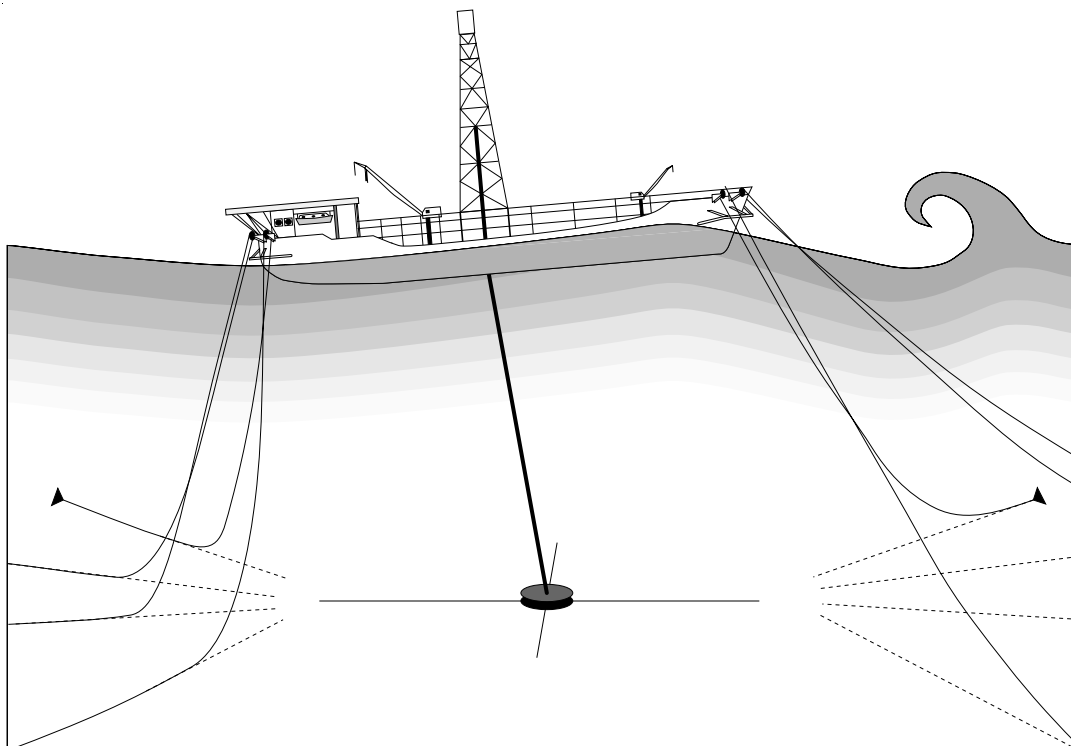# *SeaSoft® Systems' Simulation Library*

Comprehensive Dynamic Simulation Software
for Catenary-Moored Vessels

User Manual

March, 2005

SeaSoft Systems' Simulation Library

Comprehensive Dynamic Simulation Software
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http://www.seasoftsys.com

Notice

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About the SeaSoft Library

The SeaSoft family of software products for the offshore industry has been developed in response to a need for high quality, easy to use analytical tools for numerical simulation of the dynamic and static characteristics of a wide variety of offshore vessels and mooring structures.

The variety of computing platforms now used in engineering and naval architectural environments requires that offshore engineering software be easily transportable to a wide variety of computers (Macintosh, Unix, Windows, etc.) so that software tools can easily be moved to new computing facilities as the need arises. The SeaSoft program library was developed with these considerations in mind.

SeaSoft's products are capable, in most circumstances, of exceeding the physical modeling capabilities of older, operationally more complex codes while far surpassing them in terms of versatility and ease of use. Benchmark efforts by the DeepStar Committee (http://www.deepstar.org), using high-quality model test data as simulation quality arbiter, have shown unequivocally that the quality of the SeaSoft simulations surpasses all other available mooring tools, be they time-domain, frequency-domain or hybrid.

In the development of this suite of programs, the principal objectives have been (1) to deliver state of the art computational abilities to the offshore industry in packages that would permit their utilization by any technically trained individual with a need for the information, and (2) to insure that the quality and robustness of the underlying physical and analytical modeling are second to none.

The software is oriented specifically towards the practicing marine/offshore engineer and naval architect. In order to be of maximum utility to this audience, the software has been designed so that first-time or infrequent users can produce meaningful results.

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Chapter 1

Introduction

This manual describes the operation of a family of comprehensive catenary-based mooring simulation offerings from SeaSoft Systems. The most widely-used of these offerings comprise Moorsim® and SPMsim®. Unless specifically indicated otherwise, all information presented herein applies equally to both of these simulations, as well as to their siblings comprising CALMsim®, Sparsim®, TLPsim®, and Towsim®. Simulation-specific features limited to the latter products are treated in Addenda to this manual. Therefore, unless a topic is treated separately in an Addendum, discussions and feature descriptions in this manual will apply equally to CALMsim, Sparsim, TLPsim, and Towsim as well as Moorsim and SPMsim. Furthermore, additional information specific to wave-frequency vessel motion simulations can be found in the Shipsim®/Discsim® or Semisim® manuals. Finally, reference may be made to other SeaSoft offerings, including Catsim®, Slowsim® and Statmoor® and their respective user manuals . SALMsim® has a separate user manual, although many of the expanded discussions herein, particularly of low-frequency phenomena and modeling, apply to SALMsim as well.

Outside of limited simulation-specific comments, all simulations will be collectively referred to as "Moorsim" herein to simplify discourse.
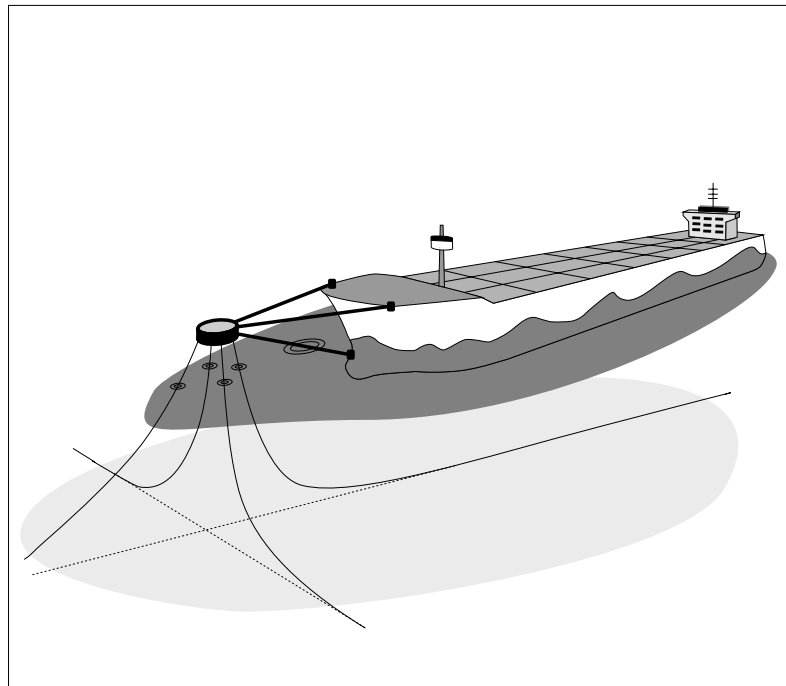
Catsim, CALMsim, Discsim, Moorsim, SALMsim, Semisim, Shipsim, Slowsim, Sparsim, SPMsim, Statmoor, TLPsim and Towsim are registered trademarks of SeaSoft Systems.

Background

Moorsim and its siblings have evolved from the clear need for a complete and reliable numerical simulation of catenary-based mooring systems. The principal economic motivation for this development has been to minimize and, as an ultimate goal, eliminate expenses associated with repetitive model testing of standard mooring systems. Cost for a modest one or two week program to investigate a few vessel load conditions for a single mooring design typically amounts to several hundred thousand dollars.

Performance analysis done on these systems to supplement model tests has, generally speaking, been limited to one or two small aspects of the overall design (for example, the analysis of static offset properties or a limited time-step analysis of wave-frequency dynamics). Moorsim permits, for the first time, the integrated investigation of all aspects of this problem as easily as specifying the physical parameters for a model test program. Moorsim is capable of producing basin-quality results for every aspect of the dynamic problem, including static, low-frequency and wave-frequency vessel motion and mooring load response and characteristic and peak motions and loads in a storm of specified duration. It is clear from the following considerations that a reliable numerical simulation of these systems is a far more powerful tool than the most exhaustive model test program:

• Each setup and complete simulation run of a distinct vessel, mooring design and/or environmental condition requires minutes, rather than days.

• For design purposes, gross variations in mooring characteristics such as the location and size of buoyant or weighted segments, can easily be analyzed to determine an optimum configuration for a particular set of static and dynamic load requirements.

• Variations in environmental conditions for each mooring configuration can be made to investigate the sensitivity of loads to environmental variables.

• Statistical vagaries arising from inadequate storm durations forced by economical considerations on most model test programs are eliminated. Model tests often are of a duration permitting only ten or so cycles of low-frequency vessel surge and, in SPMsim, CALMsim or Towsim, as little as one cycle of the lowest frequency sway-yaw mode. This means the probability of obtaining an anomalously high or low significant and/or peak value for the low-frequency motions and loads is substantial. Economic considerations rarely permit the luxury of adequate repeat testing of a given storm intensity in order to obtain statistically reliable estimates of mean, significant and peak motion/load values. This statistical uncertainty also exists for each run of a "time-domain" numerical simulation; corresponding statistical uncertainties are absent from SeaSoft simulations because the statistical calculations automatically represent an infinite ensemble of test runs.

• Wave basin physical limitations often prevent the investigation of important environmental effects such as time-varying current loads, azimuthal spreading of wave energy and crossed swell conditions underlying the local wind sea.

• Economic considerations often result in elimination of experimental channels which would otherwise be included in the study. For instance, it is seldom feasible to instrument every fairlead and every anchor, or the top and bottom of all risers, although such measurements would, in general, be useful for design purposes. With a numerical simulation, of course, no limitations exist on the number of channels analyzed.

These considerations are not meant to suggest that model tests can ever be wholly eliminated in the study of mooring systems. However, it is likely that now-common routine model tests of standard mooring systems for differing water depths, vessel size, and environmental conditions will be increasingly supplemented or even replaced by numerical simulation, just as similar exhaustive routine testing was eliminated long ago in the aerospace industry. New design features and unusual circumstances will, of course, always require testing.

Batch Processing Capabilities

The stand-alone versions of all SeaSoft applications can be scripted using standard scripting tools available on all platforms. This provides a repetitive execution mechanism that can provide simulation output for any collection of environmental or mooring system data (the latter being used in mooring optimization analyses). Because of short simulation execution times, Moorsim is capable of completing many tens of thousands of simulations in a single overnight batch run even on consumer-class computers.

Audience

In the development of the simulations, the principal objective has been to produce a state of the art computational tool usable by any technically trained individual. The package is thus directed specifically towards the practicing system designer, marine/offshore engineer and naval architect. In order to be of maximum utility to this audience, this software has been designed so that even a first-time user can produce meaningful results.

Logical Program Flow

Moorsim can be characterized as a nonlinear spectral analysis (or "nonlinear frequency domain") tool comprising a five-step simulation process:

• Determine mean vessel position and orientation. This step, along with a low-frequency (LF) motions evaluation described below, utilizes built-in or user-supplied coefficients describing quasi-static vessel response to mean and variable forces from current,.wind, wave reflection, and wave dissipation. Wave-current interactions, which are commonly ignored or inadequately modeled in numerical simulations, form an integral part of the analytical model.

• Evaluate wave-frequency (WF) vessel motions in the mean condition. This step utilizes one of SeaSoft's WF vessel modules (Shipsim, Semisim, Discsim) or, alternatively, a user-supplied set of vessel wave-frequency

RAOs. SeaSoft's modules accommodate all important nonlinearities in wave-frequency vessel response, including standard nonlinear pitch and roll analysis for buoys and shipshapes and fully nonlinear treatments of heave, pitch and roll in semisubmersibles. Furthermore, CALMsim utilizes a fully nonlinear six-DOF model for CALM buoy wave-frequency response; this treatment is required by the relative importance of mooring loads (in addition to wave loads) on modestly-sized CALM buoys.

• Evaluate LF system damping. Average damping contributions from all relevant mechanisms (current, wind, wave reflection, wave dissipation, WF line damping, etc.) are determined for the "step one" mean vessel position and orientation. Note that some damping mechanisms also depend on the "step two" WF vessel motions; e.g., damping arising from hull-mediated wave dissipation and from WF line motions.

• Evaluate modal low-frequency oscillation amplitudes. The coefficients used in step one, in conjunction with a spectral representation of their associated environmental excitations, are used to compute generalized forcing functions that are then applied to the three LF normal modes of the system. (The three normal modes of a spread-moored vessel are simply "surge", "sway" and "yaw". The three normal modes of a turret-moored vessel can be roughly characterized as a high-energy "surge" mode and two coupled lower-energy sway-yaw modes.) Important non-linearities in the mooring-riser restoration characteristic and in system hydrodynamic damping contributions from vessel and mooring structures are fully accommodated by direct analytical modeling of the nonlinear processes. In addition, non-Gaussian responses arising from the non-Gaussian nature of wave "drift" forces (i.e., wave reflection and dissipation forces) are fully integrated with the nonlinear modal analysis.

• Re-evaluate WF motions at selected points within the LF configuration envelope. Once LF motions are characterized, the boundary of an abstract three-dimensional configuration space (whose axes represent surge, sway and yaw amplitudes) enclosing all energetically achievable LF vessel location and orientation combinations is determined. Within this abstract 3-D volume, a collection of statistically meaningful points is chosen at which to re-evaluate vessel WF motions and the associated (nonlinear) mooring line and riser dynamics. Finally, overall system statistics and extremes are evaluated based on the selected subset of the vessel's LF/WF sample space in the specified environment.

Program Package Contents

The basic Moorsim package comprises the user manual, the principal machine-executable program units, and user-support services, if any, contracted to SeaSoft.

File Naming Conventions

Because this Manual serves as the central repository of documentation for all comprehensive simulations (CALMsim, Moorsim, Sparsim, SPMsim, TLPsim, and Towsim), certain self-evident file name substitutions will

apply depending on the simulation in use. For example, the main binary datafile for all simulations is named *DAT, where * represents any one of (CALM, MOOR, SPAR, SPM, TLP or TOW). Thus, a discussion of the properties of MOORDAT applies equally to SPMDAT, SPARDAT, etc. The basic rule of thumb is: Either (1) the file name will have an obvious association with a particular simulation by virtue of its prefix (e.g., MOORDAT, SPMDAT, MOORIN.stxt, SPMIN.stxt) or (2) the file names will be the same across all simulations (e.g., LOWOUT.stxt, DYNOUT.stxt, RANOUT.stxt, etc. are all produced by *each* of the comprehensive simulations; that is there is no difference in these file names between SPMsim and Sparsim, etc.) Furthermore, wave-frequency output files are labelled with prefixes that identify their *vessel type* (e.g., SHIPRAN.stxt, for a shipshape in Moorsim or SPMsim; SEMIRAN.stxt for a semi in Moorsim, TANKRAN.stxt for the tanker vessel in CALMsim, BUOYRAN.stxt for the CALM buoy in CALMsim, etc.). Some simulations (e.g., Moorsim) can accommodate more than one vessel type (e.g., Moorsim can produce SHIPRAN.stxt, SEMIRAN.stxt, or DISCRAN.stxt depending on the type of vessel specified), while others will generally be limited to a single vessel type (e.g., TLPsim and Sparsim both produce wave-frequency output files of the "SEMI" type, such as SEMIRAO.stxt, SEMIRAN.stxt, reflecting the fact that Semisim is the wave-frequency module used to analyze the wave-frequency forces on and responses of both Spar and TLP-type vessels.)

Program Modules and Files

Permanent, Executable Program Files and Modules:

The SeaSoft simulations comprise integrated software modules whose individual invocation is invisible to the user. That is, the user simply executes "Moorsim" and the details discussed below are all accomplished automatically when and as needed. A brief discussion of these "hidden" details is useful for understanding the logical program structure and flow.

All simulations consist of three logical components: the Editor, the Simulator, and the wave-frequency vessel motions calculator. Each of these components is logically divided into modules; in particular, the Simulator is composed of statics, low-frequency dynamics and wave-frequency line dynamics modules. To implement this logical structure may require from one to many runtime submodules depending on the target computer, compiler, and operating system. However, these details are handled automatically at runtime, without user intervention.

All user interface activities occur within the Editor. This facility, fully integrated into each simulation, is used to create the MOORDAT data file (the binary "input" file) which is required for execution of the Simulation. (Under certain circumstances, the Editor may also produce a binary LOWDAT file containing user-specified low-frequency vessel forcing coefficients.) The Editor is also used to modify previously created input data files, which will be necessary if vessel, mooring, site or environmental characteristics need to be changed prior to re-execution of the Simulator. Formatted output will be transmitted to the console or to formatted output file(s) according to choices made during preparation of the input file.

• The Simulator carries out all computations requested during input file creation and prepares formatted output containing results of the run. Moorsim requires an input file with file name MOORDAT to be present on the disk before execution; if the input file is absent when execution is attempted, an error message is generated. As mentioned above, the other simulations use a similar binary data file, appropriately named to match the particular simulation.

• Vesselsim - A vessel wave-frequency motion module, generically referred to herein as "Vesselsim", is called repeatedly during both low-frequency and wave-frequency dynamics analysis, primarily to service fairlead motion requests from the Simulator. SeaSoft offerings for these wave-frequency vessel motion modules include Shipsim (displacement hull vessels), Semisim (semisubmersible-type vessels and spars) and Discsim (buoy or round vessels). Wave-frequency vessel motion characteristics in the form of a vessel characteristics summary, regular wave RAOs and irregular ("random") wave statistical summaries can be found in formatted output data file(s) with a "SHIP", "SEMI", or "DISC" prefix depending on the vessel type associated with the output files (e.g., SHIPSUM, SHIPRAO, SHIPRAN). These output files are generically designated in this manual as VESLSUM, VESLRAO and VESLRAN. Note that in the sibling simulations CALMsim, Sparsim, TLPsim, and Towsim, the associated file prefixes comprise: "TANK" and "BUOY" (CALMsim); "SEMI" (Sparsim): "SEMI" (TLPsim); "TUG" and "BARG" (Towsim).

Machine-Readable Binary Data Files:

• MOORDAT (also SPMDAT, CALMDAT, SPARDAT, TLPDAT, TOWDAT) - The binary data file which contains all relevant physical information on the vessel, mooring system and environmental characteristics required by the Simulation. (See Appendix E for a sample problem and Chapter 7 for discussion of the Editor). Management and recommended archival procedures for these files are discussed in Appendix B. Note that the input file is in machine-readable format and cannot be viewed without aid of the Editor.

• MOORBAK (also SPMBAK, etc.) - A backup binary data file created from the unmodified contents of any existing MOORDAT file just before a new or modified MOORDAT file is written to the disk, thereby temporarily avoiding inadvertent loss of data which may, through user oversight, not have been archived.

• LASTBAK - A "second-generation" binary backup data file created from the contents of any pre-existing MOORBAK file just before a new MOORBAK file is written to disk. Datafile archiving and protection is thus extended back only "two generations"; that is, data in a pre-existing LASTBAK file will be lost when the Editor creates a new LASTBAK file.

• LOWDAT - This binary data file is created and/or backed up *only* if there is a change to the status of *user-supplied* environmental load coefficients which are input directly into the Editor (an alternate method using external text files to provide this data *without* using the Editor is also available and is described in Chapter 7 and Appendix D). Because of the

extensive built-in environmental coefficient databases, and because most users prefer to prepare their environmental coefficient databases in a text editor, the LOWDAT data file is now deprecated, serving primarily to provide backwards compatibility with archived files. Note: when LOWDAT-style user-input coefficients *are* in use, the LOWDAT file *must be archived with the MOORDAT file* or the user-specified coefficients will be lost. LOWDAT files can be transferred at will between simulations to import/export user-specified coefficients. The possible loss of a LOWDAT file is another strong reason to include in simulation data archives the *formatted* input streams comprising MOORIN.stxt (or SPMIN.stxt, etc.).

• LOWBAK - A backup binary data file created from the contents of any existing LOWDAT file just before a new or modified LOWDAT file is written to the disk, thereby temporarily avoiding inadvertent loss of data which may, through user oversight, not have been archived.

• LASTLOW - A "second-generation" binary backup data file created from the contents of any pre-existing LOWBAK file just before a new LOWBAK file is written to disk. Protection is thus extended back only "two generations"; that is, data in a pre-existing LASTLOW file will be lost when the Editor creates a new LASTLOW file.

• FAIRMOT - A temporary binary data file, written by Vesselsim for use by the Simulator in calculation of wave-frequency line loads.

• LINEANG - A temporary binary data file, written by the Simulator for use by Vesselsim in calculation of wave-frequency fairlead motions and loads.

Formatted Output Data Files:

Formatted output files are written with a ".stxt" filename extension to distinguish them (in scripting operations, for example) from formatted *input* files (which have a ".txt" extension) and from binary files (which have no extension). See also Appendix B and Chapter 6.

• MOORIN.stxt (SPMIN.stxt, etc.) contains a formatted hardcopy image of all input data displayed during the editor session.

• MOOROUT.stxt (SPMOUT.stxt, etc.) is the first formatted output file to be written; it contains the title page and individual line static offset characteristics. (Section I)

• MEANOUT.stxt contains the quiescent (zero environment) and static mean characteristics of the system in the given environment. (Section II)

• LOWOUT.stxt contains miscellaneous echoed input data and the low-frequency dynamic characteristics of the system in the given environment. (Sections III - VI)

• DYNOUT.stxt contains the results of all dynamic regular wave motion and load calculations (i.e., motion and load RAO's at fairlead and anchor). (Sections VII - IX)

• RANOUT.stxt contains statistical ("random wave") summaries for wave-frequency fairlead and anchor variables relating to the mean, "characteristic" and "extreme" *individual fairlead* offset points. (Sections X - XII)

• SNAPOUT.stxt contains statistical "shapshots" of wave-frequency variables taken at "characteristic" and "extreme" *vessel* offset points. (Sections X and XIII - XV)

• XCLDAT.stxt contains wave-basin style summary tables comprising a collection of static and dynamic output variables in a single text file (not implemented for CALMsim or Towsim).

• VESLSUM.stxt contains (1) a summary of vessel physical characteristics, (2) a summary of roll, pitch and heave natural periods and damping levels associated with resonant excitation of these degrees of freedom and, for displacement-type vessels, (3) the dimensions of a "dynamically similar box" used for simplified analysis of some aspects of vessel motions. See the Vesselsim manual for details. (Vesselsim Sections I and II)

• VESLRAO.stxt contains regular wave vessel motion and load RAOs for relevant regular wave periods and directions. (Vesselsim Section II)

• VESLRAN.stxt contains a statistical motion summary for the specified irregular wave condition(s). (Vesselsim Section III)

Formatted Plotter Files:

Note that the use of formatted plotter files is now a rarity due to the ease of manipulation of tabular output data by any of a number of extremely flexible and inexpensive commercial plotting routines and spreadsheet programs.

• STATPLT.stxt contains a subset of the static offset data in a format readable by SeaSoft's discontinued plotting package. The use of STATPLT is no longer supported, but remains available for output stream backwards compatibility.

The User Manual

The user manual constitutes the principal tutorial tool provided with the program package. Because each installation of Moorsim is to some extent distinct, depending on options selected by the licensee and on the capabilities and limitations of the host computer and operating system, it is impossible for a single general manual to cover all possible installation peculiarities. For this reason, discussions of program capabilities, disk file particulars, and other installation-dependent items are given in general terms, with appropriate indications of which discussions are effected by installation dependencies.

To derive maximum benefit from the package, the manual should be thoroughly reviewed on two occasions: Upon initial package acquisition (before and during the first few simulation executions), and again after

perhaps eight to ten weeks of concentrated experience with the program. The second review of the manual, if carried out as recommended after some time has elapsed and after practical experience has been gained in the use of the program, is of inestimable value in sharpening the user's understanding of the program, its workings and its capabilities. The manual includes a reasonably extensive glossary and an index, which, along with the table of contents and internal cross-references should permit quick location of specific topics. Further, this manual is available in PDF format for easy keyword searches using any compatible PDF reader program. The most recent PDF version can always be obtained at the SeaSoft web site (http://www.seasoftsys.com).

The organization of Chapter 2 through Chapter 4 follows basically the organization of the Simulation itself. They are orientational and nonspecific in nature, spelling out general capabilities of the Simulation and each of its composite logical modules.

Chapter 5 discusses the various classes of input data required and provides some details regarding special features and limitations of the Simulation. It complements Chapter 7 by providing additional details on items of special importance and is therefore a valuable cross-reference point for the material in Chapter 7.

Chapter 6 discusses in detail the use of and options for output control. It, too, is an important cross-reference point for Chapter 7, complementing the physical description of the output selection process given there.

Chapter 7 gives a Screen-by-Screen description of most required input items and serves as a "super index" which can be used to answer most of the day-to-day operational questions that arise during execution. Many cross-references to other portions of the user manual are given at appropriate points in this chapter.

The most important appendices are Appendix A, which contains an extensive glossary of terms used in the manual and the input/output streams, and Appendix E and Appendix Z which contain a sample problem useful in understanding the output stream.

Frequently Asked Questions (FAQ)

A database of "Frequently Asked Questions", or "FAQ", is maintained at the SeaSoft web site (http://www.seasoftsys.com) which contains a wealth of detailed real-life explanations and problem resolutions that supplements the User Manual, particularly for advanced users. In addition, the FAQ is updated more frequently than the user manuals and therefore may contain information pertinent to recent changes or additions that have not yet migrated into the manuals. The FAQ can be freely downloaded and searched by keyword(s); it is an invaluable resource for obtaining quick guidance on a wide range of issues from the mundane to the highly technical.

Organization of the Simulation

The executable portion of the Simulation organizes and integrates three logically independent software modules associated with the three important time scales governing vessel motions (statics, low-frequency and wave-frequency). These modules and a brief description of their role in the overall simulation is given below. The modules are discussed in more detail in subsequent chapters.

The Statics Module comprises **mrstat**, a powerful design tool which can be used to quickly evaluate a large number of design options in a search for a system configuration satisfying the static restoring force requirements of a project. Note: The SeaSoft mooring statics tools Catsim and Statmoor offer specialized capabilities that go beyond those found in Moorsim or its related dynamical siblings.

The Low-Frequency Module comprises **qstat**, **qdynam**, and **quasot**, mooring analysis modules which compute a moored vessel's static equilibrium configuration and its low-frequency, or quasi-static, motions under the action of specified environmental forces. In this context "low-frequency" refers to motions which occur on a time scale that is much greater than naturally-occurring wave periods (i.e. greater than 20 seconds or so). The "wave-frequency" (or "high-frequency") regime, by comparison, comprises the band of naturally-occurring wave frequencies (i.e., periods between about 3 and 20 seconds). Natural periods of low-frequency mooring system oscillations (the so-called "normal modes") are computed, as are the static and slowly-varying components of forces arising from currents, wind and waves acting on the vessel and moorings. This information is used to compute mean position and orientation of the vessel in prescribed environmental conditions and to estimate the amplitude of long-period (low-frequency) motions in response to slowly-varying forces. Vessel response to slowly-varying wave drift forces are computed either from built-in wave-drift models or, at the user's option, from alternative external sources as described in Appendix D. A related SeaSoft low-frequency and quasi-static analysis tool is Slowsim, which provides details of internal low-frequency forcing models which are otherwise unavailable directly through the Simulation.

The Wave-Frequency Module comprises four separate executable logical units, Vesselsim, **dynlin**, **ranlin** and **snpout**.

• Vesselsim is the generic name of any of several SeaSoft vessel motion and load simulators (e.g., Shipsim, Semisim, Discsim) which are used to compute wave-frequency motions and loads on the moored vessel in preparation for a dynamic analysis of mooring system behavior. Vesselsim is capable of obtaining vessel characteristics directly from Moorsim input data files and carrying out a vessel motion simulation independent of Moorsim. This capability allows separate debugging of the "vessel" and "moor" portions of the Moorsim input stream, if necessary. See the subsection on "execution procedures" and "Data Files from other SeaSoft Simulations" below for more details. Additionally, at the user's option, vessel wave-frequency response can be supplied from external sources, as described in Appendix D.

• **dynlin** computes inertial, hydrodynamic and quasi-static mooring loads associated with *sinusoidal* ("regular") motions of the moored vessel.

• **ranlin** and **snpout** compute inertial, hydrodynamic and quasi-static mooring loads associated with *stochastic* ("irregular") motions of the moored vessel.

• **xcldat** provides a comprehensive wave-basin style summary of static, low- and wave-frequency motion and load variables.

Usage Notes and Recommendations

The first execution of Moorsim should be carried out using the sample problem data supplied in Appendix E. This will permit careful checking of procedures against the user interface Screen images in Chapter 7 and the sample output data presented in Appendix Z. The detailed discussions accompanying the Screen images of Chapter 7 should answer most of the questions that might arise during a first simulation execution.

Questions Related to Input

The most valuable portions of the user manual for inexperienced users with questions on input data items are the discussions accompanying the Screen images in Chapter 7. These discussions are easily located because of their association with the accompanying Screen images. Thus, the user finds in Chapter 7 the Screen image corresponding to the computer console Screen precipitating his question, and then consults the associated textual material. These discussions contain cross-references to pages or chapters giving additional detail on a given topic. Extensive input-related information is also available through each simulation's on-line help facilities.

Questions Related to Output

The discussion of conventions used and the meaning of terms and abbreviations used in the output files (Chapter 6 and Appendix Z) should answer most questions arising during the interpretation of output file data. The discussions are labelled by Roman output section numbers appearing at the top of each output page to facilitate easy location of a particular output item.

General Questions

The specific order of search for information on a particular subject is not particularly important, but before giving up entirely, the index, glossary, table of contents and on-line FAQ should each be searched for key words related to the area of confusion. Also, the PDF version of the user manual can be easily searched directly for keywords or phrases not found in the index.

Execution Procedures

Moorsim is exceptionally flexible and offers far too many modes of operation to review them all in detail. However, a typical full execution, including evaluation of static, low- and wave-frequency dynamic response for a completely new system might entail the following sequence of events:

1. A MOORDAT input data file containing all necessary vessel and mooring system data is prepared. (See Chapter 5 and Chapter 7.)

2. Moorsim is executed, resulting in the following sub-series of events:

• The Statics Module is automatically called in order to evaluate static properties of the moor. Output from this module (and all other modules) can be sent to the Screen or to a disk file for viewing. Output from this module, found in a data file named MOOROUT, should be checked for obvious problems before time is spent evaluating output from subsequent calculations. (See Chapter 2.)

• The Low-Frequency Module is then called, assuming low-frequency data had been requested and that there had occurred a satisfactory completion of the previous step. Output from this module, found in data files named MEANOUT and LOWOUT, should be inspected and evaluated for unexpected or physically impossible results stemming from data input errors during the input session. (See Chapter 3.)

• A vessel motion module, generically referred to herein as Vesselsim, is called repeatedly during both low-frequency and wave-frequency dynamics analysis, primarily to service requests for fairlead motion information. Wave-frequency vessel motion characteristics in the form of regular wave RAOs and irregular wave statistical summaries can be found in formatted output data files with meaningful prefix identifiers: For example, "SHIP" (displacement hull; SHIPSUM, SHIPRAO, ...), "SEMI" (semisubmersible; SEMISUM, SEMIRAO, ...) or "DISC" (buoy or round vessel; DISCSUM, DISCRAO, ...). These should be carefully inspected for unexpected or physically impossible results arising from data input errors. In particular, for displacement hull vessels, the dimensions of the "dynamically similar box" given in SHIPSUM should be slightly less, but comparable to, the overall dimensions of the simulated vessel. Refer to the Shipsim manual for further information and to the sample problem in this manual for a typical case.

• Finally, the wave-frequency mooring system module is executed, assuming it had been requested and that there had occurred a satisfactory completion of the previous steps. A final check of the output from this last phase of simulation would complete the sequence of events, at which time a listing of the full output stream might be made for detailed inspection. (See Chapter 4.)

In addition to the specific chapters noted, Chapter 5 contains a more detailed discussion of general data requirements for execution and Chapter 6 contains a general discussion of output control. Examples of input procedures and simulation results from a specific sample problem are contained in Chapter 7, Appendix E and Appendix Z.

Importing Data Files from other SeaSoft Simulations

There are two mechanisms available to transfer data between various SeaSoft simulations:

• To transfer mooring system or vessel and site data between simulations, you may use the "import" facility displayed and discussed on page 119 ff.

• The simulations are also capable of reading each other's data files as a means of easily transferring input data from one simulation to another. Thus, a copy of the Moorsim data file prepared as part of the sample problem in Appendix E can, after being renamed "SHIPDAT", be read directly by Shipsim, if desired. Conversely, a Shipsim file can be imported into Moorsim, although of course mooring data may then need to be added or imported prior to execution. To import only vessel or only mooring data, the "import" facility of page 119 will normally be preferable.

Coordinate Systems

Many coordinate systems come into in play during a comprehensive mooring analysis. A brief overview of these is useful in understanding the logical flow of the simulation.

All our coordinate systems comprise a set of (x,y,z) axes in which the z-axis is associated with a "dominant" spatial direction, typically Earth-vertical, deck-vertical (or in special cases, along a local direction of interest, such as the tangent vector to an individual mooring line as it approaches its fairlead). All these coordinate systems obey the "right-hand-rule".

One special coordinate system, the "Fairlead" or "Vessel-Bound" (or simply "Vessel") system, is pre-defined and invariant; this is the system in which all vessel and fairlead properties are specified: The origin of coordinates lies at baseline, in the deck-vertical centerline plane at the longitudinal position of the vessel waterplane centroid. (Note, however, a similarly named "Vessel" system, associated with the environmentally-determined but *Earth-fixed* vessel offset and orientation, is discussed further below.) The x-axis of the Fairlead system lies along vessel centerline and the z-axis is deck-vertical. Since it is a right-hand system, the y-axis lies to port. Note that the "baseline" is user-specified; it is typically, but not necessarily, at keel level. Note also that the vessel waterplane centroid, the LCG and the Lpp/2 point are all considered equivalent in the SeaSoft simulations; inevitable real-life departures from this idealized circumstance are generally of negligible consequence and are ignored.

Note: In situations where the (LCG, Lpp/2, waterplane centroid) positions differ substantially, the preferred "vessel centroid" (i.e., the plan-view origin of the Fairlead system) should mirror the coordinate origin about which wind and current moment coefficients are defined; for tankers and other displacement-hull vessels this is typically the Lpp/2 point.

Simulation begins with the "Mooring Centroid" (see comments below) placed over a prescribed plan-view "map" location (the Global Coordinate

Origin) Gx = Gy = 0. The user defines "North", by which we mean an earth-fixed direction to be associated with the global direction 0 degrees; global directions, such as the plan-view departure angles of mooring lines and risers are supplied in this reference frame. (This direction may or may not coincide with true or magnetic North. For simplifying analysis of "as-built" installations, it is sometimes useful, but not necessary, to choose true or magnetic North as the simulation global 0 degree direction.)

Note: The longitudinal location of the "mooring centroid" or "fairlead centroid" for Moorsim-type spread-moor simulations (i.e., Moorsim, Sparsim, TLPsim) coincides with the Vessel-bound coordinate origin discussed above, typically Lpp/2. For SPMsim-type turret and single-point simulations, the mooring centroid is the center of the turret structure, or the location of the single-point mooring attachment. For the two-vessel simulations (i.e., CALMsim and Towsim), the equivalent point of interest, analogous to the turret centroid in SPMsim, is the hawser (or towline) attachment point on the "tanker" (CALMsim) or "barge" (Towsim). The Global coordinate system origin, whose purpose is to relate vessel location relative to the Earth-fixed anchors, is by definition associated with the null-environment mooring centroid (turret center, hawser attachment, or vessel center according to simulation type).

The global 0 degree direction defines the Gx axis of the Global (Gx,Gy,Gz) coordinate triad, within which system the directions of environmental influences (e.g., wind, waves and current) and other global-relative parameters (such as mooring line departure angles) are specified.

The mooring system specification includes (a) the physical properties of all lines, risers, etc., which connect the vessel to the earth or to other vessels; (b) all fairlead coordinates (in the Vessel-Bound or Fairlead system); (c) plan-view line/riser fairlead departure angles (in the Global system); (d) individual line/riser pretensions (specified as tensions, horizontal tension components, vertical departure angles, or fairlead-anchor horizontal distances).

The user also specifies an "initial" vessel heading relative to the Global system; the freedom to define "North" (see above) is often used so that the initial vessel heading will be 0 degrees, which (a) reduces the chance of erroneous data input and (b) simplifies interpretation of results, since this allows the initial (null-environment) line departure angles to be numerically identical in the Fairlead and Global coordinate systems.

> Note: For a single-point or turret-type mooring, the initial null-environment vessel heading, while arbitrary, is nonetheless important since it is used to "connect" the vessel-relative fairlead locations with the global-relative plan-view line departure angles. Thus, for example, a change in the vessel's initial heading applied after line departure angles are specified will result in a (probably unanticipated) "twisting" of the fairlead complex relative to the anchors (since the vessel and fairleads will be rotated to accommodate the new initial heading but the anchors, whose plan-view location is determined by the global departure angles, will remain fixed).

At runtime, the simulation begins by determining the anchor locations, in

the Global coordinate system, that produce the requested departure angles and pretensions.

An immediate complication arises if, as frequently happens, the specified mooring layout does not produce a mechanical equilibrium; that is, if the net computed mooring forces and moments on the vessel do not vanish. In this case, the simulation will automatically translate and re-orient the vessel (keeping the previously established anchor locations fixed) so as to achieve a mechanical equilibrium and will adjust the initial vessel (or turret) heading, the null-environment fairlead centroid location relative to the anchors, and all line tensions and departure angles to values required to achieve equilibrium. *This internal adjustment to establish equilibrium results in a reset of the Global coordinate system origin to the location of the resulting null-environment equilibrium fairlead centroid.*

> Note: For single-point or turret moors, no adjustment of initial vessel *heading* will be made (in response to a non-equilibrium initial condition) since the net mooring moment about the mooring centroid automatically vanishes regardless of vessel heading; however for turret moors, a slight rotational adjustment of the turret-mounted fairleads relative to the vessel may be required to achieve equilibrium.

The null-environment vessel equilibrium position and orientation establishes what we call the "Datum" coordinate system (Dx,Dy,Dz), a second earth-bound global system that differs from the "Global" system by *at most* a simple rotation about the vertical (i.e., the "Datum" vessel heading is not necessarily aligned with global 0 degrees). Dx lies along the quiescent equilibrium vessel centerline, Dz vertical, Dy to port. Note: It is evident that if there is no internal adjustment required to achieve quiescent equilibrium, and if the vessel initial heading is zero degrees, the Datum system is *identical* to the Global system.

The magnitude and direction of vessel surge, sway and yaw offsets, if any, required to achieve a mooring equilibrium is reported in the output stream but is thereafter discarded and the simulation proceeds exactly as if the initially supplied mooring specifications had in fact produced an equilibrium.

In this regard, note that if the initial mooring layout possesses sufficient symmetry, or if by careful data preparation the initial mooring parameters, vessel heading, etc., produce an equilibrium state without further intervention, the equilibrium "adjustment" step described above is not required and the user-specified initial conditions themselves determine the "Datum" system. This will often be the case in the mooring design phase since the symmetry of most mooring system designs will generally produce an equilibrium automatically.

After a satisfactory null-environment mooring configuration is established (and the Datum and Global coordinate systems adjusted, if necessary, to their final states), the Simulation next sums the mean environmental

forces/moments and balances these against mooring/riser forces/moments to determine a new *environmentally-determined* vessel equilibrium configuration comprising the associated quasi-static vessel offset and yaw. These mean surge, sway and yaw offsets are reported relative to the Global coordinate system.

The establishment of the mean environmentally-dependent position and orientation produces yet another earth-fixed coordinate system, which system is important because it forms a natural framework for reporting low-frequency vessel motions about the environmentally-established equilibrium. This coordinate system is referred to in the output stream as the "Vessel" system and differs from the "Global" system by a rotation about the vertical (z) axis and by a horizontal (x,y) offset vector. Confusion between this Earth-fixed "Vessel" system and the "Vessel-Bound" or "Fairlead" system discussed at the beginning of this section is avoided by the fact that the latter is vessel-bound (and moves at both low- and wave-frequencies with the vessel) whilst the environmental equilibrium-associated "Vessel" system of this paragraph is fixed in space.

Caveats

In this manual the terms "heading" and "direction" consistently refer to the direction towards which the vector variable in question is pointing. Thus a vessel, wind, current or wave heading of 90 degrees means that vessel bow, mean wind velocity vector, mean current velocity vector or mean wavevector is oriented towards the 90 degree point ("West") in the global coordinate system. This convention may generate some confusion at first because it differs from meteorological conventions (in which, for example, a West wind blows from and not to the West) and mapping conventions (in which 90 degrees is usually associated with "East"). It was felt that a consistent definition of heading and direction, valid for all vectorial assignments, would be less problematic than the inconsistency which would arise from definitions attempting to satisfy traditional usage for each of the many vectorial assignments.

Shallow Water

Vesselsim uses shallow-water wave properties in computing the quasi-static, or Froude-Krilov, component of wave forces and moments. However, vessel added mass and damping characteristics utilized in Vesselsim are computed assuming that the vessel oscillates in deep water. Normally this will not have a significant effect on computed motions or loads. In extremely shallow water, with depth comparable to the half-beam of the vessel, the flow field due to the oscillating vessel may begin to interact with the sea bottom and some degradation in simulation performance may occur. In this case, it would be prudent to prepare a USERRAOS.txt file (see Appendix D) using a high-quality 3-dimensional diffraction code to assess the degree of degradation of vessel wave-frequency motions.

Chapter 2

Statics Analysis

Capabilities

Moorsim provides capabilities for the exhaustive analysis of static restoring properties of extremely complex mooring systems comprising multiple nonlinear elasto-gravitational line elements, concentrated weights (or "clumps") and submerged or surface buoys.

Calculation Methods

The principal calculation effort in the Statics Module is evaluation of static restoring force characteristics of the catenary-elastic lines as a function of offset distance from fairlead to anchor. This calculation is done in complete generality; the algorithm used can accommodate mooring systems of virtually unlimited complexity, including highly nonlinear elastic properties, although as noted elsewhere the number of sublines allowed is limited in deference to computer memory requirements.

Related Mooring Statics Tools

The SeaSoft program library has two comprehensive mooring statics utilities that expand on the basic mooring statics capabilities of Moorsim. These are Catsim and Statmoor. As noted in the Catsim documentation, Statmoor is deprecated in favor of Catsim but is supported for backwards compatibility and for it's more rigorous handling of sloping bottom profiles.

Chapter 3

Low-Frequency Analysis

Overview

The Low-Frequency Module serves five major functions:

1. Calculation of mean (static) environmental forces and moments acting on the vessel and moorings.

2. Calculation of equilibrium position and orientation of the vessel under specified environmental conditions and externally imposed loads. These comprise:

- Irregular wave spectral type, azimuthal wave spreading characteristics, mean wave heading, significant wave height and, for two-parameter analytical spectra, spectral peak period. (Page 104; page references are to related discussions.)

- Swell significant wave height, period, bandwidth and direction. (Page 109)

- Mean wind speed and heading; wind speed fluctuation spectrum. (Page 98)

- Mean current speed and heading; current speed fluctuation spectrum; current profile with depth (Page 100)

- A comprehensive collection of highly customizable user-specified external forces and moments; e.g., thruster or tugboat forces. (Page 91)

3. Calculation of natural periods of low-frequency motions of the vessel about the environmentally-determined equilibrium position/orientation (the so-called "normal mode" periods).

4. Calculation of damping associated with low-frequency resonant motions of the system.

5. Estimation of the amplitude of low-frequency motion and load fluctuations about their mean values due to the specified slowly-varying environmental forces.

Environmental Condition Specification

Waves

Irregular waves play a unique role in the analysis of catenary-based mooring systems because they participate in every phase of static and dynamic analysis:

1. In static calculations they define the steady wave drift force which contributes to the determination of mean equilibrium position and mean forces on the system.

2. In estimation of low-frequency motions and loads, waves often dominate slowly-variable drift forces which contribute to low-frequency surge, sway and yaw motions.

3. In wave-frequency dynamic calculations waves determine vessel and mooring system forces and moments, thereby completely defining wave-frequency motion response and system loads.

Wave Drift Force Terminology Note

As a result of the introduction into the simulations of nonlinear wave "drag" estimates for all vessel types (previous to version 5.0 these estimates were only available for semisubmersible-type vessels), we have adopted a more suggestive and logically consistent terminology when discussing wave "drift" forces.

Historically, the designations "wave drift force" and "wave drift coefficient" have been applied to the wave-energy conserving second-order process of momentum transfer from waves to vessel via diffraction and reflection. In SeaSoft's simulations, these energy-conserving forces and coefficients derive either from built-in models, or from user-supplied text files, the latter usually being produced from the output of three-dimensional diffraction codes.

Notwithstanding historical conventions, from a purely logical perspective wave "drift" forces actually comprise *two* components, the above-mentioned energy-conserving component, which we now call the "reflective" component, and a "dissipative" (or "absorptive") component. The dissipative component will on occasion be called the "drag" component, which use is also in keeping with our "legacy" terminology for the same effects as applied to semisubmersibles.

Because of the long (and misleading) historical association of "wave drift force" with the energy-conserving component (which we now call the "wave reflection force"), there will be times when we lapse into historical usage and say or write "wave drift force" when we actually mean the *reflective* component only of the total drift force. In case of such lapses, the context of the remarks should serve to clarify whether we are in fact speaking of the reflective component or the *combined* reflective and dissipative components. A reference to the "wave drag force" always refers to the dissipative component.

Wind

Wind is characterized by (a) mean wind speed at a height of 10 meters above the sea surface, (b) wind heading and, for purposes of determining low-frequency vessel motions arising from time-variable wind forces, (c) a wind speed spectrum. The paucity of data on wind speed fluctuations over the sea surface, as contrasted with the wealth of data on wave conditions

and wave spectral properties, has limited the built-in wind speed spectral choices somewhat compared to waves. See Page 98 ff for additional details.

Current

Current modeling capabilities more or less mirror those for wind, with two exceptions: (1) There are no built-in current spectral models analogous to the Davenport wind spectrum (i.e., current spectral properties, if any, must be user-specified); and (2) the depth dependence of current speed must be characterized due to the mean and variable current forcings on moorings, risers, and other submerged structures.

Note that historically both simulation and physical (i.e., wave-basin) modeling of time-variable currents has been largely neglected in offshore design and analysis. Although the consequences of this neglect have been powerfully and repeatedly demonstrated in both model test and prototype situations, as of this writing (2005) most "industry standard" analytical tools continue to ignore this crucial aspect of system performance, primarily because most simulation tools are time-domain based and require a time history for the current fluctuations (which history can be difficult to obtain or estimate). Unlike slowly-varying wave drift forces, for which a statistically representative time series can be simply obtained from the wave spectrum, a meaningful current time history is much more difficult to infer, either in the model basin or in full-scale operations. Current spectra can, however, be at least roughly estimated in both model basin and full-scale environments; the neglect of this important dynamical excitation at this late date in the development of offshore design and analysis borders on engineering malpractice. Moorsim accommodates time-varying current forces by means of a current speed spectrum in a fashion completely analogous to specification of the empirical wind speed spectrum.

The vertical profile of current speed as a function of distance from the surface may be described by (a) the commonly utilized "one-seventh" power law (default), (b) a uniform current (no variation with depth) or (c) a user-specified data array. (See page 100 ff for additional details.)

Environmental Forcing Models

A wide range of built-in models for estimation of environmental forces, both static and fluctuating, are available within the simulations. For circumstances in which the built-in models are inappropriate or insufficient, any (or all) environmental forcings can be supplied via text files containing tabular forcing coefficients (Appendix D).

Vessel Wind and Current Coefficients

Wind and current forces are assumed to be square-law in nature; they are computed according to the following analytical model: Mean forces and moments are assumed to vary in proportion to (a) the dynamic pressure of the associated mean flow (i.e., proportional to fluid density and the square of the fluid speed) and (b) vessel area subjected to the flow.

Empirically-determined dimensionless force and moment coefficients,

dependent on the angle between vessel centerline and direction of mean fluid motion ("angle of attack"), particularized to the form of typical crude-carrying seagoing tankers (ULCC's and VLCC's), comprise Moorsim's built-in "Tanker" description of wind and current forces and moments. These coefficients have been taken from the 1976 tanker study by OCIMF[1] and from an update conducted by the Netherlands Ship Model Basin (NSMB '91). The built-in wind and current models are indicated below.

Built-in Wind Models: (See page 83 ff for additional details.**)**

- User-Specified
- Barge (SeaSoft)
- OCIMF Tanker '77 (extended)
- Cylindrical Vessel

Built-in Current Models: (See page 84 ff for additional details.**)**

- User-Specified
- Barge (SeaSoft)
- NSMB Tanker 91'
- Tanker (Extreme Cylindrical Bow) '91
- OCIMF Tanker '77
- Cylindrical Vessel

Wave-Drift Modeling

Static wave-drift forces and moments are assumed to vary in proportion to (1) the static forces which would be exerted on a fixed breakwater, (2) the waterline length subjected to wave action and (3) empirically or theoretically determined regular wave drift force coefficients. This modeling has a rich history in the offshore industry and we make no attempt to review the physics of this phenomenon here. A discussion of some issues relating to semisubmersibles can be found in Appendix G. The available wave drift force models are indicated below.

Built-in Wave Drift Force Models: (See page 89 ff for additional details.**)**

- User-Specified (DRFTCOFS.txt)
- Tanker (Legacy)
- Semi (Legacy)
- Buoy
- Caisson Spar
- Tanker (2001)
- Semi/TLP (2001)

Equilibrium Configuration Analysis

The equilibrium configuration analysis built into Moorsim comprises an exhaustive search of physically realizable vessel orientations in order to identify all possible equilibrium configurations that exist under a given set

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[1] "Prediction of Wind and Current Loads on VLCC's", Oil Companies International Marine Forum Report, 1976.

of environmental influences. Environmental forces and moments appropriate to the discussion of this section are static wind and current forces and moments, and steady forces associated with the mean wave-drift force; these forces are in addition to any constant forces or moments specified to simulate the effects of thrusters or tugboats. Equilibrium configurations are identified by searching for any vessel position and heading combinations which produce, in the specified environment, zero net force and zero net moment about the fairlead centroid (or turret point in SPMsim).

Stability of Configurations

The stability character of each identified equilibrium position and orientation is determined by the slope of a moment versus angle curve; a potential energy function for the system is determined from the integral of that curve. The potential energy at any equilibrium point is a measure of the quasi-static stability of the corresponding configuration. Under most naturally-occurring conditions only two equilibria, one stable and one unstable, will exist. In uncommon circumstances, however, it is possible that several equilibrium conditions can exist simultaneously. In that case, the equilibrium point of greatest stability (identified as having the deepest potential energy "well") determines the reported mean position and is used for subsequent low- and wave-frequency motions and loads analyses.

Low-Frequency Dynamics

The low-frequency dynamic calculations comprise estimation of low-frequency natural periods of motion, and damping levels and amplitudes associated with those motions. Motions are assumed to occur about the mean position determined by the most stable static equilibrium position, as discussed above. Note that the "stable equilibrium position", which by our definition is the point at which the *mean* forces and moments on the vessel vanish, is not formally identical to the mean position derived from the time-average of position time histories (as might be produced by an analysis of model test time histories). This is due to nonlinearities in the mooring reaction forces which nonlinearities produce nonsinusoidal vessel response to sinusoidal forcing inputs. For practical applications, the time-averaged "mean" position and the SeaSoft "equilibrium" position will be nearly the same except for extreme circumstances when highly nonlinear portions of the force-versus offset curve are being regularly visited by the vessel during its low-frequency motions. For related discussion, see page 39; for a discussion of related load-specific quantities, see page 54. This effect often accounts for simulation predictions which differ slightly from model test mean position results, which always represent the time-average of position time histories.

Normal Modes: Spread and Single-Point Mooring Differences

The characterization of low-frequency motions differs considerably between "spread-moor" simulations (Moorsim, TLPsim and Sparsim; generically referred to as "Moorsim") and "single-point" mooring simulations (SPMsim, CALMsim, SALMsim and Towsim; generically referred to as "SPMsim") due to the differing nature of the mooring restoring forces for the two mooring types. The low-frequency normal modes of Moorsim are, in most

cases, well approximated by uncoupled surge, sway and yaw in the moor. This is because most spread mooring systems possess sufficient symmetry that there is little mooring-related coupling between these three degrees of freedom. Moorsim assumes in fact that there exists sufficient symmetry to enforce, at least approximately, this uncoupled condition, permitting the modeling of surge, sway and yaw low-frequency motions as three uncoupled single-degree-of-freedom systems. SPMsim, on the other hand, manifestly couples the sway-yaw degrees of freedom which must therefore be treated as a two-degree of freedom sub-system. (See also page 42.)

Low-frequency Normal Modes: SPMsim Discussion

The three plan-view degrees of freedom of vessel motion (surge, sway and yaw), in conjunction with the restoring force characteristics of a single-point mooring system, result in three normal modes of oscillation about the equilibrium point. An analysis of this problem shows that these three normal modes can be broken into a single normal mode associated with the surge degree of freedom of the vessel, plus two sway-yaw modes in which each normal mode comprises a computable mix of sway and yaw motion. The higher-frequency sway-yaw mode can, in an approximate way, be visualized as a pure yawing motion about a point slightly aft of the vessel c.g. (for a bow-located turret or hawser attachment); the lower-frequency sway-yaw mode can be understood by visualizing the vessel motion, in plan view, as that of a compound pendulum oscillating about a point near the turret. In practical systems, the period ordering of these modes is: high-frequency sway-yaw mode (typically 50-150 seconds), surge mode (typically 150-500 seconds) and low-frequency sway-yaw mode (typically 500-2000 seconds).

Surge Mode   *Low Sway-Yaw Mode*   *High Sway-Yaw Mode*
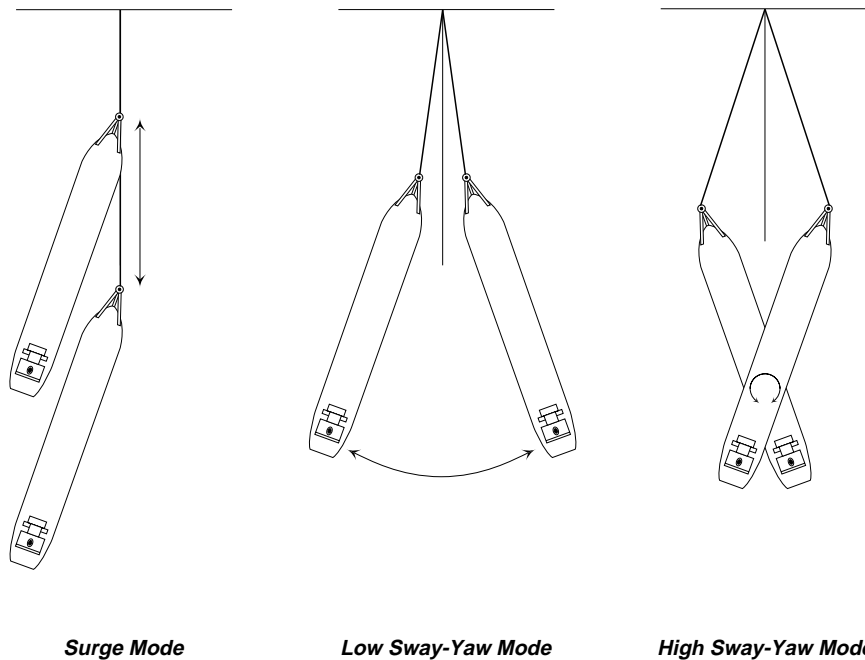
Evaluation of oscillation periods and damping of the system can be carried out once the restoring force versus offset characteristics of the mooring system are known. The system is treated as a simple quasi-linear oscillator

for this purpose, whose normal mode periods are completely determined by (a) the slope of the force versus offset curve at the equilibrium point, and (b) the vessel mass, yaw moment of inertia and the vessel hydrodynamic added masses in surge, sway and yaw.

Damping

Low-frequency damping levels, like their associated natural periods, are dependent on the intensities of environmental conditions specified, and will therefore vary with simulated conditions. Generally speaking, the greater the mean environmental force on the system, the greater the damping associated with the occurrence of that force. In particular wave damping, which is closely related to the generation of the static wave-drift forces on the vessel, depends on the wave spectrum in addition to wave height and peak period. Experimental work[2] done on this problem fully validates the proprietary analytical model for low-frequency surge damping in waves used in Moorsim.

Motion Amplitudes

Estimation of resonant oscillation amplitudes associated with time-varying components of the prescribed environmental forces requires a spectral model for the temporally-varying part of those forces. The details of the spectral model are not particularly important for long-period motions, since only spectral densities at frequencies very close to the natural periods of motion of the system contribute in an important way. In this regard, the low-frequency vessel motions are quite different from wave-frequency motions in which a much broader band of the wave spectrum participates in development of vessel response.

Calculation of motions and loads experienced by individual mooring lines due to environmentally-produced *low-frequency* vessel oscillations are carried out quasi-statically. That is, computed low-frequency motion amplitudes are used in conjunction with static offset curves determined in the Statics Module to produce estimates of root-mean-square (RMS) motion and load level fluctuations about the mean values. Wave-frequency load analysis, by contrast, is *non-static* and depends on a nonlinear wave-frequency dynamical model in lieu of the static mooring offset characteristics.

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[2] See, for example, Wichers, J.E.W., "On the Low-Frequency Surge Motions of Vessels Moored in High Seas", Offshore Technology proceedings contribution # 4437, 1982 proceedings.

Chapter 4

Wave-Frequency Analysis

Overview

Moorsim incorporates powerful analytical methods for estimating wave-frequency motions of and loads on the mooring system and attached vessel. By "wave-frequency" we mean periods between three and twenty seconds, which spans the range of waves found in nature that have a significant influence on vessel motions. All calculations are fully three-dimensional, providing force components and motions at required system points.

The principal analytical simplification employed in the Wave-Frequency Module is the assumption that wave-frequency loads transmitted to the vessel from the mooring system have no influence on vessel motions; that is, wave-frequency mooring system loads are assumed to be negligible in comparison to loads associated with direct wave action on the vessel. This "large vessel" assumption can be confirmed *a posteriori* by comparing wave-frequency mooring system load fluctuations with direct wave loads on the vessel; it is generally justifiable (except for CALM buoys and TLP systems; see below). Each mooring line is therefore modeled as an independent dynamical subsystem, excited by imposed wave-frequency motions of its upper endpoint.

CALM and TLP Considerations

Note that because of the small size of buoys used for tanker moorings in CALM-type systems, the "large vessel" assumption is inappropriate; CALMsim therefore uses a fully coupled and nonlinear mooring-buoy-hawser model to determine wave-frequency motions of the CALM buoy.

Similarly, because of the extremely taut moorings (tendons) of a TLP installation, "mooring" (i.e., tendon) loads are comparable to or greater than wave loads; again the "large vessel" model which ignores mooring loads is inapplicable and must be replaced by a fully coupled model in which TLP wave-frequency response depends on both wave loads and mooring loads.

Imposed Mooring System Upper Endpoint Motions

In order to provide physical insight into the dynamic characteristics of the mooring subsystem, two distinct types of imposed upper endpoint wave-frequency motions are accommodated in Moorsim. These comprise (1) fairlead motions produced indirectly by wave action acting on the vessel and (2) directly imposed (user-specified) constant amplitude fairlead motions tangential to the mooring lines at the fairleads. These options are discussed more thoroughly further below. (See also page 101.)

Regular Wave Excitation

In a normal simulation run, regular waves of constant amplitude (or slope) and selected periods will be specified as the mechanism responsible for system wave-frequency motions and loads. These regular waves are, in a sense, only indirectly responsible for the upper-endpoint motions imposed on the mooring system since these "fairlead" motions are produced by vessel oscillations which are themselves the direct result of wave action. These endpoint motions evidently involve the six-degree-of-freedom transfer functions between waves and vessel motions about the instantaneous vessel position. The transfer functions may be produced by one of SeaSoft's wave-frequency vessel motion modules (Shipsim, Semisim or Discsim; generically, "Vesselsim") or a comparable vessel motions package. Details on interfacing an external vessel motions program to Moorsim can be found in Appendix D. Details on the functioning of "Vesselsim" can be found in the relevant SeaSoft user manual. The amplitude, direction and phase of the tangential motions imposed on the mooring lines by wave-frequency vessel motions are thus determined solely by the vessel motions program employed. Note that the phase reported for mooring system load RAOs is measured relative to the wave crest at the vessel centroid and not relative to the motion imposed by the moving vessel at the fairleads. Positive phase angles represent phase leads. Note also that direct hydrodynamic wave loads on the mooring lines are not considered in the Simulation; *mooring line excitation and the related loads derive exclusively from fairlead motions.*

Tangential Line Extension Excitation

The second mooring system excitation mechanism provided in Moorsim is useful in isolating basic wave-frequency mooring line dynamics from the dynamics of the attached vessel. With this option, the user requests a specified, fixed tangential fairlead motion amplitude and a set of oscillation periods to be used in the calculation. The specified amplitude of motion is used for all lines, and the imposed fairlead motion is tangential to the mooring line at the equilibrium offset position. This option evidently completely bypasses the vessel insofar as wave frequency vessel excitations are concerned[3]. The phase convention for this case assigns a zero phase angle to maximum upwards (i.e., away from the anchor) line extensions at the fairlead. Here, as elsewhere, a positive phase angle corresponds to a phase lead.

Mooring System Wave Loads

Wave loads acting directly on the mooring lines, as mentioned above, are not accommodated in Moorsim. The errors associated with this assumption

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[3] ***Note***: irregular waves specified during a simulation run using the fairlead tangential extension option will be used only for determining mean vessel position and low-frequency behavior; they will be ignored with respect to "wave-frequency" calculations. This also means that no wave-frequency statistical calculations of motions or loads will be carried out since they require regular wave RAOs.

are set by the ratio of maximum wave force integrated along the mooring line to forces produced by fairlead motions, which ratio is generally negligible in environmental conditions producing non-trivial mooring system loads.

- Effects of hydrodynamic added-mass on the apparent inertia of mooring line elements are generally negligible. This is because quasi-static loads are independent of the hydrodynamic added mass and wave-frequency loads are overwhelmingly dominated by hydrodynamic drag forces, as contrasted with hydrodynamic inertia forces, for moorings with conventional "sagging" catenary profiles. For extremely taut lines with little catenary sag, as sometimes encountered in spar moorings or synthetic materials, the influence of a line's hydrodynamic added mass may be appreciable.

- Nonlinear hydrodynamic drag effects due to fluid motion relative to the moving mooring lines are important in setting the level of damping of low-frequency modes of oscillation of the vessel and in setting the magnitude of wave-frequency load oscillations in the line itself. Nonlinear low-frequency damping effects are treated in a way which is, essentially, analytically exact in the limit of excitation of a lightly damped system; the wave-frequency line load calculation is fully nonlinear.

