z  0.0000E+00  0.0000E+00  8.1414E+07 -7.8525E+01 -7.8525E+01  0.0000E+00

  R  0.0000E+00  0.0000E+00 -7.8525E+01  2.4408E+10  0.0000E+00  9.4230E+02

  RY  0.0000E+00  0.0000E+00 -7.8525E+01  0.0000E+00  2.4408E+10  2.6698E+03

  RZ  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
```

Figure 7.8 - Hydrostatic Stiffness Matrix Output

7.3.2 Wave Drift Forces

The wave drift forces and moments, as functions of wave period and direction, are output as shown in Figure 7.9. They are given for each body and for the range of user specified frequencies.

The mean wave drift forces are functions of the wave amplitude squared and are given for unit wave amplitude.

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

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


FORCES   FREQUENCY   DIRECTION(DEGREES) (FREEDOM X,Z,RY=COS, Y,R,RZ=SIN)
------   ---------   ----------------------------------------------------
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 7.9 - Wave Drift Forces/Moment

7.3.3 Drift Added Mass and Wave Damping

The added mass and wave damping corresponding to horizontal planar motion approach asymptotic values for low frequencies, and can therefore be expressed as single added mass and damping matrices. The added mass and wave damping are expressed in matrix form, and Figure 7.10 shows a typical added mass matrix for body one at the drift frequency (wave damping being output in a similar fashion).

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

                    ADDED MASS AT DRIFT FREQUENCY
                    -----------------------------

      X           Y           Z          R          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

 R 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+00  0.0000E+00

 RZ 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.2690E+11
```

Figure 7.10 - Added Mass Matrix Output

7.4 DESCRIPTION OF STRUCTURE LOADING

This section outputs details of the loads on each structure, whether due to wind and current, thrusters, user applied constraints or mooring lines.

7.4.1 Thruster Forces and Wind and Current Coefficients

The thruster number and associated force vectors (relative to the relevant structure's centre of gravity axis system), along with the point of application (expressed in the FRA system), are output as shown in Figure 7.11.

```
    * * * * WIND/CURRENT LOADS FOR UNIT AMPLITUDE/VELOCITY * * * *
            ----------------------------------------------
         * * * * AND THRUSTER FORCES FOR STRUCTURE 1 * * * *
                 ------------------------------------

                            THRUSTER  FORCES
                            ----------------

THRUSTER NODE  POSITION OF THRUSTER(FRA)    LOCAL THRUSTER FORCES IN
NUMBER  NUMBER    X       Y       Z      SURGE(X)   SWAY(Y)    HEAVE(Z)
-----------------------------------------------------------------------
   1      15    45.000  0.000  -20.000 -2.000E+06  0.000E+00  0.000E+00
```

Figure 7.11 - Thruster Force Output

In addition, the wind and current, forces and moments, which are functions of direction, are output for each structure as shown in Figure 7.12.

The wind and current forces which are both a function of the square of velocity are given for unit velocity.

```
     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(R)
                   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+00
HEAVE(Z)
                   0.00E+00  0.00E+00  0.00E+00
ROLL(R)
                   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 7.12 - Wind And Current Force Coefficients

7.4.2 Structure Constraints

The degree of freedom active for each structure during the analysis is signified by the character X in the constraint table as shown in Figure 7.13.

```
          * * * *  CONSTRAINTS  * * * *
                   -----------


 STRUCTURE           ACTIVE FREEDOM TABLE

  NUMBER     X       Y       Z      R      RY      RZ
--------------------------------------------------------

   1         X       X       X      X       X       X
```

Figure 7.13 - Structure Constraints Table

7.4.3 Cable/Line Mooring Configurations

The mooring line configurations table (as shown in Figure 7.14), consisting of the individual mooring type and properties, is output along with the mooring combination and group number. The location of the line is identified by a pair of structure numbers and node numbers. In the case of linear moorings (i.e. linear lines, winch loads and constant forces), the properties are included in the general output, either as stiffnesses or forces. However, in the case of non-linear moorings (i.e. a non-linear hawsers or catenaries), the properties are output in an additional table as shown in Figure 7.15. The parameter list depends on the mooring type, and is defined in the following table:

Parameter number	Polynomial (curve-fit of non linear stiffness)	Catenary
1	1st order polynomial coefficient	Weight/Unit Coefficient Length
2	2nd order polynomial coefficient	Equivalent Cross-Sectional Area
3	3rd order polynomial coefficient	Minimum Tension at Attachment Point
4	4th order polynomial coefficient	Maximum Tension at Attachment Point
5	5th order polynomial coefficient	Maximum Tension at Anchor Point

Table : Parameters List for Non-linear Moorings

Note: (i) Non-linear moorings can have group properties, whereas the linear moorings have specific individual properties.

(ii) A structure number of zero means that the mooring is attached to ground (e.g. a pier, sea-bed, etc).

(iii) The Equivalent Cross-Sectional Area is equal to the Volumetric Displacement per unit length of the Catenary. In general, this area is not the same as the Cross-Sectional Area (e.g. a chain will have a varying Cross-Sectional Area along its length). It is used to calculate the buoyancy force on the catenary which is assumed to be constant along its length.

```
          * * * * CABLE/MOORING  LINE  CONFIGURATIONS * * * *
                  -----------------------------------

              CABLE ATTACHMENTS( STRUCTURE - 0 - IS GROUND)
              ---------------------------------------------


COMBINATION    CABLE       ATTACHED TO AT NODE LINKED TO AT NODE  UNSTRETCHED  FORCE OR

 NUMBER   NUMBER/GROUP/TYPE STRUCTURE   NUMBER STRUCTURE NUMBER   LENGTH     STIFFNESS
---------------------------------------------------------------------------------------

  1        1  2  NON-LINEAR      1          1       0        54    90.501

           2  2  NON-LINEAR      1         10       0        22    72.524

           3  3  NON-LINEAR      1         10       0        22    72.524

           5  0  LIN  ELASTIC    3         53       0        57    50.000     0.500E+07

           6  0  CONST F/DIRN    1         37       0        42     0.000     0.323E+07
```

Figure 7.14 - Mooring Configuration Table

```
          * * * * CABLE/MOORING  LINE  CONFIGURATIONS * * * *
                  -----------------------------------

------------------------------------------------------------------------
GROUP   GROUP      PARAMETER  PARAMETER  PARAMETER  PARAMETER  PARAMETER
NUMBER   TYPE          1          2          3          4          5
------------------------------------------------------------------------

  1   POLYNOMIAL  5.6481E+04 1.9731E+05 5.8376E+04 0.0000E+00 0.0000E+00

  2   POLYNOMIAL  6.0853E+04 1.4328E+05 2.8868E+04 0.0000E+00 0.0000E+00

  3    CATENARY   2.9790E+02 3.8070E-02 0.0000E+00 0.0000E+00 0.0000E+00
```

Figure 7.15 - Non-Linear Mooring Properties

7.5 DESCRIPTION OF ENVIRONMENTAL CONDITIONS

This section outputs the details of the environmental conditions at which equilibrium is required (i.e. wind, wave and current).

7.5.1 Wind and Current Conditions (no waves)

The wind and current conditions not associated with wave spectra are output as shown in Figure 7.16 (i.e. the data input in Deck 11). This output consists of uniform wind and current fields with a superimposed profiled current condition, characterised by a variation of current speed and direction with water depth. However the latter variable can be set to a default value.

```
             * * * * ENVIRONMENTAL PARAMETERS * * * *
                     ------------------------

       UNIFORM CURRENT VELOCITY  . . . . . . . . . =     0.000

       UNIFORM CURRENT DIRECTION . . . . . . . . . =     0.000

       UNIFORM WIND VELOCITY . . . . . . . . . . . =     0.000

       UNIFORM WIND DIRECTION  . . . . . . . . . . =     0.000

       DEFAULT DIRECTION OF PROFILED CURRENT . . . =     0.000


                         CURRENT PROFILES
                         ----------------

          Z-ORDINATE             CURRENT              CURRENT
       W.R.T. SEA LEVEL          VELOCITY            DIRECTION

          -10.000                 1.000                0.000
           -5.000                 1.000                0.000
            0.000                 2.000                0.000
```

Figure 7.16 - Wind and Current Conditions

From the consideration of the influence of sea state on the system equilibrium, the environmental parameters are specified either as those corresponding to formulated spectra (i.e Pierson-Moskowitz or Jonswap), or user defined spectra. In the case of formulated spectra, the environmental parameters are output as shown in Figure 7.17. Included in the parameter list is the spectral type, and the spectral resolution limits, (i.e. the number of lines and rasters, and the upper and lower frequency cut-offs). The spectral parameters depend on the spectrum type, and are defined in the following table:

Parameter Number	Pierson-Moskowitz	Jonswap
1	Significant wave height	Gamma constant
2	Zero cross over period	Alpha constant
3	....	Peak spectral frequency

Table : Spectral Parameters for Formulated Spectra

The wave direction is also defined for each spectrum along with the associated wind and current speeds and directions. Note this data will replace the uniform current and wind data output discussed in Section 7.5.1.

```
                  * * * * FORMULATED SPECTRA * * * *
                          ------------------



        SPECTRUM  SPECTRUM   NUMBER NUMBER     LOWER     UPPER
                               OF     OF     FREQUENCY FREQUENCY
         NUMBER     TYPE     LINES  RASTERS  (RAD/SEC) (RAD/SEC))
       --------------------------------------------------------   .......

           1    PIERSON-M    100    5000      0.2500    1.4000


         SPECTRAL PARAMETERS     SPECTRAL  CURRENT CURRENT   WIND      WIND
                                 DIRECTION   SPEED  DIRECTION  SPEED  DIRECTION
           1        2        3    (DEGREES)         (DEGREES)         (DEGREES)
cont'd . -------------------------------------------------------------------

         8.0000  11.0000   0.0000     0.0     0.000     0.0      0.0      0.0
```

Figure 7.17 - Formulated Spectra and Wind and Current Conditions

In the case of user defined spectra, the environmental parameters are output as shown in Figure 7.18. Included in the parameter list is the spectral resolution limits (i.e the number of lines and rasters, and the upper and lower frequency cut-offs). The spectral parameters are computed from the user defined spectral ordinates and frequencies (input in Deck 13), and are output as shown in Figure 7.18. These include the significant wave height, the maximum spectral value, and the associated peak frequency. The wave spectrum direction is also defined for each spectrum along with the associated wind and current speeds and directions. This data will replace the uniform current and wind data output discussed in Section 7.5.1.

