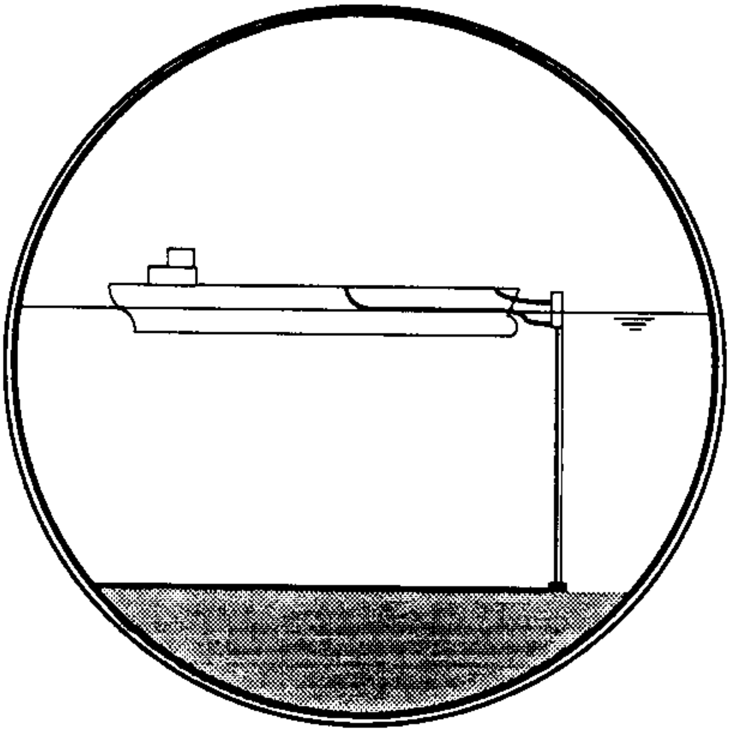
Offshore Single Point Mooring Systems for Import of Hazardous Liquid Cargoes

SEA GRANT PROJECT R/OE-26



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September 1994

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ABSTRACT

The goal of this project was the determination of feasibility of single point mooring systems (SPMS) for use as deepwater ports for the import of hazardous liquid cargoes offshore southern California. The use of deepwater ports is advocated because it has been determined by the U.S. Coast Guard that they represent the least risky form of crude oil import, lessening the likelihood of occurrence and environmental impact severity of accidents. Two configurations of SPMS were examined as deepwater ports in this project : catenary anchor leg mooring (CALM) and single anchor leg mooring (SALM). Two sites for these systems were chosen offshore southern California by the California State Lands commission : El Segundo and Morro Bay. The project examined the environmental conditions at both sites, developed analytical models with which to evaluate the suitability of SPMS to these environmental conditions, determined the reliability of the systems by use of state-of-the-art reliability methods, and evaluated the feasibility of the systems by comparing reliability to system costs.

The results of this project indicate that SPMS for offshore southern California conditions are feasible and do not require major technological developments to allow such systems to be designed, constructed, and operated. Use of these systems should lower the number of accidents due to hazardous liquid cargo import, as well as reduce the impact of those accidents which do occur.

Acknowledgments

Many people have been instrumental in the development of this paper. We would like to thank Professor William C. Webster for his contribution to the direction of this research. We would also like to thank Wei Ma (Graduate Student Researcher), who was responsible for a parallel effort to develop analytical models for CALM moorings.

We would like to express thanks to California Sea Grant for its sponsorship of this paper. This work has given us the opportunity to examine the state of hazardous cargo transportation and transfer, and learn the means for avoiding accidents by designing against their occurrence.

Many industry contacts helped guide this work. We would like to thank Dale G. Rollins of the Louisiana Offshore Oil Port for taking the time to show us around the LOOP facility, as well as for answering many questions at other times concerning single point moorings and deepwater ports. We would also like to thank Michael J. LeBlanc and Wayne E. Lolan of LOOP for their input and assistance.

M. Steven Mostarda of IMODCO was of great help in the systems design of the SPMS, as well as in providing helpful background on the systems. We would like to thank Capt. A. F. Fantauzzi of the Chevron Shipping Company and Christopher P. Whatley of the Chevron Petroleum Technology Company for their help in understanding the challenges involved in design and operation of facilities of this type.

We would also like to thank the following for their contribution to the success of this research : Jay Phelps of the California State Lands Commission, Paul Palo of the Naval Civil Engineering Laboratory, Dr. Malcolm Sharples of Noble, Denton and Associates, Inc., and Gavin Cleator of Bruce Anchor Limited.

This paper is funded in part by a grant from the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U. S. Department of Commerce, under grant number NA36RG0537, project number R/OE-26 through California Sea Grant College, and in part by the California State Resources Agency. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its sub-agencies. The U. S. Government is authorized to reproduce and distribute for governmental purposes.

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A	Projected area
A_S	Side surface area of pile
B	Stress range model error parameter
B_B	Beam
B_K	Bias on K
C_{USS}	Undrained shear strength
C_B	Coefficient of variation of B
C_D	Drag coefficient
C_{Df}	Drift coefficient
C_{Drift}	Average drift coefficient
C_K	Coefficient of variation of K
C_S	Wind shape coefficient
C_{WS}	Wetted surface area coefficient
C_Δ	Coefficient of variation of Δ
D_{Buoy}	Buoy diameter
D_P	Pile diameter
f_{CO}	Friction coefficient, chain and ocean bottom
f_{SC}	Unit skin friction capacity
f_0	Average stress frequency
$F_{Bow,\ drift}$	Mean wave drift force, bow-on
$F_{Current,\ buoy}$	Current force on buoy
$F_{Current,\ Ship}$	Current force on ship, bow-on
$F_{Mean\ drift}$	Mean wave drift force
F_{Wind}	Steady wind force
FS	Factor of safety
F_{SF}	Fatigue safety life factor

H_{fD}	Design wave height
H_{max}	Maximum wave height
H_S	Significant wave height
K	Log life intercept of S-N curve
L	Length
L_C	Length of chain in contact with ocean bottom
m	Negative slope of S-N curve
N	Number of elements
N_T	Stress cycles
P_C	Chain holding power
P_{conn}	Probability tanker is present at facility
P_f	Annual probability of failure
$P_{sea\ state}$	Probability of sea state being maximum annual sea state
Q_P	Ultimate pull-out capacity
R_{50}	Mean capacity
S	Wetted surface area
S_{fD}	Fatigue design stress range
S_m	Largest expected stress range
S_{50}	Mean load
t	Wind gust duration
T_{DP}	Design time period
T_{fL}	Mean fatigue life
T_S	Significant wave period
T_{SF}	Design time period, with safety factor
T_{SL}	Service life
T_{WT}	Minimum pile wall thickness
V_C	Current velocity
V_R	Coefficient of variation of resistance
V_S	Coefficient of variation of load
V_t	Wind gust velocity, duration t
V_{tz}	Wind gust velocity, modified by elevation and duration
V_X	Coefficient of variation of X
V_Z	Wind velocity at centroid elevation

$V_{1\ min}$	Wind gust velocity, 1 minute duration
V_{10}	Wind velocity at 10 meter elevation
V_{II}	Coefficient of variation of type II variances
W_C	Submerged unit weight of chain
W_P	Pile weight
X	Mean value of X
X_{50}	2-year force
X_{99}	100-year force
Z	Centroid elevation
α	Wave height exponent
α_P	Dimensionless pile factor
β	Safety index
β_E	Element safety index
β_S	System safety index
Δ	Accumulated fatigue damage
Δ_{Vol}	Displaced volume
ε	Stress range parameter
Φ	Standard cumulative normal distribution
Γ	Gamma function
$\lambda\ (m)$	Rainflow correction factor
ρ_{Air}	Air density
ρ_E	Correlation of elements
ρ_{FM}	Failure mode correlation
ρ_{RS}	Correlation coefficient, load to capacity
ρ_{SW}	Salt water density
$\sigma_{ln\ K}$	Standard deviation log K
$\sigma_{ln\ R}$	Standard deviation log R
$\sigma_{ln\ S}$	Standard deviation log S
$\sigma_{ln\ T}$	Standard deviation log T
$\sigma_{ln\ X}$	Standard deviation log X
σ_X	Standard deviation X
Ω	Stress range parameter

Chapter 1

Introduction

1.1 Project Overview

The purpose of this project (Sea Grant project R/OE-26) was to perform an evaluation of the reliability and feasibility of deepwater ports, specifically those consisting of a single point mooring system (SPMS) and support equipment for tanker discharge, for offshore southern California. These deepwater ports could serve as discharge ports for tankers delivering crude oil from Valdez, Alaska, or other supply points, to southern California. Two locations along the California coast, El Segundo and Morro Bay, were studied as potential locations for these facilities. These two locations were specified by the California State Lands Commission. The water depth for both facilities was proposed as one thousand feet.

Direction in this project was provided by Professor Robert Bea (principal investigator) and Professor William Webster (co-principal investigator). The research was performed by Mr. Aaron Salancy and Mr. Wei Ma. Mr. Salancy was responsible for the work presented in this report, consisting of the systems engineering of the facilities. Mr. Ma was responsible for the development of the analytical models used in this project [Ma, 1994].

1.2 Project Background

This project investigated the feasibility of deepwater ports at the two locations proposed by the California State Lands Commission. This investigation required examining the existing types of SPMS, evaluating how they would function in the offshore southern California environment, determining what configurations would adequately withstand the environmental conditions while performing satisfactorily, and establishing the financial and technical feasibility of the resulting configurations. The determination of feasibility was based on an assessment of the reliability characteristics of each proposed system and the costs to build and operate the system.

Two facility systems were chosen for detailed examination. Each facility was to be capable of servicing tankers up to roughly very large crude carrier (VLCC) size (loosely defined as 200,000 to 275,000 DWT), with the tankers requiring no major modification to use the facility. Each facility would also meet all major relevant requirements and guidelines for an offshore installation of this type. It was desirable that the facilities should not require major leaps in technology from that currently existing in any component, or in installation, maintenance, or regular operation. This was considered necessary to insure that reasonable reliability, feasibility, and cost estimates could be obtained. Above all else, the facility should be capable of rapid, safe disconnection in deteriorating sea states and be capable of surviving intact the 100-year storm and seismic conditions with a sufficiently high probability of success. Only once these requirements were met by a system would the financial feasibility analysis be conducted for that system.

The scope of this project includes : the SPMS, the tankers which are expected to use the facility, all equipment necessary for connection and discharge of the tankers, and the piping system to transfer oil from the facility to the shore. The pipeline to shore itself is not a main focus of this project, however, and the shoreside facilities have not been examined. These aspects of the systems should be given attention in the future, as they will heavily impact system feasibility by their effect on facility cost.

1.3 Deepwater Ports

Deepwater ports, defined as ports several miles offshore which can service VLCC's and ULCC's (ultra-large crude carriers, loosely defined as 275,000 DWT and up), have several obvious advantages over other methods of crude oil delivery. They lessen the impact of accidents due to their distance from shore and reduce the probability of accidents by keeping tankers from entering congested ports. However, until recently, no quantifiable evidence proving the worth of deepwater ports existed. This changed when the U.S. Coast Guard declared deepwater ports to be the least environmentally risky form of crude oil import in their report "USCG Deepwater Ports Study" [U.S. Department of Transportation, 1993].

In the report, deepwater ports were compared with three other methods of crude oil import : direct vessel delivery (tanker enters port and discharges at a terminal), offshore lightering (tanker off-loads to a smaller tanker or barge offshore, and this second vessel then transports oil to the port terminal) and offshore mooring delivery (tankers less than VLCC size discharge through pipeline to shore at a shallow water facility). Offshore moorings are defined as being within 1 to 2 miles offshore in the study. Although the Louisiana Offshore Oil Port (LOOP) facility was the only deepwater port examined, approximately 14% of all foreign-source crude oil imported to the U.S. has gone through LOOP in recent years, making it significant [U.S. Department of Transportation, 1993].

The determination of environmental risk in this report was based upon historical frequency of spills, average spill size, and an environmental impact coefficient for each different environmental area entered or transited by tankers for each method of delivery. This produced an average environmental impact for each method of delivery. Deepwater ports were found to pose the lowest environmental risk primarily because : the transfers of crude oil occur offshore, where environmental impact is lower; the crude oil is delivered into port by means of a pipeline, which is a very safe means of transportation; and no ships are exposed to through-port transit dangers. Deepwater ports also allow for the pre-positioning of spill response equipment at the port site. However, for "worst case" spills, the study found all methods of import to pose roughly equal environmental risk, due to the disastrous consequences of complete loss of a tanker's cargo [U.S. Department of Transportation, 1993].

Of course, deepwater ports have their drawbacks, and these should be mentioned. They require enormous capital expenditure as well as efforts to obtain state and federal permits for construction and operation.

1.4 Single Point Mooring Systems

The first parameter in this project was the use of a SPMS as a deepwater port. A SPMS is a mooring which allows a ship to weather vane around the mooring, thus minimizing the environmental loads on the system by allowing the moored ship to head into the prevailing weather. In this case, the SPMS also provides the interface between the tanker and the pipeline for the discharge of crude oil.

1.4.1 SPMS Around the World

SPMS have been used successfully in many applications around the world in many different conditions. The challenge posed in this project for the use of SPMS is the specified water depth of one thousand feet and the offshore California oceanographic and seismic conditions. This is not an unprecedented depth for the use of SPMS, as the Marlim Field catenary anchor leg mooring (CALM) off the coast of Brazil is located in approximately 1312 feet of water [Hwang and Bensimon, 1990]. However, the environmental conditions offshore California, including seismic activity, are more severe than those encountered by most SPMS. Even so, the design of a SPMS for use in one thousand feet of water off the California coast should require no major breakthrough developments.

Single point mooring systems are in operation in many locations around the globe. Appendix 1 gives a representative list of approximately 400 SPMS, their locations and their installation date. There are currently SPMS in California, but these existing systems are in significantly shallower water.

SPMS have been designed in many different configurations, some of which are discussed in Chapter 3, System Configurations. Two specific systems which best meet the needs of this project are chosen for analysis in Chapter 3.

1.4.2 LOOP Facility

In the course of developing background for this project, we visited the Louisiana Offshore Oil Port (LOOP) facility in Louisiana. This facility was considered to be highly relevant to the project, as it is currently the only deepwater facility in the U.S. and makes use of three SPMS. The LOOP facility is owned and operated by LOOP Inc., and is governed by the laws of the United States in the same manner as if the port were an area of exclusive federal jurisdiction located within a state. The United States Coast Guard's Marine Safety Office has governmental authority over LOOP [LOOP Operations Manual, 1992]. We conducted several interviews at LOOP, and the findings were very helpful in many aspects of this project.

The LOOP facility encompasses (offshore) three SPMS of the single anchor leg mooring (SALM) type and a platform complex consisting of a pumping platform and a control platform. The LOOP offshore pumping facility is located at 28 degrees, 53.2 minutes North latitude, 90 degrees, 1.5 minutes West longitude. The SALM's are located in a radial pattern from the platform at a distance of 8150 feet, and were built to accommodate vessels of up to 700,000 DWT. LOOP began operations in 1986 and over recent years has received approximately 14% of all foreign-source US import crude oil. It has been visited by tankers ranging in size from 80,000 DWT to 556,000 DWT [US Department of Transportation, 1993].

The major physical difference between LOOP and the facilities proposed in this project is the water depth. Although LOOP is considered a deepwater port -- because it is capable of servicing VLCC's and ULCC's -- it is located in approximately 115 feet of water. The environmental conditions are also milder in the Gulf of Mexico than along the southern California coast. LOOP is located approximately 18 nautical miles offshore Louisiana, a greater distance than the facilities in this project. The LOOP facility was designed to support a much greater amount of tanker traffic than the facility in this project.

Bearing these differences in mind, there is still much to be learned from LOOP. All components at or near the water surface will be very similar to those in this project, as will operational procedure. Installation and maintenance will have the largest differences due to factors related to water depth.

1.5 Report Structure

This report examines environmental conditions, SPMS types, analytical models, reliability, and feasibility of SPMS. Chapter 2 presents background on the sites chosen by the California State Lands Commission and the environmental conditions encountered at these sites. The main environmental components examined are wind, wave, current, and seismic activity. The ocean floor and soil conditions at each site are also examined.

In Chapter 3 the various types of SPMS configurations are examined, and the configurations deemed most suitable for this project, CALM and SALM, are detailed. The supporting components of these systems are also examined. These include the tankers visiting the facility, the pipeline from the facility to the shore, and all tending vessels required for facility operation.

Chapter 4 discusses the analytical models used to determine the effects of environmental components on the facilities. Environmental loadings and environmental-induced motions are modeled for their effect on the horizontal offset of the SPM buoy, from which line tensions in the SPMS anchor legs can be determined. The environmental loadings consist of steady forces (wind, current, and mean wave drift force), oscillating motions (first order wave motions and second order wave motions) and seismic loadings. The restoring force of both the CALM and SALM systems are modeled.

Reliability is examined in Chapter 5. The reliability of each facility is measured by its annual probability of failure. The probability of failure is divided into four relatively independent components : failure due to storm loadings, failure due to seismic loadings, failure due to fatigue, and failure attributable to human and organizational error (HOE). Each of these components is examined. The annual probability of failure of each facility for each component is examined and calculated.

Chapter 6 discusses the feasibility of the proposed facilities. This is done by comparing the cost of each facility with its reliability. The financial analysis includes the cost of the system components, system development and engineering, construction and transportation, installation, operation and maintenance, and permitting. The feasibility of the systems is the result of this analysis.

Chapter 7 presents a summary of this work, as well as recommendations for future work on this topic.

Chapter 2

Environmental Conditions

2.1 Introduction

The goal of this chapter is the description of the environmental conditions which have an impact on the design of the SPMS systems at the two chosen sites. A SPMS is always subject to forces from the surrounding ocean and atmosphere, in the form of wind, wave and current. In a location such as southern California, seismic events must be considered as well. The topography of the ocean floor needs to be considered, as well as the nature of the soil with regards to anchor and anchor pile holding power. Therefore, the conditions examined in this chapter include wind, waves, current, seismic activity, ocean floor topography, and soil type.

2.2 Project Sites

Two sites along the southern California coast were identified by California Sea Grant as prospective SPMS facility sites : El Segundo and Morro Bay. El Segundo is located at 33 degrees, 55 minutes North latitude and 118 degrees, 25 minutes West longitude, while Morro Bay is located at 35 degrees, 22 minutes North latitude and 120 degrees, 53 minutes West longitude (Figure 2.1). The specified water depth of 1000 feet gives a distance offshore ranging from 6 to 12 miles at both sites, for a variety of specific locations (Appendix 2).

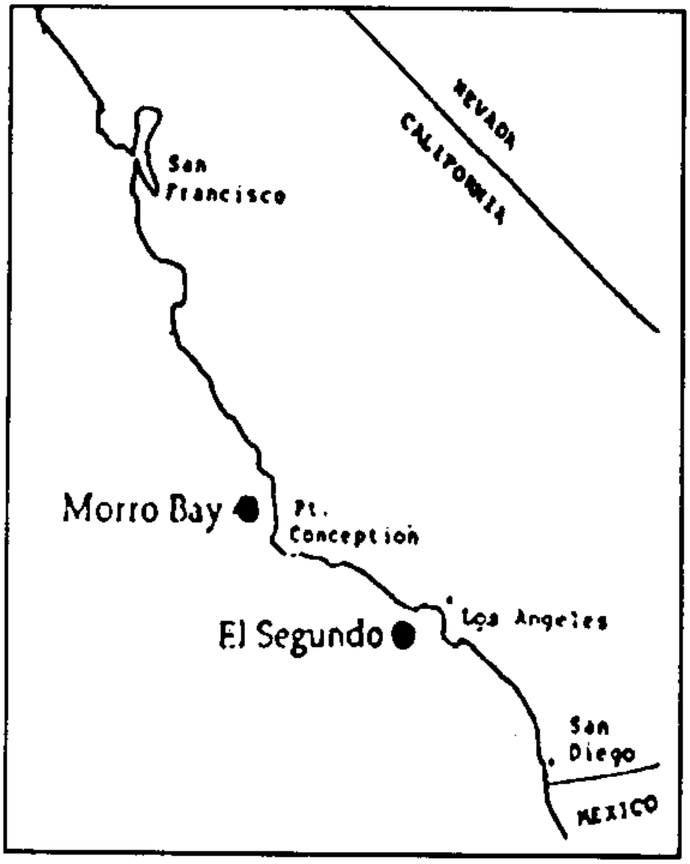

Figure 2.1 : Site Locations

2.3 Environmental Conditions

The weather along the southern California coast is primarily a product of extra-tropical storms originating in the Northeast Pacific during winter [Stevens, 1977]. Other weather phenomena such as tropical storms, thunderstorms, tornadoes and waterspouts are rare at best.

The main environmental components of wind, waves, current and seismic activity are discussed in the following sections and summarized in Table 2.1. The environmental conditions are presented in a probability framework, which will allow for rapid integration with the methods used to determine probability of failure in Chapter 5, "Reliability". This method is based on the concept of "return period". The return period is the mean elapsed time expected between occurrences of an event. For example, if a thirty-foot wave is expressed as the 50-year return period wave, this means that a wave of thirty foot height is expected to occur once every fifty years. These values are based on past statistical data and extrapolation.

It is customary to assume that all of the environmental components considered here follow a log normal distribution, and this has been done. This type of distribution will be discussed more fully in Chapter 5.

Return Period (years)	Wind Velocity (@ 10m) (knots)	Surface Current Velocity (knots)	Expected Maximum Wave Height (feet)	Peak Vertical Ground Acceleration (gravities)
2	39	1.2	29	0.01
10	55	1.7	37	0.05
100	72	2.2	46	0.18
1000	88	2.7	54	0.40

Table 2.1 : Environmental Conditions by Return Period

Another environmental component, visibility, should be noted. Heavy fog is possible in these areas, and visibility is typically reduced to under one mile for approximately 2.5% of the year, varying by location [Stevens, 1977]. This may have an adverse effect on operations in a less direct manner than other environmental components.

2.3.1 Wind

Wind in this region is primarily from the northwest, circulating around the Pacific High, and varies from winter to summer. The most notable exception to this trend are the Santa Ana winds, generated inland and blowing out over the coast. However, given the distance offshore of these facilities, the effects of this type of wind can be ignored. Another phenomenon of this region is the Catalina Eddy. This eddy causes recurvature of winds locally near the coast, but, for this project, it can also be considered insignificant [Stevens, 1977].

The wind speed can be expected to vary throughout the region under consideration, but estimates for the area should prove sufficient for this project. Values for wind speed were researched from several sources [Intersea Research Corporation, 1974; Stevens, 1977] and are given by return period in Table 2.1.

2.3.2 Waves

The primary wave direction offshore southern California is north to northwesterly, with little seasonal variation. Values for maximum wave height were researched from several sources [Intersea Research Corporation, 1974; Department of Navigation and Ocean Development, 1977; Stevens, 1977; API, 1989] and are given by return period in Table 2.1. It should be noted that for these values, maximum wave height is related to significant wave height by Equation 2.1 [Stevens, 1977].

$$H_{max} = 1.86\, H_S \tag{2.1}$$

2.3.3 Current

Currents in this region are usually relatively small. It is normal practice to estimate current speed by a combination of two components. The first component is shear force imparted by wind. The second component consists of tidal flows and currents arising from the topography of the ocean floor. Surface currents are usually wind-driven, while subsurface currents are driven by geostrophic factors and tides.

In this project, the surface current speed will be taken as 4% of the steady wind speed, subsurface currents at mid-depth will be taken as one-half surface current speed, and near-bottom currents will be taken as one-third surface current speed [Stevens, 1977]. This approximation includes the small effect of tides. The resulting values for current speed correlate well with those found in other sources [Intersea Research Corporation, 1974]. Values for maximum current are given by return period in Table 2.1.

2.3.4 Weather Directionality

For the analyses done later in this paper involving environmental loads, it is necessary to know the primary direction of wind, wave and current. Since only extreme conditions are examined, directionality need only be known for these conditions.

In this region, storms are usually from the northwest. In a large storm, wind and wave direction will tend to coincide, especially when short wind gusts are discounted. Surface current will also follow the direction of the wind, as discussed in the previous section. Therefore, the environmental components will be assumed to act unidirectionally. There are some flaws to this assumption, as some directional spreading is inevitable and subsurface currents are ignored. However, directional spreading can be addressed, and it is proven in Chapter 4 that subsurface currents have little effect on the analytical models. Therefore, unidirectionality of wind, wave and currents will be assumed.

2.3.5 Seismic Activity

The southern California area has a relatively high degree of seismic activity. Offshore structures are usually analyzed for seismic safety by examining the effects of local activity as well as distant, more severe activity. The seismicity of a specific region, however, is highly variable, depending on local and distant fault positions. Since the area of interest in this project is located in deep water, fault positions are relatively unknown, and an accurate portrayal of seismicity in the region is not possible. Therefore, values from a study of the entire offshore southern California area have been used for peak ground accelerations by return period [Bea, 1992]. These values are given in Table 2.1.

2.3.6 Ocean Floor Topography

The features of the ocean floor of both sites were evaluated by examination of nautical charts prepared by the National Ocean Service [U.S. Department of Commerce, 1991]. The purpose of this examination was to determine the slope of the floor in these locations and discover which locations would be unfavorable due to excessive slope, which may indicate a likelihood of sliding.

At El Segundo, the slope of the floor was found to vary from 12.8 degrees to 2.2 degrees at 1000 feet depth, with the slopes growing steeper to the south (Appendix 2). The only feature of note in this area is the Santa Monica Canyon, which is not especially deep. The slopes at Morro Bay were found to be less severe, ranging from 1.9 degrees to 0.9 degrees (Appendix 2).

2.3.7 Soils

Soils were investigated for the purpose of calculating anchor and anchor pile holding power, as well as determining the possibility of scour, sliding and other ocean floor phenomena which may have an effect on the facilities. The soils in this region consist of "clayey silt" to a depth of approximately 15 feet below the sea floor, and "stiff, silty clay" below this level to a depth of approximately 200 feet. The former type of soil has an undrained shear strength of approximately 1.5 kilopounds per square foot, while the latter soil type has an undrained shear strength of approximately 2.0 kilopounds per square foot [Woodward-Clyde, 1984].

Scour, slumping and sliding are all possible in this area, but risks should be lower in areas with shallower floor slopes [Intersea Research Corporation, 1974]. Silt soils, such as those at the sea floor, have a low resistance to scour. Clay soils have a lower susceptibility to scour, however, so while some scour may occur, it will not be severe, due to the presence of the stiff clay soils below the silt soils [Woodward-Clyde, 1983].

Liquefaction is probably a greater concern. This phenomenon involves the sudden loss of soil strength due to ground shaking or wave effects, and could have a severe effect on the holding power of pile anchors. The top soil type, "clayey silts" will be expected to experience some loss in strength, on the order of 15%, but soil strength loss below 50 feet should be negligible [Woodward-Clyde, 1978]. Therefore, if piles extend more than 50 feet below the sea floor, they should be relatively safe from liquefaction risks.

Chapter 3

System Configurations

3.1 Introduction

The purpose of this chapter is the examination of various configurations of SPMS in operation around the world, and the selection from these of two configurations which best meet the specific requirements of this project. All equipment necessary for tanker discharge, such as hawser lines, pipelines, transfer hoses and product risers, is also discussed. However, the main thrust of this project is the design of the SPMS, so only components directly related to the operation of the SPMS are examined in detail. Onshore facilities and offshore pipeline pumping stations are considered to be outside the scope of this project.

In the course of the project, systems were designed and then tested against the analytical models, reliability framework and feasibility criteria of later chapters. The designs were then reiterated as necessary to produce systems which met all applicable guidelines and rules. The trials of this iterative procedure are not repeated here; for the sake of conciseness only the final designs are presented.

3.2 Existing SPMS Types

Many types of SPMS are in use around the world, as can be seen in Appendix 1. The following is a non-exhaustive list of configurations of SPMS in operation : catenary anchor leg mooring (CALM), single anchor leg mooring (SALM), turret mooring, and fixed, articulated loading or catenary articulated tower. This list covers the major systems implemented to date. These systems are illustrated in Figures 3.1 through 3.4. Systems which use dynamic positioning can also be considered SPMS, although these were not considered in this project due to the cost associated with a purpose-built vessel of this type.