Statistical Synthesis

The procedure used in Moorsim for combining wave-frequency and low-frequency motion and load statistics to determine net root-mean-square (RMS) fluctuation levels requires some justification. Briefly, long-period motions resulting from wind and current fluctuations can certainly be considered statistically uncorrelated without further discussion. However, it is not as readily apparent that the wave- and low-frequency components of wave-induced motion on the vessel are statistically uncorrelated, which lack of correlation has been *assumed* in Moorsim. That long and short period wave-induced vessel motions are in fact uncorrelated to a good approximation flows from the following considerations:

- Wave-related driving forces for low-frequency motions (i.e., the wave groups) can be considered the sum of three narrow-banded excitations with central frequencies at the three natural periods of low-frequency motion, plus a broad-banded excitation containing all remaining (non-resonant) excitation frequencies. The broad-banded excitation response produces vessel motions which are negligible to and uncorrelated with the resonant response, because the latter will comprise narrow-banded nearly sinusoidal oscillations at the lightly-damped normal mode frequencies while the broad-banded part of the response spectrum will lack contributions near the natural frequencies of vessel motion.

- With respect to the remaining narrow-banded components of driving force near low-frequency normal mode frequencies, the following conditions prevail:

  > 1. Because the long-period motions are very nearly pure resonant excitations of a lightly damped system, the motions lag the driving force by 90 degrees.

  > 2. In the case of waves, the long-period driving force, i.e. the variable wave-drift force, is in phase with wave groups. This means that the maximum driving force for long-period oscillations is "in phase" with the occurrence of the larger waves; by this we mean that the maximum wave drift forces occur at approximately the same time as the maximum wave-frequency forces (and motions).

  Thus the maximum wave-frequency forces on the vessel and mooring system occur 90 degrees out of phase with the maximum long-period offsets which are responsible for the low-frequency fluctuations in the mooring system motions and loads; this condition assures the motions are, at least approximately, uncorrelated.

Chapter 5

Input File Preparation

For its execution, Moorsim requires data of three distinct generic types: (1) site data consisting of water depth and water density, (2) physical data on mass, volumetric and geometrical properties of vessel and mooring system, and (3) environmental data comprising principally wind, current and regular and irregular wave conditions desired for simulation. This data is then used to sequentially evaluate mooring system performance in up to three "frequency" regimes: zero-frequency (statics), low-frequency (relating to natural periods of surge, sway and yaw in the moor) and high-frequency (wave-frequency). The ordering of topics in this chapter for the most part matches the ordering of input data requested during an interactive session with the Editor. Refer to Appendix E for sample data required in a typical simulation. Printed images of Screen presentations produced by the Editor and additional details concerning required input parameters are included in Chapter 7.

Site Data

Characteristics of the site chosen for simulation must be available to the program and are requested as input on the first console Screen presented by the Editor. These are site water depth and water density. Fluid density is completely specifiable so that unusual conditions, such as very high salinity (and hence high density) water, can be easily simulated. Water depth, in addition to individual anchor depths, is required so that correct shallow-water wave characteristics can be simulated. Moorsim accounts automatically for shallow water effects including wavelength foreshortening and wave speed reduction. The choice of units to be used in simulation, which may be either English or metric, is made on this Screen as well.

Note that Moorsim does not rigorously support the simulation of a sloping site bottom, although it *does* support variable anchor depths, which support has proven to be sufficient in virtually all practical circumstances. Simulation errors associated with neglect of a gently sloping bottom have proven to be comparable to many similarly uncontrollable modeling shortcomings; that is to say, it generally lies "in the noise" and is not considered of sufficient importance to justify the additional simulation complexity. In this regard, the statics utility Statmoor fully supports sloping bottoms for mooring statics evaluations. See additional discussion on page 71 ff.

Mooring System Data

For purposes of quantifying its properties, the mooring line is logically decomposed into two levels of structure; individual "elements" or "sublines" of arbitrary size and mass properties, and "lines", which are by definition conglomerates of connected "elements" representing the fundamental mooring units.

Treatment of Submerged Buoys and Clumped Weights

Special line elements can be easily created which faithfully simulate the action of concentrated weights or of submerged or surface buoys. These special "sublines" should possess the net weight (or buoyancy) and the square-law drag properties of the simulated buoy or clump. The drag coefficient times the net projected area (length times diameter) of the subline should match that of the modeled buoy or clump in order to properly mimic the important square-law drag forces. The net weight or buoyancy of the subline (length times submerged weight/unit length) should likewise match that of the buoy or clump. For this purpose, a negative submerged weight/unit length should be used for buoy simulations.

Risers and Other Mooring-Type Structures

Like buoys and clumped weights, production risers, SCRs (Steel Catenary Risers), etc., are all modeled as mooring elements, with exactly the same considerations as mooring lines. In particular, there is no capability to analyze or model bending stresses in these elements which, like mooring lines, are assumed to support only axial stresses.
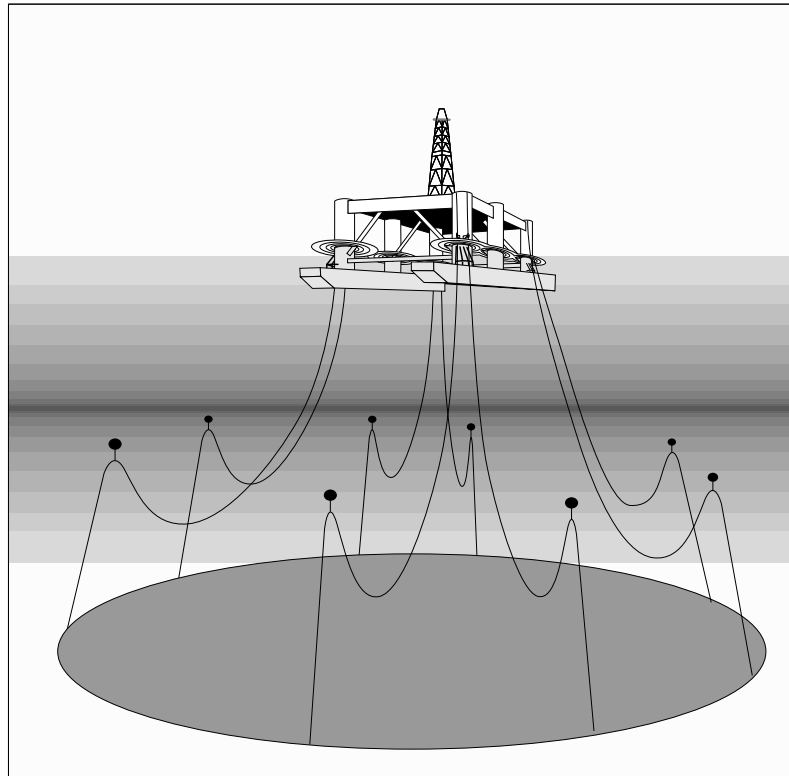
Special Considerations

Vessel Data

In order to obtain a complete dynamic simulation of environmentally-driven motions and loads experienced by the mooring system, it is necessary to

evaluate the wave-frequency motion response of the moored vessel. This evaluation is normally carried out using one of the SeaSoft wave-frequency vessel simulations (Discsim, Semisim, Shipsim or, generically,"Vesselsim") although Moorsim can also be interfaced to other non-SeaSoft vessel motions programs using the mechanism described in Appendix D. Details of vessel motion evaluation as carried out by Vesselsim are covered in the appropriate user manual; only a brief review of required vessel input data will be given here. (See page 76 ff.)

Vessel data required by Moorsim is the minimum information necessary to permit faithful simulation of the vessel's wave- and low-frequency dynamic characteristics. This minimum data is logically divided into two groups, each specific to a particular frequency regime.

Vessel Data Necessary for Wave-frequency Analysis:

- Total vessel displacement.

- Longitudinal and transverse metacenter locations. These are input relative to vessel baseline (i.e. as KML and KMT).

- Vertical center of buoyancy from baseline (KB).

- Vertical center of gravity from baseline (KG).

- Vessel water-plane area at the required displacement.

- Radii of gyration in Pitch, Roll and Yaw.

- Bilge characteristics at maximum beam station; bilge radii and details of bilge keel, if any.

In addition, for semisubmersible vessels, spars or TLPs, a more detailed description of the submerged portion of the vessel must be supplied. See the Semisim manual for hull specification details required for such vessels.

Vessel Data Required for Quasi-Static Analysis:

1. Length between perpendiculars (LBP or Lpp), beam and draft. Length and beam are used in quasi-static analysis for the calculation of slowly-varying environmental forces, particularly the wave-drift forces. Some judgement is required in the specification of length and beam for semisubmersible-type vessels; basically, the "length" and "beam" specified should represent the waterline length exposed to incident waves, projected onto the appropriate vertical plane. Whether or not fore and aft (or port and starboard) columns will "blanket" each other will depend on column size and shape, separation and wavelength. A conservative approach that can be used when significant blanketing is considered likely is to count only half of the waterline supplied by the blanketed members in the length and beam values. (See also Appendix G.)

Note that the coordinate system in which all vessel physical properties are specified is the "vessel-fixed" system used elsewhere in this manual, namely, a right-handed coordinate system with origin at the user-specified baseline

(normally vessel keel), positive x-axis towards the bow, positive y-axis to the port, and positive z-axis vertically upwards. The general discussion of coordinate systems utilized in Moorsim appearing in Chapter 1 and on page 64 ff should be noted.

2. A description of certain features of the vessel hull shape required for determination of environmental forces of wind, waves and current. (See page 80 ff.)

• Overall vessel shape - Moorsim currently supports several generic types, including "Barge" and "Tanker", which are appropriate to extremely box-shaped vessels and conventional VLCC and ULCC vessels, respectively.

• Bow types - "Conventional", "Cylindrical", "bulbous" and/or "non-bulbous". These designations are appropriate only to the "Tanker" type noted above and refer to the shape of the bow in side-view profile; they have become standard terminology in the single-point mooring industry as a result of studies by OCIMF on effects of tanker size and geometry on environmental forces. See extended discussion on page 80 ff.

• Load condition - This percentage is defined in two ways, one applying to wind (freeboard or "F.B."), the other to current (Draft):

> Freeboard Load % = 100*(Full Load F.B.)/(Simulation F.B.)
> Draft Load % = 100*(Simulation Draft.)/(Full Load Draft.)

"Load Condition" data are used only for built-in tanker wind and current load calculations. For example, to obtain the OCIMF '77 "Fully Loaded" wind data, enter 100% for freeboard-based load; to obtain the OCIMF "Ballasted" data, enter 32%. Other percentages will result in linear interpolation between the "Ballasted" and "Loaded" curves. Typical "Lightship" is about 20% in this scheme.

• "Deadweight" is used to distinguish between built-in data for VLCC's (DWT > 155,000 Tons) and smaller tankers (DWT < 80,000 Tons) in the OCIMF '77 (extended) database and to serve as an interpolation variable for intermediate DWT. (See page 80 ff.)

Description of Wave Types Supported

Wave conditions that can be specified for simulation comprise two classes: regular waves and irregular waves.

Regular Wave Characteristics

Regular waves are simply long-crested surface waves of well-defined period. Waves of this type were historically used in wave basin measurements to determine the RAOs ("Response Amplitude Operators") of a vessel, but are less frequently employed experimentally these days. (This "modern" tendency represents a serious philosophical failing in our view; the starting point for understanding a complex dynamical system, particularly a highly non-linear one, should always be a collection of single-frequency input

excitations.) Moorsim begins all simulation runs by calculating a user-specified collection of regular wave force, moment and motion response characteristics. The choice of regular wave periods to be used in RAO calculations will depend on whether or not irregular wave performance is to be estimated: (See page 102 ff.)

- If no irregular wave data is required, any wave periods whatever may be selected for regular wave response data. For example, exact wave periods determined in model basin tests or in full-scale measurements can be specified for response estimation.

- If irregular wave calculations are required, the regular wave periods selected must be equally spaced. This is true whether the irregular waves are required for determining the static and low-frequency components of the slowly-varying wave drift force or for evaluation of statistical measures of wave-frequency motions and loads in response to irregular wave excitation, or both. This is because numerical integration routines used in all irregular wave computations require equally spaced periods. The Editor, which will not permit input of unequal regular-wave period intervals when irregular waves are selected, provides an automatic mechanism to achieve the required equal spacing. This mechanism is described in Chapter 7. (See page 103.)

- If irregular wave data is requested, the regular wave periods chosen should span a sufficiently wide band of periods to completely bracket important wave periods present in the irregular wave spectrum to be employed. The adequacy of the bracketing can be established by the Simulation itself, but this requires that it be executed at least twice. To accomplish this check, a range of equally-spaced periods is selected and the Simulation executed with the desired irregular wave spectra. The irregular wave output will indicate the irregular wave height computed from numerical integration of the wave spectrum. If this value is not within 10 or 15 percent of the requested value, the range or density of wave periods was inadequate, and should be modified by increasing the largest wave period, reducing the smallest wave period, reducing the wave period interval, or some combination of these.

Drift Forces in Regular Waves

Occasionally it is desired to simulate the action of a single regular wave acting on a system, including the static drift force associated with the regular wave. This situation most commonly develops when analyzing wave basin data where tests utilizing a single regular wave to excite the system are sometimes used. This need is most simply addressed using Slowsim, which will display in tabular form the drift-force and moment data available to Moorsim. However, to simulate this condition directly using Moorsim, one should choose a swell of wave height equal to the

square root of 2 (1.414...) times the desired regular wave height in order to simulate the static drift force produced by the regular wave. (See page 109.) Thus, to simulate a regular wave of 20 feet height and 10 second period, Moorsim should be executed with a swell of 28.28 feet and 10 second period. The wave period array used in the Simulation should include the desired regular wave period, in this case 10 seconds. The *variable* part of the wave-drift force associated with the swell input can be quenched, if desired, using the drift force coefficient controls described on page 95 ff.

Additional RAO considerations are discussed in Chapter 4.

Irregular Wave Characteristics

Irregular waves in nature comprise a superposition of regular waves of differing periods and headings. (See page 104 ff.)

Many standard irregular wave spectra are built into Moorsim, including Bretschneider, Pierson-Moskowitz, and several implementations of the JONSWAP spectrum (including the full 5-parameter representation; see page 106). In addition, there are two ways to input a user-defined spectrum. (See page 108 and Appendix D.) The individual spectral densities required as input for the user-supplied frequency spectrum must:

- Be in a set of units consistent with those of the vessel properties; metric example: [meter^{2}sec] or, equivalently, [meter^2/(rad/sec)].

- Represent a wave *variance* spectrum S(ω), where ω is the circular frequency variable (in radians/sec). The integral of S(ω) from $\omega = 0$ to $\omega = $ infinity is equal to the variance of the sea surface elevation about the still water point. For spectra of interest in offshore applications, the square root of this variance is very close to one-fourth of the significant wave height associated with the spectrum. The significant height is defined as the average height of the one-third largest waves. Some care must be exercised here as spectra are sometimes reported as wave *height* spectra or wave *amplitude* spectra, whose spectral values are, respectively, eight or two times greater than the associated wave variance spectral values. Also, if the supplied spectrum is given in terms of hertz (cycles/second) rather than circular frequency (radians/second), each spectral value must be divided by $2\pi = 6.2832...$ before input.

- For the mechanism described on page 108, the spectral values must be given at exactly the same wave *periods* as those specified for regular wave RAO determinations (see page 103), which periods must possess equal period-to-period intervals as discussed above. This may require some interpolation of experimental or tabular spectral data since spectra are normally reported at equal frequency intervals and not equal period intervals. Note that the WAVESPEC.txt mechanism (Appendix D) does not share this requirement and is now the preferred mechanism for user-specification of wave spectral data.

The spectral values, to reiterate, are those associated with a *frequency* spectrum and not a *period* spectrum; these differ from one another by a factor proportional to the square of the frequency. Since the significant height associated with a measured spectrum is usually known, the output significant wave height given by Moorsim can be compared with the known value. This comparison will alert the user to any errors in spectrum scaling.

Differences Between Moorsim and Vesselsim

Because Moorsim uses "Vesselsim" (i.e., one of Shipsim, Semisim or Discsim) to evaluate wave-frequency motions of the attached vessel, which motions contribute importantly to loads on the mooring system, a large amount of the data required for an execution of Moorsim is identical to the data required for an execution of Vesselsim, which data is discussed fully in the appropriate user manual. In Moorsim however, only a single irregular wave direction can be accommodated in each execution of the Simulation; this direction must be the same for the regular and irregular waves specified. The Editor enforces this restriction automatically; any change in either regular or irregular wave direction is automatically incorporated into both. *Swell* direction, however, is independent of regular and irregular wave direction, as in Vesselsim.

Chapter 6

Output Control And Description

Moorsim provides extensive output control which can be used to select and limit data for output. This keeps printout volume to a manageable level. The output options should be carefully studied so that an intelligent selection can be made. (See page 110 ff.)

Output Control

The highest level of output control governs which logical modules of Moorsim will be executed. These are:

1. The Statics Module

2. The Low-Frequency Module

3. The Wave-Frequency Module comprising:

    The Vessel Motion Submodule

    The Wave-Frequency Mooring System Dynamics Submodules

All simulations begin by evaluating static offset properties of the specified mooring system; results of this analysis are required by the remaining modules, should they be required. Likewise, results of analyses carried out in the Low-Frequency Module are required by the Wave-Frequency Module, so that execution of the latter requires execution of the former in the indicated temporal sequence. This logical structure is completely automatic and requires no special consideration; it is outlined here for completeness only. In particular, a request for execution of a wave-frequency simulation without a prior low-frequency evaluation will be rejected by the Editor. Evidently, only three possible combinations of the three execution modules are possible in any simulation: statics alone, statics plus low-frequency analysis, or a full simulation consisting of all three frequency regimes. Output from the Statics Module, consisting of a summary of the physical properties of the mooring lines and a detailed presentation of static restoring properties for each line, can be deselected, as can output from the Low-Frequency Module. This de-selection may be desirable to eliminate unwanted repetitive output in situations where repeated executions of the Wave-Frequency Module for a given mooring system is necessary.

Edit Session Hardcopy

A disk image of the entire collection of Screen images comprising a Moorsim session will be made automatically at runtime or at any time during the editing session via user request. (See page 119 ff.)

Output Destination

All output data can be vectored to either the console or disk at the user's discretion.

RAO Selection Control

Moorsim evaluates motion RAOs for the vessel and regular wave line load responses for all mooring lines. Specifically, dynamic responses are available for the following mooring system motion and load variables, evaluated at mooring line endpoints:

• Fairlead motions normal and tangential to the mooring line.

• Net maximum and minimum loads at fairlead and anchor using a fully nonlinear wave-frequency dynamic model (that is, line loads are *not* simply proportional to motion amplitudes. See page 48 and page 102.)

• Net maximum and minimum loads at fairlead and anchor using a simple "quasi-static" wave-frequency dynamic model (in many situations, this simplified load response measure is roughly linear; that is, it is approximately proportional to motion amplitude).

For most applications, only a small subset of this large volume of available regular wave response data is of interest, and Moorsim allows any or all of these variables to be selected for output. *Irregular* wave statistical summaries, by contrast, are automatically included in the output stream for all variables.

Vessel Motion RAOs

Computed motion RAOs comprise all six degrees of vessel freedom and resulting fairlead motions; these are included in the output stream whenever the "Vessel Motions Summary" is requested.

Output Description by Output Section

The following discussion details the description of the output pages in Appendix Z.

Statics Module Output Notes

Output from the Statics Module can be found in output Section I.

Output Section I (MOOROUT)

This section contains individual static offset information (in the form of interpolation tables) for each mooring line. This tabular information is the starting point for all per-line static force versus offset data used in and provided by the Simulation. Linear or cubic spline interpolation on this tabular data defines completely all aspects of line static behavior. The table limits are determined by user choices made during the Editor session

(see pp 62). When more than a single "interpolation layer" has been specified, each table in this section is repeated for each required "layer" (see pp 66).

> **Section Ib** ("Element Endpoint Position Table") contains element *endpoint* position. Subline counting begins at the fairlead (i.e., Subline 1 begins at the fairlead and its "endpoint" is at its anchor-ward end.) Should more detailed line position data be needed, individual *uniform* sublines can be broken up into shorter segments, provided that the maximum allowable number of sublines per line is not exceeded. The first table in Section Ib comprises horizontal endpoint positions, while the second comprises vertical endpoint positions relative to the fairlead. The sign convention is that positive X values are towards the anchor, while positive Z values are upwards (above the fairleads). Therefore, most "Z" locations have a negative sign.

> **Section Ic** ("Element Endpoint Angle Table") contains element endpoint *angles*. For example, the "T1" angle is the vertical angle (in degrees) at the fairlead end of the *first* subline. A zero angle corresponds to a horizontal tangent and a positive angle represents a tangent line sloping *downwards* towards the anchor.

Low-Frequency Dynamics Module Output Notes

Output generated during and after execution of the Low-Frequency Module of the Simulation is presented in Output Sections II through VI.

Output Section II (MEANOUT)

The "Equilibrium Condition Summary" characterizes (1) the user-specified quiescent (zero-environment) condition and (2) the mean condition in the specified environment. In the event that the user-specified line tensions, fairlead positions and plan-view departure angles do not result in a condition of zero net force and moment on the system, the Simulation will report (1) the user-specified conditions and (2) a Simulation-corrected pretension and line departure angle profile which *does* result in a condition of zero net force and moment. Note that strictly speaking, the "mean" line loads discussed in this document are not actually mean loads in the sense of being a time average of a variable line load. Rather, they are the loads associated with the mean environmental forces. This distinction is only important when the system becomes highly nonlinear, as it may under conditions of large mean tensions or static offsets. Then the typical line load time history becomes strongly antisymmetrical about its time average value and the position associated with the mean force is no longer equal to the mean (time-averaged) position. See pages 22 and 54.

Note: Simulations for which vessel "pull-down" (resulting from the development of vertical mooring forces during offset) is an important design variable (e.g., Sparsim and TLPsim), the "Z Displacement" values in MEANOUT will be non-zero and there will appear quasi-static "Trim" and "Heel" Displacements in addition to a "Yaw Displacement". Simulations for which pull-down is considered negligible (e.g., SPMsim and Moorsim) will show a "Z Displacement" of zero and will display no Trim or Heel values (which are assumed to be negligible in that context).

Output Section III (LOWOUT): The "Vessel and Environment Summary" documents most important vessel and environment data specified by the user during input file preparation. The single exception is that the significant wave height given, as indicated, is a computed value. It will normally be close, but seldom exactly equal, to the requested value. This is discussed further in Chapter 5.

Output Section IV (LOWOUT)

The "Static Equilibrium Summary" presents a description of the most stable equilibrium of the system found by the Simulation for the prescribed external and user-specified fixed forces.

- "Vessel heading" and "Fairlead centroid Global displacements and offset directions" are reported in the same global coordinate system in which wind, wave and current directions were defined. For purposes of interpreting these data, a coordinate system centered on the fairlead centroid with x-axis pointing towards the 0 degree point is used. In this system a vessel heading of 90 degrees would correspond to the vessel bow pointing towards the positive y-axis.

- The "Environmental forces" breakdown shows contributions to total environmental force arising from wind, waves and current. It should be noted that these forces are resolved in vessel-fixed coordinates in which the x-axis coincides with the centerline of the vessel, positive forwards, y positive to port; all static force calculations are carried out, and reported, in the vessel-fixed frame.

- Any user-specified fixed forces and moments are likewise summarized.

Output Section V (LOWOUT)

The "Low-Frequency Dynamics Summary" documents the low-frequency performance of the system in the specified environmental conditions. Performance is quantified by the characteristic periods and damping of the system normal modes on the one hand, and the degree of motion experienced in the given conditions on the other. The individual contributions to system damping and excitation are estimated and broken out separately. Although most of these items are self-explanatory. Generally speaking, only the three plan-view degrees of freedom are represented in this section (surge, sway and yaw). However, for simulations in which substantial low-frequency pitch and roll are encountered (Sparsim, for example), additional summaries will appear for each of these angular degrees of freedom.

Low-Frequency Oscillation and Damping

- The natural periods of low-frequency motion in the moor are computed by the Simulation from the inferred static restoring force characteristics of the moor and by the mass and hydrodynamic added mass properties of the vessel.

- Research on damping of slow oscillatory motions of large vessels in still water indicates that there exists an approximately linear damping

under these conditions, possibly related to the incomplete development of a turbulent boundary layer.

- Wind and current, although associated with square-law fluid forces on the vessel, actually produce approximately linear damping of low-frequency motions except in the limit of very small wind or current speed, where their effect can usually be neglected in comparison with other important damping sources.

- The damping of low-frequency oscillations includes contributions due to second-order and third-order wave interactions (wave drift force, AKA wave "reflection" and wave "absorption" or "dissipation" or "drag"). As a result, the "linear" wave damping contribution will depend upon the wave height, spectrum and vessel mean orientation, but will be independent of the magnitude of the low-frequency oscillations themselves.

- Wave-frequency line motions produce damping of all low-frequency modes. This effect contributes an approximately linear component to low-frequency damping in the limit of a small wave-frequency/low-frequency motion amplitude ratio, even though the damping itself arises from square-law drag forces opposing wave-frequency line motions. It is frequently the dominant contributor to damping of low-frequency motions.

- Linearized square-law line damping arises from square-law energy dissipation by the mooring lines as the vessel undergoes low-frequency oscillations in the moor. This contribution exists even in the absence of wave-frequency vessel motions; that is, the Simulation would produce a nonzero value for this damping even in the absence of irregular wave excitation. This is a true nonlinear damping contribution whose magnitude will depend on the level of low-frequency motions and must therefore be determined self-consistently with the motions (producing, by an effective linearization scheme, an environment-dependent "linearized" damping coefficient). This is in contrast to the "true" linear damping contributions, which are independent of motion levels. This contribution is generally quite small in normal environmental conditions.

- Linearized square-law hydrodynamic damping arises from square-law hydrodynamic form drag on the vessel as it undergoes low-frequency oscillations in the moor. This contribution is independent of current-associated linear damping, although it is related to it. Like the linearized square-law line damping discussed above, this is a true nonlinear damping effect which must be determined self-consistently with the vessel motions to produce an "effective" damping coefficient. This contribution is frequently negligible.

- Net damping is a simple algebraic sum of individual damping contributions.

- The characteristic low-frequency motions due to combined effects of variable environmental forces are reported, as are contributions from individual variable forces. Here and elsewhere "sigma" refers to the

root-mean-square (RMS) value of a fluctuating variable. For processes exhibiting a Rayleigh amplitude distribution, two sigma is approximately equal to the "significant single-amplitude" deviation of the variable, or the average of the one-third largest "single-amplitude" excursions in a period of time containing many oscillation cycles. "Double-amplitude" values are twice the "single-amplitude" values. Note that variable environmental forces are presumed uncorrelated. Thus the total RMS motion is the square root of the sum of the squares of the individual contributions. Because of the nonlinearity of catenary-based mooring systems, the low-frequency variations about the mean are *not* necessarily symmetric; the vessel often moves further *into* the mean environment than *away* from it when measured from the mean offset point. This asymmetry is captured in the Simulation by providing motion components that both *increase* and *decrease* the mean offset. These values are *signed*; positive values increase the mean offset, negative values decrease it. Note that a similar, but unrelated, motion asymmetry arising from the non-Gaussian nature of slowly-varying wave forces is discussed in the next sub-section.

Treatment of Non-Gaussian Wave Processes

One of the great simplifications of offshore engineering work is that many of the underlying stochastic excitation processes (wind, current and first-order wave forces) are Gaussian in nature, or at least approximately so. Unfortunately, this simplification does not extend to the higher order wave drift forces (both reflective and dissipative), whose statistical character is decidedly non-Gaussian by virtue of their nonlinear dependence on wave amplitude.

Another widely-utilized simplification holds that low-frequency oscillations in the moor can often be treated, at least to a first approximation, as lightly damped processes. It is a fundamental feature of lightly-damped oscillatory systems that the response of such systems is approximately Gaussian regardless of the statistical nature (i.e., Gaussian or not) of the excitation. (This powerful result arises from the Central Limit Theorem.) Engineering inferences flowing from this approximation naturally become progressively less satisfactory as damping levels rise from vanishingly small values towards criticality.

Most (perhaps all) "frequency domain" analytical treatments of the response to variable wave forcing of moored offshore platforms utilize this "lightly damped" approximation to simplify estimates of low-frequency system oscillations. An unavoidable consequence of this simplification (at least for mooring systems with approximately *linear* force-versus-offset characteristics such as might be encountered in moderate to deep water) is that oscillation amplitude predictions, including "characteristic" and "extreme", are *symmetric* about the equilibrium point; that is, the extreme maximum and minimum offsets lie equidistant from the mean offset. However, the level of damping commonly encountered in offshore designs is not always "light"; system low-frequency damping levels of 25% to 50% or even greater are common. For such systems, the "lightly-damped" simplification is inadequate.

The SeaSoft simulations do not utilize the "lightly-damped" model, but rather implement a robust non-Gaussian response model that gives moderate-to-heavily damped systems a realistic (and asymmetric) response characteristic. The signature of this model is that in a waves-only environment, low-frequency extremes of the "principal" normal mode (i.e., "surge") in the "down-wave" direction will, for moderate damping levels of approximately linear mooring systems, be noticeably larger than the extremes in the "up-wave" direction.

It should be noted that the oscillation asymmetry arising from *mooring nonlinearities* discussed in the previous subsection is unrelated to the asymmetry due to *non-Gaussian excitation forces* discussed here. [It is interesting to note that these two asymmetries work in opposite directions: the mooring asymmetry biases towards larger oscillation amplitudes in the direction of the quiescent equilibrium point, while the non-Gaussian asymmetry biases towards larger oscillations in the direction *away* from quiescent equilibrium. Therefore, depending on the interplay between mooring nonlinearity and non-Gaussian system response, the *net* asymmetry may favor either direction, or the oscillations may be nearly symmetric due to cancellation of these two asymmetric contributions.]

Moorsim & SPMsim: Low-Frequency Dynamics Differences

Moorsim and SPMsim differ considerably in their treatment of low-frequency oscillations in the moor. While Moorsim relates to spread-mooring systems, SPMsim relates to "single-point" mooring systems, principally turret-moored vessels. For turret and other single-point systems, the three low-frequency degrees of vessel freedom (surge, sway and yaw) can be approximately characterized by three normal modes comprising a "surge" mode lying in a plane defined by the equilibrium offset vector of the mooring point (i.e., of the turret) and two coupled "sway-yaw" modes. This classification, which depends specifically on the single-point nature of the mooring system, requires a different low-frequency dynamical model than spread-mooring configurations of the type simulated by Moorsim. This difference is reflected in the terminology used in low-frequency normal mode descriptions. Moorsim considers small amplitude low-frequency oscillations about the mean position to be comprised of pure uncoupled surge, sway and yaw motions, each with their own mooring-system dependent restoring characteristics, while SPMsim, as noted, treats low-frequency motions as normal modes which are composites of surge/sway/yaw components. (See also page 22 ff.)

For bow-resident turret installations, the high sway/yaw mode produces nearly a pure yawing motion about a point aft of the vessel c.g.; similarly, the low sway/yaw mode is reasonably close to a pure swaying motion. This similarity leads to some looseness in terminology; in particular the quoted "sway" motion for the SPMsim "low sway-yaw mode" is the sway (that is, the lateral motion of the vessel center of mass) associated with the low sway-yaw mode oscillations; the quoted "yaw" motion for the "high sway-yaw mode" is likewise the yaw (the angular motion of the vessel centerline in plan view) associated with the high sway-yaw mode oscillations.

Surge Mode   *Low Sway-Yaw Mode*   *High Sway-Yaw Mode*
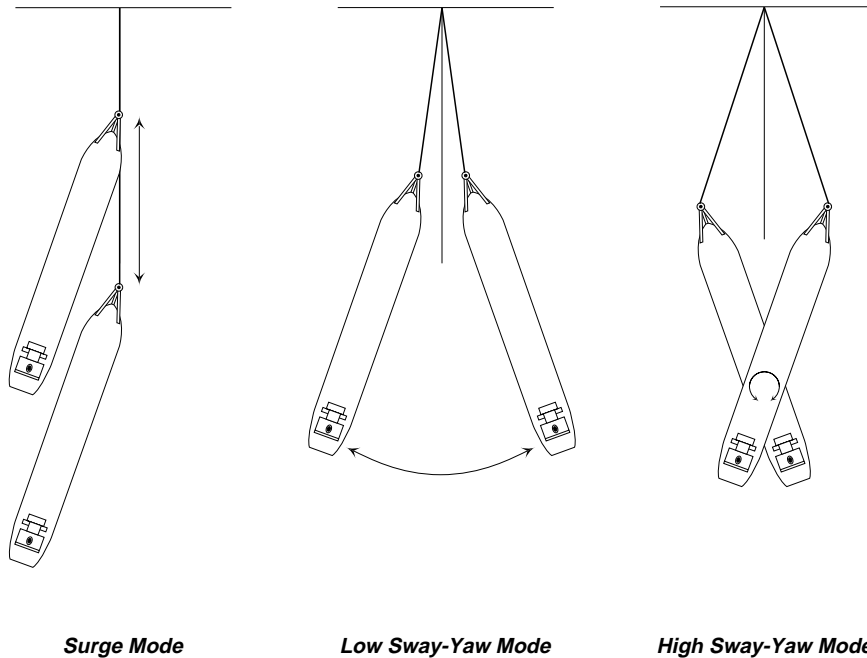
Output Section VI (LOWOUT)

The "Low-Frequency Maximum/Minimum Line Loads Summary" displays in tabular form the maximum and minimum "characteristic" and "extreme" line loads and related line characteristics associated with the low-frequency components of vessel motion. That is, wave frequency load variations are ignored in this portion of the output stream (although wave-frequency line motions *are* used in order to properly characterize low-frequency system damping, as discussed above). Note that these max/min values will not in general occur at the same time in all lines; for example, the "exposed" forward lines will experience their maximum low-frequency tension values at roughly the same time the aft lines experience their minimum values. In order to provide a complete picture of the state of both the individual lines and the vessel as a whole, load summaries have therefore been produced in three ways (see page 48 ff for related wave-frequency and composite wave-frequency, low-frequency discussion):

- In order to provide the statistical information relevant to each *individual* line (i.e., a statistical summary of data obtained from low-pass filtered load cells mounted on each fairlead) we give "low-pass load cell"-type summaries providing the "n-sigma" and "extreme" low-frequency loads experienced by each line individually. As mentioned above, the peak values so quoted will *not* occur at the same instant in time for all lines because some lines will be "taut" when the opposing lines are "slack". "Maximum" and "minimum" values, corresponding to the "taut" and "slack" side of each line's cycle, are given for both "n-sigma" and "peak" load measures.

- "Line Load Snapshots" are provided that tabulate the quasi-static state of each line at *a particular instant* corresponding to certain vessel "extreme turnaround" points reached during its low-frequency meanderings; these points correspond to maximum and minimum net

low-frequency Fx and Fy mooring forces (i.e., longitudinal and transverse to vessel centerline).

- Finally, the *net* quasi-static mooring loads and moments acting on the entire vessel at various "Maximum Load", "Minimum Load" and "typical n-sigma potential energy points" are provided.

Note: Although the "Maximum" and "Minimum" storm extreme turnaround points are reasonably well defined, the "n-sigma" points are not, rather there is an "n-sigma" surface in the 3-D surge, sway and yaw configuration space (see discussion below) surrounding the mean offset point. The points selected for output display in this section are simply representative samples of points on the "n-sigma" surface. See page 48 ff for a related discussion.

All low-frequency associated maximum/minimum values are derived quasi-statically; that is, vessel motions are evaluated and the *static* force versus offset tables are used to determine the resulting loads and other line characteristics. This approximation is valid provided that hydrodynamic square-law loads on the lines remain small compared to gravitational or elastic loads, a condition that is normally satisfied in the low-frequency regime for realizable amplitudes and periods of vessel motion.

The "characteristic" line loads, sometimes referred to as the "n-sigma" loads, comprise either one or two standard deviation (sigma) values, at the user's discretion. "Storm extreme" loads are loads associated with the most probable extreme low-frequency vessel offset in a storm of the specified duration. In synthesizing net load estimates from the various contributions to low-frequency motions (wind, waves, current), the excitations are assumed to be statistically independent; the resultant vessel normal mode motions are assumed to be uncorrelated.

Wave-Frequency Dynamics Module Output Notes

There are an overwhelming number of options for analyzing wave-frequency and composite (static plus low-frequency plus wave-frequency) system performance. We wish to begin the discussion of these options with a piece of advice: Until you are *very* comfortable with the wide-ranging discussions and explanations presented below, you should limit your analysis tools to RANOUT sections XI and XII and the net vessel load summaries in SNAPOUT. The RANOUT stream will depend upon the peak load synthesis algorithms discussed on page 115 ff; even these should be restricted at first to intuitively comfortable options such as the "upper" bound option. As you gain experience, you can experiment with the more esoteric possibilities.

Physical Overview

It is important to establish some common language for the understanding of vessel and line performance estimates produced by the Simulation. The "Wave-Frequency Dynamics Module" performs two central tasks: (1) the evaluation of wave-frequency motions and associated line loads for each fairlead (found in DYNOUT) and (2) the combination of these wave-

frequency estimates with low-frequency estimates from the "Low-Frequency Dynamics Module" to produce composite load estimates built up from the contributions of all three frequency regimes (statics, low- and wave-frequency); these composite estimates can be found in RANOUT, SNAPOUT and XCLDAT. The first of these tasks is carried out by estimating linear and nonlinear "RAOs" for fairlead motions and loads; because of the nonlinear nature of mooring forces, these "RAOs" must be computed for each fairlead at a specific fairlead location as the vessel undergoes its low-frequency surge, sway and yaw motions in the moor. This is necessary because important line variables, such as the vertical tangent angle at the fairlead (i.e., the "scope") changes as each fairlead moves towards and away from its anchor. This purely geometrical change in each line, caused by low-frequency vessel motions, combined with the strong nonlinearity in the wave-frequency line dynamics model, means that wave-frequency tangential motions and the resulting wave-frequency line load variations are a strong function of instantaneous fairlead position as the fairlead wanders about during the complex low-frequency motion of the vessel. Fairlead locations of specific interest (the "cardinal" locations for each fairlead) are the "mean", the "n-sigma" and the "storm extreme" (or, simply, "extreme"), each location being characterized by a particular fairlead-anchor distance.

Notes:

- The line load "RAOs" presented in DYNOUT are not RAOs in any literal sense, but the terminology is convenient since they are complex quantities having an amplitude *and* phase.

     (1) They are *not* scaled by the input wave amplitude. That is, the load amplitudes quoted are in kips (or metric tons) and *not*, for example, in kips/ft of wave amplitude. The amplitude of a *linear* variable, such as vessel heave, displayed in the same manner, would double with a doubling of the wave amplitude.

     (2) They are not even RAOs in the sense that they represent load *variations;* a normal RAO is the *variable* part of a quantity which might be oscillating about a nonzero mean value. For these load RAOs, the amplitudes quoted *include* the mean line tension.

- Here and elsewhere, the "characteristic" or "n-sigma" offset refers to either the "one-sigma" or "two-sigma" value (i.e., one or two times the RMS value, depending upon the choice of "characteristic" variation level; see page 115 ff).

- We can talk of "cardinal" locations (mean, n-sigma, extreme) for each fairlead *individually* as well as for the vessel as a whole; these various cardinal locations are generally unrelated. For example, the vessel could be at an "extreme" offset point (represented by its extreme potential energy surface; see discussion below) at an instant in which only *one* fairlead, *or possibly none at all*, was at an extreme distance from its *individual* anchor.

The Surge-Sway-Yaw Configuration Space

A useful mental construct and visualization aid for understanding low-frequency vessel performance and the interplay of low- and wave-frequency dynamics is the surge-sway-yaw "configuration space", a three-dimensional "hyperspace" whose three axes [x, y, z] represent the *low-frequency* surge, sway and yaw of the vessel. The coordinate (0,0,0) corresponds to the mean vessel offset position and orientation. Any point in the space represents uniquely a low-frequency offset (lateral and yaw) of the vessel from its equilibrium point (the origin). During the vessel's low-frequency meanderings, the point representing its instantaneous low-frequency surge, sway and yaw values moves about in this configuration space.

The Mooring Potential Energy

The surge, sway and yaw combination can be characterized by the system potential energy (derived from mooring system statics plus mean environmental offsetting forces and moments) associated with each point in the configuration space; many combinations of surge, sway and yaw can produce the *same* potential energy value. To plot the potential energy as a function of surge, sway and yaw would require a 4-dimensional graph, so we cannot easily display an example. However, concentric "surfaces" of constant potential energy can be drawn in the three-dimensional configuration space in order to identify the family of surge, sway and yaw combinations that produce a particular potential energy value.

Note:

• These energy surfaces will be ellipsoidal in shape near the origin, but will become distorted in general by mooring nonlinearities as we go to large offsets in configuration space; these surfaces will all have their centroids at the origin, since this is by definition our zero of potential energy. If we restrict ourselves for simplicity to zero low-frequency sway and yaw (this confines the vessel to remain on the *surge axis* of configuration space, with both sway = yaw = 0), we can plot a single 2-dimensional slice of the 4-dimensional potential energy function; this is the familiar surge-energy curve which is approximately a parabola with minimum at the environmentally-determined mean position and orientation.

Of particular importance to designers and system analysts are the "n-sigma" ("characteristic") energy surfaces and the "extreme" energy surface which bounds the possible surge, sway and yaw motions for a particular environment and environmental duration. The "mean" energy surface is of course the single point at the origin representing the mean vessel offset in the specified mean environment. The "characteristic" and "extreme" mooring potential energy conditions can evidently be met by an infinite combination of surge, sway and yaw values since these energies are represented by continuous surfaces in configuration space.

Note:

• The "extreme" potential energy surface corresponds to the locus of all "vessel extreme turnaround points"; these are the points where vessel potential energy is at a maximum (and its kinetic energy reduced to nearly zero) as it "reverses course" in configuration space to move back towards the mean position.

It *is* possible to choose a single "worst" or "design" point out of the infinite family of points in configuration space lying on the "extreme" energy surface. This is because there is a *special curve* (the "design deadman's curve") in configuration space that identifies the surge, sway and yaw combinations on each energy surface it penetrates which, of all the points lying on that surface, produces the *largest individual line load*. This is evidently a curve of some importance since it is most likely that near this curve the first line failure would occur during a storm, assuming all lines are equally strong. The curve goes through the origin and for normal mooring configurations is a relatively straight line in the approximate direction of the *mean* offset (remember that our origin is *at* the mean offset point, so we need to look back to earlier static offset information to determine this direction in configuration space. For single point moors, the equilibrium yaw can always be taken equal to zero so the tangent angle to the "deadman's curve" at the origin is equal to the "plan-view offset angle" reported in MEANOUT (or the "Fairlead centroid Global offset direction" reported in LOWOUT). For simple mooring layouts and suitably aligned environments, the "deadman's curve" will continue as a perfectly straight line all the way out to the extreme energy surface, puncturing it at the "worst" combination of surge, sway and yaw with respect to individual line failure.

Notes:

- A similar curve can be imagined for *any other* design parameter, for example the "maximum load in line #2". In fact, the "deadman's curve" for each line is used for establishing the "n-sigma" and "extreme" motions and loads for *individual lines*; see the discussion further below. (The "design deadman's curve" is normally the curve associated with the "most loaded line", i.e., the line with the highest mean load in the specified environment.) Other design parameters that merit mention are "global" parameters relating to the vessel as a *whole* rather than a single line. In this category are the "maximum total mooring load", "maximum turret moment", etc. In most practical circumstances, these various "global" definitions of the deadman's curve will lead to approximately the same design decisions as the "most loaded line" curve, which we will continue to refer to as the "design deadman's curve".

- The reflection through the origin of the "deadman's curve" is the beginning of a second curve, leading in the opposite direction, which represents the locus of *smallest* maximum individual line loads. We might call this the "blessed curve"; along it the likelihood of line failure is at an absolute minimum. This curve will normally pass from the environmentally-determined mean offset point (the origin of our configuration space), through the *zero environment* equilibrium point and "out the back" in a direction approximately opposite to the mean environmental force (or offset). This curve will also penetrate the extreme energy surface at a single point, but *this* point is of relatively less interest since the mooring loads at this point are in general relatively modest. However, the intersection of the "blessed curve" and the n-sigma and extreme energy surfaces are also important "cardinal" points which help to establish a complete picture of the load history on the vessel and the individual mooring lines.

- It is important to distinguish between (1) the "constant energy surfaces" used in this discussion, which include potential energy contributions from *both* the mooring system and the constant mean environmental forces, and (2) the potential energy surfaces associated with the mooring system *alone*. The latter surfaces center on the *zero environment* equilibrium point, while our energy surfaces center on the mean offset point in the specified environment. These two surfaces are obviously simply related.

The Wave-Frequency Output Stream

The simulation wave-frequency output stream DYNOUT.stxt consists of two types of output; line-oriented and vessel-oriented:

1. Mooring line motion and load data taken at selected fairlead locations (the "cardinal" locations) in the low-frequency offset space of each *individual line.* These locations are set by the user choice of "Line peak load calculation treatment" (see Page 115); possibilities include the mean, "n-sigma" and extreme low-frequency *individual fairlead* offset points that would lie on the "deadman's curve" for each individual line in the vessel configuration space.

Note:

The line-oriented RAO tables in DYNOUT (and also the wave-frequency statistical motion/load summaries in RANOUT) for line 1 are valid at a *different* time during the low-frequency oscillation cycle of the vessel than those for lines 2, 3, etc., since each fairlead achieves its "characteristic" or "extreme" offset at a different time in general. In terms of our configuration space discussion, as the point representing the instantaneous state of the vessel travels around configuration space, it crosses (or passes near) the "deadman's curve" of different lines at different times since these reside at large angular separations from each other (each of these departs the origin in an (x,y) direction approximately opposite to its line departure angle).

2. Net Vessel Mooring Load RAOs taken at the vessel's *mean* environmental offset position and orientation. Additional net vessel load information can be found in SNAPOUT (see below).

Note:

These vessel load RAOs are the phased sum over all fairleads of the total mooring force and moment (valid at the *same* time for each line during the low-frequency oscillation cycle), while the statistical composite loads are combinations of the low- and wave-frequency contributions taken in the statistically appropriate manner.

Output Section VII (DYNOUT): The output presented in these "nonlinear line load RAO" tables is potentially enormous in volume and, to the beginner, bewildering because of the sheer volume of data. The information is nonetheless extraordinarily valuable in understanding details of mooring line performance in a complex mixed low-and wave-frequency dynamical environment. Understanding these tables is work, but is worhwhile.

The tables provide (1) the (approximately) *linear* fairlead wave-frequency motion response parallel and perpendicular to the line tangent at each requested fairlead and (2) the highly *nonlinear* wave-frequency line load response at the fairlead and anchor. Although we present line load response in the format of an "RAO" for convenience, it must be remembered that the load responses are *highly* dependent on the assumed regular wave amplitude, *unlike* fairlead motion RAOs which are virtually independent of wave amplitude because of their approximate linear response behavior. The strength of this dependence can be visualized by doing two simulation runs, changing *only* the regular wave height (see page 102 ff) and comparing the line load RAOs for the two runs.

The following points should be noted:

• Line load RAO tables will be produced for each line chosen for "dynamic evaluation" (see page 66) and for each required wave direction involved (this can include up to 36 wave directions if swell and "azimuthal spreading" are selected and all intermediate angle RAOs have been requested for output). (See page 104 ff.) In the case of a 48 line system, the possible number of RAO output tables is over 12,000! Obviously, some thought needs to be given to output control.

• For each specified line and each wave direction, the *first* set of RAOs produced are for cardinal fairlead positions set by the user's choice of "line peak load calculation treatment" (see page 115 ff). The fairlead offset point for each RAO table is clearly indicated in the "Notes" at the top of each RAO output page. A "road map" of these RAO evaluation points as a function of "line peak load calculation treatment" follows:

> For the SeaSoft "*lower* bound" algorithm, line load response RAOs are given for each line about its own *mean* low-frequency offset point. In this case, all RAO tables can be said to apply to a "snapshot" taken whenever the vessel (and therefore each of its fairleads) is at its mean low-frequency offset point as it oscillates to and fro in its low-frequency motions.

> For both the SeaSoft "*upper* bound" algorithm *and* the API "peak LF, n-sigma HF" algorithm, line load response RAOs are given for each line about its own *extreme* low-frequency offset point. In this case, it should be clear that all RAO tables can *not* be said to apply to a "snapshot" in time since each line achieves its individual low-frequency offset at a different time as discussed earlier. For example, the *most* exposed lines achieve their *maximum* low-frequency extension at the same instant that the *least* exposed lines achieve their *minimum* extension. For both the API "n-sigma Low-Frequency, peak High Frequency" algorithm *and* the SeaSoft "n-sigma LF, peak HF" algorithm, line load response RAOs are given for each line about its own n-sigma low-frequency offset point. Again, it should be clear that these tables will *not* apply to a "snapshot" in time.

For the SeaSoft "full joint probability distribution" algorithm, there is no "special point" in the low-frequency offset space of each fairlead and a "first" set of fairlead RAO data analogous to the other "line peak load calculation treatments" is not produced.

- There exists a delicate interplay between peak wave-frequency loads and the fairlead "cardinal" position about which the wave-frequency oscillations are taken. As the fairlead offset (and hence "mean effective line tension") increases, the line departs the fairlead at an ever shallower angle; since most fairleads are far from the vessel centroid, the *vertical* motions (a phased superposition with contributions from pitch, heave and roll) are generally much larger than the *horizontal* motions. Since it is fairlead motion tangential to the departing line which is most effective in exciting tension oscillations, it is possible in some circumstances that *increasing* the mean tension will lead to a *reduction* in the peak wave-frequency load; this could even lead to a reduction in the static, wave- and low-frequency *composite* load. This effect is easily demonstrated; as a consequence the "upper-bound" algorithm does not necessarily *always* produce the largest loads in *every* line, although it will normally produce the largest load in *the most exposed line.* (See page 54 ff and page 115.)

- The component of fairlead motion *normal* to the line tangent does not contribute to wave-frequency mooring load estimates; its value is given for reference purposes only.

- The *minimum* fairlead line loads can become small but cannot go to zero unless fairlead acceleration levels become comparable to one "g", a situation that should never develop in practice. The situation at the anchor is different; the anchor-end tension can rather easily go to zero under realizable conditions, *even in the absence of bottom friction*.

- Phases for regular wave input excitation are chosen so that zero phase angle corresponds to a wave elevation maximum at the vessel centroid; a positive phase angle corresponds to a phase lead. For "line extension" input excitation, phases are relative to the extension; zero phase occurs at maximum extension away from the anchor. (See also page 101 ff.) Because the time history of line load response to regular wave input is distinctly nonsinusoidal as a consequence of the strong nonlinearity of the dynamics, the meaning of "phase" needs to be clarified: here it simply specifies the timing of the occurrence of the *maximum* load value in the periodic (but nonsinusoidal) load history relative to the wave crest at the vessel centroid.

- The wave length and slope reported in columns two and three of the output tables fully reflect the effects of shallow water.

- The following terminology appearing on the regular wave response output pages should be noted:

  - am/phase: amplitude/phase of a complex quantity.

- s.a./s.a.: refers to the fact that all *dimensionless* RAOs are in terms of "single amplitude" motion divided by "single amplitude" wave elevation (or "wave amplitude"). S.A. Load RAOs simply relate to load peak values as contrasted with peak-to-trough differences.

• Section VII has output tables for each line/wave angle combination at both fairlead and anchor.

Output Section VIII (DYNOUT): The "Dynamic/Static Line Load Comparison" containing "Quasi-Static Load Data", is presented to establish a baseline for dynamic load comparisons: The purely *static* response of the lines to the fairlead oscillations. These "Quasi-Static" loads are computed using only the static offset tables for each line, along with the instantaneous fairlead location. That is, no hydrodynamic or line inertial effects are included in this data. For very small amplitudes or very slow fairlead velocity, the quasi-static load data will closely approximate the fully dynamic data.

Output Section IX (DYNOUT): These tables contain *net vessel load and moment* "RAOs" which comprise the properly phased *sum* of contributions from individual lines. These RAOs, too, are nonlinear, although as a consequence of the averaging effect they are more nearly linear than the individual line loads themselves.

Notes:

• These tables are presented only for the mean vessel offset point, for each required wave direction.

• These net vessel "RAOs" suffer from the same formal deficiencies noted in the single-line RAO discussion above.

Composite Wave- and Low-Frequency Output Notes

Comparison of RANOUT and SNAPOUT

RANOUT and SNAPOUT are nearly identical in the *variety and format* of their output pages but present different types of data; they can therefore be confusing at first. RANOUT's output relates to the "deadman's curve" for *each individual line* discussed in detail on page 47 ff. That is, the data provided in RANOUT relates *not* to a snapshot in time but to different times for different lines, producing thereby the characteristic and peak load values that would be measured by a local strain gauge operating for a long time and ignorant of the state of the other lines or the position of the vessel. SNAPOUT, on the other hand, provides statistical summaries relating to *snapshots* in time taken at cardinal locations in the vessel's low-frequency oscillation space. Thus, for example, the "peak load" estimate for the "least exposed" mooring line (the line with the lowest *mean* load) in RANOUT will usually be higher than the estimate from SNAPOUT corresponding to a "storm-extreme vessel turnaround point", because at half of the turnaround points of interest, the "least exposed line" is slack relative to its "more exposed" sibling lines.

Note:

RANOUT is the output of choice whenever *single-line* performance information is paramount and SNAPOUT is the output of choice whenever *net* vessel mooring loads and moments, which require a snapshot analysis of all lines simultaneously, are the focus of interest.

Output Section X (RANOUT & SNAPOUT):

This is an alternative (and infrequently-used) output format for presentation of *wave-frequency* fairlead motion and line load statistics that *neglect low-frequency variations* by computing wave-frequency load statistics about one of the several possible cardinal locations, including (1) the mean offset, (2) points associated with the one or two standard deviation low-frequency offsets, and (3) the peak low-frequency offset point associated with a storm of the specified duration. Section X output format focuses on individual lines, with information specific to a single mooring line given its own page of output.

RANOUT Section X:

Output section X is produced in RANOUT, when requested, *only* for the *single* cardinal fairlead point determined by the user's choice of "line peak load calculation treatment" (see page 49 ff). The statistical summaries therefore apply at a different vessel location (and, possibly, orientation) for each line.

SNAPOUT Section X:

While cardinal point data referred to *individual fairleads* is given in RANOUT Section X, single-line data taken at the "n-sigma" and "storm-extreme turnaround" cardinal points referred to the *vessel* are given in SNAPOUT Section X. With one minor exception, the output in SNAPOUT is *independent* of the user's choice of "line peak load calculation treatment". The sole exception is in the quoted fairlead, anchor and vessel "extreme" or "peak" loads. The peak load estimates differ between certain "line peak load calculation treatments" because only *two* of those peak load algorithms accommodate the statistical notion of "exposure time":

Briefly, the likelihood of *coincidence* of a "peak wave-frequency event" and a "peak low-frequency event" is reduced by the simple fact that the vessel spends only a small portion of its time near low-frequency "extreme" points. Experimentation will show that the "SeaSoft lower bound" and the "SeaSoft two-sigma LF, peak HF" algorithms give the same "peak snapshot line load" estimates; these estimates are generally *lower* than the peak snapshot loads estimated by the related "API two-sigma LF, peak HF" option because these two "SeaSoft" options alone recognize the reduced exposure time for the occurrence of coincident low- and wave- frequency peak events. The API algorithms (and the SeaSoft Upper Bound Algorithm) ignore this reduction in exposure.

Note:

The reported "most probable peak load" values here and elsewhere are slightly mislabeled: they are determined as the loads associated with the most probable peak fairlead *motion* amplitudes; because of the

nonlinear relationship between fairlead motions and line loads, the most probable peak load as determined from a load time history will generally be slightly larger than the reported value.

Output Section XI (RANOUT): These tables summarize Simulation estimates for the "characteristic" (or "n-sigma") line loads. The "mean" tensions reported are, as noted elsewhere, actually the static mooring loads associated with the environmentally-determined "mean offset" defined in this document; that is, they are the static loads arising from the application of the *mean environmental loads* as if they were steady forces acting on the vessel. In most cases the difference, resulting from the nonlinearity of the tension versus offset curve for catenary-elastic lines, will be small. In general, the reported "mean" tension value will be somewhat *larger* than the time-averaged tension value which might be given in a wave-basin test report, for instance. The important peak tension values, comprising the quoted mean plus low- and wave-frequency variable parts, will not be effected by this difference in definition of the "mean" values.

Notes:

- Again, RANOUT reports estimates of load cell measurements at each fairlead and should therefore be used whenever line integrity is the central focus. SNAPOUT reports refer to a line load snapshot (all lines viewed at the same time) and are provided for additional information on net vessel loads that might be useful in structural and fatigue analysis, for example.

- The "maximum" and "minimum" terminology in these tables refers to the maximum and minimum values of the one- or two-sigma variations; the "peak", or extreme maximum and minimum values associated with the storm duration are given in Output Section XII.

- The minimum anchor tensions will commonly be zero, but the minimum fairlead tensions should never vanish since this would require fairlead accelerations comparable to the gravitational acceleration, a virtual impossibility.

- The "characteristic" load values are given in two ways; (1) the *net* (mean plus variable) maximums and minimums and (2) the components of the net tension, comprising the mean tension and variable contributions from both low- and wave-frequency fairlead motions. Because the low- and wave-frequency variations are considered to be uncorrelated, the net values are simply the mean plus the square root of the sum of squares of the variable parts. Strictly speaking, this procedure, which applies rigorously only to fairlead motions, breaks down when applied to a nonlinear process such as a line tension time history. This approximate procedure is considered acceptable here because the breakdown is weak in most practical situations and the notion of "characteristic" load is a bit fuzzy in any case. The ambiguity is removed for the important peak tension predictions.

- The wave-frequency variable tension values will reflect the user's choice of "Line peak load calculation treatment" (see page 117); low-frequency variation values are independent of this choice.
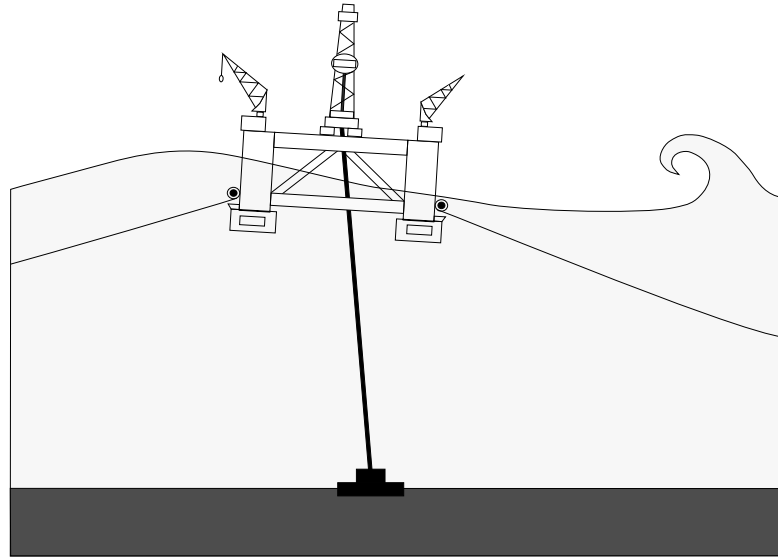
Output Section XII (RANOUT): This table summarizes Simulation estimates for the "Storm-Extreme" line loads. The mean loads are as in Section XI. The maximum and minimum values now represent Simulation estimates of the most probable peak and trough tension values for the requested storm duration. The presentation is as in Section XI except that now the maximum tension values comprise the mean plus low-frequency plus wave-frequency variable parts, rather than the uncorrelated "root sum of squares" synthesis used for the characteristic net load estimate; this procedure is a consequence of the method used to calculate the individual variable contributions.

The "line peak load calculation treatment" discussed on page 54 ff exists entirely for the benefit of RANOUT Section XII output, for it is here that the peak line load estimates which will be used for design or line failure analyses are presented. The selected peak load calculation treatment is reflected in both the n-sigma and the peak load values in these RANOUT tables.

As in Section XI, the RANOUT wave-frequency tension variation will reflect the user's choice of "Line peak load calculation treatment" (see page 117); the low-frequency variation values are independent of this choice and SNAPOUT quotations, as discussed above, are only weakly dependent.

As discussed elsewhere above, the delicate interplay between wave-frequency tension oscillations and line vertical departure angle has the consequence that the "upper bound" algorithm will not always produce the largest load estimate in every line as might be expected, although when it fails to live up to its billing, the differences in peak load estimates between the available algorithms will usually be negligible.

The peak wave-frequency load variations at the anchor end of the line are generally larger than the fairlead variations; this is a consequence of the longitudinal strain wave in the mooring line which causes load amplification

at the anchor. This effect derives from the enhancement of waves of all types as they are reflected from a rigid boundary, which reflection creates a standing wave component.

Output Sections XIII and XIV (SNAPOUT): The tables in these sections are structurally similar to those in Sections XI and XII (RANOUT), although they apply to characteristic and extreme individual line loads experienced at selected vessel "snapshot" locations visited during low-frequency meanderings. The notes above describing the difference between "RANOUT-style" loads and "SNAPOUT-style" loads are once again relevant.

The snapshot locations chosen for SNAPOUT evaluation include vessel positions and orientations in the low-frequency configuration space (surge, sway and yaw) corresponding to extreme and characteristic *net vessel* loads, including maximum (+) and minimum (-) Fy (transverse) and Fx (longitudinal) loads (as resolved in the vessel-fixed coordinate system):

- Max Fx (+) turnaround
- Max Fx (-) turnaround
- Max Fy (+) turnaround
- Max Fy (-) turnaround
- typical Two-Sigma (+)
- typical Two-Sigma (-)
- mean vessel position

Also, as discussed above under SNAPOUT section X, the choice of "peak load estimation algorithm" has only a small effect on the loads reported in this section; for practical purposes, SNAPOUT estimates can be considered to be independent of these choices.

Output Section XV (SNAPOUT): These tables summarize *net* vessel loads and moments arising from quasi-static, wave-frequency, and composite vessel motions in the moor; that is, they represent summations over load contributions from all mooring structures. They apply to the same set of selected low-frequency vessel locations indicated above.

Notes:

- The "Quasi-static contribution" refers to the *combination* of static and low-frequency loads at the indicated cardinal point.

- The "phase" of the wave-frequency portion of the net load is defined relative to the crest of a regular wave of peak wave height and period equal to the peak spectral wave period arriving at the vessel centroid. It is a *very* ill defined quantity and is provided only to give a *qualitative* indication of peak wave load timing relative to crest passage of the responsible waves.

- The loads and moments are *signed* relative to the usual vessel coordinate system.

XCLDAT Summary: The XCLDAT.stxt simulation summary is a tab-delimited text file suitable for importation into a spreadsheet program. The file contains a tabular wave-basin type summary of most dynamical variables

of interest, including means, low-, wave-frequency and total standard deviations and extremes for dynamical load and motion variables. It also contains selected wave-frequency spectral information which, along with the period, damping and standard deviation (RMS) information provided in LOWOUT, can be used to construct semi-quantitative spectral plots, spanning the entire frequency range [0, infinity], for any dynamical variable.

Irregular Wave Output Notes

The irregular wave height reported at various points in the output stream is that computed from the wave spectrum specified during the input session with the Editor. It should be close to, but seldom exactly equal to, the requested wave height. If the reported value differs by more than 10 or 15 percent from the requested value, the Simulation should be rerun with a wider range of wave periods. The most common cause of "lost wave height" is too large a minimum regular wave period. This specific circumstance is generally of little consequence to system motions or loads since short-period waves that are "lost" from the statistical analysis by this error contribute little to system dynamics.