```
                * * * * USER-DEFINED SPECTRA * * * *
                        --------------------


  SPECTRUM  NUMBER NUMBER     LOWER     UPPER   SIGNFCNT
               OF     OF    FREQUENCY FREQUENCY  WAVE
   NUMBER   LINES  RASTERS  (RAD/SEC) (RAD/SEC) HEIGHT
 -------------------------------------------------------   ........

     1       50     5000     1.6336    5.2150   13.01


         MAX       PEAK      SPECTRAL  CURRENT CURRENT   WIND     WIND
       SPECTRAL FREQUENCY DIRECTION   SPEED DIRECTION  SPEED  DIRECTION
        VALUE    (RAD/SEC) (DEGREES)         (DEGREES)         (DEGREES)
 cont'd . ---------------------------------------------------------------

         6.60    3.0788     180.0      0.5    90.0     45.4     180.0


              * * * * USER-DEFINED SPECTRA * * * *
                      --------------------


                 FREQUENCY FREQUENCY  ORDINATE
                  NUMBER   (RAD/SEC)
              ------------------------------------
                     1      1.6336    0.0000
                     2      1.8221    0.3183
                     3      2.5761    5.0134
                     4      2.7018    5.6500
                     5      2.9531    6.5651
                     6      3.0788    6.6049
                     7      3.2044    6.2866
                     8      3.3929    4.6155
                     9      3.6442    4.2972
                    10      3.7699    4.2176
                    11      4.0212    3.1831
                    12      4.2726    1.5915
                    13      4.5553    0.5570
                    14      4.7752    0.2387
                    15      5.2150    0.1592
```

Figure 7.18 - User Defined Spectra and Wind and Current Conditions

7.6 ITERATION PARAMETERS

7.6.1 Initial Equilibrium Positions

The initial equilibrium position of the centre of gravity specified by the user for each structure, spectrum and hawser combination, will be output in the format shown in Figure 7.19. If the user does not specify a structure's initial position for a given combination, that structure's initial position will correspond to that of the previous combination. If no position has been specified at all in Deck 15, the structure's centre of gravity will be output at the original location in the FRA system.

```
   * * * * INITIAL EQUILIBRIUM POSITIONS OF THE CENTRE OF GRAVITY * * * *
           ------------------------------------------------------

STRUCTURE SPECTRUM HAWS. COMB  TRANSLATIONAL POS(FRA)  ROTATN ABOUT AXES(FRA)
 NUMBER    NUMBER   NUMBER        X        Y       Z        RX       RY     RZ
----------------------------------------------------------------------------

   1         1         1      -4.673  56.000  14.770    0.000   0.000  0.000

   2         1         1     494.750 325.500 -50.800    0.000   0.000  0.000

   3         1         1    -496.250 325.500 -29.800    0.000   0.000  0.000
```

Figure 7.19 - Initial Equilibrium Positions

7.6.2 Iteration Limits

The iteration limits used in the equilibrium search are output as shown in Figure 7.20. These correspond to maximum movement in each mode per iteration, and the maximum allowable convergence error for each degree of freedom of each structure. In addition, the maximum number of iterations is also stated. If these values not are not input in Deck 16, the values in the output will correspond to the program default values (see AQWA Reference Manual).

```
                  * * * * ITERATION LIMITS * * * *
                          ----------------


               MAXIMUM NUMBER OF ITERATIONS . . .  100

 STRUCTURE                          TRANSLATION          ROTATION(DEGREES)
   NUMBER                        X       Y       Z       RX      RY     RZ
----------------------------------------------------------------------------

     1     MAXIMUM MOVEMENT       0.50    0.50    0.50    1.00    1.00    0.50
           FOR ONE ITERATION

           MAXIMUM ERROR IN FINAL 0.0100 0.0100 0.0100  0.0100 0.0100 0.0100
           EQUILIBRIUM POSITION

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

     2     MAXIMUM MOVEMENT       0.50    0.50    0.50    1.00    1.00    0.50
           FOR ONE ITERATION

           MAXIMUM ERROR IN FINAL 0.0100 0.0100 0.0100  0.0100 0.0100 0.0100
           EQUILIBRIUM POSITION

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

     3     MAXIMUM MOVEMENT       0.50    0.50    0.50    1.00    1.00    0.50
           FOR ONE ITERATION

           MAXIMUM ERROR IN FINAL 0.0100 0.0100 0.0100  0.0100 0.0100 0.0100
           EQUILIBRIUM POSITION

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

Figure 7.20 - Iteration Limits

7.6.3 Iteration Report

An iteration report for each structure is made at the conclusion of each iteration step, specifying each structure's centre of gravity position and the residual forces and moments at that structure's CG (in an axis system parallel to the Fixed Reference Axis system). These will be continuously reported, as shown in Figure 7.21 until either equilibrium is achieved or the maximum number of iterations is exceeded, whereby an error message will be output. If the user requires further data expansion, a PBIS option in the options list will generate the component force contributions in the output (e.g. gravity, stiffness, mooring forces etc). For further details see Appendix A.

```
          * * * * ITERATION TOWARDS THE EQUILIBRIUM POSITION * * * *
                  ------------------------------------------

   SPECTRUM NO.   1        MOORING COMBINATION  1 (NO. OF CABLES = 27)

                       LOCATIONS OF CG        ORIENTATIONS (DEGREES)
  STEP STRUCTURE       X         Y         Z        RX        RY        RZ
  ---------------------------------------------------------------------

    0      1        -4.67     56.00     14.77      0.00      0.00      0.00

    0      2       494.75    325.50    -50.80      0.00      0.00      0.00

    0      3      -496.25    325.50    -29.80      0.00      0.00      0.00


    1      1        -5.17     55.94     14.77      0.00      0.00      0.00

    1      2       494.75    325.50    -50.80      0.00      0.00      0.00

    1      3      -496.25    325.50    -29.80      0.00      0.00      0.00

    .      .          .         .         .         .         .         .

    .      .          .         .         .         .         .         .
                                                                           .....
    .      .          .         .         .         .         .         .

    8      1        -6.56     55.23     14.77      0.11     -0.01      0.17

    8      2       494.60    325.46    -49.47      0.00      0.00      0.00

    8      3      -496.25    325.50    -29.80      0.00      0.00      0.00
```

Figure 7.21 - Iteration Report

```
         * * * * ITERATION TOWARDS THE EQUILIBRIUM POSITION * * * *
                 ------------------------------------------

     SPECTRUM NO.   1        MOORING COMBINATION  1 (NO. OF CABLES = 27)

                 RESIDUAL FORCES AND MOMENTS    (AXES AT CG PARA. TO FRA)
                    X         Y         Z        RX        RY        RZ
                 --------------------------------------------------------


               -3.24E+06 -6.05E+05 -6.53E+04 -4.29E+06  5.42E+05 -3.87E+06

                0.00E+00  0.00E+00 -6.87E+04  0.00E+00  0.00E+00  0.00E+00
  continued
                0.00E+00  0.00E+00 -6.87E+04  0.00E+00  0.00E+00  0.00E+00
  from

  previous     -2.32E+06 -4.95E+05 -1.03E+05 -2.99E+06  9.64E+05 -1.86E+06

  page         -1.95E+05 -1.12E+05 -4.33E+04  0.00E+00  0.00E+00  0.00E+00

                0.00E+00  0.00E+00 -6.87E+04  0.00E+00  0.00E+00  0.00E+00

                 .         .         .         .         .         .

  ......         .         .         .         .         .         .

                 .         .         .         .         .         .

                5.02E+02 -2.80E+03 -2.56E+02 -2.28E+04  1.13E+04 -1.43E+05

                2.06E+02  1.18E+02  1.87E+01  0.00E+00  0.00E+00  0.00E+00

  ......        0.00E+00  0.00E+00 -6.87E+04  0.00E+00  0.00E+00  0.00E+00


                5.02E+02 -2.80E+03 -2.56E+02 -2.28E+04  1.13E+04 -1.43E+05

                2.06E+02  1.18E+02  1.87E+01  0.00E+00  0.00E+00  0.00E+00

                0.00E+00  0.00E+00 -6.87E+04  0.00E+00  0.00E+00  0.00E+00
```

Figure 7.21 - Iteration Report (continued)

7.7 STATIC EQUILIBRIUM REPORT

At the conclusion of the equilibrium analysis, a stiffness report is generated for the global system along with a general static stability assessment. In addition, hydrostatic particulars of the structures and mooring forces are output to allow the user to assess the contributions from the system components.

7.7.1 Hydrostatic Reports of Freely Floating Structures

Two reports are generated for the structure hydrostatics. The first is common to other programs within the AQWA-SUITE, and creates hydrostatic fluid loading details output by AQWA-LIBRIUM for each body in the EQUILIBRIUM position. This hydrostatic output is grouped into the following four categories, and as shown in Figure 7.22.

1 Hydrostatic Stiffness Matrix at the Centre of Gravity

The coordinates of the centre of gravity are output with respect to the FRA with the body in the prescribed analysis position. The heave, roll and pitch components of the hydrostatic stiffness matrix are given with respect to the body's centre of gravity.

2 Hydrostatic Displacement Properties

The actual and equivalent volumetric displacements are given together with the coordinates of the centre of buoyancy. These coordinates are measured with the body in the equilibrium position and with respect to the FRA system. The accuracy of the structure equilibrium is checked by considering the normalised force/moment components output.

3 Cut Water Plane Area Properties

The properties of the body's cut water plane are output, and these include the total area, centre of area and principal second moments of area. The angle PHI output is the angle between the body's principal cut waterplane axes and the FRA. (N.B. the X and Y axes of the FRA are on the free surface.)