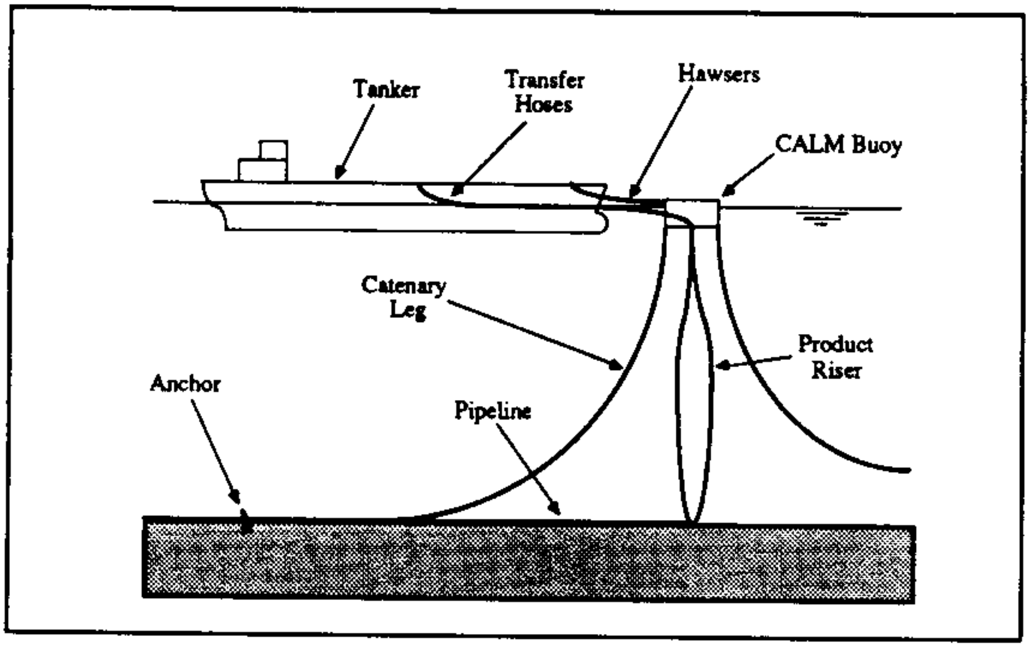

Figure 3.1 : Typical Catenary Anchor Leg Mooring Schematic

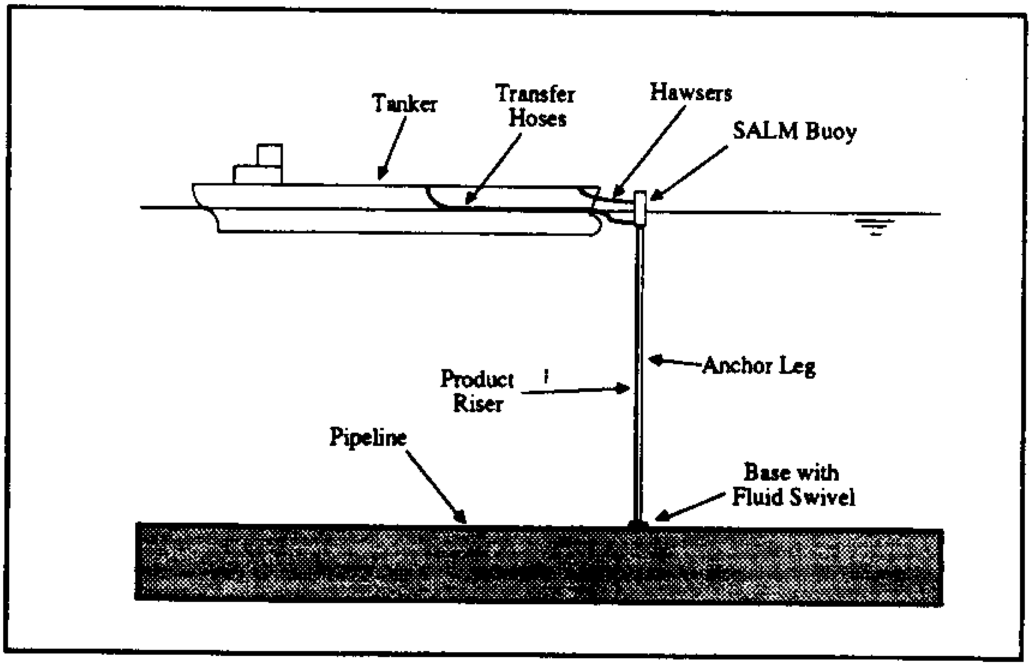

Figure 3.2 : Typical Single Anchor Leg Mooring Schematic

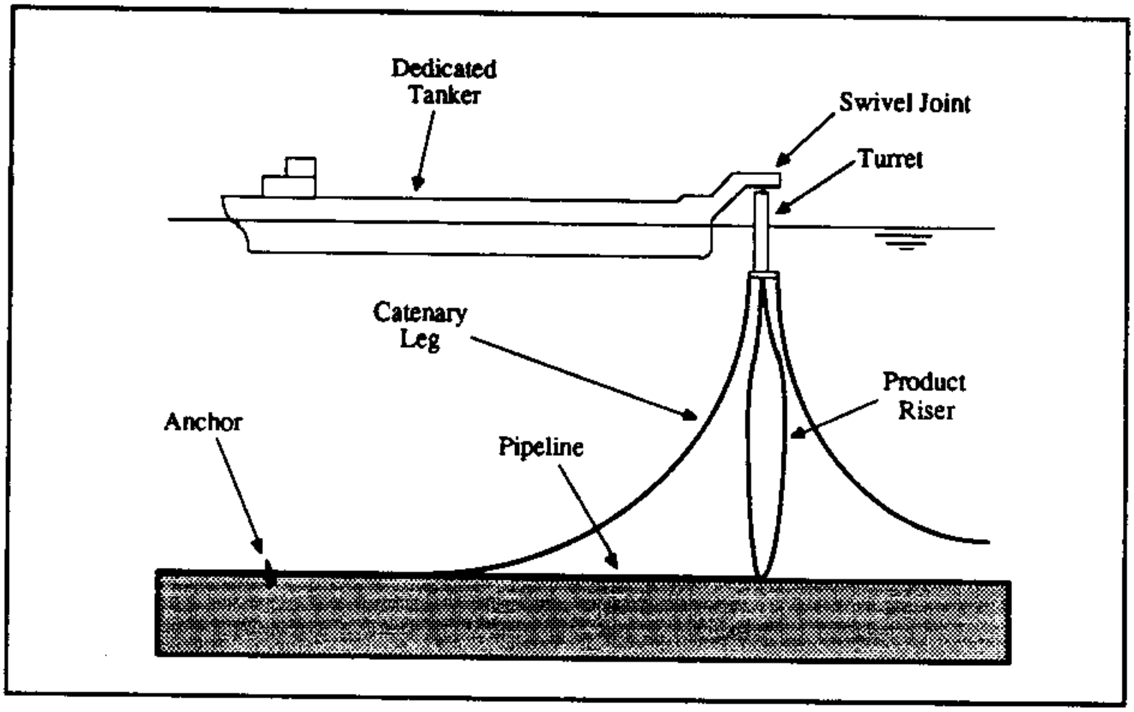

Figure 3.3 : Typical Turret Mooring Schematic

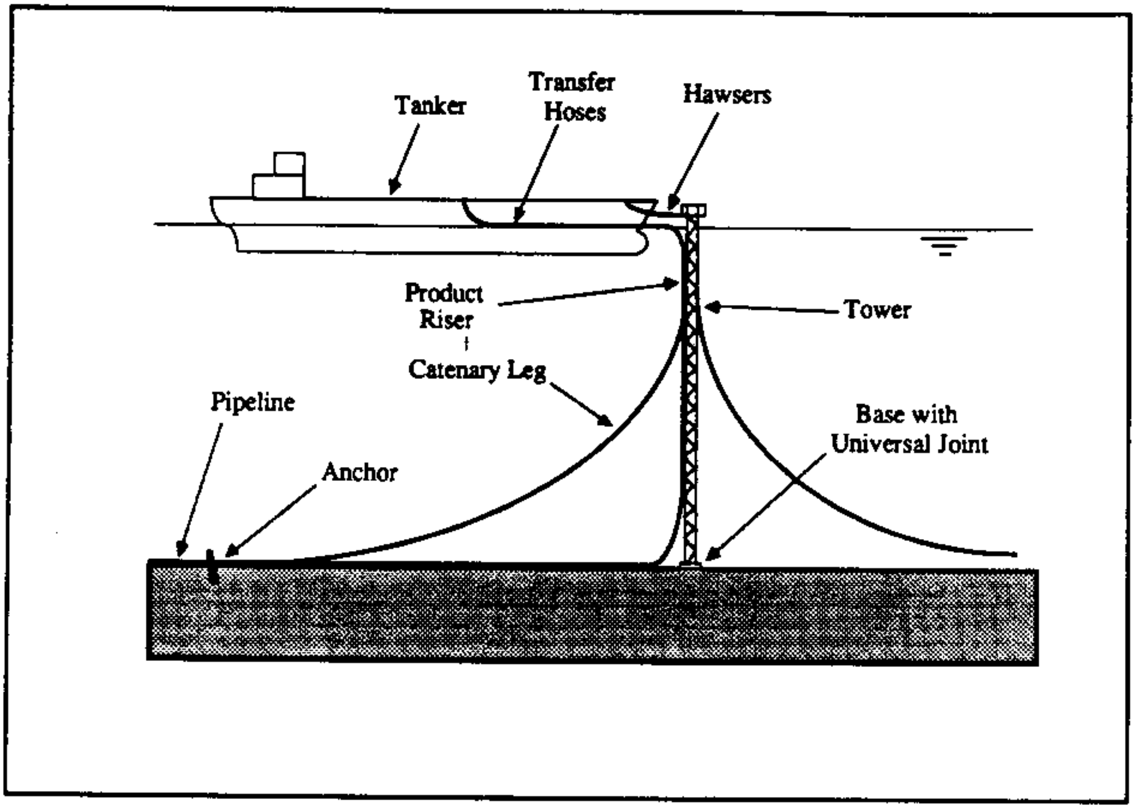

Figure 3.4 : Typical Tower Mooring Schematic

There is an even greater diversity of systems once the nature of major components is considered. The attachment between SPMS and tanker can be made by hawser, soft yoke or hard yoke (Figure 3.5). A SALM system can have either a flexible riser or a rigid riser, and the rigid riser may be articulated. The anchor legs of a CALM system can be made of chain, wire rope, or a combination of the two, with or without spring buoys. The CALM can use either drag-embedment anchors or pile anchors. Turret moorings can be internal or external to the moored vessel. Facilities can employ a permanent, dedicated tanker.

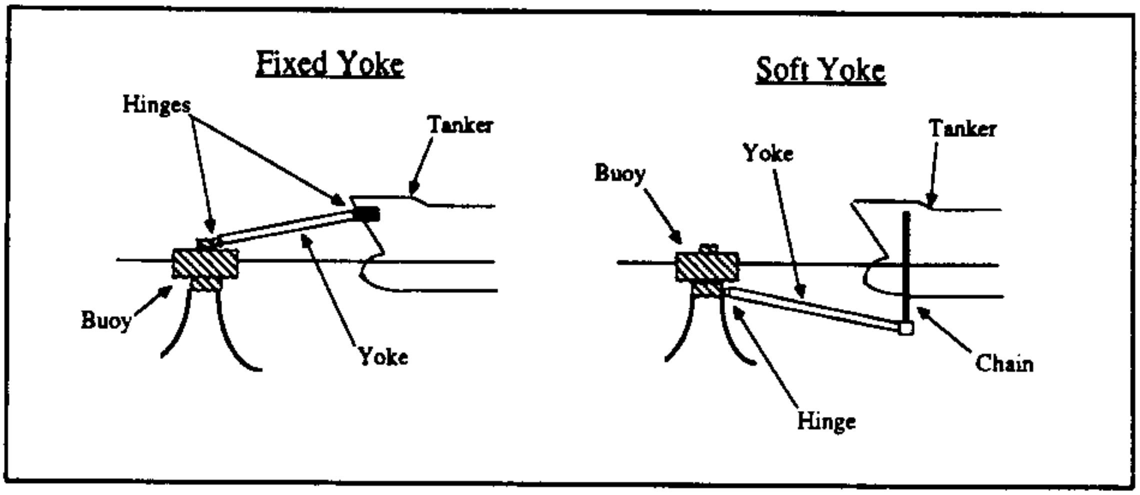

Figure 3.5 : SPMS Connection Type

Most of these decisions do not need to be made until the detailed design phase of the project. However, the type of systems to be examined and the nature of the connection from the SPMS to the tanker are decisions which must be made initially. The requirements already imposed upon this project limit the choices available for system configuration. Of the systems mentioned, towers are not suitable for unprotected waters or use in deep water depths. Turret moorings require either significant vessel modification or a permanently moored tanker. A permanently moored tanker was considered too costly to pursue, while vessel modification was prohibited in the project definition. Therefore, towers and turrets were discounted as inappropriate for this project.

The connection type was also decided based upon project requirements. While a hawser system is the simplest form of connection, it leaves motions of the tanker and buoy completely uncoupled. This is a drawback, as it can be a liability in withstanding harsh environments. This problem can be ameliorated by the use of a rigid yoke, ensuring that the tanker and buoy will have strongly coupled motions, or a soft yoke, causing some degree of coupling (Figure 3.5). However, use of either type of yoke requires vessel modification, and is therefore inappropriate for this project.

Therefore, due to the restrictions on vessel modification and the specified water depth, only the following systems remain as viable possibilities for this project : CALM with hawser connection and SALM with hawser connection. The CALM is the oldest and most common type of SPMS (Appendix 1), is relatively simple, and can be considered a baseline SPMS case. SALM systems are also well-proven, but have not been employed in this water depth to date.

The specific nature of the systems, such as the components of the CALM anchor legs, as well as the number of anchor legs and their layout, the type of anchor, and the type of anchor leg for the SALM system, are discussed in later sections.

3.3 Applicable Requirements

An initial criteria for this project was the requirement that both facilities meet all relevant rules and guidelines governing safety. In this project, the primary guidelines are the ABS factors of safety on mooring lines, anchors and fatigue, and the API "watch circle" guideline governing maximum buoy offset based on product riser type [Jones, 1992; API, 1991].

A factor of safety (F.S.) of 2.0 is required by ABS on mooring lines for floating production systems examined by quasi-static analysis in the intact condition [Jones, 1992]. The factor of safety is defined as the ratio of the capacity to the 100-year load, as calculated by either quasi-static or dynamic analysis. This factor of safety drops to 1.6 for the damaged condition, which refers to one mooring line broken. These and all other applicable ABS Factors of Safety are given in Table 3.1 [Jones, 1992]. Appendix 12 enumerates SPMS that have been classified by the ABS criteria.

Mooring Component / Method of Analysis	Holding Power	F.S. : Intact Condition	F.S.: Damaged Condition
Mooring Lines			
Quasi-static	Tension	2.0	1.6
Dynamic	Tension	1.67	1.33
Foundation			
Anchors			
Quasi-static	Tension	2.0	1.5
Dynamic	Tension	1.5	1.1
Piles			
Quasi-static	Vertical Load	2.0	1.5
	Horizontal Load	1.5	1.3
Dynamic	Vertical Load	1.5	1.25
	Horizontal Load	1.5	1.1
Fatigue			
Quasi-static	Tension	3.0	NA
Dynamic	Tension	3.0	NA

Table 3.1 : Applicable ABS Factor of Safety Requirements

As Table 3.1 shows, factors of safety for dynamic analysis are lower than those for quasi-static. The methods of analysis employed in some parts of this project (line tensions and anchor loads for the CALM system) are considered dynamic, while the remainder of the analyses are considered quasi-static.

The watch circle specified by API states that the maximum horizontal buoy offset from calm water position under the maximum design conditions (taken as the 100-year storm in this project) for systems employing flexible production risers in deep water (2000 feet to 3000 feet) must not exceed 15% of the water depth. For shallow water (below 300 feet) the criteria is 15% to 25% offset [API, 1991]. In this case, "flexible product riser" refers to any hose or pipe falling from a buoy in a catenary shape or attached to a vertical leg system such as a SALM. Therefore, a maximum offset of 15% of water depth (150 feet in this project) will be used as a design guideline.

Limits on operational sea states are another requirement that will be placed on these facilities. Requirements on operational sea states for the facility will be set by the Facility Manager, in conjunction with the Coast Guard. Establishing these operational constraints is necessary because both systems are disconnectable, and require disconnection in order to be adequately resilient to severe storm conditions. In operation, the tanker captain and the facility pilot must decide when to stop cargo transfer and disconnect from the SPMS due to adverse or expected adverse environmental conditions. Details of operation and disconnection are covered in Section 3.7.

3.4 Catenary Anchor Leg Mooring

A catenary anchor leg mooring (CALM) system consists of a set of anchored catenary legs arranged in a radial pattern around a large buoy, with some type of flow line from the sea floor to the buoy for transporting liquids (Figure 3.1). This is the most common type of SPMS (Appendix 1). A CALM system derives its restoring force to offset from the tension in the anchor legs due to the weight of the legs and an initial pretension [Ma, 1994].

The disadvantages of these systems are : disconnection requires substantial amounts of time (except for emergency disconnection) while weather may be deteriorating; operation is limited by the sea-keeping ability of the vessels assisting in line recovery; and tankers and other vessels can come into contact with the catenary legs, causing damage to the legs. A problem which this system shares with all other systems not involving dedicated vessels is the presence of floating hoses on the water surface. Two sections of approximately 1000 foot long hose will be floating on the surface when the facility is not in operation. These hoses are vulnerable to damage from passing vessels. This is why it is necessary to establish zones for the facility that are free of most maritime traffic and are constantly monitored for stray vessels (see Section 3.7, Operations, and [LOOP, 1992]).

The final design of the CALM for this facility is illustrated in Figure 3.6. This design is the result of iteration between the analytical models of Chapter 4 and the reliability and feasibility analysis of Chapters 5 and 6. The two main components of this system are the buoy and the anchor legs. The buoy is

60' in diameter, 25' in depth and weighs 271 LT. There are 8 anchor legs, arranged in a 45 degree spread. Each leg has three components : an upper chain section, a wire rope section and a lower chain section. The upper section is made of chain for tensioning and wear purposes, while the lower section is chain for bottom-abrasion purposes. The lower section also adds to the system holding power. Wire rope is used in the supported section of the leg because it gives a higher restoring force for a given pretension, due to its lower weight when compared with chain [API, 1991]. The other components of the CALM system are described in Section 3.6.

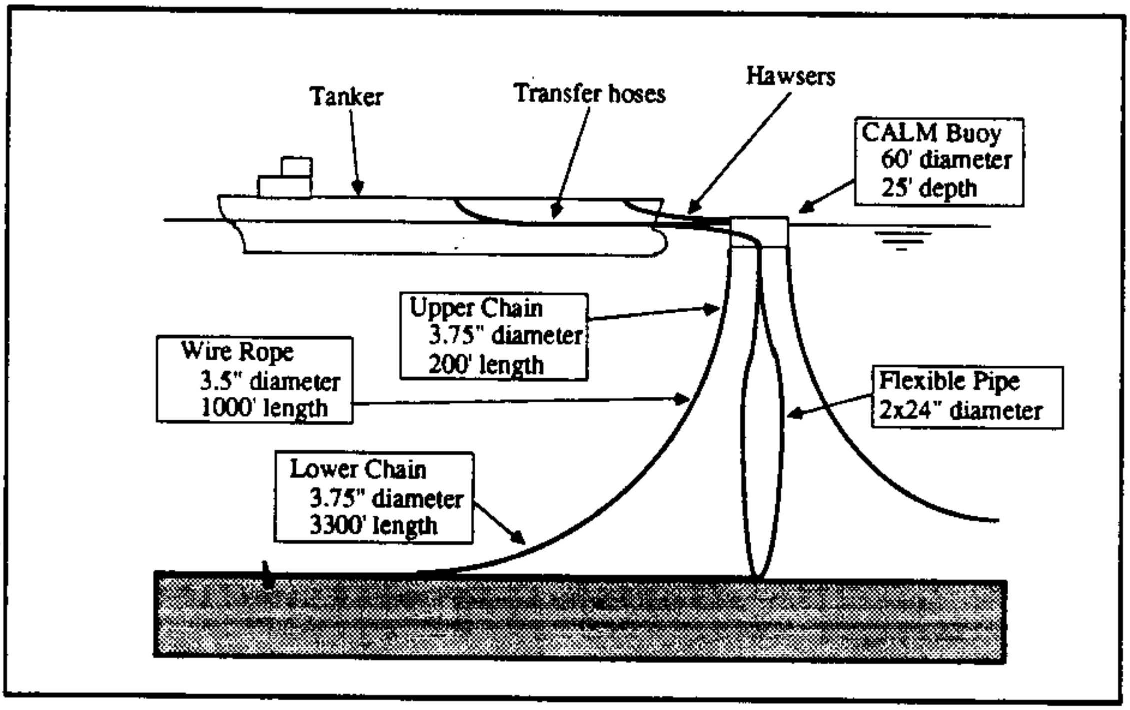

Figure 3.6 : Final CALM Design

3.5 Single Anchor Leg Mooring

A single anchor leg mooring (SALM) system differs from a CALM in that it has only one anchor leg, which is vertical and highly tensioned. A SALM derives its restoring force from this single tensioned leg by the horizontal component of the leg tension when angularly displaced, as well as the added buoyancy from the buoy resulting from horizontal displacement. A simple description of the physics of the system would be to describe it as an inverted pendulum (see Chapter 4, Figure 4.1). A SALM consists of a vertical buoyant riser, a foundation, a pretensioned leg from the sea floor to the riser, and a flow line from the sea floor to the surface. A SALM has the same connection possibilities as a CALM system, which, in this project, means that only hawser connections are under consideration. The foundation is typically of the pile anchor type in deep water depths.

There is some variation in SALM designs in the nature of the tensioned leg employed : chains, wire rope, tubular risers and articulated risers have all been used, along with various combinations of these elements. In this project, wire rope was initially investigated as the anchor leg, but loadings and resulting tensions required switching to an articulated tubular riser.

A SALM has the advantages over a CALM of being more forgiving of collisions, due to the nature of its restoring force, and has a lower likelihood of contact and entanglement problems as the leg is located directly beneath the buoy.

A SALM system has many drawbacks, however. They are more complicated and expensive than a comparable CALM system. They have not yet been proven in this water depth. Maintenance can be a problem, as a SALM fluid swivel is considered to be a high-maintenance item, and is usually located at the sea floor. And, like the CALM, the floating hoses on the surface are vulnerable to damage.

The final SALM design for this project is illustrated in Figure 3.7. As with the CALM, this design is the result of iteration between the analytical models of Chapter 4 and the reliability and feasibility analysis of Chapters 5 and 6. The SALM buoy is 15' in diameter, 70' in depth and weighs 47.4 LT. The tubular riser is divided into three sections. The sections are, from top to bottom, 300', 350' and 320' in length. All four are four feet in outer diameter. The wall thickness varies by section due to the differences in hydrostatic pressures. The uppermost section has 0.5" thick walls, the middle section has 0.75" thick walls and the lower section has 1.0" thick walls. In this design, the fluid swivel is located in the bottom of the buoy, which makes it easily accessible. The articulated leg is divided into three sections, each of which is slightly buoyant prior to installation and made negatively buoyant during installation. The transfer hoses connect to the bottom of the SALM buoy.

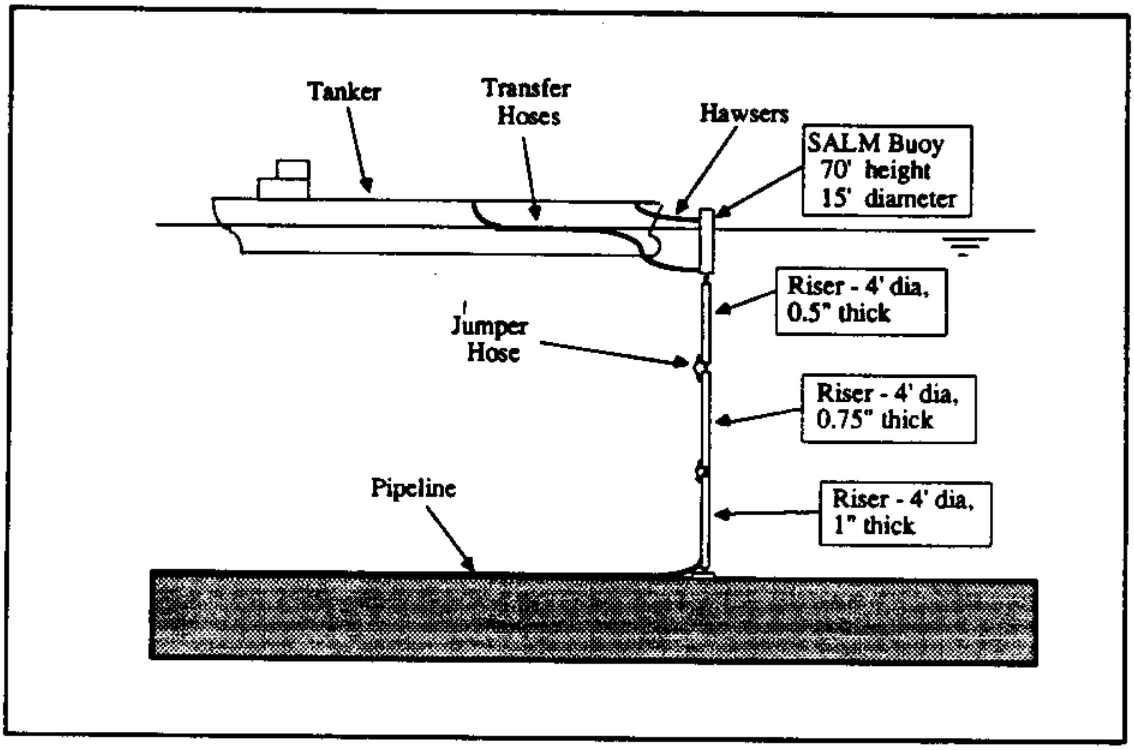

Figure 3.7 : Final SALM Design

3.6 Supporting Components and Systems

The elements of each facility under consideration in this project are : the SPMS, including buoy, anchor legs and anchors or anchor piles; the crude oil tanker discharging cargo to the facility; the pair of hawsers to hold the tanker in position while it is using the facility; two tending vessels to assist the tanker in the use of the facility; two transfer hoses for the transfer of crude oil from the tanker to the product riser(s); the product riser(s) to the sea floor; and the pipeline itself, running from the sea floor to the shore-side facility. It should be noted that some form of pumping stations will be required, but these are considered to be outside the scope of this project.

3.6.1 Tankers

The San Diego class of crude oil tanker was examined in this study, as this class is considered typical of the Valdez, Alaska to southern California trade. The particulars of this tanker class can be found in Table 3.2.

L. B. P. (feet)	Beam (feet)	Draft (feet)	Lightship (LT)	Full Load (LT)
915	166	59.3	30,000	188,500

Table 3.2 : San Diego Class Tanker Particulars

A typical rate of discharge for this size of tanker is 80,000 to 100,000 barrels per hour. This gives a time for discharge of approximately 17 hours for an entire cargo load of crude oil.

3.6.2 Product Risers and Pipeline

Product risers -- the flow line(s) used to transfer crude oil from the moored tanker to the ocean floor pipeline -- can be of three types : hoses, rigid pipe or flexible pipe. Hose will be used for the SALM system, as the product riser is attached to the anchor leg and need not support itself. Flexible pipe will be used for the CALM system. The flexible pipe will be free to hang in a catenary curve from the buoy to the sea floor.

Flexible pipe is preferred over rigid pipe because flexible pipe allows for larger relative motions and does not require heave compensation equipment. Flexible pipe consists of seven or more separate layers of material. These layers may be bonded or unbonded, although unbonded pipes are becoming the standard. The layers are typically (from inside out) : a steel carcass, a plastic sheet, a layer of wound steel wire, a flat steel carcass, an anti-friction plastic sheet, armor layers and an external plastic sheet. A typical value for minimum radius of curvature of flexible pipe is ten times pipe outer diameter [Sødahl, 1991].

Flexible pipe is well-proven in offshore applications. It has been used in water depths up to 850 meters. Over 2500 kilometers total of flexible pipe have been installed to date, with approximately half of that total presently over ten years old [Coutarel, 1992].

The design of the pipeline necessary for these facilities was considered to be outside the scope of this study. However, some important points concerning pipeline design for offshore southern California were found, and these are summarized here to give some feel for the difficulties involved in pipeline design.

Laying and servicing pipeline in 1,000 feet of water is within the reach of today's technology. However, the equipment required is not readily available on the West Coast, and would probably need to be delivered from the Gulf of Mexico, the North Sea, or Brazil. This would have a substantial impact on the installation and maintenance costs of the pipeline. Of the environmental conditions present at the locations examined in this study, only one significantly affects the design of sub-sea pipeline. This is the seismic activity of the southern California region [California Coastal Commission, 1978].

Seismic events can cause three possible actions : soil liquefaction, elastic ground waves, and inelastic, permanent ground movement. The issue of soil liquefaction has already been mentioned. Elastic ground waves typically have peak-to-peak lengths of several miles, and amplitudes of inches or fractions of inches. These waves will not have a significant effect on ocean floor pipeline. Inelastic, permanent ground movement occurs along faults during seismic events, and may be either horizontal or vertical, with rupture regions up to several hundred feet in length. These ruptures are a major source of concern in pipeline design. Locating pipelines clear of faults is the best design solution, but this is often not feasible, as faults in deep water are difficult to locate. When it is known that a section of pipeline must cross a fault, the pipeline may be reinforced at this section or lifted off the ocean floor by bents. If the latter course of action is taken, the area must be prohibited to commercial fishing and any drag-type operations [California Coastal Commission, 1978].

Federal regulations specify that offshore pipelines for the transfer of liquids must be buried. Burial eliminates the possibility of damage from anchors and other ocean floor equipment. However, burial is very expensive, especially for large diameter pipelines such as those considered in this study. Of course, pipelines should not be buried in regions where they cross known faults. Burial can also be counter-productive in areas where liquefaction is likely [California Coastal Commission, 1978].

3.6.3 Tending Vessels and Connection Equipment

The following information on operations is based upon recommendations from Captain A. F. Fantauzzi of Chevron Shipping, the LOOP Operations Manual [LOOP, 1992] and interviews conducted at LOOP during this study.

Two vessels will be required for normal operations. One of these vessels will handle the hawsers during connection while the other retrieves the hoses. The primary mooring vessel must be sufficiently large and powerful to assist the tanker in adverse sea conditions. This vessel will be a standby/towing vessel of 60 to 80 meters length. It should be capable of operating in all weather conditions under which operation of the facility is to be conducted, with an added margin for emergencies. It will have hose handling capability of 10 meters by 22 meters with deck containment and drainage for crude oil. Wooden clad will be provided for servicing floating hoses. It must be highly maneuverable, with twin-ducted propellers, twin rudders and transverse thrust units. It should be equipped with two towing wires of approximate strength to the bollard pull, two towing winches (or a dual winch) and all necessary wire pennants and ancillary towing equipment. The required bollard pull will be based on the vessel being able to assist the tanker in the following environmental conditions : 35 knot wind, 1 knot adverse current and 3.5 meter significant wave height. This should give a required bollard pull of at least 60 tonnes. The vessel should also have fire-fighting capability. This vessel would be similar to the **LOOP Responder**, a 155 foot tractor tug with twin 7,300 hp engines, employing Voith Schneider propulsion.

The secondary mooring vessel is a line handling vessel which is smaller in size and does not require the same bollard pull capacity or sea-keeping capability. This vessel will pass the hawser messenger lines to the tanker in connection. This vessel will be similar to the **LOOP Line** and **LOOP Loader**. These vessels are launches of 85 foot length, with twin 1,200 hp engines.

Two hawsers will be used to connect the tanker to the SPMS buoy. The use of two hawsers for safety through redundancy is considered standard. The hawsers for use with both facilities examined in this project will be 200 foot long, 21 inch diameter nylon ropes with chafe chain attachments at both ends.

3.7 Operation

Figure 3.8 is a schematic of standard operational procedure with the two vessels assisting the tanker. It should be noted that a facility of this nature will require some type of vessel traffic control [LOOP, 1992]. This is considered to be outside the scope of this project, however.

A tanker using the facility will be guided to the SPMS by the vessel traffic controller (VTC) of the facility, and will be escorted by the primary mooring vessel, to insure against possible damage resulting from a loss of power by the tanker and subsequent drifting in the area of the facility. Once the tanker reaches the facility, the primary mooring vessel will be responsible for keeping the floating hoses clear of the tanker, while the secondary mooring vessel passes the hawser messenger lines to the tanker, connecting the tanker to the SPM buoy. The primary vessel then assists in connection with the floating hoses to the tanker manifold. Discharge can begin once the hoses are attached. The primary vessel maintains a stern tow on the tanker during operations to avoid sudden swings by the tanker which can result in very high transient loadings on the hawsers. Disconnection is handled in a similar fashion, removing the hoses from the manifold, lowering them into the water and then disconnecting the hawser lines from the tanker. Total time for connection, discharge and disconnection for both facilities is estimated to be 19 hours for San Diego class tankers.

Disconnection states must be determined for both systems. Disconnection will be carried out to avoid sea states which result in excessive loadings on the system for the attached condition. There will also be a margin on this disconnection sea state, to allow for worsening of weather during disconnection. Normal disconnection is estimated to take approximately one hour, including disconnection of the hoses and lowering the hoses into the water, but emergency disconnection should take no more than five minutes. This emergency disconnection involves the use of cargo pump emergency trips, and is not recommended for non-emergency use. Normally 20 to 30 minutes notice is recommended before hose disconnection is performed.

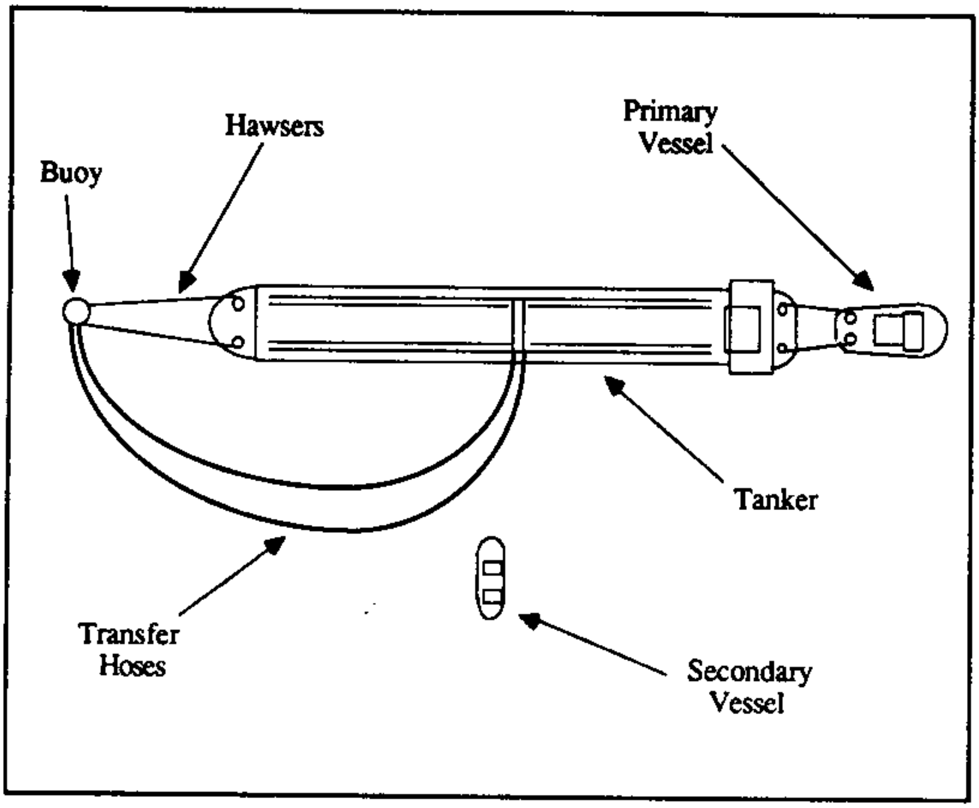

Figure 3.8 : Schematic of Operating Procedure

The determination of disconnection while in operation will be made by the captain of the tanker in conjunction with the pilot/facility manager. General guidelines for disconnection will be set by the facility in conjunction with the Coast Guard, as discussed in Section 3.3.

Chapter 4

Analytical Models

4.1 Introduction

The goal of this chapter is the examination of the effect of the environment on the proposed facilities in terms of line tensions, anchor/pile loadings and fatigue damage. This is done by first modeling the loads in the systems caused by the environmental components and then modeling the response of each facility to these loads. The environmental effects have been separated into four groups : steady forces, oscillating motions, seismic motions and fatigue. Which category each environmental component contributes to will be discussed in the following sections. The analytical models of each facility are also discussed, including line tensions and anchor loadings.

