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DEFINITION OF THE REQUIREMENTS OF A STATION KEEPING
SUBSYSTEM (SKSS) ENGINEERING EVALUATION TOOL (SKEET)

Final Report

MASTER

December 1979

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Hoffman Maritime Consultants, Inc.
Glen Head, New York

U.S. Department of Energy

Solar Energy

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DEFINITION OF THE REQUIREMENTS
OF A STATION KEEPING SUBSYSTEM (SKSS)
ENGINEERING EVALUATION TOOL (SKEET)

Final Report

Submitted to
NOAA Office of Engineering
in fulfillment of the requirements of Task V
Contract No. NA-79-QA-C-00141

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I. SUMMARY

A study of the requirements of an OTEC Station Keeping Subsystem (SKSS) Engineering Evaluation Tool (SKEET) has been completed by Hoffman Maritime Consultants Inc. SKEET is intended to provide a basis for quantitative comparison and assessment of candidate SKSS performance based on realistic predictions of expected loads, motions and displacements obtained by modeling all significant environmental and operational factors.

The objectives of the study are:

- to define the required elements of a SKEET, and
- to assess the state of the art of technology related to SKEET.

The results provide a technical basis for decisions regarding the planning, acquisition and implementation of a SKEET. It is noted that selection of specific analytical methods to be incorporated in SKEET is beyond the scope of the present study.

This report summarizes the requirements for formulation of a SKEET, based on supporting documentation provided in separate volumes. The results of the study have shown that:

- existing technology and methods of analysis are adequate to fulfill the basic requirements of SKEET, except that
- further validation is required for methods of predicting second order wave drift forces for cases other than "ship in beam seas".

Therefore, it is concluded that:

- development of a SKEET is essentially a process of selection, adaptation, integration and validation, and that
- a basic SKEET capability could be achieved within a one year period.

II. INTRODUCTION

One of the fundamental requirements for the successful implementation of an ocean thermal energy conversion (OTEC) plant is that it must remain on station throughout all seasons and weather. The term "on station" must be defined in the context of the operational mode of the platform. If the only requirement is to maintain adequate water depth to prevent grounding of the cold water pipe (CWP), as in the case of a grazing platform, then the concept of "station keeping" becomes quite loosely defined. However, if the plant is linked to submarine power transmission cables, then its potential mobility is virtually eliminated, and the lateral excursion (watch circle) becomes a critical limiting factor. Until the electrical cable requirements are better defined, an interim specification has been established that the watch circle should not exceed 10% of water depth. Furthermore, these requirements must be met even under the most extreme weather conditions expected to occur at the site over the projected life of some 30 years.

Preliminary designs of OTEC Station Keeping Subsystems (SKSS) are being developed in parallel by M. Rosenblatt & Son Inc. (MRS) and Lockheed Missiles and Space Co. (LMSC). In addition, it is anticipated that in the future other investigators will propose and develop alternative concepts, with whatever design factors they consider appropriate. Due to limited experience with large, permanent, deeply-moored offshore structures, it is necessary to rely heavily on analytical techniques as a basis for design and evaluation of SKSS. Furthermore, due to the multiplicity of approaches adopted by various investigators in evaluating the performance of the SKSS, it becomes increasingly difficult to make rational comparisons between various alternatives. This situation becomes compounded by the increasingly common trend of using analyses in the form of proprietary computer programs.

To permit an objective and consistent assessment of SKSS

performance and reliability, as a basis for meaningful comparison and evaluation, consideration is given to defining the requirements for development of a SKEET. A SKEET should have the capability to model all of the significant elements and physical processes that are relevant to OTEC platform SKSS, and to provide realistic predictions of loads, motions, displacements and stress levels.

This report documents the results of a study which has been undertaken to define the requirements of a SKEET. The work entailed formulation of a concept definition, evaluation of sensitivities and interaction effects, identification of recommended outputs and an assessment of the state of the art. It also included a review of MRS and LMSC reports to date on OTEC SKSS Preliminary Designs, the results of which have been incorporated in the present study. The work was performed in the context of the following tasks, which are summarized in more detail in Appendix A, Task Summary.

- Task I - Provide a Preliminary Plan for Development of a SKEET

Objective

Define the SKEET concept and formulate a preliminary technical approach to be used as a roadmap for subsequent investigation of SKEET requirements.

- Task II - Assessment of the State-of-the-Art Technology Related to SKEET

Objective

Ascertain the capabilities and limitations of existing analyses that have potential applicability within the framework of a comprehensive SKEET. A wide range of analyses are considered that vary in scope and format from a general theoretical formulation to an existing computer program.

- Task III - Identify and Classify the Physical Characteristics and Phenomena and Evaluate Interaction Effects

Objective

- Define the physical parameters to be incorporated into the SKEET.
- Indicate their necessary degree of generality and level of detail they must possess, individually and on an interactive basis.
- Assess the most appropriate manner in which to incorporate each of these parameters.

- Task IV - Establish Mooring Performance Criteria

Objective

Define the required outputs from SKEET.

- Task V - Prepare Summary of Recommended SKEET Requirements

Objective

Consolidate the results of Task I to IV into a single, concise document representing the recommended requirements for the development of SKEET.

III. SKEET CONCEPT DEFINITION

The fundamental purpose for SKEET is to provide a means of simulating and evaluating OTEC platform SKSS performance. This evaluation capability may be employed in the process of design review, comparison of alternative concepts, operational planning, establishing risk and reliability criteria and a host of other applications. However, the central requirement is that SKEET have the capability to predict the motions and loads of the vessel and SKSS as a result of environmental effects under a range of operational conditions.

The principal elements which should be represented by the SKEET model include:

- environment (wind, current, waves)
- vessel/CWP configuration
- mooring system (including anchor/soil and electrical riser cable interactions)
- dynamic positioning system effects

The principal physical elements and forces which will affect the performance of the SKSS are shown in Figure 1. Each block represents an element for which certain descriptive information may be input into the mathematical model. The arrows represent physical processes (primarily forces and moments) which must be simulated by a suitable mathematical model. Corresponding to each of these processes are outputs, such as displacements or loads which will be predicted by the simulation. These outputs can be interpreted in terms of various criteria to evaluate the performance of a particular SKSS.

Each of the elements can be described in terms of several physical characteristics or parameters, the extent and level of detail of each being dependent on the physical processes that are being considered. The physical processes, in turn, are generally the forces and moments that result from the interaction of two or more elements, and can generally be represented by an appropriate function in either the time or frequency domain.

ELEMENTS OF SKEET

FIG. 1. PRINCIPAL SYSTEM ELEMENTS AND FORCES

NOTE: NUMBERS SHOWN ABOVE REFER TO TABLES INCLUDED AS APPENDIX B.