4 Small Angle Stability Parameters

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

```
*** HYDROSTATIC PROPERTIES IN THE FREE FLOATING POSITION FOR STRUCTURE 2 ***
    --------------------------------------------------------------------

               1.STIFFNESS MATRIX AT THE CENTER OF GRAVITY
               -------------------------------------------
          C.O.G      GX=  -120.000 GY=     0.000 GZ=    10.000

          HEAVE( Z) =      1.974E+05    -6.904E-01    -1.235E+01
          ROLL(RX)  =     -6.904E-01    -5.281E+08     1.227E+00
          PITCH(RY) =     -1.235E+01     1.227E+00    -5.281E+08

               2.HYDROSTATIC DISPLACEMENT PROPERTIES
               -------------------------------------
          ACTUAL VOLUMETRIC DISPLACEMENT . . . . . . = 1.522E+03
          EQUIVALENT VOLUME OF STRUCTURE . . . . . . = 2.927E+03
          POSITION OF THE CENTRE OF BUOYANCY      BX =  -120.000
                                                  BY =     0.000
                                                  BZ =   -29.677

          AN INCOMPLETE ELEMENT DESCRIPTION OF    FX =     0.000
          THE HULL GIVES OUT OF BALANCE FORCES    FY =     0.000
          AND MOMENTS. IF THE C.O.B. IS NOT       FZ =    -0.480
          BELOW THE C.O.G. THIS GIVES OUT OF      MX =     0.000
          BALENCED MOMENTS (FORCES ARE DIVIDED    MY =     0.000
          BY THE WEIGHT AND ARE W.R.T. AXES       MZ =     0.000
          PARALLEL TO THE FIXED REFERENCE AXIS

               3.CUT WATER PLANE AREA PROPERTIES
               ---------------------------------
          CUT WATER PLANE AREA . . . . . . . . . . . = 1.963E+01

          CENTER OF FLOATATION.I.E. CENTROID       X =  -120.000
          POSITION IN THE FIXED REFERENCE AXIS     Y =     0.000

          PRINCIPAL SECOND MOMENTS OF AREA        IXX= 7.862E+03
                                                  IYY= 7.862E+03
          ANGLE THE PRINCIPAL AXES MAKE WITH      PHI=     4.731
          THE FIXED REFERENCE AXIS SYSTEM

               4.SMALL ANGLE STABILITY PARAMETERS
               ----------------------------------
          DISTANCE BETWEEN C.O.G. AND C.O.B       BG =    39.677

          METACENTRIC HEIGHTS WITH RESPECT TO     GMX=   -34.511
          THE PRINCIPAL AXES OF THE CUT AREA      GMY=   -34.511
          DISTANCE BETWEEN THE C.O.B. AND THE     BMX=     5.166
          METACENTRE (BMX=GMX+BG,BMY=GMY+BG)      BMY=     5.166

          RESTORING MOMENT ABOUT THE PRINCIPAL    MX =-9.216E+06
          AXES PER DEGREE ROTATION                MY =-9.216E+06
```

Figure 7.22 - Structure Hydrostatic Properties in the Free Floating Position

The second hydrostatic report (as shown in Figure 7.23) which is specific to AQWA-LIBRIUM, generates similar data to the first. However the output coordinate data is referred to the structure centre of gravity (in an axis system parallel to the FRA system), rather than the FRA system (as in the previous report). This report is grouped into the following three sections:

1. The Equilibrium Position

   This is the structure CG position and orientation at equilibrium in the Fixed Reference Axis system. In addition, the structure FRA direction cosines are provided.

2. Hydrostatic Forces and Moments

   The hydrostatic forces and moments acting on the structure are output along with the centre of buoyancy with respect to the centre of gravity.

3. Water Plane Properties

   The water plane properties are also referred to the structure CG (parallel to the Fixed Reference Axes) and include the centre of floatation, and the first, second and product moments of area. This retains the water surface properties used in the calculation of the angle between the principal and FRA as shown in Figure 7.22.

```
           *** HYDROSTATICS OF STRUCTURE  2 AT EQUILIBRIUM ***
               -------------------------------------------

       SPECTRUM NO.   1    MOORING COMBINATION   1   (NO. OF CABLES =   1)

                 EQUILIBRIUM POSITION WITH RESPECT TO FRA
                 ----------------------------------------

  CENTRE OF GRAVITY  ORIENTATION(DEGREES)   DIRECTION COSINES OF BODY AXES
  -----------------  -------------------    ------------------------------

    X = -120.000        RX  =   0.000       X-AXIS   1.000   0.000   0.000
    Y =    0.000        RY  =   0.000       Y-AXIS   0.000   1.000   0.000
    Z =   10.000        RZ  =   0.000       Z-AXIS   0.000   0.000   1.000

          HYDROSTATIC FORCES AND MOMENTS (AXES AT CG PARA. TO FRA)
          --------------------------------------------------------

          BUOYANCY =    1.530E+07

          CENTRE OF BUOYANCY                        MOMENTS
        --------------------                 --------------------

             X    =   0.000                    X  =   8.666E+02
             Y    =   0.000                    Y  =  -4.035E+01
             Z    = -39.677                    Z  =  -6.071E+08

             WATERPLANE AREA PROPERTIES (AXES AT CG PARA. TO FRA)
             -----------------------------------------------------

        CENTRE OF FLOATATION       AREA        FIRST MOMENT OF AREA
        --------------------    ----------     --------------------

        XBAR  =   0.000          1.963E+01    AREA*XBAR =    1.228E-03
        YBAR  =   0.000                       AREA*YBAR =   -6.866E-05

            SECOND MOMENTS OF AREA           PRODUCTS OF AREA
            ----------------------         --------------------

            X AXIS =    7.862E+03         XY AXIS   =    1.221E-04
            Y AXIS =    7.862E+03
```

Figure 7.23 - Structure Hydrostatics at Equilibrium

7.7.2 Structure Hydrostatic Stiffness Matrix

The free-floating hydrostatic stiffness matrix is output for each structure as shown in Figure 7.24. This is the stiffness matrix at the centre of gravity of the structure at equilibrium, but **does not include** the stiffness contributions generated by the structure moorings.

```
          * * * * HYDROSTATIC STIFFNESS OF STRUCTURE  1  * * * *
                  ------------------------------------


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


  X      0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00

  Z      0.000E+00  0.000E+00  5.430E+07 -4.467E+01  1.444E+08  0.000E+00

 RX      0.000E+00  0.000E+00 -4.467E+01  1.723E+09 -1.145E+04  1.733E+09

 RY      0.000E+00  0.000E+00  1.444E+08 -1.145E+04  1.446E+11  5.258E+02

 RZ      0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
```

Figure 7.24 - Structure Hydrostatic Stiffness Matrix

7.7.3 Mooring Forces and Stiffness

An output of the mooring forces and stiffness for a component mooring is shown in Figure 7.25. These are output for every mooring line and contribute additional stiffness to the global stiffness matrix (see Figure 7.26).

```
        * * * * MOORING FORCES AND STIFFNESS   ----  STRUCTURE  2 * * * *
                ----------------------------         ------------

        (SPECTRUM NO.   1   MOORING COMBINATION   1  (NO. OF CABLES =  27)

                        N.B. STRUCTURE 0 IS FIXED.

                  CABLE NO.   1     TYPE      LIN  ELASTIC
                  ----------------------------------------
          STRUCTURE  1          STRUCTURE  2     MOORING STIFFNESS AT NODE 50
            NODE    50            NODE    52              AXES // FRA
          CORD.     FORCE       CORD.     FORCE       X         Y         Z
 ---------------------------------------------------------------------------

 X 5.9810E+01 7.1386E+05 4.9460E+02-7.1386E+05 3.713E+05 2.130E+05-4.686E+04

 Y 7.4942E+01 4.1132E+05 3.2546E+02-4.1132E+05 2.130E+05 1.244E+05-2.700E+04

 Z 5.6434E+00-9.0494E+04-4.9473E+01 9.0494E+04-4.686E+04-2.700E+04 7.583E+03

    MODULUS = 8.2884E+05  MODULUS = 8.2884E+05
```

Figure 7.25 - Mooring Force and Stiffness

7.7.4 Global System Stiffness Matrix

The system stiffnesses are output in the global stiffness matrix, part of which is shown in Figure 7.26. This comprises the individual structure hydrostatic components and also the contributions from other structures passed via the moorings. Figure 7.26 shows the stiffness experienced by one structure and two other structures moored to it (the latter structure is inactive).

The global stiffness matrix is output only when the PRST option is used (see Appendix A).

```
             * * * * GLOBAL SYSTEM STIFFNESS MATRIX * * * *
                     ------------------------------

      SPECTRUM NO. 1     MOORING COMBINATION   1  (NO. OF CABLES =  27)

                                 STRUCTURE   1
 STRUCTURE
    1         X          Y          Z          RX         RY         RZ
 -------  ----------------------------------------------------------------

    X      3.197E+06 -1.754E+06 -2.689E+05 -1.311E+07 -2.130E+07  5.977E+06

    Y     -1.754E+06  3.463E+06  1.483E+05  3.784E+07  1.536E+07  6.784E+06

    Z     -2.689E+05  1.483E+05  6.770E+07  3.607E+05  3.181E+05 -2.253E+06

   RX     -1.311E+07  3.784E+07  3.607E+05  4.802E+09 -2.497E+08  1.698E+08

   RY     -2.130E+07  1.536E+07  3.181E+05 -2.498E+08  1.400E+11 -3.727E+08

   RZ      5.977E+06  6.784E+06 -2.253E+06  1.698E+08 -3.727E+08  6.065E+09

                                 STRUCTURE   1
 STRUCTURE
    2         X          Y          Z          RX         RY         RZ
 -------  -----------------------------------------------------------------

    X     -3.713E+05 -2.130E+05  4.686E+04 -1.019E+06  2.773E+05 -6.815E+06

    Y     -2.130E+05 -1.244E+05  2.700E+04 -6.022E+05  1.511E+05 -4.054E+06

    Z      4.686E+04  2.700E+04 -7.583E+03  9.683E+04  7.571E+04  8.680E+05

   RX      0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00

   RY      0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00

   RZ      0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
```