4.2 Steady Environmental Forces

Three environmental components act as relatively steady forces. These are : wind force, current force and mean wave drift force. Each is described in detail in the following sections. These forces are combined and applied to the facility to produce a steady offset, to which oscillatory offsets are added.

4.2.1 Wind

The effects of wind on the SPMS and other facility components have been evaluated by the conventional drag equation [Simiu, 1978]. Each above-water facility component (buoy, tanker hull and tanker superstructure) has been treated separately, with its own wind velocity based on centered elevation. Wind velocities were given in Chapter 2 for a 10 meter elevation above still water. These velocities must be adjusted to the component centered elevation velocity by Equation 4.1 for each component [Simiu, 1978].

$$V_Z = V_{10}\left(\frac{Z}{10m}\right)^{0.125} \tag{4.1}$$

This velocity is then modified by gust duration as in Equation 4.2 [Bea, 1993]. The velocities given in Chapter 4 are for a one-minute duration gust. It was decided that a three minute gust duration is appropriate for calculating steady force, due to the period of low frequency motions, following the example of Hunter, et al, for evaluating wind loadings on moorings and vessels [Hunter, 1993].

$$V_t = V_{1min}\left[1 + \frac{1}{2}ln\left(\frac{1min}{t}\right)\left(0.00535 + 0.00042V_{1min}\right)^{1/2}\right] \tag{4.2}$$

The steady wind force is then calculated from Equation 4.3 with this adjusted wind velocity.

$$F_{Wind} = \frac{1}{2}\rho_{Air}C_S V_Z\left|V_Z\right|A \tag{4.3}$$

The wind shape coefficient is considered typical of marine systems with relatively solid shapes [Bea, 1993]. The total steady wind force can be found in Table 4.1, while the calculations are given in Appendix 4.

4.2.2 Mean Wave Drift

The effect of waves on the facility in question have been separated into three components : first order wave motions (wave frequency motions), second order wave motions (low frequency motions) and a mean wave drift force [API, 1987]. While model tests would be a superior measure, this approach is considered to be an adequate approximation. The mean wave drift force is considered to be a steady force component, while the first and second order motions are considered oscillating motions.

Mean wave drift force was calculated based on Equation 4.4 [Le Tirant, 1990] for the tanker in the head-seas condition. It can be seen from the equation that wave drift is roughly proportional to the square of the wave amplitude, and for a constant amplitude, the mean wave drift increases as wave period decreases.

$$F_{Bow,\,drift} = 0.13\ C_{Drift}B_B{}^2LH_S^2 \tag{4.4}$$

The average drift coefficient for tankers is 0.05 [Le Tirant, 1990]. Significant wave height is determined by Equation 2.1. For the buoy and the riser, the mean wave drift force is calculated by Equation 4.5 [Le Tirant, 1990]. The drift coefficient is taken as 1175 Ns^2m^{-4}.

$$F_{Mean\ drift} = C_{Df} D_{Buoy}^{2} \left(\frac{H_S}{T_S} \right)^2 \qquad (4.5)$$

The resulting mean wave drift force can be found in Table 4.1, while the calculations are given in Appendix 4.

4.2.3 Current

The current forces have been evaluated by the drag equation for the buoys and risers [Bea, 1993] and by the API guidelines for the tanker [API, 1991] with depth effects linearized, as described in Section 2.2.3. Equation 4.6 gives the steady current force on the buoys and the risers.

$$F_{Current,\ buoy} = \frac{1}{2} \rho_{SW} C_D V_C |V_C| A \qquad (4.6)$$

The drag coefficient was taken as 1.0 for the buoys and 0.9 for the risers [Bea, 1993]. The steady current force on a tanker for the head-seas condition is given by Equation 4.7 [API, 1991].

$$F_{Current,\ Ship} = 0.016\ S V_C^2 \qquad (4.7)$$

The wetted surface was calculated by Equation 4.8 [Lewis, 1988].

$$S = C_{WS} \left(\Delta_{Vol} L \right)^{1/2} \qquad (4.8)$$

The wetted surface coefficient was taken as 2.7, a typical value for tankers of the San Diego class size [Lewis, 1988]. The current force can be found in Table 4.1, while the calculations are given in Appendix 4.

System Component	Wind Force (Long Tons)	Mean Wave Drift Force (Long Tons)	Current Force (Long Tons)
SALM buoy	0.60	0.33	1.18
CALM buoy	0.76	5.36	1.65
Tanker, lightship, superstructure	12.25	—	—
Tanker, full load, superstructure	11.53	—	—
Tanker hull, lightship	11.82	9.12	0.86
Tanker hull, full load	4.37	9.12	2.16
Flexible Pipe	—	0.01	1.24
Hoses	—	0.04	2.06

Table 4.1 : Steady Environmental Forces, Two-Year Return Period Conditions

4.3 Oscillating Environmental Motions

Two of the environmental components can be treated as oscillating components. These are first order (wave frequency) motions and second order (low frequency) motions, both due to wave action. For the connected condition, the tanker was considered to generate the governing motion, and buoy motions were ignored. The motions were combined by adding the maximum wave frequency motions to the significant low frequency motions [API, 1987].

4.3.1 First Order Wave Motions

Wave frequency motions have been determined by the use of a ship motions program, SEAWAY [Journée, 1992]. SEAWAY is a PC-based ship motions program using ordinary and modified strip theory method. It calculates wave-induced loads and motions with six degrees of freedom. SEAWAY can simulate moorings as well, by adding up to six linear springs to the model.

SEAWAY was used to model the San Diego class tanker and both the CALM and SALM buoys. Springs were then added to these models to simulate the mooring restoring force. Although the mooring restoring force is not perfectly linear, for small offsets this is a relatively good approximation. These models were tested against the given wave events for various return periods. The details of this program and the results of this analysis can be found in Appendix 5. The offsets due to first order motions are given in Table 4.2.

4.3.2 Second Order Wave Motions

Low frequency motions have been determined by use of the API curves [API, 1987]. These curves were generated for drill ships in the 400 foot to 540 foot range, but with the given correction factors for vessels outside this length range, these curves should be an adequate approximation for tankers. A separate set of curves for semisubmersible hulls was used for low frequency motions of the SPMS buoys. The calculations for these motions can be found in Appendix 5. The offsets due to second order motions are given in Table 4.2. Total motions were determined by adding the maximum wave frequency motions to the root mean square low frequency motions.

	Wave Frequency Motions (feet)	Low Frequency Motions (feet)
Tanker, full load	2.4	2.9
Tanker, lightship	2.7	2.9
CALM buoy	6.2	11.4
SALM buoy	7.2	8.6

Table 4.2 : Oscillating Motions, Two-Year Return Period Conditions

4.4 Seismic Activity

Seismic motions were examined for the SALM system only. This is because seismic motions will effect only systems with significant vertical stiffness. The SALM must have a high vertical stiffness due to its method of providing restoring force, but the CALM system does not require a high vertical stiffness.

The SALM system was modeled as a spring. PCNSPEC [Mahin, 1983], an earthquake analysis program, was used to determine peak motions. PCNSPEC is an inelastic response program for viscously damped single-degree-of-freedom systems. The SALM system was tested against the El Centro earthquake, scaled to have the peak ground accelerations given in Table 2.1 for the various return period events. The resulting offsets are given in Table 4.3. As the values in the table indicate, seismic motions are not large, especially considering the anchor leg's 1000 foot length.

The input and output of PCNSPEC are described more fully in Appendix 6.

Return Period	Maximum Relative Vertical Offset (feet)
2-year	0.0123
10-year	0.0617
100-year	0.2217
1000-year	0.4922

Table 4.3 : SALM Vertical Seismic Offsets

4.5 Fatigue

Fatigue is defined as the degradation of component characteristics (such as strength or stiffness) due to cyclic straining and stressing. In this application, the cycling is due to wave action. Cycling can also result from operations (cargo pumping, operation of other equipment), construction (installation, transport to installation, launching) or other environmental components (thermal changes, wind, current, earthquakes) [Bea, 1990]. However, wave cycling is considered to be the dominant source of cyclic loading in this project.

Fatigue effects are calculated for the chain, wire rope and connections in the CALM system, and for the riser and articulations in the SALM system. These components are considered to be the most likely components to fail due to fatigue.

The calculation of fatigue "load" is done in a different manner than for other environmental loads. Since fatigue failure is a result of cumulative damage over a (usually) long period of time, it is more appropriate to determine a mean fatigue life. This mean fatigue life is the expected life of the component or structure before failure due to cyclic fatigue occurs. The mean fatigue life is calculated by Equation 4.9 [Bea, 1990].

$$T_{fL} = \frac{\Delta K}{B^{m}\Omega} \tag{4.9}$$

The accumulated fatigue damage parameter is set equal to 1.0 for fatigue failure. The stress range model error parameter is taken as 0.80, a standard value for the marine environment [Bea, 1990]. The values for the negative slope and the log life intercept are taken from the S-N curve for a particular component [API, 1989; API, 1991; Bea, 1990]. These values are given in Table 4.4.

Component	m	K (cycles)
Wire Rope	4.09	1.30×10^{10}
Chain	3.36	4.60×10^{9}
Connections	3.74	1.79×10^{10}
Tubular Riser	4.38	1.50×10^{12}
Articulations	3.74	1.79×10^{10}

Table 4.4 : Component Fatigue Characteristics

These values for K are biased, however. This bias is a result of the standard practice of offsetting S-N curves by two standard deviations for design guidelines. This bias is removed by Equation 4.10, which, in effect, adds the two standard deviations back to K.

$$B_K = \frac{\overline{K}_{True}}{\overline{K}_{Nominal}} = \frac{exp\left[ln\left(\overline{K}_{Nominal}\right) + 2\sigma_{lnK}\right]}{\overline{K}_{Nominal}} \tag{4.10}$$

The natural log of the standard deviation of the fatigue life is calculated by Equation 4.11.

$$\sigma_{lnT} = \left[ln(1 + C_\Delta^2)(1 + C_K^2)(1 + C_B^2)^{m^2}\right]^{1/2} \tag{4.11}$$

where :

$$C_\Delta = 0.3$$
$$C_K = 0.73$$
$$C_B = 0.5$$

The values given for the various coefficients of variation are considered typical for marine systems [Bea, 1990].

The unbiased values for K can be found in Table 4.5. The stress range parameter is calculated by Equation 4.12.

$$\Omega = \lambda(m) f_0 S_m^m \left[lnN_T\right]^{-m/\varepsilon} \Gamma\left[\frac{m}{\varepsilon} + 1\right] \tag{4.12}$$

The rainflow correction and epsilon are both taken as 1.0, considered a typical value for both variables for marine systems [Bea, 1990]. The design period was taken as 100 years, and the number of cycles was based on this length of time and an average wave period of 13 seconds. The average frequency of the stresses was taken as the inverse of the period of the waves. The gamma function has been approximated by Sterling's asymptotic formula, Equation 4.13 [Froberg, 1985].

$$\Gamma(z)=\left(\frac{z}{e}\right)^{z}\sqrt{\frac{2\pi}{z}}\left[1+\frac{1}{12z}+\frac{1}{288z^{2}}-\ldots\right] \tag{4.13}$$

The fatigue design stress range is calculated in Equation 4.14.

$$S_{fD}=\left[\frac{KH_{fD}^{\alpha m}}{T_{SF}Y_{0}}\right]^{1/m} \tag{4.14}$$

where :

$$T_{SF}=F_{SF}T_{DP}$$

$$Y_{0}=\frac{N_{T}}{T_{DP}}H_{fD}\left(lnN_{T}\right)^{-m\alpha/\varepsilon}\Gamma\left(1+\frac{\alpha m}{\varepsilon}\right)$$

The fatigue life safety factor is typically 3.0 for marine systems [Bea, 1990]. This value is related to the nominal design stress range by the stress concentration factor, as given in Equation 4.13. This nominal design stress range is then used as the largest stress value in Equation 4.10.

These relations result in the mean fatigue lives given in Table 4.5. The calculations of these values can be found in Appendix 7.

Component	Unbiased K value	Mean Fatigue Life (years)
Wire Rope	$4.8\text{x}10^{10}$	66,820
Chain	$1.7\text{x}10^{10}$	25,460
Connections	$6.6\text{x}10^{10}$	42,072
Tubular Riser	$5.5\text{x}10^{12}$	98,034
Articulations	$6.6\text{x}10^{10}$	42,072

Table 4.5 : Summary of Mean Fatigue Life

These mean fatigue life values may seem surprisingly large. This question is addressed in Section 5.6.

4.6 CALM Analytical Model

The details of the analytical model of a CALM are not discussed in depth here. The reader is referred to Ma [1994] for a detailed explanation of the model used in this project. After several design iterations, it was decided to use a system pretension of 23.6 LT for the CALM. The line tensions and anchor loads are summarized in Table 4.6 by return period.

	Line Tension (LT)	Anchor Load (LT)
CALM Buoy		
2-year conditions	31.7	15.6
10-year conditions	36.6	19.6
100-year conditions	42.9	25.4
Buoy with Lightship, 2-year conditions	45.5	26.3

Table 4.6 : CALM Line Tensions and Anchor Loads

The holding power of drag-embedment anchors needed to be determined for the CALM system [API, 1991]. The chain section of the anchor leg lying on the sea floor also contributes to the holding power of the system, as described by Equation 4.15.

$$P_C = f_{CO} L_C W_C \tag{4.15}$$

The coefficient of friction between chain and the ocean bottom is taken as 0.7 [API, 1991]. The unit weight of 3.75" chain is 132 pounds per foot. Approximately 2000' of chain will be in contact with the ocean bottom during extreme conditions. This results in a chain holding power of 82.5 LT.

The anchor was then selected based on anchor loads and the given chain holding power. Bruce FFTS anchors of 6.7 LT weight (15 kilopounds) and 192 LT holding power (430 kilopounds) were selected, giving a total anchor leg holding power of 274 LT.

4.7 SALM Analytical Model

A SALM derives its restoring force from the tension in its leg, as described in Section 3.5. This leg may be a chain, wire rope or solid riser. The choice depends on the tension required and the specifics of the application. In this project it was decided that a solid riser would be necessary to support the tension required. Articulations were necessary in the riser due to the water depth of 1000 feet.

There are two components involved in SALM restoring force : the horizontal component of the leg tension and the added buoyancy due to offset which acts to increase leg tension. The design inputs for a

SALM are : buoy size, riser size, number of riser sections, weight of buoy and risers, and the dimensions of the anchor pile. The anchor leg of a SALM is given a pretension so that it will develop an adequate restoring force. In this design, a pretension of 300 LT was decided upon.

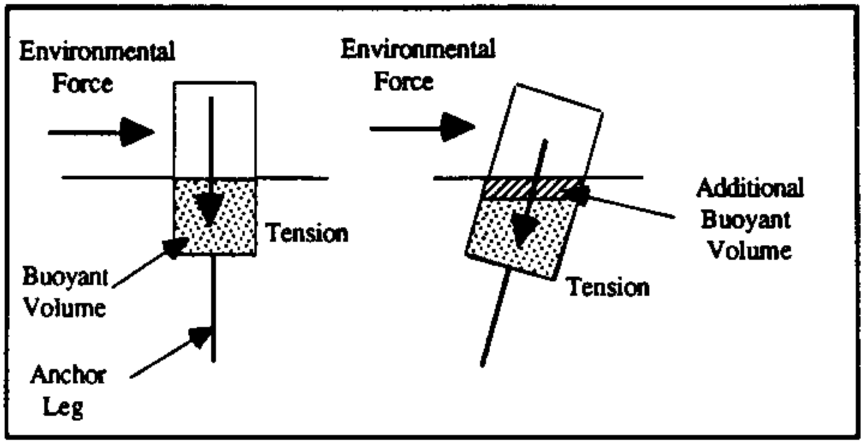

Figure 4.1 : SALM Restoring Force Schematic

With system dimensions, weights and pretension decided, the SALM could be modeled analytically. The horizontal environmental force acting on the system must be offset by the horizontal component of the system tension, which is a function of the system pretension and the added buoyancy due to offset, which are both functions of the angular displacement of the anchor leg. The spreadsheets used for the calculation of this iterative procedure are given in Appendix 9. The line tensions for storms and seismic events are given in Table 4.7.

	Leg Tension, Storm (LT)	Leg Tension, Seismic (LT)
SALM Buoy		
2-year conditions	275	272.8
10-year conditions	278.3	273.8
100-year conditions	284.5	277.3
Buoy with Full-load ship, 2-year conditions	300.5	200.3
Buoy with Lightship, 2-year conditions	311.7	200.3

Table 4.7 : SALM Storm and Seismic Leg Tensions

The determination of anchor pile characteristics were based on the leg tensions, as theses act directly on the anchor. The anchor load is considered to be strictly vertical, due to the small angular displacement values involved (usually under 10 degrees for extreme conditions). It was decided, based upon the reliability analysis described in Chapter 5, to have a target pull-out capacity of 2,000 LT. The ultimate pull-out capacity is given by Equation 4.16 [API, 1989].

$$Q_P = f_{SC} A_S + W_P \tag{4.16}$$

The unit skin friction capacity is determined by Equation 4.17 [API, 1989].

$$f_{SC} = \alpha_P c_{USS} \tag{4.17}$$

The undrained shear strength was determined to be 2.0 kilopounds per foot in section 2.3.7. The dimensionless pile factor is taken as 1.0 [API, 1989].

From these relations, the length of a pile can be estimated. Wall thickness was based upon API criteria for minimum wall thickness, as given in Equation 4.18 [API, 1989].

$$T_{WT} = 0.25 + \frac{D_P}{100} \tag{4.18}$$

With these criteria, a pile was selected of 140' length, 60" diameter and 1" wall thickness. This gives a pull-out load of approximately 2,000 LT.

Chapter 5

Reliability

5.1 Introduction

This chapter examines the determination of the probability of failure for each SPMS facility. Failure is defined as the breakage of one or more legs of the SPMS, insufficient holding power developed by the anchors or anchor pile, major damage to the risers / hoses, or damage to the buoy which would halt operations. The total probability of failure is the sum of the annual chances of these events occurring, as given in Equation 5.1 (neglecting small cross-product terms).

$$P_{f,\,Total} = P_{f,\,Mooring\,Legs} + P_{f,\,Anchors} + P_{f,\,Risers} \tag{5.1}$$

The probability of failure of the facilities under consideration is dependent upon four relatively independent failure hazards. Failure may be due to storm loadings, seismic loadings, cyclic fatigue loadings, or human and organizational error (HOE). The total annual probability of failure is expressed in Equation 5.2 (again neglecting small cross-product terms).

$$P_{f,total} = P_{f,storms} + P_{f,seismic} + P_{f,fatigue} + P_{f,HOE} \tag{5.2}$$

The method of computation of each one of these components is examined in depth in the following sections.

5.2 Component Probability of Failure Calculations

The procedure for calculating probabilities of failure for storm loadings, seismic loadings and cumulative fatigue damage is outlined in this section. The analyses are based on a log normal - log normal relationship between component loadings and component capacities, whether loadings are due to storms, seismic events or fatigue degradation. This type of relationship is considered typical of large marine systems analyzed over a long time period [Bea, 1990]. The mean values of load (line tensions, anchor loadings and fatigue damage) and capacity (line strength, anchor holding power and mean fatigue life) are known, either by calculation (in Chapter 4) or from manufacturer's specifications. Variances of these properties are considered, as well as possible correlation between load and capacity.

The probability of failure for a lognormal system is determined by Equation (5.3).

$$P_f = 1 - \Phi(\beta) \tag{5.3}$$

In some cases, values for the safety index fall outside those tabulated in the standard normal distribution table. In these cases, an approximation due to Abramowitz [Melchers, 1987] is used. This approximation was found to be a superior fit for the values of beta encountered in this project (Appendix 10).

The safety index, β, is defined in Equation 5.4 for components exposed to lognormally distributed loadings due to storms or seismic events. This equation relates the median load to the mean capacity, with the effect of variations and correlations included.

$$\beta = \frac{ln\left(\frac{R_{50}}{S_{50}}\right)}{\sqrt{\sigma_{lnR}^2 + \sigma_{lnS}^2 - 2\,\rho_{RS}\sigma_{lnR}\sigma_{lnS}}} \tag{5.4}$$

The safety index is defined by Equation 5.5 for cyclic fatigue degradation. This fatigue analysis differs from the environmental analysis in that it is based on a time frame instead of a peak loadings frame, as explained in Section 4.5. This means that capacity will be replaced by mean fatigue life and load will be replaced by accumulated fatigue damage, as in Equation 5.5, where mean fatigue life is that calculated in section 4.5.

$$\beta = \frac{ln\left(\frac{T_{fL}}{T_{SL}}\right)}{\sigma_{lnT}} \tag{5.5}$$

The components of both peak load-based and time-based relations are discussed in the following sections.

5.2.1 Load and Capacity

The mean loadings used in the peak load analysis are the 2-year return period loadings determined in Chapter 4 for storms and seismic events, and the mean fatigue life for the seismic analysis. The capacities are the ultimate limit state capacities given by the manufacturer, which are listed in Table 5.1 [Avallone, 1987; Bureau Veritas, 1980].

5.2.2 Variance and Deviation

There are two types of uncertainty in structures analyzed by reliability methods. Type I uncertainties refer to natural or inherent randomness, such as peak environmental conditions. This type of uncertainty cannot be controlled. Type II uncertainties refer to modeling uncertainties. This type of uncertainty includes uncertainties in computations of forces, uncertainties in measurement and uncertainties due to limited data sets. This type of uncertainty is systematic. It is also information sensitive and can be reduced by acquiring additional information, whether the information is research, inspection or quality control / assurance [Bea, 1992].

For distributions with Type I uncertainties, the variance of the distribution can be measured by two parameters. The coefficient of variation is a normalized measure of the variability of a parameter. The standard deviation is a measure of dispersion or variability of a distribution, as is the natural log standard deviation. The relations between these parameters are given in Equations 5.6 and 5.7.

$$V_X = \frac{\sigma_X}{X} \tag{5.6}$$

$$\sigma_{lnX} = \sqrt{ln\left(1 + V_X^2\right)} \tag{5.7}$$

However, these relations require more information than has been generated to this point. Therefore, Equation 5.8 is more suitable for the calculation of Type I uncertainties, as loads for the 2-year and 100-year return periods are known. Equation 5.8 calculates the coefficient of variation from the 2-year return period and the 100-year return period loads.

$$\sigma_{lnX} = \frac{ln\left(X_{99}/X_{50}\right)}{2.33} \tag{5.8}$$

Systems were analyzed for the disconnected case to determine loading variance, as the systems should never be connected for the 100-year condition. This gave the variances listed in Table 5.2 for environmental Type I uncertainty. The values for capacity Type I uncertainty [Yong, 1991; Bea, 1990] are considered typical for marine system components. The anchor / anchor pile variation is based on the soil type [Bea, 1990]. These uncertainties are listed in Table 5.1 It should be noted that the systems were designed so that the connections are the most likely element of each system to fail. This was done because the connections are the easiest component of each system to maintenance and replace. Their failure should also cause the least amount of damage. However, for the SALM system, nearly any failure will be a serious one, as its single load-path allows for no redundancy.

Component	Capacity (LT)	Variance
CALM		
Wire rope	447	0.10
Chain	321	0.10
Connections	100	0.10
Anchors	274	0.40
SALM		
Articulations	600	0.10
Riser	700	0.10
Anchor Pile	2000	0.40

Table 5.1 : Component Reliability Characteristics

Type II uncertainties are more difficult to determine, as they must be based on historical analysis of analytical methods. Therefore, representative values were taken from existing literature for this project. For storm loadings on marine structures, the Type II variation has been estimated as 0.07 to 0.11 [Bea, 1992; Nikolaidis, 1992]. A value of 0.10 was taken for this project. For seismic loadings, literature Type II variation ranged from 0.0 to 0.31 [Bea, 1992; Nikolaidis, 1992]. A value of 0.10 was selected for this project, based on the modeling tool used (PCNSPEC) and the small effect of seismic loadings in line tensions. Type II uncertainties in fatigue analysis are discussed in section 5.6.

System	Leg Loads (Storm)	Leg Loads (Seismic)	Anchor Loads (Storm)
CALM	0.115	—	0.186
SALM	0.015	0.007	0.015

Table 5.2 : Environmental Variance

The Type I and II variances are combined into a single variance by Equation 5.9. This relation is valid for systems which have independence between load and capacity. This independence is discussed in the next section.

$$V_X = \sqrt{V_S^2 + V_R^2 + V_H^2} \tag{5.9}$$

5.2.3 Correlation

The correlation coefficient expresses how strongly two variables are related. A value of 1.0 indicates perfect correlation, while a value of 0.0 indicates complete independence. The correlation coefficient can be negative as well, up to a value of -1.0, which indicates perfect negative correlation. There are three types of correlation which required examination in this project : correlation between load and capacity, correlation between capacities of different components, and correlation between failure modes of different components.

The determination of load to capacity correlation is best carried out by model testing, as it is very difficult to determine analytically. There may be some small positive correlation in these systems due to larger wave heights (higher loads) encountering more structure (higher capacity), but this may be offset by slight changes in environmental directionality. Therefore, it was assumed that there would be no correlation between load and capacity.

The correlation between capacities of different elements is likely to be very high, due to similarities in design and manufacture, and has been taken as 1.0.

5.3 System Probability of Failure Calculations

The system probability of failure is determined by calculating component probabilities of failure from the given relations and reducing the systems into series and parallel elements. The CALM system is composed of eight catenary anchor legs, which are modeled as series-loaded subsystems. These subsystems are combined to form an eight element parallel system. The SALM system is much simpler, being composed of one tensioned leg modeled as a series system.

One new attribute of a system must be considered in the calculation of system reliability. Correlation can exist between system components, due to their manufacture and due to their modes of failure. An estimate of system failure mode correlation based on relative uncertainties attributed to Cornell [Bea, 1990] is used here (Equation 5.10).

$$\rho_{FM} = \frac{V_S^2}{V_R^2 + V_S^2} \tag{5.10}$$

For series elements, the system reliability is calculated by Equation 5.11. This equation is valid for systems with perfect element-to-element correlation. Although this assumption concerning correlation may not be completely true here, it is a good approximation. As has been pointed out elsewhere [Bea, 1990], the probability of failure of a system is well approximated by the probability of failure of the most-likely-to-fail element in the system.

$$P_{f,system} = max(P_{f,element}) \tag{5.11}$$

For parallel elements, the system reliability is calculated by Equation 5.12. This equation is valid for normally distributed identical parallel elements.

$$\beta_S = \beta_E \sqrt{\frac{N}{1+\rho_E(N-1)}} \tag{5.12}$$

It should be noted that failure of one leg is essentially system failure for the CALM system (it has already been defined as failure for the SALM). Failure of one leg of the CALM will halt operation. Therefore, "system failure" for the CALM refers to one leg broken or severely damaged.

5.4 Failure due to Storm Loadings

The probability of failure due to storms must cover two separate cases : the SPMS alone and the SPMS with an attached tanker. Loads in the system will be much higher with a tanker present. The facility will have guidelines governing when a tanker using the facility should disconnect from the SPMS to reduce loads. Therefore, the probability of failure due to storm loadings can be expressed as given in Equation 5.13.

$$P_{f,storms} = \left(P_{f,storms} | disc\right)\left(1 - P_{conn}\right) + \left(P_{f,storms} | conn\right)\left(P_{conn}\right) \tag{5.13}$$

The percent of time in which a tanker is using the facility is an economic decision, affected only slightly by environmental conditions and facility downtime. The downtime of the facility is expected to be very small, according to gathered data. Typical downtime values for systems operating for one year or more range from 0% to 3.2% [Key, 1993]. For this study, three San Diego class tankers will use the facility per week. Given the 17 hour discharge time of this tanker class and the estimated 2 hour connection and disconnection time, the facility will be in use approximately 31% of the time, allowing for a 3% system downtime.

The probability of failure while disconnected is a relatively straightforward calculation, comparing disconnected loadings with capacities, as in Equation 5.4. All data for this calculation have already been determined, and the resulting probability of failure can be found in Table 5.5. Failure while connected is a more difficult calculation, due to the question of what sea states will be encountered before disconnection will occur. Disconnection can be ordered to occur at the appearance of a certain sea state, but the actual occurrence of disconnection depends upon perception of the sea state by the captain and pilot, and weather deterioration which may occur before disconnection can be completed. Therefore, it is necessary to model disconnection as a probability distribution in relation to sea state. The probability of failure while connected can therefore be expressed as in Equation 5.14.

$$P_{f,storms}|conn = \sum_{all\ sea\ states}\left[(P_f|conn, sea\ state)(P_{sea\ state})(P_{conn}|sea\ state)\right] \tag{5.14}$$

The probability of a given sea state being the annual maximum encountered is a function of the annual maximum wave height distribution. The probability of connection in a given sea state is based upon assumed behavior and the uncertainty associated with identifying sea states and weather deterioration. The values for these probabilities are given in Table 5.2. The probability of connection in a given sea state is based on an instruction to disconnect to avoid operation (and connection) during conditions with wind exceeding 32.5 knots or waves exceeding 25.5 feet maximum, or a 13.7 foot significant wave height. The distribution is log normal over the spectrum of sea states. The distribution is based on the mean disconnection state being the 25.5 maximum wave height state, with a 5% chance of being connected at the 29.5 foot maximum wave height state. This distribution has been assumed and should be verified.

P|sea state	Wave Height (feet)	Wind Velocity (knots)	Current Velocity (knots)	Probability of Connection
10	21	26.5	0.8	0.90
10	23.5	30	0.9	0.70
10	25.5	32.5	1.02	0.50
10	27	35.5	1.1	0.25
10	28.5	38	1.18	0.10
10	29.5	40.5	1.28	0.05
10	31	43.5	1.35	0.01
10	32.5	46.5	1.45	0.002
20	37	55	1.7	0.0005

Table 5.3 : Probability of Connection by Sea State

The probability of failure for a given sea state while connected is then calculated based on Equation 5.3, with the mean loading based on the mean wave height, wind speed and current speed for a given sea state, and variance as previously determined. The probabilities of failure are then summed over all sea states to produce a total probability of failure for the SPMS while connected to a tanker. The results of this calculation are given in Table 5.4.

5.4.1 Storm Loadings by Sea State

The loadings due to various sea states are given in Table 5.3. These loadings are based on the same approach used to calculate loadings for the various environmental return periods. The variance on the loadings are those for Type I and Type II uncertainties given earlier in the chapter. The correlation of load and capacity remains equal to 0.0. The probability of failure is also given in Table 5.3. This is the probability of failure for the connected condition and the given sea state being the maximum sea state encountered in a year.

Plsea state	Maximum Wave Height (feet)	CALM Leg Tension (LT)	CALM Anchor Tension (LT)	SALM Leg Tension (LT)	CALM Probability of Failure	SALM Probability of Failure
10	21	32.1	15.4	283.4	$2.4x10^{-13}$	$4.8x10^{-7}$
10	23.5	35.0	17.7	289.3	$3.0x10^{-12}$	$6.3x10^{-7}$
10	25.5	37.7	19.9	297.2	$2.3x10^{-11}$	$7.1x10^{-7}$
10	27	41.1	22.6	301.9	$1.9x10^{-10}$	$1.1x10^{-6}$
10	28.5	44.1	25.1	309.1	$3.5x10^{-9}$	$1.6x10^{-6}$
10	29.5	46.4	27.5	316.5	$4.3x10^{-8}$	$3.5x10^{-6}$
10	31	50.7	30.6	326.2	$7.9x10^{-7}$	$9.4x10^{-6}$
10	32.5	55.8	34.9	337.3	$1.9x10^{-5}$	$2.7x10^{-5}$
20	37	70.1	47.1	373.3	$6.7x10^{-3}$	$4.5x10^{-5}$

Table 5.4 : Storm Loadings and Probability of Failure by Sea State

5.4.2 Reliability for Storm Loadings

System reliability is calculated for each facility based on the component probabilities of failure, as explained earlier. The probabilities of failure are combined with the probabilities of given sea states being encountered and connection during that sea state, as in Equation 5.13. The probabilities of failure are then summed over all sea states, as in Equation 5.14. The resulting values for probability of failure are given in Table 5.5 for the case of storm loadings.