The one (or two) sigma "single amplitude value" reported on the wave-frequency statistics output pages is, as in the low-frequency case, twice the square root of the variance of the amplitude spectrum of the motion or load. This may create some confusion since vessel motions, in particular, are often reported as "double amplitude" or "peak-to-peak". To obtain double amplitude values, simply double the single amplitude values given.

Vesselsim Output Notes

In the output stream for wave-frequency vessel motion modules (generically, "Vesselsim"), fairlead motion components are reported in a rotated coordinate system to accommodate more readily the requirements of the Simulation; vectorial fairlead motion components are in a rotated right-handed coordinate system with (x,z) in the plane of the line, z upwards along the line tangent. Point coordinates are given in the vessel system as always. This comment applies both to fairlead motion RAOs (Vesselsim Section II) and fairlead motion statistical summaries (Vesselsim Section III).

Chapter 7

Description of the Editor

This chapter is devoted to a description of the user interface to the Simulation. The interface is comprised of an Editor which is used for creation of new data files and editing of existing data files. The following pages contain printed images of most console Screens produced by the Editor, along with annotated comments regarding meaning of selected items on the Screen.

Screen images are numbered sequentially according to the order of their appearance; SubScreens that service the main Screen are indexed sequentially. Thus SubScreen 3a would be the first SubScreen of Screen 3.

General Information

The editing session is largely self-explanatory; the editing alternatives consist of several simple, fundamental types:

1. The "toggle": Many editing items are configured as toggles between two possible values; selection of these items will require no further data input from the user. For example, selection of "units of measure" on Screen 1 below will cause the selected units to toggle between "English" and "metric". All items displaying a value of "yes" or "no" are of the toggle type.

2. Single datum input: Most of the selections in the Editor require input or modification of a single item on a Screen. To change a particular item, input the item number followed by a "Carriage Return" (or "Return" or *<c/r>*) at the "Enter number of selection:" prompt. (Note: on keyboards lacking a "Return" key, try the "Enter" key instead). An appropriate prompt line requesting the new input value will appear at the Screen bottom. It is not necessary to input decimal points for floating point numbers without fractional parts (i.e. 10.0 can be input as 10). When more that one input value is required on an input line, the values should be separated by commas. A carriage return in response to a request for data will leave the current value of the data unchanged.

3. Expanded data input: For situations in which many numbers must be entered, or a choice more complicated than a simple datum input is involved, the Editor will produce a "SubScreen" subordinate to the active Screen to accomplish the input operation. For example, a SubScreen is used to permit semi-automatic input of regular wave periods for RAO evaluation, the input of which one period at a time would be laborious.

4. Screen access "Help" menu: Entering "*H*" (*without* quotation marks) at any "Enter number of selection:" prompt will produce the Help menu displayed after console Screen 1 below. These paging options, which, like the "*H*" command, can be given at any "Enter number of selection:" prompt, are designed to permit ease of access to any Screen of the Editor from any other Screen. Either upper or lower case letters can be used.

5. Help with specific items: As illustrated further below, concise descriptions of many required input items can be obtained by entering "*?n<c/r>*" at any "Enter selection number" prompt; n is the item number of interest on the current Editor Screen. Entering "*?<c/r>*" will reveal all help associated with the current Screen.

The following mechanisms for paging through the Editor should be noted: To page forward to the next sequential Screen, press the carriage return at the "Enter selection number" prompt; to page *B*ackwards to the previous Screen, enter "*B<c/r>*"; the *F*irst and *L*ast input Screens can be accessed from any numbered Screen in the Editor by entering, respectively, "*F<c/r>*" or "*L<c/r>*"; one can *S*kip a Screen by entering "*S<c/r>*" or *J*ump to Screen "n" by entering "*Jn<c/r>*" (for example, *J5<c/r>* will effect a jump to Screen 5 from any numbered Screen in the Editor).

Editor Screen Images

Note that not all possible Screen images are displayed in this chapter; the images are intended only as aids to discussion and do not portray a realistic session in its entirety.

```
        +==========================================================+
        |                                                          |
        |                                                          |
        |                                                          |
        |              **    Welcome to SPMsim    **               |
        |                                                          |
        |                                                          |
        |                  SPMsim Version 5.05                     |
        |            Copyright (C) 2004 by SeaSoft Systems         |
        |                                                          |
        |                                                          |
        +==========================================================+
 -----------------------------------------------------------------------------
 (M) Modify existing data file, (C) Create a new file, (E) Execute simulation
 Enter letter of selection: M<c/r>
```

This is the title Screen on which appears the choice to Modify (*M*) an existing data file, Create (*C*) a wholly new one or Execute (*E*) the Simulation using an existing data file. No response but *M*, *C*, or *E* (upper or lower case) will be accepted. In either case (*M*) or (*C*), an existing file found on

the logged disk with the name MOORDAT (or SPMDAT or ...) will be renamed to MOORBAK (or SPMBAK or ...) while any pre-existing MOORBAK file is renamed to LASTBAK to avoid inadvertent loss of data. A MOORDAT file containing the new data will be created on the logged disk at the end of the Editor session. Any pre-existing LASTBAK file is lost. In this way, two generations of data files are maintained to protect against inadvertent data loss. In the same way, user-input environmental coefficients, if any, reside in a binary data file LOWDAT which is loaded automatically at simulation startup if it is present. LOWDAT's first and second generation backup files (analogous to MOORBAK and LASTBAK) are called LOWBAK and LASTLOW. Appendix B discusses file management procedures.

```
                ****  Screen 1: Site conditions  ****


    Two-line Identification for this simulation:

1) [Moorsim/SPMsim Manual Sample Problem                                 ]
2) [Turret moored 150,000 DWT tanker                                     ]

3) Units of measure: English

4) Site water depth:           450.00 feet
5) Water density:               64.00 lbs/cubic foot

Enter number of selection: H<c/r>
```

See Also: pp 29   Screen 1: This Screen contains necessary site data and other miscellaneous information. Replacement of numerical data (e.g., item 4) or character string data (e.g., item 1) is accomplished by selecting the relevant numbered item and responding appropriately to the ensuing prompts. In this example, we have requested "Navigational Help" by entering "*H*" at the "Enter number of selection:" prompt; the "Help Screen" response to this action is displayed below.

```
At any "Enter number of selection" prompt:

(F)  First page
(L)  Last page
(S)  Skip ahead a page
(E)  Execute program
(B)  Back a page
(Jn) Jump to page "n"
(?)  Help summary for current page
(?n) Help on current page for selection "n"

Press <RETURN> to continue: <c/r>
```

Help Screen: This Screen contains instructions for access to various interface Screens and on-line help. The described actions are accomplished by entering the appropriate letter (uppercase or lowercase),

followed by a carriage return, at an "Enter number of selection:" prompt on any numbered Screen.

```
                **** Screen 1: Site conditions ****


     Two-line Identification for this simulation:

1) [Moorsim/SPMsim Manual Sample Problem                            ]
2) [Turret moored 150,000 DWT tanker                               ]

3) Units of measure: English

4) Site water depth:          450.00 feet
5) Water density:              64.00 lbs/cubic foot

Enter number of selection: H<c/r>
```

Screen 1: Site conditions

Item 1-2:   Two text records for documentation purposes.

Item 3:   The units of measure can be toggled between English and metric by selecting item 3. Selection of this item produces the following SubScreen:

```
     >>> Units Conversion Options <<<

1) Convert only water density and unit labels to metric units
2) Convert ALL data values and units labels to metric units

Enter number of selection ("H" for help):
```

SubScreen 1a: This SubScreen permits two types of units conversions; it appears upon selection of item 3 on Screen 1.

Item 1   With a single exception (the water density value), this item alters *only* the *displayed* dimensional units (ft <=> meters, etc.). This is generally of use only during original creation of a data file (to change to metric from the English default); this action is always perfectly reversible. That is, two invocations of this option will return an existing data file to its unaltered original state regardless of the contents of the data file.

                   Note: To convert an *existing* data file between English and metric units, use Item 2.

Item 2   This item will convert all dimensional *values* in an existing data file between English and metric units. This option should be exercised with care; several things to consider:

        • Executing this option twice will not in general reproduce *exactly* the

original data file due to floating-point roundoff errors. Thus, two "equivalent" data files (original and twice-converted) may produce slightly differing output streams.

- Using this option may compromise the usefulness of inter-simulation data file transfers. Conversions to an existing data file should in general be carried out in the originating simulation. For example, to transfer a data file from Moorsim (English) to Shipsim (metric), you should do the conversion to metric in Moorsim, then use the *converted* MOORDAT file as input to Shipsim.

  Note: The problem arises because the converted variable sets differ between simulations; for example, mooring data 'hidden" in a SHIPDAT file imported from Moorsim will *not* be properly converted within Shipsim, resulting in a data file with mixed data types. A re-import of that converted SHIPDAT file back into Moorsim will therefore be problematic, with mooring data in one set of units and vessel data in the other.

- Any user-supplied external data files (see Appendix D) that are *dimensional* must be converted separately by hand. For example, WINDSPEC.txt and CRNTSPEC.txt files contain dimensional data; if they are to be used after a units conversion, they must also be converted by the user to the correct new set of units. Coefficient-type data files (DRFTCOFS, USERRAOS, WINDCOFS, etc.) are dimensionless and are independent of the system of units employed.

```
-- Water density --

1) Seawater
2) Freshwater
3) User-specified fluid density in lbs/cubic foot

Enter number of selection: <c/r>
```

See Also: pp 29   SubScreen 1b: This SubScreen permits water density specification; it appears upon selection of item 5 on Screen 1.

```
 **** Screen 2: General Mooring Information ****

 1) Number of mooring legs (Max 16) ..............   8
 2) Number of distinct mooring leg types (Max 16)   2
 3) Maximum horizontal interpolation table load ..   1350.00 kips
 4) Smallest nonzero horizontal load .............      5.00 kips
 5) Number of points in interpolation table(s) ... 90
 6) Mean line profile determined by .............. line tension
 7) Modify individual values of line tension


 8) Default bottom friction coefficient ..........       .00

16) Reset default Anchor depth ...................    450.00 feet
17) Specify anchor depths individually ........... Yes
18) Default bottom boundary is "transparent" ..... No
19) First buoyant element remains below waterline: No
```

Screen 2: This Screen contains miscellaneous data pertaining to the overall physical description of the mooring system.

Item 1:   The number of mooring legs; that is, the total number of fairlead points. A "mooring leg" comprises the entire mooring line from fairlead to anchor. This number should include all structures simulated as "mooring legs", including risers, etc.

Item 2:   Two mooring legs are indistinguishable only if their mooring elements (sublines, buoys, etc.) are identical *and* their anchor depths and fairlead heights are the same.

Item 3:   This specifies the largest horizontal load value used in the internally computed static load versus offset tables. Generally speaking it should be comparable to the breaking strength of the weakest subline in the system, although it can take any value. Selection of an excessively large value will result in unnecessarily inaccurate interpolated values. Selection of an excessively small value may result in the table bounds being exceeded during interpolation near large offset values.

Item 4:   This value specifies the first *nonzero* horizontal load in the internally computed load versus offset tables; it thus defines the *second* row in the tables since the first row corresponds to *zero* horizontal load. It should normally be *smaller* than any anticipated quasi-static line load; a typical range comprises 0.1% to 1% of the maximum horizontal load. If this value is set exactly to zero, the Simulation will choose a reasonable default value. When buoyant elements (represented by negative values of weight/unit length) are present, table rows associated with several of the smallest values of horizontal tension represented in the interpolation table may represent unphysical line configurations (see, for example, the discussion of Item 19).

Item 5:   The number of points in the interpolation table influences the computer time required for simulation and the volume of output in the interpolation

table stream. Normally, this should be set to its maximum value (90).

Item 6:   The line profile associated with the null-environment "pretension" condition can be defined by specifying any of the following "pretension variables":

1. Vertical line departure angle at fairlead

The vertical line departure angle at fairlead is given in degrees from the horizontal; i.e., smaller angles correspond to higher pretensions.

2. Horizontal distance from fairlead to anchor

This refers to horizontal distance as seen in plan view. The facility for specifying horizontal distances from anchor to fairlead is useful for exploring the effect of changes in water depth as might occur, for example, due to the action of tides. One first executes at the nominal water depth with the desired line tension or declination angle at the fairlead. Anchor distances for this nominal condition are then used as data for a second run with the same line lengths but new anchor and water depths.

3. Total fairlead tension

4. Horizontal component of tension at fairlead.

Item 7:   Selection of this item produces a SubScreen to input the required numerical values of the chosen pretension variables.

Item 8:   The bottom friction coefficient affects tension estimates evaluated at the anchor by reducing all reported anchor loads by the weight of line lying on the bottom times the specified coefficient; it has no effect on fairlead load estimates.

Item 16:   Changes the default anchor depth for each mooring leg. When changed, the new default anchor depth will be applied to all mooring legs; anchor depths for each leg can be individually specified by setting the "Specify anchor depths individually" toggle to "Yes" and re-defining the desired anchor depths on the "Anchor" subline Screen for each mooring leg type.

Item 17:   When this toggle is set to "No", the indicated default anchor depth will be used for all anchor legs. To specify anchor depths individually, toggle this value to "Yes". Anchor depths are then set on the "Anchor" subline Screens for each line type.

Item 18:   When this toggle is set to "No", the normal solid-bottom condition applies; that is, in the absence of uplift at the anchor, there is line lying on the ocean bottom. When the toggle is set to "Yes", the bottom is "transparent"; that is, the line is allowed to hang from the anchor as if there were no bottom. This feature is normally used in conjunction with individually set anchor depths for mooring to towers or docks

where the bottom boundary is absent. The boundary condition for individual line types can be set on the "anchor" SubScreen.

Item 19:   When this toggle is "Yes", the *first* (if any) buoyant element in each line type (i.e., the closest to the fairlead) is restricted to lie at or beneath the water surface; this capability is provided to permit analysis of surface-resident "spring buoys" common in some offshore terminal applications. When this toggle is "No", the water surface is "invisible" to *all* buoyant line elements. This can, in some cases, result in a simulated buoyant element positioned *above* the waterline, a physically impossible condition which nonetheless may be useful in special situations.

```
 **** Screen 3: More General Mooring Information ****

 1) Number of mooring legs associated with each type --
    6 in Type A      2 in Type B

 2) Number of sublines associated with each type (max 10) --
    2 in Type A      1 in Type B

 3) Edit fairlead positions
 4) Edit plan-view line departure angles

 5) Edit mooring moment evaluation center

 6) Vessel x-coordinate of turret centroid:   500.00 feet
 7) Vessel heading in quiescent conditions:      .00 Degrees

10) Number of excluded or broken lines:  0
```

Screen 3: This Screen contains additional miscellaneous data pertaining to the overall physical description of the mooring system.

Item 1:   The number of mooring legs associated with each physically distinct line type must be given. These values must sum to the correct total number of lines or an error message will be displayed. Recall, two line types are distinct if the anchor depth, fairlead height or any subline differ.

Item 2:   The number of sublines associated with each distinct line type must be specified. The maximum value applies *not* to the total number of sublines but to the number of sublines in each line type. Buoys and clump weights should be counted as sublines; a single mooring leg broken in the middle by a spring buoy would therefore require a minimum of 3 sublines for proper specification.
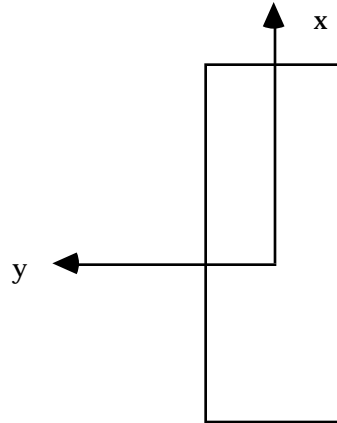
Item 3:	The vessel coordinate system, which is used to define fairlead locations in space, is a right-handed system with x pointing towards the bow and y to Port (left when facing forwards). z is positive upwards, measured from vessel keel. The plan-view origin of coordinates is at the vessel plan-view centroid (c.g., Lpp/2, etc. See Page 13.).
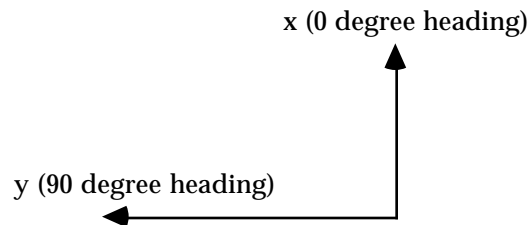
Item 4:	Plan-view line departure angles are defined in a "right-handed" earth-fixed ("Global") coordinate system with z positive upwards. The zero of angle is in the positive x direction; angles increase in a counter-clockwise direction. Thus, 90 degrees lies along the positive y axis. With a vessel heading of zero degrees, the global coordinate system coincides with the vessel coordinate system.
Item 5:	The point about which mooring moments are evaluated must be specified by the user. The point is given in the vessel coordinate system with (0,0,0) being at keel level (usually, directly underneath the vessel centroid).
Item 6:	The (x,y,z) coordinates of the turret centroid (or hawser/towline attachment point in CALMsim/Towsim) must be defined relative to the Vessel coordinate system.
Item 7:	The initial (zero environment) vessel heading relative to the "Global" zero of angle must be given. The Global x axis is often taken towards the North, but this is arbitrary; the Global zero angle can be chosen to lie along a particular mooring leg, for example.
Item 10:	To simulate line failures, any number of lines can be excluded during

analysis. Note that this will affect the equilibrium-determination process and the resulting distribution of loads across the remaining uncompromised lines.

When the "excluded line" value is nonzero, the line numbers to be excluded must also be specified. In line-related tabular portions of the output stream, all loads and geometrical properties (angles, etc.) of these excluded lines will display as zero (0, 0.0, etc.) to permit identification of the excluded lines.

```
 **** Screen 4: Dynamics-Related Mooring Information ****

 1) Number of lines for dynamic evaluation (Max 16):  8
 2) Line numbers selected for dynamic evaluation:
     1, 2, 3, 4, 5, 6, 7, 8,

 3) Number of vertical interpolation layers (Max 29, Min 1) ...  5
 4) Total span of vertical interpolation region ............... 100.00 feet

10) Reset default added mass coefficient ...........    1.00
11) Reset default square-law drag coefficient ......    2.50
```

Screen 4: Miscellaneous dynamics-related mooring items.

Items 1 & 2:   Because comprehensive line dynamic computations impacts simulation execution times and can also produce a great deal of output, the number of lines desired for dynamic analysis can be restricted to those lines of interest. The lines selected for analysis must then be specified.

Item 3 :   Use this option to set the number of vertical interpolation levels, which must be an odd number greater than or equal to 1. The maximum permissible number (29) is typically only used for TLPsim; for conventional catenary moorings you will seldom need more than 5 and generally 3 will suffice. Stiffer moorings, such as those for caisson spars (in Sparsim) will often benefit from more layers (say, 9 or 11). Setting an optimal number of layers (and an optimal span; see below) is sometimes a trial-and-error process; the simulation will produce warnings in circumstances where the choices are inadequate.

Item 4 :   Use this option to specify the vertical span necessary to contain the vertical fairlead motions. The value should be large enough that all fairleads remain confined vertically within the selected span as they move in response to wave-induced vessel motions. For simulations that accommodate pulldown (Sparsim and TLPsim) the layer thickness should be sufficient to bracket the complete vertical range of fairlead motions produced by pulldown *plus* wave-frequency motions. Insufficient layer thickness will be reported by the simulation so that the shortcoming can be remedied. Obtaining an optimum layer thickness may occasionally require trial-and-error simulation repetitions, especially for Sparsim and TLPsim, since a total span that is unnecessarily excessive is as undesirable as one which is insufficient.

Note: For all simulations but TLPsim and Sparsim, the layer distribution

in the "span" is symmetric; that is, layers are distributed both above and below the "mean position" layer (i.e., the one associated with fairleads in the quiescent condition) in equal amounts. This is because when the principal vertical fairlead motion arises from wave action, the motion is reasonably symmetric about the mean. For Sparsim and TLPsim, however, a large portion of the vertical fairlead motion comes from quasi-static vessel pulldown due to mean environmental offsetting forces. In those cases, the wave-frequency contributions to fairlead motions are relatively small. Therefore the interpolation layer span is adjusted downwards (i.e., it is asymmetric about the "mean position" layer) to reflect the fact that the fairlead motion is one-sided (i.e., downwards due to vessel pulldown). So for Sparsim and TLPsim, the relevant span is set by the expected pulldown height, while for other simulations, the total span is set by the "double amplitude" maximum vertical wave-frequency fairlead oscillations.

Item 10:   Changes the default added-mass coefficient used in wave-frequency dynamics calculations. When changed, the new added mass coefficient will be applied to all sublines; added mass coefficients for each subline can later be individually set, if necessary, on the appropriate subline Screen. (See page 29.)

Item 11:   Changes the default square-law transverse line drag coefficient used in wave-frequency dynamics calculations. When changed, the new square-law drag coefficient will be applied to all sublines; drag coefficients for each subline can later be individually set, if necessary, on the appropriate subline Screen. (See page 29.)

```
              ****** Screen 5A:  Subline Specifics *****
          ("C", "D", "I", "X" to Copy, Delete, Insert, Exchange)

---> Subline attached to fairlead

 1) Mooring leg type A (type 1 of 2)
 2) Subline number:  1 of  2

 3) Subline composition .........................         Wire
 4) Subline length ...............................     1000.00 feet
 5) Subline outside diameter .....................        4.50 inches
 6) Immersed weight/unit length ..................       31.20 lbs/foot
 7) Dry weight/unit length .......................       37.58 lbs/foot
 8) Breaking strength ............................     1860.97 kips
 9) Added mass coefficient .......................        1.00
10) Transverse drag coefficient .................         2.50

11) Take elastic properties from an input file? .. No
12) Compliance coefficient #1  (alpha1) .......... 0.699E-05 (k.lbs)**-1
13) Compliance coefficient #2  (alpha2) .......... 0.000E+00 (k.lbs)**-2
14) Compliance coefficient #3  (alpha3) .......... 0.000E+00 (k.lbs)**-3

20) Type A line numbers:  1, 2, 4, 5, 6, 8,

21) >> HELP << for subline physical property estimates
```

Screen type 5: The essential features of this Screen type are repeated a number of times equal to the sum of the number of sublines over all line types as specified on Screen 2. Screen 5A, 5B, etc., refer to line types A and B (or, equivalently, 1 and 2), etc., and is repeated a number of times equal to the number of sublines in each line type.

Note: When there are more than 26 line types (the 26th type being type "Z"), line identifiers in the editor and output stream track the ASCII character sequence; thus line 27, 28, 29, ..., 49 are line types "[", "/", "]", ..., "q". Thus, it is possible to have both a line type "A" and a line type "a" which are different. In that situation, when moving between line types using item "1" in the screen above, you will have to use the line *number* rather than it's ASCII equivalent, because ASCII entry is case insensitive and will only accept values in the range [A-Z] or [a-z]. This circumstance is indicated in the response prompt to the item "1" selection and should therefore cause no confusion.

These Screens possess powerful "C"opy, "D"elete, "I"nsert and e"X"change facilities to ease data manipulation of identical or similar line segments. Input of "C" (*without* quotation marks, as always) will produce prompts to accomplish an automated copy from a previously defined line type and subline number. Input of "D" will completely delete the current subline; data for all larger subline numbers of the same line type thereby "collapse" by one subline number. In the above Screen, for example, the data for subline 2 of type A would "fall" into the current Screen and the subline 2 Screen would become void of data. Input of "I" pushes all subline data up by one number and clears

all data from the current Screen. In order to simply clear the current Screen without effecting other subline data, input "D" followed immediately by "I". Input of "X" will cause a series of prompts to be issued to determine whether it is desired to "exchange" only the *displayed* subline or whether the *entire* line type, including sublines not visible on the immediate Screen, should also be exchanged, and with which line type/subline the exchange should be made.

Item 1:   This item, if selected, will permit "jumping" to any other mooring leg type Screen, or, if a value larger than the maximum value of leg types is input, to the last leg Screen. Access to individual mooring leg Screens is accomplished by this means or by advancing, one leg at a time, from the current location.

Item 2:   This item, if selected, will permit "jumping" to the first subline of any other mooring leg type, or, if a value larger than the maximum value of leg types is input, to the first subline of the last leg. Access to individual mooring leg Screens is accomplished by this means or by advancing, one subline at a time, from the current location.

Item 3:   Subline composition is for output documentation only. The maximum number of ASCII characters that will be saved and displayed is 8.

Item 4:   Self-explanatory.

Item 5:   The diameter required is the "nominal" diameter as used in standard line property tables. Thus, "3 inch chain" is fabricated out of 3 inch thick metal stock; the links themselves will be much larger in general. For standard cables of wire or synthetic material, the nominal diameter is the actual diameter of the cable. The diameter is used in hydrodynamic drag calculations and for the internal algorithms used to provide estimates of line weights, elastic properties and breaking strengths.

Item 6:   Self-explanatory. See page 72 for a special application of this item and page 30 for a discussion of buoy or clump weight specification.

Item 7:   The dry weight/unit length (i.e., the line inertia) influences dynamical line load variations arising primarily from wave-frequency fairlead motions. A dry weight/unit length of zero or less will cause the simulation to produce an estimate equal to the immersed weight/unit length plus a displacement correction based on the subline diameter.

Item 8:   Breaking strength is used only in checking the load range to be covered by the force versus offset interpolation table produced internally for each line.

Item 9:   The added mass coefficient (for transverse motions only) is not an important variable; it can safely be set to 1.0 for all cylindrical rope- or cable-type lines. For chain, values are typically in the range [3.0,4.0].

Item 10:   The transverse drag coefficient is based on the "nominal" outside diameter. Thus, drag coefficients for simple cables are typically near 1.0 while drag coefficients for chain, whose nominal (stock) diameter is much less than the effective diameter for drag calculations, are

typically in the range [2.5,3.0].

Item 11:   When this toggle is set to "Yes", elastic properties for the active page's (type, subline) will be read from a user-supplied ASCII database file named "LINE_STRAIN_DB.txt". The file is comprised of a repeating block of ASCII data, one block for each (type, subline) page for which the toggle indicates "yes". See Appendix D for datafile description and example.

Items 12-14:   The compliance coefficients (alpha1, alpha2, alpha3), abbreviated here $(\alpha_1,\alpha_2,\alpha_3)$, are defined by a cubic tension-elongation characteristic:

$$e(t) = \alpha_1 t + \alpha_2 t^2 + \alpha_3 t^3$$

where "e" is strain (dimensionless) and "t" is tension (in kips or metric tons). Thus a strain of $e = 0.1$ means a stress-associated elongation of 10%. For materials possessing an approximately linear tension-elongation characteristic (e.g., wire rope and chain), $\alpha_2 = \alpha_3 = 0$ and

$$\alpha_1 = 1/(AE) = 1/[(\text{effective Area})*(\text{Young's modulus})]$$

Note: Because of the use of "nominal diameter" in the definition of chain size, care must be taken when inferring the "effective" AE for chain from the AE of the stock material. In all cases, the first equation above defines unambiguously what is meant by the "α" coefficients. Checking user-supplied line properties with internal estimates will help to avoid errors.

```
                      ****** Screen 5B:  Subline Specifics *****
                 ("C", "D", "I", "X" to Copy, Delete, Insert, Exchange)

---> Subline attached to fairlead
---> Subline attached to anchor

 1) Mooring leg type B (type 2 of 2)
 2) Subline number:  1 of  1

 3) Subline composition .........................        Wire
 4) Subline length ...............................    2500.00 feet
 5) Subline outside diameter .....................       4.00 inches
 6) Immersed weight/unit length ..................      24.65 lbs/foot
 7) Dry weight/unit length .......................      29.70 lbs/foot
 8) Breaking strength ............................    1470.40 kips
 9) Added mass coefficient .......................       1.00
10) Transverse drag coefficient ..................       2.50

11) Take elastic properties from an input file? .. No
12) Compliance coefficient #1  (alpha1) ..........  0.884E-05 (k.lbs)**-1
13) Compliance coefficient #2  (alpha2) ..........  0.000E+00 (k.lbs)**-2
14) Compliance coefficient #3  (alpha3) ..........  0.000E+00 (k.lbs)**-3

16) Bottom is transparent to mooring line ........ No
17) Anchor depth for this leg type ..............     450.00 feet

20) Type B line numbers:  3, 7,

21) >> HELP << for subline physical property estimates
```

Items 16 & 17:   These items are displayed only for the "Anchor" subline. Bottom transparency (see page 62 ff) can be controlled on a per-line basis.

The anchor depth option appears only if the "Specify anchor depths" toggle on Screen 2 is set to "yes", in which case anchor depths may be specified at different levels to simulate the effects of irregular bottom topography or anchor placement on towers or docks. See the related comments on page 62 ff. Note that this capability does not rigorously simulate a sloping bottom. Each anchor and its associated anchor leg are treated as if they lay on or above a level ocean bottom, whose depth can be made to vary from line to line by this mechanism. For true sloping bottom capabilities, an analysis using SeaSoft's "Statmoor" statics utility may be of value.

Item 20:   The line numbers associated with each line type must be specified; this item only appears on the "Fairlead" Subline page for each type.

Item 21:   Selection of this item produces a Screen which will facilitate the estimation of weight/unit length, breaking strength and elastic coefficients for many mooring materials including IWRC wire rope, ORQ chain and a number of synthetics including nylon, Nystron, polypropylene and polyester. Selection of this Item calls up the following help Screen:

```
 ****  Simulation Help Facility  ****

 1) HELP with submerged weight per unit length...
 2) HELP with breaking strength...
 3) HELP with compliance coefficients...
 4) HELP with dry weight per unit length...
 5) Fairlead subline length for specified tautwire tension...

Enter number of selection ("H" for help):
```

SubScreen 5a: This is the Line Help Facility SubScreen. These calculations depend on the line diameter displayed on the Calling Screen from which Help was requested. Also, the line type (chain, wire, ...) required for specifying weight, strength, etc., is taken, not from the "subline composition" on Screen 5, but from a subsequent Screen display (see below).

Item 1:   Submerged weight per unit length in air, seawater or freshwater will be estimated for the specified line diameter and line type.

Item 2:   Breaking strength will be estimated for the specified line diameter and line type.

Item 3:   Compliance coefficients will be estimated for the specified line diameter and line type. Either the built-in compliance database or a user-input tension versus elongation curve can be used (see below). Compliance properties can, alternatively, be prepared and supplied via an external data file as described in the first "Screen 5" discussion block above.

Item 4:   Dry weight per unit length (i.e., the weight per unit length in air) will be estimated for the specified line diameter and line type.

Item 5:   This item is normally used for taut-wire or tension-leg calculations. Its selection results in the computation of the length of fairlead-attached subline required to produce the requested pretension for the associated Screen 5 line type. The line is assumed to be perfectly vertical for the calculation and to have a height-dependent local strain due to its self-weight. *All* weights and elastic coefficients for sublines of the relevant line type must first be provided.

```
┌─────────────────────────────────────────────────────────────────┐
│                                                                   │
│  ***  Help for line compliance coefficients  ***                  │
│                                                                   │
│         >>> Chain Types <<<                                       │
│                                                                   │
│  1) Stud-link chain (generic O.R.Q.; 1975)                        │
│  2) Stud-link chain (Ramnas  O.R.Q.; 1994)                        │
│  3) Studless Grade RQ4 Chain                                      │
│  4) Inextensible stud-link chain                                  │
│                                                                   │
│         >>> Wire Rope Types <<<                                   │
│                                                                   │
│  6) I.W.R.C. wire rope (O.R.Q.)                                   │
│  7) Brydon spiral strand wire rope (unsheathed)                   │
│  8) Brydon spiral strand wire rope (unsheathed; remodeled 1995)   │
│                                                                   │
│         >>> Synthetic Rope Types <<<                              │
│                                                                   │
│ 11) Kevlar stranded rope (Samson)                                 │
│ 12) Braided nylon rope (Samson "two-in-one")                      │
│ 13) Samson Nystron rope                                           │
│ 14) Vermeire 100% polyester braided rope                          │
│ 15) Vermeire "Monogrip" 100% polypropylene rope                   │
│ 16) Vermeire manilla rope                                         │
│                                                                   │
│ Enter number of selection ("H" for help):                         │
│                                                                   │
└─────────────────────────────────────────────────────────────────┘
```

A window similar to the one above is displayed for most help items 1-4 in order to specify the line material to be used in the estimate.

```
┌─────────────────────────────────────────────────────────────────┐
│                                                                   │
│  ***  Help for line compliance coefficients  ***                  │
│                                                                   │
│                                                                   │
│ 1) User-specified stress/strain curve                             │
│ 2) Built-in compliance coefficients                               │
│                                                                   │
│                                                                   │
│ Enter number of selection ("H" for help):                         │
│                                                                   │
└─────────────────────────────────────────────────────────────────┘
```

The Compliance Coefficient Sub-SubScreen.

Item 1:   A user-supplied array of (tension, elongation) data points will be used to estimate the three required compliance coefficients. (See input Screens associated with this item below.)

Note: The built-in curve-fitting routine associated with Item 1 produces a cubic stress-strain polynomial. This can at times can be problematic because of the vagaries of cubic polynomials. For more complex stress-strain curve shapes, the "LINE_STRAIN_DB.txt" mechanism, discussed further above and in Appendix D, should be used instead.

Item 2:   A built-in database covering a number of important line types will be

used to estimate compliance coefficients. In this database, chain, wire rope and Kevlar exhibit Hooke's law behavior (linear stress-strain characteristic) using a *single* nonzero compliance coefficient; other synthetics will display three distinct coefficients.

```
Enter number of data points (max 20, min 4): 6

-->> Array input for NONZERO Tension values (a point at [0,0] is ASSUMED)


 1)        10.00
 2)        20.00
 3)        40.00
 4)        80.00
 5)       160.00
 6)       320.00

Enter number of selection ("H" for help):
```

In order to compute compliance coefficients from a tension-elongation curve, the number of data points to be used must first be specified (from 4 to 20), then the values themselves must be provided. This window illustrates a sample tension input array. Tension values must be given in simulation-consistent units (kips or metric tons). The data point (0,0) is automatically included; no zero values of tension or elongation will be accepted. The maximum input tension value should be 1.25 to 1.5 times the material breaking strength for best curve fitting results. Since manufacturers data obviously cannot go beyond the breaking strength, the data should be extrapolated in a reasonable way to the necessary unphysically large tension values. A linear extrapolation of the supplied curve will usually suffice.

```
-->> Array input for NONZERO Elongation values (a point at [0,0] is ASSUMED)


 1)         .01
 2)         .02
 3)         .05
 4)         .12
 5)         .26
 6)         .60

Enter number of selection ("H" for help):
```

This window illustrates a sample input of the elongation array associated with the tension array in the previous window. Elongation values are input as a decimal fraction (i.e., an elongation of 10% is entered as 0.1). The data point (0,0) is automatically included; no zero values of tension or elongation will be accepted. The built-in routine produces a simple cubic fit to the supplied data which will be either *unweighted* or weighted by [1/elongation]; a prompt will be given just before execution

of the curve fit to implement this final choice. Weighting the fit with 1/elongation will usually produce a better fit to the data at lower tension values. It is instructive at least once to execute a fit both ways and visually compare the resulting cubics (using a spreadsheet program, for example) against the data using the stress-strain relation given above with the output values of $(\alpha_1, \alpha_2, \alpha_3)$.

Tip: To achieve the most satisfactory cubic fit using this mechanism, the *density* of supplied points should be greatest in the tension region of most importance to the simulation (typically, near the upper end of the tension range).

```
         ****   Screen 6: Low-frequency dynamics selection   ****


  1) Calculate low-frequency dynamics: .............   Yes

  2) Low-frequency surge damping is ...............    Computed
  4) Low-frequency sway  damping is ...............    Computed
  6) Low-frequency  yaw  damping is ...............    User-specified
  7) Yaw damping (percent of critical) .............      33.00
```

Screen 6: Item 1 is a toggle, the value of which determines whether or not the Low-Frequency Dynamics Module will be executed. If the toggle is selected ("yes") additional Screens will be presented for further necessary data. Otherwise these additional Screens are omitted.

Items 2, 4, 6:   These are toggles. Damping of low-frequency normal mode oscillations in the moor is typically computed internally. However, in special circumstances a linear damping coefficient may be specified by the user in percent of critical. Note that computed values contain both nonlinear and environment-related contributions so that computed "equivalent linear" damping will change when, for example, some aspect of the environment changes. User-specified damping values, by contrast, are not influenced by environmental changes. Here the "sway" and "yaw" damping refers respectively to the low and high sway/yaw modes in the case of SPMsim, CALMsim and Towsim. (See page 42 ff.)

Items 3, 5, 7:   These items, which are only displayed when required by the setting of their associated toggles in items 2, 4, 6, permit specification of the numerical damping values.

```
***************  Screen 7: Vessel Hydrostatic Characteristics  **************

 1) Vessel displacement ...............................  407000.00 k.lbs
 2) Transverse metacentric height (KMT) ................      61.00 ft
 3) Longitudinal metacentric height (KML) ..............    1225.00 ft
 4) Vertical center of buoyancy (VKB) ..................      34.00 ft
 5) Vertical center of gravity (VKG) ...................      36.00 ft
 6) Vessel water plane area ............................  126000.00 ft^2
 7) Length of vessel at waterline ......................     929.00 ft
 8) Beam of vessel at waterline ........................     146.60 ft
 9) Mean vessel draft ..................................      64.00 ft

10) Vessel type for simulation ........................ Ship/barge/tanker

11) Help for Tanker-Type Physical Characteristics
```

See Also: pp 30   Screen 7: This Screen contains vessel hydrostatic data. Data required here services both Low- and Wave-Frequency Modules of the Simulation, as discussed in Chapter 5. Note that vessel length, beam and draft are required data in the Simulation, while they are optional in Shipsim, Semisim, etc.. Items 1-9 are largely self explanatory; reference can also be made to the Shipsim and Semisim manuals for further discussion of these variables and their roles in simulation of vessel wave-frequency forces, moments and motions.

Item 1:   Displacement comprises total simulated vessel weight. Note that the displacement of Item 1 is a true displacement, and not the "dead-weight" often used in description of VLCC's and ULCC's.

Items 2-3:   Note that these are metacentric heights *above baseline* ("KM") and *not* above the cg ("GM").

KM (transverse or longitudinal), GM, VKG, VKB and IWP (waterplane moment of inertia) are related by:

$$GM = KM - VKG$$
$$GM = IWP/(\text{Displacement Volume}) - (VKG-VKB)$$

For a *rectangular* waterplane of width B and length L,

$$IWP \text{ (transverse)} = LB^3/12$$
$$IWP \text{ (longitudinal)} = BL^3/12$$

For a circular waterplane of radius R,

$$IWP = \pi R^4/4$$

Item 4:   VKB should be obtained from hydrostatics, but is generally in the range of 1.0-1.2 times (Draft/2) for displacement-hull offshore vessels

Item 5:   VKG should include free-surface corrections, if any.

Item 6:   Water plane area can be obtained from:

                     (a) Calculation or estimation,

                     (b) The product of beam, length and waterplane coefficient at the
                     desired draft,

                     (c) Hydrostatic immersion curves by dividing the curve value at required
                     draft (e.g., in tons/foot) by water density (e.g., in tons/cubic foot) used
                     for curve preparation.

Items 7-8:   Vessel Length and Beam comprise total waterline lengths projected on
                     a vertical plane. This applies to all types of vessels including
                     semisubmersibles (but see Appendix G for more detailed
                     semisubmersible discussion).

Item 9:   Draft comprises mean draft in the simulated condition.

Item 10:   Vessel type specification is used for selecting the wave-frequency
                     simulation to use for evaluation of vessel motion characteristics. The
                     options can be seen by selecting this item's SubScreen.

Item 11:   Average physical characteristics of VLCC's and ULCC's have been
                     tabulated and characterized in a way that permits their estimation as
                     continuous functions of two variables: (1) Vessel Deadweight (DWT)
                     and (2) Simulation Draft.

```
***********   Screen 8: Vessel Gyradii and Bilge Specifications   ***********

  1) Pitch Gyradius ...................................     232.00 ft
  2) Roll Gyradius ....................................      51.20 ft
  3) Yaw Gyradius .....................................     235.00 ft

  4) Bilge radius at maximum beam station ..............       5.00 ft
  5) Is there a bilge keel .............................    No

  9) Vessel speed (knots) ..............................        .00

 11) Trim angle (deg; bow down positive) ...............        .00
 12) Heel angle (deg; starboard down positive) .........        .00

 13) Utilize user-supplied vessel RAO data .............    No
```

                     Screen 8: This Screen permits gyradii, bilge, vessel speed and vessel
                     trim and heel specification.

Items 1-3:   Gyradii are about the vessel center of gravity.

                 •   Pitch gyradii for slender displacement-hull vessels are usually between
                     .24*Length and .30*Length.

                 •   Roll gyradii for displacement-hull vessels of conventional form are
                     usually between .28*Beam and .40*Beam, with most vessels falling in

a narrower range {.32*Beam < roll gyradius < .36*Beam}. Loaded wing tanks or especially deep hulls tend to produce gyradii near the indicated upper limits.

- Yaw gyradii for slender displacement-hull vessels are usually comparable to, but slightly larger than, pitch gyradii. A useful approximate rule is

$$\text{Yaw gyradius} \approx \sqrt{(P_g{}^2 + R_g{}^2)}$$

where P_g and R_g are, respectively, pitch and roll gyradii.

Items 4-5:   The bilge radius and presence or absence of a bilge keel determines the level of square-law roll damping. If a bilge keel is present, the bilge radius information is not used.

Item 9:   Mean motion of the vessel relative to the surrounding fluid affects the frequency versus wavelength relationship of waves as viewed from the vessel frame of reference; that is, for a specified wave length, the encounter frequency depends on vessel motion according to:

Shifted frequency = unshifted frequency - **VFWD•K**

Here, **VFWD** is the vessel velocity (whose *magnitude* is supplied by item 9 and *direction* by item 10, which will display only if item 9 is nonzero), **K** is the wave vector (2π/wavelength in the direction of wave advance) and **VFWD•K** is the wave vector magnitude times the projection of the vessel velocity vector on the wave vector direction.

In unusual cases (for example, when vessel motion is in the direction of wave propagation) the encounter period versus wavelength dependency can become multi-valued (i.e., two different wavelengths can be associated with a single encounter period). This makes the definition of the wave spectrum in irregular wave simulations problematic since the spectrum is defined in a vessel-fixed frame and there is no way of knowing how to apportion the wave energy in a given frequency band between the two associated wavelengths. The vessel speed option should therefore be used with special caution and particular attention given to its effect on irregular wave vessel responses.

Item 10:   A non-zero vessel speed (item 9) requires specification of a direction of motion in the global coordinate system; the usual right-handed coordinate system applies with 0 degrees corresponding to a forward speed condition. Note that vessel motion in the 90 degree direction equates physically to a "current" with a 270 degree "heading".

Items 11 -12:   Vessel trim and heel can be specified; nonzero values will change the absolute (global) locations of the fairleads, which are specified in the *vessel*-fixed frame. Specification of trim or heel enormously complicates many aspects of the simulation and is very rarely of significant value; it should be avoided except as an occasional "check" that the anticipated level of trim or heel is not problematic.

Item 13:   User specification of vessel RAOs requires preparation of a formatted

input file containing, for all six degrees of freedom, complex *dimensionless* RAOs for a two-dimensional array of circular wave frequencies and wave headings. RAOs for arbitrary frequencies and headings are obtained by interpolation within the array. The description and format of this data file is discussed in Appendix D.

```
***********  Screen 9: Vessel Period and Damping Specifications  ***********

 1) Heave damping is .................................. Specified
 2) Heave damping (percent of critical) ................    16.00

 3) Pitch damping is .................................. Computed
 5) Roll damping is ................................... Computed

 7) Heave period is ................................... Computed
 9) Pitch period is ................................... Computed
11) Roll period is .................................... Specified
12) Roll period (sec) ................................    14.00
```

Screen 9: This Screen permits user-specification of wave-frequency vessel periods and damping.

Items 1, 3, 5:   Activation of these toggles produces a prompt for a user-specified damping value. Pitch, roll and heave damping will be computed internally unless specified by the user in percent of critical. User-supplied values become simple linear damping coefficients which do not depend on wave conditions. On the other hand, in many cases internal damping estimates produce an "equivalent linear damping" coefficient which depends on wave conditions, with larger waves resulting in larger damping coefficients.

Items 7, 9, 11:   Pitch, roll and heave periods are normally computed internally. They can, however, be set by the user in special circumstances. Toggling of these items to "Specified" produces a prompt for a user-supplied value.

```
+-----------------------------------------------------------------------+
|                                                                       |
|    ****   Screen 10: Vessel Low-Frequency Dynamics Characteristics  ****|
|                                                                       |
|   1) Toggle independent <<Wind>> Cx, Cy, Cz                           |
|   2) Wind force model ........................... OCIMF '77 (extended)|
|                                                                       |
|   6) Above-Water Bow Shape ...................... Conventional        |
|   7) Freeboard-Based Load ........................     100.00 Percent |
|                                                                       |
|  11) Toggle independent <<Current>> Cx, Cy, Cz                        |
|  12) Head-on Coefficients (Cx) .................. User-Specified LOWDAT|
|  13) Beam-on Coefficients (Cy) .................. NSMB Tanker '91      |
|  14) Moment Coefficients  (Cz) .................. Barge (SeaSoft)      |
|  15) Specify current force coefficients                               |
|                                                                       |
|  16) Below-Water Bow Shape ...................... Interpolated        |
|  17) Draft-Based Load ...........................     100.00 Percent  |
|  18) Bow Interpolation Factor ...................        .50          |
|                                                                       |
|  21) Toggle independent <<Wave>> Cx, Cy, Cz                           |
|  22) Wave force model ........................... Tanker (2001)       |
|                                                                       |
|  31) Vessel Deadweight ..........................  300000.00 kips     |
|                                                                       |
+-----------------------------------------------------------------------+
```

See Also: pp 31 ff   Screen 10: This Screen permits definition of wind, wave and current parameters for the moored vessel. For each environmental influence, three vessel force/moment coefficients must be specified: Cx (longitudinal force coefficient), Cy (lateral force coefficient) and Cz (vertical moment coefficient). These parameters uniquely determine all static and low-frequency environmental forces and moments. The state of this Screen is strongly context-sensitive; that is, many items appear and disappear depending on the state of other items. For example, items 3, 4, 5 and 8 are invisible in the above sample because of the state of item 1 and environmental model selected in item 2.

> *Note:*   Cz is often called "Cxy"; in particular, "Cxy" is the original (1977) OCIMF notation.

Items 1, 11, 21:   Normally, Cx, Cy and Cz will be *simultaneously* determined from the *same* environmental model, for example the 1977 OCIMF VLCC tanker wind model. However, Cx, Cy and Cz may also be specified *independently*; for example, Cx can be "user-specified LOWDAT" while Cy and Cz can utilize built-in environmental models such as the "OCIMF" or "NSMB" models discussed below. These items "toggle" between "independent" and "simultaneous" specification of [Cx, Cy, Cz].

Item 2:   This item connects to SubScreen 10a offering a selection of built-in and user-specified wind coefficient models. Related items 3, 4 and 5 (analogous to items 13, 14 and 15 for current, discussed below) are invisible due to the state of items 1 and 2.

Item 6:   This item connects to SubScreen 10b for selection of bow types to be

used with the specified environmental load database. It is relevant and visible *only* if the wind model selected for at least one of [Cx, Cy, Cz] is "OCIMF '77".

Item 7:   The *wind-specific* load condition for VLCC tankers, as defined by the OCIMF 1977 report, is determined by simulation freeboard ("FB"):

Freeboard Load % = 100*(Full Load FB)/(Simulation FB)

The freeboard-based load condition is used *only* for wind force calculations. To access OCIMF "Loaded" data, enter 100%. To access OCIMF "Ballasted" data, enter 32%. Other percentages will result in linear interpolation or extrapolation using OCIMF "Ballasted" and "Loaded" curves; care should be exercised when extrapolating outside the range [32%, 100%]. The freeboard-based load percentage for a given vessel loading is generally close to, but seldom exactly the same as, the draft load percentage used in current load calculations. This item is relevant and visible *only* if the wind model selected for at least one of [Cx, Cy, Cz] is "OCIMF '77".

Item 8:   This item, the wind analogue of item 18 (see below) will become visible whenever item 7 indicates "interpolation" between wind-force dependent bow types is in effect. See also the bow selection comments (SubScreen 10b).

Items 12-14:   These items connect to SubScreen 10c offering a selection of built-in and user-specified current coefficient models. They collapse into *one* item (Item 12) for *simultaneous* specification of [Cx, Cy, Cz] from a single model by invoking the toggle Item 11. See the analogous items 1-4 for wind above.

Item 15:   This item (and Item 5 for wind coefficients) only becomes visible if at least one of the coefficients [Cx, Cy, Cz] is "user-specified LOWDAT". When visible, it connects to SubScreen 10f permitting user specification of the designated coefficients. When this item or the analogous item 5 for wind is visible, a LOWDAT file containing user-supplied coefficient data will be produced, along with the MOORDAT file, upon exiting the Editor.

Item 16:   This item (and Item 6 for wind coefficients) only becomes visible if at least one of the coefficients [Cx, Cy, Cz] is OCIMF '77 or NSMB '91. When visible, it connects to a model-dependent SubScreen (see SubScreen 10d below) permitting selection of underwater bow configuration.

Item 17:   The *current-specific* load condition for VLCC tankers, as defined by the NSMB 1991 rework ("NSMB") of the earlier OCIMF 1977 results, is determined by simulation draft percentage:

Draft Load % = 100*(Simulation Draft)/(Full Load Draft)

The draft-based load condition is used *only* for current load calculations; further, this option is unnecessary (and invisible) unless the NSMB '91

database is accessed. To access NSMB "Loaded" data, enter 100%. To access NSMB 40% draft condition, enter 40%. Other percentages will result in linear interpolation or extrapolation using the NSMB "40%" and "100%" curves; care should be exercised when extrapolating outside the range [40%, 100%]. The draft percentage for a given vessel loading is generally close to, but seldom exactly the same as, the freeboard-based load percentage used in wind load calculations.

Note: OCIMF 1977 reported that current loads were roughly independent of vessel load condition, depending *only* on bow type and water depth-to-draft ratio. Said another way, in water of given depth the OCIMF '77 coefficients would be the *same* for a large *lightly* loaded tanker and a small *fully* loaded one if their depth-to-draft ratios were the same.

Item 18:   When above- or below-water bow shape characterization is "interpolated", the interpolation factor (which lies between 0 and 1) must be specified. Additional information concerning this variable can be found following the bow shape selection SubScreens for current (SubScreens 10d & 10e).

Items 22-24:   These items connect to SubScreen 10g offering a selection of built-in and user-specified wave drift coefficient models. They collapse into *one* item (Item 22) for *simultaneous* specification of [Cx, Cy, Cz] from a single model by invoking the toggle Item 21. See the analogous items 1-4 for wind above.

Note: User specification of wave-drift coefficients requires a supplemental user-prepared database permitting evaluation of wave coefficients [Cx, Cy, Cz] at any wave period for every vessel-relative wave direction. The database must be available to the simulation in the form of a data file with a particular structure. See Appendix D.

Items 25-30:   Unused.

Item 31:   Vessel "Deadweight" is used *only* to distinguish between VLCCs (kDWT > 155) and smaller tankers (kDWT < 80) in the "OCIMF '77 (extended)" wind model database. Midrange tankers (size 80 kDWT < DWT < 155 kDWT) are treated by interpolating between OCIMF VLCC data and the "Small Tanker" data using the specified Deadweight. This item is neither used nor displayed for any wind model other than "OCIMF '77 (extended)".

```
+++  Wind Model Selection  +++

1) User-Specified LOWDAT
2) User-Specified WINDCOFS.txt
3) Barge (SeaSoft)
4) OCIMF Tanker '77 (extended)
5) Cylindrical Vessel
```

SubScreen 10a: This SubScreen permits selection of available built-in wind coefficient models or user specification of wind coefficients.

Item 1:   This item permits user specification of wind angle and coefficient arrays via the "LOWDAT" binary input mechanism; see SubScreen 10f comments.

Item 2:   This item permits user specification of wind coefficient arrays via the WINDCOFS.txt textfile input mechanism (see Appendix D).

Item 3:   Winds acting on "SeaSoft"-type barges are assumed to produce square-law loads; net force and vertical moment are computed from specified values of air mass density ("Dm"), projected area ("Ap"), area centroid location, drag coefficient ("Cd") and wind speed ("V"). For any wind direction a projected area is computed using supplied bow-on and beam-on areas. The resulting loads follow from:

$$\text{Force} = .5*Dm*Cd*Ap*V^2$$
$$\text{Moment} = \text{Force}*(\text{moment arm to Ap centroid}).$$

The direction of the computed force is aligned with the wind.

Item 4:   The "OCIMF '77 (extended)" wind database comprises empirical wind load coefficients presented in The Oil Companies International Marine Forum 1977 report "Prediction of Wind and Current Loads on VLCC's" ("OCIMF"; VLCC size 155 kDWT and greater), supplemented with data for "Small" (less than 80 kDWT) deckhouse-aft tankers. Midrange tankers with DWT in the range [80, 155] can, on user request, be treated in the "extended" implementation by interpolation between the two ("OCIMF" and "Small") tanker data sets.

Note: • Interpolation is carried out using the specified "Deadweight", which need *not* physically correspond to the simulated vessel but can be adjusted as necessary to obtain the desired coefficients. For example, to use the OCIMF VLCC coefficients for a "Small" 20 kDWT tanker, simply specify a Deadweight of 155 kDWT or greater. The Deadweight is used *only* in this capacity and is therefore not requested for any wind model other than "OCIMF '77 (extended)".

```
 +++  Wind-Related Bow Type Selection  +++

1) Conventional (with bulb)
2) Cylindrical (no bulb)
3) Interpolated (on 1 & 2)
```

SubScreen 10b: This SubScreen, which can be accessed whenever Screen 10 items 2-4 display "OCIMF '77 (extended)", permits selection of above-water bow shape; this shape is a variable in the OCIMF '77 wind load database.

Items 1, 2:   "OCIMF '77" and "Small" tanker wind databases contain comprehensive wind load data for two distinct bow shapes: "Conventional" bows comprise a wedged-shape waterline and above-water profile (i.e., a "V"-shaped profile in plan view) , while "Cylindrical" bows comprise a blunt, nearly cylindrical waterline and above-water profile. According to the OCIMF report, the "Conventional" vessel data applies to a bulbous bow configuration while the "Cylindrical" data does not; naturally, only the above-water portions of the bow influences wind loads, so the presence or absence of a *submerged* bulbous bow is irrelevant. These "Conventional" coefficients would therefore presumably apply to "Conventional" bows with or without bulbs, at least in a loaded configuration with bulb completely submerged. For lightly ballasted conditions, when the top portion of the bulb may broach the surface, there may be small differences in wind load coefficients, but the OCIMF report does not address this issue.

Item 3:   The SeaSoft implementation of this database permits selection of either bow type, or a linear interpolation between bow types. If "Interpolation" is selected, one must also supply the interpolation "factor", which varies between 0 ("Conventional" bow) and 1 ("Cylindrical" bow); a factor of 0.5 will produce an *average* of the two OCIMF bow types.

```
 +++  Current Model Selection  +++

 1) User-Specified LOWDAT
 2) User-Specified CRNTCOFS.txt
 3) Barge (SeaSoft)
 4) NSMB Tanker '91
 5) Extreme Cylindrical Bow '91
 6) OCIMF Tanker '77
 7) Cylindrical Vessel
```

SubScreen 10c: This SubScreen permits selection of available built-in current coefficient models or user specification of current coefficients.

Caveat: The array of current options available is extensive and can be confusing. Unrestricted use of these capabilities should, except in the simplest cases, be undertaken only with the aid and understanding of the indicated

original reports. Especially confusing are subtle differences between "Cylindrical" and "Conventional" nomenclature used in the two OCIMF reports.

Item 1:   This item permits user specification of current angle and coefficient arrays via the "LOWDAT" binary input mechanism; see SubScreen 10f comments.

Item 2:   This item permits user specification of current coefficient arrays via the CRNTCOFS.txt textfile input mechanism; see Appendix D.

Item 3:   Currents acting on "SeaSoft"-type barges are assumed to produce square-law loads; net force and vertical moment are computed from specified values of water mass density Dm, projected area, area centroid location, drag coefficient ("Cd") and current speed ("V"). For any current direction a projected area ("Ap") is computed using supplied bow-on and beam-on areas. The resulting loads follow from:

$$Force = .5*Dm*Cd*Ap*V^2$$
$$Moment = Force*(moment\ arm\ to\ Ap\ centroid).$$

The direction of the computed force is aligned with the current.

Item 4:   The "NSMB '91" database comprises measurements made at the Netherlands Ship Model Basin (NSMB) to assess (and correct) deficiencies in earlier measurements (see the "OCIMF '77" help notes).

Notes: • The 1991 NSMB data were MORE comprehensive than OCIMF '77 in one respect: in characterizing current loads they acknowledge the role of vessel load condition, in addition to water depth/draft ("WD/T") ratio. Thus, measurements were made for load conditions of 40% and 100% of full load draft for bow configurations with a submerged bulb ("Conventional" in the 1977 report) and without bulb ("Cylindrical" in the 1977 nomenclature; see also the "OCIMF '77" help notes).

            • The '91 NSMB data were, however, LESS comprehensive than the OCIMF '77 data in that WD/T values were limited to 1.1, 1.2, 1.5, 3.0 and 4.4 for 100% load cases and 1.1, 1.5 and 4.4 for 40% load cases.

            • For 40% and 100% load conditions, the SeaSoft implementation uses linear interpolation within the respective database WD/T ranges and endpoint data for WD/T values outside the database range. For other load conditions, the SeaSoft implementation utilizes appropriate linear interpolation or extrapolation using the 100% and 40% data.

            • Linear interpolation for bow configurations intermediate to the two NSMB '91 bow types ("Conventional" bow with submerged bulb and "Cylindrical" bow lacking a bulb) is accommodated by the SeaSoft implementation.

Item 5:   The "Extreme Cylindrical" database comprises measurements made on a single 200 kDWT model at NSMB; this vessel evidently was not a counterpart to the earlier OCIMF '77 "Cylindrical" vessel type but rather represents a much more extreme cylindrical bow configuration. These measurements were carried out only for a single water depth/draft condition (WD/T = 1.1) and a single vessel load condition (100% load). As a result, the SeaSoft implementation of the "Extreme Cylindrical" database performs NO interpolation on WD/T values, load values or bow configuration but reproduces ONLY the single measured condition.

Item 6:   The "OCIMF '77" current database comprises empirical current load coefficients presented in The Oil Companies International Marine Forum 1977 report "Prediction of Wind and Current Loads on VLCCs" (VLCC size 190 kDWT and greater).

Notes: • The OCIMF measurements encompass two sub-surface vessel bow profiles: "Conventional" bows possess a submerged bulbous bow and exhibit a knife-edged, "V"-shaped waterline while "Cylindrical" bows lack the bulbous bow and exhibit a blunt, somewhat cylindrical waterline. Linear interpolation on intermediate bow configurations is accommodated by the SeaSoft implementation.

• Water depth to draft ("WD/T") ratios of 1.05 1.1, 1.2, 1.5, 3.0 and 6.0 were studied. The SeaSoft database implementation interpolates within the database range [1.05 < WD/T < 6.0] and uses appropriate endpoint data [WD/T = 1.05 or WD/T = 6.0] for WD/T values outside the database range.

• The OCIMF '77 data are known to posses certain inadequacies, particularly in the longitudinal current load data and in lack of vessel loading dependence. These deficiencies were partially addressed in later measurements (see the "NSMB '91" help notes).

```
 +++  Current-Related Bow Type Selection  +++

1) Conventional (with bulb)
2) Cylindrical (no bulb)
3) Interpolated (on 1 & 2)
```

SubScreen 10d: This SubScreen permits selection of below-water bow shape for *OCIMF '77* data; in OCIMF '77 this shape has an effect *only* on the Cx current load coefficients, *but on no others*. It is evidently identical to SubScreen 10c.

Items 1, 2:   The "OCIMF '77" current database contains comprehensive load data for two distinct bow shapes: "Conventional" bows comprise knife-edged, "V"-shaped waterlines and bulbous below-water profiles, while

"Cylindrical" bows comprise blunt, nearly cylindrical waterlines and below-water profiles. Naturally, only the below-water portion of the bow influences current loads, so the OCIMF "Conventional" coefficients would presumably be inapplicable to "Conventional" bows *lacking* submerged bulbs. This deficiency was addressed in later measurements which included "Conventional" bows with *and* without bulbs; see "NSMB '91" notes.

Item 3:   The SeaSoft implementation of the OCIMF '77 data permits selection of either bow type, or linear interpolation between bow types. If "Interpolation" is selected, the interpolation "factor", which varies between 0 ("Conventional" bow) and 1 ("Cylindrical" bow) must be supplied; a factor of 0.5 will produce coefficients which are the *average* between the two OCIMF '77 bow types.

```
 +++  Current-Related Bow Type Selection  +++

1) Conventional (with bulb)
2) Conventional (no bulb)
3) Interpolated (on 1 & 2)
```

SubScreen 10e: This SubScreen permits selection of below-water bow shape for *NSMB '91* data; this shape has an effect on *all* [Cx, Cy, Cz] current load coefficients, in contrast to the OCIMF '77 case, for which only Cx was affected by bow shape. It is evidently identical to SubScreen 10c and 10d.

Items 1, 2:   The "NSMB '91" current load database contains *comprehensive* data for two distinct bow shapes: "Conventional" bows with *and* without "bulbous" below-water profiles. Both of these "Conventional" subtypes posses knife-edged, "V"-shaped waterlines, at least in loaded vessels, but differ in their underwater forms.

Note: The NSMB '91 data includes only a single "Cylindrical" bow configuration and therefore lacks sufficient breadth of data to provide interpolation between bow types, load conditions, or water depth-to-draft ratios for this bow type. Therefore, no interpolation options exist in the SeaSoft implementation of the NSMB '91 "Cylindrical" type. In this regard, the OCIMF '77 data is more comprehensive, containing a complete family of coefficients for the "Cylindrical" bow type permitting several levels of interpolation.

Item 3:   The SeaSoft implementation of the NSMB '91 "Conventional" bow data permits selection of either bow type (with and without bulb), or a linear interpolation between these. If "Interpolation" is selected the interpolation "factor", which varies between 0 ("Conventional" bow with bulb) and 1 ("Conventional" bow without bulb) must be supplied. A factor of 0.5 will produce coefficients which are the *average* between the two NSMB '91 "Conventional" bow sub-types.

```
+++ <<Current Force>> Coefficient Specification +++

Bow-Relative     Cx
Attack Angle

     .00        -1.000
   20.00         -.940
   40.00         -.770
   60.00         -.500
   80.00         -.170
  100.00          .170
  120.00          .500
  140.00          .770
  160.00          .940
  180.00         1.000

1) Number of angles (21 Maximum): 10
2) Specify Angle array
3) Specify Coefficient array
```

SubScreen 10f: This SubScreen, which is generic in that it is used for both current and wind coefficients, provides for direct numerical input of coefficients. Data supplied to this SubScreen is saved in a "LOWDAT" file upon exiting the Editor.

Notes: • An array of angles and coefficients spanning the semi-circular angular interval [0, 180] degrees must be specified using the indicated maximum number of values. This semi-circular interval is extended internally to the full circle [0, 360) assuming bilateral vessel symmetry.