Figure 7.26 - Components of Global Stiffness Matrix

7.7.5 System Small Displacement Static Stability

An eigenvalue analysis of the global stiffness matrix is carried out from which the system stability can be assessed. This information is output in the system small displacement static stability report as shown in Figure 7.27. The system stability is assessed from an eigenvalue analysis of the global stiffness matrix, **all** eigenvalues of which must either be defined as stable or neutral for the system to be free from static instabilities.

```
          * * * * SMALL DISPLACEMENT STATIC STABILITY * * * *
                  -----------------------------------

      SPECTRUM NO.   1     HAWSER COMBINATION   1  (NO. OF HAWSERS =  27)

       PRINCIPAL COORD.  LOAD PER UNIT DISPLACEMENT           STABILITY
                           IN THE PRINCIPAL COORD.
       ----------------------------------------------------------------

              1              1.449E+06                         STABLE

              2              4.782E+06                         STABLE

              3              6.770E+07                         STABLE

              4              4.780E+09                         STABLE

              5              1.400E+11                         STABLE

              6              6.086E+09                         STABLE

              7              5.563E+06                         STABLE

              8              1.807E+04                         STABLE

              9              2.025E+04                         STABLE

              10                 0                            *NEUTRAL*

              11                 0                            *NEUTRAL*

              12                 0                            *NEUTRAL*

              13                 0                            *NEUTRAL*

              14                 0                            *NEUTRAL*

              15                 0                            *NEUTRAL*

              16                 0                            *NEUTRAL*

              17                 0                            *NEUTRAL*

              18                 0                            *NEUTRAL*
```

Figure 7.27 - Small Displacement Static Stability Table

7.8 DYNAMIC EQUILIBRIUM REPORT

If the user has requested a dynamic stability analysis, the program will output a dynamic stability report giving the transient stability characteristics of each moored structure for small perturbations from equilibrium. This information allows the user to assess the dynamic stability of each vessel (e.g. due to a random seaway, wind gusting, etc), and identify any problem modes of motion which may require a redesign of the mooring configuration.

7.8.1 Stability Characteristics of Moored Vessel

The dynamic stability characteristics are output as shown in Figure 7.26, and are only generated for the asymmetric motions (i.e. surge, sway and yaw). This option generates dynamic stability information for only one spectrum. Eigenvalues are determined for each mode of motion, from the real and imaginary parts of which the critical damping, fishtailing period and stability of that mode of motion can be assessed. The stability regions are defined as follows:

1. STABLE — The structure returns to the equilibrium position by an exponentially decreasing oscillation at the specified fishtailing period (excessively large fishtailing periods indicate a non-oscillatory exponential decay).

2. UNSTABLE — There is a steady exponential drift away from the equilibrium position.

3. FISHTAILING — There is an exponentially increasing oscillation about the equilibrium position at the fishtailing frequency.

In addition, the real and imaginary parts of the eigenvectors, corresponding to the velocities and displacements of the asymmetric degrees of freedom are output. The individual components of the eigenvectors are as shown in the table overleaf.

Parameter	Location in Output
Surge Velocity	1 real eigenvectors
Sway Velocity	2 real eigenvectors
Yaw Velocity	3 real eigenvectors
Surge Displacement	4 real eigenvectors
Sway Displacement	5 real eigenvectors
Yaw Displacement	6 real eigenvectors
Surge Velocity	1 imag eigenvectors
Sway Velocity	2 imag eigenvectors
Yaw Velocity	3 imag eigenvectors
Surge Displacement	4 imag eigenvectors
Sway Displacement	5 imag eigenvectors
Yaw Displacement	6 imag eigenvectors

Table : Composition of Real and Imaginary Eigenvectors

These are output (as shown in Figure 7.28), and can be used to identify the transient vessel response for modes of motion of interest.

```
                STABILITY CHARACTERISTICS OF MOORED VESSEL
                ------------------------------------------

                            STRUCTURE NUMBER  1
                            -------------------


                      1ST MODE OF    2ND MODE OF    3RD MODE OF
                        MOTION         MOTION         MOTION

    CRITICAL DAMPING      1.3812E-07     2.0670E-07    -2.9776E+06

    FISHTAILING PERIOD    0.1367E+04     0.2454E+04     0.4838E+10

    STABILITY REGION       STABLE         STABLE       FISHTAILING    .....

    REAL EIGENVECTORS     1.2997E-12     1.1090E-10    -2.1916E-03

    REAL EIGENVECTORS     3.3563E-10     4.7307E-09     3.1856E-03

    REAL EIGENVECTORS    -5.0259E-13    -1.3483E-11     1.8567E-05

    REAL EIGENVECTORS     2.1101E-01     9.9794E-01    -5.6678E-01    .....

    REAL EIGENVECTORS     9.7746E-01    -6.4121E-02     8.2385E-01

    REAL EIGENVECTORS    -3.7685E-03     1.7644E-03     4.8018E-03

    IMAG EIGENVECTORS     9.7009E-04     2.5548E-03     2.4836E-10

    IMAG EIGENVECTORS     4.4937E-03    -1.6415E-04    -2.4836E-10    .....

    IMAG EIGENVECTORS    -1.7325E-05     4.5170E-06    -2.5871E-12

    IMAG EIGENVECTORS    -4.0025E-11     0.0000E+00     4.2386E-07

    IMAG EIGENVECTORS     0.0000E+00    -5.2239E-07     0.0000E+00

    IMAG EIGENVECTORS     1.1141E-10     3.5667E-09    -1.9869E-09
```

Figure 7.28 - Moored Vessel Dynamic Stability Characteristics

CHAPTER 8 - EXAMPLE OF PROGRAM USE

In this chapter an example problem using AQWA-LIBRIUM 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 Problem Definition

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

In addition, a thruster force acts on the vessel side in the X direction, as shown in Figure 8.1.

Structure thruster force, F_T = 2E6 newtons

It is required to obtain the equilibrium position of the box in irregular waves for three given sea states. Note that the analysis is performed using SI units.

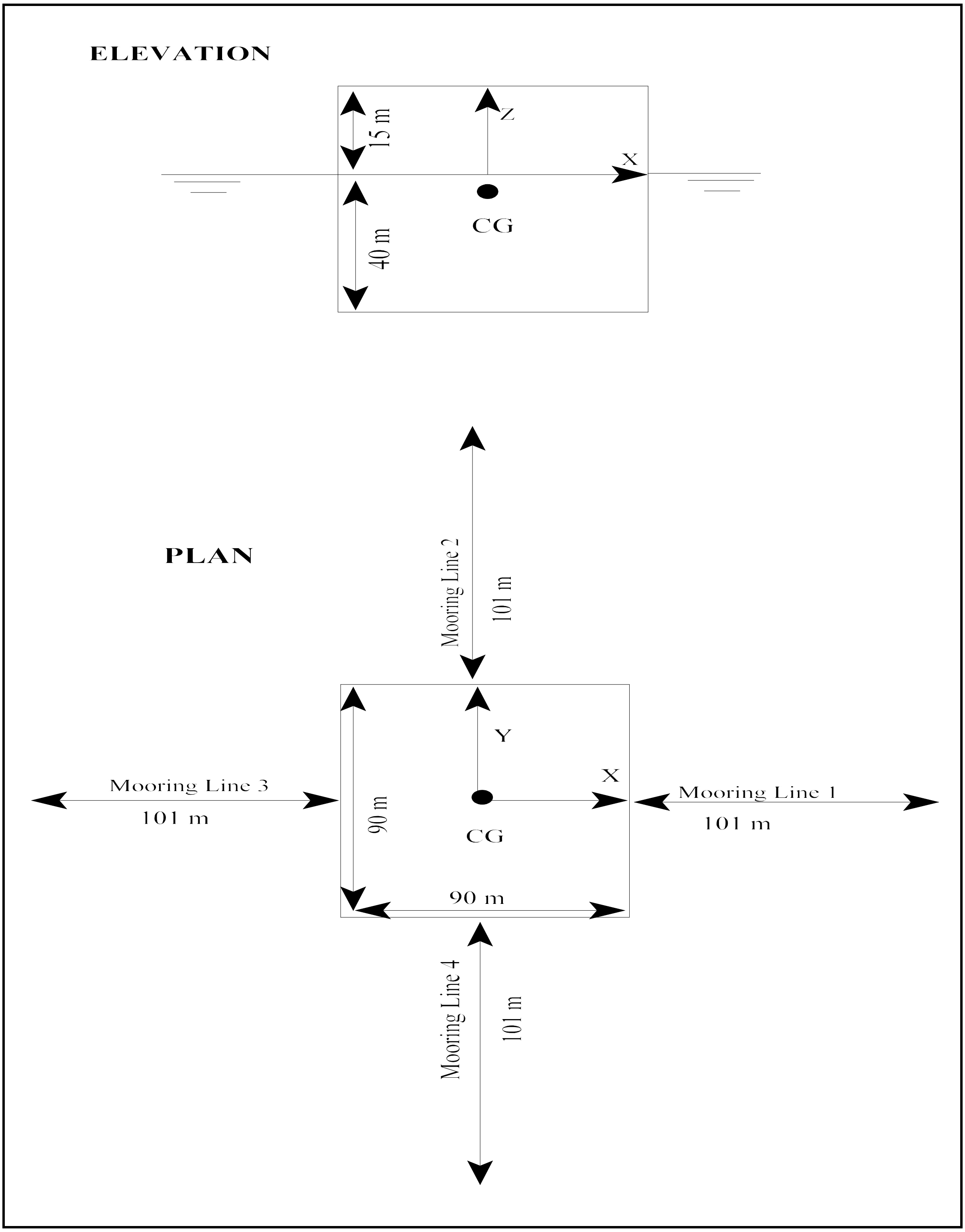

Figure 8.1 - Box Structure

8.1.2 Idealisation of Box

The following requires modelling:

- The mass and inertia properties of the body
- The surface of the body

Before starting the modelling exercise, it is necessary to decide the definition position of the body with respect to the FRA. The body is defined such that the bottom of the box is 40 metres below the X-Y plane of, and parallel to, the FRA. In this example, the DEFINITION position and ANALYSIS position of the body are the same.

8.1.3 The Body Surface

The body has the property of 4-fold symmetry, and this may be utilised when modelling the surface of the body. We need only describe, therefore, one quarter of the box's surface and this is shown in Figure 8.2.

Type of Plate Element

Since each of the box surfaces is rectangular and planar, we may best utilise QPPL elements.