System State	Percent Time	CALM P_f	SALM P_f
Connected	31%	6.7×10^{-7}	2.4×10^{-7}
Disconnected	69%	1.6×10^{-11}	3.4×10^{-7}
TOTAL	100%	2.1×10^{-7}	3.0×10^{-7}

Table 5.5 : Probability of Failure due to Storm Loadings

5.5 Failure due to Seismic Loadings

The probability of failure due to seismic loadings is calculated in the same manner as the storm loadings for the unconnected facility. However, seismic loadings are considered to be significant for the SALM system only, as the CALM system has relatively little vertical stiffness. Seismic loadings were calculated in Section 4.4, while capacities are given in Table 5.1. Variations in load are as given in section 5.2.2. Correlation between load and capacity is again assumed to be equal to 0.0.

It will be noted that the variance on seismic loadings is lower than that of storm loadings, which may seem counter-intuitive. However, seismic loadings on the SALM system are of relatively low magnitude, and tend to be overshadowed by the constant pretension force of the system.

System reliability for seismic loadings is similar to that for storm loadings. Since there is only one load path, the system is a series one. As in other system reliability sections, the system probability of failure of a series system is well approximated by the probability of failure of the most-likely-to-fail component.

The probability of failure of the SALM system due to seismic loadings is given in Table 5.7.

5.6 Failure due to Cyclic Fatigue Loadings

Fatigue reliability is characterized by mean fatigue life (analogous to capacity), service life (analogous to load) and a deviation on the fatigue life, as in Equation 5.5. Mean fatigue life is calculated in section 4.5, while service life is a design decision. The natural log of the standard deviation of the fatigue life is calculated by Equation 4.11.

The resulting natural log standard deviation is found to be 1.53. It should be pointed out that this variance is *very* high in comparison with other variances calculated in this chapter.

The fatigue probabilities of failure, as calculated by Equation 5.5, are given in Table 5.6. It can be seen that the large mean fatigue lives calculated in Section 4.5 are offset by the large variance calculated in equation 5.15, giving probabilities of failure similar to those for other environmental components.

Component	Probability of Failure
CALM	
Chain	2.4×10^{-7}
Wire Rope	5.8×10^{-8}
Connections	1.2×10^{-7}
SALM	
Riser Sections	3.3×10^{-8}
Articulations	1.2×10^{-7}

Table 5.6 : Component Probability of Failure due to Fatigue

These probabilities of failure are for a service life of 20 years. To see the effect of service life on probability of failure, Figure 5.1 is a graph of reliability versus service life for chain, the element most likely to suffer from fatigue degradation.

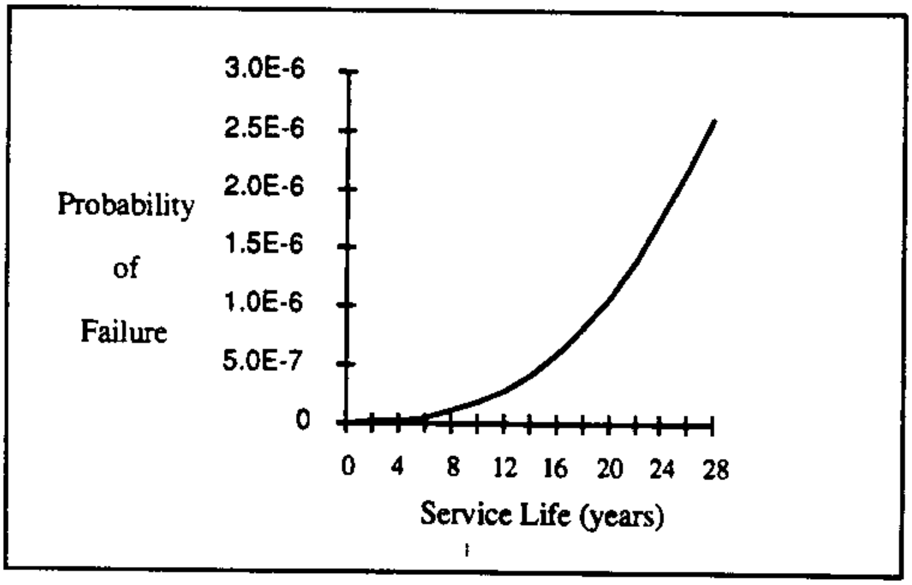

Figure 5.1 : Fatigue Reliability versus Service Life

This figure serves to illustrate the concept of preventative maintenance. By periodically replacing the elements of a system which are likely to suffer fatigue damage, the probability of failure is lowered.

The system effect of fatigue reliability is similar to that for other types of system reliability with high correlation. The most likely to fail element's probability of failure is taken as the system probability of failure.

5.7 Failure due to Human and Organizational Error

Human and Organizational Error (HOE) covers failures attributable to humans (individuals), organizations (groups of individuals) and systems (structures and equipment) [Moore, 1993]. Approximately 80% of high-consequence marine accidents can be attributed to HOE.

The modeling of HOE is very complex. It involves the culture and specific work methods of an organization, which have not been detailed in this project for these facilities and are considered to be outside the scope of this research. However, a description of the procedures and contingencies at the LOOP facility will be helpful in understanding the type of culture and work methods encountered at this type of facility in the US [LOOP, 1992]. LOOP experiences the same types of risk from HOE that these facilities can be expected to face : vessel traffic problems, exposed floating transfer hoses, communication between ship, tending vessels and shoreside facility, etc.

At the LOOP facility, a Port Superintendent is always physically present at the facility. It is the Port Superintendent's responsibility to direct all actions in the event of an emergency. The LOOP facility defines emergency conditions as those which involve or could involve : safety, environmental protection, personnel injury or property damage. These conditions could occur at the Marine Terminal, on a tanker, on any other vessel or aircraft, or at any other location lying within the port's safety zone. Examples of emergency conditions include :

- Oil spill
- Fire or explosion
- Tanker collision (actual or potential, with other vessel or platform)
- Tanker grounding
- Electrical power failure on platform
- Disruption of communications between shore and port
- Aircraft disaster
- Serious illness, injury or death
- Presence of poisonous gas
- Evacuation operation of the platform

The LOOP facility has a Safety Zone established around it. This zone consists of three sections : the approach section, the anchorage section and the terminal section. The approach section is a 2 nautical mile wide corridor leading to the terminal. The anchorage section is a 2 NM by 4 NM area adjacent to the approach section. The terminal section is approximately 2.5 nautical miles in radius from the pumping complex platform.

Inside the terminal section, there are four "Areas to be Avoided." One is a 600 meter radius around the platform, the other three are 500 meter radii about the SALM buoys.

5.8 Facility Probability of Failure

The probabilities of failure calculated in the previous sections are summarized in Table 5.7. These probabilities are the annual probabilities of failure due to each loading case for each facility. The total probability of failure for each facility is the sum of these individual probabilities of failure for each facility. This total probability of failure assumes independence between the individual probabilities of failure. Although values for probability of failure have not been calculated for HOE, it should be noted that these probabilities of failure may be very significant.

Failure Component	CALM Facility	SALM Facility
Storm Loadings	2.1×10^{-7}	3.0×10^{-7}
Seismic Loadings	—	4.6×10^{-6}
Fatigue Degradation	2.4×10^{-7}	1.2×10^{-7}
Human and Organizational Error	???	???
TOTAL	4.5×10^{-7}	5.0×10^{-6}

Table 5.7 : Facility Probabilities of Failure

5.9 Acceptable Reliability

An acceptable reliability can be determined from the factors of safety given in Table 3.1. This is done by equating the factor of safety (FS) to the 100-year load and the mean capacity, as in Equation 5.16 [Jones, 1992; Bea, 1990].

$$FS = \frac{R_{99}}{S_{50}} \tag{5.16}$$

Using the relations developed in this chapter, Equation 5.16 can be manipulated to give Equation 5.17, relating the safety index to the deviations and factor of safety.

$$\beta_{acceptable} = \frac{2.33\sigma_{lnS} + ln(FS)}{\sigma_{ln}} \tag{5.17}$$

Table 5.8 presents the applicable factors of safety and the calculated target probabilities of failure (for the intact condition only).

System Component	Factor of Safety	Acceptable P_f
SALM anchor legs	2	7.1×10^{-8}
CALM anchor legs	1.67	9.8×10^{-6}
Fatigue (all components)	3	1.0×10^{-3}
CALM anchors	1.5	3.2×10^{-4}
SALM anchor leg	2	3.8×10^{-5}

Table 5.8 : Acceptable Reliabilities

It can be seen that all components meet the acceptable reliability except for the SALM anchor legs.

Chapter 6

Feasibility

6.1 Introduction

This chapter examines the cost associated with the two facilities investigated in this study. Cost information is relatively rare in published literature. Therefore, all information given in this chapter has been obtained from industry contacts, based on existing structures or extrapolated from existing structures. The information regarding SPMS costs is courtesy of M. Steven Mostarda of IMODCO, while the information regarding tankers and tending vessels is courtesy of Capt. A.F. Fantauzzi. Unfortunately, it was not possible to obtain an estimate of the cost of the pipeline during the research. The pipeline is expected to account for a large percentage of the total facility cost, due to the water depth, the pipeline length and the lack of deepwater equipment on the West Coast. The cost of shoreside facilities, vessel traffic control equipment and personnel is considered to be outside the scope of this study.

6.2 System Hardware

The cost of the hardware of the CALM system has been estimated as $13.5 million. This figure includes the cost of the CALM buoy, eight catenary anchor legs, drag embedment anchors, product risers, hawsers and transfer hoses. It does not include the cost of the pipeline or any onshore facilities, including vessel traffic control. This cost estimate was based upon the existing Marlim CALM facility offshore Brazil [Hwang and Bensimon, 1990].

The cost of the hardware of the SALM system has been estimated as $12.5 to $14 million. This price is more uncertain than that of the CALM, as no SALM systems have been constructed for this water depth to date.

6.3 System Development and Engineering

For the both the CALM and the SALM system, the total cost of engineering, certifying, project management, construction and installation supervision, and transportation has been estimated as $1.25 million. This figure is also based on the Marlim CALM facility.

6.4 Installation

The installation of the CALM system is expected to take 20 to 25 days. The installation is estimated to cost from $3 to $5 million. This high cost is due in part to the necessity of bringing equipment to the site from the Gulf of Mexico, as deepwater equipment is not readily available on the West Coast.

The installation of the SALM system cannot be estimated as accurately. It is expected to be more expensive, due to the necessity of driving the anchor pile at the sea floor. An estimate of $5 million is used in this study.

6.5 Total Initial Costs

The total facility costs are given in Table 6.1. These total costs do not include the pipeline or any onshore facilities. The costs also do not include vessel traffic control. The entry "Other" refers to contingencies, insurance and overheads.

Cost Component	CALM Facility (millions of $)	SALM Facility (millions of $)
Hardware	13.5	12.5 to 14
Development & Engineering	1.25	1.25
Installation	3 to 5	5
Other	1.5	1.5
TOTAL	19.25 to 21.25	20.25 to 21.75

Table 6.1 : Total Initial Facility Costs

These figures indicate that the initial cost of the two systems are comparable. However, there is a greater degree of uncertainty regarding the SALM estimates, as no comparable system exists.

6.6 Costs of Operation and Maintenance

Table 6.2 outlines the cost of operation for the tending vessels which will be used at the facilities. The total yearly cost is based on three days of operation per week, following the earlier assumption that the facility will be visited by three tankers per week, each taking approximately 19 hours to connect, discharge and disconnect. No spot chartering has been assumed in the cost estimate.

Activity	Annual Estimated Cost
Yearly contract (vessel and crew, per tending vessel)	$2.4 million
Fuel (on a consumption basis)	1000 gallons per day @ $0.50 per gallon
Spot Charter	$6500 per day (plus fuel consumption)
TOTAL ANNUAL COST	$4.96 million

Table 6.2 : Annual Operation Costs

The cost of tanker charter is approximately $40,000 per day.

Preventative maintenance will be carried out on the hawsers used to connect tankers to the SPM buoys. These hawsers can have severe fatigue problems, and they can cause serious problems when they break by snapping back. It is common practice to replace them often -- LOOP uses only 20% of the calculated fatigue life before replacing hawsers. Hawsers will be replaced every six months at the facilities to avoid fatigue problems. The cost of hawsers was not available.

Chapter 7

Conclusions and Recommendations

7.1 Summary

This study has examined the determination of feasibility of single point mooring systems (SPMS) for use as deepwater ports for the import of hazardous liquid cargoes offshore southern California. Two configurations of SPMS were examined : CALM and SALM. The study examined the environmental conditions at two sites. developed analytical models with which to evaluate the suitability of SPMS, determined the reliability of the systems by use of state-of-the-art reliability methods, and evaluated the feasibility of the systems.

7.2 Conclusions

Several preliminary conclusions can be drawn from the work conducted in this study. These conclusions have been divided into two groups : deepwater ports and SPMS, and reliability analysis of SPMS. The conclusions are detailed in the following sections.

7.2.1 Deepwater Ports and SPMS

It has been proven by the US Coast Guard that deepwater ports are a viable way to reduce the environmental risks arising from the import of crude oil. This study has shown that two types of single point moorings can be used -- without stretching today's technology -- as deepwater ports offshore southern California.

The CALM system developed in this study is a relatively simple design. The engineering is not complex and the system does not require custom-built components other than the CALM buoy itself. The

CALM proved to be relatively robust in reliability analysis, due to its inherent safety by redundancy -- failure of one anchor leg will not entail catastrophic failure for the system.

The SALM system was also a relatively straightforward design. However, it requires more complex engineering and more custom construction of components. It also requires much more attention for reliability, as the system is not inherently robust -- failure in one leg is a catastrophic failure. The system also required a very high pretension to provide adequate restoring force to meet API guidelines concerning system offset. This high pretension dictated the need for the unusual components. It also necessitated the high vertical stiffness of the SALM also means that more attention must be paid to seismic effects.

The study also showed that disconnection criteria are very important in reliability based design of systems which disconnect to avoid extreme environmental conditions. The greater probabilities of failure associated while connected strongly affect total system reliability.

In summary, there are no technical barriers to the use of SPMS for deepwater ports offshore southern California in 1,000 feet of water. However, a CALM system appears to be much simpler than a SALM, with a greater degree of control of risk in the design.

7.2.2 Reliability Analysis of SPMS

The reliability analysis showed the importance of characteristics which might otherwise have been overlooked. It was shown that seismic loadings, although low in magnitude, can have a substantial effect on system reliability. Type II uncertainties can have a large effect on reliability of systems, especially systems which have relatively little Type I variation in loading and capacity. These Type II uncertainties are often overlooked, due to the difficulty in their determination.

The correlation between load and capacity has a great effect on reliability. This is also often overlooked, as it can rarely be determined without the use of model testing. Human and Organizational Error can play a substantial role in system reliability, and is perhaps the most difficult reliability component to evaluate. The benefits of preventative maintenance were clearly proven in the reliability analysis.

7.3 Recommendations for Future Work

In the course of this research, several topics were touched upon which were too broad for detailed examination, or required tools or testing facilities which were unavailable. These topics would make good subjects for future work. These recommendations for future work are divided into three groups : environmental analysis, facility design, and reliability analysis.

7.3.1 Environmental Analysis

Several components of the environmental analysis carried out in this study could be further pursued. The exact directionality of the environmental components at the specified sites would result in more exact loadings modeling. This would require environmental data more specific to the sites than that currently available.

Further examination of seismic characteristics, i.e. the exact positions of local and distant faults, would enhance the precision of the seismic analysis. The low frequency modeling could be carried out by a more exact tool than the API guidelines.

The most substantial work in extension of this study would be to create an uncoupled model for tanker and SPM loads and motions. This would give more accurate dynamic offsets for given environmental conditions.

7.3.2 Facility Design

Other types of SPMS deepwater ports could be examined, such as permanently moored tankers, or deepwater port systems employing dynamic positioning. These types of facilities were not examined in this study because their cost was considered to be too high.

The design of the facilities could be extended to include shoreside operations, pipeline and vessel traffic control (VTC). The effect of other tanker sizes using the facilities could be investigated.

7.3.3 Reliability Analysis

The reliability analysis could be extended in several ways. Further examination of Type II uncertainties, in the form of more historic data on analytical modeling, would result in a more accurate model. Model testing to determine load/capacity correlation would also improve the accuracy of the reliability model. The reliability for the case of one leg damaged could be investigated for the CALM system. Lastly, the disconnection distribution could be verified and improved by examination of historical disconnection data.

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Appendices

Appendix 1 : Partial List of Existing SPMS

The following is a partial list of existing SPMS, their location, installation date and configuration. This list has been provided by M. Steven Mostarda of IMODCO. The configuration listing of "CALM" (Catenary Anchor Leg Mooring) includes all SPMS connected by rigid or soft means to permanent production/storage tankers utilizing catenary legs. The listing of "SALM" (Single Anchor Leg Mooring) includes all single anchor leg systems (single chain, rigid leg or articulated rigid leg). The listing of "Tower" refers to any unarticulated fixed mooring structure, including jacket structures when they are attached to soft moorings.

NORTH AMERICA

Canada

Location/Name	Installed	Config.	Location/Name	Installed	Config.
St. John's, NB	1970	CALM	St. John's, NB	1987	CALM

United States

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Louisiana	1967	CALM	Worldwide	1984	SALM
LOOP-SPM 102	1980	SALM	Worldwide	1986	SALM
LOOP-SPM 103	1980	SALM	Worldwide	1986	SALM
LOOP-SPM 104	1980	SALM	Worldwide	1986	SALM
Worldwide	1980	CALM	Hawaii	1986	CALM
Hondo	1981	SALM			

CENTRAL AMERICA

Mexico

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Tuxpan I	1973	CALM	Dos Bocas I	1982	CALM
Tuxpan II	1976	CALM	Cayo Arcas I	1981	CALM
Santa Cruz I	1976	CALM	Cayo Arcas II	1982	CALM
Santa Cruz II	1977	CALM	Cayo Arcas III	1982	SALM
Rabon Grande I	1978	CALM	Santa Cruz III	1982	CALM
Rabon Grande II	1980	CALM	Back up Buoy	1985	CALM
Rosarito Beach	1980	CALM	Vera Cruz	1988	CALM
Dos Bocas II	1980	CALM			

Panama

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Chiriqui Grande	1981	CALM	Chiriqui Grande	1983	CALM
Chiriqui Grande	1981	CALM			

Dominican Republic

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Santo Domingo	1972	CALM	Palenque	1984	CALM

Trinidad & Tobago

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Galeota Point	1972	CALM	Galeota Point	1976	CALM
Pointe a Pierre	1973	CALM			

SOUTH AMERICA

Colombia

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Covenas	1985	CALM	Covenas	1986	CALM

Venezuela

Location/Name	Installed	Config.
Moron	1968	CALM

Chile

Location/Name	Installed	Config.
Quintero Bay	1971	CALM

Brazil

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Tramandai SBM I	1969	CALM	Pampo	1981	CALM
Tramandai SBM II	1971	CALM	Corvina	1982	CALM
Sao Francisco	1976	CALM	Garoupa	1982	CALM
Garoupa	1977	SALM	Linguado	1982	CALM
Garoupa	1977	SALM	Albacora SBM 05	1987	CALM
Garoupa	1978	CALM	Albacora	1987	CALM
Enchova	1978	CALM	Pirauna SBM 02	1988	CALM
Tramandai & SF	1979	CALM	Bicudo SBM 01	1988	CALM
Arembepe	1980	CALM	Bonito EMH 01	1989	CALM
Garoupa	1981	CALM	Garoupa SBM 03	1989	CALM
Badejo	1981	CALM	Marlim	1990	CALM
RJS 28A	1981	CALM			

Uruguay

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Jose Ignacio	1976	CALM	Jose Ignacio	1988	CALM

Argentina

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Puerto Rosales	1970	CALM	Punta Ciquena	1980	CALM
Caleta Olivia	1974	CALM	Hidra	1989	CALM
Caleta Cordova	1979	CALM			

Ecuador

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Balao Terminal	1972	CALM	Balao Terminal	1978	CALM
Balao Terminal	1972	CALM			

NORTH EUROPE

Sweden

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Oxno	1959	CALM	Dalaro	1959	CALM

Norway

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Ekofisk	1971	CALM	Gullfaks	1983	SALM
Ekofisk	1971	CALM	Gullfaks	1983	SALM
Statfjord A	1976	SALM	Statfjord A	1987	CALM
Statfjord B	1979	SALM	Statfjord B	1990	CALM
Statfjord C	1982	SALM			

Denmark

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Dan	1971	CALM	Frederikshavn	1982	SALM
Gorm	1979	CALM			

Britain

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Nore Estuary	1965	SALM	Buchan	1979	CALM
Tetney	1971	CALM	Maureen	1980	SALM
Auk	1972	CALM	Beryl	1981	CALM
Argyll	1974	CALM	Fulmar	1981	SALM
Beryl 1	1974	SALM	Beryl 2	1981	SALM
Flotta	1975	Tower	Tetney	1981	CALM
Flotta	1975	Tower	Falkland Isles	1985	CALM
Montrose	1975	CALM	Beryl 3	1985	SALM
Montrose	1975	CALM	Birch	1988	CALM
Anglesey	1975	CALM	Crawford	1989	CALM
Brent	1975	CALM	SWOPS	1989	CALM
Thistle	1975	SALM	Emerald	1990	SALM
Brent Standby	1977	CALM	Kittiwake	1990	CALM

West Germany

Location/Name	Installed	Config.
Cuxhaven	1962	CALM

MEDITERRANEAN

Spain

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Huelva	1967	CALM	Algeciras	1975	SALM
Amposta	1972	CALM	Castellon	1976	SALM
Taaragona	1974	CALM	Badalona	1979	SALM

Italy

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Flumicino	1963	CALM	Nilde	1978	SALM
Flumicino	1963	Tower	Rospo Mare	1981	CALM
Ravenna	1963	CALM	Genoa	1983	Tower
Flumicino	1970	Tower	Vega	1985	SALM
Porto Torres	1971	CALM	Mila	1985	CALM
Ancona	1972	Tower	Rospo Mare	1985	SALM
Genoa	1973	Tower	Nilde	1985	CALM
Ravenna	1975	Tower			

Egypt

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Ras el Shaqiq	1968	CALM	Alexandria	1976	CALM
Alexandria	1974	CALM	Agami	1976	CALM
Alexandria	1974	CALM	Alamein	1978	CALM
Alexandria	1974	CALM	Ras Bhudran	1980	CALM
Suez	1974	CALM	Suez	1981	CALM
Suez	1976	CALM	Alexandria	1982	CALM
Suez	1976	CALM	El Zeit Bay	1983	CALM
Alexandria	1976	CALM	El Zeit	1984	CALM

Libya

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Marsa el Brega	1963	Tower	Assawiya	1976	SALM
Ras es Sider	1965	CALM	Assawiya	1976	SALM
Zuetina	1968	CALM	Zuetina	1979	CALM
Zuetina	1969	CALM	Ras es Sider	1980	CALM
Marsa el Brega	1970	SALM	Ras es Sider	1983	CALM
Ras es Sider	1970	CALM	Marsa el Brega	1984	CALM
Ras Lanouf	1970	CALM	Marsa el Brega	1985	CALM
Assawiya	1974	SALM	Bouri	1989	SALM
Assawiya	1974	SALM			

Tunisia

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Ashtart	1972	CALM	Ashtart	1979	CALM
Ashtart	1975	CALM	Tazerka	1980	SALM

Morocco

Location/Name	Installed	Config.	Location/Name	Installed	Config.
El Aaium	1961	CALM	Mohammedia	1971	CALM

France

Location/Name	Installed	Config.
Frontignan	1973	CALM

AFRICA

Ivory Coast

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Bouet	1980	CALM	Espoir	1982	CALM

Ghana

Location/Name	Installed	Config.
Saltpond	1979	SALM

Equitorial Guinea

Location/Name	Installed	Config.
Bata	1963	CALM

Nigeria

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Apapa	1967	CALM	North Apoi Field	1975	CALM
Escravos	1968	CALM	Brass River	1976	CALM
Forcados	1969	CALM	North Apoi Field	1977	CALM
Forcados	1969	CALM	Escravos	1977	CALM
Escravos	1970	CALM	Que Iboe	1979	CALM
Que Iboe	1971	CALM	Antan	1986	Tower
Forcados	1972	CALM	Forcados	1986	CALM
Brass River	1972	CALM	Brass River	1987	CALM
Bonny	1973	CALM	Que Iboe	1989	CALM
Bonny	1973	CALM	Forcados	1990	CALM
North Apoi Field	1975	CALM			

Cameroon

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Kole	1977	CALM	Kole	1981	CALM
Limboh Point	1979	CALM	Victoria	1982	CALM
Rio del Ray	1980	CALM			

Gabon

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Gamba	1965	CALM	Inguessi	1983	CALM
Lucina	1967	CALM	Mayumba	1983	CALM
Gamba	1969	CALM	Gamba	1989	CALM
Mayumba	1980	CALM			

Congo

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Djeno	1973	CALM	Yombo	1990	CALM

Zaire

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Moanda	1975	CALM	Moanda	1989	CALM
Moanda	1976	CALM			

Angola

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Cabinda	1967	CALM	Palanca	1984	CALM
Essungo	1980	CALM	Takula	1985	CALM
Takula	1980	CALM	Takula	1988	CALM
Takula	1980	CALM	Takula	1989	CALM

South Africa

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Durban	1970	CALM	Durban	1974	CALM

Tanzania

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Dar es Salaam	1972	CALM	Dar es Salaam	1983	CALM

Sudan

Location/Name	Installed	Config.
Marsa Nimeiri	1983	CALM

MIDDLE EAST

Yemen Arab Republic

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Saleef	1987	CALM	Saleef	1988	CALM

South Yemen

Location/Name	Installed	Config.
Bir Ali	1989	CALM

UAE

Location/Name	Installed	Config.
Saleh Field	1983	CALM

Oman

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Mina al Fahal	1967	CALM	Mina al Fahal	1974	CALM
Mina al Fahal	1967	CALM	Mina al Fahal	1979	CALM
Mina al Fahal	1967	CALM	Mina al Fahal	1984	CALM

Sharjah

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Mubarek	1973	CALM	Mubarek	1987	CALM
Sharjah	1981	CALM			

Dubai

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Fateh	1969	CALM	Fateh	1979	CALM
Fateh	1972	CALM	Fateh	1984	CALM

Abu Dubai

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Das Island	1972	CALM	Arzanah	1977	CALM
Muharras	1972	CALM	Abu Al Bu Koosh	1981	CALM
Abu Al Bu Koosh	1974	CALM	Zakum	1981	CALM
Das Island	1977	CALM	Zakum	1981	CALM

Qatar

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Halul	1964	CALM	Doba	1976	CALM
Halul	1965	CALM	Halul	1980	CALM
Halul	1972	CALM	Umm Said	1983	CALM
Umm Said	1972	CALM			

Saudi Arabia

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Zuluf	1972	CALM	Ju'Aymah	1974	CALM
Zuluf	1972	CALM	Ju'Aymah	1976	SALM
Ju'Aymah	1974	CALM	Ju'Aymah	1976	SALM
Ju'Aymah	1974	CALM	Asir	1985	CALM

Neutral Zone

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Ras al Khafji	1967	CALM	Ras al Khafji	1980	CALM
Ras al Khafji	1972	CALM	Ras al Khafji	1987	CALM

Iraq

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Khor al Amaya	1980	CALM	Khor al Amaya	1980	CALM
Khor al Amaya	1980	CALM	Khor al Amaya	1980	CALM

Iran

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Cyrus	1970	CALM	Ganaveh	1986	CALM
Iman Hasan	1971	CALM	Bandar Kangan	1987	CALM
Ganaveh	1986	CALM	Bandar Kangan	1987	CALM
Ganaveh	1986	CALM	Bandar Kangan	1987	CALM
Ganaveh	1986	CALM	Bandar Taheri	1989	CALM

Kuwait

Location/Name	Installed	Config.
Mina al Ahmadi	1980	Tower

INDIAN SUBCONTINENT

India

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Bombay High	1975	CALM	Gulf of Kutch	1984	CALM
Bombay High	1975	CALM	Panna	1985	CALM
Gulf of Kutch	1977	CALM	Bombay High D18	1989	CALM
Ralangiri R12	1982	CALM	Hazira	1990	CALM
Bombay High SH	1983	CALM			

Sri Lanka

Location/Name	Installed	Config.
Colombo Harbor	1986	CALM

Bangladesh

Location/Name	Installed	Config.
Chittagong	1967	CALM

FAR EAST

Singapore

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Singapore Harbour	1971	CALM	Singapore Harbour	1980	CALM
Pulau Bukom	1974	CALM			

Malaysia

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Miri	1960	CALM	Bintulu	1978	CALM
Miri	1960	CALM	Trengganu	1981	SALM
Port Dickson	1963	CALM	Trengganu	1981	SALM
Miri	1964	CALM	Korteh	1982	CALM
Miri	1964	CALM	Port Dickson	1983	CALM
Tembungo	1974	SALM	Miri	1984	CALM
Labuan	1974	CALM	Miri	1984	CALM
Pulai	1974	SALM	Miri	1985	CALM
Pulai	1977	SALM	Miri	1985	CALM

Brunei

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Seria	1971	CALM	Seria	1981	CALM
Seria	1975	CALM			

Vietnam

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Tan My	1969	CALM	White Tiger	1989	CALM
Da Nang	1969	CALM	White Tiger	1990	CALM
White Tiger	1986	CALM			

China

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Hainan	1984	CALM	Bozhong 34-2/4E	1990	Tower
Liuhua	1987	CALM	Huizhou 16/08	1990	CALM
Bozhong 28-1	1988	Tower	Lufeng 17/16	1990	CALM

Taiwan

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Tai Chung	1967	CALM	Sha-Lung	1974	CALM
Tai Chung	1968	CALM	Sha-Lung	1976	SALM
Kaohsiung	1968	CALM	Sha-Lung	1979	CALM
Kaohsiung	1972	CALM	Kaohsiung	1981	CALM
Kaohsiung	1972	CALM			

Korea

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Ulsan	1963	CALM	Pusan	1979	CALM
Ulsan	1969	CALM	Jiseapo	1984	CALM
Yosu	1969	CALM	Daesan	1987	CALM
Onsan	1978	CALM	Daesan	1989	CALM

Japan

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Niigata	1961	CALM	Toyama	1969	CALM
Oita	1963	CALM	Ube Onoda	1970	CALM
Yokkaichi	1964	CALM	Atsumi	1970	CALM
Yokkaichi	1964	CALM	Himeji	1970	CALM
Chiba	1965	CALM	Yokkaichi	1971	CALM
Koshiba	1967	CALM	Onoda	1972	CALM
Yokkaichi	1968	CALM	Kawasaki	1974	CALM
Kawasaki	1968	CALM	Ogishima	1974	CALM
Hakodate	1968	CALM	Yokkaichi	1976	CALM
Hakozaki	1968	CALM	Mutsu Ogawara	1983	SALM
Ogishima	1969	CALM	Fukui	1984	SALM
Yokohama	1969	CALM			

Okinawa

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Buckner Bay	1970	CALM	Nakagusuki Bay	1971	SALM
Tengan	1970	CALM			

Phillipines

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Subic Bay	1967	CALM	Bataan	1980	SALM
Nido	1977	CALM	Nido	1982	CALM
Cadlao	1980	CALM			

Indonesia

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Pangkalan Susu	1970	CALM	Cinta	1981	CALM
Ardjuna	1971	CALM	Ardjuna	1981	CALM
Java Sea	1971	CALM	Balikpapan	1981	CALM
Balikpapan	1971	CALM	Krisna	1983	CALM
Java Sea	1972	CALM	Balongan	1983	CALM
Ardjuna	1972	CALM	Lalang	1984	Tower
Djati Barang	1973	CALM	Chengkareng Air	1984	CALM
Bekapai	1974	CALM	Kakup	1984	CALM
Ardjuna	1974	CALM	Arun	1984	CALM
Ardjuna	1974	CALM	Bima	1985	CALM
Poleng	1975	CALM	Bima	1985	CALM
Ardjuna	1975	CALM	Bima	1985	CALM
Handii	1976	CALM	Mdura Island	1985	CALM
Balongan	1977	CALM	Intan	1989	CALM
Udang	1978	CALM	Anoa	1990	CALM
Semarang	1980	CALM			

Thailand

Location/Name	Installed	Config.
Erewan	1981	CALM

AUSTRAILASIA

Austrailia

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Botany Bay	1971	CALM	Jabiru	1989	CALM
Talisman	1989	CALM	Challis	1989	SALM

New Zealand

Location/Name	Installed	Config.	Location/Name	Installed	Config.
Waipipi Point	1971	CALM	Taharoa	1976	CALM
Taharoa	1972	CALM			

New Caledonia

Location/Name	Installed	Config.
Moumea	1977	CALM

Appendix 2 : Floor Slopes at Designated SPMS Sites

Floor slopes were evaluated at six locations for each site specified by the California State Lands Commission [NOAA, 1991]. These slopes are given in the tables below.