• The angle array must be monotonic, beginning with 0 degrees and ending with 180 degrees, and must contain at least two values. Conventional choices include 19 values at 10 degree increments, 13 values at 15 degree increments, or 10 values at 20 degree increments, although any monotonic angle array may be used and the increments *need not be uniform.* Coefficient values for intermediate angles are determined from the specified arrays by interpolation.

• Wind *and* current coefficients [Cx, Cy, Cz] determine the corresponding forces (Fx, Fy) and moment (Mz) according to the original OCIMF *wind* prescription:

$$Fx = .5*Dm*Cx*Ah*V^2$$
$$Fy = .5*Dm*Cy*Ab*V^2$$
$$Mz = .5*Dm*Cz*Ab*LBP*V^2$$

Here "Dm" and "V" are water (or air) mass density and speed; Ah and Ab are the relevant specified head-on and beam-on projected vessel areas; LBP is length between perpendiculars (also called Lpp) or vessel waterline length.

Note that the original report called the moment coefficient "Cxy".

Caveat:

For undisclosed reasons, the longitudinal OCIMF '77 *current* force definitions differed from the (sensibly chosen) *wind* force definitions in that the OCIMF "Cx" current coefficient, which we will distinguish here with a prime (Cx'), was based on submerged *beam-on* area rather than *head-on* area. That is,

$$Fx = .5*Dm*(Cx')*Ab*V^2.$$

For this reason, the "Cx" current *coefficients* (but not the *forces*) as defined by SeaSoft and OCIMF differ by an (angle-independent) constant factor of (Ah/Ab), the SeaSoft coefficients being larger.

```
+++  Wave Model Selection  +++

1) User-Specified DRFTCOFS.txt
2) Tanker (Legacy)
3) Semi (Legacy)
4) Buoy
5) Caisson Spar
6) Tanker (2001)
7) Semi/TLP (2001)
```

SubScreen 10g: This SubScreen provides for specification of wave drift coefficients.

Regular wave drift force coefficients [Cx, Cy, Cz] determine the corresponding forces (Fx, Fy) and moment (Mz) according to the following prescription:

$$Fx = .5*Dw*Cx*B*a^2$$
$$Fy = .5*Dw*Cy*LBP*a^2$$
$$Mz = .5*Dw*Cz*LBP^2*a^2$$

Here "Dw" is water *weight* density, "a" is regular wave amplitude, B is vessel beam and LBP (or Lpp) is length between perpendiculars or waterline length.

Item 1:

User specification of wave-drift coefficients requires a supplemental user-prepared database file permitting evaluation of wave coefficients [Cx, Cy, Cz] at any wave period for every vessel-relative wave direction. The database must be available to the simulation in the form of a text file ("DRFTCOFS.txt") with a particular structure. See Appendix D.

Item 2:

The "Tanker (Legacy)" wave drift force implementation was the default built-in tanker model prior to SeaSoft version 4.4. It has been superseded by the "Tanker (2001)" implementation but remains available for backwards compatibility. It comprises a mixture of empirical wave drift data from a variety of sources and an assortment of displacement-hull vessel types. Head-on (Cx) coefficients lean heavily on careful

wave drift measurements for VLCC tankers possessing "Conventional" (V-shaped waterline profile) bow shapes. The empirical data have been non-dimensionalized and tied to the important natural periods of heave and pitch for application to vessels geometrically similar in underwater form to VLCCs. A simplified bow-stern symmetric waterline profile is used in conjunction with the empirical data and with analytical short-wavelength results in order to produce the required wave-drift force and moment coefficients.

Item 3:   The "Semi (Legacy)" wave drift force implementation comprises a mixture of empirical wave drift data from a variety of sources, combined with analytical short-wavelength results tied to user-specifiable waterplane shapes in order to produce the necessary wave-drift force and moment coefficients. The model is azimuthally symmetric; that is, it produces zero wave drift moment for all incident wave directions. For most semisubmersible applications, the "Semi/TLP (2001)" model will produce more satisfactory results.

Item 4:   The "Buoy" wave drift force implementation comprises a mixture of empirical wave drift data from a variety of sources in conjunction with analytical short-wavelength results in order to produce the required wave-drift force coefficients. The empirical data relates to azimuthally symmetric puck-shaped bodies with relatively small draft-to-beam ratios (as contrasted to spar-shaped bodies with large draft-to-beam ratios).

Item 5:   The "Spar" wave drift force implementation derives from a wave-diffraction analysis of long vertical circular cylinders penetrating the waterplane.

Item 6:   The "Tanker (2001)" wave drift force implementation became the default built-in tanker model at SeaSoft version 4.4. It addressed several theoretical and practical limitations of the "Legacy" Tanker Model that it replaced. In particular, the new model permits user specification of fore-aft vessel asymmetry and limited control over the long-period fall-off behavior of head-on and beam-on wave drift coefficients. It supersedes the "Legacy" model, which remains available as an option for backwards compatibility.

Item 7:   The "Semi/TLP (2001)" wave drift force implementation derives from a wave-diffraction analysis of a distributed array of vertical circular cylinders penetrating the waterplane. It is generally superior to the "Semi (Legacy)" model.

```
 ****   Screen 11: Vessel External Force/Moment Specification   ****


 1) ++> Simulate auxiliary force/moment on vessel:    Yes

 2) Coordinate system of applied force .......    <<global>>
 3) Force applied to .......................    <<vessel>>
 4) Mean X force component ...................         .00 kips
 5) Mean Y force component ...................         .00 kips
 6) Mean applied Z moment (force couple) value   0.000E+00 k. ft-lbs
 7) Spectral value of force at resonance .....   0.000E+00 (kips)^2/(rad/s)
 8) Spectral value of Z moment at yaw resonance  0.000E+00 (ft*kip)^2/(rad/s)
 9) Force-related damping at resonance .......         .00 percent
10) Moment-related damping at yaw resonance            .00 percent
11) Peak Factor Multiplier ..................         Rayleigh


   <<Vessel>>-System Coordinates of Applied Force:

12) Applied force X-coordinate (from c.g.) ...        .00 feet
13) Applied force Y-coordinate (from c.g.) ...        .00 feet

21) ++> Simulate SECOND auxiliary force/moment on vessel:    No
```

Screen 11: This SubScreen provides for user-specification of externally-applied forces and moments as might be necessary to simulate the action of thruster, tugboats, drag-producing appendages, etc.

Item 1: Up to three independent steady or variable forces and/or moments, defined in either a vessel-fixed or globally-fixed coordinate system, can be applied to simulate the action of thrusters, tugboats, constant tension lines to an earth-fixed point (for model basin testing support), or to mimic environmental or other applied forces which have no built-in method of implementation, such as hydrodynamic vortex-induced oscillations acting on the vessel or mooring system.

Item 2: The applied force components can be specified relative to either a vessel-bound or globally-fixed (and stationary) coordinate system. For example, the action of a vessel-attached thruster would require a vessel-fixed specification, while a tugboat pulling in a constant earth-fixed direction should utilize the global system.

Applied moments (which, in this context, are pure force couples) are restricted to a vertical axis.

Item 3: The force and moment can be applied to either the vessel or to the mooring structures. This is a subtle distinction that affects how net vessel load estimates are reported; a simple example will highlight the difference:

In a turret-moored FPSO, a constant "extra" force applied to the *vessel* (say, by a line from the stern to a tugboat) will be passed directly through the turret to the mooring system, which will provide the ultimate reaction against the "extra" force when the system is in static equilibrium.

In this event the "extra" force obviously must be included by the simulation in the reported net mooring loads; note in this case the "extra" force would clearly also be included in the output of a vessel-bound transducer mounted so as to measure net structural loads in the turret.

The same "extra" force applied to the *mooring lines* just below the turret fairleads produces about the same vessel offset, but has little effect on reported (or measured) net turret loads since the mooring system reaction takes place below the fairleaders on the turret.

Evidently, in this comparison, the two options would result in net vessel loads that differed essentially by the "extra" applied force.

Items 4 & 5:   (x,y) components of the net force are applied at the point specified on the vessel. The coordinates of this point are in the vessel coordinate system, a right-handed system with x pointing towards the bow and y to Port (left when facing the bow). z is positive upwards. The plan-view origin of coordinates is the vessel center of gravity (AKA vessel centroid; see page 13 for additional discussion).

Item 6:   The specified moment (actually, in this context, a force couple) is applied about an earth-vertical axis.

Note that any force not acting through the vessel center of gravity will automatically produce a moment about the cg independent of any other moments specified.

Items 7 & 8:   Temporal fluctuations in the applied force and/or moment (about the requested mean value) can be achieved by specifying a suitable force and/or moment spectral value at the appropriate system natural period. This value will produce excitation of the appropriate normal mode at the simulation-estimated resonance period. These estimates use standard vibration-theory methods for lightly-damped systems subject to a broad-band excitation.

Note: To simulate a variable force with zero mean, such as an excitation to mimic vortex induced vibration (VIV), combine negligibly small values for the applied force with a large spectral value; the components of the (small) mean force must reflect the desired direction of the variable force. For example, a VIV perpendicular to a North-South current flow might be represented by a (negligible) global mean force in the East-West (Gy) direction:

$(Gfx, Gfy) = (0, 0.1)$

combined with a suitably large spectral value.

Items 9 & 10:   One use of the "external force" option is to mimic the action of an external agent which also produces damping; a simple example would be a current force acting on a submerged vessel appendage. Such a current force produces an associated damping that can be included if desired using this option.

The damping value must be expressed in percent of critical, which requires a knowledge of the appropriate system mass and stiffness. Therefore, this option may require a preliminary simulation run to establish the necessary system values. The generic single degree-of-freedom equation of motion is:

$$M(d^2x/dt^2) + C(dx/dt) + Kx = F(t)$$

Where M is system mass, C is an effective linear damping coefficient, K is the system stiffness (or "spring constant"), and F is an applied forcing function. To use this option, you need to first estimate "C" above for your case. For example: In the low-speed limit of a square-law flow normal to a submerged appendage, the "C" value would be

$$C = 2*F/V$$

where F is the *mean* current force on the appendage and V is the mean current speed. The percent damping contribution from this current acting on the appendage would then follow from:

$$\text{Percent Damping} = C/[\text{Damping Conversion}]$$

where the "Damping Conversion" system constant for the appropriate degree of freedom (which is associated with 1% of critical damping and is constructed from the appropriate system mass and stiffness) is quoted in LOWOUT.

Item 11:   If a nonzero value for spectral force or moment has been specified, you may also specify the "Peak Factor Multiplier", which is the ratio of the "peak" response to its "RMS" value. This option is evidently irrelevant for constant forces which produce an RMS response value of zero.

The default selection is "Rayleigh", which will automatically apply the appropriate peak factor associated with Rayleigh distributed response peaks using the specified storm duration and fundamental oscillation period. Typically, this peak factor will be in the range of 2-4 for the slow oscillations (50-1000 seconds) and long durations (1-10 hours) typical of offshore systems.

For special purposes, however, a different peak factor can be specified. For example, to mimic a purely sinusoidal oscillation in a structure for which the response exhibits a peak factor ratio of sqrt(2), you would set the Peak Factor Multiplier to 1.414, which would produce, in the absence of other stochastic forcings, the desired sinusoidal peak values.

The "Rayleigh" option may be restored by entering a value of 0.

Items 12 & 13:   See discussion for Items (4 & 5) above.

Notes: • The (x,y) components of the net force and moment are applied at the point specified on the vessel. The coordinates of this point are in the vessel coordinate system, a right-

handed system with x pointing towards the bow and y to Port (left when facing the bow). z is positive upwards. The plan-view origin of coordinates is the vessel center of gravity.

- Any force not acting through the vessel center of gravity will automatically produce a moment about the cg. The moment specified here is independent of and in addition to any moment resulting from the action of the specified force.

Item 21:   This item will uncover the data block for a second independent auxiliary force/moment specification.

```
   ****   Page 11b: Dynamic Positioning Controls   ****


 1) Simulate Dynamic Heading Control:              Yes

 2) Global DP Heading Target ................        .00 deg
 3) DP-imposed Yaw Damping ..................        .00 percent
 4) Use simulation DP torsion spring estimate   No
 5) DP Torsional Spring Constant ............        .00 ft*kip/radian
```

Screen 11b: SubScreen to set Dynamic Positioning variables.

Item 1:   This item permits implementation of a simple dynamic heading control mechanism of the kind that might be achieved with laterally-disposed thrusters in a turret mooring system. In order to (approximately) emulate the action of these thrusters the target vessel heading and desired linear damping coefficients must be given. The simulation assumes sufficient thruster force to accomplish the requested control in the specified environment. The thrust required can be estimated by hand after the fact from thruster force and moment data provided in the simulation output stream.

```
****   Screen 13: Vessel Environmental Area, Moment and Enhancement Data   ****

 1) Simulate <<Wind>>?    Yes

 2) Head-on effective drag area ...................    7400.00 square feet
 5) Beam-on effective drag area ...................   23000.00 square feet
 8) Wind force enhancement factor .................       1.00


11) Simulate <<Current>>?    Yes

12) Head-on effective drag area ...................    9600.00 square feet
13) Head-on drag area centroid (y, from CG) ........        .00 feet

15) Beam-on effective drag area ...................   61000.00 square feet
16) Beam-on drag area centroid (x, from CG) ........        .00 feet

18) Current force enhancement factor ..............       1.00


20) Micromanage wave reflection (AKA "drift") settings?       Yes

21) Bow shape factor .............................       1.00
22) Stern shape factor ...........................       1.25
23) Wave reflection HEAD-ON enhancement factor .....       1.00
24) Wave reflection BEAM-ON enhancement factor .....       1.00
25) Wave reflection MOMENT enhancement factor.......       1.00
26) Variable wave reflection enhancement factor ....       1.00


30) Micromanage wave absorption (AKA "drag") settings?       Yes

31) Wave absorption HEAD-ON enhancement factor .....       1.00
32) Wave absorption BEAM-ON enhancement factor .....       1.00
33) Wave absorption MOMENT enhancement factor.......       1.00
34) Variable wave absorption enhancement factor ....       1.00
```

See Also: pp 31 ff   Screen 13: This Screen permits detailed specification of various wind, wave and current-related vessel parameters. The state of this Screen is context-sensitive; for example, items [3, 6] and [13, 16] are invisible unless there is, on Screen 10, a request for a "SeaSoft Barge" environmental force model.

Items 2, 5, 12, 15: These are the areas that will be used in calculating head-on and beam-on components of static and variable wind/current forces. They should normally represent the true above- or below-water areas of the vessel as projected upon the appropriate vertical planes. In unconventional circumstances, any values whatever can be used to create special effects.

Note: The OCIMF current loads use beam, length and draft rather than submerged areas as input variables; to duplicate OCIMF loads, the specified current areas MUST therefore equal draft times beam for head-on area and draft times length (Lpp) for beam-on area.

Items 3, 6, 13, 16: The "area centroid" parameters are displayed, for example, if a wind- or current-force model of type "barge" or "cylinder" was selected on Screen 10. They are required to determine wind/current moments acting on the vessel in accordance with the "simplified force-moment model" discussed in Chapter 3. The coordinate requested must be given in the vessel-fixed system. For tankers, the effect of off-cg area centroids and other asymmetries are *automatically* taken into account by the OCIMF '77 and NSMB '91 coefficients; in those cases these items are not displayed.

Items 4, 7, 14, 17: "Vertical area centroid" parameters are required for spar- or TLP- type vessels so that environmental overturning moments due can be estimated. These items are not displayed here because the effects they represent are ignored for ship-shapes.

Items 8 & 18: These parameters serve as adjustable "drag" coefficients which multiply, without regard to wind/current direction, all wind/current force and moment quantities. In this respect, they are redundant since the same effect can be obtained by scaling all the appropriate areas. They are useful, however, in keeping the correct areas for documentation purposes; they can therefore be regarded as effective drag coefficients. Their values default to unity, which will prove appropriate for most cases. The factors multiply all force/moment quantities for all forcing models (e.g., "tanker" *and* "barge") in the same way.

Item 20: This toggle provides access to several adjustable parameters of the built-in wave SeaSoft reflection force (AKA wave "drift" force) models. See also page 18 ff.

Note: Not all of these parameters apply to every wave drift model. In particular, the bow & stern "shape factors" are ignored for non-shipshapes (spars, semis, buoys, TLPs, etc.).

Item 21: The "bow shape factor" is used in the computation of wave reflection moments and head-on wave reflection forces for ship-shaped vessels. A value of 1.0 corresponds roughly to a conventional VLCC tanker bow. Smaller or larger values correspond to more sharply pointed or more blunt bow configurations respectively. The shape factor will normally lie in a narrow range (e.g., between 0.5 and 2.0), with an extreme upper bound of 2.78. Head-on reflection forces are proportional to this factor. For example, the default value of 1.0 might be increased to 2.0 to simulate a barge having an extremely blunt bow; this increase will produce an approximate doubling of head-on wave reflection forces as well as more subtle effects on computed wave-reflection moments.

Item 22: The "stern shape factor" is analogous to the "bow shape factor" and is used in the computation of wave reflection moments and stern-on wave reflection forces for ship-shaped vessels. A value of 1.25 corresponds roughly to a conventional VLCC tanker stern. Smaller or larger values correspond to more acute or more blunt stern configurations respectively. The shape factor will normally lie in a narrow range (e.g., between 1.0

and 2.0), with an extreme upper bound of 2.78. Stern-on reflection forces are proportional to this factor. For example, the default value of 1.25 might be increased to 2.0 to simulate a vessel having an extremely blunt stern; this increase will produce a 33 percent increase in stern-on wave reflection forces as well as more subtle effects on computed wave-reflection moments.

Items 23-25:   For *ship-shaped* vessels, the "wave reflection enhancement" factors govern the decline of regular wave reflection coefficients with increasing wave period. These factors can be used to modify the behavior of the built-in reflection force models.

For short period wave spectra, such as wind waves with a peak period of 7 or 8 seconds or so, these factors have very little effect on wave reflection forces. However, for spectra relatively rich in long-period waves, these factors can markedly affect the wave reflection force estimates.

Increasing the factors from their default values of 1.0 will produce an increase in the magnitude of long-period wave reflection coefficients. The coefficients are sensitive; you should never need to use factors more than 1.5 or less than .5. You can use Slowsim to explore the sensitivity to these factors of the reflection force coefficients.

Note: For *non* ship-shaped vessels (semis, spars, etc.), these coefficients act as simple constant multipliers that can be used to uniformly increase or decrease wave reflection coefficients at all wave periods. That is, they behave somewhat like the bow/stern "shape factors" do for ship-shaped vessels.

Item 26:   The "variable wave reflection enhancement factor" provides a simple method to independently adjust the strength of *slowly-varying* wave reflection-based force oscillations. This capability may be of use in simulating wave-basin test conditions which produce experimental wave group spectra inconsistent with the theoretical group spectra used in the simulation. This factor (default value 1.0) multiplies all low-frequency wave-reflection forcing functions (i.e., surge, sway and yaw). For simple linear mooring systems, the low-frequency VARIANCE of these variables will be multiplied by the same factor; for nonlinear mooring systems, variance changes will depend, in addition to this enhancement factor, on the details of mooring system and mean environment.

Item 30:   This toggle provides access to several adjustable parameters, analogous to the wave reflection parameters described above, for the built-in SeaSoft wave absorption force (AKA "drag" force) model. This is a higher-order wave effect that may produce an important low-frequency forcing and damping mechanism in some circumstances.

Items 31-34:   These wave absorption enhancement factors are simple multipliers, analogous to the similarly-named wave reflection enhancement factors, which are applied to the built-in wave absorption-based force and moment estimates. Default coefficients, as usual, are 1. Values outside the range [.5, 2.0] are not likely to be physically meaningful.

```
****   Screen 14: Wind Conditions   ****



1) Wind speed ....................................       60.00 knots
2) Wind heading .................................      150.00 degrees

3) Wind spectral type ...........................     Davenport
```

Screen 14: This Screen permits specification of wind speed, direction and spectrum.

Item 1:   This is the wind speed as measured 10 meters above the sea surface.

Item 2:   Angles are defined in a "right-handed" earth-fixed coordinate system with z positive upwards. The zero of angle is in the positive x direction; angles increase in a counter-clockwise direction. Thus, 90 degrees lies along the positive y axis. "Heading" is the direction towards which the wind blows, so a 180 degree wind blows towards negative x and a 90 degree wind blows from right to left. With a vessel heading of zero degrees, the global coordinate system coincides with the vessel coordinate system.

Item 3:   There are several options for wind speed spectra which characterize the time variation, or gustiness, of the wind.

```
-- Wind type --

1)   Davenport
2)   Legacy point spectrum
3)   Steady wind
4)   A.P.I.
5)   N.P.D.
6)   WINDSPEC.txt input file

Enter number of selection ("H" for help):
```

SubScreen 14a: Wind Spectral Types.

Item 1:   Selection of type "Davenport" will cause automatic calculation of all aspects of the variable component of wind force required for determining low-frequency oscillation amplitudes due to wind. The Davenport wind speed spectrum[4] is a widely-used spectrum characterized by mean wind speed and surface roughness. Surface roughness applicable to the sea surface has been preset, so that the only remaining parameter is the mean wind speed at the 10 meter level.

Item 2:   Selection of "Legacy point spectrum" will result in a prompt for the

---

[4] Davenport, A.G., "The Spectrum of Horizontal Gustiness near the Ground in High Winds", Quarterly Journal of the Royal Meteorological Society 87, 194, Apr. 1961.

value of a wind speed spectral density to be used in low-frequency computations. Selection of Item 2 with a spectral density of *zero* (that is, no time-dependent component of wind force or moment) will produce the same result as choosing Item 3 on this SubScreen since a steady wind has no time variation and produces no low-frequency vessel oscillations in the moor.

Note: *Any* user-specified empirical wind-speed "amplitude spectrum" must be normalized in such a way that the integral of the spectrum from $\omega = 0$ to $\omega = $ infinity is equal to the variance of total horizontal component of wind speed in the direction of the mean wind velocity vector. Note that the variance must be in units selected for the Simulation (viz. $(\text{m/sec})^2$ or $(\text{ft/sec})^2$). Here ω is the circular frequency variable (in radians/second) equal to 2π divided by the period. For the purpose of a "Point" spectrum, wind spectral density need only be specified at the anticipated natural frequency of surge or sway motion of the moored vessel. This extreme simplification is meaningful for two reasons:

• Because of typically weak damping associated with low-frequency motions of the system, only those spectral components with frequencies near to the resonant periods of the system contribute appreciably to motions.

• Low-frequency motions of typical moored vessels almost invariably occur at periods in excess of one minute, at which periods the spectra of physical interest are reasonably constant over bandwidths of importance.

Use of an empirical wind speed point spectrum may, if natural periods of motion are not at least approximately known, require that a preliminary simulation be carried out to first determine approximately the natural low-frequency resonant periods. This will allow determination of the correct spectral density to use in a second simulation execution.

Item 3:   A steady wind has no time variation and produces no low-frequency vessel oscillations in the moor.

Item 4:   For elevations less than 20 meters above the sea surface (the "surface layer" thickness), the American Petroleum Institute Wind Speed Spectrum is characterized by a single dimensionless parameter ("A" = $f_p z/u$ where z is elevation, u is mean wind speed and f_p is a frequency parameter with a range of possible values indicated by the "A" range below) in addition to the mean wind speed. "A" is normally confined to the range (.01<A<.1); the default value is (A=.025). For elevations "z" greater than 20 meters, the spectral value associated with the 20 meter level can be multiplied by $(20/z)^{0.3}$ and input manually using the "user specified spectrum" option, if necessary.

Item 5:   The Norwegian Petroleum Directorate (N.P.D.) wind speed spectrum is based on a one-hour mean wind speed as measured 10 meters above the sea surface. Like the Davenport spectrum, it is completely specified by a single wind speed value.

Item 6:   This item permits user specification of a wind velocity spectrum via a
               textfile input mechanism; see "WINDSPEC.txt" in Appendix D.

```
                ****   Screen 15: Current Conditions   ****

 1) Current speed .......................         2.00 knots
 2) Current heading .....................       180.00 degrees
 3) Current variation with depth .........    1/7 power law

 6) Current spectral type ................      Steady current
```

Screen 15: The material on this Screen, relating to environmental current
conditions, is similar to the material on Screen 14:

Item 1:   The current speed is specified at the surface.

Item 2:   As on Screen 14.

Item 3:   The current profile is used (1) for the determination of an "average"
               current acting on the submerged portion of the vessel and, if requested,
               (2) for estimation of current loads on subsurface mooring structures
               (lines, risers, etc.).

Item 6:   There are several options for current speed spectra which characterize
               the temporal variation of the current. See SubScreen 15b below for
               additional details.

```
+++ Current Profile Specification Options +++

1) 1/7 power law
2) No variation
3) User-Specified
```

SubScreen 15a: Current variation with depth specification. Note that
current variation with depth, as used in the calculation of mean current
loads on the vessel; is accomplished by evaluating an "effective" current
(the current averaged over vessel draft using the indicated profile) and
applying that effective current to the specified current areas.

Item 1:   A standard 1/7th power law is available. A "1/7 power law" means that
               current speed, in water of depth "D", decays with depth "H" below the
               surface according to

$$\text{Speed} = (\text{Surface Current}) * \{1 - H/D\}^{1/7}.$$

Item 2:   No variation, constant current with depth.

Item 3:   A flexible user-specified current profile is permitted allowing up to 5
               different current speeds to be defined at five levels below the surface.
               The current speed is assumed to vary linearly between specified levels.

Depth values must be positive, with the water surface corresponding to zero depth, and must increase monotonically down the table. An implicit data point comprising the surface current at depth = 0 is automatically included and should NOT appear as a first point in this array. For current-associated mooring loads, the last depth entry should correspond either (1) to the full water depth and bottom current if any, or (2) to a subsurface level with zero current speed.

```
+++ Current Type +++

1) Steady current
2) Legacy point spectrum
3) CRNTSPEC.txt input file
```

SubScreen 15b: Current Spectral Types. There are no built-in current spectral models other than "steady current"; all current spectral information must be user-supplied.

Item 1:   A steady current has no time variation and produces no low-frequency vessel oscillations in the moor.

Item 2:   Selection of "Legacy point spectrum" will result in a prompt for the value of current speed spectral density to be used in low-frequency computations. See the discussion of this quantity in Chapter 3. Selection of Item 1 on this SubScreen will produce the same result as Item 2 with zero spectral density assigned; that is, no time-dependent component of current force or moment; a steady current has no time variation and produces no low-frequency vessel oscillations in the moor.

Item 3:   This item permits user specification of a current velocity spectrum via a textfile input mechanism; see "CRNTSPEC.txt" in Appendix D.

```
 ****  Screen 16: Line Extension / Regular wave characteristics  ****


1) Regular wave characteristics follow
```

See Also: pp 25   Screen 16: This Screen permits toggling between "Line extension" and "regular waves" as the driving mechanism for achieving wave-frequency fairlead oscillations. Refer to Chapter 4 for additional details.

•   In the "Line extension" option, a fixed-amplitude (frequency-independent) motion tangential to the line at the fairlead attachment is imposed, at periods specified on the regular wave Screen. This option contrasts with the frequency-dependent fairlead motion amplitudes arising from direct wave action on the system (i.e., the "regular wave" excitation option). Although irregular waves and/or swell can be

specified in this case, they are used only for determination of equilibrium positions and low-frequency response. No wave-frequency responses are output, and no spectral analysis can be done, since this would require RAOs based on wave excitation.

- In the case this Screen is toggled to "regular waves", wave forces on the system produce frequency-dependent motions of the fairlead(s) whose amplitude and phase depend upon details of vessel physical characteristics and orientation; the latter being defined by mean position predictions made in the Low-Frequency Module of the Simulation.

```
           ****   Screen 17: Regular Wave Characteristics   ****


1) Number of different periods (Max 100): 15
2) Periods (seconds) --
     6.00          6.50          7.00          7.50          8.00          8.50
     9.00          9.50         10.00         10.50         11.00         11.50
    12.00         12.50         13.00         13.50         14.00         14.50
    15.00         15.50         16.00         16.50         17.00         17.50
    18.00         18.50

3) Use constant wave height or wave slope:   height
4) Wave height .............................          14.00 feet
```

See Also: pp 32 ff   Screen 17: The choice of regular wave periods (or line extension periods) determines periods at which RAOs will be computed. The period array specified here is also used for spectral integrations required to characterize motion and load response to random seas. The array should therefore span all wave periods at which substantial irregular wave or swell energy exists. Whenever irregular wave computations are to be done, the wave periods must be equally spaced; use the "auto repeat" feature, discussed further below, to assure equal spacing.

Item 2:   Selection of Item 2 results in appearance of a SubScreen which facilitates the required data input. Note that, as always, the wave direction convention used here is that of wave "heading"; a wave heading of 180 degrees corresponds to waves coming from 0 degrees.

Items 3-4:   The value of wave height or wave slope chosen effects the calculation of nonlinear responses. The wave slope/height selection is a toggle. As in Shipsim and its wave-frequency siblings, specification of wave height/slope affects computation of vessel roll response, in addition to other nonlinear hydrodynamic effects associated with the square-law drag and damping forces acting on immersed mooring lines. Generally speaking, simulation of irregular wave motion and load characteristics will be most faithfully executed by choosing a regular wave height or slope which, at the period corresponding to the peak of the irregular wave spectrum employed, produces a regular wave height equal to .707 (the square root of one-half) times the requested irregular wave height. Although line load response, being highly nonlinear, is extremely sensitive to the choice of regular wave height or slope, vessel motion RAOs are relatively insensitive to this parameter so that the important

statistical (RMS and storm peak) line load predictions, which are determined by the fairlead motions, are relatively insensitive to the value of the regular wave height chosen.

```
-- Table of periods (seconds) --

 1)     6.00      16)     13.50
 2)     6.50      17)     14.00
 3)     7.00      18)     14.50
 4)     7.50      19)     15.00
 5)     8.00      20)     15.50
 6)     8.50      21)     16.00
 7)     9.00      22)     16.50
 8)     9.50      23)     17.00
 9)    10.00      24)     17.50
10)    10.50      25)     18.00
11)    11.00      26)     18.50
12)    11.50
13)    12.00
14)    12.50
15)    13.00

27) Auto repeat

28) Delete a row & collapse array
29) Insert a null row & expand array

Enter number of selection ("H" for help):
```

SubScreen 17a: This SubScreen contains an example of the "auto repeat" feature of the Editor applied to the input of regular wave periods required for simulation. By selecting the auto repeat item number, prompts will be issued to permit automatic input of multiple values beginning at a user specified first value and separated by a user specified interval. The prompts for the required user input are self explanatory. If the auto repeat feature is not desired, specific values can be entered individually.

```
            ****  Screen 18: Irregular wave specifications  ****


  1) Simulate irregular waves?    Yes

  2) Wave type:  Bretschneider
  4) Wave heading:    180.00 degrees

                      -- Wave parameters --

  6) Significant height:      20.00 feet
  7) Spectrum peak period:    13.00 seconds

 20) Use long-crested irregular wave model
```

See Also: pp 34 ff   Screen 18: If irregular waves are required for the Simulation, the irregular wave toggle (Item 1) must be set to 'yes', which action will call up Screen 18 in its entirety (as shown).

Item 2:   Available built-in wave spectra fall into five categories: (1) One-parameter spectra (i.e., Pierson-Moskowitz, which requires significant wave height specification only); (2) Two-parameter spectra (Bretschneider and the specialized two-parameter JONSWAP spectra, which require specification of significant wave height *and* spectral peak period); (3) Five-parameter spectra (i.e., a full JONSWAP implementation); (4) The Legacy Custom Spectrum (which requires user-supplied spectral values at each period of the specified regular wave period array of Screen 17); and (5) the WAVSPEC.txt spectral option, which has no restrictions as to the period values used for spectral data.

          To change to a different spectrum choice, select Item 2 and a SubScreen will appear to accomplish the spectrum type selection.

Item 4:   The irregular wave heading, defined in the global coordinate system, is directly tied to the regular wave heading (Screen 18) in the Simulation, as discussed in Chapter 5. Setting of either will result in the setting of the other.

Items 6-7:   Depending on whether a single-parameter wave spectrum (i.e. Pierson-Moskowitz) or a two-parameter spectrum (e.g., Bretschneider) has been selected, one must specify the irregular wave height (one-parameter case) or wave height and spectral peak period (two-parameter case).

Item 20:   To simulate short-crested irregular waves representing an azimuthally spread distribution of irregular wave energy, Item 20 must be toggled to "Use azimuthal spreading of irregular wave energy". In this case items 21-23 will appear for the specification of wave spreading parameters. The peak of the wave spectrum, when considered a function of azimuthal angle for fixed wave frequency, is presumed to occur at the "wave heading" specified in item 4. Wave crest shortening is accomplished in the Simulation by assuming that the azimuthal

distribution of wave energy can be approximated by a power of the cosine of the angle away from the direction of maximum seas.

Note: Items 21-23 only display if item 20 is toggled to the "azimuthal spreading" option.

Item 21:   The wave spreading index is the power "p" of cosine in a "$\cos^p$" wave energy distribution with azimuthal angle. The wave energy spectrum is thus

$$S'(\omega,\theta) = S(\omega) \bullet K \bullet \cos^p (\pi \bullet \theta/\theta_c) \qquad\qquad -\theta_c/2 < \theta < +\theta_c/2$$
$$S'(\omega,\theta) = 0. \qquad\qquad\qquad\qquad\qquad\qquad\qquad abs(\theta) > \theta_c/2$$

where S represents the direction-*independent* wave energy spectrum, ω is wave frequency and θ is azimuthal angle, with $\theta = 0$ corresponding to the direction associated with the maximum seas. K is a normalization constant. Wave energy is evidently limited to an angular sector within $\theta_c/2$ degrees on either side of zero. θ_c must be > 0 but is otherwise not restricted.

Exponents ("p") in the range 2-4, and θ_c values near 180 degrees, have been found useful to match the azimuthal distribution of wave energy in many cases of naturally occurring wind-driven waves. Note that in principle the use of a very large spreading index in the Simulation should cause all measures of dynamical response to approach those obtained using the long-crested irregular wave model since long crested waves represent the limiting case of an extremely peaked azimuthal distribution. This can, in fact, be used as a test of the proper functioning of the azimuthal spreading feature. It should, however, be noted that the two methods of simulating long-crested waves, although theoretically equivalent in the limit of large spreading index, will in practice only lead to approximately the same results because of the built-in maximum spreading index (p = 67) and the limited fineness of the angular integration interval (Item 23).

Item 22:   This is the size (in degrees) of the angular sector encompassing all approaching wave energy ("θ_c"). θ_c must be positive but is otherwise not restricted. Historically, a value θ_c of 180 degrees has been used, simulating waves coming from one-half of the azimuthal circle, with zero energy at and beyond +/- 90 degrees from the direction of maximum wave energy. In most practical cases θ_c will be equal (or close to) 180 degrees; however, θ_c can have any positive value and can be adjusted to simulate conditions, such as the eye of a hurricane, in which wave energy approaches from *all* directions. Specifically, for values of θ_c greater than 360, the distribution of wave energy with angle will possess components from all directions. In particular, a very large value of θ_c will produce a wave field which is nearly azimuthally symmetric (equal wave energy in all sectors), as quantified in the expression for $S'(\omega,\theta)$ above.

Item 23:   The specified wave-energy sector "θ_c" must be broken into a user-specified number of angular wedges; this grid of wedges is used in the integration over angles required to characterize motion and load response

to seas containing azimuthally-spread wave energy. The number must be an even integer, which requirement is enforced by the program. The default value is 6, which means the angular spacing will be 30 degrees for $\theta_c = 180$. Although this seems rather coarse, the smoothness of the cosine function and the relatively slow variation in vessel RAOs with wave heading angle means that only a small number of angular intervals need be utilized in the integrations. The maximum assignable number is 12. The computer time required for simulation is a sensitive function of this number because vessel RAOs at all angular integration points must be computed whether or not their output has been requested by the user (only specifically user-requested RAOs are output--the rest are used in statistical calculations and then discarded).

```
 -- Irregular wave spectral types --

1)   Pierson-Moskowitz
2)   Mean JONSWAP
3)   Sharp JONSWAP
4)   Squat JONSWAP
5)   General JONSWAP
6)   Bretschneider
7)   WAVSPEC.txt input file
8)   Legacy Custom Spectrum

Enter number of selection ("H" for help):
```

See Also: pp 34 ff   SubScreen 18a: This is the spectral type option SubScreen. The detailed features of spectra provided are beyond the scope of this manual, but the following items should be noted:

Item 1:   The **Pierson-Moskowitz** spectrum is a widely used single-parameter spectrum comprising a specific representation of a "fully developed" wind-driven sea condition. Only the significant wave height is specified for this spectrum.

Items 2-5:   The **JONSWAP** spectrum[5] resulted from a synthesis of data compiled in the North Sea and is a five-parameter spectrum whose most notable characteristic is a somewhat narrower spectral bandwidth (i.e. a more peaked spectrum) than other widely-used spectra. Three special two-parameter cases of this five-parameter spectrum are incorporated into the Simulation in addition to the full five-parameter spectrum. The JONSWAP parameters for each of these cases follow:

Mean JONSWAP --> $\gamma = 3.3$, $\sigma_a = .07$, $\sigma_b = .09$

Sharp JONSWAP --> $\gamma = 4.2$, $\sigma_a = .05$, $\sigma_b = .07$

Squat JONSWAP --> $\gamma = 7.0$, $\sigma_a = .68$, $\sigma_b = .123$

General JONSWAP --> $\gamma, \sigma_a, \sigma_b$ user-specified

The "Mean" incarnation is the one normally identified with JONSWAP; the "Sharp" spectrum is somewhat higher and more narrow (i.e., slightly more swell-like) while the "Squat" spectrum has a lower spectral peak and is rich in long-period wave components and poor in short-period components.

"γ" above corresponds to the Greek letter gamma occurring in the referenced paper while "σ" above corresponds to the Greek letter sigma occurring in that paper. The elimination of three parameters of the five-parameter JONSWAP spectrum in the first three choices above reduces each of the three derived JONSWAP spectral types to a two-parameter spectrum. They therefore become completely defined once the significant wave height and spectral peak period have been selected by the user.

Item 6:   The **Bretschneider** spectrum is a widely used and convenient two-parameter spectrum which also requires specification of both significant wave height and spectral peak period. It has a somewhat greater bandwidth than commonly used JONSWAP spectra (although it can be represented by the full JONSWAP implementation with appropriate parameter values). It is equivalent to the so-called ISSC two-parameter spectrum except that one specifies the peak spectral period for the Bretschneider spectrum, while the ISSC spectrum is usually specified in terms of the mean period. The distinction is not important because either (mean or peak) can be derived from the other. The spectrum peak period has a much clearer physical significance and a much greater bearing on vessel motions than the mean period.

Item 7:   This item permits user specification of a wave height spectrum via a textfile input mechanism; see "WAVSPEC.txt" in Appendix D.

Item 8:   The **Legacy Custom Spectrum** is discussed below.

_____

[5] Rye, H., Byrd, R.C., and Torum, A., "Sharply Peaked Wave Energy Spectra in the North Sea", Offshore Technology Conference Proceedings paper #2107, pp 739, 1974.

```
  Specify spectral densities at regular wave periods

  1)      .00       16)       .00
  2)      .00       17)       .00
  3)      .00       18)       .00
  4)      .00       19)       .00
  5)      .00       20)       .00
  6)      .00       21)       .00
  7)      .00       22)       .00
  8)      .00       23)       .00
  9)      .00       24)       .00
 10)      .00       25)       .00
 11)      .00       26)       .00
 12)      .00
 13)      .00
 14)      .00
 15)      .00

 27) Auto repeat

 28) Delete a row & collapse array
 29) Insert a null row & expand array
 30) Add a constant value to each array element
 31) Add a constant value to each array element (modulo 360)
```

SubScreen 18aa: This "sub-SubScreen", which appears upon selection of item 8 on SubScreen 18a, allows input of a user-specified wave spectrum. The comments in Chapter 5 (page 34) are relevant here regarding the definition of this spectrum. Although "Auto repeat" input is allowed, it is of limited value here since the spectral densities at each wave period are not in general simply related to one another. No checking is done to see that values have actually been provided. If all values are zero, it is likely that the simulation will crash due to divide by zero errors in the statistical routines. To use the custom wave spectrum, wave spectral energy in appropriate units (ft^2sec/radian for English units; m^2sec/radian for metric) must be specified at each of the periods in the regular wave period array on page 102. The wave spectrum must be defined so that the total area under the spectral curve between angular frequencies of (0,infinity) is equal to the variance {"sigma squared", $(r.m.s.)^2$ or $(standard\ deviation)^2$} of the sea surface elevation.

Note: If the supplied spectrum is given in terms of Hertz (cycles/second) rather than angular frequency (radians/second), each spectral value must first be divided by 2π to convert to angular frequency values.

Because the spectral densities at each wave period are not in general simply related to one another, automatic input is not normally needed, although it is allowed. No checking is done to see that spectral values have actually been input when Item 8 of SubScreen 18a is selected. If they are all zero, the Simulation may crash due to divide by zero errors in the statistical routines.

```
                **** Screen 19: Background swell characteristics ***

 1) Specify background swell?       Yes


 2) Swell significant height:       10.00 feet
 3) Swell significant period:       16.00 seconds
 4) Swell spectral bandwidth:         .10
 5) Global Swell heading:          210.00 degrees
```

Screen 19: Setting the Item 1 toggle to "yes" produces a short menu to permit specification of a swell in addition to, or in lieu of, wind-driven irregular waves. The heading, significant height and period of the swell must be specified. The internal swell spectrum used is a Gaussian function of wave frequency, with spectral peak at the specified significant period and user-specified bandwidth (i.e., spectrum width at half maximum divided by peak frequency). The total area under the Gaussian curve is proportional to the ocean surface level variance. Because swell is assumed to be extremely narrow-banded, the swell spectrum peak period, swell significant period, average swell period, etc., are all assumed to be equal to each other. Angles are defined as for regular waves.

Note: A reasonable spectral bandwidth value, in the absence of better information, is the SeaSoft default value of 1/10.

```
                    ****  Screen 20: Output options 1 ****


  1) Output static offset data ............................... Yes
  2) Output element endpoint & angle interpolation tables ...... No
  4) Output mean orientation & line loads data ................. Yes
  5) Output low-frequency motions/loads data ................... Yes
  6) Simulate wave-frequency dynamics .......................... Yes

 16) Output wave-frequency fairlead motions and line load RAOs   Yes
 17) Output static/dynamic line load RAO comparisons at fairlead Yes
 18) Output wave-frequency line load RAOs at anchor ............ Yes
 19) Analyze wave-frequency motion/loads at specified LF offset  Yes

 20) Use large-amplitude nonlinear model for w.f. loads ........ Yes
 21) Apply inertial correction to wave frequency load model .... No
 22) Use constant energy surface for wave-frequency loads ...... No
 23) Use Moorsim-style 3-DOF equilibrium search ................ No
 25) Search for alternate equilibrium position ................. No

++> Begin Version 5.0 Flags

 30) Estimate current loads on mooring lines and risers ........ No
 31) Eliminate individual line load reports in SNAPOUT ......... No
 32) Use elliptical bounding box for snapshot coordinates ...... No
 33) Use "Legacy" current-wave drift force interaction model ... Yes
 34) Use "Legacy" peak low-frequency motion and loads model .... Yes
 35) Exclude wave absorption damping and excitation ............ Yes
 40) Prepare tab-delimited output summary file (XCLDAT.stxt) ... Yes
 41) Use basin load units (kiloNewtons) for XCLDAT.stxt file ... No

++> End Version 5.0 Flags


 51) Storm duration (hours) for peak motion/load statistics.....  6.00
 52) Estimate peak variability across an ensemble of storms .... No

 55) Apply clockwise rotation to Global Coordinate System
```

Screen 20: This is the first of two output options Screens. Most choices are toggles which enable or disable output from the various modules of the Simulation.

Item 1:   Selects/deselects output of the static offset interpolation table that is computed in the Statics Module.

Item 2:   Element endpoint data (endpoint positions and endpoint tangent angles) can be included or excluded from the output stream using this flag. Omitting this data considerably reduces the size of the interpolation table output file.

Item 4:   Selects/deselects output, at the environmentally produced mean offset positions, of a line tension and departure angle summary.

Item 5:   Selects/deselects output of motions and loads in the system arising from purely low-frequency oscillations in the moor.

Item 6:   Selects/deselects line and vessel wave-frequency dynamics reports. Execution time can be reduced, when only low-frequency dynamics are important, by toggling this item to "No".

Item 16:   Selects/deselects output of wave-frequency RAOs for fairlead motions and line loads. Output volume can be reduced by toggling this item to "No" when only irregular wave statistical summaries of motions and loads are desired.

Item 17:   Estimation of dynamic contributions to mooring line loads arising from wave-frequency fairlead motions is often accomplished by applying fairlead motions to the *static* offset curves for the mooring lines. This toggle permits line tension evaluation using this approximation, which can then be compared directly with the full nonlinear dynamic treatment used in the SeaSoft simulations.

Item 18:   Selects/deselects output of wave-frequency RAOs for anchor-end line loads.

Item 19:   Selects an alternative output format (one mooring line per page) for fairlead motion and line load estimates that eliminates low-frequency variations. Wave-frequency load statistics are computed about one of several possible vessel offsets from the mean position, including (1) zero offset, (2) points associated with the one or two standard deviation low-frequency offset, and (3) the peak low-frequency offset point associated with a storm of the specified duration. The offset point used is determined by the setting of the "one/two" sigma flag and the "Line Peak Load Calculation" option on the next output options page. Note that this option produces unreasonably low "peak" load estimates (entirely lacking a low-frequency contribution) when the "SeaSoft lower bound" algorithm for peak load estimation is selected.

Item 20:   This flag permits access to a more comprehensive nonlinear wave-frequency line load algorithm in lieu of a simpler algorithm valid in the limit of small amplitude fairlead motions. The small-amplitude algorithm is generally sufficient, is far less problematic, and is preferred whenever it is applicable (a runtime alert will advise if it is inappropriate). For very stiff systems (e.g., chain moorings in shallow water) the large- amplitude nonlinear model will give more precise wave-frequency line load estimates; in these situations the small-amplitude model will tend to underestimate the wave-frequency line load fluctuations. When in doubt, the simulation should be executed using both methods and the results inspected for differences.

Item 21:   This flag triggers a more comprehensive, but relatively untested, inertial correction to wave frequency line load estimates; this correction generally results in a modest reduction of mooring line and vessel loads which has not yet been thoroughly reviewed and verified; it therefore defaults to the "off" condition which produces slightly more conservative load estimates. This feature should be considered "pre-release" or "beta" quality until further notice.

Item 22:   When set to "yes", this option causes the component of fairlead motion along the normal to the surface of constant energy to be used as input to the wave-frequency line load estimator; the default behavior is to use the component parallel to the fairlead line tangent. In most cases, these two directions are very nearly parallel. This flag is available as an option to provide compatibility with early versions of "mooring feedback" simulations for small CALM-type buoys. In most cases, the "energy surface" option will produce differences in the wave-frequency load estimates of 20% or less (from the values using the default option) although in unusual circumstances the differences can be larger. This flag should be set to "No", the default value, unless you are quite confident you understand what you wish to accomplish by changing it.

Item 23:   This flag provides access to a generalized 3-degree of freedom equilibrium search algorithm, required for spread-mooring simulations such as Moorsim and TLPsim, for use in single-point mooring applications such as CALMsim, SPMsim and Towsim. This generalized algorithm is available to provide backwards compatibility with early versions of single-point mooring simulations, which used the generalized algorithm. Currently, single-point mooring simulations use a more efficient specialized algorithm that eliminates occasional failures to find a stable equilibrium configuration.

Item 25:   In some circumstances there exist two or more stable equilibrium vessel positions and orientations in the specified environment. These circumstances fall into two categories: (1) situations with crossed environmental conditions in which one of the stable equilibrium points is more stable than the other(s) and (2) situations such as a tanker moored in a current-only or waves-only environment in which there are generally exactly *two* equally stable (and hence, equally probable) equilibria. In the first case, the simulation generally seeks and uses the most stable equilibrium. In the second case, with two physically equivalent equilibria, it has no way to choose one over the other and in fact just selects the first one it finds. Setting this flag will force the simulation to select the alternate equilibrium point. This capability is used to force the Simulation to choose the *observed* equilibrium configuration when model-testing a bi-stable system such as a turret moor in a current-only environment; this facilitates comparison of simulation output with model test data.

Item 30:   Setting this flag causes the simulation to estimate the mean current load acting on each mooring line and to include those forces in the vessel equilibrium determinations and the net vessel loads and moments.

Item 31:   Setting this flag eliminates the (voluminous marginally useful) individual line load data in SNAPOUT, which then reports only net forces (Fx,Fy,Fz) and moments (Mx,My,Mz) acting on the vessel.

Item 32:   LOWOUT produces an estimate of the plan-view "bounding box" which describes the limits of motion of the vessel mooring centroid (turret for SPMsim, hawser or barge towline attachment point for CALMsim/Towsim, Lpp/2 for Moorsim, etc.). This bounding box estimate can be prepared assuming that the bounding region is rectangular

(the default) or elliptical. The elliptical calculation is less conservative in general (i.e., produces smaller vessel extremes) and therefore should be used with caution. It is relatively untested and should be considered a "beta" feature until further notice.

Item 33:   In order to reproduce the "Legacy" current-wave drift force interaction in effect prior to version 4.4, set this flag to "Yes". In general, this feature should only be used with one of the "Legacy" vessel models (e.g., Legacy Semisubmersible or Legacy Tanker).

Item 34:   In order to reproduce the "Legacy" Gaussian low-frequency peak motion and load model in effect prior to version 4.4, set this flag to "Yes". In general, this feature should only be used with one of the "Legacy" vessel models (e.g., Legacy Semisubmersible or Legacy Tanker).

Item 35:   In order to eliminate the effects of low-frequency wave absorption damping and excitation, set this flag to "Yes".

Item 40:   This flag is used to trigger output of a tab-delimited text file named XCLDAT.stxt, suitable for importing into a spreadsheet program. The file contains a tabular wave-basin-type summary of most dynamical variables of interest, including means, low-frequency, wave-frequency and total standard deviations and extremes for most dynamical load and motion variables. This file is a "work in progress" and should be considered a "beta" feature until further notice.

Item 40:   When metric units are in play, model basins generally report loads in kiloNewtons rather than historical metric nautical units (i.e., metric tons). This toggle controls the units used for loads in the XCLDAT.stxt output file only. Note that the conversion factor is the gravitational constant (approximately 9.81); i.e., 1 metric ton = 9.81 kiloNewtons.

Item 42:   (Sparsim only) Strong currents or high winds can affect somewhat the vertical force balance at equilibrium by so-called "suction" effects. This toggle permits an estimate of these effects to be included in vessel static and quasi-static pull-down computations. It is presently implemented for spars only.

Item 44:   (Sparsim only) In an attempt to better accommodate the high pretensions and steep fairlead departure angles characterizing spar moors, the default wave-frequency line dynamic algorithms used for Sparsim differ slightly from those used with the more conventional catenary profiles and pretensions characterizing SPMsim and Moorsim. This flag permits access to the more conventional SPMsim/Moorsim legacy algorithms.

Item 51:   Storm duration specification is required to estimate the peak value of statistical quantities such as wave height, vessel motions and line loads. Peak values are rather insensitive to this quantity for reasonable storm durations.

Item 52:   The "storm extreme values" normally quoted in offshore mooring system design analyses (and in the SeaSoft simulations) are, formally, the "most probable extreme" values for the specified environment and storm duration. That is, if one were to analyze an infinite ensemble of

"identical" storms (i.e., with equivalent mean environments as characterized by significant wave height and direction, wind speed and direction, etc.), and collect the observed extreme values (i.e., one value per storm) of any dynamical variable (low- or wave-frequency vessel motions, mooring loads, deck accelerations, etc.), one could construct a probability density for the likelihood of observing any particular range of values for that variable. In particular, the value associated with the maximum of this probability density function (the "modal" value) is, by definition, the "most probable peak" value for the specified environment. It is the most likely value to obtain if one were to choose at random a *single* storm in the infinite ensemble.

The probability density is not, however, infinitely narrow so that the ensemble-wide extremes of any variable have a mean, median and standard deviation in addition to the modal value. In fact, because of the shape of the ensemble-wide extreme value density, the ensemble-wide "mean" extreme value of any variable is always greater than the "most probable extreme" value. The standard deviation associated with these extreme values is rather sensitive to the number of cycles in the underlying process. Thus, for example, the standard deviation of the extreme low-frequency surge offset across the ensemble may be quite large since there are very few cycles of this process over a typical storm duration.

Setting this flag to "yes" will produce rough estimates of extreme value variability for selected dynamical quantities including low- and wave-frequency motions and loads. These estimates are intended to provide a qualitative measure of statistical variability when working from wave-basin or prototype data from a single storm realization.

Item 53:   Selection of this item facilitates a simple clockwise rotation of *all* global angular variables (line departure angles, wind, wave and current headings, vessel initial headings, etc.) through a specified angular increment.

```
┌────────────────────────────────────────────────────────────────────┐
│                   ****  Screen 21: Output options 2 ****            │
│                                                                      │
│                                                                      │
│   1) Use <<two>> sigma values for statistical estimates             │
│   2) Use spectral estimates for standard deviations (sigma)? ....   No │
│   3) Line peak load calculation treatment:                          │
│                                                                      │
│      ++> SeaSoft "upper bound" algorithm                            │
│                                                                      │
│   8) Output vessel motions summary ............................   Yes │
│   9) Motions & loads reported at "natural" rotation centers         │
│  10) RAO units for angular motions: degrees/ degrees                │
│                                                                      │
│  11) Create plotter file .....................................   No │
│                                                                      │
│  12) Debug option is off                                            │
│  13) Output goes to Disk, on logged drive                           │
│                                                                      │
└────────────────────────────────────────────────────────────────────┘
```

Screen 21: This is the second of two output options Screens. Most options are toggles.

Item 1:   Characteristic motions and loads are quantified by the standard deviation of these variable quantities. This toggle permits selection of either "one" or "two" standard deviations for the "characteristic" value of all low- and wave-frequency statistical variables.

Item 2:   Wave-frequency line load variations are problematic because of the highly nonlinear nature of load response to vessel motions. Vessel motions are easily quantifiable because they are Gaussian; motion histories and "characteristic" and "extreme" motions are therefore typified by an RMS value and a spectral decomposition. In contrast, characteristic and extreme loads must in principal be estimated using a non-Gaussian, non-spectral model or a temporal analysis of a load time history.

            Nonetheless, useful "characteristic" load estimates approximating the true standard deviation can be determined in the "frequency domain" in one of two ways: (1) As a quasi-linear spectral average of a "characteristic" line load RAO or (2) as the load response to a sinusoidal vessel motion whose amplitude and period reflect the RMS amplitude and spectral peak period of the vessel motions producing the load variation. The first method calculates characteristic loads by averaging over wave periods which average may be particularly useful for fatigue analyses. The second method, which samples only a single frequency from the input motion spectrum, is intuitively satisfying as the precise load response to a definable regular wave input.

Item 3:   Line load time histories can be characterized by a mean contribution arising from the specified pretension *plus* a mean environmental contribution *plus* a slowly varying (low-frequency) contribution *plus* a rapidly varying (wave-frequency) contribution. These are determined in the indicated order by the Simulation, with each calculation depending

upon all previous ones. Several built-in options exist to simplify and approximate the task of combining system response in the wave- and low-frequency regimes and to set bounds on peak line load values. For systems with relatively weak mooring nonlinearities, the various options will produce a narrow range of peak load estimates. For highly nonlinear mooring systems, the various estimates will be more dissimilar.

Item 8:   Selection of this item will cause a summary of vessel physical data, vessel wave-frequency motion RAOs and statistical data to be produced. This output, when requested, also contains detailed information regarding the motions at fairlead points on the vessel.

Item 9:   For a "free body" (e.g., a vessel in empty space, free of hydrodynamic influence), the center of gravity (or more accurately, center of mass) is that point to which an arbitrary force can be applied without producing *any* angular motions of the body. Due to coupling between fluid and vessel motions, the central role of the center of gravity in dynamical evaluations for floating vessels is compromised. For example, the "natural" roll center for a floating object lies at that point above the keel through which a transverse (sway-directed) force will produce *no* roll moment and hence no roll motion. Due to the presence of the enveloping fluid, this "natural" roll center lies in general somewhat below the vessel center of gravity; its position can be roughly described as the center of the combined vessel mass and hydrodynamic "sway added mass". Note that in general, the "natural" roll and pitch centers will lie at different levels above the keel, resulting from the inequality in sway and surge hydrodynamic added mass. Vessel forces and motions will be reported relative to the vessel center of gravity or the appropriate "natural" centers depending on the state of this toggle.

Item 10:   The RAOs for angular motions are commonly given in either dimensionless units (e.g., degrees of motion/degree of wave slope) or dimensional units (e.g., degrees of motion/foot of wave amplitude). This item toggles between these two common angular RAO conventions.

Item 11:   This toggle enables or disables production of a plotter file for use with a legacy SeaSoft plotting package (which is no longer available). Due of the advent of powerful special-purpose plotting packages and the great convenience of plot-capable spreadsheet programs, built-in plotting capabilities are no longer supported but the legacy output file remains available for backwards compatibility with the (discontinued) legacy software.

Item 12:   The "debug" option, when activated ("on"), causes multiple run-time prompts "Enter NBUG:" at which prompt a response of 1 (0) will produce (suppress) a rather unintelligible flow of debugging output to the Screen during program execution. The principal use of this feature is to aid SeaSoft in determining the cause of program failures. Its activation has no effect on program operation, other than a crippling reduction in execution speed and the need for user intervention at each "NBUG" prompt.

Item 13:   Governs selection of output device. Actual selection occurs on SubScreen 21b.

```
+++ Peak Line Load Computation Options +++

1) >>> SeaSoft "lower bound" algorithm
2) >>> SeaSoft "upper bound" algorithm
3) >>> API "two-sigma LF, peak HF" algorithm
4) >>> SeaSoft "two-sigma LF, peak HF" algorithm
5) >>> API "peak LF, two-sigma HF" algorithm
6) >>> SeaSoft "full joint probability distribution" algorithm

Enter number of selection ("H" for help):
```

SubScreen 21a: Peak Line Load Computation Options

Item 1:   The SeaSoft "lower bound" algorithm computes wave-frequency line
                load statistics assuming the vessel is at the *mean* position determined
                by the environment. In effect, this presumes that the extreme wave-
                frequency vessel oscillations occur with greatest likelihood near the
                mean offset position as the vessel undergoes low-frequency oscillations
                in the moor. Peak loads are then estimated by combining the peak
                low-frequency oscillation estimate and the peak wave-frequency load
                estimate according to a simplified statistical algorithm. This produces
                "most loaded line" peak load estimates lower than other SeaSoft options.
                When low- and wave-frequency load magnitudes are comparable,
                however, even the "lower bound" SeaSoft option may produce loads
                larger than *either* of the "API" options, which are particularly vulnerable
                to load underestimation in these circumstances. Note that the "Analyze
                wave-frequency motion/loads at specified LF offset" option produces
                unreasonably low peak load estimates (entirely lacking low-frequency
                contribution) when this algorithm is selected.

Item 2:   The SeaSoft "upper bound" algorithm computes wave-frequency line
                load statistics assuming the vessel is near the *extreme* low-frequency
                offset position produced by the varying environmental forces; that is,
                at the mean offset plus the *peak* excursion due to low-frequency vessel
                oscillations. In effect, this algorithm assumes peak wave-frequency
                vessel oscillations occur with greatest likelihood when the vessel is
                near its maximum low-frequency offset position as it undergoes low-
                frequency oscillations. This normally produces the largest peak load
                estimates in the "most loaded line" of all available options. Note that
                the auxiliary statistical output produced by the "Analyze wave-frequency
                motion/loads at specified LF offset" option will produce identical peak
                load estimates when this algorithm is selected. (See page 51)

Item 3:   The API "n-sigma LF, peak HF" algorithm produces peak load estimates
                by assuming vessel wave-frequency motions occur at the "n-sigma"
                low-frequency offset point, where n is 1 or 2 according to user
                specification. Storm extreme line load estimates are then produced
                according to a prescription advocated by the API in which the computed
                peak wave-frequency loads are added directly to quasi-static loads
                associated with the "n-sigma" low-frequency offset point (the "Analyze
                wave-frequency motion/loads at specified LF offset" option also uses

this procedure). The closely-related "SeaSoft n-sigma LF, peak HF algorithm" will produce larger load estimates in the most loaded line than the corresponding API method.

Note: When low- and wave-frequency load magnitudes are comparable, the available "API" options are vulnerable to load underestimation. In those circumstances, we strongly advocate use of the "Upper Bound" algorithm (the default). Better safe than sorry...

Item 4:   The SeaSoft "n-sigma LF, peak HF" algorithm, like the "API n-sigma LF, peak HF algorithm", assumes vessel wave-frequency motions occur at the "n-sigma" low- frequency offset point, where n is 1 or 2 according to user specification. Storm extreme line load estimates are then produced by combining the peak wave-frequency load estimates with the *peak* low-frequency loads according to a simplified statistical algorithm. The SeaSoft method will produce larger load estimates in the most loaded line than the API method; either will usually produce "most loaded line" peak loads intermediate between the "lower" and "upper" bound algorithms.

Item 5:   The API "peak LF, n-sigma HF" algorithm produces peak load estimates by adding the "n-sigma" wave-frequency load, computed assuming the vessel to be at its extreme low-frequency excursion point, to the quasi-static load associated with the same extreme excursion, in accordance with an API-recommended practice for peak load estimation. "n", which is user-specified, can be 1 or 2. In the most loaded line, this estimate will always be less than that produced by the "SeaSoft upper bound algorithm".

Item 6:   The SeaSoft "full joint probability distribution" algorithm implements a rigorous joint probability of occurrence treatment for wave and low-frequency motion and load statistical calculations. In this treatment, estimates of wave-frequency motions and line loads are carried out for a wide range of surge, sway and yaw configurations, each configuration representing a possible vessel position and orientation resulting from slow-drift oscillations in the moor. Each position and orientation is assigned a probability of occurrence using the statistical and dynamical properties of the low-frequency motions; these probabilities are then combined with wave-frequency vessel motions about each point to form the joint probability distribution function required for rigorous peak load calculations. (This algorithm is undergoing development and is not available for use at this time.)

```
>>> Output Device Selection: <<<

1) Console
2) Disc

Enter number of selection:
```

SubScreen 17b: This Screen permits selection of the device to receive output from the Simulation. The normal choice will be the disk, since

at the end of execution, output files can be viewed at leisure, inspected for errors and omissions and later sent to the printer if desired. Output vectored to the Screen will be lost once it scrolls by.

```
****  Screen 22: End of Session  ****


1) Exit to operating system and update data file
2) Exit to operating system WITHOUT updating data file

3) Execute simulation in interactive mode
4) Execute simulation in silent mode

5) Produce diskfile of input data
6) Produce "WAVEOUT" file containing regular wave kinematics data

7) Import vessel and environment data from an external file
8) Import mooring system data from an external file

  (Press <RETURN> to review data.)

Enter number of selection:
```

Screen 22: This is the final Screen image of the Editor.

Item 1:   This option will save the current *DAT data file (and, if necessary, produce appropriate *BAK and/or LASTBAK backup files) and exit to the operating system. It is used to "save" an incomplete *DAT data file prior to completion of data entry (to avoid data loss from unexpected power outages, for example).

                 No error checking is involved in this operation; a save and exit will always be accomplished without further ado.