Sizing of QPPL Elements

The model beneath the free surface is the same as that used in AQWA-LINE and satisfies the AQWA-LINE modelling criteria (see AQWA-LINE Manual Section 8.1.1). The superstructure is composed of non-diffracting quadrilateral plates whose only limitation is that the superstructure geometry should be properly modelled.

Additional nodes were placed on the structure and the seabed to represent the mooring attachment points (see Figure 8.1).

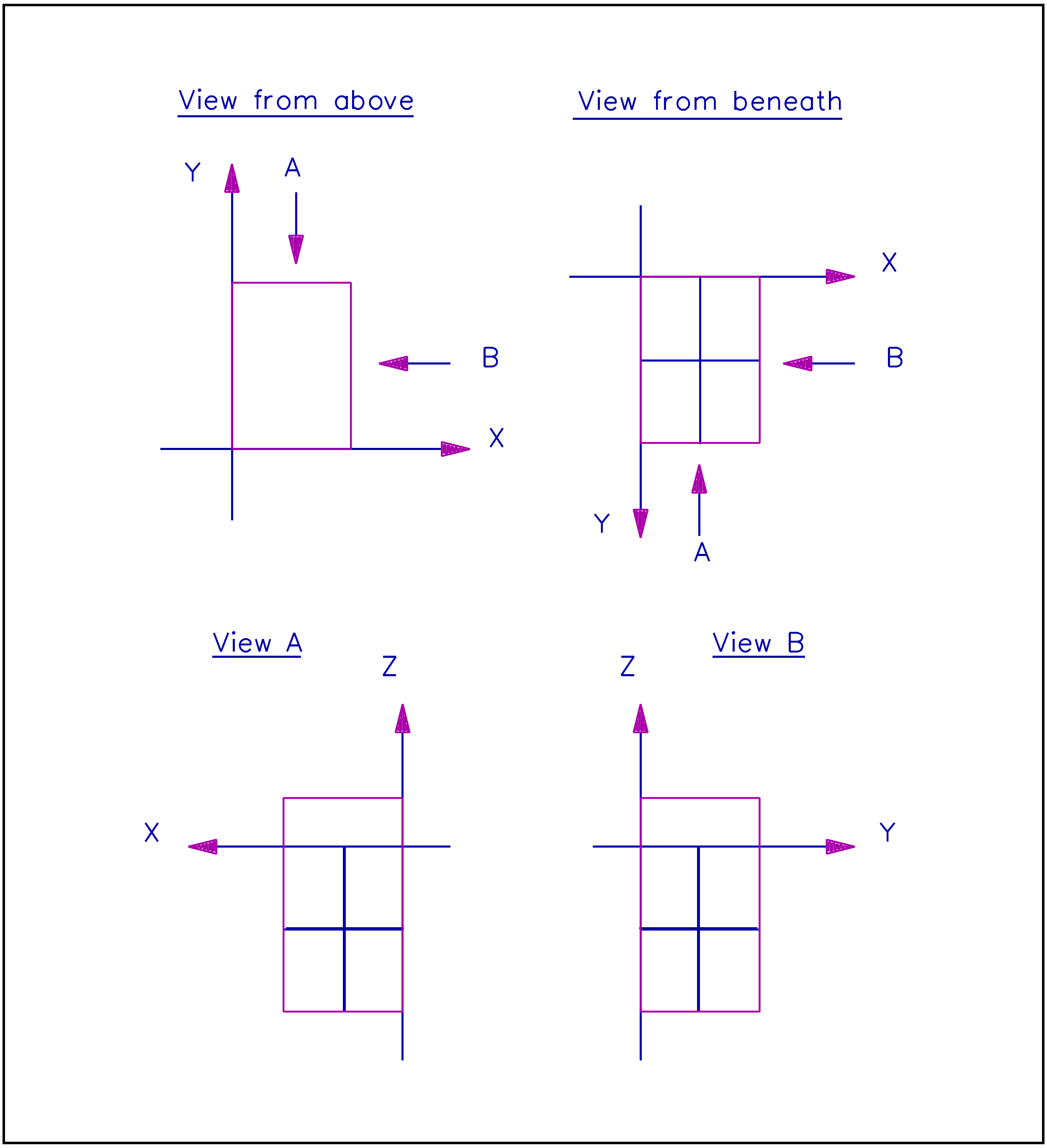

Figure 8.2 - Modelling of Body's Wetted Surface

8.1.4 The Body Mass and Inertia

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

Mass input via material group 1 with associated value of 3.321E8 kg

Inertia input via geometry group 1 with associated values of

I_{xx} = 3.6253E11 kgm^2
I_{yy} = 3.4199E11 kgm^2
I_{zz} = 3.5991E11 kgm^2

and $I_{xy} = I_{yz} = I_{zx} = 0.0$

8.1.5 AQWA-LINE Analysis

The equilibrium position used to position the structure for each analysis is normally obtained from an AQWA-LIBRIUM analysis where each drift force has been estimated manually. In simple cases, the equilibrium positions may be calculated manually as in this case. The equilibrium positions calculated for the chosen spectra are as shown below:

	Surge(X)	Sway(Y)	Heave(Z)	Roll(RX)	Pitch(RY)	Yaw(RZ)
Spectrum 1	0.0	0.0	-10.62	0.0	0.0	0.0
Spectrum 2	0.0	0.0	-10.62	0.0	0.0	0.0
Spectrum 3	0.0	0.0	-10.62	0.0	0.0	0.0

The model as described in the previous sections was run using AQWA-LINE for Stages 1 to 3 in order to generate the hydrodynamic data required by the AQWA-LIBRIUM analysis.

8.1.6 Wave Frequency Drift Forces

The wave drift loads for unit wave amplitude, necessary to determine the equilibrium position of the structure in the wave spectra, are calculated by AQWA-LINE for each wave frequency and direction. These mean wave drift forces are proportional to the square of the wave amplitude, and at present only the horizontal wave forces and yaw moment are calculated.

8.1.7 Low Frequency Added Mass and Damping

The dynamic stability analysis requires that the drift frequency added mass and damping are defined. It may be assumed that at low frequency, the added mass and damping remain constant, as values of drift added mass for the horizontal freedoms have finite value asymptotes at low frequency. The values often used are those of the lowest wave frequency input in AQWA-LINE. This is normally a good approximation. However, for damping, empirical values may be input based on either the experience of the user, or experimental results. For this example, values of added mass and damping at a frequency 0.349 (period 18 secs) will be used.

8.1.8 Hull and Superstructure Loading Coefficients

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

Wind and Current forces per unit velocity acting on the body are given by:

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

Thus the forces in the X and Y directions, due to currents at 0,45 and 90 degree headings, are respectively:

F_x (0), F_y (90)	=	0.5 ∗ 1025.0 ∗ 40.0 ∗ 90.0 ∗ 1.6 ∗ cos (0)	=	2.95E6 Ns^2/m^2
F_y (0), F_x (90)	=	0.5 ∗ 1025.0 ∗ 40.0 ∗ 90.0 ∗ 1.6 ∗ sin (0)	=	0.00E0 Ns^2/m^2
F_x (45), F_y (45)	=	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:

At a heading of 0	M_x (0)	=	0.00E0	M_y (0)	=	-2.77E7
At a heading of 45	M_x (45)	=	2.25E7	M_y (45)	=	-2.25E7
At a heading of 90	M_x (90)	=	2.77E7	M_y (90)	=	0.00E0

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:

F_x (0), F_y (90)	=	0.5 ∗ 1.22 ∗ 15.0 ∗ 90.0 ∗ 1.6 ∗ cos (0)	=	1.32E3 Ns^2/m^2
F_y (0), F_x (90)	=	0.5 ∗ 1.22 ∗ 15.0 ∗ 90.0 ∗ 1.6 ∗ sin (0)	=	0.00E0 Ns^2/m^2
F_x (45), F_y (45)	=	0.5 ∗ 1.22 ∗ 15.0 ∗ 127.0 ∗ 1.3 ∗ cos (45)	=	1.07E3 Ns^2/m^2

The moments at the centre of gravity, 10.62 metres below the waterline, and centre of area at Z = +7.5, are:

At a heading of 0	M_x (0)	=	0.00E0	M_y (0)	=	2.39E4
At a heading of 45	M_x (45)	=	-1.94E4	M_y (45)	=	1.94E4
At a heading of 90	M_x (90)	=	-2.39E4	M_y (90)	=	0.00E0

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

In addition, a thruster force of 2E6 N was applied to the box as shown in Figure 8.3, i.e. a thruster force vector of (-2E6,0,0) newtons.

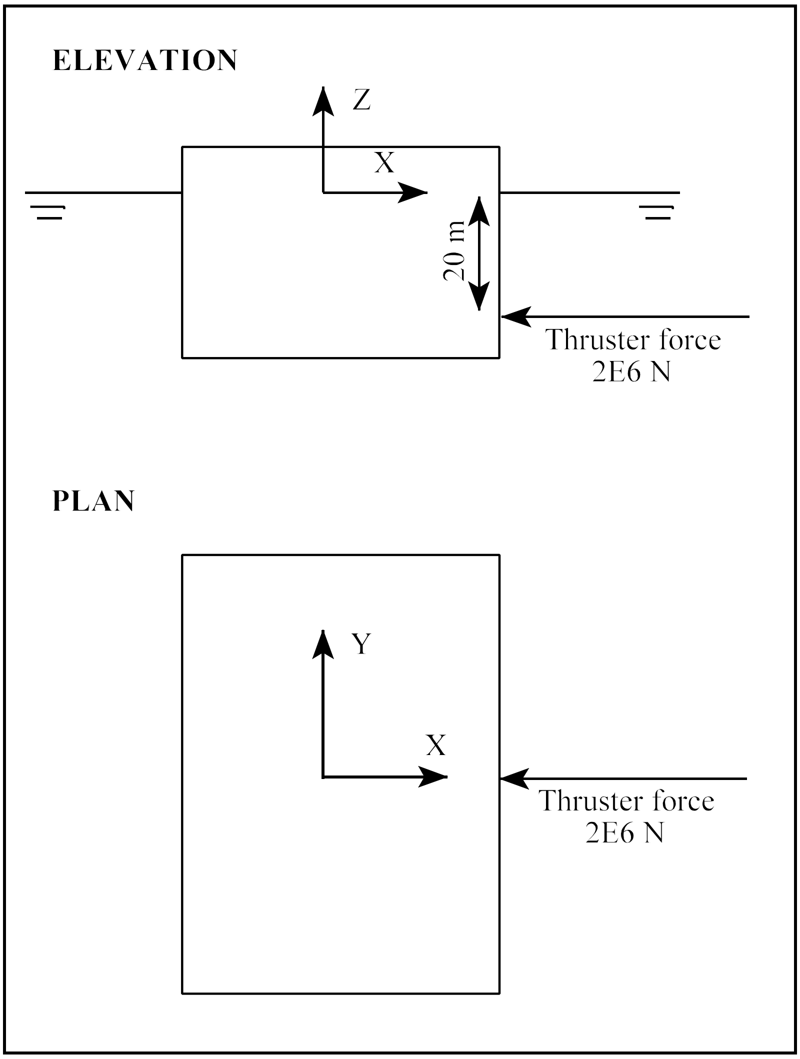

Figure 8.3 - Thruster Force

8.1.9 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

For each spectrum the wind and current speeds and directions used were as follows:

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

8.1.10 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 attachment 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 100 metres unstretched length has a stiffness of 1.471E6 newtons per metre.