Location No.	Location (deg-min N/ deg-min W)	Slope (degrees)	Description
1	33-48 / 118-30	12.8	6.3 miles WNW of Flat Rock Pt
2	33-50 / 118-35	6.8	11.0 miles WNW of Flat Rock Pt
3	33-52 / 118-38	6.4	13.9 miles WNW of Flat Rock Pt
4	33-55 / 118-36	5.4	11.8 miles ESE of Pt Dume
5	33-56 / 118-39	2.2	10.3 miles ESE of Pt Dume
6	33-57 / 118-40	2.5	8.8 miles ESE of Pt Dume

Table A.2.1 : Ocean Floor Slopes at El Segundo

Location No.	Location (deg-min N/ deg-min W)	Slope (degrees)	Description
1	35-10 / 121-0	1.6	7.8 miles SW of Pt Buchon
2	35-13 / 121-1	1.7	7.5 miles WSW of Pt Buchon
3	35-19 / 121-5	1.1	12 miles WNW of Pt Buchon
4	35-23 / 121-7	0.9	9.2 miles SW of Pt Estero
5	35-26 / 121-11	1.1	9.9 miles W of Pt Estero
6	35-31 / 121-13	1.9	8.5 miles S of San Simeon Pt

Table A.2.2 : Ocean Floor Slopes at Morro Bay

Appendix 3 : Calculations of Steady Forces

Steady forces were calculated based on the relations described in Chapter 4, with the environmental conditions described in Chapter 2. The calculations of steady forces were carried out using Microsoft Excel spreadsheets, which are reproduced here. Calculations for the CALM and the SALM are given for three return periods : the 2-year, the 10-year and the 100-year.

Steady Force Evaluation for CALM, 2-year return period conditions

WIND FORCES

Velocity @ 10m	*39* knots

Wind Speed by Centroid Elevation

	Full - Load Tanker		Lightship Tanker		Buoy
	Super	Hull	Super	Hull	CALM
Centroid Elevation (feet)	*39*	*9*	*50*	*20*	*5*
Velocity @ Centroid (knots)	39.85	33.18	41.11	36.66	30.83

Wind Speed by Gust Duration

	Full - Load Tanker		Lightship Tanker		Buoy
	Super	Hull	Super	Hull	CALM
Gust Duration (seconds)	*180*	*180*	*180*	*180*	*180*
1-minute Velocity (knots)	39.85	33.18	41.11	36.66	30.83
Gust Factor	0.94	0.94	0.93	0.94	0.94
Speed, gust @ centroid	37.27	31.14	38.42	34.34	28.97

Element Dimensions *(All areas in feet squared)*

	A	Bs	Bh	B	Cx	Vk, hull	Vk, sup
Element	long. area above WL	trans area superstruct	trans area hull	total trans area	shape coefficient	wind speed knots	speed knots
Full Load	*0*	*5500*	*2988*	6396.4	*1.0*	31.14	37.27
Lightship	*0*	*5500*	*6640*	7492	*1.0*	34.34	38.42
CALM	*NA*	*NA*	*600*	600	*1.0*	28.97	NA

Air density :	*0.002* slugs/ft^3

Steady Wind Forces

Bow-on Wind Only

Element	Force, kips

Total Wind Forces

Element	Force, kips
CALM alone	**1.70**

Full Load Tanker Hull	9.79
Lightship Tanker Hull	26.47
Full Load Super	25.82
Lightship Super	27.44
CALM	1.70

Lightship, CALM	**55.61**
Full-load, CALM	**37.31**

CURRENT FORCES

Surface Current (knots)	*1.2*
Surface Current (feet/second)	2.0268

Tanker

Dimensions (ft ^2)						Bow-on	Beam-on
	Displacement long tons	Length feet	Cws	D vol., ft^3	S ft^2	Force kip	Force kip
Full Load	*188500*	*915*	2.7	7E+06	209780	4.8333	120.83
Lightship	*30000*	*915*	2.7	1E+06	83689	1.9282	48.205

Buoy

	Cd	Draft feet	Diameter feet	Vcurrent ft/sec	Frontal area ft^2	Force kip
CALM	*1*	*15*	*60*	2.0268	900	3.6971

Riser

Cd	Water Depth feet	Diameter feet	Vsurface ft/sec	Vcentroid ft/sec	Frontal area ft^2	Force kip
0.9	1000	*3*	2.0268	*1.01*	3000	2.7728

Total Current Forces

Element	Force, kips
CALM alone	**6.47**
Lightship, CALM	**8.40**
Full-load, CALM	**11.30**

AVERAGE DRIFT LOAD

Significant Wave Height (feet)	14.5	Period (seconds)	12

Tanker

	Length	Beam	Draft	Char wave period	Cd	FORCE kips
Full load, bow wave	*915*	*166*	*59.3*	10.805	*0.05*	20.422
Full load, cross wave	915	166	59.3	10.805	*0.05*	157.09
Lightship, bow wave	*915*	*166*	*20*	9.1929	*0.05*	20.422
Lightship, cross wave	915	166	20	9.1929	*0.05*	157.09

Buoy, Riser

	Cd	Diameter	FORCE
CALM	1175	60	12.006
Riser	1175	3	0.03

Total Wave Drift Forces

Element	Force, kips
CALM alone	**12.04**
Lightship, CALM	**32.46**
Full-load, CALM	**32.46**

TOTAL STEADY ENVIRONMENTAL FORCES

Element	Force, kips	Force, LT
CALM alone	**20.21**	**9.02**
Lightship, CALM	**96.46**	**43.06**
Full-load, CALM	**81.07**	**36.19**

Steady Force Evaluation for CALM, 10-year return period conditions

WIND FORCES

Velocity @ 10m	55 knots

Wind Speed by Centroid Elevation

	Full - Load Tanker		Lightship Tanker		Buoy
	Super	Hull	Super	Hull	CALM
Centroid Elevation (feet)	*39*	*9*	*50*	*20*	*5*
Velocity @ Centroid (knots)	56.20	46.79	57.98	51.70	43.48

Wind Speed by Gust Duration

	Full - Load Tanker		Lightship Tanker		Buoy
	Super	Hull	Super	Hull	CALM
Gust Duration (seconds)	*180*	*180*	*180*	*180*	*180*
1-minute Velocity (knots)	56.20	46.79	57.98	51.70	43.48
Gust Factor	0.93	0.93	0.93	0.93	0.93
Speed, gust @ centroid	52.12	43.59	53.72	48.05	40.58

Element Dimensions *(All areas in feet squared)*

	A	Bs	Bh	B	Cx	Vk, hull	Vk, sup
Element	long. area above WL	trans area superstruct	trans area hull	total trans area	shape coefficient	wind speed knots	speed knots
Full Load	*0*	*5500*	*2988*	6396.4	*1.0*	43.59	52.12
Lightship	*0*	*5500*	*6640*	7492	*1.0*	48.05	53.72
CALM	*NA*	*NA*	*600*	600	*1.0*	40.58	NA

Air density	*0.002* slugs/ft^3

Steady Wind Forces

Bow-on Wind Only

Element	Force, kips
Full Load Tanker Hull	19.19
Lightship Tanker Hull	51.82
Full Load Super	50.50
Lightship Super	53.64
CALM	3.34

Total Wind Forces

Element	Force, kips
CALM alone	**3.34**
Lightship, CALM	**108.80**
Full-load, CALM	**73.03**

CURRENT FORCES

Surface Current (knots)	1.7
Surface Current (feet/second)	2.8713

Tanker

Dimensions (ft ^2)						Bow-on	Beam-on
	Displacement long tons	Length feet	Cws	D vol., ft^3	S ft^2	Force kip	Force kip
Full Load	188500	915	2.7	6597500	209780	9.7002	242.51
Lightship	30000	915	2.7	1050000	83689	3.8698	96.745

Buoy

	Cd	Draft feet	Diameter feet	Vcurrent ft/sec	Frontal area ft^2	Force kip
CALM	1	15	60	2.8713	900	7.4199

Riser

Cd	Water Depth feet	Diameter feet	Vsurface ft/sec	Vcentroid ft/sec	Frontal area ft^2	Force kip
0.9	1000	4	2.8713	1.44	4000	7.4199

Total Current Forces

Element	Force, kips
CALM alone	**14.84**
Lightship, CALM	**18.71**
Full-load, CALM	**24.54**

AVERAGE DRIFT LOAD

Significant Wave Height (feet)	18.5	Period (seconds)	13

Tanker

	Length	Beam	Draft	Char wave period	Cd	FORCE kips
Full load, bow wave	915	166	59.3	10.805	0.05	33.244
Full load, cross wave	915	166	59.3	10.805	0.05	255.72
Lightship, bow wave	915	166	20	9.1929	0.05	33.244
Lightship, cross wave	915	166	20	9.1929	0.05	255.72

Buoy, Riser

	Cd	Diameter	FORCE
CALM	1175	60	16.653
Riser	1175	4	0.074

Total Wave Drift Forces

Element	Force, kips
CALM alone	**16.73**
Lightship, CALM	**49.97**
Full-load, CALM	**49.97**

TOTAL STEADY ENVIRONMENTAL FORCES

Element	Force, kips	Force, LT
CALM alone	**34.91**	**15.58**
Lightship, CALM	**177.48**	**79.23**
Full-load, CALM	**147.54**	**65.87**

Steady Force Evaluation for CALM, 100-year return period conditions

WIND FORCES

Velocity @ 10m	*72* knots

Wind Speed by Centroid Elevation

	Full - Load Tanker		Lightship Tanker		Buoy
	Super	Hull	Super	Hull	CALM
Centroid Elevation (feet)	*39*	*9*	*50*	*20*	*5*
Velocity @ Centroid (knots)	73.58	61.25	75.90	67.68	56.91

Wind Speed by Gust Duration

	Full - Load Tanker		Lightship Tanker		Buoy
	Super	Hull	Super	Hull	CALM
Gust Duration (seconds)	*180*	*180*	*180*	*180*	*180*
1-minute Velocity (knots)	73.58	61.25	75.90	67.68	56.91
Gust Factor	0.92	0.93	0.92	0.92	0.93
Speed, gust @ centroid	67.68	56.67	69.75	62.43	52.76

Element Dimensions *(All areas in feet squared)*

	A	Bs	Bh	B	Cx	Vk, hull	Vk, sup
Element	long. area above WL	trans area superstruct	trans area hull	total trans area	shape coefficient	wind speed knots	speed knots
Full Load	*0*	*5500*	*2988*	6396.4	*1.0*	56.67	67.68
Lightship	*0*	*5500*	*6640*	7492	*1.0*	62.43	69.75
CALM	*NA*	*NA*	*600*	600	*1.0*	52.76	NA

Air density	*0.002* slugs/ft^3

Steady Wind Forces

Bow-on Wind Only

Element	Force, kips
Full Load Tanker Hull	32.43
Lightship Tanker Hull	87.47
Full Load Super	85.16
Lightship Super	90.44
CALM	5.65

Total Wind Forces

Element	Force, kips
CALM alone	**5.65**
Lightship, CALM	**183.55**
Full-load, CALM	**123.24**

CURRENT FORCES

Surface Current (knots)	2.2
Surface Current (feet/second)	3.7158

Tanker

Dimensions (ft ^2)						Bow-on	Beam-on
	Displacement long tons	Length feet	Cws	D vol., ft^3	S ft^2	Force kip	Force kip
Full Load	*188500*	*915*	2.7	7E+06	209780	16.245	406.13
Lightship	*30000*	*915*	2.7	1E+06	83689	6.4809	162.02

Buoy

	Cd	Draft feet	Diameter feet	Vcurrent ft/sec	Frontal area ft^2	Force kip
CALM	*1*	*15*	*60*	3.7158	900	12.426

Riser

Cd	Water Depth feet	Diameter feet	Vsurface ft/sec	Vcentroid ft/sec	Frontal area ft^2	Force kip
0.9	1000	*4*	3.7158	*1.86*	4000	12.426

Total Current Forces

Element	Force, kips
CALM alone	**24.85**
Lightship, CALM	**31.33**
Full-load, CALM	**41.10**

AVERAGE DRIFT LOAD

Significant Wave Height (feet)	23	Period (seconds)	14

Tanker

	Length	Beam	Draft	Char wave period	Cd	FORCE kips
Full load, bow wave	*915*	*166*	*59.3*	10.805	*0.05*	51.383
Full load, cross wave	915	166	59.3	10.805	*0.05*	395.25
Lightship, bow wave	*915*	*166*	*20*	9.1929	*0.05*	51.383
Lightship, cross wave	915	166	20	9.1929	*0.05*	395.25

Buoy, Riser

	Cd	Diameter	FORCE
CALM	1175	60	22.194
Riser	1175	4	0.0986

Total Wave Drift Forces

Element	Force, kips
CALM alone	**22.29**
Lightship, CALM	**73.68**
Full-load, CALM	**73.68**

TOTAL STEADY ENVIRONMENTAL FORCES

Element	Force, kips	Force, LT
CALM alone	**52.79**	**23.57**
Lightship, CALM	**288.56**	**128.82**
Full-load, CALM	**238.01**	**106.26**

Steady Force Evaluation for SALM, 2-year return period conditions

WIND FORCES

Velocity @ 10m	*39* knots

Wind Speed by Centroid Elevation

	Full - Load Tanker		Lightship Tanker		Buoy
	Super	Hull	Super	Hull	SALM
Centroid Elevation (feet)	*39*	*9*	*50*	*20*	*10*
Velocity @ Centroid (knots)	39.85	33.18	41.11	36.66	33.62

Wind Speed by Gust Duration

	Full - Load Tanker		Lightship Tanker		Buoy
	Super	Hull	Super	Hull	SALM
Gust Duration (seconds)	*180*	*180*	*180*	*180*	*180*
1-minute Velocity (knots)	39.85	33.18	41.11	36.66	33.62
Gust Factor	0.94	0.94	0.93	0.94	0.94
Speed, gust, centroid, kts	37.27	31.14	38.42	34.34	31.54

Element Dimensions *(All areas in feet squared)*

	A	Bs	Bh	B	Cx	Vk, hull	Vk, sup
Element	long. area above WL	trans area superstruct	trans area hull	total trans area	shape coefficient	wind speed knots	speed knots
Full Load	*0*	*5500*	*2988*	6396.4	*1.0*	31.14	37.27
Lightship	*0*	*5500*	*6640*	7492	*1.0*	34.34	38.42
SALM	*NA*	*NA*	*400*	400	*1.0*	31.54	NA

Air density :	*0.002* slugs/ft^3

Steady Wind Forces

Bow-on Wind Only

Element	Force, kips
Full Load Tanker Hull	9.79
Lightship Tanker Hull	26.47
Full Load Super	25.82
Lightship Super	27.44
SALM	1.35

Total Wind Forces

Element	Force, kips
SALM alone	**1.35**
Lightship, SALM	**55.25**
Full-load, SALM	**36.96**

CURRENT FORCES

Surface Current (knots)	*1.2*
Surface Current (feet/second)	2.0268

Tanker

Dimensions (ft ^2)						Bow-on	Beam-on
	Displacement long tons	Length feet	Cws	D vol., ft^3	S ft^2	Force kip	Force kip
Full Load	*188500*	*915*	2.7	7E+06	209780	4.8333	120.83
Lightship	*30000*	*915*	2.7	1E+06	83689	1.9282	48.205

Buoy

	Cd	Draft feet	Diameter feet	Vcurrent ft/sec	Frontal area ft^2	Force kip
SALM	*1*	*43*	*15*	2.0268	645	2.6496

Riser

Cd	Water Depth feet	Diameter feet	Vsurface ft/sec	Vcentroid ft/sec	Frontal area ft^2	Force kip
0.9	1000	*5*	2.0268	*1.01*	5000	4.6214

Total Current Forces

Element	Force, kips
SALM alone	**7.27**
Lightship, SALM	**9.20**
Full-load, SALM	**12.10**

AVERAGE DRIFT LOAD

Significant Wave Height (feet)	*14.5*	Period (seconds)	*12*

Tanker

	Length	Beam	Draft	Char wave period	Cd	FORCE kips
Full load, bow wave	*915*	*166*	*59.3*	10.805	*0.05*	20.422
Full load, cross wave	915	166	59.3	10.805	*0.05*	157.09
Lightship, bow wave	*915*	*166*	*20*	9.1929	*0.05*	20.422
Lightship, cross wave	915	166	20	9.1929	*0.05*	157.09

Buoy, Riser

	Cd	Diameter	FORCE
SALM	1175	15	0.7504
Riser	1175	5	0.0834

Total Wave Drift Forces

Element	Force, kp
SALM alone	**0.83**
Lightship, SALM	**21.26**
Full-load, SALM	**21.26**

TOTAL STEADY ENVIRONMENTAL FORCES

Element	Force, kp	Force, LT
SALM alone	**9.45**	**4.22**
Lightship, SALM	**85.70**	**38.26**
Full-load, SALM	**70.32**	**31.39**

Steady Force Evaluation for SALM, 10-year return period conditions

WIND FORCES

Velocity @ 10m	*55* knots

Wind Speed by Centroid Elevation

	Full - Load Tanker		Lightship Tanker		Buoy
	Super	Hull	Super	Hull	SALM
Centroid Elevation (feet)	*39*	*9*	*50*	*20*	*10*
Velocity @ Centroid (knots)	56.20	46.79	57.98	51.70	47.41

Wind Speed by Gust Duration

	Full - Load Tanker		Lightship Tanker		Buoy
	Super	Hull	Super	Hull	SALM
Gust Duration (seconds)	*180*	*180*	*180*	*180*	*180*
1-minute Velocity (knots)	56.20	46.79	57.98	51.70	47.41
Gust Factor	0.93	0.93	0.93	0.93	0.93
Speed, gust, centroid, kts	52.12	43.59	53.72	48.05	44.16

Element Dimensions *(All areas in feet squared)*

	A	Bs	Bh	B	Cx	Vk, hull	Vk, sup
Element	long. area above WL	trans area superstruct	trans area hull	total trans area	shape coefficient	wind speed knots	speed knots
Full Load	*0*	*5500*	*2988*	6396.4	*1.0*	43.59	52.12
Lightship	*0*	*5500*	*6640*	7492	*1.0*	48.05	53.72
SALM	*NA*	*NA*	*400*	400	*1.0*	44.16	NA

Air density	*0.002* slugs/ft^3

Steady Wind Forces

Bow-on Wind Only

Element	Force, kips
Full Load Tanker Hull	19.19
Lightship Tanker Hull	51.82
Full Load Super	50.50
Lightship Super	53.64
SALM	2.64

Total Wind Forces

Element	Force, kips
SALM alone	**2.64**
Lightship, SALM	**108.10**
Full-load, SALM	**72.33**

CURRENT FORCES

Surface Current (knots)	*1.7*
Surface Current (feet/second)	2.8713

Tanker

	Dimensions (ft ^2)					Bow-on	Beam-on
	Displacement long tons	Length feet	Cws	D vol., ft^3	S ft^2	Force kip	Force kip
Full Load	*188500*	*915*	2.7	7E+06	209780	9.7002	242.51
Lightship	*30000*	*915*	2.7	1E+06	83689	3.8698	96.745

Buoy

	Cd	Draft feet	Diameter feet	Vcurrent ft/sec	Frontal area ft^2	Force kip
SALM	*1*	*43*	*15*	2.8713	645	5.3176

Riser

Cd	Water Depth feet	Diameter feet	Vsurface ft/sec	Vcentroid ft/sec	Frontal area ft^2	Force kip
0.9	1000	*5*	2.8713	*1.44*	5000	9.2749

Total Current Forces

Element	Force, kips
SALM alone	**14.59**
Lightship, SALM	**18.46**
Full-load, SALM	**24.29**

AVERAGE DRIFT LOAD

Significant Wave Height (feet)	*18.5*	Period (seconds)	*13*

Tanker

	Length	Beam	Draft	Char wave period	Cd	FORCE kips
Full load, bow wave	*915*	*166*	*59.3*	10.805	*0.05*	33.244
Full load, cross wave	915	166	59.3	10.805	*0.05*	255.72
Lightship, bow wave	*915*	*166*	*20*	9.1929	*0.05*	33.244
Lightship, cross wave	915	166	20	9.1929	*0.05*	255.72

Buoy, Riser

	Cd	Diameter	FORCE
SALM	1175	15	1.0408
Riser	1175	5	0.1156

Total Wave Drift Forces

Element	Force, kp
SALM alone	**1.16**
Lightship, SALM	**34.40**
Full-load, SALM	**34.40**

TOTAL STEADY ENVIRONMENTAL FORCES

Element	Force, kp	Force, LT
SALM alone	**18.39**	**8.21**
Lightship, SALM	**160.96**	**71.86**
Full-load, SALM	**131.02**	**58.49**

WIND FORCES

Velocity @ 10m	*72* knots

Wind Speed by Centroid Elevation

	Full - Load Tanker		Lightship Tanker		Buoy
	Super	Hull	Super	Hull	SALM
Centroid Elevation (feet)	*39*	*9*	*50*	*20*	*10*
Velocity @ Centroid (knots)	73.58	61.25	75.90	67.68	62.07

Wind Speed by Gust Duration

	Full - Load Tanker		Lightship Tanker		Buoy
	Super	Hull	Super	Hull	SALM
Gust Duration (seconds)	*180*	*180*	*180*	*180*	*180*
1-minute Velocity (knots)	73.58	61.25	75.90	67.68	62.07
Gust Factor	0.92	0.93	0.92	0.92	0.92
Speed, gust, centroid, kts	67.68	56.67	69.75	62.43	57.40

Element Dimensions

(All areas in feet squared)

Element	A long. area above WL	Bs trans area superstruct	Bh trans area hull	B total trans area	Cx shape coefficient	Vk, hull wind speed knots	Vk, sup speed knots
Full Load	*0*	*5500*	*2988*	6396.4	*1.0*	56.67	67.68
Lightship	*0*	*5500*	*6640*	7492	*1.0*	62.43	69.75
SALM	*NA*	*NA*	*400*	400	*1.0*	57.40	NA

Air density	*0.002* slugs/ft^3

Steady Wind Forces

Bow-on Wind Only

Element	Force, kips
Full Load Tanker Hull	32.43
Lightship Tanker Hull	87.47
Full Load Super	85.16
Lightship Super	90.44
SALM	4.45

Total Wind Forces

Element	Force, kips
SALM alone	**4.45**
Lightship, SALM	**182.36**
Full-load, SALM	**122.05**

CURRENT FORCES

Surface Current (knots)	2.2
Surface Current (feet/second)	3.7158

Tanker

	Dimensions (ft ^2)					Bow-on	Beam-on
	Displacement long tons	Length feet	Cws	D vol., ft^3	S ft^2	Force kip	Force kip
Full Load	*188500*	*915*	2.7	7E+06	209780	16.245	406.13
Lightship	*30000*	*915*	2.7	1E+06	83689	6.4809	162.02

Buoy

	Cd	Draft feet	Diameter feet	Vcurrent ft/sec	Frontal area ft^2	Force kip
SALM	*1*	*43*	*15*	3.7158	645	8.9056

Riser

Cd	Water Depth feet	Diameter feet	Vsurface ft/sec	Vcentroid ft/sec	Frontal area ft^2	Force kip
0.9	1000	5	3.7158	*1.86*	5000	15.533

Total Current Forces

Element	Force, kips
SALM alone	**24.44**
Lightship, SALM	**30.92**
Full-load, SALM	**40.68**

AVERAGE DRIFT LOAD

Significant Wave Height (feet)	23	Period (seconds)	14

Tanker

	Length	Beam	Draft	Char wave period	Cd	FORCE kips
Full load, bow wave	*915*	*166*	*59.3*	10.805	*0.05*	51.383
Full load, cross wave	915	166	59.3	10.805	*0.05*	395.25
Lightship, bow wave	*915*	*166*	*20*	9.1929	*0.05*	51.383
Lightship, cross wave	915	166	20	9.1929	*0.05*	395.25

Buoy, Riser

	Cd	Diameter	FORCE
SALM	1175	15	1.3871
Riser	1175	5	0.1541

Total Wave Drift Forces

Element	Force, kp
SALM alone	**1.54**
Lightship, SALM	**52.92**
Full-load, SALM	**52.92**

TOTAL STEADY ENVIRONMENTAL FORCES

Element	Force, kp	Force, LT
SALM alone	**30.43**	**13.59**
Lightship, SALM	**266.20**	**118.84**
Full-load, SALM	**215.66**	**96.28**

Appendix 4 : Calculations of Oscillating Motions

Two types of oscillating motions were investigated in this study : low frequency and wave frequency oscillations. Low frequency oscillations were based on the methods recommended by the American Petroleum Institute [API, 1987], while wave frequency motions were calculated with the use of the ship motions program, SEAWAY [Journée, 1992], as described in section 4.3.

Calculation of low frequency motions was carried out using Microsoft Excel spreadsheets, which are given below. For further information on this analysis, the reader is referred to API RP 2P.

Low Frequency Motions

Summary, rms amplitudes

	Low Frequency		
	2-year	10-year	100-year
Full load tanker	2.87	4.30	5.56
Lightship tanker	2.87	4.30	5.56
SALM	8.61	9.50	10.04
CALM	11.38	12.57	13.28

Summary, max amplitudes

	Low Frequency		
	2-year	10-year	100-year
Full load tanker	6.13	9.20	11.88
Lightship tanker	7.26	10.89	14.07
SALM	28.60	31.57	33.36
CALM	37.83	41.77	44.13

Low Frequency Vessel Motions

	Full Load Tanker			**Lightship Tanker**		
	2-year	10-year	100-year	2-year	10-year	100-year
Stiffness (kips/ft)	1.4	1.4	1.4	1.4	1.4	1.4
Actual Length (ft)	915	915	915	915	915	915
Displacement (LT)	188500	188500	188500	30000	30000	30000
Reference Length(ft)	540	540	540	540	540	540
Sig. Wave Height (ft)	14.5	18.5	23	14.5	18.5	23
Ref. Sig. W.H. (ft)	8.56	10.92	13.57	8.56	10.92	13.57
Reference surge/sway, rms						
Xs, bow seas :	0.8	1.2	1.55	0.8	1.2	1.55
Xs, quarter seas :	1	1.3	1.7	1	1.3	1.7
Ys, quarter seas :	1.55	2	2.4	1.55	2	2.4
Ys, beam seas :	2.15	2.9	3.3	2.15	2.9	3.3
Actual surge/sway, rms						
Xs, bow seas :	2.87	4.30	5.56	2.87	4.30	5.56
Xs, quarter seas :	3.59	4.66	6.10	3.59	4.66	6.10
Ys, quarter seas :	5.56	7.17	8.61	5.56	7.17	8.61
Ys, beam seas :	7.71	10.40	11.83	7.71	10.40	11.83
Actual surge/sway, sig. single amplitude						
Xs, bow seas :	5.74	8.61	11.12	5.74	8.61	11.12
Xs, quarter seas :	7.17	9.32	12.19	7.17	9.32	12.19
Ys, quarter seas :	11.12	14.34	17.21	11.12	14.34	17.21
Ys, beam seas :	15.42	20.80	23.67	15.42	20.80	23.67
Natural Per., vessel	1098	1098	1098	438	438	438
Rayleigh Factor	1.07	1.07	1.07	1.27	1.27	1.27
Actual surge/sway, max. single amplitude						
Xs, bow seas :	6.13	9.20	11.88	7.26	10.89	14.07
Xs, quarter seas :	7.67	9.97	13.03	9.08	11.80	15.43
Ys, quarter seas :	11.88	15.33	18.40	14.07	18.16	21.79
Ys, beam seas :	16.48	22.23	25.30	19.52	26.33	29.96

	SALM			CALM		
	2-year	10-year	100-year	2-year	10-year	100-year
Stiffness (kips/ft) :	*1.4*	1.4	1.4	*0.8*	0.8	0.8
Displacement (LT)	292	292	292	400	400	400
Sig. Wave Height (ft)	14.5	18.5	23	14.5	18.5	23
Reference surge/sway, rms						
Xs, bow seas :	2.4	2.65	2.8	2.4	2.65	2.8
Xs, quarter seas :	1.25	1.35	1.4	1.25	1.35	1.4
Ys, beam seas :	2.2	2.7	3.1	2.2	2.7	3.1
Actual surge/sway, rms						
Xs, bow seas :	8.61	9.50	10.04	11.38	12.57	13.28
Xs, quarter seas :	4.48	4.84	5.02	5.93	6.40	6.64
Ys, beam seas :	7.89	9.68	11.12	10.44	12.81	14.70
Actual surge/sway, sig. single amplitude						
Xs, bow seas :	17.21	19.00	20.08	22.77	25.14	26.56
Xs, quarter seas :	8.96	9.68	10.04	11.86	12.81	13.28
Ys, beam seas :	15.78	19.36	22.23	20.87	25.61	29.41
Natural Per., vessel	43.2	43.2	43.2	66.9	66.9	66.9
Rayleigh Factor	1.66	1.66	1.66	1.59	1.59	1.59
Actual surge/sway, max. single amplitude						
Xs, bow seas :	28.60	31.57	33.36	37.83	41.77	44.13
Xs, quarter seas :	9.58	10.35	10.73	12.68	13.69	14.20
Ys, beam seas :	16.87	20.70	23.77	22.31	27.38	31.44

Wave frequency motions were calculated by the use of the ship motions program SEAWAY. The reader is referred to the SEAWAY manual for a detailed explanation of this program. The program requires two input files : a file describing the hull form of the ship in question, and a file describing the environmental conditions and the ship loading. The program produces one output file, describing wave frequency motions. Input files are given below for the CALM buoy, the SALM buoy, and the San Diego class tanker in light ship and full load conditions. Output files are given for the four input cases.