A description of the physical properties of each element and each of the physical processes is included in Appendix B. Physical properties are given in Tables 1-9, with the corresponding processes covered in Tables 10-18, as shown in Figure 1.

Associated with each table is a list of references citing relevant background material pertaining to each topic. The reference lists are included in the Task II Report, "Assessment of the State of the Art Technology Related to SKEET", HMC Report 79144, December 1979.

The diagram shown in Figure 1 illustrates the interrelationship between the elements to be represented by SKEET. However, SKEET itself is fundamentally a mathematical model which may consist of most or all of the following stages:

- DATA INPUT
- PREPROCESSING (preliminary calculations)
- STATIC ANALYSIS (quasi-steady equilibrium)
- DYNAMIC ANALYSIS (perturbation of the equilibrium condition)
- OUTPUT (loads, motions, displacements, stresses, etc.)
- POST-PROCESSING (operability, fatigue, long term prediction, etc.)

The flow between the various stage of the model is shown in Figure 2.

Several stages of the model have elements in common which can be grouped as follows:

● Environmental Modeling

Encompasses data input for

- wind
- current
- waves

● Quasi-Steady Factors

Forces due to

- wind (drag on vessel)
- current (drag on vessel/CWP and mooring lines)
- waves (mean drift forces on vessel/CWP)

as well as the effects of

- dynamic positioning
- anchor, soil and bathymetry

which determine the static equilibrium of

- vessel/CWP
- mooring line
- electrical riser.

The remaining modules are:

● Vessel/CWP Dynamic Response

- high frequency response to waves is principal excitation of mooring
- long period oscillation due to slowly varying drift force may cause large mooring loads

● Mooring Dynamic Response

- high frequency response to waves effects primarily fatigue
- long period oscillations and quasi-steady loads determine maximum loads and displacements

These four main topics serve as a basis for organization of the evaluation of the recommended concept, presented in the following section. In addition, because of the extreme importance of the second order wave drift forces, and the fact that they may be represented as quasi-steady or slowly varying phenomena, a fifth category has been created to highlight this subject:

● Wave Drift Forces

- mean
- slowly varying

Each of these topics is summarized in the following section of this report.

It is noted that, throughout the report, reference is made to various "forces". It is implied that, unless otherwise stated, the term "force" shall refer to forces and moments.

Note

= Data Input/Preprocessing

Figure 2. SKEET Flow Diagram

IV. EVALUATION OF RECOMMENDED CONCEPT

In order to establish the requirements for the SKEET analytical model, it is necessary to ascertain the relative importance of each of the contributing factors, and to estimate the sensitivity of the results to any simplifying assumptions and restrictions that may be imposed. It will then be possible to identify the degree of complexity and sophistication required to achieve a tool that is suitable for engineering purposes, without incurring unnecessary penalties in development or implementation cost or complexity.

In the same vein, it is necessary to evaluate possible interaction effects, to ascertain if certain phenomena can be analyzed separately, or if results are materially affected by other processes. The interaction that may be present, for example, between wave and current effects, or vessel and mooring line motions will determine the need to introduce coupling terms in the mathematical model. Strong interaction effects will markedly reduce the degree of modularity that can be achieved, and may lessen the versatility or economy of the model.

These factors are discussed in detail in the Task III and IV Report, and are summarized under the following categories in the remainder of this section:

- Environmental Modeling
- Quasi-Steady Factors
- Wave Drift Forces
- Vessel/CWP Dynamics
- Mooring Line Responses

Also included in each category is a brief summary of the state of the art; greater detail is provided in the Task II Report.

Environmental Modeling

The environment is the principal source of loading that acts on the SKSS. Consequently, the adequacy of the environmental description will dictate to a large extent the degree to which predicted results will be representative of actual SKSS performance. However, it is not practical to require a complete representation of all possible environmental conditions; it is necessary to adopt certain assumptions and to restrict the environmental model to those properties which will significantly influence the SKSS performance.

The approach to modeling shown in Figure 2 suggests that one appropriate assumption would be to categorize the environmental conditions as either steady or unsteady. It is noted that the term "steady" is not wholly accurate, since the environment is in fact continually changing. However, many changes are of a small magnitude, or occur over a long period of time, and may therefore be treated as if they were steady. Such conditions will hereinafter be referred to as quasi-steady. Recommendations for environmental modeling are summarized in Table 1, and are discussed below.

Quasi-Steady Conditions

The primary quasi-steady conditions are wind and current velocities, which can be represented by some characteristic speed and direction during any period of interest. However, a further determination is required, as to whether mean values can be used to characterize these variables, or if some spatial distribution must be defined.

In the case of wind velocity, variations along the length and height of the platform will be rather small, and can be adequately characterized by mean values. Current velocity, on the other hand, will generally vary from 1-2 knots or more at the surface down to zero at the bottom, with cross currents and reversals being quite common.

TABLE 1
Environmental Modeling

Quasi-Steady Conditions	Qualities		Recommendations for SKEET	
	Speed Profile	Directional Uniformity	Basic	Enhanced
Wind velocity	Vertical variation insignificant for reasonable size platform	Direction generally uniform along length of platform	Use nominal speed, uniform planar direction	Include effect of vertical speed profile
Current Velocity	Large variations between surface and bottom	Frequently current reversals, cross currents, upwelling	Treat vertical speed profile; reverse current; assume flow is in one plane	Treat cross flows and upwelling

Unsteady Conditions	Qualities		Recommendations for SKEET	
	Wave Energy	Directionality	Basic	Enhanced
<u>Wave Charac- teristics</u> -parametric values	Equivalent wave height and period	Mean wave direction (head, beam, quartering seas, etc.)	Use height, period and mean wave direction	Synthesize wave time history
-energy spectra	Mathematical formulations, or measured or hindcast data	Mean wave direction and spreading function or directional spectra	Use hindcast or measured spectral families, with spreading	Use directional spectra
<u>Wind and Current</u> -gusts	Duration too short and irregular to excite dynamic response		Treat as quasi-steady	
-slow oscillations	Period too long to excite dynamic response		Treat as quasi-steady	

Even though detailed current profile data may not be available for potential deployment sites, it is nonetheless desirable to be able to parametrize possible variations, to assess their possible effects.

Wind and current will also interact, particularly since a primary component of the current is due to wind. However, this physical interaction does not affect the resulting loads, and therefore the two load sources can be treated independently.

Unsteady Conditions

The principal time varying load source is due to wave action. Ocean waves are random undulations of the water's surface, accompanied by velocity and pressure distributions that may cause oscillatory loads on a floating or submerged body. The waves acting on an OTEC platform and SKSS may be described in terms of a time history of the elevation of the water's surface; however, it is more common to describe the waves in terms of various statistical measures.