                 Be warned, however, that repeated invocations of this option will cause the *original* data file to be lost "off the end" of the backup process as repeated [*DAT -> *BAK -> LASTBAK -> deletion] cascades take place. You should therefore always work on a copy of important data files lest you lose valuable data.

Item 2:   Permits exit of the Editor with *no changes* to the current data file; all data modifications made during the current editing session *will be lost.*

Item 3:   This option causes simulation execution to proceed with a comprehensive information stream directed to the console. This stream is useful for troubleshooting purposes. This is the same as the "E"xecution item available from any editor page or from the opening screen.

Item 4:   This option causes the normal console messages that accompany execution to be written instead to a text file ("Diagnostics.stxt"). Because console output is very CPU-intensive, executions will run to completion substantially faster with this option; batch operations in particular will enjoy a considerable speed increase.

The downside: Should unusual conditions be encountered during simulation, there is no mechanism for user control or intervention. Problematic simulations may therefore terminate prematurely in "silent" mode. These should be re-run in "interactive" mode because they can often be coaxed to completion with appropriate user response(s) to run-time error conditions.

Item 5:   Produces a diskfile named MOORIN.stxt (or SPMIN.stxt, or ...) of all Editor session Screen images for documentation purposes.

Item 6:   This option will produce a text file, "WAVEOUT.stxt", with comprehensive tables of regular wave properties applicable to the current simulation (including group and phase speeds, horizontal and vertical water particle accelerations, velocities and amplitudes, etc.) at each of the user-specified wave periods.

Item 7:   This option permits importation of vessel and environmental data from any SeaSoft data file. It is particularly useful for importing complex vessels such as Semisubmersibles.

Item 8:   This option permits importation of an entire mooring system from any SeaSoft data file.

Notes: The source data file(s) for Items 7 and 8 can be from any simulation, but should have been created by or updated to the same version number as the importing application or the imported data may be corrupted. For example, to import Semisubmersible vessel data from a prehistoric "legacy" Moorsim project, you must first update the legacy MOORDAT (or SEMIDAT) file using the *current* version of Moorsim (or Semisim).

The file selection mechanism is very rudimentary to preserve cross-platform independence: The editor will produce a prompt to which you must supply, in the notation of your operating system, a valid *absolute* or *relative* path to the target file. Some examples:

• *Absolute* path to a file in any directory

        C:\SeaSoft\SPM\Proj_1\SEMIDAT   (Windows OS)
        HD3:SeaSoft:SPM:Proj_1:SEMIDAT   (Classic Macintosh)
        \SeaSoft\SPM\Proj_1\SEMIDAT   (Linux, Mac OS X)

The *relative* path method is simpler and is recommended, especially if the desired import file is in a deeply-buried directory. Place a copy of the target file in your working directory, give it a convenient short name (e.g., "ND" for New Data), and type that short name at the simulation prompt.

Then, for a resident file "ND" in the *working* directory, the *relative* path is simply:

        ND   (All Operating Systems)

Appendix A

Glossary

acceleration RAOs	These are acceleration responses to wave action at selected points on the vessel. Note that these are accelerations that would be measured by a vessel-fixed accelerometer, and are not second order time derivatives of the displacement RAOs.
added mass	Refers to the enhancement of inertial properties of a body undergoing accelerated motion in a surrounding fluid.
AKA	An acronym for "Also Known As".
angular wedge	The basic unit of angle used in numerical integrations involving angular-dependent quantities, such as wave amplitude spectra, for short-crested ("azimuthally spread") irregular waves.
Auto Repeat	A feature permitting rapid input of a long string of equally spaced input variables, such as regular wave periods.
azimuthal spreading	Refers to irregular sea conditions in which waves approach simultaneously from many directions; i.e., appear short-crested.
background swell	A long-period, long-crested wave underlying, and often obscured by, locally generated wind driven seas.
ballasted	Refers to a condition of partial load for a VLCC or ULCC which represents the smallest practical operational displacement. Normally definition is in terms of freeboard (with ballast condition freeboard typically defined as approximately three to four times full load freeboard); in this manual it refers to any tanker load condition, substantially less than full, which is more appropriately represented by characteristics of a lightly loaded vessel than a fully loaded one.
bandwidth	A characteristic width (in units of radians/sec or hertz) of a spectrum. Typically, this is the spectral width at or near the level at which the spectrum has fallen to one-half its peak; also sometimes used: The integrated area under the spectral curve divided by the spectral peak value.
bilge	The area at the bottom of a vessel where the nearly flat bottom turns upwards to form the nearly vertical side.
bilge keel	A protuberance, situated near the bilge, whose function is to create turbulence in the surrounding fluid during rolling motions, thereby dissipating roll energy and reducing the

	magnitude of roll excursions.
block coefficient	The displacement of a vessel at a given waterline divided by the product of its molded beam, length, and draft; a measure of the "boxiness" of the hull form (symbolized by Cb).
bounding box	The plan-view curve which forms an approximate boundary for mooring centroid locations during a simulation or model test run. This is generally limited to low-frequency motions (surge, sway, yaw), although in principle it could as well include wave-frequency contributions. In SeaSoft simulations, this "box" is specified as a rectangle or ellipse with suitable length and width (or semi-major, semi-minor axis) parameters.
bracketing	This refers to the procedure of selecting regular wave periods for a simulation of vessel performance in irregular waves; in particular the highest and lowest regular wave periods selected must "bracket" the periods in which the irregular waves, as characterized by the wave spectrum, possess substantial wave energy.
Bretschneider	A widely used two-parameter wave spectrum specified by the significant wave height and the spectral peak period.
Cargo Weight	The difference between "Displacement" and "Lightship Weight".
characteristic period	The ratio of the r.m.s. value to the r.m.s. rate of a particular dynamical variable; same as the zero-upcross period.
characteristic wind speed	The wind speed which would, if acting for an infinite period of time in deep water with no fetch limitations, create waves of the height specified in an irregular wave analysis request. It is a measure of severity of environmental conditions associated with specified sea conditions.
conventional bow	Refers to a conventional tanker bow design with prominent bulbous protrusion and a deeply notched profile; this bow is generally more sharply pointed in plan view than the contrasting "cylindrical" bow shape.
coordinate convention	In this document, x is positive forward, y positive to port (left when facing forward), z positive upwards; origin at vessel baseline directly below the center of gravity.
crossed sea	Simultaneous occurrence of two or more distinct and identifiable wave systems from different sources.
custom spectrum	A user-specified irregular wave spectrum for which values of wave spectral densities are individually specified at each wave period rather than computed from Simulation-resident formulas.

cylindrical bow

Refers to a tanker bow configuration which, viewed from the side, is indented to such a small degree that it appears almost cylindrical; when viewed from the top, this bow type is considerably more blunt and rounded that the contrasting "conventional" type.

Davenport

A widely used wind gust spectrum which is completely defined by the mean wind speed and a surface roughness factor.

deadweight (DWT)

Formally, the deadweight is simply cargo weight and comprises the difference between displacement and lightship weight; it is therefore a continuous function of mean vessel draft condition. However, for our purposes DWT refers to the design maximum deadweight, which corresponds to the maximum cargo carrying capacity of a VLCC and is commonly used as a standard measure of tanker size.

diffraction theory

A method for computing wave forces and moments on a body in waves which utilizes potential (ideal) fluid theory in conjunction with a finite lattice of fluid sources and sinks distributed about the body so that the boundary condition of zero velocity component normal to the body surface is approximately satisfied.

displacement RAOs

These characterize the motion of selected points on the vessel. They include contributions from all six degrees of freedom, combined with proper phase to produce three components (vertical, lateral and forward) of displacement at the indicated point. Coordinates are specified in the vessel-fixed frame, as are the components of motion.

double amplitude

See "single amplitude".

dry weight

Refers to the weight of an object out of water, in contrast to the submerged, or "wet" weight which is influenced by the buoyancy of the displaced fluid.

dynamic pressure

One-half of the mass density of a flowing fluid times the square of the flow speed.

dynamical variable

Any of the forces, moments, accelerations, velocities or motions that might be selected for dynamic analysis.

dynamically similar box

A special construct whose most important dynamical properties, including all mass, added mass and hydrostatic properties, are chosen to closely approximate those of the simulated vessel. The selection process insures, in particular, that the important natural periods of roll, pitch and heave are properly modeled.

enhancement factor

A multiplicative coefficient that can be assigned by the

	user to increase or decrease the relative importance of wind, wave and current forces on the vessel.
Epsilon	The "Fullness Parameter", or "Epsilon", is a measure of variation in waterplane area as draft is varied; an imaginary vessel whose waterplane area was independent of draft would have Epsilon = 1, while a "knife-keeled" vessel whose waterplane went to zero at zero draft would have Epsilon = 0. Epsilon is used internally to model variations of certain vessel hydrostatic properties with changes of draft.
floating point	Refers to a numerical variable in Fortran which is used and stored in memory in exponential format as opposed to simple integer ("fixed point") format.
frequency spectrum	A spectral density function whose independent variable is frequency, as opposed to period or wavelength or otherwise.
Froude-Krilov	Identifies the so-called "principal part" of the driving force/moment produced on a fixed structure in the presence of waves. It is the force that would be produced on a floating body were the pressure field due to the waves not affected by the presence of the body itself; a condition that is approximately realized in the long wavelength limit.
Full Load Draft	The design maximum draft of a vessel corresponding to the design maximum load for seagoing operations. This is sometimes known as Maximum Draft, Design Draft, Loaded Draft, Summer Draft, or in England as the Summer Draught.
fully-developed	The limiting sea condition associated with a given wind speed and fetch corresponding to an infinite duration of the specified wind conditions.
global coordinates	Any coordinate system fixed to the earth which provides a suitable reference system for definition of environmental forces and directions. The origin is at the mooring centroid.
GM	The vertical distance between the center of gravity and metacenter. Equal to KM minus KG. Transverse and longitudinal values are associated respectively with KMT and KML.
gyradius	The square root of the ratio between the mass moment of inertia of a body about its center of gravity and its mass. A measure of the angular inertia of a body.
high-frequency	Refers to frequencies contained within the bandwidth of naturally-occurring surface waves; for practical purposes, the range of periods indicated by this qualifier is three to twenty seconds.

high-speed	In this document, high-speed refers to speeds comparable to the phase speed of waves of primary interest to operations, namely six to sixteen seconds or so, which corresponds to deep water phase speeds of thirty to eighty feet per second.
Hull Area	The above- or below-water projected area of the hull, neglecting contribution from any superstructure such as deck houses or production equipment, subject to hydrodynamic forces of wind or current.
in-plane	Refers to points lying in a vertical aligned with the mean offset direction from the quiescent-condition mooring centroid to the displaced (environmentally-determined) mean mooring centroid.
input file	File produced by the Editor containing input data.
JONSWAP	The JOint North Sea WAve Project. A systematic study of North Sea wave conditions carried out in response to the high level of petroleum exploration and development activities there.
KB, KG, KML, KMT	The vertical positions of the center of buoyancy, center of gravity, and longitudinal and transverse metacenters, all measured from the keel baseline.
kgw	Kilogram weight; a unit of weight equal to 1/1000 of a metric ton.
kip	The unit of weight used when English units are selected. Equal to 1000 pounds.
Lightship Weight	The weight of vessel and machinery without crew, cargo or consumables such as stores or fuel.
long crested	Refers to naturally occurring waves, such as swell, which are highly unidirectional and possess long, unbroken wave crests and troughs.
low-frequency	In this manual this refers to oscillations whose period is much greater than periods associated with naturally occurring waves. In particular, the natural periods of oscillation of moored vessels fall in this category, these being typically from one to ten minutes.
Lpp, LBP	"Length between perpendiculars" is a common measure of vessel length that is generally quite close to the waterline length at maximum draft. It is usually about 5% less than the overall vessel length (LOA).
machine-readable	Data files which remain in machine-encoded format and which cannot be easily interpreted without a computer program equipped to display them, such as the Editor.

mainframe   A large data processing machine with special floating point mathematics processors, high speed circuitry and core addressing capabilities measured in hundreds of megabytes.

metric ton   The unit of weight used when metric units are selected. Equal to the weight of 1000 kilograms at a nominal gravitational acceleration of 9.8 meters/second**2, or roughly 2205 pounds.

moulded depth   For practical purposes, this is the profile height of the hull from keel to main deck level; it is by definition draft plus freeboard in this document.

N.A.   Not Applicable.

natural period   The period with which a vessel will oscillate in a particular degree of freedom, once displaced from equilibrium. For unmoored vessels, this only applies to degrees of freedom (roll, pitch, heave) which experience static restoring forces upon displacement from equilibrium. For highly asymmetric vessels, well-defined natural periods for roll, pitch and heave may not exist due to coupling between the degrees of freedom.

nonlinear damping   The damping associated with the finite viscosity of water is of the "square law" type for conditions of relevance. This means that response characteristics do not scale linearly with wave amplitude. For practical purposes, nonlinear effects can usually be ignored except near system resonances, where natural linear damping contributions, for instance those arising from wave radiation, are small.

paging   The facility in the Editor which permits progress through the input file in either the forward (with a "carriage return") or backward (by inputting a "B") directions.

period spectrum   A spectral density function using wave period as the independent variable, as opposed to wave frequency.

phase   The property of a dynamical variable such as the force or moment which, in the presence of a regular wave, indicates the timing of the maximum of that variable with respect to the occurrence of the wave crest at a prescribed datum, usually the waterplane centroid. A positive phase angle indicates that the maximum of the variable occurs in advance of ("leads") the arrival of the wave crest.

phase speed   The advance speed of a wave crest.

Pierson-Moskowitz   A widely used one-parameter wave spectrum which is completely specified by significant wave height and is characteristic of a fully-developed sea condition in deep water with an infinite fetch.

quasi-linear

This refers to a method of linearization of non-linear phenomenon, such as roll damping, which is accomplished by choosing a linear variable which behaves, in most important respects, like the nonlinear variable to be modeled. In the case of roll damping, this amounts to choosing a linear damping coefficient that produces the same dissipation per regular wave cycle at a given wave height as the true nonlinear roll damping. Unlike a linear damping coefficient, the "quasi-linear" coefficient will depend on the value of wave height selected.

quasi-static

This refers to dynamic phenomena which occur on a time scale which is so long that the system is at each instant very near to an equilibrium configuration; in particular acceleration, damping and other quantities which depend explicitly upon time derivatives of dynamical variables can be considered negligible.

RAO

The Response Amplitude Operator; in practical usage, this refers to the amplitude of the transfer function from wave height (or amplitude, or slope) to force, moment, or motion variables. Formally, however, the RAO includes both the amplitude and the phase of the transfer function.

S.A.

Single Amplitude. Also occurs in the form S.A./S.A. for "single amplitude over single amplitude" in the display of RAOs.

scale factor

The force and moment RAOs produced are presented in dimensionless form; except for yaw, these tend to a constant, non-zero value at long wavelengths in the deep water limit. (This constant value is 1 for heave, pitch and roll; for surge and sway the constant value may be greater than one.) The scale factors used to non-dimensionalize the force/moment RAOs are given in the force- and moment-specific printouts. For each degree of freedom, the physical force or moment is determined from the RAO value, the wave amplitude (or slope), and the scale factor by multiplying these three quantities together. The forces and moments for all degrees of freedom except heave scale with wave slope; heave scales with wave amplitude. The units of the scale factors indicate whether to use wave slope or amplitude as a multiplier in determining the dimensional force or moment.

shallow water

Shallow here refers to bottom influence on the phase speed and vertical pressure distribution of waves. For most practical purposes, water can be considered "deep" whenever its depth exceeds 1/4 of the wavelength. The effects of shallow water wave characteristics on vessel performance are taken into account.

sigma

The square root of the variance of a time history such as

low-frequency surge motions or wave-frequency loads. It corresponds to the root-mean-square (RMS) value (the standard deviation) of the variable. For many processes, the "significant" value is nearly equal to twice the sigma value.

significant   In most discussions of statistical properties of wave-excited motion or load variables, the significant value is defined as the average of the one-third highest occurrences of a particular record. For a narrow-banded process whose peaks are distributed according to a Rayleigh distribution, which for practical purposes includes most processes of interest to the offshore industry, the significant value is very nearly equal to twice the root-mean-square (RMS) value of the variable.

significant rate   This is a slight misnomer; in this manual it is twice the RMS value of the time derivative of a particular dynamical variable.

significant value   Formally, this is the average of the one-third largest excursions of a dynamical variable; in this manual it is taken to be twice the RMS value of that variable.

significant wave height   The average of the one-third largest waves in a particular sample of water surface elevations. For spectra of interest in offshore operations, this is very closely equal to four times the square root of the variance of the wave amplitude spectrum, which is also four times the root-mean-square deviation of the water surface from the calm water level.

significant wave period   The average period of the one-third largest waves in a particular statistical sample.

Simulation Draft   The mean draft associated with the desired partial loading condition for the target vessel.

single amplitude   This refers to the use of "single amplitude" (S.A.), or mean-to-maximum of variables in quoting RAOs or statistical measures of motions and loads. This is to be compared with "double amplitude" (D.A.) measure which is a measure of peak-to-trough, or maximum to minimum, values of a motion or load variable. The former is exactly one-half the latter, except that S.A./S.A. RAOs are exactly the same as D.A./D.A. RAOs, because the factors of one-half cancel out of the ratio.

spectrum peak period   The period corresponding to the highest spectral density value of a particular frequency spectrum. For well-behaved spectra, this is very close to the "significant period"; or the average period of the significant waves. This contrasts with the "average" wave period which is generally considerably smaller than the significant period and is therefore of limited value in the practical characterization

of wave periods.

strip theory

This is a theory of the "diffraction" type which is particularized to the case of long, slender vessels and short wave periods.

superstructure wind area

The projected areas (beam-on and head-on) of above-deck structures, primarily comprising the aft-end deckhouse in conventional VLCC designs.

toggle

This is a generic mechanism used to change an input variable having two possible values, such as metric versus English units specification.

turnaround point

This refers to any plan-view location of the mooring centroid at the instant of minimum vessel kinetic energy when the vessel, during its low-frequency meanderings, "reverses course" and begins to build kinetic energy once again as it is pulled back towards its equilibrium position by the mooring system and environment.

ULCC

"Ultra Large Crude Carrier".

variance

The total area under a spectral plot; it corresponds to the squared root-mean-square fluctuations of the spectral variable about its mean value.

velocity RAOs

These characterize the velocity of selected points on the vessel relative to an inertially fixed coordinate system. Note, however, that both point coordinates and velocity components are resolved in the vessel-fixed frame.

vessel-fixed

This refers, in particular, to a coordinate system fixed with respect to the vessel with x-axis forward, y-axis to port and z-axis vertical. The origin of this system is generally taken to be at keel level below the plan-view centroid of the waterplane area.

Vesselsim

This is the generic name used in some SeaSoft manuals to apply to any of SeaSoft's wave-frequency vessel motions modules, including Shipsim, Semisim, Discsim and Jacksim.

VLCC

"Very Large Crude Carrier".

waterplane coefficient

The waterplane area of a vessel at a given waterline divided by the product of its waterline beam and length; a measure of the rectangularity of the waterplane (symbolized by Cwp).

wave absorption forces

The energy-dissipating component of the so-called "wave drift forces". Also sometimes called the "wave drag" contribution. See also "wave reflection force". This coefficient is proportional in strength to the cube of the

wave amplitude and has historically been neglected in the analysis of wave drifting forces.

wave amplitude — Because waves are not symmetrical about the still water position, the "wave amplitude" as such is not a well defined quantity. This expression, where it occurs, refers to the vertical amplitude of water particle excursions at the surface. This value is equal to one-half of the wave height for waves satisfying the usual assumption of linearity (i.e. wave height "small" compared to wave length).

wave drift force — Historically, this force has been associated with "energy conserving" wave reflection and diffraction effects; that is, it was associated with what we now call the "wave reflection coefficient" (see below). However, we now know that energy dissipation via wave absorption phenomena also contribute in important ways to slowly-varying "wave drift forces"; as a result, the "wave drift force" is best considered a combination of wave reflection and wave absorption contributions.

wave heading — This is the direction which the waves are actually heading. Thus a 180 degree wave heading is associated with waves impinging on the bow; that is, they are "head waves".

wave height — The elevation as measured from a wave crest to the immediately adjacent trough.

wave reflection forces — The energy-conserving component of the so-called "wave drift force". This "second order" force, acting on a floating body in the presence of waves, is proportional in strength to the square of the wave amplitude; in an irregular sea it has a frequency spectrum with significant components at zero frequency (static force) and very low frequency. The low-frequency components, sometimes called "slowly variable wave-drift forces" contribute to the excitation of long-period oscillations in moored systems. See also "wave absorption force".

wave slope — The tangent of the angle which a regular wave surface, viewed in profile, makes to the horizontal at the point of maximum slope (near the still-water line).

wave spreading index — The exponent of cosine in the analytical description of angular distribution of wave energy used in the Simulation. The short-crested sea spectrum is assumed to be representable in the form f(a)S(w) where a is the angle relative to the direction of maximum seas, f(a) is a power of the cosine of that angle, and S(w) is the frequency spectrum of the wave amplitudes.

zero-upcross period — The ratio of the r.m.s. value to the r.m.s. rate of a particular dynamical variable; same as the characteristic period.

Appendix B

File Management

File Requirements

The file structures of all comprehensive simulations (CALMsim, Moorsim, SALMsim, Sparsim, SPMsim, TLPsim, Towsim) follow similar naming conventions, with the "root" of the simulation name in each case providing the identifying ingredient (i.e., CALM, Moor, SALM, Spar, SPM, TLP, Tow). In the following we will demonstrate file management using Moorsim as an example template.

For example: Because Moorsim and SPMsim are completely equivalent with respect to their file structures, the equivalence map of the relevant files between Moorsim and SPMsim follows:

```
Moorsim          ------> SPMsim
MOORDAT          ------> SPMDAT
MOORBAK          ------> SPMBAK
LASTBAK          ------> LASTBAK

LOWDAT           ------> LOWDAT
LOWBAK           ------> LOWBAK
LASTLOW          ------> LASTLOW
```

As discussed earlier, the Editor produces an unformatted binary input file called MOORDAT containing particulars of a given simulation including vessel, site and environmental characteristics. If any *user-input* environmental coefficients have been specified *within the editor*, these are saved in a binary input file called LOWDAT. (An alternate method comprises creating one more text-based coefficient files, referred to generically herein as "*.txt"; see Appendix D.) Once a satisfactory MOORDAT (and, possibly, LOWDAT and/or *.txt) file(s) has/have been produced, as determined by satisfactory output from Moorsim, these input file(s) should be *archived* for later use by giving them more meaningful names and/or placing copies in a meaningfully named archive directory along with a descriptive note. A copy of the archived file(s) can then, at any later time, be copied to the Moorsim working area on the disk, renamed if necessary, and Moorsim executed anew using the archived data. The same procedure should be used to archive the final copy of all *formatted* output for future reference. It is important to use meaningful names for the archival file copies (or directories or tar/zip archives, etc.) so that they may be easily identified later. (See page 6 ff.) The entire input/output package can further be compressed with any of a number of widely available compression and archival utilities (tar, zip, Stuffit, etc.) and saved for later reference.

Importance of Archiving MOORIN.stxt

It is *essential* to archive, along with the binary MOORDAT, LOWDAT, and formatted *.txt input files, the formatted MOORIN.stxt Editor mirror file produced at runtime. This is important because it is impossible to view the data in binary files without the Editor. Although it is SeaSoft policy to provide upgrade paths for data files as the Simulation's data structures change over time, these changes may in unusual circumstances make reading very old MOORDAT files problematic. In such cases it may be advantageous to create a new data file manually from an archived MOORIN.stxt file. Also, because creation and/or alteration of a LOWDAT file will be a relatively infrequent occurrence (because of the comprehensive collection of built-in environmental coefficient options), it is possible that LOWDAT will be overlooked occasionally at archive time. A lost LOWDAT can be rebuilt, if necessary, from the formatted MOORIN.stxt file which contains a textual version of the binary LOWDAT data. Note, however, that data provided in Appendix D-type text files is *not* recorded in MOORIN; if one of these files is lost, it is lost forever and cannot be retrieved from the MOORIN.stxt, MOORDAT or LOWDAT files.

Appendix C

Execution Errors

Runtime Problems

The amount of input error checking done by the Editor is rather limited, in keeping with the necessity of maintaining the high degree of flexibility required of programs which are to be operated by users with advanced technical abilities. By far the most common runtime errors are the result of physically unreasonable input data that has found its way into the Simulation. This kind of problem can arise from typographical errors, transcription errors or simple omissions of data. When runtime problems of any kind occur, the first course of action is to carefully inspect and re-inspect the input file, especially mooring system and vessel physical data, to be sure that the data is reasonable.

Since Moorsim calls Shipsim (or Semisim, or Discsim; generically "Vesselsim") whenever wave-frequency dynamic response of the mooring system is requested, one must first determine whether the runtime problem is in Moorsim or in Vesselsim. The vessel data summary provided in VESLSUM is useful in these cases.

True code-related runtime problems with Moorsim should be rare, although in any computer code of its complexity undetected bugs will inevitably surface from time to time. When all reasonable measures fail to produce a meaningful simulation, a bug report should be made to SeaSoft.

Error Messages

Error messages which may be encountered during the execution of Moorsim are of several generic types:

Operating System Error Messages

One class of error message, generated by the operating system and hence dependent on the computing platform, arise from any of a large class of problems, including failure to find Moorsim's executable modules or input files, inadequate disk space to store output files, etc. These messages are system-dependent and are beyond the scope of this manual.

Editor Termination Error Messages

Error messages issued by the Editor at the end of an editing session. These are of two types, fatal and nonfatal. Fatal errors will prevent exit from the Editor program until the offending error is corrected. Nonfatal errors are for information only; failure to correct these may or may not lead to meaningless simulation results. There are a *very* large number of these error messages, which are designed to be self-explanatory and to provide

suggestions for correcting any fatal problems. We provide here only a few examples:

• *++> Warning: discrepancy between regular and irregular wave heights. To disable warning, use regular ht = (irregular ht.)/sqrt(2).*

This warning message is issued when the regular wave height specified and the requested irregular wave heights do not satisfy the condition discussed on pages 32 ff and 102 ff. This is a nonfatal condition that may well be intentional; the Simulation will execute normally.

• *++> Fatal warning: Unequal RAO period intervals. Either deselect random wave option or go back to the RAO period table and equalize the period intervals.*

This fatal warning is issued when the RAO period intervals are not equally spaced, which condition is *required* whenever irregular wave calculations are to be carried out (See page 32). The Editor will not pass control to the Simulation while this condition exists; it *must* be fixed first.

• *++> Fatal warning: Vessel draft, beam or length incorrectly specified...*

The Editor found zero or negative vessel dimensions which would lead to simulation failure.

Moorsim-Related Error Messages

Error messages built into the mainline Moorsim Fortran source code often will suggest a course of action to correct the fault leading to the problem. Examples:

• *++> Iteration Overflow...*

This error may occur whenever an iterative procedure within Moorsim fails to converge. Iterative procedures are used in both the static offset calculations and the determination of static equilibrium points of the system. An error of this sort is usually caused by physically impossible or unrealistic input parameters.

• *++> Swell Outside Wave Period Range...*

This message will occur whenever a swell period outside the range of regular wave periods is passed to the Simulation. The period range should be expanded to include the specified swell period.

• *++> WARNING: specified initial conditions did not produce an equilibrium configuration in quiescent conditions but produced the following net forces and moment in the global coordinate system. Initial line tensions/departure angles have been modified to produce a quiescent-condition equilibrium configuration.*

This warning is issued when the user-specified fairlead positions, line

pretensions and plan-view departure angles did not produce a condition of zero net force and moment. See related discussion on page 38.

• ++> *Warning: User-supplied vessel RAOs not found; Dimensionless RAOs will default to unity.*

This message is issued when user-supplied vessel RAOs were specified but the required data were not found.

• ++> *Gamma function error in DMPINT*

• ++> *Possible iteration failure in DMPINT*

• ++> *FATAL error: unfixable roundoff error in DMPINT*

• ++> *FATAL error: NDIM > 80 in DMPINT*

• ++> *FATAL error: XU.GT.100 in DMPINT error checking loop*

These extraordinarily rare errors relate to the evaluation of low-frequency damping from wave-frequency line motions. When they occur, it is generally because the mean mooring line profiles are pathologic in some way (possess vertical line segments, etc.). Review the input and available output for pathologies and if the simulation will still not execute, contact SeaSoft.

• ++> *Convergence failure In SLOMOR/QDYNAM square-law damping algorithms... Check data file and rerun simulation OR input 99 after "<<RETURN>> to continue" prompt:*

This message may appear under normal circumstances; the input of "99" causes the Simulation to execute more iterations in order to produce convergence in the square-law damping algorithms. If the problem cannot be solved by repeated attempts, it is indicative of a pathology in the input data.

• ++> *Warning: A negative stress-strain curve slope was encountered in subline (element #n, type m). The slope value will be replaced by infinity (inextensible line) if you choose to continue.*

• ++> *Warning: A negative dry segment weight was encountered in subline (element #n, type m). The value will be replaced by zero (weightless line) if you choose to continue.*

These messages can occur when physically impossible line properties are encountered. The simulation will continue, first taking the indicated actions, or the user will be allowed to abort to investigate and correct the unphysical line properties.

• ++> *Warning: Singular denominator in orientation iteration loop.*

• ++> *Iteration failure in mean position determination:*

• ++> *Designated mooring arrangement is statically unstable. Finishing attempt at reconciliation; check departure angles, fairlead positions for* consistency.

These messages indicate that the Simulation is having problems determining the equilibrium vessel position in the specified environment. The problem may be an unphysical mooring layout, pathological static mooring offset tables caused by invalid line physical data, or, rarely, by numerical problems in the iterative algorithms. The input data and static offset tables should first be inspected carefully. If the problem is in fact numerical, it can often be solved by making a trivial change in the input data (such as a slight change in quiescent vessel heading, wind direction, etc.).

Vesselsim Errors

The appropriate user manual (Shipsim or Semisim) should be consulted for vessel-specific messages.

Fortran runtime errors.

These are errors trapped by the Fortran runtime package. They are typically announced in rather opaque jargon, with references to floating overflows, divide by zero, attempted square roots of negative numbers, and the like. They often result in immediate program termination; in any event the output is not likely to be useful even if the simulation runs to completion. In a complex engineering-oriented analysis code such as Moorsim the requirement of maximum flexibility of application is at odds with the highly protective programming practices normally associated with business software. As a result, Fortran runtime errors will from time to time occur. Some situations that may result in these errors include:

• Wave period too short. Wave periods less than three or four seconds can lead to runtime errors on some installations. To explore short period limitations for a particular computer and vessel type, simply execute Moorsim repeatedly with shorter and shorter periods and note where the first sign of trouble appears.

• Wave period too long. Same type of problem as too short a wave period.

• Irregular waves specified with zero significant height.

• Regular waves specified with zero height or slope.

Runtime problems will not normally develop if a physically reasonable range of wave periods is requested. Note that, strictly speaking, the parameter of importance in these discussions is not the wave period, but a dimensionless quantity involving the wave period and the physical dimensions of the body being simulated. The wave period values given here assume a body of typical offshore dimensions, that is, one measured in hundreds of feet.

Precision

Many calculations in Moorsim are carried out in Fortran single precision. The number of significant digits associated with single precision variables varies widely among different central processors and Fortran compilers, ranging from only six significant decimal digits to as many as eighteen. For this reason, occasionally a large input value, such as a vessel displacement of 1,000,000.00 will appear in the output stream as a different value, for instance 1,000,000.71.

Appendix D

User-Supplied Data Formats

Many of the built-in SeaSoft data structures and models can be superseded with user-supplied information in tabular ASCII (i.e., text) format. Available user-supplied modeling constructs comprise:

Vessel Wave-Frequency RAOs   (USERRAOS.txt)

Wind Force Coefficients   (WINDCOFS.txt)
Current Force Coefficients   (CRNTCOFS.txt)
Wave-Drift Force Coefficients   (DRFTCOFS.txt)

Wind Velocity Spectrum   (WINDSPEC.txt)
Current Velocity Spectrum   (CRNTSPEC.txt)
Wave-Energy Spectrum   (WAVESPEC.txt)

Slender-body elastic properties   (LINE_STRAIN_DB.txt)

General Comments

These user-defined input capabilities can be combined without restriction. The naming conventions are meant to be self-descriptive; the ".txt" suffix indicates they are *input* files, distinguished from *output* files which have a ".stxt" suffix.

The required user data files can be produced "by hand" using any text editor or word processor, or from electronically copied tabular output from any source. The data can be in any Fortran-compatible floating-point format, for example either ".123E-2" or ".00123", with any number of significant digits. Refer to the various sample data files given below (constructed to be unrealistically small to minimize manual display space).

Notes: • The data files *must* contain purely ASCII text characters (i.e., no formatting). The files are record-based, with one data record per line. Each line must end with the End Of Line(EOL) character(s) appropriate to the operating system being used. Normally, this will happen automatically provided the text file is prepared using tools on the computing platform hosting the simulation. Problems can arise in moving these data files across platforms (such as from Windows to Macintosh or Linux). In that event, the EOL markers will in general need to be modified to match those of the host platform using standard text-processing tools and procedures.

• The data files must reside in the working directory (i.e., the same directory as the MOORDAT file in use).

USERRAOS.txt and DRFTCOFS.txt

Although the two types of data are quite distinct, the structure of the "USERRAOS" and "DRFTCOFS" files is nonetheless similar. User data is provided at each of NAZ user-specified azimuthal wave headings (in degrees) for a one-dimensional array WARRAY(i) of NFREQ wave frequencies. This produces two-dimensional arrays (of RAOs or drift coefficients, as appropriate), with one RAO or coefficient for each (frequency, angle) combination. The specific format of these files is reflected in the Fortran code snippets used to read the files (see below). Data for arbitrary frequencies and headings are obtained at runtime by interpolation within the user-specified array. The maximum values of NFREQ and NAZ are currently 51 and 37 respectively for both "USERRAOS" and "DRFTCOFS"; any changes in these values can be found on-line in the relevant help item. NOTE: If both "USERRAOS" and "DRFTCOFS" are being prepared, they may each have their own independent NFREQ and NAZ values, (NFREQrao, NFREQdrft, NAZrao, NAZdrft) subject only to the maximum value limitation on each file type indicated above.

General USERRAOS and DRFTCOFS Notes:

- The frequencies in WARRAY should extend *beyond* the wave period limits specified on page 102 for RAO evaluation. This is because during simulation, response is evaluated at each of these periods. Thus, if the *period* array on page 102 has endpoints of 6 and 20 seconds, then WARRAY should extend on either end *beyond* the values (2pi/6 ≈ 1.047... and 2pi/20 ≈ 0.314...). In the event this condition is *not* met, a runtime warning will be issued and a linear extrapolation will be performed using endpoint data. Note that the use of the truncated endpoint values (i.e., 1.047 and 0.314) will likely produce the mentioned runtime warning for the RAO array of page 102 due to floating-point round-off error, while WARRAY endpoints of (1.048, 0.313) would eliminate the runtime warning. Note that the WARRAY values *must* be identical for each angle block; that is, the same WARRAY data will be represented and repeated a number of NAZ times in the data file.

- For consistency with usage throughout this documentation, wave "directions" are specified as wave *heading*s. That is, 0 degrees corresponds to stern-on waves, 90 degrees to waves approaching from starboard (propagating in the positive y direction), etc.

- To insure proper handling of circular symmetry in all conditions, the supplied angular array, containing NAZ elements, must comprise the *closed* interval [0, 360]; i.e., should contain data for *both* 0 degrees and 360 degrees, even though these are physically the same angle. Normally, this array will comprise equally-spaced angle points (for example 10 degree increments giving 37 angles in the closed interval [0, 360]), although equal angle increments are not a requirement.

- Each record in the data files, *including the last*, must be terminated by an end-of-record identifier (normally, a "carriage return" or "newline" character) or a runtime error will result.

- The file must terminate with at least one empty line; text appended below that empty termination line will be ignored (this can be used for documentation purposes, as in the examples below).

- No testing is done to assure that the arrays are complete or logically consistent; Slowsim is useful for testing the DRFTCOFS file for errors and the Shipsim, Semisim or Discsim applications are useful for testing the USERRAOS file for errors (by verifying that the *output* RAOs and/or coefficients match the user-specified *input* RAOs and/or coefficients).

Format of the DRFTCOFS Data File

The format of the "DRFTCOFS.txt" file is reflected in the following code snippet.

```
C  Begin Snippet

      IMPLICIT NONE
      INTEGER NFREQ, NAZ, IA, IW, UNIT
      REAL HEAD(NAZ), WARRAY(NFREQ), CX(NFREQ,NAZ), CY(NFREQ,NAZ), CZ(NFREQ,NAZ)
C
C  NFREQ     - Number of wave frequencies
C  NAZ       - Number of wave headings
C  HEAD      - Wave heading in degrees, [0,360] inclusive
C  WARRAY    - Array of frequencies (radians/second)
C  Cx,Cy,Cz  - Arrays of dimensionless drift coefficients at each frequency & angle
C
C  Read "DRFTCOFS"
C
      READ (UNIT,*) NFREQ,NAZ          !Number of frequencies & headings
      DO 50 IA = 1,NAZ                 !Outer, angle loop
          READ (UNIT,*) HEAD(IA)       !Wave heading in degrees
      DO 50 IW = 1,NFREQ               !Inner, frequency loop
          READ (UNIT,*) WARRAY(IW),CX(IW,IA),CY(IW,IA),CZ(IW,IA)
50      CONTINUE

C  End Snippet
```

DRFTCOFS-Specific Notes:

The coefficients and their signs are defined as follows: in a regular wave field of amplitude A, the forces and moment on a vessel of length LWL, beam BWL are represented by:

$$Fx = .5*WATRWT*Cx*(A**2)*BWL$$
$$Fy = .5*WATRWT*Cy*(A**2)*LWL$$
$$Mz = .5*WATRWT*Cz*(A**2)*(LWL**2)$$

Here, WATRWT is the weight density of water, Fx, Fy are the net x and y components of the wave drift force on the vessel (in the usual vessel-fixed coordinate system) and Mz is the wave drift moment about the plan-view centroid. Note that all coefficients are dimensionless, that the sign of the moment is given by the right-hand rule with z positive upwards, and the signs of the coefficients for a given angle and frequency are the same as the signs of the forces/moment.

A file with drift coefficient data at four frequencies for each of 9 headings might look like:

```
>>> Begin DRFTCOFS.txt example (data should be tab, comma or space delimited)
4         9
0.000
0.785     0.375     0.000     0.000
0.628     0.554     0.000     0.000
0.524     0.489     0.000     0.000
0.449     0.260     0.000     0.000
45.000
0.785     0.500     0.388     -0.044
0.628     0.739     0.426     -0.065
0.524     0.652     0.333     -0.057
0.449     0.346     0.163     -0.030
90.000
0.785     0.000     0.928     0.000
0.628     0.000     0.954     0.000
0.524     0.000     0.721     0.000
0.449     0.000     0.343     0.000
135.000
0.785     -0.500    0.388     0.044
0.628     -0.739    0.426     0.065
0.524     -0.652    0.333     0.057
0.449     -0.346    0.163     0.030
180.000
0.785     -0.375    0.000     0.000
0.628     -0.554    0.000     0.000
0.524     -0.489    0.000     0.000
0.449     -0.260    0.000     0.000
225.000
0.785     -0.500    -0.388    -0.044
0.628     -0.739    -0.426    -0.065
0.524     -0.652    -0.333    -0.057
0.449     -0.346    -0.163    -0.030
270.000
0.785     0.000     -0.928    0.000
0.628     0.000     -0.954    0.000
0.524     0.000     -0.721    0.000
0.449     0.000     -0.343    0.000
315.000
0.785     0.500     -0.388    0.044
0.628     0.739     -0.426    0.065
0.524     0.652     -0.333    0.057
0.449     0.346     -0.163    0.030
360.000
0.785     0.375     0.000     0.000
0.628     0.554     0.000     0.000
0.524     0.489     0.000     0.000
0.449     0.260     0.000     0.000

>>> End DRFTCOFS.txt example (note blank line terminates data)
```

Format of the USERRAOS Data File

The format of the "USERRAOS.txt" file is reflected in the following code snippet.

```
C  Begin Snippet

      IMPLICIT NONE
      INTEGER NFREQ, NAZ, IA, IW, UNIT
      REAL HEAD(NAZ), WARRAY(NFREQ)
      COMPLEX CUSRG(NFREQ,NAZ),CUSWY(NFREQ,NAZ),CUHEV(NFREQ,NAZ)
      COMPLEX CUROL(NFREQ,NAZ),CUPIT(NFREQ,NAZ),CUYAW(NFREQ,NAZ)
C
C  NFREQ    - Number of wave frequencies
C  NAZ      - Number of wave headings
C  HEAD     - Wave heading in degrees, [0,360] inclusive
C  WARRAY   - Array of frequencies (radians/second)
C  CUSRG,CUSWY,CUHEV - Complex Dimensionless RAO data at each frequency & angle
C  CUROL,CUPIT,CUYAW - Complex Dimensionless RAO data at each frequency & angle
C
C  Read "USERRAOS"
C
      READ (UNIT,*) NFREQ,NAZ     !Number of frequencies & headings
      DO 50 IA = 1,NAZ            !Outer, angle loop
          READ (UNIT,*) HEAD(IA) !Wave heading in degrees
      DO 50 IW = 1,NFREQ          !Inner, frequency loop
          READ (UNIT,*) WARRAY(IW),
     1                  CUSRG(IW,IA),CUSWY(IW,IA),CUHEV(IW,IA),
     1                  CUROL(IW,IA),CUPIT(IW,IA),CUYAW(IW,IA)
50        CONTINUE

C  End Snippet
```

USERRAOS-Specific Notes:

- The relationship between RAO amplitude and phase output by the various SeaSoft simulations (see Appendix Z for an example) and the complex quantities required for USERRAOS can be deduced from the following discussion for surge, which applies equally to all degrees of freedom:

  Vessel surge RAOs reported by Semisim, Moorsim, or any other SeaSoft application is quoted in terms of the amplitude and phase angle of the complex surge RAO. That is, at each required wave period and wave heading, the surge RAO is reported as an "amplitude/phase" combination (for example, .75/ -95.1 for an RAO amplitude of 0.75 and phase angle of -95.1 degrees). The corresponding real and imaginary parts of CURSG for that amplitude/phase pair are given by:

  $$\text{Real[CUSRG]} = \text{amplitude} * \cos(\text{phase})$$
  $$\text{Imaginary[CUSRG]} = \text{amplitude} * \sin(\text{phase})$$

- When importing RAO data from non-SeaSoft applications, keep in mind the SeaSoft phase angle convention in which a positive phase angle corresponds to a phase lead. If the imported RAO data is taken from an application with a different phase convention, the data will

need to be adjusted to comply with the SeaSoft convention before creating USERRAOS.

- Angular RAOs (roll, pitch, yaw) must be supplied in *dimensionless* form; i.e. degrees/degree.

- A file with RAO data for three frequencies at each of 5 headings might look like:

```
>>> Begin USERRAOS.txt example (data should be tab, comma or space delimited)
3      5
0.0
0.698  0.000  -0.070 0.000  0.000  0.001  -0.010 0.000  0.000  0.000  0.000  0.000  0.000
0.419  0.011  0.240  0.000  0.000  -0.266 0.159  0.000  0.000  0.034  0.115  0.000  0.000
0.299  0.081  -0.237 0.000  0.000  0.160  -0.010 0.000  0.000  0.017  0.480  0.000  0.000
90.0
0.698  0.000  0.000  -0.008 -0.450 0.007  -0.090 -0.020 0.004  0.000  0.000  0.000  0.000
0.419  0.000  0.000  0.210  -0.896 1.245  -0.742 -1.324 -2.891 0.000  0.000  0.000  0.000
0.299  0.000  0.000  0.468  -1.457 1.118  -0.072 -0.008 -1.180 0.000  0.000  0.000  0.000
180.0
0.698  0.000  0.070  0.000  0.000  0.001  -0.010 0.000  0.000  0.000  0.000  0.000  0.000
0.419  -0.011 -0.240 0.000  0.000  -0.266 0.159  0.000  0.000  -0.034 -0.115 0.000  0.000
0.299  -0.081 0.237  0.000  0.000  0.160  -0.010 0.000  0.000  -0.017 -0.480 0.000  0.000
270.0
0.698  0.000  0.000  0.008  0.450  0.007  -0.090 0.020  -0.004 0.000  0.000  0.000  0.000
0.419  0.000  0.000  -0.210 0.896  1.245  -0.742 1.324  2.891  0.000  0.000  0.000  0.000
0.299  0.000  0.000  -0.468 1.457  1.118  -0.072 0.008  1.180  0.000  0.000  0.000  0.000
360.0
0.698  0.000  -0.070 0.000  0.000  0.001  -0.010 0.000  0.000  0.000  0.000  0.000  0.000
0.419  0.011  0.240  0.000  0.000  -0.266 0.159  0.000  0.000  0.034  0.115  0.000  0.000
0.299  0.081  -0.237 0.000  0.000  0.160  -0.010 0.000  0.000  0.017  0.480  0.000  0.000
```

You can put file documentation here, after the last empty line...
```
>>> End USERRAOS.txt example (note blank line terminates data)
```

Format of the *WINDCOFS.txt* and *CRNTCOFS.txt* Data Files

File structure: The first line (or record) of the text file is the number of [Angle, (Cx, Cy, Cz)] data records present in the file, followed by the data records themselves, with one record per line.

The format of these files is reflected in the following descriptive code snippet.

```
C  Begin Snippet

      IMPLICIT NONE
      INTEGER NAZ, IA, UNIT
      REAL HEADING, CXARRAY(NAZ), CYARRAY(NAZ), CZARRAY(NAZ)
C
C  NAZ      - Number of environmental headings to process
C  HEADING  - Environmental heading array in degrees, [0,360] inclusive
C  CX       - Array of surge force coefficients (dimensionless)
C  CY       - Array of sway force  coefficients (dimensionless)
C  CZ       - Array of moment coefficients (dimensionless)
C
C  Read WINDCOFS or CRNTCOFS
C
      READ (UNIT,*) NAZ         !Number of angles
      DO 50 IA = 1,NAZ          !Angle loop
         READ (UNIT,*) HEAD(IA),CX(IA),CY(IA),CZ(IA)
50    CONTINUE

C  End Snippet
```

Usage Notes:

- The maximum number of [Angle, (Cx, Cy, Cz)] data records = 73.

- Angles are environmental "heading" angles, specified in degrees relative to the bow and increasing in a counter-clockwise direction (e.g., a direct bow-on current "heading" is 180 degrees).

- The (dimensionless) [Cx, Cy, Cz] coefficients are defined by their associated force/moment relationships:

  ```
  Head-on force = .5*Ah*Df*(V^2)*Cx
  Beam-on force = .5*Ab*Df*(V^2)*Cy
  Moment at CG  = .5*L*Ab*Df*(V^2)*Cz

  V  = Relevant (wind or current) speed

  Ah = Head-On Projected Area
  Ab = Beam-On Projected Area
  L  = Vessel Length
  Df = Relevant fluid (air or water) mass density
  ```

- The records in the file must span the entire circle [0,360] including the endpoints (since 0 and 360 represent the same angle, the "0" and "360" angle records will have identical [Cx, Cy, Cz] data.)

- The records should be ordered monotonically by angle, beginning with 0 degrees and ending with 360 degrees.

- The angle and coefficient values on each line can be in any floating point style; i.e., ".0011", "1.1E-3", "0.11E-2" are all acceptable.

- The angle and coefficient values on each line can be separated by any standard value separator, typically a comma or tab character.

- The file must terminate with at least one empty line; text appended below that empty termination line will be ignored (this can be used for documentation purposes, as in the example below).

- A file with coefficients every 10 degrees might look like:

```
>>> Begin WINDCOFS.txt example (data should be tab, comma or space delimited)
37
     .0, .509,  .000,  .000
   10.0, .492,  .085.  .011
   20.0, .321,  .133.  .021



  350.0, .492,  -.085,  -.011
  360.0, .509,   .000,   .000
```

You can put any amount of file documentation here, after the last empty line...
```
>>> End WINDCOFS.txt example (note blank line terminates data)
```

Here only the first three and the last two records have been displayed (the remainder omitted for brevity).

Format of *WINDSPEC.txt*, *CRNTSPEC.txt* and *WAVESPEC.txt* Data Files

File structure: The first line (or record) of the text file is the number of [Frequency, Spectrum] data records present in the file, followed by the data records themselves, with one record per line.

The format of both these files is reflected in the following descriptive code snippet.

```
C  Begin Snippet

      IMPLICIT NONE
      INTEGER NFREQ, IW, UNIT
      REAL WARRAY(NFREQ), SPECTRUM(NFREQ)
C
C  NFREQ    - Number of wave frequencies
C  WARRAY   - Array of frequencies [radians/second]
C  SPECTRUM - Array of spectral values [see comments below for units]
C
C  Read SPECTRUM
C
      READ (UNIT,*) NFREQ          !Number of frequencies
      DO 50 IW = 1,NFREQ           !Frequencies loop
         READ (UNIT,*) WARRAY(IW),SPECTRUM(IW)
50    CONTINUE

C  End Snippet
```

User Spectral Files: General Usage Notes:

- The maximum number of (frequency, spectral value) pairs = 61

- You must use circular frequencies (radians/second).

- The (frequency, spectral value) pairs must be ordered monotonically in the frequencies, with either ascending or descending values of frequency.

- The frequency and spectral value on each line should be separated by any standard value separator, typically a comma or tab character.

- The file must terminate with at least one empty line; text appended below that empty termination line will be ignored.

Windspec and Curspec Usage Notes:

- You must use speed spectral values in units appropriate to the simulation: (ft/sec)^2/(radian/sec) for English units; (m/sec)^2/(radian/sec) for metric. *Knots cannot be used in these files.*

- The frequency span must include all computed low-frequency modal periods. Generally, these periods will lie in the three decade range between 10 seconds and 10,000 seconds, so a radians/second frequency range of {.0005,.5} should be generous. The program will warn of frequencies lying outside the input range and will use linear interpolation on the endpoint frequency values to extrapolate outside that range.

- The spectrum must be defined so that the total area under the spectral curve between angular frequencies of (0,infinity) is equal to the variance {AKA "sigma squared", (RMS)^2 or (standard deviation)^2} of the speed. Note: If the originating spectral data is given in terms of hertz (cycles/second) rather than angular frequency (radians/second), each spectral value must be divided by 2*pi = 6.2832... to obtain the correct variance upon integration.

- A current spectrum file with 5 frequencies might look like:

```
>>> Begin CRNTSPEC.txt example (data should be tab, comma or space delimited)
5
.0006      30.0
.006       8.0
.012       1.7
.06        0.17
.12        0.02
```

You can put any amount of file documentation here, after the last empty line...
```
>>> End CRNTSPEC.txt example (note blank line terminates data)
```

Wavespec Usage Notes:

- You must use wave height spectral values in units appropriate to the simulation: ft^2/(radian/sec) for English units; m^2/(radian/sec) for metric.

- The frequency span must include the frequencies associated with the endpoint periods in the wave period array specified on the "regular wave" data page (see page 102), but the frequency values themselves need not match the wave period array. (Note that in this regard, the WAVESPEC.txt implementation differs from the "Legacy Custom Spectrum" implementation, which is less flexible.)

- The wave spectrum must be defined so that the total area under the spectral curve between angular frequencies of (0,infinity) is equal to the variance {AKA "sigma squared", (RMS)^2 or (standard deviation)^2} of the sea surface elevation. Note: If the originating spectral data is given in terms of hertz (cycles/second) rather than angular frequency (radians/second), each spectral value must be divided by 2*pi = 6.2832... to obtain the correct variance upon integration.

  A WAVESPEC file representing a narrow rectangular spectrum (RMS = 10, peak at 10 seconds) using 11 frequencies might look like:

```
>>> Begin WAVESPEC.txt example (data should be tab, comma or space delimited)
11
10.          0.
0.70         0.
0.69999      769.2
0.6981317    769.2
0.66138793   769.2
0.62831853   769.2
0.5983986    769.2
0.57119866   769.2
0.570        769.2
0.569999     0.
0.01         0.

Comment: This Spectrum has a sigma of 10.
>>> End WAVESPEC.txt example (note blank line terminates data)
```

LINE_STRAIN_DB.txt

> This data file can be used to provide elastic properties for any or all
> subline elements in the mooring system. See comments on page #####
> ff.

Format of the *LINE_STRAIN_DB.txt* Data File

> File structure: A repeating block of data, one block for each (type, subline)
> for which user data is to be specified.

> The format of these files is reflected in the following descriptive code
> snippet.

```
C  Begin Snippet

      IMPLICIT NONE
      INTEGER NBLOKS, NVALS(NBLOKS), ITYPE(NBLOKS), ISUBLINE(NBLOKS)
      REAL TENS_ARRAY(NVALS,NBLOKS),STRAIN_ARRAY(NVALS,NBLOKS)
C
C  NBLOKS        - Total number of user-specified tension-elongation blocks
C  NVALS         - Total number data values in the active block
C  IVAL          - Local data value index
C  LTYPE         - Line Type Index Array
C  LSUBLINE      - Subline Index Array
C  TENS_ARRAY    - Array of tension values
C  STRAIN_ARRAY  - Array of elongation (AKA strain) values
C
C  Read LINE_STRAIN_DB
C
      DO 50 IBLOK = 1, NBLOKS
      READ (UNIT,*) NVALS(IBLOK),LTYPE(IBLOK),LSUBLINE(IBLOK)  !Block properties
      DO 50 IVAL = 1,NVALS(IBLOK)                              !Block data input
         READ (UNIT,*) TENS_ARRAY(IVAL,IBLOK),STRAIN_ARRAY(IVAL,IBLOK)
50    CONTINUE

C  End Snippet
```

LINE_STRAIN_DB: General Usage Notes:

> A simple example data block, suitable for a linear tension-elongation (t-e)
> relationship [e(t) = .001*t] follows immediately below

```
>>> Begin sample data block
   2,1,3
   0.00, 0.00
   500.0,0.50

>>> End sample data block
```

> The first row (AKA "record") in each data block is the number of (t,e) data
> pairs in the block (= 2 in this example) followed by the line type (= 1) and
> the subline number (= 3) to which the block relates. The (tension, elongation)
> data follows immediately (2 rows of (t,e) pairs in this case).

Multiple data blocks, one block per subline, can be concatenated within the database file.

Data Block Notes:

- The first (t,e) value must be (0,0).

- The tension range should span at least 1.5 times the (user-specified) "Maximum interpolation table horizontal load" value on page 62.

- Numeric values can be tab, space or comma delimited.

- The maximum supported number of (t,e) pairs in each block is indicated in a note on the editor page, e.g.:

```
[You must provide a maximum of 30 (tension, elongation) values for
(type, subline) = (1,3) in the LINE_STRAIN_DB.txt database file.]
```

- The file name must be as indicated on the editor page note ("LINE_STRAIN_DB.txt" in this example; the file name may vary across operating systems).

- (type, subline) data blocks in the file must occur in the same sequence as their appearance in the editor, with no intervening blank lines.

- The file must terminate with at least one blank line.

- A LINE_STRAIN_DB.txt file containing user-specified tension-elongation data for three sublines (three data blocks) might look like:

```
>>> Begin LINE_STRAIN_DB.txt example (data is tab, comma or space delimited)
   2,1,1          ! First block with two data points for (type,subline) = (1,1)
   0.00, 0.00     ! First data point
   500.0,0.50     ! Second data point
   3,1,3          ! Second block with three data points for (type,subline) = (1,3)
   0.00, 0.00     ! First data point
   250.0,0.25     ! Second data point
   500.0,0.50     ! Third data point
   3,2,1          ! Third block with three data points for (type,subline) = (2,1)
   0.00, 0.00     ! First data point
   250.0,0.20     ! Second data point
   500.0,0.40     ! Third data point

>>> End LINE_STRAIN_DB example (note blank line terminates data)
```

Appendix E

Sample Problem

As a tutorial aid in the use of Moorsim/SPMsim (SPMsim has actually been used here; this is a *turret moor* installation), this appendix includes the data required to carry out a complete simulation of a fully loaded 150,000 DWT tanker, turret moored at the bow. Output generated by SPMsim corresponding to the input data presented is given in Appendix Z.

Input Data

Vessel Particulars:

1. Displacement	407000 k. lbs
2. Length	929.0 feet
3. Beam	146.6 feet
4. Draft	64.0 feet
5. KMT	61.0 feet
6. KML	1225.0 feet
7. VKB	34.0 feet
8. VKG	36.0 feet
9. Water plane area	126000 square feet
10. Pitch gyradius	232.0 feet
11. Roll gyradius	51.2 feet
12. Yaw gyradius	235.0 feet
13. Bilge radius	5.0 feet
14. Head-on wind area	7400 square feet
15. Beam-on wind area	23000 square feet
16. Head-on current area	9600 square feet
17. Beam-on current area	61000 square feet
18. Beam-on current area centroid	50 feet

19. Conventional bow (OCIMF '77 definition)

20. Full load condition ("100% loaded")

21. Computed pitch and roll damping coefficients

22. User-specified heave damping of 16%.

23. Computed pitch and heave periods

24. User-specified roll period of 14 seconds.

25. Computed surge and low sway/yaw ("sway") damping coefficients

26. User-specified high sway/yaw ("yaw") damping coefficients of 33%.

Fairlead Particulars:

1. Number of lines.. 8

2. Maximum line load... 1350 kips

3. Height of fairlead attachment........................... 90 feet

4. Forward position of turret centroid.................. 500 feet

Line Particulars:

- Type A (two sublines, six legs): 1000'x4.5 inch IWRC wire rope to fairlead; 1000'x4.5 inch stud-link chain to anchor; on the 6 fore- and aft-most mooring legs.

- Type B (one subline, two legs): 2500'x4 inch IWRC rope; on the port and starboard legs.

- Lines laid out in a regular radial array with 45 degrees between adjacent legs; one leg aligned with global 0 degrees.

- Pretension 75 kips in each line.

Environment Particulars:

Wind:

- Davenport spectrum with mean speed of 60 knots.

- Wind heading 150 degrees.

- Wind enhancement factor = 1.0 (default).

- Wind force coefficients according to the OCIMF '77 standard.

Current:

- Steady 2.0 knot current heading 180 degrees.

- Current profile with depth according to 1/7 th power law.

- Current force enhancement factor = 1.0 (default).

- Current Cx coefficients user specified as the COSINE of the attack angle [= COS(θ)].

- Current Cy coefficients according to the NSMB '91 standard with bow shape interpolated midway on (with bulb, no bulb).

- Current Cz coefficients according to the SeaSoft barge model.

Irregular waves:

- Bretschneider wave spectrum with significant height 20 feet and peak period 13.0 seconds; long-crested irregular wave model.

- Irregular wave heading 180 degrees

- Swell with significant wave height 10 feet, peak period 16 seconds and default bandwidth.

- Swell heading 210 degrees

- Default "Tanker 2001" wave drift and absorption coefficients

- Storm duration 6 hours

Regular waves:

- Periods from 6 to 20 seconds

- One second period intervals

- Constant wave height of 14 feet

Notes:

Several items in the input stream merit special attention:

- For this sample problem, we have selected the "2001" tanker wave drift force model and several other "2001" options that are tied to the "2001" tanker model (wave absorption, current-wave interaction, peak low-frequency motion and load model).

- The turret is forward of tanker center, as indicated by the positive sign of the x fairlead coordinates. Had a stern-to mooring been adopted, the sign of the x fairlead coordinates would have been negative.

Screen Display

The Screen displays included in Chapter 7 are printed images of the editor Screens which would be displayed upon the successful completion of input of the above data. The output from SPMsim for this sample case is presented in Appendix Z.

Execution Messages

During execution of SPMsim, Screen displays of two types are possible:

• The first type of Screen display occurring during program execution, which is not under the user's control, consists of simple messages indicating the program activity taking place at the moment of message generation. This facility is useful when computation time is slow, either because of heavy system load on mainframe computers, or because of the naturally slow pace of a microcomputer.

• The second type of Screen output is that associated with the "debug" flag that can be turned on by the user, as discussed in Chapter 7. Setting this flag will cause a stream of numbers and messages to be projected on the Screen as various parts of the program are exercised. This will normally be of little value to the user except to aid SeaSoft in determining the cause of program failures.

Appendix F

On-line Tanker Model

An implementation of the SeaSoft Tanker Model is available, on-line, within the user interface of all relevant SeaSoft mooring and motion simulations. This implementation is analytically identical to the SeaSoft Minimal Data Tanker Model and produces a subset of Minimal Model properties corresponding to the supplied deadweight (as usual, in Long Tons of 2240 pounds) and Simulation Draft. Note that SeaSoft simulation requirements for vessel properties are simulation-dependent; Moorsim, for example, needs wind and current areas for execution while Shipsim does not. Because the same tanker help routine is shared by all simulations, not all displayed variables are relevant for every simulation.

Operation of the on-line model is largely self-explanatory; in addition it has an internal on-line help facility. There are only two user-specifiable variables (DWT in Long Tons and Simulation Draft in appropriate simulation units) from which the remaining vessel physical properties are inferred. The on-line window (shown below), which is updated with every change in either input variable, only *displays* estimates; it *does not* transfer data into the simulation data file until specifically so instructed by the user.

```
>>> Independent variables for    1. Deadweight (DWT).... 100000. Long Tons
    tanker property estimates:   2. Simulation Draft ...  22.00  feet

A. Vessel Displacement    123121. Kips    L. Freeboard-based load...    37.6%
B. Displacement-based load    44.1%       M. Draft-based load.......    46.6%

C. Length (LPP) ..........   799.76       N. Transverse KM .........    80.72
D. Beam .................   135.81        O. Longitudinal KM .......  2030.93
E. Draft ................    22.00        P. VKB....................    11.97
F. Roll Gyradius.........    56.93        Q. VKG ...................    36.53
G. Pitch Gyradius .......   205.92        R. Bilge radius ..........     6.24
H. Yaw Gyradius .........   213.64

I. Water Plane Area ......   96876.       W. Deadweight (DWT).......   100000.
J. Head-on Current Area ..    2988.       T. Head-on Wind Area .....    11157.
K. Beam-on Current Area ..   17595.       U. Beam-on Wind Area .....    37922.


>>> Change items 1 or 2 for new estimates or input letter(s) ("ACD...")
    to select individual replacements (or "Z" to replace all);
    "?" for help, <Return> to continue WITHOUT replacement:
```

On-Line Tanker Model Work Window

Data Replacement Options:

Options for selecting subsets of the displayed data for simulation use include (i) any single property, (ii) any subset of displayed properties or (iii) all estimated properties. To select a single property for inclusion in the simulation data file, supply the appropriate letter designator at the Screen-bottom prompt (e.g., "A", without the quotation marks). To select *all* properties input "Z" at the prompt. A subset of displayed properties is selected by supplying the desired letter designators with or without a non-letter separator; for example, to transfer to the simulation data file a subset comprising items "A", "C" and "Q" from the displayed estimates, any of the following are acceptable input strings: "ACQ", "A,C,Q", "A-C-Q". Input of letter values to the editor (as always, *without* quotation marks) is case insensitive; "Z" and "z" achieve the same result. A <return> is required at the end of any input string to activate the input process.

On first-time entry to the on-line tanker model facility during a given program execution, the tanker properties initially displayed depend on the value assigned to DWT and draft *prior* to first-time entry. If *either* DWT or draft are zero on entry, displayed variables take on values contained in the data file, if any. Otherwise, the displayed variables take on values associated with the entry [DWT, draft] combination. In this regard, it should be noted that since DWT is *not* required for Shipsim execution (or indeed anywhere *displayed* outside the tanker properties facility), DWT *will* generally be zero on first entry from within Shipsim (unless, perhaps, the data file in use was imported from a simulation, like Moorsim, which *may* contain a nonzero deadweight value).