CALM Hull Input File

```
4.12
CALM buoy  60.0 x 15.0 dia*draft (18.3*4.57)
 4.5700  0.0000  18.3000  0.3050
   10
 0.6098  0.6098  1.5244  1.5244  4.5732  4.5732  1.5244  1.5244
 0.6098  0.6098
    1
   1.0    4    0.0
   0.00   0.0   1.17   0.0   2.34   0.0   2.34   2.500
   2.34   5.00
   2.0    4    0.0
   0.00   0.0   1.99   0.0   3.99   0.0   3.99   2.500
   3.99   5.00
   3.0    4    0.0
   0.00   0.0   2.53   0.0   5.06   0.0   5.06   2.500
   5.06   5.00
   4.0    4    0.0
   0.00   0.0   3.41   0.0   6.82   0.0   6.82   2.500
   6.82   5.00
   5.0    4    0.0
   0.00   0.0   3.96   0.0   7.92   0.0   7.92   2.500
   7.92   5.00
   6.0    4    0.0
   0.00   0.0   4.57   0.0   9.15   0.0   9.15   2.500
   9.15   5.00
   7.0    4    0.0
   0.00   0.0   3.96   0.0   7.92   0.0   7.92   2.500
   7.92   5.00
   8.0    4    0.0
   0.00   0.0   3.41   0.0   6.82   0.0   6.82   2.500
   6.82   5.00
   9.0    4    0.0
   0.00   0.0   2.53   0.0   5.06   0.0   5.06   2.500
   5.06   5.00
   10.0   4    0.0
   0.00   0.0   1.99   0.0   3.99   0.0   3.99   2.500
   3.99   5.00
   11.0   4    0.0
   0.00   0.0   1.17   0.0   2.34   0.0   2.34   2.500
```

```
  2.34    5.00
 1.0000  1.0000  1.0000
*** End of file ***
```

CALM Environment Input File

```
   4.12
CALM buoy with spring
    +1      +1       0       +1      0
   4.573   0.000   0.000   304.878 1.025E+00
   123456    1       6       +5      0
    1
   0.0
    1
   180.0
   2.500     1     0.200    1.700  0.033333
   1.474
   +6.00   +7.561   4.750    4.750
    0
    3
   5.000
   0.0    61.250  105.000
    0
    1
   9.00    0.0     0.0
   11.7    0.0     0.0
   -1
  9.000   0.000   4.000
    4
   +2
   4.76   12.00
   6.06   13.00
   7.53   14.00
   8.84   15.00
    0
*** End of file ***
```

CALM Output File

```
# # # # # # # # # # # # # # # # # # # # # # # # # # # # # # #
# Program: SEAWAY                              Journee #
#                                             #
# STRIPTHEORY CALCULATIONS OF MOTIONS AND LOADS IN A SEAWAY #
#                                             #
#                Release 4.12                    #
#                (31-07-1993)                    #
# # # # # # # # # # # # # # # # # # # # # # # # # # # # # # #

User: University of California, Berkeley, U.S.A.
INPUT DATA
----------

CALM buoy with spring

PRINT-CODE INPUT DATA .............. KPR(1) :      1
```

```
PRINT-CODE GEOMETRIC DATA .......... KPR(2) :    1
PRINT-CODE HYDRODYNAMIC COEFFICIENTS KPR(3) :    0
PRINT-CODE FREQUENCY CHARACTERISTICS KPR(4) :    1
PRINT-CODE SPECTRAL DATA ........... KPR(5) :    0

ACTUAL MIDSHIP DRAFT ................ DRAFT :  4.573 m
ACTUAL TRIM BY STERN ................. TRIM :  0.000 m
DUMMY VALUE, FOR THE TIME BEING ...... DIST :  0.000

WATER DEPTH ......................... DEPTH :  304.9 m
DENSITY OF WATER ...................... RHO :  1.025 ton/m3

DEGREES OF FREEDOM CODE ............... MOT : 123456
VERSION-CODE OF STRIP THEORY METHOD ... KTH :      1
NUMBER OF TERMS IN POTENTIAL SERIES .. MSER :      6
CODE OF USED 2-D APPROXIMATION ....... KCOF :      5
NUMBER OF "FREE-CHOICE" SECTIONS ...... NFR :      0

NUMBER OF FORWARD SPEEDS ............... NV :      1
FORWARD SPEEDS (kn) ............... VK(NV) :   0.00

NUMBER OF WAVE DIRECTIONS ............. NWD :      1
WAVE DIRECTIONS (deg off stern) WAVDIR(NWD) :  180.0

MAX. FREQ. OF ENCOUNTER IN SERIES . FREQMAX :  2.500 rad/sec   (range =  0.000 -  3.125
rad/sec)
CODE FOR WAVE FREQUENCY INPUT ....... KOMEG :      1
MINIMUM CIRCULAR WAVE FREQUENCY ..... OMMIN :  0.200 rad/sec
MAXIMUM CIRCULAR WAVE FREQUENCY ..... OMMAX :  1.700 rad/sec
INCREMENT IN WAVE FREQUENCIES ....... OMINC :  0.033 rad/sec

WAVE AMPLITUDE FOR LINEARISATION ... WAVAMP :  1.474 m


INPUT DATA (continued)
~~~~~~~~~~~~~~~~~~~~~~
BASE LINE TO CENTRE OF GRAVITY ... +GKGM=KG :  6.000 m

MASS-GYRADIUS k-xx ................. GYR(1) :  7.561 m
MASS-GYRADIUS k-yy ................. GYR(2) :  4.750 m
MASS-GYRADIUS k-zz ................. GYR(3) :  4.750 m

NUMBER OF LOAD-CALCULATION SECTIONS .. NBTM :      0

CODE OF ROLL DAMPING INPUT ............ KRD :      3
AVERAGE ROLL AMPLITUDE ............. ROLAMP :  5.000 deg
HEIGHT OF BILGE KEEL .................. HBK :  0.000 m
DISTANCE OF A.P.P. TO AFT END B.K. ... XBKA :  61.25 m
DISTANCE OF A.P.P. TO FORWARD END B.K. XBKF : 105.00 m

CODE OF ANTI-ROLLING DEVICES ......... KARD :      0

NUMBER OF LINEAR SPRINGS ............. NCAB :      1
```

```
COORDINATES AND LINEAR SPRING COEFFICIENTS : 9.000   0.000   0.000 1.170E+01
0.000E-01 0.000E-01

NUMBER OF DISCRETE POINTS ........... NPTS :    -1
COORDINATES OF POINTS (m) .. PTSXYZ(NPTS,3) :  9.00  0.00  4.00

NUMBER OF SEA STATES ................ NSEA :     4
CODE OF IRREGULAR SEA DESCRIPTION .... KSEA :    2
WAVE HEIGHTS (m) HW(K) / PERIODS (s) TW(K) :  4.76  12.00
                                   6.06  13.00
                                   7.53  14.00
                                   8.84  15.00

INPUT-CODE OF CRITERA FOR SHIPMOTIONS  KRIT :     0


CALM buoy with spring                                Execution: 18-04-1994 , 18:28
SEAWAY-4.12

GEOMETRICAL HULLFORM DATA
~~~~~~~~~~~~~~~~~~~~~~~~~

ACTUAL MIDSHIP DRAFT (T) ................ :  4.573 m
ACTUAL TRIM BY STERN .... ................ :  0.000 m

LENGTH BETWEEN PERPENDICULARS (Lpp) ...... : 18.300 m
REAR SECTION TO A.P.P. .................. :  0.305 m

WATERLINE : LENGTH (Lwl) ................ : 17.683 m
            BEAM (B) .................... : 18.300 m
            AREA ........................ :    261 m2
          AREA COEFFICIENT (Lpp) ....... : 0.7785
          AREA COEFFICIENT (Lwl) ....... : 0.8056
          CENTROID TO A.P.P. ........... :  8.537 m   ( -0.613 m or -3.35 % Lpp/2)
          CENTROID TO REAR SECTION ..... :  8.842 m   ( +0.000 m or +0.00 % Lwl/2)

DISPLACEMENT : VOLUME .................. :    1304 m3
            BLOCKCOEFFICIENT (Lpp) .... : 0.8516
            BLOCKCOEFFICIENT (Lwl) .... : 0.8813
            CENTROID TO A.P.P. ........ :  8.537 m   ( -0.613 m or -3.35 % Lpp/2)
            CENTROID TO REAR SECTION .. :  8.842 m   ( +0.000 m or +0.00 % Lwl/2)
            CENTROID TO WATERLINE ..... :  2.501 m
            CENTROID TO KEELLINE ...... :  2.072 m
            MIDSHIP SECTION COEFFICIENT : 1.0913
            LONG. PRISMATIC COEFFICIENT : 0.7804
            VERT. PRISMATIC COEFFICIENT : 1.0940
             RATIO Lpp/B .............. :  1.000
             RATIO Lwl/B .............. :  0.966
             RATIO B/T ................ :  4.002
            WETTED SURFACE HULL ....... :    484 m2


STABILITY PARAMETERS
~~~~~~~~~~~~~~~~~~~~
```

```
KB ............ :  2.072 m
KG ............ :  6.000 m
BM-TRANSVERSE . :  4.229 m
GM-TRANSVERSE . :  0.300 m
BM-LONGITUDINAL :  4.092 m
GM-LONGITUDINAL :  0.164 m
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CALM buoy with spring                                    Execution: 18-04-1994 , 18:28
SEAWAY-4.12

SECTIONAL HULLFORM DATA
~~~~~~~~~~~~~~~~~~~~~~~

STATION  X-APP  HALF  HALF  DRAFT   AREA  AREA   KB   BO WETTED
 NUMBER        CL-CL  WIDTH         COEFF        LENGTH
  (-)    (m)    (m)    (m)    (m)    (m2)   (-)   (m)  (m)   (m)
  1.00  -0.305  0.000  2.340  5.003  23.4130 1.0000 2.072 2.501 14.685
  2.00   0.305  0.000  3.990  5.003  39.9221 1.0000 2.072 2.501 17.985
  3.00   0.915  0.000  5.060  5.003  50.6280 1.0000 2.072 2.501 20.125
  4.00   2.439  0.000  6.820  5.003  68.2378 1.0000 2.072 2.501 23.645
  5.00   3.963  0.000  7.920  5.003  79.2439 1.0000 2.072 2.501 25.845
  6.00   8.537  0.000  9.150  5.003  91.5507 1.0000 2.072 2.501 28.305
  7.00  13.110  0.000  7.920  5.003  79.2439 1.0000 2.072 2.501 25.845
  8.00  14.634  0.000  6.820  5.003  68.2378 1.0000 2.072 2.501 23.645
  9.00  16.159  0.000  5.060  5.003  50.6280 1.0000 2.072 2.501 20.125
 10.00  16.768  0.000  3.990  5.003  39.9221 1.0000 2.072 2.501 17.985
 11.00  17.378  0.000  2.340  5.003  23.4130 1.0000 2.072 2.501 14.685
```

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CALM buoy with spring                                    Execution: 18-04-1994 / 18:28
SEAWAY-4.12

TWO-PARAMETER LEWIS CONFORMAL MAPPING COEFFICIENTS
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STATION  X-APP  HALF  DRAFT  AREA    M(S)   A(-1)   A(1)   A(3)   RMS
HULLFORM REMARKS WITH REGARD
 NUMBER        WIDTH        COEFF     I                        TO LEWIS
CONFORMAL MAPPING
  (-)    (m)   (m)    (m)    (-)     (m)    (-)     (-)     (-)    (m)
  1.00  -0.305  2.340  5.003  1.0000  4.1765 +1.0000 -0.3188 -0.1209  0.138  BULBOUS
  2.00   0.305  3.990  5.003  1.0000  5.2190 +1.0000 -0.0970 -0.1384  0.109  TUNNELED-
BULBOUS
  3.00   0.915  5.060  5.003  1.0000  5.8528 +1.0000 +0.0049 -0.1403  0.113  TUNNELED-
BULBOUS
  4.00   2.439  6.820  5.003  1.0000  6.8484 +1.0000 +0.1327 -0.1368  0.150  TUNNELED-
BULBOUS
  5.00   3.963  7.920  5.003  1.0000  7.4505 +1.0000 +0.1958 -0.1327  0.189  TUNNELED
  6.00   8.537  9.150  5.003  1.0000  8.1115 +1.0000 +0.2556 -0.1276  0.235  TUNNELED
  7.00  13.110  7.920  5.003  1.0000  7.4505 +1.0000 +0.1958 -0.1327  0.189  TUNNELED
  8.00  14.634  6.820  5.003  1.0000  6.8484 +1.0000 +0.1327 -0.1368  0.150  TUNNELED-
BULBOUS
```

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  9.00  16.159  5.060  5.003  1.0000   5.8528  +1.0000  +0.0049  -0.1403   0.113   TUNNELED-
BULBOUS
  10.00  16.768  3.990  5.003  1.0000   5.2190  +1.0000  -0.0970  -0.1384   0.109   TUNNELED-
BULBOUS
  11.00  17.378  2.340  5.003  1.0000   4.1765  +1.0000  -0.3188  -0.1209   0.138   BULBOUS


CALM buoy with spring                                      Execution: 18-04-1994 / 18:28
SEAWAY-4.12

N-PARAMETER CLOSE-FIT CONFORMAL MAPPING COEFFICIENTS
----------------------------------------------------

STATION   M(S)  A(-1)   A(1)   A(3)   A(5)   A(7)   A(9)   A(11)  A(13)  A(15)  A(17)
A(19)    RMS
  (-)     (m)    (-)    (-)    (-)    (-)    (-)    (-)    (-)    (-)    (-)    (-)    (m)
  1.00  +4.2559  +1.0000  -0.3345  -0.1430  +0.0274  +0.0057  -0.0058  +0.0000  +0.0000  +0.0000
+0.0000  +0.0000   0.014
  2.00  +5.2786  +1.0000  -0.1031  -0.1589  +0.0096  +0.0108  -0.0024  +0.0000  +0.0000  +0.0000
+0.0000  +0.0000   0.025
  3.00  +5.9161  +1.0000  +0.0052  -0.1610  -0.0005  +0.0115  +0.0001  +0.0000  +0.0000  +0.0000
+0.0000  +0.0000   0.032
  4.00  +6.9291  +1.0000  +0.1408  -0.1570  -0.0127  +0.0101  +0.0031  +0.0000  +0.0000  +0.0000
+0.0000  +0.0000   0.028
  5.00  +7.5555  +1.0000  +0.2071  -0.1540  -0.0184  +0.0092  +0.0043  +0.0000  +0.0000  +0.0000
+0.0000  +0.0000   0.025
  6.00  +8.2437  +1.0000  +0.2695  -0.1492  -0.0231  +0.0076  +0.0052  +0.0000  +0.0000  +0.0000
+0.0000  +0.0000   0.026
  7.00  +7.5555  +1.0000  +0.2071  -0.1540  -0.0184  +0.0092  +0.0043  +0.0000  +0.0000  +0.0000
+0.0000  +0.0000   0.025
  8.00  +6.9291  +1.0000  +0.1408  -0.1570  -0.0127  +0.0101  +0.0031  +0.0000  +0.0000  +0.0000
+0.0000  +0.0000   0.028
  9.00  +5.9161  +1.0000  +0.0052  -0.1610  -0.0005  +0.0115  +0.0001  +0.0000  +0.0000  +0.0000
+0.0000  +0.0000   0.032
  10.00  +5.2786  +1.0000  -0.1031  -0.1589  +0.0096  +0.0108  -0.0024  +0.0000  +0.0000  +0.0000
+0.0000  +0.0000   0.025
  11.00  +4.2559  +1.0000  -0.3345  -0.1430  +0.0274  +0.0057  -0.0058  +0.0000  +0.0000  +0.0000
+0.0000  +0.0000   0.014


CALM buoy with spring                                      Execution: 18-04-1994 / 18:28
SEAWAY-4.12

NATURAL ROLL AND COEFFICIENTS AT FIXED AMPLITUDE
------------------------------------------------

FORWARD SHIP SPEED . (kn) :   0.00
MEAN ROLL AMPLITUDE (deg) :  5.000

NATURAL ROLL PERIOD . (s) :  30.749
NATURAL FREQUENCY . (r/s) :   0.204

LINEAR EQUIVALENT GM  (m) :   0.308
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MASS, k-phi-phi ..... (m) :   8.509
COMPONENTS k-phi-phi:
  SOLID MASS PART .. (m) :   7.561
  2-D POTENTIAL PART (m) :   3.903

DAMPING, kappa ...... (-) :  0.0142
COMPONENTS kappa:
  2-D POTENTIAL PART (-) :  0.0000
  SPEED EFFECT PART  (-) :  0.0000
  SKIN FRICTION PART (-) :  0.0007
  EDDY MAKING PART . (-) :  0.0135
  LIFT MOMENT PART . (-) :  0.0000
  BILGE KEEL PART .. (-) :  0.0000

(NON)LINEAR DAMPING COEFFICIENTS:
  Kappa-1 .......... (-) :  0.0005
  Kappa-2 .......... (-) :  0.1577


NATURAL HEAVE AT ZERO FORWARD SPEED
-----------------------------------

NATURAL HEAVE PERIOD  (s) :   6.584
NATURAL FREQUENCY   (r/s) :   0.954


NATURAL PITCH AT ZERO FORWARD SPEED
-----------------------------------

NATURAL PITCH PERIOD  (s) :  44.277
NATURAL FREQUENCY   (r/s) :   0.142


CALM buoy with spring                                   Execution: 18-04-1994 / 18:28
SEAWAY-4.12

FREQUENCY CHARACTERISTICS OF BASIC MOTIONS      FORWARD SPEED =  0.00 kn
------------------------------------------     WAVE DIRECTION =  +180 deg off stern

 WAVE  SQRT  ENC   ...SURGE...   ...SWAY....   ...HEAVE...   ...ROLL....   ...PITCH...
....YAW....   ADDED RESISTANCES
 FREQ SL/WL  FREQ    AMPL PHASE    AMPL PHASE    AMPL PHASE    AMPL PHASE
AMPL PHASE    AMPL PHASE   GER/BEU    BOESE
(r/s)  (-) (r/s)  (m/m) (deg)  (m/m) (deg)  (m/m) (deg)  (deg/m) (deg)  (deg/m) (deg)  (deg/m) (deg)
(kN/m2)  (kN/m2)
 0.200 0.116 0.200    1.270  91.9    0.000  89.9    1.001 359.7    0.000  89.3    1.422 307.2    0.000
211.5   2.49E-03  2.80E+00
 0.233 0.131 0.233    1.146  89.7    0.000  90.1    1.001 359.9    0.000 276.9    0.629 315.7    0.000
180.0   7.26E-04  8.51E-01
 0.267 0.147 0.267    1.084  90.6    0.000  90.0    1.002 359.9    0.000 269.6    0.459 180.0    0.000
180.1   2.01E-03 -5.56E-01
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 0.300 0.164 0.300   1.024  90.0   0.000  90.0   1.003 359.8   0.000 269.0   0.838 285.7   0.000
179.9  1.77E-03  2.32E-01
 0.333 0.182 0.333   0.999  90.0   0.000  90.0   1.004 359.7   0.000 272.7   0.837 278.5   0.000
180.0  2.53E-03  1.29E-01
 0.367 0.200 0.367   0.982  89.9   0.000  90.0   1.006 359.6   0.000 272.1   0.784 272.8   0.000
179.9  4.31E-03  5.89E-02
 0.400 0.218 0.400   0.965  90.1   0.000  90.0   1.007 359.4   0.000  85.9   0.829 269.3   0.000
180.0  8.59E-03  2.28E-02
 0.433 0.236 0.433   0.950  90.3   0.000  90.0   1.010 359.2   0.000  88.1   0.881 265.3   0.000
179.9  1.68E-02 -2.92E-02
 0.467 0.254 0.467   0.935  90.4   0.000  90.1   1.012 358.9   0.000  89.3   0.935 262.6   0.000
179.9  3.15E-02 -4.42E-02
 0.500 0.272 0.500   0.919  90.6   0.000  90.1   1.015 358.6   0.000  89.3   1.012 260.8   0.000
179.9  5.58E-02 -1.71E-02
 0.533 0.291 0.533   0.903  90.7   0.000  90.1   1.019 358.2   0.000  89.3   1.089 259.7   0.000
179.8  9.50E-02  8.26E-02
 0.567 0.309 0.567   0.886  90.9   0.000  90.2   1.024 357.6   0.000  89.4   1.161 258.7   0.000
179.8  1.57E-01  2.87E-01
 0.600 0.327 0.600   0.870  91.1   0.000  90.2   1.029 357.0   0.000  89.4   1.231 258.0   0.000
179.7  2.53E-01  6.41E-01
 0.633 0.345 0.633   0.852  91.3   0.000  90.2   1.035 356.2   0.000  89.5   1.300 257.5   0.000
179.6  3.96E-01  1.21E+00
 0.667 0.363 0.667   0.834  91.5   0.000  90.3   1.043 355.2   0.000  89.7   1.365 257.4   0.000
179.5  6.09E-01  2.11E+00
 0.700 0.381 0.700   0.815  91.8   0.000  90.4   1.053 353.9   0.000  89.9   1.426 257.7   0.000
179.4  9.25E-01  3.47E+00
 0.733 0.400 0.733   0.795  92.0   0.000  90.4   1.064 352.4   0.000  90.1   1.486 258.0   0.000
179.3  1.39E+00  5.44E+00
 0.767 0.418 0.767   0.775  92.3   0.000  90.5   1.077 350.3   0.000  90.3   1.543 258.6   0.000
179.1  2.07E+00  8.31E+00
 0.800 0.436 0.800   0.753  92.6   0.000  90.6   1.092 347.6   0.000  90.6   1.598 259.4   0.000
179.0  3.08E+00  1.25E+01
 0.833 0.454 0.833   0.731  93.0   0.000  90.7   1.107 343.9   0.000  91.0   1.651 260.6   0.000
178.7  4.58E+00  1.86E+01
 0.867 0.472 0.867   0.708  93.4   0.000  90.8   1.115 339.0   0.000  91.4   1.704 261.8   0.000
178.5  6.76E+00  2.72E+01
 0.900 0.490 0.900   0.684  93.9   0.000  90.9   1.106 332.4   0.000  91.8   1.758 263.1   0.000
178.3  9.75E+00  3.85E+01
 0.933 0.509 0.933   0.659  94.4   0.000  91.0   1.059 324.0   0.000  92.1   1.811 264.5   0.000
178.1  1.33E+01  5.13E+01
 0.967 0.527 0.967   0.634  95.0   0.000  91.1   0.951 314.2   0.000  92.6   1.869 266.2   0.000
177.8  1.64E+01  6.11E+01
 1.000 0.545 1.000   0.608  95.6   0.000  91.3   0.784 305.7   0.000  92.9   1.925 267.7   0.000
177.5  1.72E+01  6.18E+01
 1.033 0.563 1.033   0.581  96.4   0.000  91.4   0.602 301.3   0.000  93.3   1.983 269.2   0.000
177.3  1.57E+01  5.39E+01
 1.067 0.581 1.067   0.554  97.2   0.000  91.6   0.449 303.0   0.000  93.6   2.045 270.8   0.000
177.0  1.32E+01  4.27E+01
 1.100 0.599 1.100   0.527  98.2   0.000  91.8   0.352 310.9   0.000  93.9   2.105 272.3   0.000
176.7  1.07E+01  3.26E+01
 1.133 0.618 1.133   0.500  99.3   0.000  92.0   0.302 322.0   0.000  94.2   2.164 273.6   0.000
176.4  8.82E+00  2.49E+01
 1.167 0.636 1.167   0.473 100.5   0.000  92.2   0.283 332.4   0.000  94.4   2.222 274.9   0.000
176.1  7.40E+00  1.91E+01
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 1.200 0.654 1.200   0.446 101.8   0.000  92.5   0.280 340.6   0.000  94.6   2.281 276.1   0.000
175.8   6.34E+00  1.48E+01
 1.233 0.672 1.233   0.420 103.3   0.000  92.7   0.281 346.3   0.000  94.8   2.335 277.2   0.000
175.6   5.61E+00  1.17E+01
 1.267 0.690 1.267   0.394 105.1   0.000  93.1   0.283 350.1   0.000  95.0   2.384 278.2   0.000
175.3   5.08E+00  9.23E+00
 1.300 0.708 1.300   0.369 107.0   0.000  93.4   0.282 352.7   0.000  95.2   2.428 279.0   0.000
175.1   4.70E+00  7.24E+00
 1.333 0.727 1.333   0.344 109.0   0.000  93.7   0.280 354.6   0.000  95.3   2.467 279.7   0.000
174.9   4.40E+00  5.54E+00
 1.367 0.745 1.367   0.320 111.3   0.000  94.1   0.275 355.9   0.000  95.4   2.497 280.4   0.000
174.7   4.17E+00  4.06E+00
 1.400 0.763 1.400   0.297 113.9   0.000  94.5   0.268 356.9   0.000  95.6   2.519 281.0   0.000
174.5   3.99E+00  2.70E+00
 1.433 0.781 1.433   0.276 116.6   0.000  95.0   0.259 357.6   0.000  95.7   2.532 281.4   0.000
174.4   3.84E+00  1.44E+00
 1.467 0.799 1.467   0.255 119.7   0.000  95.5   0.249 358.2   0.000  95.8   2.535 281.8   0.000
174.3   3.72E+00  2.46E-01
 1.500 0.817 1.500   0.235 123.0   0.000  96.1   0.237 358.6   0.000  96.0   2.528 282.1   0.000
174.2   3.59E+00 -8.89E-01
 1.533 0.836 1.533   0.216 126.6   0.000  96.7   0.225 358.9   0.000  96.1   2.510 282.4   0.000
174.1   3.46E+00 -1.96E+00
 1.567 0.854 1.567   0.199 130.6   0.000  97.5   0.212 359.2   0.000  96.3   2.481 282.6   0.000
174.2   3.35E+00 -2.95E+00
 1.600 0.872 1.600   0.183 134.9   0.000  98.3   0.198 359.4   0.000  96.5   2.441 282.7   0.000
174.2   3.22E+00 -3.86E+00
 1.633 0.890 1.633   0.168 139.6   0.000  99.4   0.184 359.5   0.000  96.6   2.391 282.8   0.000
174.3   3.08E+00 -4.67E+00
 1.667 0.908 1.667   0.154 144.7   0.000 100.6   0.170 359.6   0.000  96.8   2.330 282.9   0.000
174.4   2.94E+00 -5.37E+00
 1.700 0.926 1.700   0.141 150.2   0.000 102.1   0.156 359.7   0.000  97.0   2.258 282.9   0.000
174.5   2.81E+00 -5.92E+00
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CALM buoy with spring                                   Execution: 18-04-1994 / 18:28
SEAWAY-4.12

FREQUENCY CHARACTERISTICS OF MOTIONS POINTS        FORWARD SPEED =  0.00 kn
-------------------------------------------       WAVE DIRECTION = +180 deg off stern
POINT NR =     01
X-APP   =  9.000 m
Y-CL    =  0.000 m
Z-BL    =  4.000 m

                  ...........ABSOLUTE MOTIONS...........   ..REL MOT..
 WAVE  SQRT   ENC    .....X.....    .....Y.....   .....Z.....   .....Z.....
 FREQ SL/WL  FREQ    AMPL PHASE    AMPL PHASE    AMPL PHASE    AMPL PHASE
(r/s)  (-) (r/s)   (m/m) (deg)   (m/m) (deg)   (m/m) (deg)   (m/m) (deg)
0.200 0.116 0.200    1.311  93.2   0.000  89.8   0.994   0.2   0.062 182.0
0.233 0.131 0.233    1.162  90.4   0.000  90.0   0.997   0.1   0.087 179.7
0.267 0.147 0.267    1.084  89.8   0.000  90.2   1.006 359.9   0.121 177.5
0.300 0.164 0.300    1.052  90.4   0.000  90.2   1.001   0.2   0.143 180.0
0.333 0.182 0.333    1.028  90.2   0.000  90.3   1.003   0.1   0.173 178.9
0.367 0.200 0.367    1.009  90.0   0.000  90.4   1.005 360.0   0.206 178.0
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0.400 0.218 0.400   0.994  90.1   0.000  90.4   1.007 359.8   0.241 177.2
0.433 0.236 0.433   0.980  90.2   0.000  90.5   1.010 359.6   0.277 176.4
0.467 0.254 0.467   0.967  90.1   0.000  90.6   1.013 359.4   0.314 175.4
0.500 0.272 0.500   0.954  90.2   0.000  90.7   1.017 359.1   0.353 174.4
0.533 0.291 0.533   0.940  90.3   0.000  90.9   1.020 358.7   0.393 173.3
0.567 0.309 0.567   0.926  90.4   0.000  91.0   1.025 358.2   0.435 171.9
0.600 0.327 0.600   0.911  90.5   0.000  91.1   1.031 357.5   0.479 170.4
0.633 0.345 0.633   0.896  90.6   0.000  91.3   1.037 356.8   0.525 168.5
0.667 0.363 0.667   0.880  90.8   0.000  91.5   1.045 355.8   0.573 166.4
0.700 0.381 0.700   0.863  91.0   0.000  91.7   1.054 354.6   0.625 163.7
0.733 0.400 0.733   0.845  91.2   0.000  91.9   1.065 353.0   0.682 160.5
0.767 0.418 0.767   0.827  91.4   0.000  92.1   1.078 351.0   0.745 156.6
0.800 0.436 0.800   0.807  91.7   0.000  92.3   1.091 348.3   0.817 151.7
0.833 0.454 0.833   0.787  92.1   0.000  92.6   1.105 344.6   0.899 145.3
0.867 0.472 0.867   0.766  92.5   0.000  92.8   1.112 339.7   0.991 137.2
0.900 0.490 0.900   0.744  93.0   0.000  93.1   1.101 333.1   1.085 126.5
0.933 0.509 0.933   0.721  93.5   0.000  93.4   1.052 324.7   1.162 113.0
0.967 0.527 0.967   0.698  94.2   0.000  93.7   0.941 314.9   1.190  96.5
1.000 0.545 1.000   0.674  94.8   0.000  94.1   0.772 306.4   1.136  79.3
1.033 0.563 1.033   0.650  95.6   0.000  94.5   0.589 302.1   1.022  63.4
1.067 0.581 1.067   0.625  96.5   0.000  94.8   0.435 304.2   0.889  49.8
1.100 0.599 1.100   0.600  97.4   0.000  95.3   0.339 312.7   0.773  39.4
1.133 0.618 1.133   0.575  98.5   0.000  95.7   0.291 324.5   0.684  31.3
1.167 0.636 1.167   0.550  99.7   0.000  96.2   0.274 335.6   0.620  25.0
1.200 0.654 1.200   0.526 101.0   0.000  96.7   0.273 344.1   0.575  20.1
1.233 0.672 1.233   0.501 102.3   0.000  97.2   0.275 349.9   0.549  16.5
1.267 0.690 1.267   0.477 103.9   0.000  97.7   0.277 353.9   0.534  13.7
1.300 0.708 1.300   0.453 105.5   0.000  98.3   0.277 356.6   0.530  11.7
1.333 0.727 1.333   0.429 107.2   0.000  98.9   0.275 358.6   0.533  10.3
1.367 0.745 1.367   0.406 109.0   0.000  99.6   0.270   0.1   0.542   9.3
1.400 0.763 1.400   0.384 110.9   0.000 100.3   0.263   1.2   0.557   8.6
1.433 0.781 1.433   0.362 113.0   0.000 101.0   0.255   2.1   0.574   8.1
1.467 0.799 1.467   0.340 115.1   0.000 101.8   0.245   2.9   0.594   7.9
1.500 0.817 1.500   0.319 117.3   0.000 102.7   0.233   3.5   0.617   7.7
1.533 0.836 1.533   0.298 119.7   0.000 103.7   0.221   4.0   0.641   7.7
1.567 0.854 1.567   0.278 122.2   0.000 104.8   0.208   4.5   0.665   7.7
1.600 0.872 1.600   0.259 124.8   0.000 106.1   0.194   5.0   0.691   7.8
1.633 0.890 1.633   0.240 127.5   0.000 107.4   0.181   5.5   0.716   7.9
1.667 0.908 1.667   0.221 130.5   0.000 109.0   0.167   6.0   0.741   8.1
1.700 0.926 1.700   0.203 133.6   0.000 110.9   0.153   6.4   0.766   8.3


CALM buoy with spring                              Execution: 18-04-1994 / 18:28
SEAWAY-4.12

STATISTICS OF BASIC MOTIONS               FORWARD SPEED =  0.00 kn
---------------------------              WAVE DIRECTION =  +180 deg off stern

...........SEA..........    ....................SIGNIFICANT VALUES OF BASIC
MOTIONS......................      MEAN ADDED
....INPUT... .CALCULATED.  ...SURGE...  ....SWAY...  ...HEAVE...  ....ROLL...  ...PITCH...
....YAW....    RESISTANCE
HEIGHT  PER  HEIGHT  PER   AMPL  PER   AMPL  PER   AMPL  PER   AMPL  PER
AMPL  PER   AMPL  PER  GER/BEU  BOESE
```

```
 (m)  (s)    (m)  (s)    (m)  (s)    (m)  (s)    (m)  (s)  (deg)  (s)  (deg)  (s)  (deg)  (s)    (kN)
(kN)
 4.76 12.00   4.75 12.16   2.16 13.13   0.00 12.87   2.39 12.47   0.00  7.27   2.64  9.67   0.00
7.89     2.3    7.9
 6.06 13.00   6.05 13.14   2.82 14.12   0.00 13.84   3.05 13.39   0.00  7.56   3.17 10.39   0.00
8.17     2.8    9.5
 7.53 14.00   7.52 14.12   3.58 15.13   0.00 14.82   3.79 14.33   0.00  8.34   3.73 11.11   0.00
8.43     3.3   11.1
 8.84 15.00   8.83 15.10   4.28 16.17   0.00 15.81   4.44 15.27   0.00 10.91   4.16 11.83   0.00
8.67     3.4   11.8
```

```
CALM buoy with spring                                  Execution: 18-04-1994 / 18:28
SEAWAY-4.12

STATISTICS OF MOTIONS IN POINTS            FORWARD SPEED =  0.00 kn
-------------------------------           WAVE DIRECTION =  +180 deg off stern
POINT NR =     01
X-APP    =   9.000 m
Y-CL     =   0.000 m
Z-BL     =   4.000 m
                    .......................................SIGNIFICANT VALUES
OF.........................................
                    .........DISPLACEMENTS.........     ..........VELOCITIES...........
.........ACCELERATIONS..........
.....SEA....      ....X....   ....Y....   ....Z....      ....X....   ....Y....   ....Z....      ....X....   ....Y....   ....Z....
HEIGHT  PER     AMPL  PER   AMPL  PER   AMPL  PER     AMPL  PER   AMPL  PER   AMPL
PER     AMPL  PER   AMPL  PER   AMPL  PER
 (m)  (s)       (m)  (s)   (m)  (s)   (m)  (s)     (m/s) (s)  (m/s)  (s)  (m/s)  (s)    (m/s2)  (s) (m/s2)  (s)
(m/s2)  (s)
 4.76 12.00      2.25 13.0   0.00 12.8   2.39 12.5      1.13 10.8   0.00 10.5   1.26 10.5      0.30 7.54
0.00 6.28   0.79 8.74
 6.06 13.00      2.92 14.0   0.00 13.7   3.05 13.4      1.37 11.4   0.00 11.1   1.50 11.0      0.33 7.80
0.00 6.28   0.90 9.00
 7.53 14.00      3.69 15.0   0.00 14.7   3.79 14.3      1.62 12.1   0.00 11.7   1.75 11.6      0.38 8.24
0.00 7.50   1.00 9.25
 8.84 15.00      4.41 16.0   0.00 15.7   4.44 15.3      1.82 12.8   0.00 12.4   1.93 12.2      0.41 8.94
0.00 9.02   1.06 9.48

                 ........VERTICAL RELATIVE MOTIONS........
                ..SIGNIFICANT VALUES OF...   .EXCEEDING.
.....SEA....      DISPLACEMENT    .VELOCITY.   ....Z-BL...
HEIGHT  PER       AMPL  PER      AMPL  PER     PROB  NR/H
 (m)  (s)         (m)  (s)   (m/s)  (s)      (%)  (1/h)
 4.76 12.00       1.03  8.87    0.69  7.44     54.0 230.0
 6.06 13.00       1.18  9.20    0.76  7.50     62.5 258.4
 7.53 14.00       1.33  9.52    0.82  7.55     69.0 277.0
 8.84 15.00       1.42  9.83    0.85  7.60     72.2 282.2
```