The simplest parameters describe ocean waves in terms of regular (sinusoidal) waves having an equivalent height and period. Regular waves rarely, if ever, occur in nature, however, and the sinusoidal waves are used mainly in evaluating frequency response characteristics. Height and period are also used as a basis to specify a "design wave" condition, primarily in the design of fixed structures.

In the design and evaluation of floating vessels, wave height and period are most commonly used in conjunction with a wave energy spectrum. Wave spectra define the distribution of wave energy over a range of frequencies (and directions, in the case of directional spectra). Since the responses of a vessel and mooring are generally frequency dependent, it is important to define the frequency distribution of the wave energy.

The simplest method of defining a wave condition is to specify height and period parameters, in conjunction

with an assumed mathematical spectra. However, since long term predictions can be effected by 50% or more, depending on spectral shape, it is important to allow for the eventual utilization of actual or hindcast wave spectra, in lieu of idealized formulations.

Similarly, for non-axi-symmetric vessels, wave directionality may be significant. Short crestedness of the sea is commonly approximated by an idealized spreading function about some mean direction. A more refined approach would utilize actual directional wave spectra.

Quasi-Steady Factors

The quasi-steady environmental conditions (wind and current) naturally give rise to quasi-steady loadings. In addition, regular waves produce a steady or mean drift force on the vessel/CWP. These quasi-steady loads will produce an equilibrium offset in the SKSS, which is influenced by bottom contour effects.

The state of the art (SOA) of modeling each of these factors is summarized in Table 2, along with comments and recommendations related to SKEET requirements. It is noted that mean wave drift forces are dealt with more completely in the following section.

The general technique employed for predicting steady wind and current loads on a vessel/CWP or mooring is to assume that the body can be represented by a characteristic area and an associated drag coefficient. This approach is widely accepted in many areas of engineering, and seems to be viable for SKEET as well. However, its successful application requires a good assessment of the drag coefficient especially for current which can account for up to 50% of the total SKSS loading.

For shapes other than ship or barge configurations, it is recommended that tests be conducted to experimentally determine the drag coefficient, unless empirical data exists for the shape. Furthermore, the possibility of vortex shedding

TABLE 2
Quasi-Steady Factors

Parameters	SOA	Comments	Recommendations for SKEET	
			Basic	Enhanced
Wind and Current Loads on Vessel/CWP	6 DOF forces and moments can be estimated using characteristic area and empirical drag coefficients	lift force is negligible, has no effect on SKSS performance	-use area and C_D to estimate 5 DOF forces and moments -treat vortex shedding as quasi-steady by increase in C_D	-use area and C_D to estimate 5 DOF forces and moments -treat vortex shedding as quasi-steady by increase in C_D
Mean Wave Drift Force	various strip theory, 3-D and finite element methods have been developed, as well as empirical methods using shape coefficients for tanker shapes	-predictions of forces on ships and barge shapes in beam seas generally agree with model test results -validation of predictions for other headings and shapes is limited	treat barge, ship and spar shape vessels, in head, oblique and beam seas	generalized model of second order forces on arbitrary shape vessel at any heading
Current Loads on Mooring	methods exist for modeling multi-leg moorings in current fields varying in all 3 dimensions	generalized (3D) capability requires substantial increase in computer time	model lift and drag on multi-anchor mooring in planar current field, speed variable with depth	generalized capability for special cases
Bottom Contour Effects	uniform slope or zero slope with arbitrary depth at each anchor	10° slope may affect tension by up to 20%	arbitrary depth and slope in vicinity of each anchor to correctly model suspended cable	add arbitrary local slope at each anchor to modify anchor holding power

provides an additional reason for experimental evaluation of drag properties. It is noted that although vortex shedding is strictly speaking an unsteady effect, it is most commonly represented by an increase in the effective drag coefficient used for estimating quasi-steady drag.

The last quasi-steady factor does not represent a load source, but rather a set of parameters which will modify the response of the SKSS to applied loads. Bottom contour (depth and slope in the vicinity of each anchor) effects may alter line tension by 10-20% for a typical 5-10 degree slope. Bottom slope may also have a significant affect on the holding power of drag imbedment type anchors.

Wave Drift Forces

Wave drift forces are caused by wave reflections off of a fixed or floating body and by the diffracted wave system generated by the bodies own resultant motion. Wave drift forces are "second order effects" that are often neglected in the design of floating vessels. However, structures that are fixed or moored in a location exposed to severe weather conditions can be subjected to large wave drift forces; in the Preliminary Designs of OTEC SKSS, MRS and LMSC both predict that roughly 50% of the total environmental loading is caused by wave drift forces.

Regular, sinusoidal waves give rise to a steady drift force; random (irregular) waves result in a time varying drift force which oscillates about some mean value. Various methods have been developed for determining mean drift forces on different vessels in head, beam and oblique seas. More recently, technique have been devised for estimating the slowly varying drift force in irregular waves.

The theoretical models for drift force prediction can be classified as either near field or far field theories. The former theory represents the wave velocity and pressure distributions on the surface of the body, while the latter

TABLE 3
Wave Drift Forces

Stage of Analysis	SOA	Comments	Recommendations for SKEET	
			Basic	Enhanced
Theory	-near field -far field	both theories give consistent results	-use either, pending further validation	-use either, pending further validation
Computational Methods	-strip theory -3D models -finite element	listed in order of increasing computational requirements	-use strip theory for ship and barge -use 3D model for axisymmetric shapes	-use finite element method for arbitrary shape bodies (semisubmersible or very full shapes)
Solution Procedure Mean	frequency domain or time domain	-drift force coefficients used in frequency domain -analysis of time history also yields mean drift force	-use frequency domain for estimating design values	-use time domain for evaluating contingencies and transients
Time varying	time domain	-synthesis of time history based on mean drift force results	-use approximation based on mean drift	-include effects of wave grouping

more common approach estimates the drift forces on the basis of conditions far removed from the body. Consistent results have been obtained for ship shapes in beam seas using either approach.

A variety of computational methods are available, each being most suited for a particular vessel type. Strip theory is a computationally efficient method for ship and barge shapes. Three-dimensional source/sink distribution methods are well suited for axisymmetric shapes. Finite element methods are available for representing virtually any shape, but require substantial computational resources.

Any of the theoretical models and computational methods can be solved in either the time or frequency domain. One approach is to estimate the mean drift force in random seas based on the contribution at each of several discrete frequencies. The coefficients for each frequency can be determined analytically or empirically.

The slow varying drift forces are most generally determined by a time domain simulation, although the use of a factor applied to the mean drift force may be an acceptable approximation for preliminary design. Additional validation is required before definite conclusions can be reached regarding extreme drift force magnitudes. One potentially serious factor is the effect of wave grouping. Wave dispersion properties are such that waves of nearly the same frequency will travel in a group or packet; this increases the prospects of exciting a resonant condition, with the attendant result of an increase in the wave drift force.