Full Load and Lightship Data:

For a given DWT, the properties of either the fully-loaded vessel or the lightship can be obtained from the help facility in the following way:

> To obtain vessel properties associated with the fully loaded vessel, input a draft which is unrealistically large (e.g., 1000 feet or meters). After issuing a nonfatal error message, the facility will, if requested, return properties associated with the full load condition.

> To obtain vessel properties associated with the lightship (zero cargo) condition, input a draft which is unrealistically small (e.g., 1 foot or meter). Again, after issuing an error message the facility will, if requested, return properties associated with the lightship condition.

The minimum size vessel that can be accommodated by the on-line model is 2000 DWT. There is no maximum vessel size, although no tanker larger than about 600,000 DWT has been constructed at this writing.

The "freeboard-based load percentage" is defined as 100 times the ratio [(fully loaded freeboard)/(simulation freeboard)]; other load measures are simple ratios of the simulated quantities to their full load counterparts (e.g., [simulation draft]/[fully loaded draft)]).

Appendix G

Semisubmersible Wave Drift Considerations

The second-order wave drift characteristics of semisubmersible-type vessels are intimately connected to the details of vessel waterplane geometry, including water-piercing column layout and column shape (i.e., round or rectangular). Because semisubmersible designs differ widely in waterplane geometry, it is more difficult to create a simplified wave-drift force model for semisubmersibles than for tankers, which can be characterized quite nicely by "effective" values of beam, length and draft and bow/stern configurations.

To facilitate fast preliminary design work and "quick look" evaluations of configurations, SeaSoft has provided two simplified built-in semisubmersible wave-drift force implementations: the "Legacy" model and the "2001" model.

The "Legacy" Model

This represents an "average" semisubmersible in the sense discussed further below. Because of the wide variation in semisubmersible designs, it is most important that when wave drift effects play a defining role in a mooring design that the final design or evaluation be carried out with a complete set of semi-specific user-supplied wave-drift coefficients.

For simplicity, this "Legacy" built-in implementation assumes that wave drift properties of any semisubmersible can be approximately characterized by only two variables: an "effective" waterline length and breadth. These are based on the LWL, BWL values from the "principal vessel characteristics" page (see page 76) and a pair of "shadowing and geometry" factors specified on the "Vessel Low-Frequency Dynamics" page (see page 80; these items only appear for "semisubmersible" vessel types). A more comprehensive wave-drift treatment, when necessary, requires user specification of a complete array of surge, sway and yaw drift force coefficients, as described in Appendix D.

Note that the built-in (default) implementations assume semisubmersibles possess sufficient symmetry that the second-order yaw moment vanishes for all wave periods and approach angles, a simplifying approximation that in most circumstances is justified for engineering analyses.

The optimal evaluation of the "shadowing and geometry" factors is unfortunately somewhat qualitative in consequence of the various waterplane geometry and shadowing complications mentioned above. As an aid to discussion, wave drift forces acting on a semisubmersible can be simplified by considering waves in the "geometrical optics" limit, in which the wavelength is small compared to the diameters of principal columns; indeed much of the wave drift force acting on a typical semi derives from just these short wave components. (By nature of its design, a semisubmersible is relatively "transparent" to waves of length long compared to a column diameter.) Using the "geometrical optics" limit as a visualization aid, one straightforward and useful procedure for evaluation of the shadowing and geometry factors follows:

> • The starting point is the total waterline length of the water-piercing members, projected upon the appropriate vertical plane (transverse vertical plane for BWL, longitudinal vertical plane for LWL). This preliminary accounting ignores "shadowing" or "blanketing" effects arising from columns "hiding" behind up-wave structures or other columns. For semisubmersibles with round columns, the LWL and BWL thus determined are equal; for semisubmersibles with rectangular columns, the LWL and BWL values will in general differ.

> • A first refinement is a geometrical correction for column waterline shape. Because of their rounded aspect, in the short-wavelength limit round columns produce only 2/3 (67%) of the wave drift force of square (or more generally, rectangular) columns, assuming a square of side equal to the circle diameter and wave approach perpendicular to a flat face. Therefore, the "effective" waterline length or beam contribution from any round column is reduced by a "geometry" factor of 0.67. Rectangular columns evidently enjoy no such reduction. In the case of mixed column types (some round, some rectangular), a suitable weighted average geometrical reduction factor may be used, with round columns contributing 67% of their diameters and rectangular columns contributing 100%.

In most cases, the simple column geometry refinement described above is the only adjustment that should be attempted for the built-in SeaSoft semisubmersible wave-drift model. The integrated wave drift forces in irregular seas produced by this procedure will generally be somewhat conservative (i.e., will overestimate the actual forces) since effects of column interference, in particular blanketing or shadowing, are neglected and these will in most cases reduce overall wave drift forces and moments, as discussed further below. Note that for unidirectional regular waves at a few special frequencies, diffraction effects can cause an *enhanced,* rather than *reduced* drift force; at these special angle/frequency combinations the SeaSoft drift forces would be underestimates. However, real-world averaging over frequencies and wave approach angles makes this a wholly academic observation with no practical consequence.

The extent and nature of drift force reduction or enhancement resulting from neglected diffractive effects such as shadowing and blanketing will depend critically on column layout; regarding this several comments are in order:

• It is easily understood (on the basis of an optical diffraction analog) that semisubmersible wave drift coefficients will, for long-crested waves, have prominent peaks and dips, both as a function of regular wave frequency and wave approach angle, owing to the "diffraction grating" produced by a collection of water-piercing columns possessing regular and symmetric inter-column spacing. On the other hand, in a realistic ocean environment both a broad band of frequencies and a significant range of wave directions are normally present; this tends to average out these peaks and dips in practice. As a result, details of the peaks and dips are of limited practical consequence. (Of course, in the context of a model basin test with highly unidirectional regular waves, these grating affects are readily demonstrable). It is therefore defensible, from an engineering point of view, to average over wave diffraction variations (with respect to the estimation of static and variable wave drifting forces on a semi) by using smoothed drift coefficients which eliminate, in an average way, the sharp frequency and angle-dependent variations. With regard to mean drift forces and slow-drift oscillation amplitudes, such smoothed coefficients will be relatively insensitive to column layout details, thereby simplifying considerably an otherwise complicated estimation problem. This is the central justification for the SeaSoft procedure; it will generally give results of engineering utility using surprisingly incomplete information. In a final design simulation, of course, the full vessel drift coefficient complement, as derived from 3-d diffraction simulation or model test results, should be used whenever possible to guard against unforeseen behaviors or exotic vessel designs unanticipated by the simplified model.

• In special cases, further refinements can be cautiously considered which will usually act to reduce overall wave drift force estimates. As a specific example, consider a conventional twin-hull, 8 column, spread-moored semi (e.g., of the Aker H-3 type) in a location where the expected variation in direction of design storm waves is very small. Further assume the semi to be moored bow into the design storm. In this case, the "geometrical optics" model argues for a complete shadowing of all but the two fore-most columns from approaching waves. In this special circumstance, the procedure described above for determining the "effective beam" from BWL and a "shadowing and geometry" factor of 1.0 will significantly overestimate the mean and variable wave-drift force on the vessel in unidirectional head seas. In this case, the use of judgement can be used to reduce the value of the "shadowing and geometry" factor, although it would not be wise to reduce

it to the implied limit (set by the two forward columns acting alone), because any error in storm direction or the presence of significant azimuthal wave energy spread about the mean direction would quickly eliminate some, if not all, of the favorable shadowing. In this circumstance, one could usefully use a "shadowing and geometry" factor of as small as 0.40 depending on the expected level of shadowing and the confidence in mean wave direction and wave unidirectionality about the mean direction.

Unfortunately, such "down-sizing" requires substantial experience to carry out wisely and consistently; in general a conservative approach (that is, slightly oversized values for the "shadowing and geometry" factors) should be taken whenever any doubt exists. *In any event, a final mooring design should be made using a carefully measured or computed set of drift force coefficients specific to the target semisubmersible whenever the static and slowly-varying wave drift forces constitute an important ingredient in the mooring design.*

Appendix H

Current Drag on Mooring Lines and Risers

It has recently (2005) come to our attention that, with the exception of SeaSoft's simulations, most (and probably all) widely used simulation tools rely, for current load estimates on slender submerged bodies (i.e., lines and risers), on a "principle" rather widely used in sub-sonic aerodynamics called the "cross-flow principle" (hereafter, the "CFP"; see, e.g., index items in Hoerner, <u>Fluid Dynamic Drag</u>). The SeaSoft calculation of slender body current drag does not invoke the CFP and therefore our estimates are, not surprisingly, often in marked conflict with it.

After a rather careful review of this matter, we have concluded that for offshore engineering purposes the CFP is inapplicable to either prototype scale or model scale structures, although for quite different reasons. That this issue was not settled experimentally and theoretically in this industry 50 years ago is a mystery, considering the ubiquitous occurrence of cylindrical structures at all scales in ocean engineering and their importance in all aspects of the art, including analysis, testing, installation, operation, and survival. In view of its importance, this issue will doubtless be addressed soon in the literature. We have not ourselves conducted a careful literature search, but the uncritical application of the CFP by some of the most visible analysts and wave basin centers in our industry suggests that at the very least its inadequacy has either not been widely understood or not sufficiently publicized.

A brief history of the CFP and some preliminary physical considerations:

• The CFP has been shown (beginning nearly 100 years ago) to be valid for "sub-critical" flows around smooth cylinders in the pristine (non-turbulent) flow environment of the worlds best wind tunnels. In this context, "sub-critical" refers to flows whose Reynolds number (Re) is less than the so-called "critical Reynolds number" associated with partial re-attachment of a detached boundary layer following the onset of turbulence within the boundary layer. This re-attachment, which permits partial pressure recovery behind the cylinder, generally leads to a (sometimes dramatic) drop in the drag coefficient of smooth cylinders at Reynolds numbers in the super-critical range beyond 3×10^5 or so.

• The CFP has also been known for over 50 years to be *inapplicable* to super-critical flow (which occurs, again, at Reynolds numbers in excess of about 3×10^5 for smooth circular cylinders in non-turbulent flow, and at substantially lower values for rough cylinders and/or in a turbulent incident flow field).

What is the physical basis for our assertion above of the non-applicability of the CFP for ocean engineering applications? Some brief motivational comments will help to frame the basic argument:

- For smooth cylinders in non-turbulent flow, the success of the CFP for sub-critical flow and the failure of the CFP for super-critical flow suggests that the loss of the principal qualitative flow characteristic associated with sub-criticality, to wit a well-developed and coherent vortex street behind the cylinder, plays a central role in the failure of the CFP for super-critical flows.

- As one increases either turbulence in the incident flow, or roughness of the cylinder, the critical Reynolds number is reduced until a point is reached (somewhere around Re = 10^4 or even less) where there is in fact no identifiable transition between "super" and "sub" critical flow; this circumstance is also identifiable by a drag coefficient that departs little from 1.0 over a range of Re of five or more orders of magnitude. Again, the existence of an identifiable transition appears to be closely tied to the trans-critical disappearance of a highly structured downstream vortex street. In conditions which, because of a harsh flow environment or a severely roughened cylinder, there is no organized downstream vortex street even at low Reynolds number, there is likewise no identifiable transition from sub- to super-critical flow, either from the point of view of changes in the drag coefficient, or in the disappearance of an organized vortex street. It appears likely therefore that under such adverse conditions, which nonetheless apply to most ocean engineering circumstances (at both prototype and model scales; see additional discussion below), the CFP is inapplicable at any Reynolds number.

- Reynolds numbers of these structures at model scale are of the order of 10^2 or 10^3 and would therefore easily be sub-critical in very steady flow conditions; therefore one might at first glance feel justified in applying the CFP to model scale analyses. However, the level of turbulence in basin current flows is immense compared to that of the pristine environments for which the validity of the CFP was established. It is very doubtful that in the basin environment any coherent vortex structures whatever can be maintained, and it therefore seems extremely doubtful to us that the CFP maintains any validity in this environment, despite the suggestively small Re values. To our knowledge, its validity has certainly never been established in these harsh conditions, although it would be nearly trivial for any commercial model test facility to carry out the measurements necessary to confirm or refute these conjectures. The vessel offsets in all model tests we have reviewed are at least suggestive that our analysis is correct.

- The special case of mooring chains, with their convoluted and complex profiles, certainly cannot be treated as "smooth cylinders" capable of producing coherent downstream vortex structures; therefore the CFP must be considered experimentally unjustified for this type of line, even highly polished chains in smooth, non-turbulent flows.

- Reynolds numbers of mooring structures and risers at prototype scale are generally in the range of 10^5 to 10^6 at the high current speeds of

greatest importance; that is, they are almost certainly always super-critical (even assuming non-turbulent flow) given the expected level of roughness due to line construction (wire rope, braided polyester, chain, etc.) or marine growth.

• It has been our experience in the analysis of model tests that the SeaSoft line drag model, which usually produces substantially greater current loads than CFP-based codes (often a factor of 2 or so), reproduces extremely well the observed experimental vessel offsets.

To summarize our thoughts on the validity of the CFP: At prototype scale, the large Reynolds numbers and roughness parameters of mooring or riser structures prevents the formation of the coherent downstream vortex street required for applicability of the CFP. At model scale, despite very small Reynolds numbers, the free stream turbulence is generally so severe that, once again, the establishment of a coherent downstream vortex street is prevented. In virtually all cases of relevance to offshore engineering, therefore, we feel the CFP is inappropriate.

Our strong recommendation therefore is to eschew use of the CFP for the calculation of current loads on mooring or riser structures at either model scale or prototype scale.

Appendix U

CALMsim Supplement
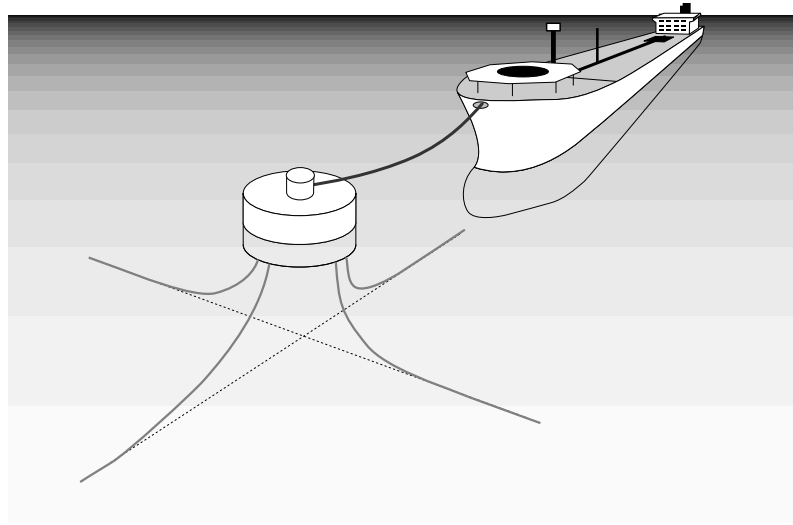
Relationship to SPMsim, Shipsim and Discsim

Despite the vastly more complex underlying dynamics of the CALM-hawser-tanker system, from the user's perspective it is only slightly more complicated than, say, a turret-moored vessel of the type simulated by SPMsim. In fact, the user interface and output stream of CALMsim are virtually identical to SPMsim. The similarities and differences between these two simulations are collected and outlined below for convenience.

Vessel Definition

The description of the *storage* vessel in CALMsim is *identical* to the vessel description required for SPMsim, with a single additional required data item: The location of the hawser attachment. The buoy specification and interface in CALMsim is operationally identical to the tanker specification. Indeed, CALMsim is sufficiently flexible to simulate a turret-moored vessel with a tandem, hawser-attached vessel of smaller or larger size. All vessel characteristics, including mass and hydrostatic properties used primarily for wave-frequency motion analyses and wind, current and wave-drift properties used primarily for low-frequency motion analyses, must be supplied for *both* "tanker" and "buoy". For the purpose of tandem vessel mooring, the "tanker" vessel is the one attached by a hawser only; the "buoy" vessel is the turret- or spread-moored object.

Environment Definition

Naturally, the environment is unaware of the type of system being simulated, so the environmental specification is *identical* between SPMsim and CALMsim.

Mooring System Definition

CALMsim is set up to assume that the "buoy" is the moored object to which fairlead locations and line departure angles are referred. The hawser is treated like an additional mooring line, with a buoy attachment point and line characteristics specification procedure identical to any other mooring line. As stated above, the hawser attachment point on the "tanker" must be specified as part of the "mooring system" definition.

Miscellaneous Differences

Aside from the addition of the buoy physical data discussed above, and the hawser attachment point specification, there are very few additional differences in the input stream between CALMsim and its single-vessel siblings (e.g., SPMsim). In all cases, the differences are described in the on-line "help" for those items. See, for example, the "Swap tanker, buoy data" Item on the Output Options page. (This item would appear on the screen depicted on page 110 of the CALMsim editor, but is hidden on page 110, which applies to SPMsim.)

In the output stream (MEANOUT and LOWOUT in particular), offsets and loads that relate separately to the buoy and tanker are labelled as such.

Note that the center of the Global coordinate system is the quiescent-condition centroid of the buoy mooring system. Further, in the quiescent (null-environment) condition, the tanker position is such that the hawser attachment point lies *also* at the Global coordinate origin; that is, it is directly atop the buoy mooring centroid. This (physically impossible) circumstance is a mathematical artifice adopted for convenience; the presence of any non-zero environment will move the tanker away from the buoy and eliminate this tanker-buoy mating dance. Further, as the tanker and buoy undergo their relative motions, CALMsim is similarly unaware of their physical boundaries; the tanker may freely pass through the buoy should its motion become excessive. If so indicated by the simulation, this of course should be prevented by appropriate system design modifications.

Mooring Feedback on CALM Buoy

Perhaps the most important simplification in the dynamical analysis of moored vessels is the approximate independence of wave-frequency vessel motions from mooring-system load fluctuations. That is, wave-frequency "fairlead tugging" by mooring lines is usually insufficient to influence wave-frequency vessel motions. This circumstance is due primarily to the large displacements of vessels commonly used offshore and the correspondingly large wave-frequency vessel loads. The adequacy of the neglect of mooring loads in wave-frequency vessel motion analysis is

easily verified on a case-by-case basis by directly comparing simulation-estimated mooring loads and vessel wave loads as presented in the Simulation output stream.

The CALM buoy component of a terminal mooring system, by contrast, is typically a modest-sized vessel which nonetheless contains mooring structures sufficient to restrain a *much* larger vessel. As a result, it is *not* generally the case that buoy wave loads can be neglected when compared to wave-frequency mooring line and hawser loads. Furthermore, perhaps the most critical component of a CALM-hawser-tanker system, namely the interconnecting hawser, depends on the low- and wave-frequency motions of *both* tanker and CALM buoy. The composite dynamical system is much more complex than, for example, a similarly configured turret-moored tanker. For these reasons, CALMsim incorporates a mooring feedback option for the "buoy" object.

Notes:

- The mooring feedback option can be disabled whenever the "buoy" vessel size obviates the need for mooring feedback. It is automatically disabled whenever the "buoy" vessel type is other than "Puck-shaped Buoy".

- Mooring feedback on the stand-alone buoy can be studied by importing the CALMDAT file into Moorsim, which will accommodate mooring feedback on disk-shaped vessels. To accomplish this data import, you must first apply the "Swap tanker, buoy data" option on the Output Options page in CALMsim before saving the CALMDAT file to be imported into Moorsim (after renaming CALMDAT -> MOORDAT). Once Moorsim has been launched, you must also eliminate the "hawser" mooring line before proceeding.

Wave-Frequency Vessel Motions

In a conventional CALM mooring, the "buoy" is an azimuthally-symmetric hockey-puck shaped vessel; as such its default wave-frequency motions are obtained from Discsim, rather than Shipsim or Semisim. The "tanker" motions are normally obtained from Shipsim, although either the "buoy" or the "tanker" can be any available type (semi, ship or disk). The wave-frequency module that will be invoked at runtime depends on the user's vessel type designations on the "Hydrostatic Characteristics" input pages (see page 76). Of course, user-specified RAOs can substitute for the SeaSoft wave-frequency modules. (See below.)

Externally-Supplied Data

Environmental coefficients and/or RAOs for either "buoy" or "tanker" or both can be supplied via external text files (employing the flags displayed on pages 77 and 80) using the mechanisms described in Appendix D. The names of these text files must however reflect the vessel type to which they apply; the following file name map must be used when suppling external data using the Appendix D mechanism:

Appendix D File	**Tanker File**	**Buoy File**
USERRAOS.txt	UTANKRAO.txt	UBUOYRAO.txt
WINDCOFS.txt	TANKWIND.txt	BUOYWIND.txt
CRNTCOFS.txt	TANKCRNT.txt	BUOYCRNT.txt
DRFTCOFS.txt	TANKDRFT.txt	BUOYDRFT.txt

Thus, to supply *both* tanker and buoy wave drift force coefficients via the Appendix D mechanism, you will need to prepare two files, one for the tanker (named "TANKDRFT.txt") and the other for the buoy (named "BUOYDRFT.txt"), using the "DRFTCOFS.txt" instructions described in Appendix D.

Missing or misnamed files will result in a run-time error.

XCLDAT.stxt File Status

The XCLDAT data summary file is not implemented in CALMsim or Towsim.

Appendix V

Sparsim Supplement
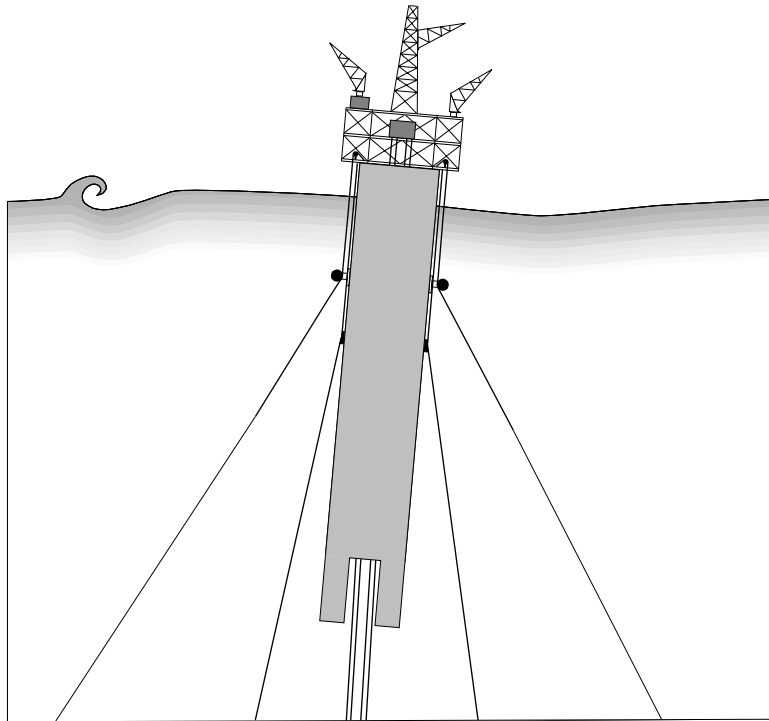
Relationship to Moorsim and Semisim

The input stream to Sparsim is virtually identical to that of a moored single-column semisubmersible in Moorsim. The mooring and vessel specification *are* identical; the only differences relate to spar-specific features such as the specification of vertical wind and current area centroid location to permit heel and trim overturning moments for the spar to be included in the simulation. (These effects are considered negligible for semisubmersible modeling in Moorsim.)

Other differences relate to the role of wind and current "suction" effects on spar pulldown performance which are ignored in Moorsim, and the availability of specialized wave-frequency line load algorithms particularized to the extremely taut moorings typical of spar installations.

These Sparsim-specific features are explained within the Sparsim Editor (in on-line help items) and will not be separately reviewed here.

For a more exhaustive wave-frequency analysis of the spar, including "green water" studies, acceleration studies, etc., Semisim may be used. In addition, for guidance in specification of the spar physical properties, the Semisim User Manual should be consulted; the spar should be modeled as a single-column semisubmersible.

Moonpool Simulation in Sparsim

A moonpool will normally not have a significant effect on vessel dynamics for a spar, semi or drillship because the volume and waterplane area of the pool will be negligible compared to the displacement and waterplane area of the vessel. In unusual cases, or for academic purposes, various corrections for the moonpool can be made, although these are necessarily somewhat approximate as a result of the complex hydrodynamics associated with the moonpool hull exit geometry and the natural heave resonance of the moonpool fluid itself, among other things.

The fundamental physical consideration is that the water in the moon pool moves with the vessel for all but vertical motions (i.e., heave for a centrally located moonpool). Thus the moonpool fluid can be considered "frozen", i.e., to be a part of the vessel for all but vertical motions.

We believe the most sensible (and most easily implemented) modeling artifice is to treat the moonpool as if its entrained fluid were frozen solid, thus including the moonpool water in all vessel mass and hydrostatic properties *except* the total vessel water plane area (i.e., include the frozen fluid mass in the KG, KB, KM, gyradii and displacement values).

Then, if AMP is the moonpool waterplane area and AWP is the total waterplane area in the "frozen moonpool" vessel model, you would use (AWP - AMP) for the "Vessel water plane area" parameter on the "Vessel Hydrostatic Characteristics" editor page (page 76). The full plan-view column area (*including* the moonpool area) should be used in all other dimensional specifications.

The only downside to this procedure is that the program will issue a hydrostatics warning that the "simulation estimate" for the water plane area differs from the user-specified area. This warning can be ignored; the user-specified water plane area will be used to determine the natural period of heave.

A related FAQ item is reproduced here for convenience:

How should I treat the water in the moonpool and in the so-called "soft tanks" commonly used in the design of caisson-type spars?

It is usually best (and simplest) to include all the water in the moonpool, "soft tanks" and "hard tanks" in the vessel hydrostatic and mass distribution quantities, including KB, KM, Displacement (hydrostatics) and KG, Gyradii (mass distribution). Note, however, that only water which will clearly

move with the vessel during its oscillations should be included; water inside a very open truss structure should therefore *not* be so included.

The lone exception to this rule is the waterplane area, which should reflect the "tons per inch" hydrostatic resistance due to incremental vessel immersion (i.e., it should exclude any contribution from the moonpool, which is clearly not a part of the waterplane area). This will result in the correct estimation of heave periods and offset-versus-pulldown characteristics.

> Note that it is perfectly reasonable to treat the KM's in a manner similar to the waterplane area; that is, to exclude the moonpool contribution to the righting moment variables since the moonpool is a "free surface". This is generally not worth the effort because the waterplane moment of inertia contribution arising from the moonpool free surface is, in most cases, utterly negligible compared to the full vessel water plane moment of inertia.

If any "hard" or "soft" tanks have free surfaces, the free surface effects can be accommodated in the usual way by suitable reduction of the KG. (For that matter, the moonpool water can as well be corrected for in this way.)

As indicated above, this procedure assumes that "frozen" water included in the displacement value is more-or-less completely entrained. This can be a gray area in some circumstances; for example, water in a moon pool is *not* entrained with regard to heaving or yawing motions (although it is, mostly, with respect to the other degrees of freedom). The vertical motion of water in the moonpool is generally not important in effecting overall vessel motions (other than the hydrostatics discussed above) and we recommend ignoring it.

In most circumstances, errors introduced by this simplifying procedure will be small and tolerable. The alternative to the simple approach includes analysis of (sometimes complex) dynamical subsystems (such as the water column in the moonpool) and its coupling to heave, in particular, through obstructions within, or partial blockages of, the moonpool.

So, for most caisson spars, the following simple procedure will produce generously sufficient accuracy:

* Set the simulation "KB" to the KB of the enclosing wetted volume. (Unless the spar has "shoulders" or other irregularities, this is simply one-half of the non-truss column length of the spar; if the spar is uniform in horizontal section and lacks submerged truss sections, this is simply the half-draft.)

* Compute the simulation displacement by adding the dry structure to the entrained water.

* Compute the simulation KG by appropriate combination of the dry structural mass and the entrained water mass as a single monolithic entity.

* Compute the simulation KM from the true waterplane moment of inertia (i.e., excluding any moonpool contribution), the KB and the displacement

volume.

* Set the simulation water plane area to the true waterplane area (i.e., exclude any moonpool contribution).

* Include the entrained water in all gyradii calculations (except, possibly, yaw, for which DOF the entrained water may not always be carried with the vessel; the yaw gyradii will obviously be problematic in some circumstances but yaw is also generally of little concern).

* If simulating a model test in which the hydrostatics are separately and independently measured, be sure that the small-angle righting moment

```
    =   (KM-KG)*Displacement
```

as computed above matches that obtained in the tests.

Mixing Tensioned Risers with Catenary Lines

An important FAQ item relating to this issue is reproduced here for convenience:

In Sparsim, I need to simulate three line types: (1) conventional high-tension mooring lines; (2) catenary-style risers; (3) constant-tensioned vertical risers. How is this best accomplished?

The mooring lines and catenary-style risers can be simply treated as two conventional mooring line "types".

The constant-tension risers are tricky, especially since they are vertical at the zero-environment equilibrium. It is generally adequate for simulation purposes to lump all the vertical constant-tension risers into a single vertical line, although this is not a requirement.

Here is one way these riser "lines" can be handled:

1. Specify as many elements as necessary to simulate the weight/unit length distribution along the riser (usually this won't make any noticeable difference; the only important simulation parameter for these line types is the riser axial tension at the keel entry point).

2. Set the "Mean line profile determined by" on editor page 2 to "line tension" and fill in the line tension arrays for all mooring lines and risers.

3. Make the vertical riser(s) *extremely* compliant (something like 1,000 times as compliant as an "equivalent" wire rope; the actual compliance value is unimportant so long as it is large enough to prevent significant riser tension oscillations during vessel motion).

4. Rather than specify a length, let the *editor* choose a length that will produce the desired top tension. This is done by using item 21 ("HELP for subline physical property estimates") on the Tensioned Riser specification page and item 5 on the subsequent Subpage ("Fairlead subline length for

specified tautwire tension"). See pages 68 and 72.This will compute the unstretched length of riser required to obtain the requested top tension when the riser top is "pulled up" to the keel level in the face of the specified large compliance value.

5. Run the simulation and get the estimated horizontal tension components or distances to anchor for all the other mooring lines (in MEANOUT).

6. Re-enter the editor, return to page 2 and reset the "Mean line profile determined by" to either horizontal tension component or distance to anchor. For the tensioned riser each of these would be exactly zero if it is vertical.

Note: Items 5 & 6 are not absolutely necessary, but they may prevent some runtime warnings that arise out of difficulties in handling vertical members; they will also usually give more cosmetically satisfying output and may therefore help reduce confusion.

This method simulates completely the constant-tension aspect of these risers since the high compliance insures that the top tension is roughly independent of vessel motion (we are treating the riser like a highly stretched rubber band). Since the only important physical parameter is the riser axial tension at the keel entry point, this "elastic riser" model works perfectly in the estimation of pitch/roll/surge/sway periods, which is the only measurable influence on vessel and mooring dynamics in practical situations.

Modeling Vortex-Induced Vibrations

A fundamental and comprehensive theory for vortex-induced vibrations (VIV) and the related oscillatory hull forces for caisson spars has yet to be completely developed. VIV may be modeled in Sparsim using the "External Forcing" capabilities described on page 91. Note in particular the discussion of VIV modeling given on that page.

Vertical Interpolation Layers in Sparsim

Sparsim requires a larger number of "interpolation layers" (see page 66) than a typical Moorsim simulation. This is because of the extreme stiffness characterizing caisson spar moorings. Interpolation on such stiff systems is therefore a much more delicate procedure requiring smaller vertical intervals between interpolation layers. (Sparsim utilizes the same "catenary-elastic" load evaluation engine as other SeaSoft simulations.)

When running Sparsim, you should therefore use a larger number of layers than you might for a conventional spread mooring. The vertical span parameter (page 66) should be large enough to accommodate the maximum pull-down anticipated for the environment. One or two preliminary simulation executions may be needed to help set this value. See the discussion on page 66 for additional detail. Also, a related FAQ is excerpted below:

I have no idea how many "interpolation layers" I should use when the simulation recommends the use of "Large-amplitude nonlinear model for w.f. loads". Should I use the maximum possible number?

This is a very subjective matter. You are always safest using the maximum allowable number of layers, but the trade-off is that simulation times increase somewhat and the interpolation output table can become inconveniently large.

For most SPMsim/Moorsim applications, you seldom need more than three layers with just enough total layer depth to span the vertical "stroke" of the most vigorously moving fairlead.

Sparsim and TLPsim require more layers in general. In any case, you should err on the side of too many, rather than too few layers. If you have lots of runs to do, you can experiment, beginning with the maximum number of available layers and reduce the number (say, by 25% at each step) until (1) the simulation protests or (2) you detect an appreciable deviation of the output values of interest from your "benchmark" max-layer-number results.

Appendix W

TLPsim Supplement
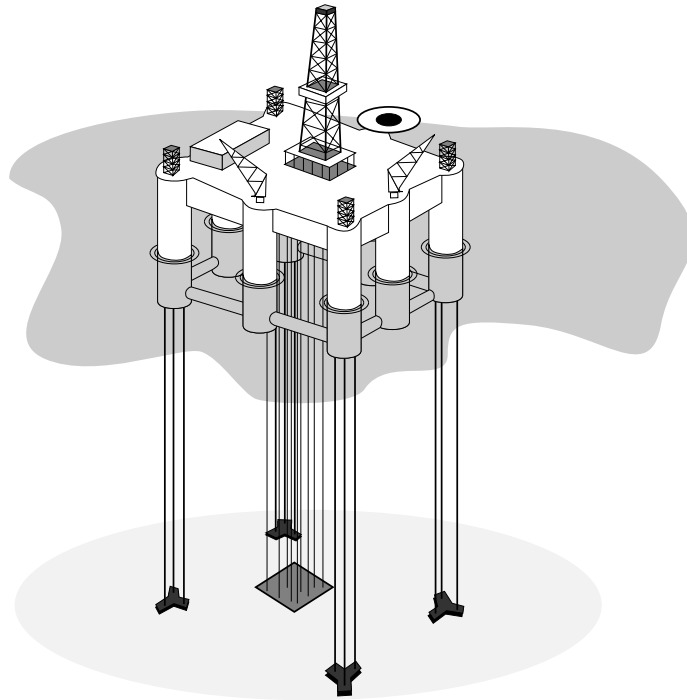
Relationship to Moorsim and Semisim

The input stream to TLPsim is virtually identical to that of a moored semisubmersible in Moorsim. The mooring and vessel specification *are* identical; the only differences relate to TLP-specific features such as the requirements for vertical wind and current area centroid locations to permit heel and trim overturning moments for the TLP to be included in the simulation. (These effects are considered negligible for semisubmersible modeling in Moorsim.)

Other differences relate to the availability of specialized static, low- and wave-frequency load algorithms particularized to the extremely taut moorings (i.e., the tendons) fundamental to TLP installations. These TLPsim-specific features are explained in the on-line help items within TLPsim and will not be separately reviewed here

Relationship to Sparsim

TLPsim and Sparsim share many of the same operational differences from Moorsim, especially with respect to pull-down, trim and heel, vertical mooring structures, etc. Therefore you should review carefully the Sparsim Supplement; features and considerations common to Sparsim and TLPsim are not repeated here.

Tendon Pretension Considerations

Some useful FAQs relating to this issue are reproduced here for convenience:

I am having difficulty setting the tendon length in TLPsim. Because the tendons are so stiff, *very* small changes in length correspond to *large* changes in top tension. Getting the tension, length and distance-to-anchor (presumably, zero) correct is therefore problematic. What should I do?

This is what we recommend:

1. Set the "Mean line profile determined by" on editor page 2 to "line tension" and set the line tension array for the tendons to the desired tension value(s).

2. Let the *editor* choose a length that will produce the desired top tension. This is done by using item 21 ("HELP for subline physical property estimates") on the tendon specification page and item 5 on the subsequent Subpage ("Fairlead subline length for specified tautwire tension"). This will compute the unstretched length of tendon required to obtain the requested top tension.

3. Return to page 2 and reset the "Mean line profile determined by" to either horizontal tension component or distance to anchor. For tendons each of these would be exactly zero since they are vertical at quiescent equilibrium. You may also, if you wish, use "Fairlead Line Angle" and set the tendon angle values to 90.

Item 3 is not actually absolutely necessary, but it prevents some runtime warnings that arise from difficulties in handling vertical members and give more cosmetically satisfying output.

I understand how to handle vertical mooring lines (such as TLP tendons, described in another FAQ) but this requires setting the "distance to anchor" or "horizontal tension" values to zero. What if I have a mixture of lines, such as normal catenary risers or flow lines in addition to the vertical tendons?

In this case, the recommended procedure is a bit more complex than for tendons alone, and depends slightly on how you wish to specify the mean line profile in the non-vertical (catenary) lines. The most common (and most problematic) situation is when you wish to specify top tension values for all lines. In that case:

1. Set the "Mean line profile determined by" on editor page 2 to "line tension" and set the line tension array for all lines, including tendons, to the desired tension value(s).

2. Let the *editor* choose a length that will produce the desired tendon top tensions. This is done by using item 21 ("HELP for subline physical property estimates") on the tendon specification page and item 5 on the subsequent Subpage ("Fairlead subline length for specified tautwire tension"). This will compute the unstretched length of tendon required to obtain the requested top tension.

3. Run the simulation and get the estimated horizontal tension components, distances to anchor or fairlead line angles for all the non-vertical lines (in MEANOUT).

4. Re-enter the editor, return to page 2 above and reset the "Mean line profile determined by" to distance to anchor, horizontal tension component or fairlead line angle. For the vertical members (tendons) use zero or 90, as appropriate.

Items 3 & 4 are not absolutely necessary, but they prevent some runtime warnings that arise out of difficulties in handling vertical members and give more cosmetically satisfying output.

Note: In the case where the mean line profile is to be determined by fairlead line angle, the intermediate simulation run is unnecessary. In that case, after determining the proper tendon lengths in item 2 above, return to page two, reset the "Mean line profile determined by" to fairlead line angle, and input the desired angles for all lines. For the vertical members, the specified angle should be 90.

TLP Wave-Frequency RAOs

Some useful FAQs relating to this issue are reproduced here for convenience:

Is it possible to use Semisim to get "batch" wave-frequency RAOs for a TLP? There seems to be no mechanism for simulating the effects of the tendons or risers.

You can accomplish this from a TLPDAT starting point as follows:

* Import a TLPDAT file into Semisim (TLPDAT -> SEMIDAT)

* Apply the desired (tendon + riser) tension using the "phantom weight" option in Semisim (see the Semisim manual or on-line help for additional details).

* Hardwire the heave, pitch and roll periods and damping using the estimates from TLPsim or from another source.

This gives a very satisfactory W.F. dynamic TLP model. The periods have to be hardwired because at this time there is no way to specify the tendon elastic properties in Semisim.

Note that TLP resonant damping is very problematic; attempts to estimate this damping are notoriously treacherous. The best source of information, if you can get it, is a real-life, full-scale estimate based on the *measured* RMS motion spectrum of an existing offshore platform in *measured* wave conditions. Lacking that, you are probably better off applying a "reasonable guesstimate" (a probable range is 5% to 20%).

What is the purpose of the "Utilize ONLY square law driving forces" option in Semisim, TLPsim and Sparsim?

The details of TLP performance can be sensitive to the square-law loading from the orbital motion of water particles in waves. Many issues complicate the simulation of this process, including:

* wave amplitude relative to member size (the "Keulegan-Carpenter" number)

* the effective Reynolds number (usually quantified in oscillatory environments by another dimensionless viscosity variable called "beta")

* member shape (For example, smoothly rounded members can have extremely different "drag" properties in oscillatory flow than rectangular members with sharp corners. This circumstance is quite different from uniform flow, in which the drag coefficients of square and round profiles are not radically different.)

* member roughness

* many current effects, including:

(1) member local flow environment (e.g., is the member of interest in the turbulent down-current wake of another member or in a pristine uniform flow field uncontaminated by upstream structures)

(2) current turbulence

The purpose of the "Utilize ONLY square law driving forces" option is to isolate that portion of TLP wave forces deriving from square-law effects from those associated with inertial or hydrostatic contributions (the so-called "Froude-Krylov", or "F-K" contributions) or first-order wave radiation damping contributions.

Note that the inverse can also be accomplished: F-K forcings can be isolated by elimination of square-law drag effects by using the "Resonant damping only; no square-law driving forces" option.

Vertical Interpolation Layers in TLPsim

TLPsim requires a larger number of "interpolation layers" than the other SeaSoft simulations (see page 66). This is because of the extreme stiffness of tendon-type moorings. Tendon interpolation tables are *very* sensitive to small vertical displacements due to their extreme stiffness. (TLPsim utilizes the same "catenary-elastic" load evaluation engine as other SeaSoft simulations.)

When running TLPsim, you should use the maximum possible number of layers unless you have specific reasons for using fewer. The vertical span parameter (see additional discussion on page 66) should be large enough to accommodate the maximum pull-down anticipated for the environment. One or two preliminary simulation executions may be needed to help set this value.

Appendix X

Towsim Supplement
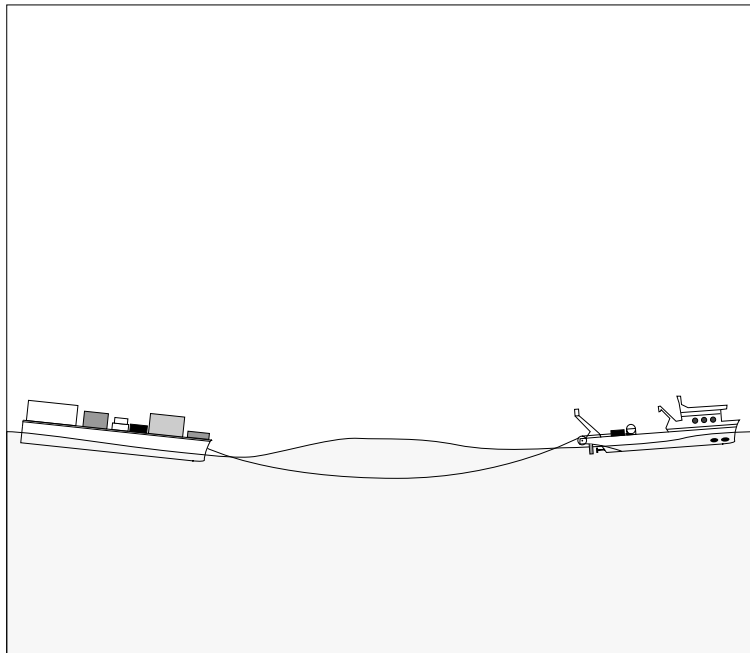
Towsim is conceptually very similar to CALMsim in that two vessels must be specified, as well as a hawser-type towline interconnection; as a result, the CALMsim Supplement should first be reviewed for relevant information.

The "mooring system" in Towsim comprises a single line (the towline). The other primary difference with CALMsim is that a non-zero forward speed for the tug will normally be specified, which has consequences on the reporting of wave periods in the output stream, which must be adjusted for the Doppler shift due to the moving system.

Externally-Supplied Data

Environmental coefficients and/or RAOs for either "tug" or "barge" or both can be supplied via external text files using the mechanisms described in Appendix D. The names of these text files must however reflect the vessel type to which they apply; the following file name map should be used when suppling external data using the Appendix D mechanism:

Appendix D File	Barge File	Tug File
USERRAOS.txt	UBARGRAO.txt	UTUGRAO.txt
WINDCOFS.txt	BARGWIND.txt	TUGWIND.txt
CRNTCOFS.txt	BARGCRNT.txt	TUGCRNT.txt
DRFTCOFS.txt	BARGDRFT.txt	TUGDRFT.txt

Thus, to supply *both* barge and tug wave drift force coefficients via the Appendix D mechanism, you will need to prepare two files, one for the barge (named "BARGDRFT.txt") and the other for the tug (named "TUGDRFT.txt"), using the "DRFTCOFS.txt" model described in Appendix D.

Missing or misnamed files will result in a run-time error.

Appendix Z

Sample Problem Output

The following pages contain output generated by SPMsim as a result of a simulation using input data presented in Appendix E. Note that the Screen images presented in Chapter 7 also correspond to the same sample problem. The output is broken into "Sections" which consist of assemblies of related output material; Section numbers are Roman-numeric and range from I to XV. See Chapter 6 for discussion and explanation of output sections. Also included at the end of this appendix are the output data files produced by the vessel wave-frequency motions module (in this case, Shipsim). This output should always be generated at least once during a simulation series to ensure that the purely vessel-associated data has been input correctly.

Note that only a small fraction of the total output stream has been reproduced here; RAOs for lines 2 through 8 have been left out, as have the anchor-end RAO tables. The remaining nonlinear load RAOs (sections VII & VIII) relate to line 1. The large volume of RAO output is partly due to the fact that a non-colinear swell was specified and results in a second wave direction for RAO calculations, thereby instantly doubling the number of RAOs. In addition, pages relating to lines 2-8 in SNAPOUT and RANOUT Section type X have been omitted for brevity.

SeaSoft Systems Simulation Library

Volume 15

Catenary Single-point Mooring Simulation

SPMsim Version 5.11

Copyright (C) 2005
By SeaSoft Systems

Moorsim/SPMsim Manual Sample Problem
Turret moored 150,000 DWT tanker

Executed at 13:08 on 2/23/05

```
**                                                          **
********************* I.  Line Characteristics Summary ********************
**                                                          **


>>> Interpolation level  3 for line type A of  2 type(s)
    Vertical distance to nominal fairlead     .00 ft
    Vertical separation between endpoints   476.00 ft


- Segment -   Length  Nominal  Submerged  ----   Elastic Coefficients   ----
   Type                Diameter  Weight     Alpha 1      Alpha 2      Alpha 3
              (ft)     (in)    (lbs/ft)  (k.lbs**-1) (k.lbs**-2) (k.lbs**-3)


 1  Wire    1000.00    4.50      31.20     0.699E-05   0.000E+00   0.000E+00
 2  Chain   1000.00    4.50     175.96     0.434E-05   0.000E+00   0.000E+00

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

Table    Top      Anchor    Horizontal  -- Line angle --   Endpoint   Bottom
Index  Tension   Tension     Tension     Top     Anchor   Separation  Length
       (k.lbs)   (k.lbs)     (k.lbs)  --  (deg)   ---        (ft)      (ft)


  1     14.85       .00         .00     90.0       .0       1524.02   1524.02
  2     19.85      5.00        5.00     75.4       .0       1713.80   1384.32
  3     20.95      6.11        6.11     73.1       .0       1730.27   1357.49
  4     22.31      7.46        7.46     70.5       .0       1746.86   1326.17
  5     23.96      9.11        9.11     67.7       .0       1763.41   1289.79
  6     25.97     11.13       11.13     64.6       .0       1779.74   1247.75
  7     28.43     13.59       13.59     61.5       .0       1795.70   1199.39
  8     31.44     16.59       16.59     58.1       .0       1811.14   1144.02
  9     35.11     20.27       20.27     54.7       .0       1825.96   1080.92
 10     39.60     24.75       24.75     51.3       .0       1840.07   1009.29
 11     45.15     30.23       30.23     48.0       .0       1852.41    986.82
 12     52.11     36.92       36.92     44.9       .0       1861.96    968.44
 13     60.76     45.10       45.10     42.1       .0       1869.53    946.07
 14     71.42     55.08       55.08     39.5       .0       1875.80    919.15
 15     84.49     67.27       67.27     37.2       .0       1881.27    887.06
 16    100.45     82.16       82.16     35.1       .0       1886.30    849.10
 17    119.91    100.34      100.34     33.2       .0       1891.15    804.52
 18    143.58    122.55      122.55     31.4       .0       1895.97    752.51
 19    172.35    149.68      149.68     29.7       .0       1900.88    692.14
 20    207.28    182.81      182.81     28.1       .0       1905.93    622.45
 21    249.70    223.27      223.27     26.6       .0       1911.14    542.37
 22    301.20    272.68      272.68     25.1       .0       1916.53    450.73
 23    363.76    333.04      333.04     23.7       .0       1922.09    346.29
 24    439.76    406.75      406.75     22.3       .0       1927.83    227.66
 25    532.14    496.78      496.78     21.0       .0       1933.72     93.37
 26    644.55    606.82      606.73     19.7      1.0       1939.66      .00
 27    782.00    742.25      741.02     18.6      3.3       1944.64      .00
 28    950.14    908.75      905.03     17.7      5.2       1948.86      .00
 29   1155.73   1113.01     1105.35     17.0      6.7       1952.77      .00
 30   1406.98   1363.19     1350.00     16.4      8.0       1956.72      .00
```

```
 **          **                                                        **          **                  **          **
 ******************  Ib.  Element Endpoint Position Table  *****************       ******************  Ib.  Element Endpoint Position Table  *****************
 **                                                          **                    **                                                          **

>>> Interpolation level 3 for line type A of  2 type(s)                           >>> Interpolation level 3 for line type A of  2 type(s)
    Vertical distance to nominal fairlead     .00 ft                                   Vertical distance to nominal fairlead     .00 ft
    Vertical separation between endpoints   476.00 ft                                  Vertical separation between endpoints   476.00 ft

>>> Element "i" endpoint coordinates (Xi or Zi; from fairlead, in ft)             >>> Element "i" endpoint coordinates (Xi or Zi; from fairlead, in ft)

 Table                                                                             Table
 Index    X1      X2                                                               Index    Z1      Z2


    2     713.8  1713.8                                                               2    -476.0  -476.0
    3     730.2  1730.3                                                               3    -476.0  -476.0
    4     746.8  1746.9                                                               4    -476.0  -476.0
    5     763.4  1763.4                                                               5    -476.0  -476.0
    6     779.7  1779.7                                                               6    -476.0  -476.0
    7     795.6  1795.7                                                               7    -476.0  -476.0
    8     811.1  1811.1                                                               8    -476.0  -476.0
    9     825.9  1826.0                                                               9    -476.0  -476.0
   10     840.0  1840.1                                                              10    -476.0  -476.0
   11     852.3  1852.4                                                              11    -475.5  -476.0
   12     861.9  1862.0                                                              12    -473.6  -476.0
   13     869.7  1869.5                                                              13    -470.3  -476.0
   14     876.4  1875.8                                                              14    -465.7  -476.0
   15     882.6  1881.3                                                              15    -459.6  -476.0
   16     888.5  1886.3                                                              16    -452.1  -476.0
   17     894.4  1891.1                                                              17    -443.3  -476.0
   18     900.4  1896.0                                                              18    -433.2  -476.0
   19     906.6  1900.9                                                              19    -421.8  -476.0
   20     913.0  1905.9                                                              20    -409.3  -476.0
   21     919.6  1911.1                                                              21    -395.7  -476.0
   22     926.3  1916.5                                                              22    -381.2  -476.0
   23     933.0  1922.1                                                              23    -366.0  -476.0
   24     939.8  1927.8                                                              24    -350.0  -476.0
   25     946.5  1933.7                                                              25    -333.6  -476.0
   26     953.0  1939.7                                                              26    -317.1  -476.0
   27     958.6  1944.6                                                              27    -303.0  -476.0
   28     963.5  1948.9                                                              28    -291.3  -476.0
   29     967.8  1952.8                                                              29    -281.8  -476.0
   30     971.9  1956.7                                                              30    -274.1  -476.0
```

```
**                                                                    **
** ********************  Ic.  Element Endpoint Angle Table  ******************** **
** ********************                                      **
```

>>> Interpolation level 3 for line type A of 2 type(s)
    Vertical distance to nominal fairlead   .00 ft
    Vertical separation between endpoints   476.00 ft

>>> Endpoint angle Ti at fairlead-end of element "i" in degrees

Table Index	T1	T2	T3
1	90.00	.00	.00
2	75.41	.00	.00
3	73.06	.00	.00
4	70.47	.00	.00
5	67.65	.00	.00
6	64.64	.00	.00
7	61.45	.00	.00
8	58.14	.00	.00
9	54.75	.00	.00
10	51.31	.00	.00
11	47.97	4.43	.00
12	44.88	8.59	.00
13	42.08	11.92	.00
14	39.53	14.52	.00
15	37.23	16.49	.00
16	35.13	17.94	.00
17	33.20	18.95	.00
18	31.40	19.59	.00
19	29.72	19.92	.00
20	28.13	20.00	.00
21	26.60	19.85	.00
22	25.13	19.53	.00
23	23.72	19.07	.00
24	22.34	18.48	.00
25	21.01	17.81	.00
26	19.72	17.07	.98
27	18.63	16.44	3.29
28	17.73	15.92	5.19
29	16.98	15.49	6.73
30	16.36	15.13	7.98

```
**                                                                    **
** ********************  I.  Line Characteristics Summary  ******************** **
** ********************                                      **
```

>>> Interpolation level 3 for line type B of 2 type(s)
    Vertical distance to nominal fairlead   .00 ft
    Vertical separation between endpoints   476.00 ft

- Segment - Type	Length (ft)	Nominal Diameter (in)	Submerged Weight (lbs/ft)	Alpha 1 (k.lbs**-1)	Alpha 2 (k.lbs**-2)	Alpha 3 (k.lbs**-3)
1 Wire	2500.00	4.00	24.65	0.884E-05	0.000E+00	0.000E+00

Table Index	Top Tension (k.lbs)	Anchor Tension (k.lbs)	Horizontal Tension (k.lbs)	Top (deg)	Anchor (deg)	Endpoint Separation (ft)	Bottom Length (ft)
1	11.73	.00	.00	90.0	.0	2024.02	2024.02
2	16.73	5.00	5.00	72.6	.0	2233.26	1852.29
3	17.84	6.11	6.11	70.0	.0	2249.87	1820.12
4	19.19	7.46	7.46	67.1	.0	2266.40	1782.79
5	20.84	9.11	9.11	64.1	.0	2282.69	1739.68
6	22.86	11.13	11.13	60.9	.0	2298.58	1690.14
7	25.32	13.59	13.59	57.5	.0	2313.94	1633.47
8	28.33	16.59	16.59	54.1	.0	2328.66	1568.93
9	32.00	20.27	20.27	50.7	.0	2342.66	1495.72
10	36.48	24.75	24.75	47.3	.0	2355.89	1412.98
11	41.96	30.23	30.23	43.9	.0	2368.33	1319.78
12	48.65	36.92	36.92	40.6	.0	2379.96	1215.09
13	56.82	45.10	45.10	37.5	.0	2390.80	1097.80
14	66.80	55.08	55.08	34.5	.0	2400.87	966.68
15	78.99	67.27	67.27	31.6	.0	2410.21	820.37
16	93.88	82.16	82.16	28.9	.0	2418.87	657.38
17	112.06	100.34	100.34	26.4	.0	2426.90	476.04
18	134.27	122.55	122.55	24.1	.0	2434.37	274.52
19	161.39	149.68	149.68	22.0	.0	2441.34	50.77
20	194.59	182.88	182.81	20.0	1.6	2447.40	.00
21	235.34	223.63	223.27	18.4	3.3	2451.94	.00
22	285.29	273.59	272.68	17.1	4.7	2455.51	.00
23	346.45	334.75	333.04	16.0	5.8	2458.54	.00
24	421.26	409.57	406.75	15.1	6.7	2461.34	.00
25	512.73	501.05	496.78	14.3	7.5	2464.14	.00
26	624.51	612.84	606.73	13.7	8.1	2467.16	.00
27	761.10	749.44	741.02	13.2	8.6	2470.57	.00
28	927.95	916.32	905.03	12.8	9.0	2474.56	.00
29	1131.76	1120.14	1105.35	12.4	9.3	2479.30	.00
30	1380.68	1369.09	1350.00	12.1	9.6	2485.00	.00

```
 **              **
******************  Ib.  Element Endpoint Position Table  *****************
 **              **
```

>>> Interpolation level 3 for line type B of 2 type(s)
    Vertical distance to nominal fairlead   .00 ft
    Vertical separation between endpoints   476.00 ft

>>> Element "i" endpoint coordinates (Xi or Zi; from fairlead, in ft)

```
 Table
 Index    X1


    2    2233.3
    3    2249.9
    4    2266.4
    5    2282.7
    6    2298.6
    7    2313.9
    8    2328.7
    9    2342.7
   10    2355.9
   11    2368.3
   12    2380.0
   13    2390.8
   14    2400.9
   15    2410.2
   16    2418.9
   17    2426.9
   18    2434.4
   19    2441.3
   20    2447.4
   21    2451.9
   22    2455.5
   23    2458.5
   24    2461.3
   25    2464.1
   26    2467.2
   27    2470.6
   28    2474.6
   29    2479.3
   30    2485.0
```

```
 Table
 Index    Z1


    2    -476.0
    3    -476.0
    4    -476.0
    5    -476.0
    6    -476.0
    7    -476.0
    8    -476.0
    9    -476.0
   10    -476.0
   11    -476.0
   12    -476.0
   13    -476.0
   14    -476.0
   15    -476.0
   16    -476.0
   17    -476.0
   18    -476.0
   19    -476.0
   20    -476.0
   21    -476.0
   22    -476.0
   23    -476.0
   24    -476.0
   25    -476.0
   26    -476.0
   27    -476.0
   28    -476.0
   29    -476.0
   30    -476.0
```

```
**                                                                        **
**  ********************  Ic.  Element Endpoint Angle Table  ********************  **
**                                                                        **
```

>>> Interpolation level 3 for line type B of 2 type(s)
     Vertical distance to nominal fairlead   .00 ft
     Vertical separation between endpoints   476.00 ft

>>> Endpoint angle Ti at fairlead-end of element "i" in degrees

Table Index	T1	T2
1	90.00	.00
2	72.61	.00
3	69.98	.00
4	67.13	.00
5	64.08	.00
6	60.87	.00
7	57.54	.00
8	54.14	.00
9	50.70	.00
10	47.27	.00
11	43.91	.00
12	40.63	.00
13	37.47	.00
14	34.47	.00
15	31.62	.00
16	28.94	.00
17	26.44	.00
18	24.12	.00
19	21.97	.00
20	20.04	1.59
21	18.43	3.28
22	17.10	4.67
23	16.00	5.80
24	15.08	6.73
25	14.33	7.49
26	13.71	8.10
27	13.19	8.60
28	12.76	9.00
29	12.40	9.32
30	12.10	9.58

```
**                                                                      **
**  ********************  II.  Equilibrium Condition Summary  ********************
**                                                                      **
```

++> User-specified still-water conditions produced the
    following net mooring force and moment components:

	Global system (Gravity Vertical)	Vessel system (Gravity Vertical)
X Mooring Force	0.00 k.lbs	0.00 k.lbs
Y Mooring Force	0.00 k.lbs	0.00 k.lbs
Z Mooring Force	-363.65 k.lbs	-363.65 k.lbs
Total Plan View Force	0.00 k.lbs	0.00 k.lbs
Plan View Force Angle	18.43 deg	18.43 deg
X Mooring Moment	0.00 foot-kips	0.00 foot-kips
Y Mooring Moment	181822.70 foot-kips	181822.70 foot-kips
Z Mooring Moment	0.00 foot-kips	0.00 foot-kips

   ---> These mooring moments are reported about the Vessel coordinate <---
         (Vx,Vy,Vz) = (0.000E-01, 0.000E-01, 0.000E-01)