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

8.1.11 Initial Position for Analysis

The initial position used to position the structure for each equilibrium analysis may be either the value used in the AQWA-LINE analysis or estimated manually. The initial positions for this analysis were selected to produce a few iterations to demonstrate the iteration and convergence information given in the program output. The positions were as shown below:

	Surge(X)	Sway(Y)	Heave(Z)	Roll(RX)	Pitch(RY)	Yaw(RZ)
Spectrum 1	0.0	0.0	-11.00	0.0	0.0	0.0
Spectrum 2	0.0	0.0	-11.00	0.0	0.0	0.0
Spectrum 3	0.0	0.0	-11.00	0.0	0.0	0.0

8.1.12 Iteration Limits for Analysis

The iteration limits used for the equilibrium search in this analysis were

Maximum number of iterations = 20
Displacement tolerances = 0.01 metres
Rotation tolerances = 0.01 degrees

Default values will be used if no data is supplied (see AQWA Reference Manual).

8.1.13 Input Preparation for Data Run (Stage 4)

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 decks for the AQWA-LIBRIUM DATA run are shown in Figure 8.4 and the input may be described as follows:

-	JOB	card	provides identifier, program and type of analysis to be used
-	TITLE	card	prescribes a title header for the run
-	OPTIONS	card	containing the selected options:
	PRDL	-	print data list from restart file
	REST	-	indicates that a restart run is required
	END	-	indicates the end of the options list
-	RESTART	card	containing 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

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

- Deck 10

  Wind and current loading coefficients and thruster forces for the structure

- 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

  Initial estimates of the equilibrium positions for the spectra and the mooring line combination required to be analysed

- Deck 16

  Iteration limits

- Deck 17

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

- Deck 18

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

```
JOB BOX1  LIBR  STAT
TITLE               TEST RUN NUMBER 20 (FLOATING BOX 40M DRAUGHT 48 FACETS)
OPTIONS PRDL REST END
RESTART   4  4
    09    NONE
    10    HLD1
    10CUFX    1    3  2.9500E6  2.4000E6  0.0000E0
    10CUFY    1    3  0.0000E0  2.4000E6  2.9500E6
    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
    10WIRY    1    3  2.3900E4  1.9400E4  0.0000E4
 END10THRS        15 -2.0000E6
    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        0.0       0.0     -11.0
    15POS1    2    1        0.0       0.0     -11.0
 END15POS1    3    1        0.0       0.0     -11.0
    16    LMTS
    16MXNI        20
 END16MERR             0.01      0.01      0.01      0.01      0.01   0.01
    17    NONE
    18    NONE
```

Figure 8.4 - Input for Data Run on Box Structure

8.1.14 Information Supplied by Data Run

The DATA run produces the following form of output and is shown in Figures 8.5 to 8.13.

Figure 8.5 AQWA-LIBRIUM Header Page Used for Identification

Figure 8.6 Card Echo (mandatory) for Decks 9 to 20
This is used to check data input

Figure 8.7 Wind/Current Loads and Thruster Forces
Tabulation of the data input in Deck 10

Figure 8.8 Constraints
This table shows all the freedoms that are active. Articulations are not yet implemented

Figure 8.9 Formulated Spectra
The wave spectrum and current and wind conditions input in Deck 13 is tabulated showing also the number of spectral lines by default

Figure 8.10 Cable/Mooring Line Configurations
Tabulation of the mooring lines input in Deck 14

Figure 8.11 Initial Equilibrium Positions of the Centre of Gravity
Tabulation of the initial position input in Deck 15

Figure 8.12 Equilibrium Iteration Limits
Tabulation of the iteration limits input in Deck 16

Figure 8.13 Morison Element Parameters
Tabulation of the (default) Morison element parameters

```
 AAAAAA    QQQQQQ   WW       WW   AAAAAA
AAAAAAAA  QQQQQQQQ  WW       WW  AAAAAAAA
AA    AA  QQ    QQ  WW       WW  AA    AA
AA    AA  QQ    QQ  WW       WW  AA    AA
AAAAAAAA  QQ    QQ  WW       WW  AAAAAAAA  IIII
AAAAAAAA  QQ    QQ  WW   WW  WW  AAAAAAAA  IIII
AA    AA  QQ    QQ  WW   WW  WW  AA    AA
AA    AA  QQ QQ QQ  WW   WW  WW  AA    AA
AA    AA  QQQQQQQQ  WWWWWWWWWWW  AA    AA
AA    AA   QQQQQQ    WWWWWWWW    AA    AA
               QQ


LL      IIIIII  BBBBBBB   RRRRRRR   IIIIII  UU     UU   MMMMMMMM
LL      IIIIII  BBBBBBBB  RRRRRRRR  IIIIII  UU     UU  MMMMMMMMMM
LL        II    BB    BB  RR    RR    II    UU     UU  MM   MM   MM
LL        II    BB    BB  RR    RR    II    UU     UU  MM   MM   MM
LL        II    BBBBBBB   RRRRRRRR    II    UU     UU  MM   MM   MM
LL        II    BBBBBBB   RRRRRRR     II    UU     UU  MM   MM   MM
LL        II    BB    BB  RRRRR       II    UU     UU  MM   MM   MM
LL        II    BB    BB  RR RRR      II    UU     UU  MM   MM   MM
LLLLLL  IIIIII  BBBBBBBB  RR  RRR   IIIIII  UUUUUUUU   MM   MM   MM
LLLLLL  IIIIII  BBBBBBB   RR   RRR  IIIIII   UUUUUU    MM   MM   MM
```

```
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 8.5 - AQWA-LIBRIUM Header Page used for Identification

```
DECK  9
-------
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
    10WIRY    1    3 2.390E+04 1.940E+04 0.000E+00 0.000E+00 0.000E+00 0.000E+00
 END10THRS    0   15-2.000E+06 0.000E+00 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     0.000     0.000   -11.000     0.000     0.000     0.000
    15POS1    2    1     0.000     0.000   -11.000     0.000     0.000     0.000
 END15POS1    3    1     0.000     0.000   -11.000     0.000     0.000     0.000

DECK 16
-------

    16MXNI    0   20     0.000     0.000     0.000     0.000     0.000     0.000
 END16MERR    0    0     0.010     0.010     0.010     0.010     0.010     0.010

DECK 17
-------
DECK 18
```

Figure 8.6 - Card Echo of Decks 9 to 18

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


                                                   THRUSTER  FORCES
                                                   ----------------

                     THRUSTER  NODE    POSITION OF THRUSTER (FRA)       LOCAL THRUSTER FORCES IN
                      NUMBER  NUMBER      X          Y          Z      SURGE(X)    SWAY(Y)     HEAVE(Z)
                     ---------------------------------------------------------------------------------------
                         1      15        45.000     0.000    -20.000  -2.000E+06   0.000E+00   0.000E+00

    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 8.7 - 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 8.8 - 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	2	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	0.000	0.0	0.0	0.0
2	PIERSON-M	50	5000	0.3000	1.0000	6.0000	11.0000	0.0000	45.0	0.000	0.0	0.0	0.0
3	PIERSON-M	50	5000	0.3000	1.0000	8.0000	11.0000	0.0000	0.0	0.000	0.0	0.0	0.0

Figure 8.9 - 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 NUMBER	CABLE NUMBER	CABLE GROUP	CABLE TYPE	ATTACHED TO STRUCTURE	AT NODE NUMBER	LINKED TO STRUCTURE	AT NODE NUMBER	UNSTRETCHED LENGTH	FORCE OR STIFFNESS
1	1	0	LIN ELASTIC	1	501	0	511	100.000	0.147E+07
	2	0	LIN ELASTIC	1	502	0	512	100.000	0.147E+07
	3	0	LIN ELASTIC	1	503	0	513	100.000	0.147E+07
	4	0	LIN ELASTIC	1	504	0	514	100.000	0.147E+07

Figure 8.10 - 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
                                  - - - - - - - - - - - - - - - - -

  STRUCTURE   SPECTRUM  HAWS. COMB      TRANSLATIONAL POSITION(FRA)          ROTATION ABOUT AXES(FRA)
   NUMBER      NUMBER      NUMBER         X           Y           Z          RX           RY           RZ
-------------------------------------------------------------------------------------------------------------



      1           1           1           0.000       0.000     -11.000         0.000       0.000       0.000

      1           2           1           0.000       0.000     -11.000         0.000       0.000       0.000

      1           3           1           0.000       0.000     -11.000         0.000       0.000       0.000
```

Figure 8.11 - Initial Equilibrium Positions of the Centre of Gravity

```
                    I T E R A T I O N   L I M I T S
                     - - - - - - - - - - - - - - - -


                 MAXIMUM NUMBER OF ITERATIONS . . .   20

STRUCTURE                                    TRANSLATION                ROTATION(DEGREES)
 NUMBER                                X          Y          Z         RX         RY         RZ
---------------------------------------------------------------------------------------------

    1     MAXIMUM MOVEMENT            2.00       2.00       0.50       0.57       0.57       1.43
          FOR ONE ITERATION

          MAXIMUM ERROR IN FINAL    0.0100     0.0100     0.0100     0.0100     0.0100     0.0100
          EQUILIBRIUM POSITION

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

Figure 8.12 - Equilibrium Iteration Limits

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



                           MULTIPLYING FACTORS FOR HYDRODYNAMIC PARAMETERS
                           -----------------------------------------------

                                 STRUCTURE    DRAG  ADDED MASS  SLAM
                                 -----------------------------------

                                     1        1.00     1.00     0.00



                    HYDRODYNAMIC ERROR LIMITS FOR SLAM AND DRAG ON TUBE ELEMENTS
                    ------------------------------------------------------------

                             SIGNIFICANT FROUDE NUMBER SQUARED    0.040

                             VELOCITY PROFILE RATIO . . . . . .   0.100

                             VELOCITY ALIGNMENT ANGLE . . . . .   5.730



                                 REYNOLDS NUMBER RELATED PARAMETERS
                                 ----------------------------------

                             SCALE FACTOR . . . . . . . . . . .   1.000

                             KINEMATIC VISCOSITY  . . . . . . .   1.569E-06

                             UNIT REYNOLDS NUMBER . . . . . . .   6.375E+05
```

Figure 8.13 - Morison Element Parameters

8.1.15 The Equilibrium Analysis Run

Once the data input in Decks 8 to 18 are correct, the equilibrium analysis stage is then performed.