Vessel/CWP Dynamics

The primary dynamic excitation of the mooring system is due to the vessel response to wave excitation. Analytical modeling of vessel motions, with and without mooring effects, is a well established technology. Special provisions must be made in order to account for the coupling

due to the CWP. However, two programs are presently available to compute the response characteristics of the vessel/CWP system. Furthermore, one of these programs was developed under NOAA sponsorship.

A summary of the various stages of analysis of vessel/CWP dynamics is shown in Table 4. The existing analytical models fulfill virtually all of the present requirements of SKEET, except for the mooring coupling effects.

Mooring coupling is generally negligible for vertical motions (heave, pitch and roll). The lateral restraint imposed by the mooring does affect the horizontal motions (sway, yaw and surge) and should therefore be added to the basic vessel/CWP model. The inclusion of even non-linear mooring restoring forces is well within the SOA, however, and presents no significant difficulties.

Mooring Line Dynamics

The mooring line is the principal constituent of the OTEC SKSS; therefore, its response is one of the main criteria by which SKSS performance can be evaluated. Fortunately, there is an abundance of existing mooring analytical models, covering a wide range of application and sophistication. It is therefore necessary only to identify the required analytical capability, as a basis for selecting and adapting an appropriate model.

The principal considerations in establishing mooring line analysis requirements are shown in Table 5, along with recommendations for SKEET. The specification of requirements has been made so as to achieve a realistic modeling of mooring performance, without incurring undue penalties in terms of computational requirements. Analysis of special cases, such as unsteady current speed, deployment transients, etc., might better be handled by utilizing existing special purpose programs rather than incorporating a completely comprehensive capability into SKEET. An extensive survey of available mooring analysis programs is included in the Task II Report, "Assessment of the State-of-the-Art Technology".

TABLE 4
Vessel/CWP Dynamics

Stage of Analysis	SOA	Comments	Recommendations for SKEET	
			Basic	Enhanced
Vessel Hydrodynamic Properties	<ul style="list-style-type: none"> -conformal mapping and distribution of source/sink singularities for any shape vessel -2D methods for ship, barge, semi submersible -3D methods for other shapes 	<ul style="list-style-type: none"> -accuracy within 10% is generally achievable -cost increases with complexity of shape, particularly for 3D modeling 	<ul style="list-style-type: none"> -use 2D (strip theory) for most shapes -use 3D for axisymmetrical shapes 	use 3D methods for extremely complex shapes
Coupled Vessel Motions	<ul style="list-style-type: none"> -rigid-body platform, 6 DOF -non-rigid CWP, 3D -vessel/CWP coupling is linear displacement and velocity dependent -vessel/mooring coupling is linear, planar, quasi-static 	available models demonstrate acceptable correlation with model tests	use NOAA/DOE model, enhanced by non-linear mooring coupling in horizontal motions	include vertical coupling for TAL
Solution Procedure	frequency domain, using equivalent linearization for coupling	present approach satisfactory, time domain simulation desirable	use NOAA/DOE model or similar	extend to time domain for evaluation of contingencies, and transients

TABLE 5
Mooring Line Dynamics

Stage of Analysis	SOA	Comments	Recommendations for SKEET	
			Basic	Enhanced
Load Sources	-quasi-static or dynamic vessel motion	primary excitation - coupled dynamic analysis may change results 25-30%	quasi-static for first approximation	full dynamic coupling
	-2D surface waves	approximate effects due to drag coefficients, density, etc.	neglect	include
	-hydrodynamic damping, added mass, unsteady current	secondary in magnitude, compared to vessel and steady loads	neglect	include
	-vortex shedding	added drag	treat as quasi-steady	treat as quasi-steady
Cable Properties	-compound, multiple leg, 2D, variable depth, attachments -extensible, elastic visco-damping	existing programs can model a wide variety of cable properties	-treat composite, compound, multi leg geometry -variable depth -linear or non-linear elastic properties	include geometric nonlinearities due to large deformations
Solution Procedure	-frequency domain (linear) -time domain (non-linear)	determine mooring loads, stresses and deformations, as well as vessel offset	-linear frequency domain for design -linear time domain for transient analysis	extend both time and frequency domain to non-linear

V. SUMMARY OF SKEET REQUIREMENTS

1.0 General

The basic core of SKEET is a simulation capable of modeling the OTEC SKSS and platform and evaluating their responses to forces and excitations resulting from environmental factors such as wind, current and waves. The simulation requires as input all of the parameters of the environment, the SKSS and the platform that will influence the static and dynamic performance of the system. It requires the analytical capability to solve the governing static and dynamic equations describing the physical system and phenomena. It must produce outputs of all significant performance qualities in terms of relevant parameters in a format suitable for interpretation and decision-making or for further analysis.

The complexity of the physical processes and analytical relationships involved dictate that SKEET be implemented as a program executable on a high speed digital computer. It is noted that the term "program" may, in fact, comprise several distinct programs or modules, and that computations be undertaken in stages or only in part, to suit the particular requirements of an investigation. Accordingly, in developing SKEET, each program or module must be defined in terms of input and output required for preceeding or succeeding modules.

Typical modules or pre-processing programs might include routines for

- hydrostatic properties
- hydrodynamic coefficients
- mooring line stiffness coefficients, etc.

These modules could provide input to a central or executive program which would perform the following functions

- compute environmental loadings
- solve equations of motion
- display outputs

Additional modules could then be employed, in a post-processing mode, to provide the following analyses:

- long term prediction (design values)
- fatigue life assessment
- operability analysis.

A block diagram for program organization based on this approach is given in Figure 3. The specific requirements for program inputs, simulation capability and outputs is given below. It is noted that basic analytical requirements are occasionally supplemented by optional enhancements. In some cases these may be implemented as substitute program modules, while in others, an alternative modeling approach is required.