>>> User-specified still-water line conditions

Line #/Type	- Total Tension - (k.lbs) Top	Anchor	Horizontal Tension (k.lbs)	Endpoint Separation (ft)	Bottom Length (ft)	Fairlead Line Angle (deg) Plan	Profile
1/a	75.00	58.42	58.42	1877.30	910.35	-.00	38.90
2/a	75.00	58.42	58.42	1877.30	910.35	45.00	38.90
3/b	75.00	63.27	63.27	2407.15	868.31	90.00	32.55
4/a	75.00	58.42	58.42	1877.30	910.35	135.00	38.90
5/a	75.00	58.42	58.42	1877.30	910.35	180.00	38.90
6/a	75.00	58.42	58.42	1877.30	910.35	225.00	38.90
7/b	75.00	63.27	63.27	2407.15	868.31	270.00	32.55
8/a	75.00	58.42	58.42	1877.30	910.35	315.00	38.90

```
**                                                    **
******************** II.  Equilibrium Condition Summary ********************
**                                                    **


++> Specified environmental conditions, applied forces and moments
    produced the following net mooring force and moment components:

                              Global system          Vessel system
                           (Gravity Vertical)      (Gravity Vertical)

         X Mooring Force         280.56 k.lbs           280.19 k.lbs
         Y Mooring Force         -23.15 k.lbs            27.30 k.lbs
         Z Mooring Force        -444.13 k.lbs          -444.13 k.lbs
         Total Plan View Force   281.52 k.lbs           281.52 k.lbs
         Plan View Force Angle    -4.72 deg               5.57 deg
         X Mooring Moment       2236.64 foot-kips     -42296.50 foot-kips
         Y Mooring Moment     249288.40 foot-kips     245684.20 foot-kips
         Z Mooring Moment     -11554.46 foot-kips     -11554.46 foot-kips


   ---> These mooring moments are reported about the Vessel coordinate <---
         (Vx,Vy,Vz) = ( 0.000E-01, 0.000E-01, 0.000E-01)


++> Specified environmental conditions, applied forces and moments produced
    the following global quasi-static mooring centroid displacements:

                              Global system          Vessel system

         X Displacement           -29.59 ft              -29.58 ft
         Y Displacement             2.59 ft               -2.73 ft
         Z Displacement              .00 ft                 .00 ft
         Total Plan View Offset    29.70 ft               29.70 ft
         Plan View Offset Angle   175.00 deg            -174.72 deg

         Yaw  Displacement        -10.28 deg                .00 deg
         Vessel Orientation       -10.28 deg                .00 deg

         Turret Rotation           -.01 deg              10.27 deg
         Turret Orientation        -.01 deg              10.27 deg


>>> Estimated mean line conditions in specified environment

                                                          Fairlead
  Line   - Total Tension -  Horizontal Endpoint   Bottom  Line Angle
  #/Type     (k.lbs)        Tension   Separation  Length  Plan  Profile
          Top     Anchor    (k.lbs)     (ft)       (ft)       (deg)


  1/a   215.13   190.29     190.29    1906.89    607.64   359.92   27.84
  2/a   146.83   125.61     125.61    1896.53    745.70    44.31   31.21
  3/b    71.86    60.13      60.13    2404.74    906.02    89.29   33.28
  4/a    46.78    31.80      31.80    1854.64    982.53   134.41   47.25
  5/a    43.04    28.15      28.15    1847.71    995.38   180.08   49.24
  6/a    49.48    34.39      34.39    1858.34    975.40   225.70   46.05
  7/b    78.62    66.89      66.89    2409.92    824.91   270.70   31.71
  8/a   168.06   145.63     145.63    1900.15    701.14   315.58   29.97
```

```
***********      III.  VESSEL AND ENVIRONMENT SUMMARY       ***********


   Water depth ...............................     450.00 feet
   Water density .............................      64.00 lbs/cubic foot
   Air density ...............................     .07831 lbs/cubic foot
   Vessel displacement .......................  407000.00 kips
   Transverse metacentric height .............      61.00 feet
   Longitudinal metacentric height ...........    1225.00 feet
   Vertical center of buoyancy ...............      34.00 feet
   Vertical center of gravity ................      36.00 feet
   Vessel water plane area ...................  126000.00 square feet
   Turret center X-coordinate ................     500.00 feet
   Length of vessel at waterline .............     929.00 feet
   Beam of vessel at waterline ...............     146.60 feet
   Vessel draft ..............................      64.00 feet

   Wind force model ..........................  OCIMF Tanker '77 (extended)
   Above-Water Bow Shape .....................  Conventional
   Freeboard-Based Load ......................     100.00 Percent

   Head-on Current Coefficients (Cx) .........  User-Specified LOWDAT
   Water depth/draft parameter ...............       7.03
   Beam-on Current Coefficients (Cy) .........  NSMB Tanker '91
   Water depth/draft parameter ...............       7.03
   Current Moment Coefficients  (Cz) .........  Barge (SeaSoft)
   Water depth/draft parameter ...............       7.03
   Below-Water Bow Shape .....................  Interpolated
   Draft-Based Load ..........................     100.00 Percent
   Bow Interpolation Factor ..................        .50

   Second Order Wave Drift Force Model .......  Tanker (2001)

   Tanker Deadweight .........................  300000.00 kips

   Surge damping is ..........................  Computed
   Sway  damping is ..........................  Computed
   Yaw   damping is ..........................  User-specified
   Yaw   damping (percent of critical) .......      33.00

   ------ WIND CONDITIONS ------

   Wind spectral type ........................  Davenport
   Wind speed ................................      60.00 knots
   Wind heading ..............................     150.00 degrees
   Head-on effective drag area ...............    7400.00 square feet
   Beam-on effective drag area ...............   23000.00 square feet
   Wind force enhancement factor .............       1.00

   ------ CURRENT CONDITIONS ------

   Current spectral type .....................  Steady current
   Current speed .............................       2.00 knots
   Current heading ...........................     180.00 degrees
   Head-on effective drag area ...............    9600.00 square feet
   Head-on drag area centroid ................        .00 feet
   Beam-on effective drag area ...............   61000.00 square feet
   Beam-on drag area centroid ................        .00 feet
   Current force enhancement factor ..........       1.00

   ------ WAVE CONDITIONS ------

   Wave spectral type ........................  Bretschneider
   Computed significant wave height ..........      19.43 feet
   Direction of maximum seas .................     180.00 degrees
   Spectrum peak period ......................      13.00 seconds
   Computed significant swell height .........       9.89 feet
   Swell direction............................     210.00 degrees
   Swell period ..............................      16.00 seconds
   Swell spectral bandwidth ..................        .10
   Head-on wave drift force factor ...........       1.00
   Variable wave drift enhancement factor ....       1.00
```

```
**********          IV.  STATIC EQUILIBRIUM SUMMARY          **********
```

```
>>> Most stable equilibrium <<<

-- (Global Coordinate System) --

  Vessel heading ............................    -10.28 degrees
  Turret heading ............................     -.01 degrees

  Fairlead centroid Global X displacement ....   -29.59 feet
  Fairlead centroid Global Y displacement ....     2.59 feet
  Fairlead centroid Global offset direction ..   175.00 degrees

Environmental forces: Most stable equilibrium

-- (Earth-Vertical Coordinates; X-Axis = Vessel Centerline) --

  Mean (x,y) forces due to wind:            (    -73.0,     52.4) kips
  Mean (x,y) forces due to wave reflection: (    -88.3,    -31.6) kips
  Mean (x,y) forces due to wave drag:       (    -13.0,      0.0) kips
  Mean (x,y) forces due to swell reflection:(     -2.3,     -1.8) kips
  Mean (x,y) forces due to swell drag:      (      -.4,      0.0) kips
  Mean (x,y) forces due to current (vessel):(   -103.2,    -46.3) kips
  Mean (x,y) forces due to current (lines): (    -30.3,     -5.5) kips

  Net mean (x,y) environmental forces:      (   -310.5,    -32.8) kips
```

```
**********          V.  LOW-FREQUENCY DYNAMICS SUMMARY          **********
```

```
Long-period single-amplitude surge motions:

        Period ......................................   186.21 sec
        Still water damping ........................     1.21 percent
        Damping due to wind ........................      .15 percent
        Damping due to current .....................     8.93 percent
        Damping due to wave reflection .............     1.55 percent
        Damping due to wave drag ...................      .17 percent
        Damping due to swell reflection ............      .03 percent
        Damping due to swell drag ..................     0.00 percent
        Damping due to wave-frequency line motions .    13.05 percent

        Total damping from linear sources ..........    25.09 percent

        Linearized square-law line damping .........      .31 percent
        Linearized square-law hull damping .........      .20 percent

        Net equivalent linear damping ..............    25.60 percent

        Damping conversion:  1% =  0.914E+01 k.lb/(ft/sec)
        Average Modal Stiffness:   0.146E+02 k.lb/ft

        Wind spectral density:     0.250E+03 (ft/s)^2/(rad/s)
        Current spectral density:  0.000E+00 (ft/s)^2/(rad/s)

        Offset associated with mean environment ....    29.70 feet

>>> Variations that <<INCREASE>> mean environmental offset:

        Two sigma variation due to wind ............      .89 feet
        Two sigma variation due to wave reflection       7.77 feet
        Two sigma variation due to wave drag .......     4.84 feet
        Two sigma variation due to swell reflection      .37 feet
        Two sigma variation due to swell drag ......      .25 feet
        Total Two sigma variation ..................     9.20 feet

        Most probable extreme (MPE) in  6.0 hr. storm   23.30 feet

>>> Variations that <<REDUCE>> mean environmental offset:

        Two sigma variation due to wind ............     -.89 feet
        Two sigma variation due to wave reflection      -8.49 feet
        Two sigma variation due to wave drag .......    -4.84 feet
        Two sigma variation due to swell reflection     -.37 feet
        Two sigma variation due to swell drag ......     -.25 feet
        Total Two sigma variation ..................   -10.04 feet

        Most probable extreme (MPE) in  6.0 hr. storm  -11.92 feet
```

```
**********          V.  LOW-FREQUENCY DYNAMICS SUMMARY          ***********
```

Long-period single-amplitude "sway" motions (low sway-yaw mode):

```
    Period ......................................  1419.03 sec
    Still water damping .........................     1.70 percent
    Damping due to wind .........................      .31 percent
    Damping due to current ......................     6.14 percent
    Damping due to wave reflection .............      .96 percent
    Damping due to wave drag ...................      .04 percent
    Damping due to swell reflection ............      .04 percent
    Damping due to swell drag ..................     0.00 percent
    Damping due to wave-frequency line motions .    41.38 percent

    Total damping from linear sources .........    50.57 percent

    Linearized square-law line damping ........     0.00 percent
    Linearized square-law hull damping ........      .81 percent

    Net equivalent linear damping ..............    51.39 percent

    Damping conversion:  1% =  0.106E+07 ft*kip/(rad/sec)
    Average Modal Stiffness:   0.332E+06 kip*ft/rad

    Wind spectral density:      0.347E+02 (ft/s)^2/(rad/s)
    Current spectral density:  0.000E+00 (ft/s)^2/(rad/s)

    Offset associated with mean environment ....    86.51 feet
```

>>> Variations that <<INCREASE>> mean environmental offset:

```
    Two sigma variation due to wind ...........      1.13 feet
    Two sigma variation due to wave reflection      13.47 feet
    Two sigma variation due to wave drag .......     0.00 feet
    Two sigma variation due to swell reflection      1.24 feet
    Two sigma variation due to swell drag ......     0.00 feet
    Total Two sigma variation at midship .......     13.57 feet
    Total Two sigma angular variation ..........      1.47 degrees

    Most probable extreme (MPE) in  6.0 hr. storm    15.84 feet

    Most probable extreme (MPE) in  6.0 hr. storm     1.71 degrees
```

>>> Variations that <<REDUCE>> mean environmental offset:

```
    Two sigma variation due to wind ...........     -1.13 feet
    Two sigma variation due to wave reflection     -13.47 feet
    Two sigma variation due to wave drag .......     0.00 feet
    Two sigma variation due to swell reflection    -1.24 feet
    Two sigma variation due to swell drag ......     0.00 feet
    Total Two sigma variation at midship .......    -13.57 feet
    Total Two sigma angular variation ..........     -1.47 degrees

    Most probable extreme (MPE) in  6.0 hr. storm   -15.84 feet

    Most probable extreme (MPE) in  6.0 hr. storm    -1.71 degrees
```

Long-period single-amplitude "yaw" motions (high sway-yaw mode):

```
    Period ......................................   107.40 sec

    Net equivalent linear damping ..............    33.00 percent

    Damping conversion:  1% =  0.164E+07 ft*kip/(rad/sec)
    Average Modal Stiffness:   0.480E+07 kip*ft/rad

    Wind spectral density:      0.390E+03 (ft/s)^2/(rad/s)
    Current spectral density:  0.000E+00 (ft/s)^2/(rad/s)

    Offset associated with mean environment ....   -10.28 degrees
```

>>> Variations that <<INCREASE>> mean environmental offset:

```
    Two sigma variation due to wind ...........     -.01 degrees
    Two sigma variation due to wave reflection      -.19 degrees
    Two sigma variation due to wave drag .......     -.00 degrees
    Two sigma variation due to swell reflection     0.00 degrees
    Two sigma variation due to swell drag ......     -.00 degrees
    Total Two sigma variation ..................     -.19 degrees

    Most probable extreme (MPE) in  6.0 hr. storm    -.30 degrees
```

>>> Variations that <<REDUCE>> mean environmental offset:

```
    Two sigma variation due to wind ...........      .01 degrees
    Two sigma variation due to wave reflection       .19 degrees
    Two sigma variation due to wave drag .......      .00 degrees
    Two sigma variation due to swell reflection     0.00 degrees
    Two sigma variation due to swell drag ......      .00 degrees
    Total Two sigma variation ..................      .19 degrees

    Most probable extreme (MPE) in  6.0 hr. storm     .30 degrees
```

```
**                                            **
********* VI.  Low-Frequency Maximum/Minumum Line Loads Summary   *********
**                                            **

+++ "Two sigma"  <<+ side>> LOW-FREQUENCY line loads +++

                                                           Line
  Line    - Total Tension -   Horizontal  Endpoint   Bottom    Line Angle
  #/Type      (k.lbs)         Tension    Separation  Length   Plan   Profile
           Top     Anchor     (k.lbs)      (ft)       (ft)        (deg)


  1/a     296.70   268.36      268.36    1916.06    458.75   359.92   25.26
  2/a     184.60   161.29      161.29    1902.65    667.71    44.31   29.16
  3/b      74.18    62.45       62.45    2406.52    878.17    89.29   32.74
  4/a      52.55    37.33       37.33    1862.34    967.32   134.41   44.74
  5/a      49.02    33.95       33.95    1857.71    976.62   180.08   46.26
  6/a      55.39    40.02       40.02    1864.82    959.97   225.70   43.82
  7/b      81.68    69.95       69.95    2411.77    791.00   270.70   31.13
  8/a     218.71   193.70      193.70    1907.33    600.89   315.58   27.72

+++ "Two sigma"  <<- side>> LOW-FREQUENCY line loads +++

                                                           Line
  Line    - Total Tension -   Horizontal  Endpoint   Bottom    Line Angle
  #/Type      (k.lbs)         Tension    Separation  Length   Plan   Profile
           Top     Anchor     (k.lbs)      (ft)       (ft)        (deg)


  1/a     148.95   127.61      127.61    1896.89    741.24   359.92   31.09
  2/a     114.78    95.54       95.54    1889.87    816.29    44.31   33.71
  3/b      69.57    57.84       57.84    2402.99    933.49    89.29   33.82
  4/a      42.98    28.09       28.09    1847.58    995.62   134.41   49.28
  5/a      39.11    24.27       24.27    1838.54   1017.03   180.08   51.68
  6/a      45.14    30.22       30.22    1852.38    986.87   225.70   47.97
  7/b      76.15    64.42       64.42    2408.02    854.56   270.70   32.28
  8/a     125.70   105.77      105.77    1892.33    791.82   315.58   32.76
```

```
**                                            **
********* VI.  Low-Frequency Maximum/Minumum Line Loads Summary   *********
**                                            **

+++ Storm extreme <<+ side>> LOW-FREQUENCY line loads +++

                                                           Line
  Line    - Total Tension -   Horizontal  Endpoint   Bottom    Line Angle
  #/Type      (k.lbs)         Tension    Separation  Length   Plan   Profile
           Top     Anchor     (k.lbs)      (ft)       (ft)        (deg)


  1/a     477.48   443.51      443.51    1930.23    172.84   359.92   21.80
  2/a     257.24   230.50      230.50    1911.93    528.95    44.31   26.39
  3/b      75.48    63.76       63.76    2407.52    862.53    89.29   32.44
  4/a      54.43    39.12       39.12    1863.99    962.45   134.41   44.13
  5/a      50.51    35.39       35.39    1859.76    972.67   180.08   45.59
  6/a      57.04    41.58       41.58    1866.27    955.69   225.70   43.28
  7/b      84.52    72.80       72.80    2413.42    759.85   270.70   30.62
  8/a     321.35   292.12      292.12    1918.32    417.09   315.58   24.68


>>> Line load snapshot taken at the low-frequency turnaround point with
    maximum net vessel loads (the "maximum VFy+" turnaround point)

              (Gx,Gy,Yaw) = (   -53.15,     2.14,   -12.18)

                                                           Line
  Line    - Total Tension -   Horizontal  Endpoint   Bottom    Line Angle
  #/Type      (k.lbs)         Tension    Separation  Length   Plan   Profile
           Top     Anchor     (k.lbs)      (ft)       (ft)        (deg)


  1/a     480.83   446.77      446.77    1930.44    167.96   359.94   21.75
  2/a     274.80   247.35      247.35    1913.77    497.72    43.83   25.89
  3/b      72.98    61.25       61.25    2405.60    892.59    88.73   33.02
  4/a      39.12    24.27       24.27    1838.56   1016.94   133.88   51.68
  5/a      34.67    19.82       19.82    1824.15   1088.61   180.07   55.16
  6/a      40.31    25.45       25.45    1841.64   1006.42   226.22   50.88
  7/b      78.55    66.83       66.83    2409.87    825.66   271.26   31.72
  8/a     303.44   274.84      274.84    1916.73    447.01   316.08   25.08
```

```
**                               **
********* VI.  Low-Frequency Maximum/Minumum Line Loads Summary   *********
**                               **

+++ Storm extreme <<- side>> LOW-FREQUENCY line loads +++

                                                    Line
 Line   - Total Tension -  Horizontal  Endpoint   Bottom   Line Angle
 #/Type      (k.lbs)        Tension   Separation  Length   Plan  Profile
          Top    Anchor     (k.lbs)      (ft)      (ft)       (deg)


 1/a    138.00  117.31      117.31    1894.83    764.79   359.92  31.83
 2/a    108.84   90.00       90.00    1888.39    829.88    44.31  34.29
 3/b     67.74   56.01       56.01    2401.58    955.48    89.29  34.25
 4/a     38.55   23.70       23.70    1836.77   1026.04   134.41  52.11
 5/a     34.72   19.87       19.87    1824.37   1087.67   180.08  55.11
 6/a     41.08   26.22       26.22    1843.37   1003.28   225.70  50.42
 7/b     74.86   63.13       63.13    2407.04    870.05   270.70  32.58
 8/a    117.93   98.49       98.49    1890.65    809.07   315.58  33.39


>>> Line load snapshot taken at the low-frequency turnaround point with
    minimum net vessel loads (the "minimum VFy-" turnaround point)

            (Gx,Gy,Yaw) = (  -17.32,     4.03,    -8.38)

                                                    Line
 Line   - Total Tension -  Horizontal  Endpoint   Bottom   Line Angle
 #/Type      (k.lbs)        Tension   Separation  Length   Plan  Profile
          Top    Anchor     (k.lbs)      (ft)      (ft)       (deg)


 1/a    136.95  116.33      116.33    1894.62    767.07   359.88  31.90
 2/a    102.28   83.86       83.86    1886.76    844.92    44.54  34.95
 3/b     69.82   58.10       58.10    2403.18    930.46    89.59  33.76
 4/a     52.42   37.21       37.21    1862.22    967.65   134.71  44.78
 5/a     50.67   35.54       35.54    1859.98    972.24   180.12  45.52
 6/a     58.97   43.41       43.41    1867.96    950.71   225.46  42.66
 7/b     80.77   69.04       69.04    2411.24    800.96   270.41  31.30
 8/a    126.14  106.19      106.19    1892.42    790.84   315.28  32.72
```

```
**                               **
********* VI.  Low-Frequency Maximum/Minumum Line Loads Summary   *********
**                               **


>>> Bounding Box estimates:

    1. A selection of "bounding boxes" of quasi-static mooring centroid
       offset points (Gx,Gy) follows immediately below:

       (a) Most Probable Gx (Max,Min) range: (   -17.32,   -53.15)
       (b) Most Probable Gy (Max,Min) range: (     7.13,    -.96)
       (c) "Typical Two Sigma" Gx range:     (   -19.44,   -38.91)
       (d) "Typical Two Sigma" Gy range:     (     5.17,    -.07)


>>> Snapshot load notes:

    1. This summary comprises "quasi-static" NET load snapshots taken at
       a selection of mooring centroid global offset points (Gx,Gy,Yaw):

       (a) The "Maximum VFx+" turnaround: (   -52.71,     7.13,    -8.38)
       (b) The "Maximum VFy+" turnaround: (   -53.15,     2.14,   -12.18)
       (c) A "typical Two Sigma+" offset: (   -38.91,     1.61,   -11.76)
       (d) The mean vessel offset:        (   -29.59,     2.59,   -10.28)
       (e) A "typical Two Sigma-" offset: (   -19.44,     3.49,    -8.80)
       (f) The "Minimum VFx-" turnaround: (   -17.76,     -.96,   -12.18)
       (g) The "Minimum VFy-" turnaround: (   -17.32,     4.03,    -8.38)


    2. Mooring moments are reported about the Vessel coordinate point

            (Vx,Vy,Vz) = ( 0.000E-01, 0.000E-01, 0.000E-01)


                ++++ Resolved in GLOBAL Coordinates ++++


            ------ Net Vessel Loads ----   ------- Net Vessel Moments -------
              X         Y         Z          X          Y          Z
            ---------- (k.lbs) --------   ---------- (k.lbs*ft) -----------

Max. VFx+:   734.60    -91.68   -597.32   8.815E+03  3.690E+05  -4.579E+04
Max. VFy+:   740.98    -26.33   -598.52   2.436E+03  3.702E+05  -1.311E+04
Two Sigma+:  430.02    -15.82   -496.26   1.462E+03  2.896E+05  -7.881E+03
Mean load:   280.56    -23.15   -444.13   2.237E+03  2.493E+05  -1.155E+04
Two Sigma-:  152.50    -27.84   -400.69   2.761E+03  2.153E+05  -1.391E+04
Min. VFx-:   133.27      7.26   -394.35  -7.601E+02  2.103E+05   3.641E+03
Min. VFy-:   129.55    -31.65   -393.20   3.147E+03  2.093E+05  -1.582E+04


                ++++ Resolved in VESSEL Coordinates ++++


            ------ Net Vessel Loads ----   ------- Net Vessel Moments -------
              X         Y         Z          X          Y          Z
            ---------- (k.lbs) --------   ---------- (k.lbs*ft) -----------

Max. VFx+:   740.12     16.40   -597.32  -4.507E+04  3.663E+05  -4.579E+04
Max. VFy+:   729.85    130.62   -598.52  -7.573E+04  3.624E+05  -1.311E+04
Two Sigma+:  424.22     72.17   -496.26  -5.761E+04  2.838E+05  -7.881E+03
Mean load:   280.19     27.30   -444.13  -4.230E+04  2.457E+05  -1.155E+04
Two Sigma-:  154.96     -4.18   -400.69  -3.022E+04  2.132E+05  -1.391E+04
Min. VFx-:   128.74     35.22   -394.35  -4.511E+04  2.054E+05   3.641E+03
Min. VFy-:   132.78    -12.43   -393.20  -2.740E+04  2.076E+05  -1.582E+04
```

```
**                                            **
**************     VII.  Line Endpoint Motion/Load Data     *************
**                                            **
                    Vessel-relative wave heading .......   190.3 deg
                    Wave height .......................    14.0 ft
                    Water depth .......................   450.0 ft
                    Endpoint separation ...............  1930.2 ft
>>> NOTES:

    1) Nonlinear motion/load "RAOs" measured at Vessel
    2) Motions/loads arise from regular wave excitation
    3) RAOs are "single amplitude/single amplitude"
    4) RAOs at specified line's extreme low-frequency offset
    5) Positive phase angles are phase leads
    6) Phase angles are relative to wave crest at c.g. of Vessel

>>> Mooring leg # 1: Line Type A of 2 Type(s) comprising 2 subline(s);
                Composition of first subline: Wire

                ++++ Quasi-Linear ++++      ++++  Nonlinear ++++
                     Motion RAOs                 Load Data
                       (ft/ft)                    (k.lbs)

 Wave    Wave   Wave    Endpoint      Endpoint
Period  Length  slope    Normal        Tangent
(sec)    (ft)   (deg)    Comp.          Comp.        Peak           Min
                        amp/phase     amp/phase    amp/phase      amp/phase

  6.00   184.2  13.7    .01/  97      .03/ -90    481.10/ -82   473.87/  97
  7.00   250.7  10.1    .03/ -80      .04/  81    481.53/  87   473.44/ -92
  8.00   327.5   7.7    .01/ -89      .09/ -87    488.42/ -74   466.55/ 105
  9.00   414.5   6.1    .30/ 134      .17/ 139    497.85/ 157   457.11/ -22
 10.00   511.7   4.9    .43/ 161      .31/ 138    518.11/ 163   436.74/ -16
 11.00   619.0   4.1    .36/  54      .34/  68    520.80/  91   434.13/ -88
 12.00   736.2   3.4   1.11/  62      .70/  62    586.29/  94   377.72/ -81
 13.00   862.3   2.9   1.51/  69      .81/  64    604.12/  95   363.30/ -79
 14.00   996.1   2.5   1.69/  71      .79/  62    594.50/  90   373.40/ -84
 15.00  1135.6   2.2   1.76/  72      .70/  61    572.96/  84   392.84/ -91
 16.00  1278.9   2.0   1.75/  71      .58/  55    551.37/  74   410.66/-102
 17.00  1424.1   1.8   1.72/  70      .48/  46    534.19/  61   423.77/-117
 18.00  1569.9   1.6   1.67/  68      .40/  33    523.71/  45   432.57/-134
 19.00  1715.4   1.5   1.63/  66      .35/  17    517.80/  26   437.42/-153
 20.00  1860.0   1.4   1.59/  65      .34/   0    516.30/   7   438.65/-172
```

```
**                                            **
*************     VIII. Dynamic/Static Line Load Comparison    *************
**                                            **
                    Vessel-relative wave heading .......   190.3 deg
                    Wave height .......................    14.0 ft
                    Water depth .......................   450.0 ft
                    Endpoint separation ...............  1930.2 ft
>>> NOTES:

    1) Nonlinear motion/load "RAOs" measured at Vessel
    2) Motions/loads arise from regular wave excitation
    3) RAOs are "single amplitude/single amplitude"
    4) RAOs at specified line's extreme low-frequency offset
    5) Positive phase angles are phase leads
    6) Phase angles are relative to wave crest at c.g. of Vessel

>>> Mooring leg # 1: Line Type A of 2 Type(s) comprising 2 subline(s);
                Composition of first subline: Wire

                ++++ Quasi-Static ++++      ++++  Dynamic  ++++
                      Load Data                   Load Data
                       (k.lbs)                     (k.lbs)

 Wave    Wave   Wave
Period  Length  slope     Peak           Min          Peak           Min
(sec)    (ft)   (deg)
                        amp/phase     amp/phase    amp/phase      amp/phase

  6.00   184.2  13.7    481.09/ -90   473.88/  90   481.10/ -82   473.87/  97
  7.00   250.7  10.1    481.52/  81   473.45/ 261   481.53/  87   473.44/ -92
  8.00   327.5   7.7    488.08/ -87   466.90/  93   488.42/ -74   466.55/ 105
  9.00   414.5   6.1    496.49/ 139   458.47/ 319   497.85/ 157   457.11/ -22
 10.00   511.7   4.9    512.53/ 138   442.34/ 318   518.11/ 163   436.74/ -16
 11.00   619.0   4.1    515.75/  68   439.18/ 248   520.80/  91   434.13/ -88
 12.00   736.2   3.4    560.64/  62   404.84/ 242   586.29/  94   377.72/ -81
 13.00   862.3   2.9    575.62/  64   394.13/ 244   604.12/  95   363.30/ -79
 14.00   996.1   2.5    573.50/  62   395.65/ 242   594.50/  90   373.40/ -84
 15.00  1135.6   2.2    561.12/  61   404.50/ 241   572.96/  84   392.84/ -91
 16.00  1278.9   2.0    545.61/  55   415.56/ 235   551.37/  74   410.66/-102
 17.00  1424.1   1.8    531.60/  46   425.61/ 226   534.19/  61   423.77/-117
 18.00  1569.9   1.6    522.55/  33   433.37/ 213   523.71/  45   432.57/-134
 19.00  1715.4   1.5    517.18/  17   437.96/ 197   517.80/  26   437.42/-153
 20.00  1860.0   1.4    515.86/   0   439.09/ 180   516.30/   7   438.65/-172
```

```
**                                           **          **                                           **
**************        VII.  Line Endpoint Motion/Load Data       *************   ************* VIII. Dynamic/Static Line Load Comparison  *************
**                                           **          **                                           **
            Vessel-relative wave heading .......  220.3 deg                     Vessel-relative wave heading .......  220.3 deg
            Wave height ........................   14.0 ft                       Wave height ........................   14.0 ft
            Water depth ........................  450.0 ft                       Water depth ........................  450.0 ft
            Endpoint separation ................ 1930.2 ft                       Endpoint separation ................ 1930.2 ft
>>> NOTES:                                                               >>> NOTES:

    1) Nonlinear motion/load "RAOs" measured at Vessel                      1) Nonlinear motion/load "RAOs" measured at Vessel
    2) Motions/loads arise from regular wave excitation                     2) Motions/loads arise from regular wave excitation
    3) RAOs are "single amplitude/single amplitude"                         3) RAOs are "single amplitude/single amplitude"
    4) RAOs at specified line's extreme low-frequency offset                4) RAOs at specified line's extreme low-frequency offset
    5) Positive phase angles are phase leads                                5) Positive phase angles are phase leads
    6) Phase angles are relative to wave crest at c.g. of Vessel            6) Phase angles are relative to wave crest at c.g. of Vessel

>>> Mooring leg # 1: Line Type A of 2 Type(s) comprising 2 subline(s);   >>> Mooring leg # 1: Line Type A of 2 Type(s) comprising 2 subline(s);
             Composition of first subline: Wire                                      Composition of first subline: Wire

                ++++ Quasi-Linear ++++    ++++  Nonlinear ++++                        ++++ Quasi-Static ++++   ++++  Dynamic  ++++
                     Motion RAOs               Load Data                                   Load Data                Load Data
                      (ft/ft)                   (k.lbs)                                     (k.lbs)                  (k.lbs)

  Wave    Wave   Wave   Endpoint   Endpoint                              Wave    Wave   Wave
 Period  Length  slope   Normal     Tangent      Peak        Min        Period  Length  slope     Peak         Min          Peak         Min
 (sec)    (ft)   (deg)    Comp.      Comp.                               (sec)    (ft)   (deg)
                        amp/phase  amp/phase   amp/phase    amp/phase                           amp/phase    amp/phase    amp/phase    amp/phase

  6.00   184.2   13.7    .01/ -79   .02/  90   480.16/  96  474.81/ -82   6.00   184.2   13.7   480.16/  90  474.80/ 270  480.16/  96  474.81/ -82
  7.00   250.7   10.1    .01/ 155   .06/ -83   483.97/ -73  471.01/ 106   7.00   250.7   10.1   483.86/ -83  471.11/  97  483.97/ -73  471.01/ 106
  8.00   327.5    7.7    .10/ 106   .10/ 127   489.07/ 140  465.91/ -39   8.00   327.5    7.7   488.65/ 127  466.32/ 307  489.07/ 140  465.91/ -39
  9.00   414.5    6.1    .13/ 121   .20/ 108   501.63/ 129  453.32/ -50   9.00   414.5    6.1   499.50/ 108  455.45/ 288  501.63/ 129  453.32/ -50
 10.00   511.7    4.9    .45/  -1   .30/  21   516.39/  45  438.48/-134  10.00   511.7    4.9   511.34/  21  443.54/ 201  516.39/  45  438.48/-134
 11.00   619.0    4.1   1.38/  32   .84/  29   634.84/  67  330.92/-107  11.00   619.0    4.1   580.67/  29  390.51/ 209  634.84/  67  330.92/-107
 12.00   736.2    3.4   1.77/  53   .99/  43   660.41/  79  308.84/ -93  12.00   736.2    3.4   599.83/  43  376.76/ 223  660.41/  79  308.84/ -93
 13.00   862.3    2.9   1.85/  61   .92/  45   630.34/  78  339.38/ -95  13.00   862.3    2.9   590.74/  45  383.30/ 225  630.34/  78  339.38/ -95
 14.00   996.1    2.5   1.81/  65   .92/  41   620.96/  71  349.91/-102  14.00   996.1    2.5   590.29/  41  383.62/ 221  620.96/  71  349.91/-102
 15.00  1135.6    2.2   1.74/  65   .77/  44   585.46/  68  382.44/-106  15.00  1135.6    2.2   570.30/  44  397.94/ 224  585.46/  68  382.44/-106
 16.00  1278.9    2.0   1.66/  64   .63/  36   559.22/  56  404.60/-120  16.00  1278.9    2.0   552.10/  36  410.93/ 216  559.22/  56  404.60/-120
 17.00  1424.1    1.8   1.58/  63   .55/  26   544.09/  42  416.52/-135  17.00  1424.1    1.8   540.30/  26  419.33/ 206  544.09/  42  416.52/-135
 18.00  1569.9    1.6   1.51/  61   .50/  14   535.80/  27  422.77/-151  18.00  1569.9    1.6   533.48/  14  424.18/ 194  535.80/  27  422.77/-151
 19.00  1715.4    1.5   1.45/  60   .48/   1   532.65/  13  425.25/-165  19.00  1715.4    1.5   531.07/   1  426.07/ 181  532.65/  13  425.25/-165
 20.00  1860.0    1.4   1.40/  58   .48/  -9   532.81/   1  425.18/-177  20.00  1860.0    1.4   531.51/  -9  425.69/ 171  532.81/   1  425.18/-177
```

```
**                                                       **
**************        VII.  Line Endpoint Motion/Load Data      *************
**                                                       **
                    Vessel-relative wave heading .......   190.3 deg
                    Wave height ......................    14.0 ft
                    Water depth ......................   450.0 ft
                    Endpoint separation ..............  1906.9 ft
>>> NOTES:

    1) Nonlinear motion/load "RAOs" measured at Vessel
    2) Motions/loads arise from regular wave excitation
    3) RAOs are "single amplitude/single amplitude"
    4) RAOs at vessel mean position
    5) Positive phase angles are phase leads
    6) Phase angles are relative to wave crest at c.g. of Vessel

>>> Mooring leg # 1: Line Type A of 2 Type(s) comprising 2 subline(s);
                    Composition of first subline: Wire

                    ++++ Quasi-Linear ++++      ++++  Nonlinear ++++
                          Motion RAOs                 Load Data
                            (ft/ft)                    (k.lbs)

 Wave     Wave    Wave     Endpoint      Endpoint
Period   Length   slope    Normal        Tangent
(sec)    (ft)    (deg)     Comp.         Comp.         Peak          Min
                          amp/phase     amp/phase    amp/phase     amp/phase

  6.00   184.2   13.7     .01/  95      .03/ -90    217.01/ -78   213.26/ 101
  7.00   250.7   10.1     .03/ -83      .03/  79    217.14/  89   213.13/ -90
  8.00   327.5    7.7    0.00/ -95      .09/ -87    221.24/ -67   209.05/ 112
  9.00   414.5    6.1     .28/ 134      .20/ 138    229.46/ 168   201.42/  -9
 10.00   511.7    4.9     .40/ 163      .35/ 141    244.15/-179   187.77/   3
 11.00   619.0    4.1     .33/  53      .37/  67    244.46/ 102   187.71/ -74
 12.00   736.2    3.4    1.03/  62      .81/  62    303.72/ 109   131.47/ -65
 13.00   862.3    2.9    1.42/  69      .96/  65    321.60/ 112   115.73/ -61
 14.00   996.1    2.5    1.60/  72      .96/  64    312.73/ 108   125.26/ -65
 15.00  1135.6    2.2    1.67/  72      .88/  63    293.43/ 103   144.04/ -71
 16.00  1278.9    2.0    1.68/  72      .76/  59    275.01/  93   161.27/ -81
 17.00  1424.1    1.8    1.66/  70      .65/  53    261.13/  81   173.94/ -95
 18.00  1569.9    1.6    1.63/  69      .55/  44    251.51/  67   182.42/-110
 19.00  1715.4    1.5    1.60/  67      .48/  33    245.67/  51   187.79/-126
 20.00  1860.0    1.4    1.57/  66      .44/  20    242.31/  35   190.82/-142
```

```
**                                                       **
**************        VIII. Dynamic/Static Line Load Comparison   *************
**                                                       **
                    Vessel-relative wave heading .......   190.3 deg
                    Wave height ......................    14.0 ft
                    Water depth ......................   450.0 ft
                    Endpoint separation ..............  1906.9 ft
>>> NOTES:

    1) Nonlinear motion/load "RAOs" measured at Vessel
    2) Motions/loads arise from regular wave excitation
    3) RAOs are "single amplitude/single amplitude"
    4) RAOs at vessel mean position
    5) Positive phase angles are phase leads
    6) Phase angles are relative to wave crest at c.g. of Vessel

>>> Mooring leg # 1: Line Type A of 2 Type(s) comprising 2 subline(s);
                    Composition of first subline: Wire

                    ++++ Quasi-Static ++++      ++++   Dynamic  ++++
                          Load Data                    Load Data
                            (k.lbs)                     (k.lbs)

 Wave     Wave    Wave
Period   Length   slope      Peak          Min          Peak          Min
(sec)    (ft)    (deg)
                          amp/phase     amp/phase    amp/phase     amp/phase

  6.00   184.2   13.7    216.98/ -90   213.29/  90   217.01/ -78   213.26/ 101
  7.00   250.7   10.1    217.12/  79   213.15/ 259   217.14/  89   213.13/ -90
  8.00   327.5    7.7    220.83/ -87   209.46/  93   221.24/ -67   209.05/ 112
  9.00   414.5    6.1    227.09/ 138   203.79/ 318   229.46/ 168   201.42/  -9
 10.00   511.7    4.9    236.18/ 141   195.97/ 321   244.15/-179   187.77/   3
 11.00   619.0    4.1    237.60/  67   194.75/ 247   244.46/ 102   187.71/ -74
 12.00   736.2    3.4    265.69/  62   172.26/ 242   303.72/ 109   131.47/ -65
 13.00   862.3    2.9    276.16/  65   165.54/ 245   321.60/ 112   115.73/ -61
 14.00   996.1    2.5    276.33/  64   165.43/ 244   312.73/ 108   125.26/ -65
 15.00  1135.6    2.2    270.45/  63   169.20/ 243   293.43/ 103   144.04/ -71
 16.00  1278.9    2.0    262.36/  59   174.76/ 239   275.01/  93   161.27/ -81
 17.00  1424.1    1.8    254.53/  53   180.63/ 233   261.13/  81   173.94/ -95
 18.00  1569.9    1.6    248.15/  44   185.60/ 224   251.51/  67   182.42/-110
 19.00  1715.4    1.5    243.87/  33   189.32/ 213   245.67/  51   187.79/-126
 20.00  1860.0    1.4    241.22/  20   191.62/ 200   242.31/  35   190.82/-142
```

```
**                                              **
**************        VII.  Line Endpoint Motion/Load Data       *************
**                                              **
                Vessel-relative wave heading ....... 220.3 deg
                Wave height ........................   14.0 ft
                Water depth ........................  450.0 ft
                Endpoint separation ................ 1906.9 ft
>>> NOTES:

    1) Nonlinear motion/load "RAOs" measured at Vessel
    2) Motions/loads arise from regular wave excitation
    3) RAOs are "single amplitude/single amplitude"
    4) RAOs at vessel mean position
    5) Positive phase angles are phase leads
    6) Phase angles are relative to wave crest at c.g. of Vessel

>>> Mooring leg # 1: Line Type A of 2 Type(s) comprising 2 subline(s);
                 Composition of first subline: Wire
```

Wave Period (sec)	Wave Length (ft)	Wave slope (deg)	++++ Quasi-Linear ++++ Motion RAOs (ft/ft) Endpoint Normal Comp. amp/phase	Endpoint Tangent Comp. amp/phase	++++ Nonlinear ++++ Load Data (k.lbs) Peak amp/phase	Min amp/phase
6.00	184.2	13.7	.01/ -82	.02/ 90	216.51/ 99	213.75/ -80
7.00	250.7	10.1	.01/ 123	.06/ -84	218.62/ -68	211.65/ 111
8.00	327.5	7.7	.09/ 103	.11/ 125	222.29/ 147	207.99/ -32
9.00	414.5	6.1	.11/ 123	.21/ 109	230.28/ 140	200.66/ -37
10.00	511.7	4.9	.42/ -2	.34/ 18	243.19/ 56	188.69/-120
11.00	619.0	4.1	1.29/ 32	.98/ 30	355.14/ 82	81.07/ -92
12.00	736.2	3.4	1.66/ 53	1.16/ 44	380.28/ 96	57.95/ -77
13.00	862.3	2.9	1.75/ 62	1.10/ 48	349.28/ 97	89.32/ -76
14.00	996.1	2.5	1.72/ 66	1.09/ 45	334.12/ 91	105.14/ -81
15.00	1135.6	2.2	1.65/ 66	.94/ 48	301.56/ 89	136.69/ -84
16.00	1278.9	2.0	1.59/ 65	.79/ 42	278.06/ 77	158.51/ -97
17.00	1424.1	1.8	1.52/ 64	.68/ 34	264.52/ 63	171.02/-112
18.00	1569.9	1.6	1.46/ 63	.61/ 25	256.50/ 49	178.15/-126
19.00	1715.4	1.5	1.42/ 62	.57/ 15	252.08/ 36	182.02/-141
20.00	1860.0	1.4	1.38/ 60	.55/ 4	250.18/ 23	183.84/-153

```
**                                              **
**************      VIII. Dynamic/Static Line Load Comparison     *************
**                                              **
                Vessel-relative wave heading ....... 220.3 deg
                Wave height ........................   14.0 ft
                Water depth ........................  450.0 ft
                Endpoint separation ................ 1906.9 ft
>>> NOTES:

    1) Nonlinear motion/load "RAOs" measured at Vessel
    2) Motions/loads arise from regular wave excitation
    3) RAOs are "single amplitude/single amplitude"
    4) RAOs at vessel mean position
    5) Positive phase angles are phase leads
    6) Phase angles are relative to wave crest at c.g. of Vessel

>>> Mooring leg # 1: Line Type A of 2 Type(s) comprising 2 subline(s);
                 Composition of first subline: Wire
```

Wave Period (sec)	Wave Length (ft)	Wave slope (deg)	++++ Quasi-Static ++++ Load Data (k.lbs) Peak amp/phase	Min amp/phase	++++ Dynamic ++++ Load Data (k.lbs) Peak amp/phase	Min amp/phase
6.00	184.2	13.7	216.51/ 90	213.76/ 270	216.51/ 99	213.75/ -80
7.00	250.7	10.1	218.49/ -84	211.78/ 96	218.62/ -68	211.65/ 111
8.00	327.5	7.7	221.67/ 125	208.61/ 305	222.29/ 147	207.99/ -32
9.00	414.5	6.1	227.60/ 109	203.34/ 289	230.28/ 140	200.66/ -37
10.00	511.7	4.9	235.71/ 18	196.38/ 198	243.19/ 56	188.69/-120
11.00	619.0	4.1	277.83/ 30	164.46/ 210	355.14/ 82	81.07/ -92
12.00	736.2	3.4	290.20/ 44	156.46/ 224	380.28/ 96	57.95/ -77
13.00	862.3	2.9	285.91/ 48	159.25/ 228	349.28/ 97	89.32/ -76
14.00	996.1	2.5	284.88/ 45	159.91/ 225	334.12/ 91	105.14/ -81
15.00	1135.6	2.2	274.45/ 48	166.63/ 228	301.56/ 89	136.69/ -84
16.00	1278.9	2.0	264.21/ 42	173.38/ 222	278.06/ 77	158.51/ -97
17.00	1424.1	1.8	256.92/ 34	178.84/ 214	264.52/ 63	171.02/-112
18.00	1569.9	1.6	251.95/ 25	182.55/ 205	256.50/ 49	178.15/-126
19.00	1715.4	1.5	249.11/ 15	184.76/ 195	252.08/ 36	182.02/-141
20.00	1860.0	1.4	247.99/ 4	185.74/ 184	250.18/ 23	183.84/-153

```
**                                                      **
**************              IX.  Net Vessel Load RAOs        *************
**                                                      **
                 Vessel-relative wave heading .......  190.3 deg
                 Wave height .......................   14.0 ft
                 Water depth .......................  450.0 ft
>>> NOTES:

     1) Nonlinear motions/loads from regular wave excitation
     2) RAOs are "single amplitude/single amplitude"
     3) RAOs at vessel mean position
     4) Positive phase angles are phase leads
     5) Phase angles are relative to wave crest at vessel c.g.


>>> Maximum Forces

                      ++++++  Nonlinear Net Maximum Forces   ++++++
                                      (k.lbs)
  Wave     Wave     Wave
 Period   Length    slope       Fx               Fy               Fz
 (sec)    (ft)     (deg)     amp/phase        amp/phase        amp/phase

  6.00    184.2    13.7    6.857E+02/ -80    6.762E-03/ -61   -4.421E+02/  98
  7.00    250.7    10.1    6.857E+02/  82    4.276E-02/ -56   -4.422E+02/-103
  8.00    327.5     7.7    6.943E+02/ -66    1.602E-02/   9   -4.372E+02/ 113
  9.00    414.5     6.1    7.306E+02/-176    1.140E-01/ 154   -4.122E+02/   5
 10.00    511.7     4.9    7.691E+02/-161    7.408E-02/-149   -3.888E+02/  21
 11.00    619.0     4.1    7.637E+02/ 108    1.231E-01/ -54   -3.942E+02/ -71
 12.00    736.2     3.4    1.008E+03/ 121    2.080E-01/ -20   -2.313E+02/ -57
 13.00    862.3     2.9    1.119E+03/ 126    2.475E-01/  21   -1.508E+02/ -50
 14.00    996.1     2.5    1.118E+03/ 127    6.928E-01/-178   -1.454E+02/ -50
 15.00   1135.6     2.2    1.055E+03/ 125    4.961E-01/ -69   -1.827E+02/ -50
 16.00   1278.9     2.0    9.846E+02/ 122    4.297E-01/ -48   -2.271E+02/ -53
 17.00   1424.1     1.8    9.239E+02/ 117    4.066E-01/ -39   -2.668E+02/ -57
 18.00   1569.9     1.6    8.756E+02/ 111    3.945E-01/ -34   -2.993E+02/ -62
 19.00   1715.4     1.5    8.384E+02/ 104    3.863E-01/ -31   -3.248E+02/ -67
 20.00   1860.0     1.4    8.097E+02/  97    3.799E-01/ -29   -3.449E+02/ -73
```

```
**                                                      **
**************              IX.  Net Vessel Load RAOs        *************
**                                                      **
                 Vessel-relative wave heading .......  190.3 deg
                 Wave height .......................   14.0 ft
                 Water depth .......................  450.0 ft
>>> NOTES:

     1) Nonlinear motions/loads from regular wave excitation
     2) RAOs are "single amplitude/single amplitude"
     3) RAOs at vessel mean position
     4) Positive phase angles are phase leads
     5) Phase angles are relative to wave crest at vessel c.g.
     6) Mooring moments are reported about the vessel coordinate point
          (Vx,Vy,Vz) = ( 0.000E-01, 0.000E-01, 0.000E-01)


>>> Maximum Moments

                      ++++++  Nonlinear Net Maximum Moments  ++++++
                                      (k.lbs-ft)
  Wave     Wave     Wave
 Period   Length    slope       Mx               My               Mz
 (sec)    (ft)     (deg)     amp/phase        amp/phase        amp/phase

  6.00    184.2    13.7   -2.200E+02/ 109    2.865E+05/ -81   -4.756E+02/ 103
  7.00    250.7    10.1   -2.144E+02/ 165    2.864E+05/  78   -4.671E+02/-112
  8.00    327.5     7.7   -2.056E+02/ 132    2.898E+05/ -66   -4.519E+02/ 116
  9.00    414.5     6.1   -8.650E+01/  21    3.056E+05/-174   -3.026E+02/  37
 10.00    511.7     4.9   -7.968E+01/  24    3.209E+05/-159   -2.918E+02/  23
 11.00    619.0     4.1   -1.510E+02/ -78    3.178E+05/ 107   -2.801E+02/ -69
 12.00    736.2     3.4    1.143E+02/ -90    4.217E+05/ 122    1.479E+02/ -75
 13.00    862.3     2.9    2.914E+02/ -99    4.720E+05/ 128    2.961E+02/ -84
 14.00    996.1     2.5    6.827E+02/ -91    4.743E+05/ 129    1.024E+03/-106
 15.00   1135.6     2.2    4.605E+02/ -81    4.496E+05/ 128    9.358E+02/ -77
 16.00   1278.9     2.0    3.315E+02/ -90    4.209E+05/ 125    6.402E+02/ -78
 17.00   1424.1     1.8    2.422E+02/ -98    3.954E+05/ 120    4.388E+02/ -81
 18.00   1569.9     1.6    1.727E+02/-106    3.747E+05/ 115    2.812E+02/ -85
 19.00   1715.4     1.5    1.201E+02/-115    3.585E+05/ 110    1.562E+02/ -89
 20.00   1860.0     1.4    8.121E+01/-123    3.459E+05/ 104    5.607E+01/ -93
```

```
**                                                    **
**************          IX.  Net Vessel Load RAOs          *************
**                                                    **
              Vessel-relative wave heading ....... 190.3 deg
              Wave height ........................  14.0 ft
              Water depth ........................ 450.0 ft
>>> NOTES:

    1) Nonlinear motions/loads from regular wave excitation
    2) RAOs are "single amplitude/single amplitude"
    3) RAOs at vessel mean position
    4) Positive phase angles are phase leads
    5) Phase angles are relative to wave crest at vessel c.g.


>>> Minimum Forces

                    ++++++  Nonlinear Net Minimum Forces   ++++++
                                     (k.lbs)
Wave      Wave     Wave
Period    Length   slope       Fx              Fy              Fz
(sec)     (ft)     (deg)    amp/phase       amp/phase       amp/phase

 6.00     184.2    13.7    6.793E+02/  99   -6.762E-03/ -61   -4.456E+02/ -81
 7.00     250.7    10.1    6.794E+02/ -97   -4.276E-02/ -56   -4.455E+02/  76
 8.00     327.5     7.7    6.708E+02/ 113   -1.602E-02/   9   -4.504E+02/ -66
 9.00     414.5     6.1    6.357E+02/   5   -1.140E-01/ 154   -4.740E+02/-170
10.00     511.7     4.9    5.983E+02/  21   -7.408E-02/-149   -4.962E+02/-154
11.00     619.0     4.1    6.055E+02/ -69   -1.231E-01/ -54   -4.910E+02/ 112
12.00     736.2     3.4    3.656E+02/ -55   -2.080E-01/ -20   -6.500E+02/ 127
13.00     862.3     2.9    2.671E+02/ -49   -2.475E-01/  21   -7.210E+02/ 134
14.00     996.1     2.5    2.832E+02/ -48   -6.928E-01/-178   -7.158E+02/ 135
15.00    1135.6     2.2    3.408E+02/ -49   -4.961E-01/ -69   -6.812E+02/ 134
16.00    1278.9     2.0    3.915E+02/ -52   -4.297E-01/ -48   -6.490E+02/ 132
17.00    1424.1     1.8    4.510E+02/ -57   -4.066E-01/ -39   -6.096E+02/ 128
18.00    1569.9     1.6    4.981E+02/ -63   -3.945E-01/ -34   -5.777E+02/ 124
19.00    1715.4     1.5    5.347E+02/ -69   -3.863E-01/ -31   -5.524E+02/ 119
20.00    1860.0     1.4    5.628E+02/ -76   -3.799E-01/ -29   -5.326E+02/ 114
```

```
**                                                    **
**************          IX.  Net Vessel Load RAOs          *************
**                                                    **
              Vessel-relative wave heading ....... 190.3 deg
              Wave height ........................  14.0 ft
              Water depth ........................ 450.0 ft
>>> NOTES:

    1) Nonlinear motions/loads from regular wave excitation
    2) RAOs are "single amplitude/single amplitude"
    3) RAOs at vessel mean position
    4) Positive phase angles are phase leads
    5) Phase angles are relative to wave crest at vessel c.g.
    6) Mooring moments are reported about the vessel coordinate point
          (Vx,Vy,Vz) = ( 0.000E-01, 0.000E-01, 0.000E-01)


>>> Minimum Moments

                    ++++++  Nonlinear Net Minimum Moments  ++++++
                                     (k.lbs-ft)
Wave      Wave     Wave
Period    Length   slope       Mx              My              Mz
(sec)     (ft)     (deg)    amp/phase       amp/phase       amp/phase

 6.00     184.2    13.7    -2.369E+02/ -72   2.841E+05/  98   -5.029E+02/ -70
 7.00     250.7    10.1    -2.395E+02/  16   2.842E+05/-101   -5.221E+02/ -30
 8.00     327.5     7.7    -2.507E+02/ -53   2.809E+05/ 113   -5.271E+02/ -40
 9.00     414.5     6.1    -3.554E+02/-149   2.659E+05/   8   -7.366E+02/-164
10.00     511.7     4.9    -3.607E+02/-153   2.513E+05/  24   -7.489E+02/-152
11.00     619.0     4.1    -3.235E+02/ 109   2.545E+05/ -68   -5.686E+02/  92
12.00     736.2     3.4    -5.672E+02/  98   1.529E+05/ -53   -9.921E+02/  88
13.00     862.3     2.9    -6.305E+02/  79   1.087E+05/ -46   -1.224E+03/  74
14.00     996.1     2.5    -9.581E+02/  71   1.130E+05/ -45   -1.581E+03/  97
15.00    1135.6     2.2    -8.185E+02/  95   1.358E+05/ -46   -1.128E+03/  92
16.00    1278.9     2.0    -8.175E+02/  99   1.567E+05/ -48   -1.205E+03/  90
17.00    1424.1     1.8    -7.152E+02/  93   1.819E+05/ -52   -1.105E+03/  79
18.00    1569.9     1.6    -6.364E+02/  87   2.022E+05/ -57   -1.033E+03/  68
19.00    1715.4     1.5    -5.763E+02/  81   2.182E+05/ -62   -9.858E+02/  57
20.00    1860.0     1.4    -5.293E+02/  74   2.306E+05/ -68   -9.557E+02/  47
```

```
**                                                            **
**************            IX.  Net Vessel Load RAOs      *************
**                                                            **
              Vessel-relative wave heading .......   220.3 deg
              Wave height .......................    14.0 ft
              Water depth .......................   450.0 ft
>>> NOTES:

    1) Nonlinear motions/loads from regular wave excitation
    2) RAOs are "single amplitude/single amplitude"
    3) RAOs at vessel mean position
    4) Positive phase angles are phase leads
    5) Phase angles are relative to wave crest at vessel c.g.


>>> Maximum Forces

                      ++++++  Nonlinear Net Maximum Forces   ++++++
                                       (k.lbs)
  Wave     Wave     Wave
 Period   Length    slope       Fx              Fy              Fz
 (sec)     (ft)    (deg)     amp/phase        amp/phase       amp/phase

  6.00    184.2     13.7    6.849E+02/ 100    7.275E-03/-132   -4.426E+02/ -80
  7.00    250.7     10.1    6.891E+02/ -61    5.910E-02/ -11   -4.402E+02/ 118
  8.00    327.5      7.7    7.078E+02/ 176    3.402E-01/ 153   -4.276E+02/  -2
  9.00    414.5      6.1    7.200E+02/ 157    1.645E-01/-143   -4.211E+02/ -20
 10.00    511.7      4.9    7.834E+02/  64    4.351E-01/ -34   -3.781E+02/-115
 11.00    619.0      4.1    1.253E+03/  90    7.619E-01/  -5   -6.490E+01/ -87
 12.00    736.2      3.4    1.405E+03/ 107    9.749E-01/  27    4.175E+01/ -69
 13.00    862.3      2.9    1.332E+03/ 114    1.615E+00/  83   -9.623E-01/ -62
 14.00    996.1      2.5    1.346E+03/ 108    4.310E+00/-177    5.720E+00/ -67
 15.00   1135.6      2.2    1.171E+03/ 110    2.717E+00/ -95   -1.081E+02/ -66
 16.00   1278.9      2.0    1.035E+03/ 107    1.931E+00/ -70   -1.970E+02/ -68
 17.00   1424.1      1.8    9.533E+02/ 102    1.621E+00/ -58   -2.521E+02/ -72
 18.00   1569.9      1.6    8.974E+02/  95    1.460E+00/ -51   -2.903E+02/ -77
 19.00   1715.4      1.5    8.579E+02/  88    1.360E+00/ -46   -3.178E+02/ -83
 20.00   1860.0      1.4    8.294E+02/  81    1.292E+00/ -42   -3.381E+02/ -90
```

```
**                                                            **
**************            IX.  Net Vessel Load RAOs      *************
**                                                            **
              Vessel-relative wave heading .......   220.3 deg
              Wave height .......................    14.0 ft
              Water depth .......................   450.0 ft
>>> NOTES:

    1) Nonlinear motions/loads from regular wave excitation
    2) RAOs are "single amplitude/single amplitude"
    3) RAOs at vessel mean position
    4) Positive phase angles are phase leads
    5) Phase angles are relative to wave crest at vessel c.g.
    6) Mooring moments are reported about the vessel coordinate point
          (Vx,Vy,Vz) = ( 0.000E-01, 0.000E-01, 0.000E-01)


>>> Maximum Moments

                      ++++++  Nonlinear Net Maximum Moments  ++++++
                                       (k.lbs-ft)
  Wave     Wave     Wave
 Period   Length    slope       Mx              My              Mz
 (sec)     (ft)    (deg)     amp/phase        amp/phase       amp/phase

  6.00    184.2     13.7   -2.137E+02/ -56    2.862E+05/  99   -4.599E+02/ -67
  7.00    250.7     10.1   -1.668E+02/ 157    2.878E+05/ -61   -4.247E+02/ 149
  8.00    327.5      7.7    1.010E+02/  22    2.957E+05/ 176   -8.131E+01/  46
  9.00    414.5      6.1   -1.273E+01/   3    3.002E+05/ 158   -2.250E+02/ -11
 10.00    511.7      4.9    2.237E+02/-107    3.275E+05/  64    3.468E+02/ -89
 11.00    619.0      4.1    1.980E+03/-105    5.272E+05/  91    2.918E+03/ -96
 12.00    736.2      3.4    2.609E+03/-106    5.942E+05/ 109    3.499E+03/ -99
 13.00    862.3      2.9    2.868E+03/-115    5.659E+05/ 116    3.282E+03/-120
 14.00    996.1      2.5    4.954E+03/-101    5.704E+05/ 111    8.564E+03/-119
 15.00   1135.6      2.2    2.692E+03/ -82    4.974E+05/ 112    5.704E+03/ -86
 16.00   1278.9      2.0    1.743E+03/ -91    4.405E+05/ 110    3.716E+03/ -85
 17.00   1424.1      1.8    1.298E+03/-101    4.055E+05/ 105    2.692E+03/ -89
 18.00   1569.9      1.6    1.032E+03/-111    3.813E+05/ 100    2.039E+03/ -93
 19.00   1715.4      1.5    8.610E+02/-121    3.640E+05/  94    1.582E+03/ -98
 20.00   1860.0      1.4    7.482E+02/-131    3.512E+05/  87    1.244E+03/-103
```

```
**                                       **              **                              **
**************          IX.  Net Vessel Load RAOs    **************          **************          IX.  Net Vessel Load RAOs    **************
**                                       **              **                              **
             Vessel-relative wave heading .......   220.3 deg                  Vessel-relative wave heading .......   220.3 deg
             Wave height ......................    14.0 ft                     Wave height ......................    14.0 ft
             Water depth ......................   450.0 ft                     Water depth ......................   450.0 ft
>>> NOTES:                                                        >>> NOTES:

    1) Nonlinear motions/loads from regular wave excitation          1) Nonlinear motions/loads from regular wave excitation
    2) RAOs are "single amplitude/single amplitude"                  2) RAOs are "single amplitude/single amplitude"
    3) RAOs at vessel mean position                                  3) RAOs at vessel mean position
    4) Positive phase angles are phase leads                         4) Positive phase angles are phase leads
    5) Phase angles are relative to wave crest at vessel c.g.        5) Phase angles are relative to wave crest at vessel c.g.
                                                                     6) Mooring moments are reported about the vessel coordinate point
                                                                            (Vx,Vy,Vz) = ( 0.000E-01, 0.000E-01, 0.000E-01)

>>> Minimum Forces                                               >>> Minimum Moments

                     ++++++  Nonlinear Net Minimum Forces   ++++++                    ++++++  Nonlinear Net Minimum Moments  ++++++
                                   (k.lbs)                                                  (k.lbs-ft)
 Wave    Wave    Wave                                             Wave    Wave    Wave
Period  Length  slope      Fx              Fy              Fz    Period  Length  slope      Mx              My              Mz
(sec)    (ft)   (deg)   amp/phase       amp/phase       amp/phase (sec)   (ft)   (deg)   amp/phase       amp/phase       amp/phase

 6.00   184.2   13.7   6.802E+02/ -79  -7.275E-03/-132  -4.451E+02/  99   6.00   184.2   13.7  -2.447E+02/ 119   2.844E+05/ -80  -5.096E+02/ 129
 7.00   250.7   10.1   6.761E+02/ 118  -5.910E-02/ -11  -4.475E+02/ -60   7.00   250.7   10.1  -2.801E+02/ -23   2.829E+05/ 119  -6.040E+02/ -20
 8.00   327.5    7.7   6.578E+02/  -2  -3.402E-01/ 153  -4.596E+02/-179   8.00   327.5    7.7  -5.190E+02/-145   2.752E+05/   0  -1.076E+03/-165
 9.00   414.5    6.1   6.463E+02/ -20  -1.645E-01/-143  -4.654E+02/ 161   9.00   414.5    6.1  -4.159E+02/-178   2.711E+05/ -18  -8.723E+02/-170
10.00   511.7    4.9   5.847E+02/-113  -4.351E-01/ -34  -5.074E+02/  68  10.00   511.7    4.9  -7.037E+02/  83   2.445E+05/-112  -1.144E+03/  60
11.00   619.0    4.1   2.548E+02/ -84  -7.619E-01/  -5  -7.231E+02/  97  11.00   619.0    4.1  -1.223E+03/  72   1.061E+05/ -82  -2.266E+03/  58
12.00   736.2    3.4   1.920E+02/ -64  -9.749E-01/  27  -7.601E+02/ 118  12.00   736.2    3.4  -1.361E+03/  51   8.173E+04/ -62  -2.839E+03/  47
13.00   862.3    2.9   2.500E+02/ -59  -1.615E+00/  83  -7.251E+02/ 124  13.00   862.3    2.9  -1.615E+03/  49   1.047E+05/ -56  -3.562E+03/  61
14.00   996.1    2.5   3.453E+02/ -55  -4.310E+00/-177  -6.697E+02/ 130  14.00   996.1    2.5  -2.580E+03/  53   1.416E+05/ -50  -3.365E+03/ 104
15.00  1135.6    2.2   3.863E+02/ -62  -2.717E+00/ -95  -6.421E+02/ 122  15.00  1135.6    2.2  -1.971E+03/  88   1.592E+05/ -58  -1.500E+03/  98
16.00  1278.9    2.0   4.179E+02/ -67  -1.931E+00/ -70  -6.228E+02/ 118  16.00  1278.9    2.0  -1.768E+03/  88   1.718E+05/ -63  -1.818E+03/  69
17.00  1424.1    1.8   4.603E+02/ -72  -1.621E+00/ -58  -5.991E+02/ 114  17.00  1424.1    1.8  -1.569E+03/  85   1.879E+05/ -67  -1.860E+03/  57
18.00  1569.9    1.6   4.977E+02/ -78  -1.460E+00/ -51  -5.730E+02/ 109  18.00  1569.9    1.6  -1.395E+03/  79   2.043E+05/ -72  -1.871E+03/  48
19.00  1715.4    1.5   5.156E+02/ -84  -1.360E+00/ -46  -5.599E+02/ 103  19.00  1715.4    1.5  -1.354E+03/  76   2.125E+05/ -78  -1.955E+03/  45
20.00  1860.0    1.4   5.441E+02/ -91  -1.292E+00/ -42  -5.399E+02/  97  20.00  1860.0    1.4  -1.188E+03/  68   2.251E+05/ -85  -1.894E+03/  35
```

```
 ********     X. Wave-Frequency Motion/Load Statistical Summaries     ********


++> NOTE:  Wave-frequency motions/loads computed at
           each line's extreme low-frequency offset


      ----  Wave Characteristics  ----

      Wave Spectral Type -- Bretschneider; Long-crested seas

            Requested Significant wave height ....      20.00 ft
            Calculated Significant wave height ...      19.43 ft
            Spectrum peak period .................      13.00 seconds
            Spectrum characteristic wind speed ...      59.02 feet/sec
            Direction of maximum seas ............     180.00 degrees

            +++ Background Swell Data +++

            Requested Significant swell height ...      10.00 ft
            Calculated Significant swell height ..       9.89 ft
            Swell direction .....................      210.00 degrees
            Swell period ........................       16.00 seconds

>>> Mooring leg #  1: Line Type A of 2 Type(s);
    Quasi-static load at indicated LF offset:       477.48 k.lbs

             +++  Wave-Frequency Characteristic Motions/Loads Summary  +++

                         Two-Sigma         Two-Sigma            Zero
     <Endpoint WF Motions:>  variation          rate             Upcross
                                                                 Period
                            (ft)              (ft/sec)           (sec)

      Fairlead tangential      6.12              2.84             13.54
      Fairlead normal         14.54              6.29             14.53

     <Endpoint WF Loads:>     LF value PLUS            LF value MINUS
                           Two-sigma WF variation   Two-sigma WF variation
                               (k.lbs)                  (k.lbs)

      Fairlead loads           615.43                   354.05
      Anchor loads             582.12                   319.49

     +++  Most Probable Extreme Wave-Frequency Motions/Loads  +++

               >>> Storm duration:   6.00 hrs. <<<

       <Endpoint WF motion variations:>        Most Probable
                                             Extreme WF Variation

          Fairlead tangential ..................      11.76 ft
          Fairlead normal ......................      27.93 ft

      >>> Extreme WF loads (LF load plus Extreme WF variation):

          Fairlead extreme load ................     851.63 k.lbs
          Anchor extreme load ..................     819.45 k.lbs
```

```
 *************        XI. Estimated Characteristic Line Loads     *************


       -----   Estimated Two-Sigma <<Maximum/Minimum>> Line Loads  -----
                          (k.lbs)


     Line          Mean           ++++ MAXIMUM ++++       ++++ MINIMUM ++++
     #/Type       Tension              Tension                 Tension

            Fairlead   Anchor      Fairlead   Anchor      Fairlead   Anchor

      1/a    215.13    190.29       375.40    349.38        67.18     43.75
      2/a    146.83    125.61       325.79    304.87        20.79      .00
      3/b     71.86     60.13       227.72    216.72         9.37      .00
      4/a     46.78     31.80       136.53    121.90        12.99      .00
      5/a     43.04     28.15        99.67     84.99        13.19      .00
      6/a     49.48     34.39       109.12     94.26        13.56      .00
      7/b     78.62     66.89       153.37    142.03        10.09      .00
      8/a    168.06    145.63       269.70    246.40        72.65     51.22


        ------   Characteristic Two-Sigma Line Load <<Variations>>  ------
                          (k.lbs)


     Line          Mean           Low-frequency          Wave-frequency
     #/Type       Tension         Contribution (+)       Contribution (+)

            Fairlead   Anchor      Fairlead   Anchor      Fairlead   Anchor

      1/a    215.13    190.29        81.57     78.07       137.96    138.62
      2/a    146.83    125.61        37.77     35.68       174.93    175.67
      3/b     71.86     60.13         2.32      2.32       155.84    156.57
      4/a     46.78     31.80         5.77      5.54        89.57     89.93
      5/a     43.04     28.15         5.98      5.80        56.31     56.54
      6/a     49.48     34.39         5.91      5.63        59.35     59.60
      7/b     78.62     66.89         3.06      3.06        74.69     75.07
      8/a    168.06    145.63        50.64     48.07        88.12     88.56
```

```
**************   XII. Estimated Storm Extreme Line Loads   *************
                         (Upper Bound Algorithm)


         ---  Estimated Storm-Extreme <<Maximum/Minimum>> Line Loads  ---
                                    (k.lbs)


Line            Mean          ++++ MAXIMUM ++++      ++++ MINIMUM ++++
#/Type         Tension             Tension               Tension

           Fairlead   Anchor    Fairlead   Anchor    Fairlead   Anchor

1/a         215.13    190.29     851.63    819.45      21.46      .00
2/a         146.83    125.61     783.78    759.28      15.97      .00
3/b          71.86     60.13     544.42    534.88       7.43      .00
4/a          46.78     31.80     369.62    355.58      11.03      .00
5/a          43.04     28.15     250.87    236.56      11.53      .00
6/a          49.48     34.39     266.63    252.06      11.92      .00
7/b          78.62     66.89     321.12    310.61       8.69      .00
8/a         168.06    145.63     570.00    542.01      20.53      .00


         ------  Estimated Storm-Extreme Line Load <<Variations>>  ------
                                    (k.lbs)


Line            Mean          Low-frequency         Wave-frequency
#/Type         Tension        Contribution (+)      Contribution (+)

           Fairlead   Anchor    Fairlead   Anchor    Fairlead   Anchor

1/a         215.13    190.29     262.35    253.21     374.15    375.94
2/a         146.83    125.61     110.41    104.89     526.54    528.78
3/b          71.86     60.13       3.62      3.62     468.94    471.12
4/a          46.78     31.80       7.65      7.32     315.19    316.46
5/a          43.04     28.15       7.48      7.24     200.36    201.17
6/a          49.48     34.39       7.56      7.19     209.59    210.48
7/b          78.62     66.89       5.91      5.91     236.60    237.81
8/a         168.06    145.63     153.29    146.49     248.65    249.89
```

```
********   X. Wave-Frequency Motion/Load Statistical Summaries   ********


++> NOTE:  Wave-frequency motions/loads computed at
           storm-extreme max Fx+ turnaround

             (Gx,Gy,Yaw) = (   -52.71,     7.13,    -8.38)


      ----  Wave Characteristics  ----

      Wave Spectral Type -- Bretschneider; Long-crested seas

          Requested Significant wave height ....     20.00 ft
          Calculated Significant wave height ...     19.43 ft
          Spectrum peak period .................     13.00 seconds
          Spectrum characteristic wind speed ...     59.02 feet/sec
          Direction of maximum seas ............    180.00 degrees

          +++ Background Swell Data +++

          Requested Significant swell height ...     10.00 ft
          Calculated Significant swell height ..      9.89 ft
          Swell direction ......................    210.00 degrees
          Swell period .........................     16.00 seconds

>>> Mooring leg #  1: Line Type A of 2 Type(s);
    Quasi-static load at indicated LF offset:      474.17 k.lbs

            +++  Wave-Frequency Characteristic Motions/Loads Summary  +++

                            Two-Sigma       Two-Sigma        Zero
      <Endpoint WF Motions:>  variation        rate         Upcross
                                                            Period
                              (ft)          (ft/sec)         (sec)

      Fairlead tangential       5.98           2.78          13.51
      Fairlead normal          14.46           6.24          14.56

      <Endpoint WF Loads:>    LF value PLUS           LF value MINUS
                            Two-sigma WF variation   Two-sigma WF variation
                                 (k.lbs)                  (k.lbs)

      Fairlead loads            607.07                   355.38
      Anchor loads              573.83                   320.92

    +++  Most Probable Extreme Wave-Frequency Motions/Loads  +++

                  >>> Storm duration:   6.00 hrs. <<<

       <Endpoint WF motion variations:>        Most Probable
                                            Extreme WF Variation

           Fairlead tangential ..................     11.48 ft
           Fairlead normal ......................     27.77 ft

     >>> Extreme WF loads (LF load plus Extreme WF variation):

           Fairlead extreme load ................    833.53 k.lbs
           Anchor extreme load ..................    801.37 k.lbs
```

```
******  XIII. Wave-Frequency Line Loads: Quasi-Static Offset Snapshot  *****

++> NOTE:  Wave-frequency motion/loads computed at
           storm-extreme max Fx+ turnaround

           (Gx,Gy,Yaw) = (   -52.71,     7.13,    -8.38)


           -----  Estimated Two-Sigma <<Maximum/Minimum>> Line Loads  -----
                                     (k.lbs)


   Line          Mean         ++++ MAXIMUM ++++      ++++ MINIMUM ++++
   #/Type       Tension            Tension               Tension

            Fairlead  Anchor    Fairlead  Anchor     Fairlead  Anchor

    1/a     215.13    190.29     607.07   573.83      341.27   306.74
    2/a     146.83    125.61     417.95   392.80       62.88    36.02
    3/b      71.86     60.13     215.46   204.56        9.11      .00
    4/a      46.78     31.80      84.22    69.59       12.45      .00
    5/a      43.04     28.15      66.14    51.44       12.77      .00
    6/a      49.48     34.39      78.57    63.86       12.86      .00
    7/b      78.62     66.89     169.75   158.49        9.94      .00
    8/a     168.06    145.63     428.18   398.77      249.54   219.26


           ------  Characteristic Two-Sigma Line Load <<Variations>>  ------
                                     (k.lbs)


   Line          Mean          Low-frequency         Wave-frequency
   #/Type       Tension        Contribution (+)      Contribution (+)

            Fairlead  Anchor    Fairlead  Anchor     Fairlead  Anchor

    1/a     215.13    190.29     259.04   249.99      132.90   133.54
    2/a     146.83    125.61      93.59    88.80      177.54   178.39
    3/b      71.86     60.13      -5.32    -5.32      148.93   149.75
    4/a      46.78     31.80      -8.71    -8.57       46.14    46.37
    5/a      43.04     28.15      -8.26    -8.21       31.36    31.51
    6/a      49.48     34.39      -7.41    -7.20       36.50    36.68
    7/b      78.62     66.89       8.36     8.36       82.78    83.24
    8/a     168.06    145.63     170.80   163.38       89.32    89.75
```

```
******  XIV. Wave-Frequency Line Loads: Quasi-Static Offset Snapshot  *****

++> NOTE:  Wave-frequency motion/loads computed at
           storm-extreme max Fx+ turnaround

           (Gx,Gy,Yaw) = (   -52.71,     7.13,    -8.38)


           ---  Estimated Storm-Extreme <<Maximum/Minimum>> Line Loads  ---
                                     (k.lbs)


   Line          Mean         ++++ MAXIMUM ++++      ++++ MINIMUM ++++
   #/Type       Tension            Tension               Tension

            Fairlead  Anchor    Fairlead  Anchor     Fairlead  Anchor

    1/a     215.13    190.29     833.53   801.37      114.82    79.20
    2/a     146.83    125.61     784.78   761.39       14.75      .00
    3/b      71.86     60.13     525.52   516.34        6.96      .00
    4/a      46.78     31.80     206.65   192.61       10.38      .00
    5/a      43.04     28.15     149.58   135.28       10.97      .00
    6/a      49.48     34.39     174.97   160.73       11.11      .00
    7/b      78.62     66.89     344.24   333.94        8.42      .00
    8/a     168.06    145.63     586.74   558.09       90.98    59.94


           ------  Estimated Storm-Extreme Line Load <<Variations>>  ------
                                     (k.lbs)


   Line          Mean          Low-frequency         Wave-frequency
   #/Type       Tension        Contribution (+)      Contribution (+)

            Fairlead  Anchor    Fairlead  Anchor     Fairlead  Anchor

    1/a     215.13    190.29     259.04   249.99      359.35   361.08
    2/a     146.83    125.61      93.59    88.80      544.36   546.98
    3/b      71.86     60.13      -5.32    -5.32      458.98   461.53
    4/a      46.78     31.80      -8.71    -8.57      168.57   169.38
    5/a      43.04     28.15      -8.26    -8.21      114.80   115.35
    6/a      49.48     34.39      -7.41    -7.20      132.90   133.54
    7/b      78.62     66.89       8.36     8.36      257.27   258.69
    8/a     168.06    145.63     170.80   163.38      247.88   249.07
```

```
**************   XV.  Net Vessel Moment and Load Summary   ****************


++> Notes:

     1) Estimated net vessel loads evaluated at mooring
        centroid storm-extreme max Fx+ turnaround

           (Gx,Gy,Yaw) = (   -52.71,     7.13,    -8.38)

     2) Wave-frequency phases are relative to wave crest at c.g. of Vessel
     3) Positive phase angles are phase leads
     4) Mooring moments are reported about the vessel coordinate point

           (Vx,Vy,Vz) = ( 0.000E-01, 0.000E-01, 0.000E-01)



  ++> Quasi-static plus <<TWO-SIGMA>> wave-frequency loads
      (Resolved in vessel-bound Coordinates)


         ------ Net Vessel Loads ------    ------- Net Vessel Moments -------
            X        Y        Z          X          Y          Z
         ---------- (k.lbs) ----------    ---------- (k.lbs*ft) -----------

 ---> Quasi-static contribution

          739.9     16.5    -597.0    -1.664E+03   3.693E+05   1.047E+04

 ---> Wave-frequency contribution & phase in degrees

  Amp:    230.6    163.0    373.5    1.585E+04   2.066E+05   8.154E+04
Phase:     96.1    107.8    -57.6      -72.0       119.5       107.7

 ---> Total (low + wave frequency) loads & moments

          970.4    179.4    -970.5    -1.752E+04   5.759E+05   9.201E+04



  ++> Quasi-static plus <<EXTREME>> wave-frequency loads
      (Resolved in vessel-bound Coordinates)


         ------ Net Vessel Loads ------    ------- Net Vessel Moments -------
            X        Y        Z          X          Y          Z
         ---------- (k.lbs) ----------    ---------- (k.lbs*ft) -----------

 ---> Quasi-static contribution

          739.9     16.5    -597.0    -1.664E+03   3.693E+05   1.047E+04

 ---> Wave-frequency contribution & phase in degrees

  Amp:    631.7    491.5   1171.6    4.818E+04   6.400E+05   2.458E+05
Phase:    100.1    104.4    -55.6      -75.5       122.0       104.4

 ---> Total (low + wave frequency) loads & moments

         1371.6    508.0   -1768.6    -4.985E+04   1.009E+06   2.563E+05
```

```
                          SeaSoft Systems Simulation Library




                                   Volume 15

                          Displacement-Hull Offshore Vessels








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

                              Shipsim Version 5.11

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                                By SeaSoft Systems

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Moorsim/SPMsim Manual Sample Problem
Turret moored 150,000 DWT tanker


Executed at 13:08 on 2/23/05
```

```
**                                                     **
****************  I.  PHYSICAL CHARACTERISTICS SUMMARY   *****************
**                                                     **


  ----  SITE CHARACTERISTICS  ----


          WATER DEPTH ...........................   450.00 FEET
          WATER DENSITY .........................    64.00 LBS/CUBIC FOOT


  ----  VESSEL CHARACTERISTICS  ----


          DISPLACEMENT .......................... 407000.00 K.LBS
          WATER PLANE AREA ...................... 126000.00 SQUARE FEET
          VERTICAL (Z) KB .......................    34.00 FEET
          DRAFT .................................    64.00 FEET

          VERTICAL (Z) KG .......................    36.00 FEET
          NATURAL ROLL CENTER (VKR) .............    31.17 FEET
          NATURAL PITCH CENTER (VKP) ............    35.40 FEET

          PITCH GYRADIUS ........................   232.00 FEET
          ROLL GYRADIUS .........................    51.20 FEET
          YAW GYRADIUS ..........................   235.00 FEET

          LONGITUDINAL KM (KML) .................  1225.00 FEET
          LONGITUDINAL GM (GML) .................  1189.00 FEET
          LONGITUDINAL IWP/DELTA ................  1191.00 FEET

          TRANSVERSE KM (KMT) ...................    61.00 FEET
          TRANSVERSE GM (GMT) ...................    25.00 FEET
          TRANSVERSE IWP/DELTA ..................    27.00 FEET


  ----  DYNAMICALLY SIMILAR BOX CHARACTERISTICS  ----


          BOX LENGTH ............................   853.53 FEET
          BOX WIDTH .............................   147.23 FEET
          BOX DRAFT .............................    50.60 FEET

          TRIM ANGLE ............................      .00 DEG
          HEEL ANGLE ............................      .00 DEG
```

```
**                                                     **
***************  II.  UNMOORED VESSEL MOTION CHARACTERISTICS  **************
**                                                     **


  ----  NATURAL PERIODS AT ZERO SPEED  ----


          NATURAL ROLL PERIOD ...................   14.0 SECONDS
          NATURAL PITCH PERIOD ..................   10.6 SECONDS
          NATURAL HEAVE PERIOD ..................   11.4 SECONDS


  ----  QUASI-LINEAR ZERO SPEED DAMPING COEFFICIENTS  ----


          NATURAL ROLL DAMPING IN BEAM WAVES .....    4.5 PERCENT
          Damping conversion: 1% =  0.402E+06 ft*kip/(rad/sec)

          NATURAL PITCH DAMPING IN HEAD WAVES ....   13.3 PERCENT
          Damping conversion: 1% =  0.164E+08 ft*kip/(rad/sec)

          NATURAL HEAVE DAMPING ..................   16.0 PERCENT
          Damping conversion: 1% =  0.292E+03 k.lb/(ft/sec)




          REGULAR WAVE HEIGHT.....................   14.0 FEET
          WATER DEPTH ...........................  450.0 FEET
```