As a program restart is being performed, the user must copy over the restart file (.RES) created by the previous program DATA run. The restart file is used to supply the program with the information contained within Decks 1 to 18 previously input.

The only data required to be input in card image format is in the preliminary deck. This contains only the information to indicate that a Stage 5 analysis is required as shown in Figure 8.14.

Note that the PRDL option has been omitted, and that there are two additional options:

PRST	-	Print global stiffness matrix
PBIS	-	Print force components at each iteration step

```
JOB BOX2  LIBR
TITLE               TEST RUN NUMBER 21 (FLOATING BOX 40M DRAUGHT 48 FACETS)
OPTIONS PBIS PRST REST END
RESTART   5  5
```

Figure 8.14 - Data Input for Stage 5 in Box Example

8.1.16 Output from Equilibrium Processing Run

The output relating to the equilibrium analysis stage (i.e. Stage 5) contains the information shown in Figures 8.14 to 8.21. The results given are for the first spectrum only.

Figure 8.15 - Iteration Report

Figure 8.16 - Structure Hydrostatic Properties in the Free Floating Position

Figure 8.17 - Global System Stiffness Matrix

Figure 8.18 - Small Displacement Static Stability

Figure 8.19 - Structure Hydrostatics at Equilibrium

Figure 8.20 - Structure Hydrostatic Stiffness Matrix

Figure 8.21 - Mooring Force and Stiffness Table

```
  JOB TITLE-TEST RUN NUMBER 21 (FLOATING BOX 40M DRAUGHT AND 48 FACETS)
 ----------------------------------------------------------------------------------------------------------
                                               D E G R E E   O F   F R E E D O M
ITER STEP  STRUCTURE    POSITION,FORCES
NUMBER     AND MOMENTS AT          X           Y           Z                RX          RY            RZ
           CENTRE OF GRAVITY     SURGE        SWAY        HEAVE             ROLL        PITCH          YAW

----------------------------------------------------------------------------------------------------------
     1
1         POSITION          0.0000       0.0000     -11.0000         0.0000       0.0000       0.0000
          MOORING           0.0000E+00   0.0000E+00   2.2161E+04     0.0000E+00   0.0000E+00   0.0000E+00
          DRIFT            -3.3958E-02   5.2013E+05   0.0000E+00     0.0000E+00   0.0000E+00   1.5744E+00
          GRAVITY           0.0000E+00   0.0000E+00  -3.2566E+09     0.0000E+00   0.0000E+00   0.0000E+00
          CURRENT DRAG      1.8880E+06   0.0000E+00   0.0000E+00     0.0000E+00  -1.7728E+07   0.0000E+00
          HYDROSTATIC      -6.3787E+01   3.1787E+01   3.2875E+09    -3.1026E+03   7.3744E+02   0.0000E+00
          WIND              2.9700E+05   0.0000E+00   0.0000E+00     0.0000E+00   5.3775E+06   0.0000E+00
          THRUSTER         -2.0000E+06   0.0000E+00   0.0000E+00     0.0000E+00   1.8760E+07   0.0000E+00
          TOTAL FORCE       1.8494E+05   5.2016E+05   3.0961E+07    -3.1026E+03   6.4102E+06   1.5744E+00


     2
1         POSITION          0.0603       0.1773     -10.6200         0.0125       0.0103       0.0000
          MOORING          -1.8503E+05  -5.2005E+05   3.4336E+01     5.4813E+06  -1.9994E+06  -1.4585E+03
          DRIFT             1.4649E-02   5.2013E+05   0.0000E+00     0.0000E+00   0.0000E+00   1.5744E+00
          GRAVITY           0.0000E+00   0.0000E+00  -3.2566E+09     0.0000E+00   0.0000E+00   0.0000E+00
          CURRENT DRAG      1.8880E+06   2.2991E-01   0.0000E+00     2.1589E+00  -1.7728E+07   0.0000E+00
          HYDROSTATIC      -4.8000E+01   9.3775E+01   3.2566E+09    -5.3143E+06  -4.3894E+06  -6.4000E+02
          WIND              2.9700E+05   3.6168E-02   0.0000E+00    -6.5485E-01   5.3775E+06   0.0000E+00
          THRUSTER         -2.0000E+06  -2.4355E-01   3.5910E+02    -1.5504E+00   1.8760E+07   4.0889E+03
          TOTAL FORCE      -8.0125E+01   1.7023E+02   8.7110E+02     1.6694E+05   2.0706E+04   1.9920E+03


     3
1         POSITION          0.0603       0.1773     -10.6200         0.0125       0.0103       0.0000
          MOORING          -1.8503E+05  -5.2005E+05   3.4336E+01     5.4813E+06  -1.9994E+06  -1.4585E+03
          DRIFT             1.4649E-02   5.2013E+05   0.0000E+00     0.0000E+00   0.0000E+00   1.5744E+00
          GRAVITY           0.0000E+00   0.0000E+00  -3.2566E+09     0.0000E+00   0.0000E+00   0.0000E+00
          CURRENT DRAG      1.8880E+06   2.2991E-01   0.0000E+00     2.1589E+00  -1.7728E+07   0.0000E+00
          HYDROSTATIC      -4.8000E+01   9.3775E+01   3.2566E+09    -5.3143E+06  -4.3894E+06  -6.4000E+02
          WIND              2.9700E+05   3.6168E-02   0.0000E+00    -6.5485E-01   5.3775E+06   0.0000E+00
          THRUSTER         -2.0000E+06  -2.4355E-01   3.5910E+02    -1.5504E+00   1.8760E+07   4.0889E+03
          TOTAL FORCE      -8.0125E+01   1.7023E+02   8.7110E+02     1.6694E+05   2.0706E+04   1.9920E+03
```

Figure 8.15 - Iteration Report

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

                        F O R   S T R U C T U R E   1
                             - - - - - - - - - - - - - - -

                         1.STIFFNESS MATRIX AT THE CENTRE OF GRAVITY
                         -------------------------------------------
                       C.O.G      GX=     0.060 GY=     0.177 GZ=   -10.620

                     HEAVE( Z) =      8.141E+07    -1.887E+05    -1.554E+05
                     ROLL(RX)  =     -1.887E+05     2.441E+10     2.852E+03
                     PITCH(RY) =     -1.554E+05     2.852E+03     2.441E+10

                            2.HYDROSTATIC DISPLACEMENT PROPERTIES
                            -------------------------------------
                     ACTUAL VOLUMETRIC DISPLACEMENT . . . . . . = 3.240E+05
                     EQUIVALENT VOLUME OF STRUCTURE . . . . . . = 3.240E+05

                     POSITION OF THE CENTRE OF BUOYANCY      BX =     0.062
                                                             BY =     0.176
                                                             BZ =   -20.000

                     AN INCOMPLETE ELEMENT DESCRIPTION OF    FX =     0.000
                     THE HULL GIVES OUT OF BALANCE FORCES    FY =     0.000
                     AND MOMENTS. IF THE C.O.B. IS NOT       FZ =     0.000
                     BELOW THE C.O.G. THIS GIVES OUT OF      MX =    -0.002
                     BALANCED MOMENTS (FORCES ARE DIVIDED    MY =    -0.001
                     BY THE WEIGHT AND ARE W.R.T. AXES       MZ =     0.000
                     PARALLEL TO THE FIXED REFERENCE AXIS

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

                     CUT WATER PLANE AREA . . . . . . . . . . . = 8.100E+03
                     CENTRE OF FLOATATION I.E. CENTROID       X =     0.062
                     POSITION IN THE FIXED REFERENCE AXIS     Y =     0.175
                     PRINCIPAL SECOND MOMENTS OF AREA        IXX= 5.468E+06
                                                             IYY= 5.468E+06
                     ANGLE THE PRINCIPAL AXES MAKE WITH      PHI=     0.000
                     THE FIXED REFERENCE AXIS SYSTEM

                              4.SMALL ANGLE STABILITY PARAMETERS
                              ----------------------------------

                     DISTANCE BETWEEN C.O.G. AND C.O.B       BG =     9.380

                     METACENTRIC HEIGHTS WITH RESPECT TO     GMX=     7.495
                     THE PRINCIPAL AXES OF THE CUT AREA      GMY=     7.495
                     DISTANCE BETWEEN THE C.O.B. AND THE     BMX=    16.875
                     METACENTER (BMX=GMX+BG, BMY=GMY+BG)     BMY=    16.875