2.0 Input Data Requirements

2.1 Environmental Conditions - noncoplanar directionality

2.1.1 Wind - uniform, planar, steady
speed
direction

2.1.2 Current - vertical gradient, planar or nonplanar, steady
speed (vertical profile)
direction (vertical profile optional)

2.1.3 Waves - spectra, directionality
significant height and period (mathematical spectra)
point spectral ordinates vs. frequency (optional)
primary direction (mathematical spreading function)
directional spectral ordinates (optional)

2.1.4 Wave Spectral Family (optional)

2.1.4.1 Wave Height Groups - spectral definition options
height vs. period array
family of point spectral ordinates
mean-covariance spectra

Figure 3. SKEET Block Diagram

2.1.4.2 Statistical Properties - for post-processing
and analysis

exceedance

persistence

2.2 Vessel/CWP Characteristics

2.2.1 Wind Drag Parameters

projected area above waterline (lateral and
longitudinal)

wind drag coefficient (2 DOF) *

wind moment coefficient (3 DOF)

2.2.2 Current Drag Parameters

projected area below waterline (lateral and
longitudinal)

current drag coefficient (2 DOF)

current moment coefficient (3 DOF)

2.2.3 Platform Geometry and Weight Distribution

offsets or geometric description of hull

location of vessel center of gravity (3 coordinates)

radius of gyration (roll, pitch, yaw)

total weight (displacement)

2.2.4 CWP Description

effective outside diameter

inside diameter

cross sectional bending moment of inertia

cross sectional area

effective CWP material density

effective CWP modulus of elasticity

* DOF = degree of freedom

2.3 Mooring System Characteristics

2.3.1 Line Geometry

- number of mooring lines
- length of each line
- location of termination points on platform
- location of anchors on bottom

2.3.2 Line Composition

- number of segments per line
- length of each segment
- diameter
- elastic modulus
- yield strength
- ultimate strength
- weight in air
- weight in water

2.3.3 Attachments

- location
- weight in air
- weight in water
- projected area (normal and tangential to line)

2.3.4 Drag Coefficients of Line Segments and Attachments

- normal
- tangential

2.4 Mooring Control Parameters

2.4.1 Dynamic Positioning

- thrust coefficient
- moment coefficient

2.4.2 Active Mooring Tensioning
activation thresholds
payout/take-up rate

2.4.3 Anchor Holding Power
horizontal
vertical

2.5 Bathymetry
water depth at each anchor
bottom slope at each anchor

3.0 Simulation Requirements - computation of applied forces
and excitation, and determination of resulting loads
and displacements or motions

3.1 Static Equilibrium - equilibrium position and orientation
of vessel and corresponding elongation, load and configuration of mooring when subjected to quasi-steady effects; wind and current, with or without wave drift forces and DP effects

3.1.1 Wind and Current Forces
5 DOF due to wind and current velocity
as well as vessel/CWP and mooring drag
characteristics

3.1.2 Wave Drift Forces
lateral and longitudinal component of mean
wave drift force; may require iterative procedure, since drift force is dependent on vessel motion. Optionally use drift force coefficients as approximation.

3.1.3 Dynamic Positioning Forces

5 DOF due to DP system

3.1.4 Mooring Line Stiffness Coefficients

horizontal and vertical forces for each mooring line as a function of lateral excursion using linear or nonlinear mooring line properties

3.1.5 Vessel Hydrostatic Properties

hydrostatic restoring coefficients and wetted hull contour computed as input to hydrodynamics

3.2 Hydrodynamic Coefficients - frequency dependent damping and added mass terms for vessel/CWP in equilibrium orientation as input to motion

3.3 Environmental Loading - frequency dependent wave excitation terms in frequency domain solution. Optionally in the time domain, synthesis of a time history of wave elevation is required in addition

3.4 Solve Equations of Motion

3.4.1 Vessel/CWP Dynamics

linear coupled equations in the frequency or time domain. Coupled with mooring motions in sway, yaw and surge.

3.4.2 Mooring Dynamics

linear or nonlinear equations in the frequency or time domain. Optional coupling with vessel motion.

4.0 Output Requirements - static and dynamic

4.1 Performance Parameters - motions, loads and displacements

4.1.1 Platform

- heading
- offset from reference position
- 6 DOF motion

4.1.2 Mooring

- length of suspended cable
- angle at top, bottom and each discontinuity
or attachment
- tension at top, bottom and each discontinuity
or attachment
- horizontal and vertical force at anchor

4.1.3 Applied Forces

- wind drag force and moment
- current drag force and moment
- wave drift forces and moments
- dynamic positioning system forces and moments

4.2 Statistical Representation - options can apply to each
reference parameter

- root-mean-square (r.m.s.)
- mean
- significant
- maximum

V. DEVELOPMENT PLAN AND RESOURCE REQUIREMENTS

Based on the foregoing assessments and investigations, it is concluded that all of the elements required to develop a basic SKEET capability are presently available. Therefore, the process of development is in fact more a task of selection, adaptation, integration and validation. Each of these four phases can be accomplished serially, in accordance with the SKEET Integration Network shown in Figure 4. Each phase is discussed below, along with an estimate of resources required.

Selection

The general characteristics of a large number of existing, applicable computer programs are documented in Appendix D of our Task II Final Report, "State of the Art Assessment". The first step in selection of modules and routines for use in SKEET should be to prepare questionnaires based on the requirements identified herein, and to distribute these to the authors of all known relevant programs. The questionnaires would pose specific detailed inquiries regarding the theoretical basis of the program as well as any updates from our reported assessment concerning the capabilities, limitations, assumptions, validation and availability. Estimates of efficiency and execution time would also be solicited.

Having a comprehensive and consistent evaluation of each program would allow an assessment of the best available alternatives, those posing the least integration problems, and those offering the potential for a cost-effective solution. This would then serve as a basis for selection of programs and approaches to use in SKEET, as well as identifying adaptations and modifications required.

Estimated Man-hours:	600
Duration:	3 months
Cost:	25 K

Figure 4. SKEET Integration Network

Adaptation

Each of the selected modules will require modification, with respect to input and output formats, or in other areas to assure consistency with the overall approach. Furthermore, in some cases it may be necessary to expand the existing capabilities of a program to account for commonly encountered situations such as a variable bottom slope and current profile variations, for example.

It is also anticipated that a certain amount of original programming will be necessary for areas where no existing module is employed. This would generally be limited to formatting, or preliminary computations where modification of existing code would be as time consuming as generating new code.

Estimated Man-hours:	1200
Duration:	5 months
Cost:	65 K

Integration

The various program modules must then be merged into a unified and consistent set of programs. This effort is largely an extension of the adaptation phase, and is required to ensure that all modules function properly and in concert with each other. Program interfaces will be checked, and consistent flow of data from one module to the next will be verified.

Estimated Man-hours:	800
Duration:	3 months
Cost:	40 K

Validation

The complete validation of a program of this magnitude and complexity is a process that may take several years, if carried to the ideal situation of validation against full scale test data. However, as an interim measure, partial validation can be achieved by several methods.

One initial approach is to perform sensitivity studies on all program input parameters, and determine whether the corresponding changes in output are reasonable. A second method is to validate specific parts of the program against model test results or benchmark computations from another validated program that uses a different theoretical or computational approach.

Beyond this, validation is customarily done on the basis of comparison with scale model, and ultimately full scale tests, where the test conditions are carefully monitored and used as input to the simulation to enable comparison of results on a common basis.