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**                                               **
***************  II.  UNMOORED VESSEL MOTION CHARACTERISTICS  **************
**                                               **


   ----  REGULAR WAVE DATA:  WAVE HEADING      = 190.3 DEG
                             WAVE HEIGHT       =  14.0 FT
                             VESSEL SPEED      =    .0 FT/SEC


              +++  DIMENSIONLESS DRIVING FORCE/TORQUE RAOS  +++


                          SURGE          SWAY          HEAVE
 WAVE    WAVE    WAVE
 PERIOD  LENGTH  SLOPE     AM/PHASE      AM/PHASE       AM/PHASE
 (SEC)   (FT)    (DEG)


  6.00   184.2   13.68    .033/ -90.0   .011/-107.6    .005/  33.5
  7.00   250.7   10.05    .049/  90.0   .016/  72.9    .011/-144.8
  8.00   327.5    7.69    .080/ -90.0   .026/-103.1    .023/  32.6
  9.00   414.5    6.08    .009/-100.5   .003/ -99.0    .003/  28.9
 10.00   511.7    4.92    .135/  91.1   .042/  84.2    .056/-154.7
 11.00   619.0    4.07    .172/  88.0   .054/  86.3    .081/-157.9
 12.00   736.2    3.42    .103/  78.4   .032/  87.6    .052/-160.6
 13.00   862.3    2.92    .039/ -37.0   .007/ -91.5    .013/  17.1
 14.00   996.1    2.53    .163/ -78.6   .050/ -91.0    .093/  15.1
 15.00  1135.6    2.22    .287/ -84.7   .089/ -90.7    .175/  13.4
 16.00  1278.9    1.97    .396/ -87.3   .123/ -90.5    .251/  11.9
 17.00  1424.1    1.77    .486/ -88.8   .152/ -90.3    .319/  10.6
 18.00  1569.9    1.61    .561/ -89.6   .175/ -90.2    .379/   9.4
 19.00  1715.4    1.47    .623/ -90.1   .194/ -90.2    .432/   8.4
 20.00  1860.0    1.35    .673/ -90.4   .210/ -90.1    .477/   7.5


   ----  REGULAR WAVE FORCE/TORQUE SCALE FACTORS   ----

     SURGE  ..................................      7122.2 KIPS/DEG
     SWAY   ..................................      7122.2 KIPS/DEG
     HEAVE  ..................................      8064.0 KIPS/FT
     ROLL   ..................................    178055.8 FT-KIPS/DEG
     PITCH  ..................................   8468334.0 FT-KIPS/DEG
     YAW    ..................................   8468334.0 FT-KIPS/DEG

++> Note: Moments evaluated about "natural" roll and pitch centers
```

```
**                                               **
***************  II.  UNMOORED VESSEL MOTION CHARACTERISTICS  **************
**                                               **


   ----  REGULAR WAVE DATA:  WAVE HEADING      = 190.3 DEG
                             WAVE HEIGHT       =  14.0 FT
                             VESSEL SPEED      =    .0 FT/SEC


              +++  DIMENSIONLESS DRIVING FORCE/TORQUE RAOS  +++


                          ROLL          PITCH          YAW
 WAVE    WAVE    WAVE
 PERIOD  LENGTH  SLOPE     AM/PHASE      AM/PHASE       AM/PHASE
 (SEC)   (FT)    (DEG)


  6.00   184.2   13.68    .001/  90.4   0.000/ -88.7   .001/ -71.4
  7.00   250.7   10.05    .002/ -87.6    .002/ -86.2   .005/ -50.6
  8.00   327.5    7.69    .004/  95.9    .002/ -78.4   .003/ -36.4
  9.00   414.5    6.08    .001/  98.6    .019/ 104.1   .014/ 154.5
 10.00   511.7    4.92    .009/ -80.3    .022/ 106.4   .010/ 165.6
 11.00   619.0    4.07    .014/ -80.7    .016/ -75.6   .006/ -12.8
 12.00   736.2    3.42    .009/ -81.8    .083/ -75.9   .021/  -6.8
 13.00   862.3    2.92    .002/  96.9    .162/ -77.6   .033/  -4.4
 14.00   996.1    2.53    .017/  95.7    .237/ -79.5   .040/  -2.9
 15.00  1135.6    2.22    .032/  94.6    .306/ -81.3   .043/  -2.1
 16.00  1278.9    1.97    .047/  93.7    .366/ -82.9   .044/  -1.5
 17.00  1424.1    1.77    .060/  93.0    .419/ -84.2   .044/  -1.1
 18.00  1569.9    1.61    .072/  92.4    .466/ -85.3   .043/   -.9
 19.00  1715.4    1.47    .082/  92.0    .508/ -86.1   .042/   -.7
 20.00  1860.0    1.35    .091/  91.6    .546/ -86.8   .041/   -.6


   ----  REGULAR WAVE FORCE/TORQUE SCALE FACTORS   ----

     SURGE  ..................................      7122.2 KIPS/DEG
     SWAY   ..................................      7122.2 KIPS/DEG
     HEAVE  ..................................      8064.0 KIPS/FT
     ROLL   ..................................    178055.8 FT-KIPS/DEG
     PITCH  ..................................   8468334.0 FT-KIPS/DEG
     YAW    ..................................   8468334.0 FT-KIPS/DEG

++> Note: Moments evaluated about "natural" roll and pitch centers
```

```
**                                            **          **                                    **
*************** II.  UNMOORED VESSEL MOTION CHARACTERISTICS **************          *************** II.  UNMOORED VESSEL MOTION CHARACTERISTICS **************
**                                            **          **                                    **


   ----  REGULAR WAVE DATA:  WAVE HEADING      = 190.3 DEG              ----  REGULAR WAVE DATA:  WAVE HEADING      = 190.3 DEG
                            WAVE HEIGHT        = 14.0 FT                                      WAVE HEIGHT        = 14.0 FT
                            VESSEL SPEED       =   .0 FT/SEC                                  VESSEL SPEED       =   .0 FT/SEC
                                                                                             ROLL DAMPING       =  2.4 PERCENT


               +++  QUASI-LINEAR RESPONSE RAOS (S.A./S.A.)  +++                        +++  QUASI-LINEAR RESPONSE RAOS (S.A./S.A.)  +++


                        SURGE         SWAY          HEAVE                                       ROLL         PITCH          YAW
                       (FT./FT.)    (FT./FT.)     (FT./FT.)                                   (DEG/DEG)    (DEG/DEG)     (DEG/DEG)
  WAVE    WAVE    WAVE                                               WAVE    WAVE    WAVE
 PERIOD  LENGTH  SLOPE    AM/PHASE     AM/PHASE      AM/PHASE        PERIOD  LENGTH  SLOPE    AM/PHASE     AM/PHASE      AM/PHASE
 (SEC)    (FT)   (DEG)                                              (SEC)    (FT)   (DEG)


  6.00   184.2   13.68    .031/ 90.0   .006/ 72.4    .002/-133.3     6.00   184.2   13.68   0.000/ -88.2   0.000/ 91.8   0.000/ 108.6
  7.00   250.7   10.05    .046/ -90.0  .009/-107.0   .006/  52.9     7.00   250.7   10.05    .001/ 94.2    .001/ 97.3    .002/ 129.4
  8.00   327.5    7.69    .076/ 90.1   .014/ 77.1    .021/-123.2     8.00   327.5    7.69    .002/ -81.8   .003/ 113.8   .002/ 143.8
  9.00   414.5    6.08    .009/ 79.7   .002/ 82.1    .005/-116.6     9.00   414.5    6.08   0.000/ -78.4   .044/ -45.2   .011/ -24.4
 10.00   511.7    4.92    .128/ -88.4  .023/ -92.2   .122/  77.0    10.00   511.7    4.92    .010/ 103.7   .079/  -9.2   .009/ -10.7
 11.00   619.0    4.07    .162/ -91.0  .029/ -85.9   .238/ 100.2    11.00   619.0    4.07    .022/ 104.9   .062/-151.0   .007/ 175.0
 12.00   736.2    3.42    .097/-100.1  .017/ -80.0   .162/ 126.0    12.00   736.2    3.42    .025/ 107.0   .279/-124.2   .029/-174.5
 13.00   862.3    2.92    .037/ 145.1  .004/ 104.5   .036/ -36.2    13.00   862.3    2.92    .014/ -65.2   .456/-110.4   .051/-168.3
 14.00   996.1    2.53    .154/ 103.8  .026/ 107.2   .226/ -26.1    14.00   996.1    2.53    .354/   5.7   .585/-102.7   .071/-164.7
 15.00  1135.6    2.22    .275/ 97.8   .047/ 108.4   .376/ -20.4    15.00  1135.6    2.22    .237/ 75.5    .676/ -98.1   .088/-163.0
 16.00  1278.9    1.97    .382/ 95.1   .066/ 108.4   .490/ -17.0    16.00  1278.9    1.97    .197/ 83.6    .739/ -95.3   .103/-162.7
 17.00  1424.1    1.77    .476/ 93.5   .082/ 107.6   .575/ -14.9    17.00  1424.1    1.77    .186/ 86.0    .783/ -93.5   .117/-163.2
 18.00  1569.9    1.61    .559/ 92.5   .097/ 106.4   .641/ -13.5    18.00  1569.9    1.61    .181/ 87.0    .815/ -92.3   .129/-164.3
 19.00  1715.4    1.47    .632/ 91.8   .111/ 105.0   .691/ -12.5    19.00  1715.4    1.47    .179/ 87.5    .838/ -91.6   .141/-165.5
 20.00  1860.0    1.35    .699/ 91.4   .123/ 103.6   .731/ -11.7    20.00  1860.0    1.35    .179/ 87.9    .855/ -91.1   .151/-166.8


>>> Note: Surge and sway RAOs evaluated at "natural" pitch and roll centers     >>> Note: Surge and sway RAOs evaluated at "natural" pitch and roll centers
```

```
**                                     **
**************** II.  UNMOORED VESSEL MOTION CHARACTERISTICS **************
**                                     **


  ---- REGULAR WAVE DATA:  WAVE HEADING      = 190.3 DEG
                           WAVE HEIGHT       = 14.0 FT
                           VESSEL SPEED      =   .0 FT/SEC


>>> Note: Point coordinates are given in vessel system.
    Vectorial motion components are in a rotated r.h. system
    with (x,z) in plane of line, z upwards along line tangent.

     +++   DISPLACEMENT RAOS IN  FT PER UNIT WAVE AMP. (S.A./S.A.)  +++


        ----    COORDINATES    ----     ----    COORDINATES    ----
        ( 514.8,    2.7,   90.0)        ( 508.5,   12.3,   90.0)


WAVE      X COMP      Y COMP      Z COMP      X COMP      Y COMP      Z COMP
PERIOD    AM/PHASE    AM/PHASE    AM/PHASE    AM/PHASE    AM/PHASE    AM/PHASE
(SEC)


  6.00   .010/  97   .008/  95   .032/ -90   .010/  97   .017/ -91   .027/ -90
  7.00   .025/ -80   .028/ 135   .036/  81   .016/ -96   .045/ 104   .020/  32
  8.00   .013/ -89   .015/ 132   .094/ -87   .013/-103   .049/ -96   .081/ -83
  9.00   .301/ 134   .077/ -22   .168/ 139   .267/ 132   .024/ -13   .223/ 142
 10.00   .429/ 161   .050/ -18   .311/ 138   .399/ 161   .088/  97   .334/ 145
 11.00   .364/  54   .024/-163   .339/  68   .351/  56   .124/  85   .329/  64
 12.00  1.110/  62   .102/-177   .696/  62  1.054/  64   .142/  88   .749/  58
 13.00  1.509/  69   .172/-179   .807/  64  1.426/  71   .110/ 109   .915/  59
 14.00  1.694/  71   .343/-173   .791/  62  1.583/  74   .146/ 176  1.016/  54
 15.00  1.755/  72   .282/-156   .699/  61  1.627/  74   .160/-132   .967/  58
 16.00  1.752/  71   .283/-158   .585/  55  1.619/  73   .227/-122   .877/  54
 17.00  1.718/  70   .288/-160   .481/  46  1.582/  72   .294/-117   .793/  49
 18.00  1.674/  68   .290/-162   .400/  33  1.537/  70   .354/-113   .720/  42
 19.00  1.630/  66   .290/-163   .352/  17  1.492/  68   .407/-111   .661/  35
 20.00  1.590/  65   .288/-165   .340/   0  1.451/  67   .454/-109   .617/  28
```

```
  **                                             **                            **                                             **
  ***************  II.  UNMOORED VESSEL MOTION CHARACTERISTICS  **************   ***************  II.  UNMOORED VESSEL MOTION CHARACTERISTICS  *************
  **                                             **                            **                                             **


  ----  REGULAR WAVE DATA:  WAVE HEADING      = 190.3 DEG                      ----  REGULAR WAVE DATA:  WAVE HEADING      = 190.3 DEG
                           WAVE HEIGHT       =  14.0 FT                                                 WAVE HEIGHT       =  14.0 FT
                           VESSEL SPEED      =    .0 FT/SEC                                             VESSEL SPEED      =    .0 FT/SEC


 >>> Note: Point coordinates are given in vessel system.                     >>> Note: Point coordinates are given in vessel system.
     Vectorial motion components are in a rotated r.h. system                     Vectorial motion components are in a rotated r.h. system
     with (x,z) in plane of line, z upwards along line tangent.                   with (x,z) in plane of line, z upwards along line tangent.

     +++   DISPLACEMENT RAOS IN  FT PER UNIT WAVE AMP. (S.A./S.A.)  +++           +++   DISPLACEMENT RAOS IN  FT PER UNIT WAVE AMP. (S.A./S.A.)  +++


       ----      COORDINATES      ----      ----      COORDINATES      ----         ----      COORDINATES      ----      ----      COORDINATES      ----
       (  485.2,   -2.7,   90.0)         (  491.5,  -12.3,   90.0)                  (  502.7,  -14.8,   90.0)         (  512.3,   -8.5,   90.0)


 WAVE      X COMP      Y COMP      Z COMP      X COMP      Y COMP      Z COMP     WAVE      X COMP      Y COMP      Z COMP      X COMP      Y COMP      Z COMP
 PERIOD   AM/PHASE    AM/PHASE    AM/PHASE    AM/PHASE    AM/PHASE    AM/PHASE    PERIOD   AM/PHASE    AM/PHASE    AM/PHASE    AM/PHASE    AM/PHASE    AM/PHASE
 (SEC)                                                                           (SEC)


  6.00   .026/ -91   .007/ -85   .021/  92   .022/ -91   .019/  89   .019/  93    6.00   .006/ -97   .033/  90   .005/ 104   .005/ 101   .029/  91   .018/ -92
  7.00   .024/  74   .026/ -44   .036/ -87   .016/  14   .044/ -76   .020/-113    7.00   .024/ -51   .041/ -96   .018/ 138   .029/ -70   .023/-137   .036/ 101
  8.00   .090/ -88   .014/ -48   .025/  94   .078/ -84   .052/  85   .018/ 110    8.00   .045/ -82   .083/  92   .017/-118   .021/ -81   .066/  98   .066/ -93
  9.00   .257/ 137   .072/ 157   .199/ 133   .293/ 139   .017/ 170   .166/ 128    9.00   .322/ 138   .049/ -28   .113/ 123   .316/ 136   .088/ -24   .127/ 131
 10.00   .425/ 146   .047/ 160   .270/ 171   .434/ 150   .092/ -79   .252/ 167   10.00   .449/ 157   .157/ -64   .211/ 155   .439/ 161   .136/ -54   .264/ 141
 11.00   .439/  65   .022/  16   .198/  47   .418/  62   .127/ -95   .209/  52   11.00   .396/  57   .187/-101   .218/  62   .370/  54   .139/-107   .299/  68
 12.00  1.020/  62   .094/   1   .706/  63  1.033/  60   .147/ -95   .702/  66   12.00  1.106/  60   .237/-118   .606/  69  1.109/  61   .211/-135   .659/  67
 13.00  1.256/  66   .160/   0  1.015/  70  1.306/  63   .111/ -79   .992/  74   13.00  1.462/  65   .202/-130   .805/  77  1.501/  67   .237/-152   .791/  72
 14.00  1.298/  66   .329/   6  1.183/  74  1.416/  62   .125/  -6  1.106/  82   14.00  1.631/  65   .164/-159   .838/  89  1.689/  69   .351/-169   .750/  79
 15.00  1.236/  65   .268/  24  1.274/  73  1.394/  63   .143/  52  1.138/  78   15.00  1.665/  66   .132/ 158   .781/  82  1.750/  69   .269/-169   .652/  74
 16.00  1.129/  63   .267/  21  1.323/  73  1.313/  61   .214/  62  1.172/  77   16.00  1.629/  65   .198/ 123   .764/  82  1.742/  68   .263/ 170   .563/  72
 17.00  1.016/  58   .272/  19  1.344/  72  1.222/  57   .284/  66  1.176/  76   17.00  1.570/  63   .289/ 110   .726/  81  1.705/  67   .286/ 154   .466/  68
 18.00   .912/  53   .275/  18  1.353/  71  1.135/  53   .346/  69  1.169/  75   18.00  1.507/  61   .379/ 104   .685/  79  1.658/  65   .322/ 142   .377/  63
 19.00   .824/  47   .275/  16  1.356/  70  1.058/  49   .402/  71  1.160/  74   19.00  1.446/  58   .463/ 100   .645/  78  1.612/  63   .364/ 134   .301/  54
 20.00   .753/  40   .273/  14  1.358/  69   .993/  44   .452/  72  1.151/  73   20.00  1.391/  56   .540/  98   .610/  76  1.569/  62   .409/ 127   .243/  41
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**                                            **            **                              **
**************  II.  UNMOORED VESSEL MOTION CHARACTERISTICS  **************         **************  II.  UNMOORED VESSEL MOTION CHARACTERISTICS  **************
**                                            **            **                              **


  ----  REGULAR WAVE DATA:  WAVE HEADING    = 220.3 DEG         ----  REGULAR WAVE DATA:  WAVE HEADING    = 220.3 DEG
                           WAVE HEIGHT     =  14.0 FT                                   WAVE HEIGHT     =  14.0 FT
                           VESSEL SPEED    =    .0 FT/SEC                               VESSEL SPEED    =    .0 FT/SEC


        +++  DIMENSIONLESS DRIVING FORCE/TORQUE RAOS  +++              +++  DIMENSIONLESS DRIVING FORCE/TORQUE RAOS  +++


                        SURGE        SWAY         HEAVE                              ROLL         PITCH         YAW
 WAVE    WAVE    WAVE                                               WAVE    WAVE    WAVE
PERIOD  LENGTH  SLOPE    AM/PHASE     AM/PHASE     AM/PHASE        PERIOD  LENGTH  SLOPE    AM/PHASE     AM/PHASE     AM/PHASE
(SEC)    (FT)   (DEG)                                             (SEC)    (FT)   (DEG)


  6.00   184.2  13.68   .021/  90.0  .031/  91.7  .004/-146.5      6.00   184.2  13.68   .005/ -89.7  0.000/  91.3  .002/ 116.3
  7.00   250.7  10.05   .042/ -90.0  .062/ -98.6  .012/  35.2      7.00   250.7  10.05   .010/  92.2  .001/ -84.9  .010/ -37.5
  8.00   327.5   7.69   .003/  93.5  .004/  80.5  .001/-147.4      8.00   327.5   7.69   .001/ -84.4  .010/  99.9  .042/ 152.7
  9.00   414.5   6.08   .102/  90.2  .150/  82.5  .047/-151.1      9.00   414.5   6.08   .030/ -81.6  .009/ 105.0  .021/ 165.6
 10.00   511.7   4.92   .107/  88.4  .157/  84.8  .058/-154.7     10.00   511.7   4.92   .036/ -80.5  .022/ -74.7  .038/ -13.3
 11.00   619.0   4.07   .032/  71.1  .044/  86.6  .018/-157.9     11.00   619.0   4.07   .011/ -80.8  .077/ -74.5  .092/  -7.9
 12.00   736.2   3.42   .083/ -78.8  .119/ -92.3  .054/  19.4     12.00   736.2   3.42   .035/  98.2  .140/ -75.7  .127/  -5.1
 13.00   862.3   2.92   .195/ -85.0  .284/ -91.5  .138/  17.1     13.00   862.3   2.92   .091/  96.9  .201/ -77.6  .146/  -3.5
 14.00   996.1   2.53   .295/ -87.5  .429/ -91.0  .222/  15.1     14.00   996.1   2.53   .147/  95.7  .254/ -79.5  .153/  -2.4
 15.00  1135.6   2.22   .378/ -89.0  .551/ -90.7  .298/  13.4     15.00  1135.6   2.22   .200/  94.6  .300/ -81.3  .153/  -1.8
 16.00  1278.9   1.97   .445/ -89.9  .649/ -90.5  .364/  11.9     16.00  1278.9   1.97   .248/  93.7  .340/ -82.8  .149/  -1.3
 17.00  1424.1   1.77   .498/ -90.4  .727/ -90.3  .422/  10.6     17.00  1424.1   1.77   .289/  93.0  .374/ -84.2  .143/  -1.0
 18.00  1569.9   1.61   .541/ -90.8  .790/ -90.2  .472/   9.4     18.00  1569.9   1.61   .325/  92.4  .405/ -85.2  .136/   -.8
 19.00  1715.4   1.47   .576/ -90.9  .840/ -90.2  .515/   8.4     19.00  1715.4   1.47   .357/  91.9  .433/ -86.1  .129/   -.6
 20.00  1860.0   1.35   .605/ -91.0  .882/ -90.1  .553/   7.5     20.00  1860.0   1.35   .384/  91.6  .458/ -86.8  .123/   -.5


  ----  REGULAR WAVE FORCE/TORQUE SCALE FACTORS  ----               ----  REGULAR WAVE FORCE/TORQUE SCALE FACTORS  ----

    SURGE  .................................    7122.2 KIPS/DEG        SURGE  .................................    7122.2 KIPS/DEG
    SWAY   .................................    7122.2 KIPS/DEG        SWAY   .................................    7122.2 KIPS/DEG
    HEAVE  .................................    8064.0 KIPS/FT         HEAVE  .................................    8064.0 KIPS/FT
    ROLL   .................................  178055.8 FT-KIPS/DEG     ROLL   .................................  178055.8 FT-KIPS/DEG
    PITCH  ................................. 8468334.0 FT-KIPS/DEG     PITCH  ................................. 8468334.0 FT-KIPS/DEG
    YAW    ................................. 8468334.0 FT-KIPS/DEG     YAW    ................................. 8468334.0 FT-KIPS/DEG


 ++> Note: Moments evaluated about "natural" roll and pitch centers    ++> Note: Moments evaluated about "natural" roll and pitch centers
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**                                              **
************** II.  UNMOORED VESSEL MOTION CHARACTERISTICS  **************
**                                              **


  ----  REGULAR WAVE DATA:  WAVE HEADING      = 220.3 DEG
                            WAVE HEIGHT       =  14.0 FT
                            VESSEL SPEED      =    .0 FT/SEC


                    +++  QUASI-LINEAR RESPONSE RAOS (S.A./S.A.)  +++


                              SURGE            SWAY            HEAVE
                             (FT./FT.)        (FT./FT.)        (FT./FT.)
    WAVE     WAVE    WAVE
   PERIOD   LENGTH   SLOPE     AM/PHASE         AM/PHASE        AM/PHASE
   (SEC)     (FT)    (DEG)


    6.00     184.2   13.68    .020/ -90.0     .017/ -88.3     .002/  46.7
    7.00     250.7   10.05    .039/  90.0     .034/  81.4     .007/-127.1
    8.00     327.5    7.69    .003/ -86.5     .002/ -99.3     .001/  56.8
    9.00     414.5    6.08    .096/ -89.7     .082/ -96.4     .066/  63.4
   10.00     511.7    4.92    .101/ -91.1     .086/ -91.5     .125/  77.0
   11.00     619.0    4.07    .030/-107.9     .024/ -85.7     .053/ 100.2
   12.00     736.2    3.42    .079/ 102.8     .064/ 100.1     .169/ -54.0
   13.00     862.3    2.92    .185/  97.0     .150/ 104.5     .386/ -36.2
   14.00     996.1    2.53    .280/  94.9     .225/ 107.3     .538/ -26.1
   15.00    1135.6    2.22    .361/  93.5     .289/ 108.4     .640/ -20.4
   16.00    1278.9    1.97    .429/  92.5     .345/ 108.4     .710/ -17.0
   17.00    1424.1    1.77    .488/  91.9     .394/ 107.6     .760/ -14.9
   18.00    1569.9    1.61    .539/  91.4     .438/ 106.4     .797/ -13.5
   19.00    1715.4    1.47    .585/  91.0     .479/ 105.0     .825/ -12.5
   20.00    1860.0    1.35    .628/  90.8     .517/ 103.6     .846/ -11.7


>>> Note: Surge and sway RAOs evaluated at "natural" pitch and roll centers
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**                                              **
************** II.  UNMOORED VESSEL MOTION CHARACTERISTICS  **************
**                                              **


  ----  REGULAR WAVE DATA:  WAVE HEADING      = 220.3 DEG
                            WAVE HEIGHT       =  14.0 FT
                            VESSEL SPEED      =    .0 FT/SEC
                            ROLL DAMPING      =   3.8 PERCENT


                    +++  QUASI-LINEAR RESPONSE RAOS (S.A./S.A.)  +++


                              ROLL             PITCH            YAW
                             (DEG/DEG)        (DEG/DEG)        (DEG/DEG)
    WAVE     WAVE    WAVE
   PERIOD   LENGTH   SLOPE     AM/PHASE         AM/PHASE        AM/PHASE
   (SEC)     (FT)    (DEG)


    6.00     184.2   13.68    .001/  92.6    0.000/ -88.2     .001/ -63.7
    7.00     250.7   10.05    .003/ -84.9     .001/  98.6     .004/ 142.5
    8.00     327.5    7.69    0.000/  99.3     .013/ -67.8     .026/ -27.2
    9.00     414.5    6.08    .021/ 103.1     .021/ -44.3     .016/ -13.3
   10.00     511.7    4.92    .038/ 105.8     .080/ 169.7     .036/ 170.4
   11.00     619.0    4.07    .018/ 108.0     .302/-149.9     .106/ 179.9
   12.00     736.2    3.42    .094/ -68.1     .469/-124.1     .172/-172.8
   13.00     862.3    2.92    .505/ -56.1     .567/-110.3     .228/-167.4
   14.00     996.1    2.53   1.952/   5.7     .627/-102.7     .274/-164.2
   15.00    1135.6    2.22   1.363/  65.9     .664/ -98.1     .312/-162.7
   16.00    1278.9    1.97   1.017/  77.9     .686/ -95.2     .346/-162.5
   17.00    1424.1    1.77    .883/  82.0     .699/ -93.5     .377/-163.1
   18.00    1569.9    1.61    .815/  83.9     .708/ -92.3     .406/-164.2
   19.00    1715.4    1.47    .775/  85.0     .714/ -91.6     .434/-165.5
   20.00    1860.0    1.35    .749/  85.7     .718/ -91.1     .460/-166.8


>>> Note: Surge and sway RAOs evaluated at "natural" pitch and roll centers
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 **                                        **                              **                                        **
 ***************  II.  UNMOORED VESSEL MOTION CHARACTERISTICS  **************     ***************  II.  UNMOORED VESSEL MOTION CHARACTERISTICS  *************
 **                                        **                              **                                        **


 ----  REGULAR WAVE DATA:  WAVE HEADING     = 220.3 DEG                      ----  REGULAR WAVE DATA:  WAVE HEADING     = 220.3 DEG
                          WAVE HEIGHT      =  14.0 FT                                                WAVE HEIGHT      =  14.0 FT
                          VESSEL SPEED     =    .0 FT/SEC                                            VESSEL SPEED     =    .0 FT/SEC


 >>> Note: Point coordinates are given in vessel system.                   >>> Note: Point coordinates are given in vessel system.
    Vectorial motion components are in a rotated r.h. system                  Vectorial motion components are in a rotated r.h. system
    with (x,z) in plane of line, z upwards along line tangent.                with (x,z) in plane of line, z upwards along line tangent.

     +++   DISPLACEMENT RAOS IN  FT PER UNIT WAVE AMP. (S.A./S.A.)  +++          +++   DISPLACEMENT RAOS IN  FT PER UNIT WAVE AMP. (S.A./S.A.)  +++


       ----      COORDINATES    ----      ----     COORDINATES    ----          ----      COORDINATES    ----      ----     COORDINATES    ----
       ( 514.8,    2.7,   90.0)        ( 508.5,   12.3,   90.0)                 ( 497.3,   14.8,   90.0)        ( 487.7,    8.5,   90.0)


 WAVE     X COMP      Y COMP      Z COMP      X COMP      Y COMP      Z COMP      WAVE     X COMP      Y COMP      Z COMP      X COMP      Y COMP      Z COMP
 PERIOD   AM/PHASE    AM/PHASE    AM/PHASE    AM/PHASE    AM/PHASE    AM/PHASE    PERIOD   AM/PHASE    AM/PHASE    AM/PHASE    AM/PHASE    AM/PHASE    AM/PHASE
 (SEC)                                                                           (SEC)


  6.00   .007/ -79   .024/ -78   .024/  90   .013/ -78   .003/   3   .032/  95     6.00   .011/ -72   .024/  91   .022/  98   .003/  38   .034/  96   .002/ 132
  7.00   .005/ 155   .077/ 122   .056/ -83   .025/ 130   .026/ 158   .087/ -71     7.00   .029/ 141   .052/ -83   .072/ -63   .019/-157   .087/ -68   .024/ -51
  8.00   .104/ 106   .253/ -27   .099/ 127   .073/  58   .144/ -24   .238/ 141     8.00   .087/  27   .047/ 138   .263/ 142   .070/  40   .205/ 150   .171/ 135
  9.00   .132/ 121   .158/ -43   .195/ 108   .089/ 111   .061/  12   .262/ 119     9.00   .089/  97   .131/ 102   .231/ 126   .133/  98   .193/ 120   .145/ 131
 10.00   .452/  -1   .217/-164   .300/  21   .371/  -2   .093/ 159   .432/  16    10.00   .318/   0   .133/  51   .449/   9   .305/   9   .232/  29   .404/   0
 11.00  1.382/  32   .512/-178   .844/  29  1.199/  36   .211/ 159  1.155/  23    11.00  1.081/  39   .252/  27  1.209/  21  1.012/  38   .515/  10  1.142/  26
 12.00  1.773/  53   .743/ 177   .986/  43  1.578/  59   .358/ 165  1.385/  31    12.00  1.435/  63   .261/  22  1.485/  31  1.289/  60   .678/   3  1.433/  42
 13.00  1.854/  61   .970/ 171   .918/  45  1.675/  69   .513/ 168  1.402/  28    13.00  1.525/  75   .236/   0  1.558/  29  1.313/  71   .831/  -7  1.500/  45
 14.00  1.813/  65  1.608/-176   .915/  41  1.584/  76   .911/-172  1.876/  25    14.00  1.382/  86   .320/ -10  2.166/  27  1.118/  84  1.336/   1  1.813/  42
 15.00  1.737/  65  1.172/-159   .767/  44  1.487/  74   .718/-149  1.557/  38    15.00  1.218/  81   .231/ -26  1.868/  41   .932/  76   .924/  13  1.722/  52
 16.00  1.655/  64  1.018/-164   .633/  36  1.437/  74   .655/-149  1.326/  33    16.00  1.175/  80   .276/ -50  1.636/  39   .859/  74   .797/   1  1.588/  52
 17.00  1.576/  63   .964/-170   .546/  26  1.379/  73   .638/-149  1.201/  26    17.00  1.118/  79   .346/ -62  1.509/  35   .777/  72   .773/  -8  1.502/  50
 18.00  1.507/  61   .934/-175   .495/  14  1.327/  71   .629/-149  1.121/  19    18.00  1.065/  78   .415/ -68  1.419/  30   .704/  70   .780/ -17  1.436/  48
 19.00  1.450/  60   .914/ 179   .476/   1  1.284/  70   .620/-149  1.070/  12    19.00  1.021/  76   .480/ -72  1.350/  26   .642/  67   .802/ -25  1.382/  46
 20.00  1.403/  58   .900/ 174   .480/  -9  1.250/  69   .611/-149  1.039/   5    20.00   .986/  75   .540/ -75  1.296/  22   .591/  63   .832/ -31  1.338/  44
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 **                                              **                              **                                              **
 ***************  II.  UNMOORED VESSEL MOTION CHARACTERISTICS  **************     ***************  II.  UNMOORED VESSEL MOTION CHARACTERISTICS  **************
 **                                              **                              **                                              **


    ----  REGULAR WAVE DATA:  WAVE HEADING      = 220.3 DEG                         ----  REGULAR WAVE DATA:  WAVE HEADING      = 220.3 DEG
                             WAVE HEIGHT       = 14.0 FT                                                      WAVE HEIGHT       = 14.0 FT
                             VESSEL SPEED      =    .0 FT/SEC                                                 VESSEL SPEED      =    .0 FT/SEC



>>> Note: Point coordinates are given in vessel system.                         >>> Note: Point coordinates are given in vessel system.
    Vectorial motion components are in a rotated r.h. system                         Vectorial motion components are in a rotated r.h. system
    with (x,z) in plane of line, z upwards along line tangent.                        with (x,z) in plane of line, z upwards along line tangent.

      +++   DISPLACEMENT RAOS IN  FT PER UNIT WAVE AMP. (S.A./S.A.)  +++             +++   DISPLACEMENT RAOS IN  FT PER UNIT WAVE AMP. (S.A./S.A.)  +++


        ----      COORDINATES     ----      ----      COORDINATES     ----             ----      COORDINATES     ----      ----      COORDINATES     ----
        (  485.2,    -2.7,   90.0)        (  491.5,   -12.3,   90.0)                   (  502.7,   -14.8,   90.0)        (  512.3,    -8.5,   90.0)


 WAVE     X COMP     Y COMP     Z COMP     X COMP     Y COMP     Z COMP       WAVE     X COMP     Y COMP     Z COMP     X COMP     Y COMP     Z COMP
 PERIOD  AM/PHASE   AM/PHASE   AM/PHASE   AM/PHASE   AM/PHASE   AM/PHASE      PERIOD  AM/PHASE   AM/PHASE   AM/PHASE   AM/PHASE   AM/PHASE   AM/PHASE
 (SEC)                                                                       (SEC)


   6.00  .019/  89  .024/ 101  .016/ -85  .025/  94  .003/-148  .024/ -81      6.00  .013/  96  .025/ -87  .020/ -76  .001/  96  .035/ -83  .003/  32
   7.00  .050/ -85  .073/ -58  .026/ 105  .072/ -73  .022/ -15  .055/ 118      7.00  .050/ -69  .056/  99  .058/ 127  .020/ -69  .091/ 112  .021/-176
   8.00  .125/ 121  .238/ 152  .057/  91  .226/ 135  .124/ 156  .104/   1      8.00  .220/ 133  .068/ -36  .166/ -12  .163/ 125  .222/ -29  .089/   1
   9.00  .223/ 110  .151/ 135  .043/ 141  .267/ 118  .054/-159  .021/ -26      9.00  .234/ 123  .137/ -73  .053/  -7  .178/ 124  .199/ -57  .088/  81
  10.00  .425/  13  .204/  16  .294/  -9  .520/  11  .076/ -25  .203/ -17     10.00  .548/   5  .145/-134  .095/ -21  .507/   1  .243/-152  .155/  15
  11.00 1.248/  30  .479/   1  .886/  33 1.455/  26  .171/ -25  .701/  43     11.00 1.563/  27  .293/-156  .480/  58 1.489/  29  .550/-170  .584/  45
  12.00 1.506/  47  .699/  -2 1.182/  56 1.762/  39  .302/ -18 1.042/  72     12.00 1.929/  42  .320/-161  .814/  89 1.874/  47  .729/-176  .778/  72
  13.00 1.469/  52  .923/  -9 1.296/  66 1.762/  41  .447/ -14 1.252/  87     13.00 1.968/  47  .308/-178 1.066/ 105 1.938/  54  .888/ 173  .840/  89
  14.00 1.405/  51 1.556/   3 1.257/  72 1.933/  39  .827/   6 1.202/ 113     14.00 2.078/  46  .405/ 173 1.245/ 141 1.956/  55 1.404/-178  .757/ 124
  15.00 1.260/  52 1.120/  21 1.227/  69 1.746/  44  .646/  32  .855/  98     15.00 1.950/  50  .293/ 164  .650/ 140 1.872/  57  .989/-166  .381/ 116
  16.00 1.112/  49  .967/  14 1.229/  68 1.558/  41  .588/  32  .918/  92     16.00 1.795/  48  .313/ 142  .639/ 129 1.762/  56  .858/-176  .343/ 111
  17.00  .994/  43  .914/   8 1.216/  68 1.429/  36  .575/  32  .946/  91     17.00 1.676/  45  .369/ 128  .650/ 125 1.666/  54  .828/ 173  .300/ 113
  18.00  .903/  37  .886/   3 1.202/  67 1.332/  31  .569/  32  .961/  89     18.00 1.580/  42  .432/ 120  .656/ 122 1.584/  52  .829/ 164  .257/ 115
  19.00  .836/  31  .867/  -1 1.190/  66 1.260/  26  .563/  32  .974/  88     19.00 1.501/  38  .494/ 115  .659/ 120 1.515/  50  .846/ 157  .216/ 117
  20.00  .789/  24  .855/  -6 1.182/  65 1.207/  20  .557/  33  .987/  87     20.00 1.437/  35  .553/ 111  .663/ 118 1.459/  47  .872/ 151  .180/ 119
```

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**                                                  **
***************   III.  IRREGULAR WAVE STATISTICS SUMMARY   ***************
**                                                  **


   ----  ENVIRONMENTAL CHARACTERISTICS  ----


   WAVE SPECTRAL TYPE -- BRETSCHNEIDER
                       : LONG-CRESTED SEAS


           CALCULATED SIGNIFICANT WAVE HEIGHT .....  19.43 FT
           SPECTRUM PEAK PERIOD ...................  13.00 SECONDS
           SPECTRUM ZERO UPCROSS PERIOD ..........  10.46 SECONDS
           CHARACTERISTIC WIND SPEED .............   58.34 FT/SECOND
           DIRECTION OF MAXIMUM SEAS .............  190.28 DEGREES

       +++ BACKGROUND SWELL DATA +++

           CALCULATED SIGNIFICANT SWELL HEIGHT ....   9.89 FT
           GLOBAL SWELL DIRECTION ................. 220.28 DEGREES
           SWELL PERIOD ..........................  16.00 SECONDS


   ----  VESSEL DYNAMICS SUMMARY  ----

>>> Note: Moments evaluated about "natural" roll and pitch centers


           +++ SIGNIFICANT SINGLE AMPLITUDE FORCES/TORQUES +++


                        SIGNIFICANT    SIGNIFICANT    ZERO UPCROSS
                          VALUE           RATE        PERIOD (SEC)

   SURGE (K.LBS)          6692.457       3420.223        12.295
   SWAY  (K.LBS)          6392.218       2603.970        15.424
   HEAVE (K.LBS)         17088.550       6652.043        16.141
   ROLL  (K.LBS-FT.)     60474.400      23748.100        16.000
   PITCH (K.LBS-FT.)   6012805.400    2538140.000        14.885
   YAW   (K.LBS-FT.)   1996031.000     872242.100        14.378

>>> Note: Surge and sway motions evaluated at "natural" pitch and roll centers


           +++ SIGNIFICANT SINGLE AMPLITUDE MOTIONS +++


                        SIGNIFICANT    SIGNIFICANT    ZERO UPCROSS
                          VALUE           RATE        PERIOD (SEC)

   SURGE (FT )             2.754          1.122          15.429
   SWAY  (FT )             1.754           .671          16.422
   HEAVE (FT )             4.107          1.662          15.526
   ROLL  (DEG)             1.831           .770          14.944
   PITCH (DEG)             1.615           .710          14.284
   YAW   (DEG)              .505           .204          15.524
```

```
**                                                  **
***************   III.  IRREGULAR WAVE STATISTICS SUMMARY   ***************
**                                                  **


   ----  ENVIRONMENTAL CHARACTERISTICS  ----


   WAVE SPECTRAL TYPE -- BRETSCHNEIDER
                          : LONG-CRESTED SEAS


           CALCULATED SIGNIFICANT WAVE HEIGHT .....  19.43 FT
           SPECTRUM PEAK PERIOD ...................  13.00 SECONDS
           SPECTRUM ZERO UPCROSS PERIOD ..........  10.46 SECONDS
           CHARACTERISTIC WIND SPEED .............   58.34 FT/SECOND
           DIRECTION OF MAXIMUM SEAS .............  190.28 DEGREES

       +++ BACKGROUND SWELL DATA +++

           CALCULATED SIGNIFICANT SWELL HEIGHT ....   9.89 FT
           GLOBAL SWELL DIRECTION ................. 220.28 DEGREES
           SWELL PERIOD ..........................  16.00 SECONDS


   ----  LOCAL MOTION SUMMARIES: SELECTED POINTS  ----



>>> Note: Point coordinates are given in vessel system.
    Vectorial motion components are in a rotated r.h. system
    with (x,z) in plane of line, z upwards along line tangent.


                    +++  SIGNIFICANT SINGLE AMP.  DISPLACEMENTS  +++

   POINT COORDINATES        X COMP        Y COMP        Z COMP
      ( X, Y, Z)

   ( 514.8,    2.7,   90.0)    13.395         5.662         6.124
   ( 508.5,   12.3,   90.0)    12.205         3.620         9.301
   ( 497.3,   14.8,   90.0)    10.850         2.251        10.828
   ( 487.7,    8.5,   90.0)     9.026         4.760        11.155
   ( 485.2,   -2.7,   90.0)     9.977         5.401         9.606
   ( 491.5,  -12.3,   90.0)    11.855         3.294         8.379
   ( 502.7,  -14.8,   90.0)    13.560         2.427         6.331
   ( 512.3,   -8.5,   90.0)    13.707         5.056         5.264
```

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===============================================================================
Moorsim/SPMsim Manual Sample Problem
Turret moored 150,000 DWT tanker
Storm Duration:  6.0 hr
===============================================================================

>>> Line peak load calculation treatment:
    ++> SeaSoft "upper bound" algorithm

         <<Mean>>   <<LF RMS>>  <<WF RMS>>  <<Bandwdth>> <<SpecPeak>>   <<Net RMS>>    <<LF Max>>    <<LF Min>>    <<WF Max>>    <<Net Max>>    <<Net Min>>

Gx        -29.59       4.85        .97        .0147       16.49         4.95         -17.32        -53.15          3.72         -13.60         -56.86
Gy          2.59       1.31       2.43        .0166       15.64         2.76           7.13         -.96          9.34          16.46         -10.30
Gxy        29.70       5.02       2.62        .0147       16.07         5.66          53.19        17.78         10.05          63.24           7.73
Gz           .00        .00       4.20        .0155       15.58         4.20            .00          .00         16.12          16.12         -16.12

Roll         .00        .00        .89        .0111       14.00          .89            .00          .00          3.43           3.43          -3.43
Pitch        .00        .00        .48        .0155       15.51          .48            .00          .00          1.84           1.84          -1.84
Yaw       -10.28        .74        .24        .0151       15.79          .78          -8.38       -12.18           .92          -7.47         -13.10

VFx       280.19      73.97      80.30        .0135       16.73       109.17         739.87       128.72        637.91        1371.60        -193.15
VFy        27.30      21.31      94.52        .0167       15.64        96.89         130.45       -12.40        730.96         861.42        -668.27
VFxy      281.52      76.98     124.02        .0135       16.19       145.97         741.23       133.29        970.18        1371.60            .00
VFz       -80.48      25.69     200.43        .0155       15.58       202.07         -29.31      -234.62       1644.55        1614.17       -1674.94
VFz+     -444.13      25.69     200.43        .0155       15.38       202.07        -392.96      -598.27       1644.55            .00       -2038.58
VMx    -42296.50   31260.43    9210.83        .0167       15.64     32589.17        1139.52    -12514.17      71113.36       66105.10      -83627.52
VMy    245684.20   22434.56  105037.90        .0135       16.73    107407.00      369289.43    209511.90     849328.12     1058989.30     -639666.81
VMxy   249298.42   38477.57  105441.00        .0135       16.19    112242.22      369293.20    209515.00     852171.00     1058989.30            .00

Line  1   215.13      40.09      55.97        .0155       15.58        68.85         477.48       138.00        374.15         851.63          19.39
Line  2   146.83      18.74      72.72        .0155       15.58        75.09         257.24       108.84        526.54         783.78          17.39
Line  3    71.86       1.16      66.31        .0155       15.58        66.32          75.48        67.74        468.94         544.42          10.32
Line  4    46.78       2.78      36.29        .0155       15.58        36.40          54.43        38.55        315.19         369.62          13.92
Line  5    43.04       2.57      22.96        .0155       15.58        23.11          50.51        34.72        200.36         250.87          13.95
Line  6    49.48       2.60      24.65        .0155       15.58        24.79          57.04        41.08        209.59         266.63          14.24
Line  7    78.62       1.51      31.33        .0155       15.58        31.36          84.52        74.86        236.60         321.12          10.87
Line  8   168.06      25.16      37.17        .0155       15.58        44.88         321.35       117.93        248.65         570.00          18.15

RelBow     -.00        .00       2.90        .0148       14.96         2.90           -.00         -.00         11.13          11.13         -11.13
RelMoon    -.00        .00       3.00        .0149       15.00         3.00           -.00         -.00         11.50          11.50         -11.50

>>> Line peak load calculation treatment:
    ++> API "net loads best estimate" algorithm

         <<Mean>>   <<LF RMS>>  <<WF RMS>>  <<Bandwdth>> <<SpecPeak>>   <<Net RMS>>    <<LF Max>>    <<LF Min>>    <<WF Max>>    <<Net Max>>    <<Net Min>>

Gx        -29.59       4.85        .97        .0147       16.49         4.95         -17.32        -53.15          3.72         -15.38         -55.08
Gy          2.59       1.31       2.43        .0166       15.64         2.76           7.13         -.96          9.34          14.51          -9.40
Gxy        29.70       5.02       2.62        .0147       16.07         5.66          53.19        17.78         10.05          63.24           7.73
Gz           .00        .00       4.20        .0155       15.58         4.20            .00          .00         16.12          16.12         -16.12

Roll         .00        .00        .89        .0111       14.00          .89            .00          .00          3.43           3.43          -3.43
Pitch        .00        .00        .48        .0155       15.51          .48            .00          .00          1.84           1.84          -1.84
Yaw       -10.28        .74        .24        .0151       15.79          .78          -8.38       -12.18           .92          -7.89         -12.68

VFx       280.19      73.97      80.30        .0135       16.73       109.17         739.87       128.72        531.90         970.44        -191.63
VFy        27.30      21.31      94.52        .0167       15.64        96.89         130.45       -12.40        679.20         751.25        -640.12
VFxy      281.52      76.98     124.02        .0135       16.19       145.97         741.23       133.29        861.90        1015.85            .00
VFz       -80.48      25.69     200.43        .0155       15.58       202.07         -29.31      -234.62       1592.81        1555.95       -1629.67
VFz+     -444.13      25.69     200.43        .0155       15.38       202.07        -392.96      -598.27       1592.81            .00       -1993.32
VMx    -42296.50   31260.43    9210.83        .0167       15.64     32589.17        1139.52    -12514.17      66543.66       63320.45      -73516.58
VMy    245684.20   22434.56  105037.90        .0135       16.73    107407.00      369289.43    209511.90     825335.90     1040440.00     -610231.90
VMxy   249298.42   38477.57  105441.00        .0135       16.19    112242.22      369293.20    209515.00     828007.90     1040440.00            .00

Line  1   215.13      40.09      55.97        .0155       15.58        68.85         477.48       138.00        364.15         660.84          19.39
Line  2   146.83      18.74      72.72        .0155       15.58        75.09         257.24       108.84        518.10         702.70          17.39
Line  3    71.86       1.16      66.31        .0155       15.58        66.32          75.48        67.74        463.14         537.32          10.32
Line  4    46.78       2.78      36.29        .0155       15.58        36.40          54.43        38.55        295.70         348.24          13.92
Line  5    43.04       2.57      22.96        .0155       15.58        23.11          50.51        34.72        189.11         238.13          13.95
Line  6    49.48       2.60      24.65        .0155       15.58        24.79          57.04        41.08        201.40         256.78          14.24
Line  7    78.62       1.51      31.33        .0155       15.58        31.36          84.52        74.86        231.19         312.86          10.87
Line  8   168.06      25.16      37.17        .0155       15.58        44.88         321.35       117.93        250.32         469.02          18.15

RelBow     -.00        .00       2.90        .0148       14.96         2.90           -.00         -.00         11.13          11.13         -11.13
RelMoon    -.00        .00       3.00        .0149       15.00         3.00           -.00         -.00         11.50          11.50         -11.50
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