                     RESTORING MOMENT ABOUT THE PRINCIPAL    MX = 4.260E+08
                     AXES PER DEGREE ROTATION                MY = 4.260E+08
```

Figure 8.16 - Structure Hydrostatic Properties in the Free Floating Position

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

         SPECTRUM NO.   1          MOORING COMBINATION   1          (NO. OF CABLES =   4)

                                                  STRUCTURE   1

     STRUCTURE   1           X           Y           Z          RX          RY          RZ
     -------------    -----------------------------------------------------------------------

           X            2.972E+06  -1.250E+01   2.331E+02   1.168E+02   3.156E+07  -4.942E+05

           Y           -1.250E+01   2.972E+06  -2.830E+02  -3.156E+07  -9.082E+01   2.268E+06

           Z            2.331E+02  -2.830E+02   8.147E+07  -4.130E+05  -7.220E+04  -2.602E+01

          RX            1.168E+02  -3.156E+07  -4.130E+05   2.493E+10  -9.240E+03   8.329E+06

          RY            3.156E+07  -9.082E+01  -7.220E+04  -1.070E+04   2.493E+10   5.400E+06

          RZ            6.879E+03   5.666E+03  -2.602E+01   1.939E+06   5.554E+06   3.829E+08
```

Figure 8.17 - Global System Stiffness Matrix

```
S M A L L   D I S P L A C E M E N T   S T A T I C   S T A B I L I T Y
- - - - -   - - - - - - - - - - - -   - - - - - -   - - - - - - - - -

SPECTRUM NO.   1          HAWSER COMBINATION   1          (NO. OF HAWSERS =   4)

PRINCIPAL COORD.    LOAD PER UNIT DISPLACEMENT              STABILITY
                    IN THE PRINCIPAL COORD.
----------------    --------------------------              ---------

       1                   2.932E+06                          STABLE

       2                   2.929E+06                          STABLE

       3                   8.147E+07                          STABLE

       4                   2.493E+10                          STABLE

       5                   2.493E+10                          STABLE

       6                   3.829E+08                          STABLE
```

Figure 8.18 - Small Displacement Static Stability

```
          H Y D R O S T A T I C S   O F   S T R U C T U R E   1   A T   E Q U I L I B R I U M
       - - - - - - - - - - - - - -   - -   - - - - - - - - -   - - - -   - - - - - - - - - - -

          SPECTRUM NO.   1          MOORING COMBINATION   1          (NO. OF CABLES =   4)
                                 EQUILIBRIUM POSITION WITH RESPECT TO FRA
                                 ----------------------------------------

  CENTRE OF GRAVITY                       ORIENTATION(DEGREES)           DIRECTION COSINES OF BODY AXES
 --------------------                     --------------------         -------------------------------------

 X   =          0.060                     RX   =         0.012         X-AXIS      1.000     0.000     0.000
 Y   =          0.177                     RY   =         0.010         Y-AXIS      0.000     1.000     0.000
 Z   =        -10.620                     RZ   =         0.000         Z-AXIS      0.000     0.000     1.000

                        HYDROSTATIC FORCES AND MOMENTS (AXES AT CG PARA. TO FRA)
                        --------------------------------------------------------

                                         BUOYANCY =    3.257E+09
                 CENTRE OF BUOYANCY                                         MOMENTS
                 --------------------                               --------------------

                 X  =          0.001                                X  =       4.388E+06
                 Y  =         -0.002                                Y  =      -5.327E+06
                 Z  =         -9.380                                Z  =      -3.055E+10

                          WATERPLANE AREA PROPERTIES (AXES AT CG PARA. TO FRA)
                          -----------------------------------------------------

                                        AREA =    8.100E+03
                 CENTRE OF FLOATATION                                   FIRST MOMENT OF AREA
                 --------------------                               -------------------------

                 XBAR =          0.002                              AREA.XBAR =     1.546E+01
                 YBAR =         -0.002                              AREA.YBAR =    -1.877E+01

                 SECOND MOMENTS OF AREA                               PRODUCTS OF AREA
                 ----------------------                             ----------------------

                 X AXIS =     5.468E+06                             XY AXIS =    2.838E-01
                 Y AXIS =     5.468E+06
```

Figure 8.19 - Structure Hydrostatics at Equilibrium

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

	X	Y	Z	RX	RY	RZ
X	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Y	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Z	0.000E+00	0.000E+00	8.141E+07	-1.887E+05	-1.554E+05	0.000E+00
RX	0.000E+00	0.000E+00	-1.887E+05	2.441E+10	2.852E+03	-4.388E+06
RY	0.000E+00	0.000E+00	-1.554E+05	2.852E+03	2.441E+10	5.327E+06
RZ	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

Figure 8.20 - Structure Hydrostatic Stiffness Matrix

```
            M O O R I N G   F O R C E S   A N D   S T I F F N E S S   ----  S T R U C T U R E  1
             - - - - - - -   - - - - - -   - - -   - - - - - - - - -          - - - - - - - - -

                         SPECTRUM NO.   1          MOORING COMBINATION   1           (NO. OF CABLES =   4)
                                             N.B. STRUCTURE 0 IS FIXED.
                                        CABLE NO.   1     TYPE      LIN  ELASTIC
                                        ----------------------------------------
              STRUCTURE  1                        STRUCTURE  0                        MOORING STIFFNESS AT NODE   501
               NODE   501                          NODE   511                                  AXES // FRA
         CORD.             FORCE             CORD.             FORCE                     X              Y              Z
   ---------------------------------------------------------------------------------------------------------------

   X   4.5062E+01       1.3801E+06       1.4600E+02      -1.3801E+06          1.471E+06     -2.527E+03      1.165E+02
   Y   1.7498E-01      -2.3925E+03       0.0000E+00       2.3925E+03         -2.527E+03      1.368E+04     -2.020E-01
   Z  -8.0681E-03       1.1031E+02       0.0000E+00      -1.1031E+02          1.165E+02     -2.020E-01      1.367E+04
             MODULUS = 1.3801E+06              MODULUS = 1.3801E+06

                                        CABLE NO.   2     TYPE      LIN  ELASTIC
                                        ----------------------------------------
             STRUCTURE  1                         STRUCTURE  0                        MOORING STIFFNESS AT NODE   502
              NODE   502                           NODE   512                                  AXES // FRA
         CORD.            FORCE             CORD.              FORCE                     X              Y              Z

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

  X    6.2250E-02      -7.4957E+02       0.0000E+00       7.4957E+02          1.204E+04     -9.011E+02      8.776E-02
  Y    4.5175E+01       1.2141E+06       1.4600E+02      -1.2141E+06         -9.011E+02      1.471E+06     -1.421E+02
  Z    9.8200E-03      -1.1825E+02       0.0000E+00       1.1825E+02          8.776E-02     -1.421E+02      1.204E+04
             MODULUS = 1.2141E+06              MODULUS = 1.2141E+06

                                        CABLE NO.   3     TYPE      LIN  ELASTIC
                                        ----------------------------------------
             STRUCTURE  1                         STRUCTURE  0                        MOORING STIFFNESS AT NODE   503
              NODE   503                           NODE   513                                  AXES // FRA
        CORD.            FORCE               CORD.             FORCE                     X              Y              Z

  ---------------------------------------------------------------------------------------------------------------
  X  -4.4938E+01       -1.5633E+06      -1.4600E+02       1.5633E+06          1.471E+06      2.521E+03      1.166E+02
  Y   1.7497E-01       -2.7066E+03       0.0000E+00       2.7066E+03          2.521E+03      1.547E+04      2.018E-01
  Z   8.0910E-03       -1.2516E+02       0.0000E+00       1.2516E+02          1.166E+02      2.018E-01      1.547E+04
             MODULUS = 1.5633E+06              MODULUS = 1.5633E+06
```

Figure 8.21 - Mooring Force and Stiffness Table

```
               M O O R I N G   F O R C E S   A N D   S T I F F N E S S   ----  S T R U C T U R E  1
         - - - - - - -  - - - - - -  - - -  - - - - - - - - -       - - - - - - - - - -

                SPECTRUM NO.   1         MOORING COMBINATION   1          (NO. OF CABLES =   4)

                                     N.B. STRUCTURE 0 IS FIXED.


                                   CABLE NO.   4     TYPE      LIN  ELASTIC
                                   ----------------------------------------
STRUCTURE  1                     STRUCTURE  0                      MOORING STIFFNESS AT NODE   504
NODE   504                       NODE   514                                AXES // FRA
CORD.            FORCE           CORD.            FORCE                 X              Y              Z

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

X   6.2257E-02    -1.0639E+03     0.0000E+00     1.0639E+03        1.709E+04     8.950E+02    -8.666E-02

Y  -4.4825E+01    -1.7290E+06    -1.4600E+02     1.7290E+06        8.950E+02     1.471E+06    -1.408E+02

Z  -9.7971E-03     1.6743E+02     0.0000E+00    -1.6743E+02       -8.666E-02    -1.408E+02     1.709E+04

                 MODULUS = 1.7290E+06             MODULUS = 1.7290E+06
```

Figure 8.21 - Mooring Force and Stiffness Table (Cont'd)

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-LIBRIUM 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-LIBRIUM:

(**.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-LIBRIUM 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-LIBRIUM, simply type:

aqwa librium 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-LIBRIUM, 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 abboxm.res

aqwa librium boxm

APPENDIX A - AQWA-LIBRIUM PROGRAM OPTIONS

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

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

PRST - PRINT GLOBAL STIFFNESS MATRIX

This option causes the global stiffness matrix, which is computed in the equilibrium analysis (Stage 5), to be output.

PPEL - PRINT PROPERTIES of Each Element on Each Structure

This option allows the user to output complete details of each element used in the body modelling. All important details of the body elements are output together with the resultant properties of the bodies. It should only be used when running AQWA-LIBRIUM as an independent program.

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 causes the program to read the data contained within the restart backing file and output it to the user. Typically all body modelling information is output, together with environmental wave loading details.

LSTF - LINEAR STIFFNESS

This option is used to instruct the program to use the linear stiffness matrix calculated by AQWA-LINE, instead of calculating the hydrostatics by integrating over the wetted surface.

RNDD - Reynolds No Drag/C for Morison Elements (switched by SC1/ CARD)

This option causes drag coefficients to be set to zero, i.e. switches off the Morison drag calculations on tube elements.

PBIS - Print Force Components at Each Iteration Step

This option causes the program to output the component forces acting on each structure (e.g. gravity, hydrostatic, current, and mooring forces) for each iteration.

PRCE - Print Card Echo For Decks 1 to 5

This option causes the program to echo 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.

APPENDIX B - REFERENCES

1. H.O.Berteaux, 1976, Buoy Engineering, J Wiley & Sons, New York.