Such efforts are generally long term projects in themselves, and are often undertaken in parallel with the regular utilization of the program, following some initial validation checks. For planning purposes, the estimate given below pertains only to the initial phase of validation.

Estimated Man-hours:	600
Duration:	3 months
Cost:	25 K

APPENDIX A
Task Summary

- Task I - Provide a Preliminary Plan for Development of a SKEET

Objective

Define the SKEET concept and formulate a preliminary technical approach to be used as a roadmap for subsequent investigation of SKEET requirements.

Summary

- Relevant physical parameters and processes associated with a general station keeping subsystem evaluation and analysis capability are defined and cataloged.
- Interactions between the environment, platform and mooring systems are identified
- Tentative program plan for development of a comprehensive SKEET is presented as well as an estimate of overall resource requirements.

Documentation

- "Preliminary Plan for Development of a SKEET", Technical Note submitted to NOAA, Office of Research and Development, HMC Report TN79144A, June 1979.

● Task II - Assessment of the State-of-the-Art Technology
Related to SKEET

Objective

Ascertain the capabilities and limitations of existing analyses that have potential applicability within the framework of a comprehensive SKEET. A wide range of analyses are considered that vary in scope and format from a general theoretical formulation to an existing computer program.

Summary

- A brief overview defining the SKEET concept is presented by describing the principal elements and illustrating a general approach to structuring the analytical procedure..
- A state of the art assessment is presented for each of the following areas:
 - Environmental modeling
 - Steady state factors
 - Wave drift forces
 - Vessel/CWP dynamics
 - Mooring line response
- Appendices are provided that supply the following information used in our state-of-the-art assessment:
 - An alphabetical listing (by author) of 269 references of significant import to the present state of technology.
 - A listing of these 269 references by subject (a total of 18 reference categories).
 - Precis of those references that are comprehensive and representative of a particular aspect of the general requirements of SKEET.
 - A review of existing static and dynamic computer programs applicable to SKEET. This review provides information concerning the technical aspects of the programs as well as general information associated with the status, availability and validation of the programs.

Documentation

- "Assessment of the State-of-the-Art Technology Related to SKEET", Report submitted to NOAA, Office of Research and Development, HMC Report 79144C, August 1979.

- Task III - Identify and Classify the Physical Characteristics and Phenomena and Evaluate Interaction Effects

Objective

- Define the physical parameters to be incorporated into the SKEET.
- Indicate their necessary degree of generality and level of detail they must possess, individually and on an interactive basis.
- Assess the most appropriate manner in which to incorporate each of these parameters.

Summary

- An evaluation of the degree of interaction between the physical parameters and processes is made on the basis of interpreting and analyzing existing data and results gathered from sources in our literature survey.
- Recommendations are made appropriate to the various options available in the development of the SKEET. These options include linear versus nonlinear analyses, solutions in the time domain versus frequency domain, etc.
- The practicality of developing a SKEET in a modularized fashion is evaluated for the purposes of providing the greatest degree of generality and versatility.

Documentation

- "Evaluation of
 - Physical Characteristics and Phenomena
 - Sensitivity and Interaction Effects
 - Performance Criteria and Output Requirements

For a Station Keeping Subsystems Engineering Evaluation Tool (SKEET)", HMC Technical Note, TN79144C, Sept. 1979.

• Task IV - Establish Mooring Performance Criteria

Objective

Define the required outputs from SKEET.

Summary

- Performance characteristics necessary to formulate meaningful evaluation criteria are presented and reviewed.
- The most appropriate format of output for each of the performance characteristics is identified.

Documentation

- "Evaluation of
 - Physical Characteristics and Phenomena
 - Sensitivity and Interaction Effects
 - Performance Criteria and Output Requirements

For a Station Keeping Subsystems Engineering Evaluation Tool (SKEET)", HMC Technical Note, TN79144C, Sept. 1979.

● Task V - Prepare Summary of Recommended SKEET Requirements

Objective

Consolidate the results of Task I to Task IV into a single, concise document representing the recommended requirements for the development of SKEET.

Summary

- Presently available elements of SKEET are identified.
- Areas requiring further development are indicated.
- A revised (from Task I) estimate of fiscal and personnel resources required to implement the plan-of-action is made.

Documentation

- "Definition of the Requirements of a Station Keeping Subsystem (SKSS) Engineering Evaluation Tool (SKEET)," Report submitted to NOAA, Office of Research and Development, HMC Report 79144 , September 1979.

APPENDIX B

Physical Elements and Processes

LIST OF TABLES

Table B-1	Vessel/CWP - Physical Properties
Table B-2	Wind - Physical Properties
Table B-3	Waves - Physical Properties
Table B-4	Current - Physical Properties
Table B-5	Mooring Line - Physical Properties
Table B-6	Anchor - Physical Properties
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Table B-16	Mooring Line on Vessel
Table B-17	Mooring Line on Anchor and Anchor on Soil
Table B-18	Dynamic Positioning System on Vessel

TABLE 1

Vessel / CWP - Physical Properties

- 1) Superstructure/areas exposed to wind
 - a. Projected area
 - b. Shape
 - c. Moment arm
- 2) Hull and CWP/areas exposed to current and waves
 - a. Principal dimensions
 - b. Geometry and shape of stressed or unstressed CWP
- 3) Weight and Mass Distribution
 - a. Center of gravity (vert., lat., long.)
 - b. Radius of gyration (pitch, roll, yaw)
 - c. Total displacement (weight)
- 4) Appendages
 - a. Control surfaces
 - b. Propeller or thruster
 - c. Bilge keels
- 5) Motion Stabilizing Systems
 - a. Active
 - b. Passive

TABLE 2
Wind - Physical Properties

- 1) Mean wind speed at reference elevation
- 2) Mean wind direction
- 3) Vertical velocity profile

The following probabilistic measures of speed and direction are useful in selecting appropriate values.

- 1) Exceedance
- 2) Persistence

The following unsteady effects can generally be neglected in a basic SKEET but could be included

- 1) Gusts
- 2) Oscillations about the mean

The wind is assumed planar.

TABLE 3
Waves - Physical Properties

1) Height

- a. Probability (exceedance)
- b. Duration (persistence)
- c. Extreme values (for given return period)

2) Spectral Characteristics

- a. Spectral ordinates
 - spectral family
 - mean/covariance spectra
- b. Characteristic periods

3) Directionality

- a. Probability
- b. Short crestedness/spreading
- c. Directional spectra

TABLE 4
Current - Physical Properties

- 1) Mean surface current speed
- 2) Mean surface current direction
- 3) Subsurface current speed profile
- 4) Subsurface current direction profile

The following probabilistic measures of speed and direction may be useful in selecting appropriate values.