SALM Hull Input File

```
4.12
SALM buoy   15.0 x 70.0 dia*draft (4.573x21.34)
  21.340   0.0000  4.57300   0.0763
```

```
   10
  0.1525  0.1525  0.3811  0.3811  1.1433  1.1433  0.3811  0.3811
  0.1525  0.1525
   1
   1.0     4     0.0
   0.00    0.0   0.295    0.0    0.585    0.0    0.585   10.00
   0.585  21.34
   2.0     4     0.0
   0.00    0.0   0.50     0.0    1.00     0.0    1.00    10.00
   1.00   21.34
   3.0     4     0.0
   0.00    0.0   0.63     0.0    1.265    0.0    1.265   10.00
   1.265  21.34
   4.0     4     0.0
   0.00    0.0   0.85     0.0    1.705    0.0    1.705   10.00
   1.705  21.34
   5.0     4     0.0
   0.00    0.0   0.90     0.0    1.98     0.0    1.98    10.00
   1.98   21.34
   6.0     4     0.0
   0.00    0.0   1.145    0.0    2.285    0.0    2.285   10.00
   2.285  21.34
   7.0     4     0.0
   0.00    0.0   0.99     0.0    1.98     0.0    1.98    10.00
   1.98   21.34
   8.0     4     0.0
   0.00    0.0   0.85     0.0    1.705    0.0    1.705   10.00
   1.705  21.34
   9.0     4     0.0
   0.00    0.0   0.63     0.0    1.265    0.0    1.265   10.00
   1.265  21.34
   10.0    4     0.0
   0.00    0.0   0.50     0.0    0.98     0.0    0.98    10.00
   0.98   21.34
   11.0    4     0.0
   0.00    0.0   0.295    0.0    0.585    0.0    0.585   10.00
   0.585  21.34
  1.0000  1.0000  1.0000
*** End of file ***
```

SALM Environment Input File

```
   4.12
SALM buoy with spring
    +1      +1       0       +1       0
   16.77    0.000    0.000   304.878  1.025E+00
   123456     1        6       +5       0
    1
   0.0
    1
   180.0
   2.500      1     0.200    1.700   0.033333
   1.474
   +3.00   +5.561    2.375    2.735
    0
```

```
     3
   5.000
    0.0    61.250   105.000
     0
     1
    4.00     0.0      0.0
    20.4     0.0      0.0
    -1
   9.000    0.000    4.000
     4
    +2
    4.76    12.00
    6.06    13.00
    7.53    14.00
    8.84    15.00
     0
*** End of file ***
```

SALM Output File

```
# # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # #
# Program: SEAWAY                              Journee #
#                                              #
# STRIPTHEORY CALCULATIONS OF MOTIONS AND LOADS IN A SEAWAY #
#                                              #
#                  Release 4.12                   #
#                  (31-07-1993)                   #
# # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # #

User: University of California, Berkeley, U.S.A.
INPUT DATA
----------

SALM buoy with spring

PRINT-CODE INPUT DATA .............. KPR(1) :      1
PRINT-CODE GEOMETRIC DATA .......... KPR(2) :      1
PRINT-CODE HYDRODYNAMIC COEFFICIENTS KPR(3) :      0
PRINT-CODE FREQUENCY CHARACTERISTICS KPR(4) :      1
PRINT-CODE SPECTRAL DATA ........... KPR(5) :      0

ACTUAL MIDSHIP DRAFT ................ DRAFT : 16.770 m
ACTUAL TRIM BY STERN ................. TRIM :  0.000 m
DUMMY VALUE, FOR THE TIME BEING ...... DIST :  0.000

WATER DEPTH .......................... DEPTH :  304.9 m
DENSITY OF WATER ...................... RHO :  1.025 ton/m3

DEGREES OF FREEDOM CODE ............... MOT : 123456
VERSION-CODE OF STRIP THEORY METHOD ... KTH :      1
NUMBER OF TERMS IN POTENTIAL SERIES .. MSER :      6
CODE OF USED 2-D APPROXIMATION ....... KCOF :      5
NUMBER OF "FREE-CHOICE" SECTIONS ...... NFR :      0
```

```
NUMBER OF FORWARD SPEEDS .............. NV :     1
FORWARD SPEEDS (kn) ............... VK(NV) :  0.00

NUMBER OF WAVE DIRECTIONS ............ NWD :     1
WAVE DIRECTIONS (deg off stern) WAVDIR(NWD) : 180.0

MAX. FREQ. OF ENCOUNTER IN SERIES . FREQMAX : 2.500 rad/sec   (range =  0.000 -  3.125
rad/sec)
CODE FOR WAVE FREQUENCY INPUT ....... KOMEG :     1
MINIMUM CIRCULAR WAVE FREQUENCY ..... OMMIN : 0.200 rad/sec
MAXIMUM CIRCULAR WAVE FREQUENCY ..... OMMAX : 1.700 rad/sec
INCREMENT IN WAVE FREQUENCIES ....... OMINC : 0.033 rad/sec

WAVE AMPLITUDE FOR LINEARISATION ... WAVAMP : 1.474 m


INPUT DATA (continued)
~~~~~~~~~~~~~~~~~~~~~~
BASE LINE TO CENTRE OF GRAVITY ... +GKGM=KG : 3.000 m

MASS-GYRADIUS k-xx ................ GYR(1) :  5.561 m
MASS-GYRADIUS k-yy ................ GYR(2) :  2.375 m
MASS-GYRADIUS k-zz ................ GYR(3) :  2.735 m

NUMBER OF LOAD-CALCULATION SECTIONS .. NBTM :     0

CODE OF ROLL DAMPING INPUT ........... KRD :     3
AVERAGE ROLL AMPLITUDE ............ ROLAMP :  5.000 deg
HEIGHT OF BILGE KEEL .................. HBK :  0.000 m
DISTANCE OF A.P.P. TO AFT END B.K. ... XBKA :  61.25 m
DISTANCE OF A.P.P. TO FORWARD END B.K. XBKF : 105.00 m

CODE OF ANTI-ROLLING DEVICES ......... KARD :     0

NUMBER OF LINEAR SPRINGS ............. NCAB :     1
COORDINATES AND LINEAR SPRING COEFFICIENTS  : 4.000    0.000    0.000  2.040E+01
0.000E-01  0.000E-01

NUMBER OF DISCRETE POINTS ........... NPTS :    -1
COORDINATES OF POINTS (m) .. PTSXYZ(NPTS,3) :  9.00  0.00   4.00

NUMBER OF SEA STATES ................ NSEA :     4
CODE OF IRREGULAR SEA DESCRIPTION .... KSEA :     2
WAVE HEIGHTS (m) HW(K) / PERIODS (s) TW(K)  :  4.76  12.00
                                               6.06  13.00
                                               7.53  14.00
                                               8.84  15.00

INPUT-CODE OF CRITERA FOR SHIPMOTIONS  KRIT :     0
```

```
GEOMETRICAL HULLFORM DATA
-------------------------

ACTUAL MIDSHIP DRAFT (T) ................ :  16.770 m
ACTUAL TRIM BY STERN .................... :  0.000 m

LENGTH BETWEEN PERPENDICULARS (Lpp) ...... :  4.573 m
REAR SECTION TO A.P.P. .................. :  0.076 m

WATERLINE : LENGTH (Lwl) ................ :  4.421 m
          BEAM (B) .................... :  4.570 m
           AREA ........................ : 16.2806 m2
         AREA COEFFICIENT (Lpp) ....... :  0.7790
         AREA COEFFICIENT (Lwl) ....... :  0.8058
         CENTROID TO A.P.P. ........... :  2.133 m  ( -0.153 m or -3.35 % Lpp/2)
         CENTROID TO REAR SECTION ..... :  2.209 m  ( -0.001 m or -0.02 % Lwl/2)

DISPLACEMENT : VOLUME ................... :     273 m3
           BLOCKCOEFFICIENT (Lpp) .... :  0.7790
           BLOCKCOEFFICIENT (Lwl) .... :  0.8058
           CENTROID TO A.P.P. ........ :  2.133 m  ( -0.153 m or -3.35 % Lpp/2)
           CENTROID TO REAR SECTION .. :  2.209 m  ( -0.001 m or -0.02 % Lwl/2)
           CENTROID TO WATERLINE ..... :  8.385 m
           CENTROID TO KEELLINE ...... :  8.385 m
           MIDSHIP SECTION COEFFICIENT :  0.9976
           LONG. PRISMATIC COEFFICIENT :  0.7809
           VERT. PRISMATIC COEFFICIENT :  1.0000
            RATIO Lpp/B .............. :  1.001
            RATIO Lwl/B .............. :  0.967
            RATIO B/T ................ :  0.273
           WETTED SURFACE HULL ....... :    204 m2


STABILITY PARAMETERS
--------------------

KB ............ :   8.385 m
KG ............ :   3.000 m
BM-TRANSVERSE . :  0.079 m
GM-TRANSVERSE . :  5.464 m
BM-LONGITUDINAL :  0.076 m
GM-LONGITUDINAL :  5.462 m
```

```
SALM buoy with spring                               Execution: 18-04-1994 , 18:19
SEAWAY-4.12

SECTIONAL HULLFORM DATA
-----------------------

STATION  X-APP  HALF  HALF  DRAFT   AREA   AREA    KB   BO  WETTED
NUMBER          CL-CL WIDTH                COEFF           LENGTH
  (-)     (m)    (m)   (m)   (m)    (m2)    (-)    (m)  (m)   (m)
```

```
  1.00  -0.076  0.000  0.585  16.770  19.6203  1.0000  8.385  8.385  34.708
  2.00   0.076  0.000  1.000  16.770  33.5389  1.0000  8.385  8.385  35.538
  3.00   0.229  0.000  1.265  16.770  42.4268  1.0000  8.385  8.385  36.068
  4.00   0.610  0.000  1.705  16.770  57.1839  1.0000  8.385  8.385  36.948
  5.00   0.991  0.000  1.980  16.770  66.4070  1.0000  8.385  8.385  37.498
  6.00   2.134  0.000  2.285  16.770  76.6365  1.0000  8.385  8.385  38.108
  7.00   3.278  0.000  1.980  16.770  66.4071  1.0000  8.385  8.385  37.498
  8.00   3.659  0.000  1.705  16.770  57.1839  1.0000  8.385  8.385  36.948
  9.00   4.040  0.000  1.265  16.770  42.4268  1.0000  8.385  8.385  36.068
 10.00   4.192  0.000  0.980  16.770  32.8682  1.0000  8.385  8.385  35.498
 11.00   4.345  0.000  0.585  16.770  19.6203  1.0000  8.385  8.385  34.708


SALM buoy with spring                                Execution: 18-04-1994 / 18:19
SEAWAY-4.12

TWO-PARAMETER LEWIS CONFORMAL MAPPING COEFFICIENTS
--------------------------------------------------

STATION  X-APP  HALF  DRAFT  AREA   M(S)  A(-1)   A(1)    A(3)    RMS
HULLFORM REMARKS WITH REGARD
 NUMBER         WIDTH        COEFF                                TO LEWIS
CONFORMAL MAPPING
  (-)    (m)     (m)    (m)    (-)     (m)      (-)      (-)      (-)      (m)
  1.00  -0.076  0.585  16.770  1.0000   8.8348  +1.0000  -0.9160  -0.0178  0.106   BULBOUS
  2.00   0.076  1.000  16.770  1.0000   9.1508  +1.0000  -0.8617  -0.0290  0.171   BULBOUS
  3.00   0.229  1.265  16.770  1.0000   9.3512  +1.0000  -0.8290  -0.0357  0.208   BULBOUS
  4.00   0.610  1.705  16.770  1.0000   9.6817  +1.0000  -0.7780  -0.0459  0.281   BULBOUS
  5.00   0.991  1.980  16.770  1.0000   9.8867  +1.0000  -0.7480  -0.0518  0.297   BULBOUS
  6.00   2.134  2.285  16.770  1.0000  10.1129  +1.0000  -0.7162  -0.0579  0.339   BULBOUS
  7.00   3.278  1.980  16.770  1.0000   9.8867  +1.0000  -0.7480  -0.0518  0.297   BULBOUS
  8.00   3.659  1.705  16.770  1.0000   9.6817  +1.0000  -0.7780  -0.0459  0.281   BULBOUS
  9.00   4.040  1.265  16.770  1.0000   9.3512  +1.0000  -0.8290  -0.0357  0.208   BULBOUS
 10.00   4.192  0.980  16.770  1.0000   9.1356  +1.0000  -0.8642  -0.0285  0.167   BULBOUS
 11.00   4.345  0.585  16.770  1.0000   8.8348  +1.0000  -0.9160  -0.0178  0.106   BULBOUS


SALM buoy with spring                                Execution: 18-04-1994 / 18:19
SEAWAY-4.12

N-PARAMETER CLOSE-FIT CONFORMAL MAPPING COEFFICIENTS
----------------------------------------------------

STATION   M(S)   A(-1)   A(1)   A(3)   A(5)   A(7)   A(9)   A(11)  A(13)  A(15)  A(17)
A(19)   RMS
  (-)     (m)     (-)     (-)     (-)     (-)     (-)     (-)     (-)     (-)     (-)     (-)     (-)     (m)
  1.00  +8.8661 +1.0000 -0.9177 -0.0211 +0.0079 -0.0001 -0.0030 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.082
  2.00  +9.2985 +1.0000 -0.8655 -0.0371 +0.0169 -0.0074 +0.0006 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.052
  3.00  +9.5451 +1.0000 -0.8344 -0.0459 +0.0208 -0.0093 +0.0014 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.044
  4.00  +9.9255 +1.0000 -0.7856 -0.0592 +0.0258 -0.0101 +0.0009 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.052
```

```
  5.00 +10.1497 +1.0000 -0.7571 -0.0665 +0.0276 -0.0099 +0.0009 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.036
  6.00 +10.3885 +1.0000 -0.7265 -0.0738 +0.0296 -0.0091 -0.0003 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.049
  7.00 +10.1497 +1.0000 -0.7571 -0.0665 +0.0276 -0.0099 +0.0009 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.036
  8.00  +9.9255 +1.0000 -0.7856 -0.0592 +0.0258 -0.0101 +0.0009 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.052
  9.00  +9.5451 +1.0000 -0.8344 -0.0459 +0.0208 -0.0093 +0.0014 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.044
 10.00  +9.2796 +1.0000 -0.8680 -0.0364 +0.0166 -0.0072 +0.0006 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.051
 11.00  +8.8661 +1.0000 -0.9177 -0.0211 +0.0079 -0.0001 -0.0030 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.082
```

```
SALM buoy with spring                              Execution: 18-04-1994 / 18:19
SEAWAY-4.12

NATURAL ROLL AND COEFFICIENTS AT FIXED AMPLITUDE
------------------------------------------------

FORWARD SHIP SPEED . (kn) :   0.00
MEAN ROLL AMPLITUDE (deg) :  5.000

NATURAL ROLL PERIOD . (s) :  4.775
NATURAL FREQUENCY . (r/s) :  1.316

LINEAR EQUIVALENT GM  (m) :  5.461

MASS, k-phi-phi ..... (m) :   5.561
COMPONENTS k-phi-phi:
  SOLID MASS PART .. (m) :   5.561
  2-D POTENTIAL PART (m) :   0.000

DAMPING, kappa ...... (-) :  2.6400
COMPONENTS kappa:
  2-D POTENTIAL PART (-) :  2.4314
  SPEED EFFECT PART  (-) :  0.0000
  SKIN FRICTION PART (-) :  0.0005
  EDDY MAKING PART . (-) :  0.2081
  LIFT MOMENT PART . (-) :  0.0000
  BILGE KEEL PART .. (-) :  0.0000

(NON)LINEAR DAMPING COEFFICIENTS:
  Kappa-1 .......... (-) :  0.0003
  Kappa-2 .......... (-) :  2.3873


NATURAL HEAVE AT ZERO FORWARD SPEED
-----------------------------------

NATURAL HEAVE PERIOD  (s) :  8.755
```

```
NATURAL FREQUENCY  (r/s) :  0.718


NATURAL PITCH AT ZERO FORWARD SPEED
-----------------------------------

NATURAL PITCH PERIOD  (s) :  2.694
NATURAL FREQUENCY  (r/s) :  2.332


SALM buoy with spring                                  Execution: 18-04-1994 / 18:19
SEAWAY-4.12

FREQUENCY CHARACTERISTICS OF BASIC MOTIONS      FORWARD SPEED =  0.00 kn
------------------------------------------     WAVE DIRECTION =  +180 deg off stem

 WAVE  SQRT  ENC   ...SURGE...   ...SWAY....   ...HEAVE...   ...ROLL....   ...PITCH...
....YAW....   ADDED RESISTANCES
 FREQ SL/WL  FREQ    AMPL PHASE    AMPL PHASE    AMPL PHASE    AMPL PHASE
AMPL PHASE    AMPL PHASE   GER/BEU    BOESE
(r/s)  (-) (r/s)  (m/m) (deg)  (m/m) (deg)  (m/m) (deg)  (deg/m) (deg)  (deg/m) (deg)  (deg/m) (deg)
(kN/m2)  (kN/m2)
 0.200 0.058 0.200   43.626   8.2    0.000  68.9    1.014 350.6    0.000  96.4   17.665   7.3    0.000
355.7   6.36E-04  5.48E+00
 0.233 0.065 0.233    4.114 151.7    0.000  94.9    1.016 352.4    0.000   7.5    1.631 173.6    0.000
323.6   1.83E-04 -2.34E-01
 0.267 0.073 0.267    1.628  91.4    0.000  85.3    1.012   0.3    0.000 141.9    0.537  23.1    0.000
178.5   7.01E-05  8.95E-02
 0.300 0.082 0.300    1.135 111.4    0.000  91.6    1.018   0.2    0.000  25.9    0.236 225.6    0.000
359.5   1.61E-04 -3.60E-02
 0.333 0.091 0.333    1.357  96.6    0.000  89.2    1.026 358.5    0.000 107.0    0.444 157.5    0.000
160.1   3.69E-04 -7.06E-02
 0.367 0.100 0.367    1.113 100.9    0.000  91.0    1.043   1.8    0.000  75.7    0.037 352.5    0.000
197.2   8.20E-04 -2.68E-02
 0.400 0.109 0.400    1.045 100.6    0.000  87.8    1.059 359.8    0.000  73.2    0.772 257.3    0.000
164.9   1.52E-03 -5.38E-02
 0.433 0.118 0.433    0.928  98.0    0.000  87.0    1.085 359.7    0.000  70.6    0.361 196.7    0.000
188.1   2.97E-03 -1.20E-01
 0.467 0.127 0.467    0.915  91.9    0.000  92.2    1.121 358.8    0.000 104.9    0.608 238.3    0.000
171.1   5.48E-03 -1.03E-01
 0.500 0.136 0.500    0.905  88.3    0.000  88.6    1.175 358.8    0.000  87.4    1.175 231.5    0.000
176.9   1.03E-02 -3.06E-01
 0.533 0.145 0.533    0.891  86.4    0.000  87.0    1.254 358.2    0.000  82.8    1.462 221.5    0.000
147.3   1.93E-02 -4.90E-01
 0.567 0.154 0.567    0.926  79.0    0.000  86.0    1.376 357.6    0.000  83.6    2.555 218.4    0.000
159.9   3.65E-02 -9.85E-01
 0.600 0.163 0.600    0.930  72.9    0.000  79.4    1.574 356.4    0.000  78.0    3.404 210.5    0.000
165.2   7.44E-02 -1.45E+00
 0.633 0.173 0.633    0.994  68.4    0.000  44.0    1.940 354.5    0.000  39.4    4.537 212.0    0.000
167.7   1.72E-01 -1.72E+00
 0.667 0.182 0.667    0.990  63.1    0.000 307.0    2.780 350.1    0.000 300.0    5.278 205.7    0.000
165.6   5.31E-01 -9.10E-01
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 0.700 0.191 0.700    1.003  58.3   0.000 310.5   6.185 332.0   0.000 287.5   6.055 202.6   0.000
160.2   3.84E+00  9.40E+00
 0.733 0.200 0.733    1.072  54.8   0.000  49.0   6.017 214.8   0.000 282.8   7.115 204.1   0.000
160.5   5.34E+00  1.32E+00
 0.767 0.209 0.767    1.108  50.9   0.000  80.0   1.906 193.1   0.000 281.9   7.963 202.9   0.000
157.2   7.87E-01 -8.17E+00
 0.800 0.218 0.800    1.154  47.1   0.000  85.7   0.969 188.4   0.000 281.3   8.867 202.1   0.000
154.1   3.01E-01 -9.75E+00
 0.833 0.227 0.833    1.187  45.7   0.000  87.4   0.573 186.4   0.000 282.6   9.430 203.8   0.000
151.9   1.57E-01 -1.05E+01
 0.867 0.236 0.867    1.234  42.9   0.000  88.7   0.363 185.4   0.000 282.9  10.255 203.8   0.000
149.0   9.62E-02 -1.16E+01
 0.900 0.245 0.900    1.290  40.1   0.000  89.4   0.235 184.8   0.000 283.6  11.159 203.9   0.000
146.4   6.45E-02 -1.29E+01
 0.933 0.254 0.933    1.352  37.2   0.000  89.7   0.152 184.5   0.000 285.1  12.137 203.9   0.000
144.2   4.57E-02 -1.43E+01
 0.967 0.263 0.967    1.413  34.3   0.000  89.8   0.095 184.6   0.000 287.8  13.120 203.6   0.000
143.2   3.41E-02 -1.58E+01
 1.000 0.272 1.000    1.481  30.6   0.000  90.0   0.055 185.2   0.000 290.6  14.234 202.6   0.000
141.9   2.59E-02 -1.76E+01
 1.033 0.282 1.033    1.561  26.8   0.000  90.2   0.026 187.2   0.000 294.2  15.502 201.4   0.000
141.2   2.02E-02 -1.97E+01
 1.067 0.291 1.067    1.646  22.1   0.000  90.2   0.005 205.1   0.000 299.2  16.891 199.2   0.000
141.6   1.68E-02 -2.20E+01
 1.100 0.300 1.100    1.736  16.7   0.000  90.3   0.011 352.1   0.000 305.0  18.396 196.4   0.000
142.2   1.38E-02 -2.47E+01
 1.133 0.309 1.133    1.815  10.3   0.000  90.3   0.022 357.4   0.000 312.2  19.868 192.5   0.000
143.5   1.14E-02 -2.75E+01
 1.167 0.318 1.167    1.874   2.9   0.000  90.4   0.030 358.8   0.000 320.6  21.206 187.5   0.000
145.3   9.43E-03 -3.01E+01
 1.200 0.327 1.200    1.901 354.5   0.000  90.4   0.035 359.3   0.000 329.8  22.239 181.4   0.000
147.8   8.43E-03 -3.21E+01
 1.233 0.336 1.233    1.868 345.6   0.000  90.4   0.039 359.6   0.000 339.0  22.623 174.8   0.000
150.5   6.73E-03 -3.27E+01
 1.267 0.345 1.267    1.777 336.7   0.000  90.4   0.042 359.7   0.000 347.4  22.304 168.2   0.000
153.4   5.02E-03 -3.18E+01
 1.300 0.354 1.300    1.641 328.6   0.000  90.4   0.043 359.8   0.000 354.7  21.363 162.2   0.000
156.5   3.51E-03 -2.98E+01
 1.333 0.363 1.333    1.486 321.5   0.000  90.3   0.044 359.9   0.000   0.3  20.081 157.2   0.000
159.4   2.80E-03 -2.72E+01
 1.367 0.372 1.367    1.323 315.9   0.000  90.2   0.044 359.9   0.000   4.7  18.594 153.6   0.000
162.2   1.84E-03 -2.44E+01
 1.400 0.381 1.400    1.171 311.5   0.000  90.1   0.044 360.0   0.000   7.9  17.132 151.2   0.000
164.7   1.13E-03 -2.20E+01
 1.433 0.390 1.433    1.035 308.4   0.000  90.0   0.043 360.0   0.000  10.1  15.795 149.8   0.000
167.0   6.52E-04 -2.00E+01
 1.467 0.400 1.467    0.920 306.1   0.000  89.8   0.042 360.0   0.000  11.2  14.641 149.3   0.000
169.0   5.29E-04 -1.84E+01
 1.500 0.409 1.500    0.820 304.7   0.000  89.7   0.041 360.0   0.000  11.8  13.641 149.5   0.000
170.8   3.00E-04 -1.71E+01
 1.533 0.418 1.533    0.736 303.9   0.000  89.4   0.040 360.0   0.000  11.9  12.802 150.3   0.000
172.3   1.46E-04 -1.61E+01
 1.567 0.427 1.567    0.666 303.6   0.000  89.2   0.039 360.0   0.000  11.2  12.109 151.3   0.000
173.5   1.23E-04 -1.53E+01
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 1.600 0.436 1.600   0.605 303.6   0.000  88.9   0.038 360.0   0.000  10.2   11.537 152.7   0.000
174.6   6.38E-05 -1.46E+01
 1.633 0.445 1.633   0.554 304.0   0.000  88.6   0.036 360.0   0.000   8.9   11.074 154.3   0.000
175.6   2.13E-05 -1.41E+01
 1.667 0.454 1.667   0.511 304.6   0.000  88.3   0.035 360.0   0.000   7.3   10.701 155.9   0.000
176.4  -6.48E-06 -1.37E+01
 1.700 0.463 1.700   0.474 305.2   0.000  88.0   0.033 360.0   0.000   5.2   10.408 157.5   0.000
177.0  -7.06E-06 -1.33E+01


SALM buoy with spring                               Execution: 18-04-1994 / 18:19
SEAWAY-4.12

FREQUENCY CHARACTERISTICS OF MOTIONS POINTS      FORWARD SPEED =  0.00 kn
-------------------------------------------      WAVE DIRECTION = +180 deg off stern
POINT NR =     01
X-APP    =   9.000 m
Y-CL     =   0.000 m
Z-BL     =   4.000 m

                        ............ABSOLUTE MOTIONS............   ..REL MOT..
 WAVE  SQRT   ENC      .....X.....     .....Y.....    .....Z.....    .....Z.....
 FREQ SL/WL  FREQ     AMPL PHASE    AMPL PHASE    AMPL PHASE        AMPL PHASE
(r/s)  (-) (r/s)   (m/m) (deg)   (m/m) (deg)   (m/m) (deg)   (m/m) (deg)
0.200 0.058 0.200   43.934   8.2   0.000   9.5   1.182 201.5   2.150  12.5
0.233 0.065 0.233    4.141 151.9   0.000  94.3   1.211 352.6   0.282 135.9
0.267 0.073 0.267    1.632  91.1   0.000 140.7   0.953 358.8   0.085  57.0
0.300 0.082 0.300    1.134 111.6   0.000  49.1   1.038   1.3   0.057 135.0
0.333 0.091 0.333    1.361  96.9   0.000  96.1   1.076 357.5   0.147 122.1
0.367 0.100 0.367    1.113 100.9   0.000  96.4   1.039   1.9   0.074 125.2
0.400 0.109 0.400    1.033 100.9   0.000  96.2   1.082   4.6   0.089 163.7
0.433 0.118 0.433    0.927  98.4   0.000  92.8   1.126   0.3   0.184 137.2
0.467 0.127 0.467    0.907  92.2   0.000 102.6   1.159   1.9   0.205 146.3
0.500 0.136 0.500    0.888  89.1   0.000  95.5   1.266   3.8   0.292 162.2
0.533 0.145 0.533    0.874  87.6   0.000  92.3   1.387   3.2   0.422 163.3
0.567 0.154 0.567    0.893  80.8   0.000  94.6   1.620   4.7   0.646 171.9
0.600 0.163 0.600    0.887  75.5   0.000  84.1   1.926   3.2   0.965 171.6
0.633 0.173 0.633    0.931  71.3   0.000  47.6   2.394   2.5   1.442 173.0
0.667 0.182 0.667    0.918  66.6   0.000 303.0   3.315 356.5   2.411 167.8
0.700 0.191 0.700    0.919  62.2   0.000 194.5   6.670 336.9   5.975 150.3
0.733 0.200 0.733    0.967  58.5   0.000 125.3   5.182 216.5   6.153  34.1
0.767 0.209 0.767    0.988  54.7   0.000 118.5   0.979 183.6   1.949  13.7
0.800 0.218 0.800    1.016  50.7   0.000 116.0   0.259  84.2   0.893  11.3
0.833 0.227 0.833    1.036  49.1   0.000 114.1   0.608  40.1   0.426  10.2
0.867 0.236 0.867    1.067  46.0   0.000 113.0   0.892  31.2   0.109  21.0
0.900 0.245 0.900    1.104  42.9   0.000 112.1   1.118  27.9   0.146 174.2
0.933 0.254 0.933    1.147  39.6   0.000 111.2   1.312  26.1   0.359 180.7
0.967 0.263 0.967    1.189  36.3   0.000 110.6   1.483  24.8   0.553 181.5
1.000 0.272 1.000    1.235  32.3   0.000 110.0   1.654  23.2   0.755 180.6
1.033 0.282 1.033    1.292  27.9   0.000 109.6   1.833  21.6   0.971 179.7
1.067 0.291 1.067    1.351  22.7   0.000 109.5   2.019  19.2   1.209 177.6
1.100 0.300 1.100    1.415  16.8   0.000 109.5   2.214  16.3   1.469 175.0
1.133 0.309 1.133    1.468   9.8   0.000 109.8   2.402  12.4   1.745 171.1
1.167 0.318 1.167    1.505   1.8   0.000 110.4   2.571   7.4   2.029 166.2
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1.200 0.327 1.200   1.516 352.7   0.000 111.2   2.701   1.4   2.303 160.2
1.233 0.336 1.233   1.479 343.1   0.000 112.2   2.750 354.9   2.518 153.6
1.267 0.345 1.267   1.398 333.6   0.000 113.5   2.714 348.3   2.656 146.9
1.300 0.354 1.300   1.282 324.7   0.000 114.9   2.602 342.5   2.710 140.9
1.333 0.363 1.333   1.152 316.8   0.000 116.4   2.447 337.6   2.703 135.9
1.367 0.372 1.367   1.019 310.3   0.000 118.1   2.268 334.1   2.646 132.3
1.400 0.381 1.400   0.895 305.1   0.000 119.8   2.092 331.7   2.568 129.9
1.433 0.390 1.433   0.785 301.0   0.000 121.6   1.931 330.5   2.484 128.5
1.467 0.400 1.467   0.693 297.7   0.000 123.5   1.791 330.0   2.408 128.1
1.500 0.409 1.500   0.613 295.3   0.000 125.3   1.671 330.2   2.337 128.5
1.533 0.418 1.533   0.545 293.5   0.000 127.1   1.569 331.0   2.278 129.5
1.567 0.427 1.567   0.489 291.9   0.000 128.9   1.485 332.0   2.230 130.9
1.600 0.436 1.600   0.440 290.8   0.000 130.6   1.416 333.4   2.191 132.7
1.633 0.445 1.633   0.400 289.9   0.000 132.3   1.360 334.9   2.162 134.9
1.667 0.454 1.667   0.365 289.2   0.000 133.9   1.314 336.5   2.141 137.2
1.700 0.463 1.700   0.335 288.3   0.000 135.4   1.278 338.1   2.129 139.7
```