- 1) Exceedance
- 2) Persistence

Unsteady speed has been neglected for the basic SKEET, but provision for non-planar current profile is recommended. Use of a time domain solution would permit investigation of unsteady speed effects in an enhanced SKEET.

TABLE 5
Mooring Line - Physical Properties

- 1) Generic Type
 - a. Single Point Mooring (SPM)
 1. SALM
 2. CALM
 3. Simple catenary
 - b. Spread Mooring
 1. Symmetric
 2. Asymmetric
 - c. Tension Leg
- 2) Dimensions
 - a. Length
 - b. Depth at Anchor
 - c. Anchor Location
 - d. Attachment Point on Vessel (fixed, variable)
- 3) Materials
 - a. Type
 1. Chain
 2. Synthetic
 3. Wire
 4. HCL
 5. Deadweight
 6. Floats
 - b. Characteristics
 1. Elasticity
 2. Yield strength
 3. Ultimate strength
 4. Weight in air
 5. Weight in water
 6. Drag coefficient
 - c. Long Term Behavior
 1. Corrosion
 2. Fatigue
 3. Fishbite
 4. Fouling properties

The basis SKEET should be able to model a variety of mooring configurations including simple, compound and complex mooring types.

Note: Definitions of the mooring types may be found in the glossary contained in Appendix C

TABLE 6
Anchor - Physical Properties

- 1) Gravity
 - a. Weight in Air and Water
 - b. Size
- 2) Drag Imbedment
 - a. Weight in Air and Water
 - b. Size
 - c. "Effectiveness" Factor
- 3) Pile
 - a. Diameter
 - b. Penetration

In general, it is assumed that anchor force is unlimited, and the maximum anchor load serves as a basis for anchor sizing and selection. However, to evaluate anchor drag transients, holding power for the appropriate anchor type would be required.

TABLE 7
Bottom - Physical Properties

1) Contour

- a. Depth
- b. Slope

2) Composition

- a. Lateral Bearing Strength
- b. Vertical Bearing Strength
- c. Friction (coefficient)
- d. Surface Cohesion

Depth and bottom slope affect mooring line response and required holding power. If anchor drag is to be modeled, the affect of soil composition on anchor holding power must be assessed in a subsidiary analysis.

TABLE 8
ELECTRICAL RISER CABLE - Physical Properties

- 1) Configuration
 - a. Simple catenary
 - b. Catenary with buoyancy elements
- 2) Dimensions
 - a. Length
 - b. Depth
 - c. Bottom termination location
 - d. Attachment point on vessel
- 3) Characteristics (of cable and/or buoyancy elements)
 - a. Elasticity
 - b. Strength
 - c. Weight in air
 - d. Weight in water
 - e. Drag coefficient

Multiple risers would be modelled individually to determine loads, bend radii and deflections, and assess the need for a bend limiter.

TABLE 9
DYNAMIC POSITIONING - Physical Properties

- 1) Propulsion System
 - a. Thrust characteristics
 - b. Moment characteristics
- 2) Control System
 - a. Position sensing system
 - b. Control logic

In a basic SKEET, implified force and moment equations and an elementary control law will be employed to determine steady state thruster effects. An enhanced SKEET could use a more complex treatment such as found in control system analysis.

TABLE 10
Wind on Vessel

Static Wind Forces and Moments

- Transfer Function - Determine from characteristic area and associated drag coefficients
- Output
 - Lateral and longitudinal components of force and yaw moments of primary importance to SKSS.
 - Heel and trim moments may be significant for some platforms.
 - Lift force generally negligible.

Unsteady Wind Effects

- Gusts and unsteadiness of wind speed not likely to excite system resonance
- Magnitudes are small compared to other forces
- Quasi-static modeling

TABLE 11
Waves on Vessel / CWP

- 1) High Frequency Effects (6 DOF, regular waves)
 - a. Frequency Dependent Hydrodynamic Coefficients
 1. Damping
 2. Added mass
 - b. Wave Pressure Forces and Moments
 - c. Vessel/CWP Dynamic Response
- 2) Slowly Varying
 - a. Mean Drift Force
 - b. Time Varying Drift Force

The primary dynamic excitation of the SKSS is due to vessel/CWP high frequency motion.

High frequency response of a linear system in the frequency domain is obtained by superposition with a wave energy spectra.

Nonlinearities may be handled by equivalent linearization techniques in the frequency domain, or by direct integration in the time domain.

Hydrodynamic coefficients may be determined or verified through model testing.

Outputs for irregular wave excitation

- High frequency forces/motions
 - root-mean-square or significant amplitude
 - maximum (within a stated return period)
 - average number of cycles per unit time
- Slow varying
 - mean wave drift force/motion (frequency domain)
 - time history of drift force/motion (time domain)

TABLE 12
CURRENT ON VESSEL/CWP

- Static Current Forces and Moments
 - Transfer Function
 - determine from characteristic area and associated drag coefficients
 - Output
 - forces and moments in 6 DOF
- Unsteady Current Effects
 - unsteadiness occurs at periods longer than the resonant period, and will not excite system resonance
 - vortex shedding is likely to occur on CWP and cause a quasi-static increase in drag

TABLE 13
WAVES ON MOORING LINE

High Frequency Pressure Forces

- Normal
- Tangential

Outputs

- Cable loads

Slow Varying Effects

- Wave drift forces acting on cables are neglected since depth attenuation will reduce this effect below several hundred feet

TABLE 14
CURRENT ON MOORING LINE

Static Current Forces

-Transfer Function

normal and tangential drag
coefficients associated with
characteristic area

-Output

three components of force
at each section or node on
mooring line

Unsteady Current Effects

-Forces due to unsteady current
speed are neglected

-Vortex shedding is likely to
occur on mooring line leading
to a modified C_D

TABLE 15
VESSEL ON MOORING LINE

1) Static

Transfer Function (spring constraint)

1. Force due to lateral translation of vessel mooring attachment point
2. Force due to vertical translation of vessel mooring attachment point
3. Force due to longitudinal translation of vessel mooring attachment point

2) Dynamic

Transfer Function

1. Inertial effects
2. Damping and added mass of mooring line due to vessel induced motion

Vessel motion is the principal source of dynamic excitation of the mooring line system.

TABLE 16
Mooring Line on Vessel

1) Static

Transfer Function

1. Vertical force due to mooring line tension
2. Lateral force due to mooring line tension
3. Longitudinal force due to mooring line tension

2) Dynamic

Mooring force components supplement exciting forces
in vessel equations of motion

- primary significance is in horizontal plane
motions (sway, yaw, surge)
- secondary effect on other motions (pitch,
roll, heave) except for tension anchor leg

TABLE 17
Mooring Line on Anchor
and
Anchor on Soil

Basic Mode - Anchor Fixed

Maximum vertical and horizontal loads will
determine required holding power

Alternate Mode - Anchor Drag Possible

Relaxation of anchor position constraint permitted
if allowable load exceeded.

New position determined, or progressive failure
results.

TABLE 18
Dynamic Positioning System on Vessel

Static Forces

- a. Net lateral force
- b. Net longitudinal force
- c. Net moment

Dynamic Excitation

Neglected - assumed quasi-steady. A more complex
treatment may be provided using control system
analysis.

APPENDIX C

Glossary

APPENDIX C

Glossary

Added mass: force due to the acceleration of a body in a fluid

Anchor types:

dragging - dragging anchors derive their holding power from their deadweight and, to some slight extent, from hooking or suction action

embedment - anchors which use powder charge, hydrostatic pressure, or pneumatic pressure to drive the fluke into the bottom from a gun barrel

pile - anchors consisting of large diameter, long, heavy pipes which are driven into the sea floor using pneumatic hammers.

self-burying - anchors whose holding power depends not on weight but on withdrawal resistance provided by flukes of large area

Catenary: the shape assumed by a perfectly flexible cable in equilibrium under its own weight and other distributed loads

Cold water pipe: large diameter (5 ft. or more) pipe extending from the OTEC platform to a depth of about 3000 ft. It is used to transport cold water to the plant's condensers.

Current: horizontal movement of ocean which extends to all depths and consists of three major components.
Eckman wind current - current due to shearing effect of local wind on the water surface.
Geostrophic current or ocean current - main currents due to mean global weather patterns, e.g., Gulf Stream.
Tidal current - current found in relatively shallow waters due to tidal action.

Direct time integration: use of numerical integration techniques to solve differential equations. Gives time history of system response to a given excitation history.

Dynamic positioning: the technique and related systems hardware necessary to maintain the position and heading of a floating vessel by means of active thrust controlled by a computer.

Equivalent linear damping: the use of linear damping to approximate nonlinear damping. The damping coefficient is such that the energy dissipated per cycle by the linear damping is equal to that dissipated by the nonlinear mechanism.

Excursion: movement in the horizontal plane of a moored vessel away from its equilibrium position.

Excursion reliability: the probability that the maximum excursion of a moored vessel remains within acceptable limits for a given time period under specified conditions.

Extensible: a cable is extensible if it is able to deform along its own length.

Faired cable: a cable which has streamers or similar devices attached along its length to give a more streamlined profile, and so, reduce vortex shedding.

Far field method: method determining wave drift forces and moment on a vessel by integrating pressures over a control surface at a considerable distance from the vessel.

Fetch: distance over water that a wind blows. When this distance is limited, the maximum sea state that can be generated by a given wind is also limited.

Finite element method: the analysis of a continuous system through its representation as a system of smaller discrete elements in which assumptions associated with field quantities are made.

Frequency domain: in a frequency domain analysis the relation between excitation and response is found as a function of frequency. The superposition principle is used to express the solution in terms of factors which represent the participation of each frequency.

Heave: see vessel motions.

Hydrodynamic coefficients: coefficients used in the equations of motion of a vessel to represent the inertial, damping, and restoring forces which are due to the interaction between vessel and fluid.

Hydrodynamic damping: the damping of vessel motions due to the wave motions propagation which results from ship motions.

Imaginary reactions, method of: a force-equilibrium method for treating complex redundant structures.

Keulegan-Carpenter number: defined to be $K = U_m^T / D_e$ where U_m is the amplitude of the oscillatory velocity, T is the period of oscillation, and D_e is the external diameter. This non-dimensional coefficient is used to characterize unsteady flow around a cluster of cylinders.

Magnus effect: transverse force due to flow around a helically stranded cable.

Mechanical reliability: survival probability of structure and power plant.

Mooring line: line running between vessel and anchor which may be one of two types.

Simple mooring line - line composed of only one material such as wire rope or chain.

Compound mooring line - line composed of several segments of different materials with or without attached weights.

Mooring system: a system of lines and anchors designed to keep a vessel on station. Figure illustrates several configurations which are defined as follows:

Multiple anchor leg - system with more than one mooring line.

Single anchor leg - system with single mooring line.

Single point moor - mooring system anchors a surface buoy to which the vessel or platform is attached by a rigid mooring yoke.

Spread mooring - mooring lines are radially distributed over 360 degrees.

Tensioned anchor leg - excess platform buoyancy is used to vertically tension the anchor connection.

Turret mooring - mooring lines are attached to a turret structure on the vessel which allows the vessel to adapt its heading to wave direction.

Morison's equation: expression for force exerted by fluid on an accelerating body which consists of two terms - one representing friction effects and one representing the inertia of the displaced fluid.

Near field method: method for determining wave drift forces and moment on a vessel by integrating pressures on the vessel's surface.

Figure E-1. Types of Mooring Systems

Pitch: see "Vessel Motions"

Potential theory: general theory used to determine forces exerted by an ideal fluid on an accelerating body.

Response amplitude operator (RAO): a function which gives the relationship between unit excitation and response amplitude as a function of frequency.

Riser: for an OTEC plant, this refers to the submarine electrical power transmission cable which links the plant into a shore-based power grid.

Roll: see "Vessel Motions".

Significant wave height: the average height of the highest third of the waves found in a particular sea state.

Spectrum: a function which indicates the relative importance in an infinite number of different component frequencies which combine to produce a given random process.

Strip theory: a method for determining the hydrodynamic coefficients of a vessel which is based on the assumption that the hull is made up of a number of transverse strips the flow about each is essentially two dimensional, i.e., confined to that one step.

Strouhal number: defined as $Sn = fD/V$ where V is the fluid velocity, D is the diameter of the cylinder over which the fluid flows, and f is the vortex shedding frequency in hertz. Thus, Sn defines a relation between fluid speed and vortex shedding frequency. It depends on cylinder profile, smoothness, and Reynolds number.

Surge: see "Vessel Motions"

Sway: see "Vessel Motions"

Time domain: in a time domain analysis the equations of motion are solved using numerical methods to yield the system response as a function of time.

Vessel motions: a vessel may respond to wave, wind and current forces in six degrees of freedom which are commonly labeled as indicated in Figure E-2.

Viscous damping: the damping of ship motions due to skin friction and appendage drag.

Vortex shedding: a phenomenon of fluid flow around cylinders which occurs at subcritical and transcritical Reynolds numbers and in which eddies form and are shed from alternating sides of the cylinder.

Watch circle radius: maximum allowable horizontal displacement of a moored platform from its equilibrium position.

Wave drift force: in irregular seas, this is the second order, nonlinear, low-frequency wave forces on the body due to the reflection of waves.

Yaw: see "Vessel Motions"

Figure E-2. Vessel Motions