```
SALM buoy with spring                                  Execution: 18-04-1994 / 18:19
SEAWAY-4.12

STATISTICS OF BASIC MOTIONS                  FORWARD SPEED =  0.00 kn
---------------------------               WAVE DIRECTION =  +180 deg off stem

...........SEA..........     :....................SIGNIFICANT VALUES OF BASIC
MOTIONS.....................       MEAN ADDED
....INPUT... .CALCULATED.   ...SURGE...   ....SWAY...   ...HEAVE...   ....ROLL...   ...PITCH...
....YAW....     RESISTANCE
HEIGHT  PER HEIGHT  PER   AMPL  PER   AMPL  PER   AMPL  PER   AMPL  PER
AMPL  PER   AMPL  PER  GER/BEU  BOESE
  (m)  (s)   (m)  (s)    (m)  (s)    (m)  (s)    (m)  (s)  (deg)  (s)  (deg)  (s)  (deg)  (s)    (kN)
(kN)
  4.76 12.00   4.75 12.16    2.51 11.75    0.00 11.48    4.15 10.11    0.00  9.91   10.90 6.46    0.00
13.14      0.7    -4.3
  6.06 13.00   6.05 13.14    3.32 13.24    0.00 12.04    4.85 10.57    0.00  9.93   11.96 6.51    0.00
17.12      0.8    -5.2
  7.53 14.00   7.52 14.12    4.58 15.59    0.00 12.68    5.60 11.12    0.00  9.97   12.94 6.56    0.00
19.69      1.0    -6.1
  8.84 15.00   8.83 15.10    7.43 20.69    0.00 13.41    6.18 11.74    0.00 10.02   13.49 6.71    0.00
21.17      1.0    -6.5
```

```
SALM buoy with spring                                  Execution: 18-04-1994 / 18:19
SEAWAY-4.12

STATISTICS OF MOTIONS IN POINTS              FORWARD SPEED =  0.00 kn
-------------------------------           WAVE DIRECTION =  +180 deg off stem
POINT NR =     01
X-APP   =  9.000 m
Y-CL    =  0.000 m
Z-BL    =  4.000 m
                   ..........................................SIGNIFICANT VALUES
OF..............................................
```

```
               ..........DISPLACEMENTS..........      ...........VELOCITIES............
..........ACCELERATIONS..........
.....SEA....       ....X....  ....Y....  ....Z....      ....X....  ....Y....  ....Z....      ....X....  ....Y....  ....Z....
HEIGHT  PER     AMPL  PER  AMPL  PER  AMPL  PER     AMPL  PER  AMPL  PER  AMPL
PER     AMPL  PER  AMPL  PER  AMPL  PER
 (m)  (s)     (m)  (s)   (m)  (s)   (m)  (s)    (m/s)  (s)  (m/s)  (s)  (m/s)  (s)   (m/s2)  (s) (m/s2)  (s)
(m/s2)  (s)
 4.76 12.00     2.42 12.3   0.00 11.7   4.43 9.80     1.33 8.91   0.00 10.4   2.94 8.48     1.10 7.13
0.00 9.26   2.28 7.03
 6.06 13.00     3.24 13.8   0.00 12.5   5.16 10.2     1.59 9.69   0.00 10.7   3.30 8.65     1.23 7.32
0.00 9.29   2.51 7.11
 7.53 14.00     4.51 16.2   0.00 13.5   5.94 10.8     1.92 10.8   0.00 11.2   3.65 8.82     1.37 7.65
0.00 9.33   2.73 7.17
 8.84 15.00     7.41 21.2   0.00 14.7   6.52 11.4     2.39 13.1   0.00 11.7   3.83 9.01     1.55 8.75
0.00 9.38   2.82 7.22
```

```
              ........VERTICAL RELATIVE MOTIONS........
             ..SIGNIFICANT VALUES OF...   .EXCEEDING.
.....SEA....     DISPLACEMENT    .VELOCITY.    ....Z-BL....
HEIGHT  PER      AMPL   PER    AMPL   PER     PROB  NR/H
 (m)   (s)      (m)   (s)   (m/s)   (s)     (%) (1/h)
 4.76 12.00      3.40  8.56    15.86  8.61      0.0   0.0
 6.06 13.00      3.77  8.58    17.51  8.61      0.0   0.0
 7.53 14.00      4.09  8.61    18.98  8.62      0.0   0.0
 8.84 15.00      4.24  8.66    19.58  8.62      0.0   0.0
```

San Diego Hull Input File

```
4.12
San Diego class Tanker. 278.89 x 50.6 x 23.77 meter. Hull-draft = ? meter.
 18.0790   0.0000 278.8920   6.7060
    26
  3.048   3.0480   3.048    3.048    3.048    3.658    5.944    6.096
 10.668  10.6680  13.716   13.716   13.716   13.716   27.432   27.432
 27.432  27.4320  13.716   13.716   11.43    11.43    6.4      6.096
  3.023   2.9210
    2
 -6.706       4   0.0000
 13.970   0.0000  15.2400   2.1840  16.4590   3.9310  17.678    5.359
 18.079   5.6980
 -3.658       4   0.0000
 13.2060  0.0000  14.0210   1.6370  16.4590   5.4120  17.0000   5.9980
 18.0790  7.1670
 -0.610       4   0.0000
 12.4070  0.0000  14.6300   4.2540  17.0690   7.6070  17.5000   8.0490
 18.0790  8.6420
  0.50        6   0.0000
 11.6260  0.0000  12.1920   1.0840  14.6300   5.7530  15.8500   7.5220
 17.0690  9.0170  17.5000   9.3180  18.0790   9.7220
  1.00        6   0.0000
 10.9480  0.0000  13.4110   5.1820  14.6300   7.2260  15.8500   8.9280
 17.0690 10.3790  17.5000  10.6750  18.0790  11.0710
  2.00        8   0.0000
  9.5930  0.0000   9.7540   0.1840  10.3630   0.8830  10.9730   1.9810
 11.5820  3.2290  13.4110   6.7120  15.2400   9.5060  16.4590  11.0140
```

```
18.0790 12.7000
  3.00     12  0.0000
 0.0000  0.0000  0.3050  0.1830  0.6100  0.3140  2.4380  0.9910
 3.6580  1.3050  7.9250  1.8670  9.1440  2.3050  9.7540  2.7300
10.3630  3.3750 15.2400 11.1060 16.4590 12.5320 17.6780 13.7890
18.0790 14.1270
  4.00     14  0.0000
 0.0000  0.0000  0.0000  1.2190  0.3050  2.0420  0.6100  2.7080
 1.2190  3.2070  1.8290  3.5590  3.0480  4.0610  6.7060  5.0260
 7.9250  5.4390  9.1440  6.1020 10.3630  7.1750 15.2400 13.5950
17.0690 15.4560 17.5000 15.8210 18.0790 16.3110
  5.00     14  0.0000
 0.0000  0.0000  0.0000  3.3530  0.3050  4.4200  0.6100  5.1910
 1.2190  5.8390  1.8290  6.2860  3.0480  6.9090  6.7060  8.2930
 7.9250  8.9060  9.1440  9.7150 10.3630 10.7890 14.0210 14.8080
16.4590 17.1230 17.0000 17.5320 18.0790 18.3480
  6.00     10  0.0000
 0.0000  0.0000  0.0000  7.3150  0.3050  8.7780  0.6100  9.5030
 1.2190 10.2460  1.8290 10.7630  3.6580 11.9000  6.0960 13.3190
14.0210 19.0310 17.6780 21.2150 18.0790 21.3930
  7.00     10  0.0000
 0.0000  0.0000  0.0000 11.2780  0.3050 12.8020  0.6100 13.5860
 1.2190 14.3830  1.8290 14.9800  6.7060 18.4210  9.1440 19.8180
11.5820 21.0690 16.4590 23.0190 18.0790 23.5240
  8.00     10  0.0000
 0.0000  0.0000  0.0000 16.4590  0.3050 17.6780  0.6100 18.3450
 1.8290 19.8020  4.2670 21.6090  5.4860 22.2470  7.9250 23.1580
10.3630 23.7870 13.4110 24.3650 18.0790 24.7740
  9.00     10  0.0000
 0.0000  0.0000  0.0000 20.2390  0.3050 21.4580  0.6100 22.1330
 1.2190 22.8730  2.4380 23.7680  3.6580 24.3050  4.8770 24.6440
 7.3150 25.0030 10.3630 25.1940 18.0790 25.2880
 10.00     10  0.0000
 0.0000  0.0000  0.0000 22.2500  0.3050 23.4090  0.6100 24.1710
 1.2190 24.6890  1.8290 24.9780  2.4380 25.1460  3.0480 25.2380
 4.2670 25.2980 12.0000 25.2980 18.0790 25.2980
 11.00      8  0.0000
 0.0000  0.0000  0.0000 22.8600  0.3050 23.8350  0.6100 24.4730
 1.2190 24.9710  1.8290 25.2220  2.4380 25.2980 10.0000 25.2980
18.0790 25.2980
 12.00      8  0.0000
 0.0000  0.0000  0.0000 22.8600  0.3050 23.8350  0.6100 24.4730
 1.2190 24.9710  1.8290 25.2220  2.4380 25.2980 10.0000 25.2980
18.0790 25.2980
 13.00      8  0.0000
 0.0000  0.0000  0.0000 22.8600  0.3050 23.8350  0.6100 24.4730
 1.2190 24.9710  1.8290 25.2220  2.4380 25.2980 10.0000 25.2980
18.0790 25.2980
 14.00      8  0.0000
 0.0000  0.0000  0.0000 22.8600  0.3050 23.8350  0.6100 24.4730
 1.2190 24.9710  1.8290 25.2220  2.4380 25.2980 10.0000 25.2980
18.0790 25.2980
 15.00      8  0.0000
 0.0000  0.0000  0.0000 22.2500  0.3050 23.5920  0.6100 24.4760
```

```
 1.2190  24.9710   1.8290  25.2220   2.4380  25.2980  10.0000  25.2980
18.0790  25.2980
 16.00       10   0.0000
 0.0000   0.0000   0.0000  21.3360   0.3050  23.4700   0.6100  24.0790
 1.2190  24.6480   1.8290  24.9940   2.4380  25.2030   3.0480  25.2950
 8.0000  25.2950  14.0000  25.2950  18.0790  25.2950
 17.00       10   0.0000
 0.0000   0.0000   0.0000  20.4220   0.3050  21.7930   0.6100  22.4310
 1.2190  23.2120   1.8290  23.7390   3.0480  24.4090   4.2670  24.7680
 5.4860  24.9020  12.0000  25.0110  18.0790  25.1130
 18.00       10   0.0000
 0.0000   0.0000   0.0000  16.1540   0.3050  18.2880   0.6100  19.3070
 1.2190  20.3490   1.8290  21.0720   3.0480  22.0220   4.2670  22.5650
 5.4860  22.8890   7.925   23.1710  18.0790  23.6970
 19.00       10   0.0000
 0.0000   0.0000   0.0000   9.4490   0.3050  11.8870   0.6100  13.6720
 1.2190  14.8720   2.4380  16.3930   3.6580  17.4150   4.8770  18.1010
 7.3150  18.8850  10.3630  19.3830  18.0790  19.6440
 19.50       12   0.0000
 0.0000   0.0000   0.0000   5.1820   0.3050   7.4680   0.6100   8.9410
 1.2190  10.3440   1.8290  11.2840   3.0480  12.7190   4.2670  13.5190
 5.4860  14.2050   7.9250  15.0530  10.3630  15.4810  14.0000  15.6830
18.0790  15.9090
 19.60       10   0.0000
 0.3050   0.0000   0.6100   2.9430   1.2190   4.5690   1.8290   5.7020
 2.4380   6.5630   3.6580   7.7600   4.8770   8.5880   6.0960   9.1950
 7.3150   9.6040   8.5340   9.8520  18.0790  10.3970
 19.70       12   0.0000
 1.6760   0.0000   1.8290   2.0290   2.4380   3.2320   3.0480   4.0290
 3.658    4.6420   4.2670   5.1310   4.8770   5.5090   5.4860   5.8010
 6.0960   6.0230   7.3150   6.3090   8.5340   6.3850  12.0000   6.4640
18.0790   6.6020
 19.80        2   0.0000
17.0120   0.0000  17.5000   1.1490  18.0790   3.1020
 1.0000   1.0000   1.0000
*** End of file ***
```

San Diego Full Load Environment File

```
    4.12
San Diego class tanker (full load) motions with spring
      +1        +1        0        +1        0
   18.290     0.000     0.000   304.878  1.025E+00
   123456        1        6        +5        0
      1
     0.0
      1
   180.0
   2.500        1     0.200     1.700   0.033333
   1.474
 +16.800   +20.981    69.750    69.750
      0
      3
   5.000
```

```
     0.0    61.250   105.000
      0
      1
   278.00      0.0      0.0
    11.66      0.0      0.0
     -1
  278.000     0.000    10.000
      4
     +2
    4.76    12.00
    6.06    13.00
    7.53    14.00
    8.84    15.00
      0
*** End of file ***
```

San Diego Full Load Output File

```
# # # # # # # # # # # # # # # # # # # # # # # # # # # # # # #
# Program: SEAWAY                              Journee #
#                                                    #
# STRIPTHEORY CALCULATIONS OF MOTIONS AND LOADS IN A SEAWAY #
#                                                    #
#                    Release 4.12                      #
#                    (31-07-1993)                      #
# # # # # # # # # # # # # # # # # # # # # # # # # # # # # # #

User: University of California, Berkeley, U.S.A.
INPUT DATA
~~~~~~~~~~

San Diego class tanker (full load) motions with spring

PRINT-CODE INPUT DATA .............. KPR(1) :     1
PRINT-CODE GEOMETRIC DATA .......... KPR(2) :     1
PRINT-CODE HYDRODYNAMIC COEFFICIENTS KPR(3) :     0
PRINT-CODE FREQUENCY CHARACTERISTICS KPR(4) :     1
PRINT-CODE SPECTRAL DATA ........... KPR(5) :     0

ACTUAL MIDSHIP DRAFT ................ DRAFT : 18.290 m
ACTUAL TRIM BY STERN ................ TRIM :  0.000 m
DUMMY VALUE, FOR THE TIME BEING ...... DIST :  0.000

WATER DEPTH ......................... DEPTH :  304.9 m
DENSITY OF WATER ...................... RHO :  1.025 ton/m3

DEGREES OF FREEDOM CODE ............... MOT : 123456
VERSION-CODE OF STRIP THEORY METHOD ... KTH :     1
NUMBER OF TERMS IN POTENTIAL SERIES .. MSER :     6
CODE OF USED 2-D APPROXIMATION ....... KCOF :     5
NUMBER OF "FREE-CHOICE" SECTIONS ...... NFR :     0

NUMBER OF FORWARD SPEEDS .............. NV :      1
```

```
FORWARD SPEEDS (kn) ............... VK(NV) :   0.00

NUMBER OF WAVE DIRECTIONS ............ NWD :     1
WAVE DIRECTIONS (deg off stern) WAVDIR(NWD) : 180.0

MAX. FREQ. OF ENCOUNTER IN SERIES . FREQMAX : 2.500 rad/sec   (range =  0.000 -  3.125
rad/sec)
CODE FOR WAVE FREQUENCY INPUT ....... KOMEG :     1
MINIMUM CIRCULAR WAVE FREQUENCY ..... OMMIN : 0.200 rad/sec
MAXIMUM CIRCULAR WAVE FREQUENCY ..... OMMAX : 1.700 rad/sec
INCREMENT IN WAVE FREQUENCIES ....... OMINC : 0.033 rad/sec

WAVE AMPLITUDE FOR LINEARISATION ... WAVAMP : 1.474 m


INPUT DATA (continued)
~~~~~~~~~~~~~~~~~~~~~~
BASE LINE TO CENTRE OF GRAVITY ... +GKGM=KG : 16.800 m

MASS-GYRADIUS k-xx ................ GYR(1) : 20.981 m
MASS-GYRADIUS k-yy ................ GYR(2) : 69.750 m
MASS-GYRADIUS k-zz ................ GYR(3) : 69.750 m

NUMBER OF LOAD-CALCULATION SECTIONS .. NBTM :    0

CODE OF ROLL DAMPING INPUT ........... KRD :     3
AVERAGE ROLL AMPLITUDE ............ ROLAMP :  5.000 deg
HEIGHT OF BILGE KEEL ................. HBK :  0.000 m
DISTANCE OF A.P.P. TO AFT END B.K. ... XBKA :  61.25 m
DISTANCE OF A.P.P. TO FORWARD END B.K. XBKF : 105.00 m

CODE OF ANTI-ROLLING DEVICES ......... KARD :     0

NUMBER OF LINEAR SPRINGS ............ NCAB :     1
COORDINATES AND LINEAR SPRING COEFFICIENTS  :278.000    0.000    0.000  1.166E+01
0.000E-01  0.000E-01

NUMBER OF DISCRETE POINTS ........... NPTS :    -1
COORDINATES OF POINTS (m) .. PTSXYZ(NPTS,3) : 278.00   0.00  10.00

NUMBER OF SEA STATES ................ NSEA :     4
CODE OF IRREGULAR SEA DESCRIPTION .... KSEA :     2
WAVE HEIGHTS (m) HW(K) / PERIODS (s) TW(K)  :  4.76  12.00
                                    6.06  13.00
                                    7.53  14.00
                                    8.84  15.00

INPUT-CODE OF CRITERA FOR SHIPMOTIONS  KRIT :     0


San Diego class tanker motions with  spring                Execution: 18-04-1994 , 18:44
SEAWAY-4.12

GEOMETRICAL HULLFORM DATA
```

```
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ACTUAL MIDSHIP DRAFT (T) ................ :  18.290 m
ACTUAL TRIM BY STERN .................... :  0.000 m

LENGTH BETWEEN PERPENDICULARS (Lpp) ...... : 278.892 m
REAR SECTION TO A.P.P. .................. :  6.706 m

WATERLINE : LENGTH (Lwl) ................ : 285.598 m
          BEAM (B) .................... :  50.596 m
          AREA ........................ :  12909 m2
          AREA COEFFICIENT (Lpp) ....... :  0.9148
          AREA COEFFICIENT (Lwl) ....... :  0.8934
          CENTROID TO A.P.P. .......... : 139.862 m   ( +0.416 m or +0.15 % Lpp/2)
          CENTROID TO REAR SECTION ..... : 146.568 m   ( +3.769 m or +1.32 % Lwl/2)

DISPLACEMENT : VOLUME ................... :  217682 m3
          BLOCKCOEFFICIENT (Lpp) .... :  0.8434
          BLOCKCOEFFICIENT (Lwl) .... :  0.8236
          CENTROID TO A.P.P. ........ : 147.407 m   ( +7.961 m or +2.85 % Lpp/2)
          CENTROID TO REAR SECTION .. : 154.113 m   (+11.314 m or +3.96 % Lwl/2)
          CENTROID TO WATERLINE ..... :  8.870 m
          CENTROID TO KEELLINE ...... :  9.420 m
          MIDSHIP SECTION COEFFICIENT :  0.9970
          LONG. PRISMATIC COEFFICIENT :  0.8459
          VERT. PRISMATIC COEFFICIENT :  0.9220
          RATIO Lpp/B .............. :   5.512
          RATIO Lwl/B .............. :   5.645
          RATIO B/T ................ :   2.766
          WETTED SURFACE HULL ....... :  21184 m2


STABILITY PARAMETERS
--------------------

KB ........... :   9.420 m
KG ........... :  16.800 m
BM-TRANSVERSE . :  11.366 m
GM-TRANSVERSE . :   3.986 m
BM-LONGITUDINAL : 334.977 m
GM-LONGITUDINAL : 327.597 m


San Diego class tanker motions with  spring                  Execution: 18-04-1994 , 18:44
SEAWAY-4.12

SECTIONAL HULLFORM DATA
-----------------------

STATION  X-APP  HALF  HALF  DRAFT   AREA   AREA   KB   BO  WETTED
NUMBER          CL-CL WIDTH                COEFF          LENGTH
  (-)     (m)    (m)   (m)    (m)    (m2)    (-)   (m)    (m)    (m)
 -6.71  -6.706  0.000  5.876  4.320  28.6977 0.5652 16.777 1.513  14.683
 -3.66  -3.658  0.000  7.396  5.084  42.6789 0.5676 16.448 1.842  18.054
```

```
 -0.61  -0.610  0.000  8.858  5.883   59.4725 0.5706 16.194 2.096 21.405
  0.50   2.438  0.000  9.869  6.664   76.8099 0.5839 16.066 2.224 24.116
  1.00   5.486  0.000 11.215  7.342   98.2492 0.5966 15.664 2.626 27.184
  2.00   8.534  0.000 12.920  8.697  122.8398 0.5466 15.340 2.950 31.352
  3.00  12.192  0.000 14.305 18.290  181.2260 0.3463 13.722 4.568 49.443
  4.00  18.136  0.000 16.490 18.290  290.7200 0.4820 11.928 6.362 52.077
  5.00  24.232  0.000 18.508 18.290  396.6815 0.5859 11.096 7.194 55.617
  6.00  34.900  0.000 21.487 18.290  565.9597 0.7201 10.419 7.871 62.097
  7.00  45.568  0.000 23.590 18.290  707.2645 0.8196 10.003 8.287 68.457
  8.00  59.284  0.000 24.792 18.290  835.6859 0.9215  9.554 8.736 75.811
  9.00  73.000  0.000 25.291 18.290  904.0583 0.9772  9.296 8.994 81.533
 10.00  86.716  0.000 25.298 18.290  921.0693 0.9953  9.184 9.106 84.506
 11.00 100.432  0.000 25.298 18.290  922.6645 0.9970  9.171 9.119 85.031
 12.00 127.864  0.000 25.298 18.290  922.6645 0.9970  9.171 9.119 85.031
 13.00 155.296  0.000 25.298 18.290  922.6645 0.9970  9.171 9.119 85.031
 14.00 182.728  0.000 25.298 18.290  922.6645 0.9970  9.171 9.119 85.031
 15.00 210.160  0.000 25.298 18.290  922.4080 0.9968  9.173 9.117 84.991
 16.00 223.876  0.000 25.295 18.290  920.7101 0.9950  9.187 9.103 84.440
 17.00 237.592  0.000 25.117 18.290  902.6983 0.9825  9.256 9.034 82.071
 18.00 249.022  0.000 23.708 18.290  834.1783 0.9619  9.361 8.929 77.039
 19.00 260.452  0.000 19.651 18.290  673.5606 0.9370  9.558 8.732 67.274
 19.50 266.852  0.000 15.921 18.290  524.3181 0.9003  9.769 8.521 58.800
 19.60 272.948  0.000 10.409 17.985  323.5187 0.8641 10.229 8.061 47.811
 19.70 275.971  0.000  6.607 16.614  198.3256 0.9034 10.579 7.711 40.672
 19.80 278.892  0.000  3.814  1.278    4.3194 0.4431 17.911 0.379  8.062
```

```
San Diego class tanker motions with  spring                    Execution: 18-04-1994 / 18:44
SEAWAY-4.12

TWO-PARAMETER LEWIS CONFORMAL MAPPING COEFFICIENTS
--------------------------------------------------

STATION  X-APP  HALF  DRAFT  AREA    M(S)   A(-1)    A(1)     A(3)     RMS
HULLFORM REMARKS WITH REGARD
 NUMBER         WIDTH        COEFF                                   TO LEWIS
CONFORMAL MAPPING
  (-)    (m)    (m)    (m)    (-)     (m)     (-)      (-)      (-)      (m)
 -6.71  -6.706  5.876  4.320 0.5652   4.4761 +1.0000 +0.1739 +0.1390    0.100
CONVENTIONAL
 -3.66  -3.658  7.396  5.084 0.5676   5.4934 +1.0000 +0.2104 +0.1359    0.121
CONVENTIONAL
 -0.61  -0.610  8.858  5.883 0.5706   6.5054 +1.0000 +0.2287 +0.1330    0.136
CONVENTIONAL
  0.50   2.438  9.869  6.664 0.5839   7.3483 +1.0000 +0.2181 +0.1250    0.222
CONVENTIONAL
  1.00   5.486 11.215  7.342 0.5966   8.3125 +1.0000 +0.2330 +0.1162    0.187
CONVENTIONAL
  2.00   8.534 12.920  8.697 0.5466   9.4092 +1.0000 +0.2244 +0.1487    0.356
CONVENTIONAL
  3.00  12.192 14.305 18.290 0.3463  12.7238 +1.0000 -0.1566 +0.2809    0.660
REENTRANT       Cm:0.3591
  4.00  18.136 16.490 18.290 0.4820  14.5149 +1.0000 -0.0620 +0.1981    0.746
CONVENTIONAL
```

```
  5.00  24.232  18.508  18.290  0.5859   16.3016  +1.0000  +0.0067  +0.1286    1.040
CONVENTIONAL
  6.00  34.900  21.487  18.290  0.7201   19.0979  +1.0000  +0.0837  +0.0414    1.181
CONVENTIONAL
  7.00  45.568  23.590  18.290  0.8196   21.3989  +1.0000  +0.1238  -0.0214    0.954
CONVENTIONAL
  8.00  59.284  24.792  18.290  0.9215   23.5525  +1.0000  +0.1380  -0.0854    0.425
CONVENTIONAL
  9.00  73.000  25.291  18.290  0.9772   24.7977  +1.0000  +0.1412  -0.1213    0.157    TUNNELED
 10.00  86.716  25.298  18.290  0.9953   25.1472  +1.0000  +0.1393  -0.1333    0.365    TUNNELED-
BULBOUS
 11.00 100.432  25.298  18.290  0.9970   25.1809  +1.0000  +0.1392  -0.1345    0.405
TUNNELED-BULBOUS
 12.00 127.864  25.298  18.290  0.9970   25.1809  +1.0000  +0.1392  -0.1345    0.405
TUNNELED-BULBOUS
 13.00 155.296  25.298  18.290  0.9970   25.1809  +1.0000  +0.1392  -0.1345    0.405
TUNNELED-BULBOUS
 14.00 182.728  25.298  18.290  0.9970   25.1809  +1.0000  +0.1392  -0.1345    0.405
TUNNELED-BULBOUS
 15.00 210.160  25.298  18.290  0.9968   25.1755  +1.0000  +0.1392  -0.1343    0.404
TUNNELED-BULBOUS
 16.00 223.876  25.295  18.290  0.9950   25.1402  +1.0000  +0.1393  -0.1332    0.364
TUNNELED-BULBOUS
 17.00 237.592  25.117  18.290  0.9825   24.8018  +1.0000  +0.1376  -0.1249    0.221    TUNNELED
 18.00 249.022  23.708  18.290  0.9619   23.6549  +1.0000  +0.1145  -0.1123    0.119    TUNNELED
 19.00 260.452  19.651  18.290  0.9370   21.0209  +1.0000  +0.0324  -0.0975    0.190
CONVENTIONAL
 19.50 266.852  15.921  18.290  0.9003   18.4575  +1.0000  -0.0642  -0.0733    0.167
CONVENTIONAL
 19.60 272.948  10.409  17.985  0.8641   14.8914  +1.0000  -0.2544  -0.0466    0.098
CONVENTIONAL
 19.70 275.971   6.607  16.614  0.9034   12.3704  +1.0000  -0.4045  -0.0614    0.077
CONVENTIONAL
 19.80 278.892   3.814   1.278  0.4431    2.2268  +1.0000  +0.5694  +0.1433    0.096
REENTRANT       Cm:0.4908


San Diego class tanker motions with  spring                   Execution: 18-04-1994 / 18:44
SEAWAY-4.12

N-PARAMETER CLOSE-FIT CONFORMAL MAPPING COEFFICIENTS
------------------------------------------------------------

STATION    M(S)   A(-1)    A(1)    A(3)    A(5)    A(7)    A(9)   A(11)   A(13)   A(15)   A(17)
A(19)     RMS
  (-)      (m)     (-)     (-)     (-)     (-)     (-)     (-)     (-)     (-)     (-)     (-)     (-)     (m)
 -6.71  +4.4569 +1.0000 +0.1844 +0.1180 -0.0086 +0.0156 -0.0011 +0.0103 +0.0000 +0.0000
+0.0000 +0.0000   0.017
 -3.66  +5.4582 +1.0000 +0.2158 +0.1157 -0.0009 +0.0195 -0.0032 +0.0080 +0.0000 +0.0000
+0.0000 +0.0000   0.024
 -0.61  +6.4834 +1.0000 +0.2347 +0.1151 -0.0018 +0.0217 -0.0036 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.048
  0.50  +7.3368 +1.0000 +0.2350 +0.1005 -0.0151 +0.0263 -0.0014 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.065
```

```
  1.00  +8.3004 +1.0000 +0.2436 +0.0968 -0.0083 +0.0210 -0.0020 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.067
  2.00  +9.3781 +1.0000 +0.2433 +0.1182 -0.0133 +0.0343 -0.0049 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.115
  3.00 +12.6285 +1.0000 -0.1523 +0.3011 -0.0159 -0.0105 +0.0104 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.443
  4.00 +14.7506 +1.0000 -0.0998 +0.2053 +0.0407 -0.0264 -0.0019 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.301
  5.00 +16.5655 +1.0000 -0.0562 +0.1305 +0.0642 -0.0199 -0.0014 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.173
  6.00 +19.2021 +1.0000 +0.0216 +0.0350 +0.0614 +0.0007 +0.0002 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.102
  7.00 +21.4104 +1.0000 +0.0790 -0.0291 +0.0417 +0.0071 +0.0031 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.157
  8.00 +23.5495 +1.0000 +0.1213 -0.0900 +0.0185 +0.0048 -0.0018 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.066
  9.00 +24.8596 +1.0000 +0.1433 -0.1269 -0.0003 +0.0034 -0.0022 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.047
 10.00 +25.3491 +1.0000 +0.1472 -0.1475 -0.0106 +0.0073 +0.0017 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.036
 11.00 +25.4068 +1.0000 +0.1473 -0.1502 -0.0117 +0.0080 +0.0022 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.047
 12.00 +25.4068 +1.0000 +0.1473 -0.1502 -0.0117 +0.0080 +0.0022 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.047
 13.00 +25.4068 +1.0000 +0.1473 -0.1502 -0.0117 +0.0080 +0.0022 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.047
 14.00 +25.4068 +1.0000 +0.1473 -0.1502 -0.0117 +0.0080 +0.0022 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.047
 15.00 +25.3995 +1.0000 +0.1474 -0.1498 -0.0118 +0.0079 +0.0023 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.044
 16.00 +25.3400 +1.0000 +0.1473 -0.1471 -0.0110 +0.0071 +0.0019 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.034
 17.00 +24.9161 +1.0000 +0.1412 -0.1348 -0.0051 +0.0058 +0.0009 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.055
 18.00 +23.6883 +1.0000 +0.1118 -0.1174 +0.0026 +0.0039  0.0000 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.038
 19.00 +21.0235 +1.0000 +0.0255 -0.0897 +0.0043 -0.0079 +0.0026 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.107
 19.50 +18.4766 +1.0000 -0.0736 -0.0703 +0.0027 -0.0040 +0.0068 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.083
 19.60 +14.8984 +1.0000 -0.2541 -0.0497 -0.0066 +0.0026 +0.0064 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.051
 19.70 +12.3611 +1.0000 -0.4066 -0.0603 -0.0057 -0.0004 +0.0075 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.033
 19.80  +2.1695 +1.0000 +0.6015 +0.1370 -0.0201 +0.0364 +0.0030 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000  0.038


San Diego class tanker motions with  spring                Execution: 18-04-1994 / 18:44
SEAWAY-4.12

NATURAL ROLL AND COEFFICIENTS AT FIXED AMPLITUDE
------------------------------------------------
```

```
FORWARD SHIP SPEED . (kn) :    0.00
MEAN ROLL AMPLITUDE (deg) :   5.000

NATURAL ROLL PERIOD . (s) :  22.731
NATURAL FREQUENCY . (r/s) :   0.276

LINEAR EQUIVALENT GM  (m) :   4.005

MASS, k-phi-phi ..... (m) :  22.672
COMPONENTS k-phi-phi:
  SOLID MASS PART .. (m) :  20.981
  2-D POTENTIAL PART (m) :   8.591

DAMPING, kappa ...... (-) :  0.0042
COMPONENTS kappa:
  2-D POTENTIAL PART (-) :  0.0007
  SPEED EFFECT PART  (-) :  0.0000
  SKIN FRICTION PART (-) :  0.0002
  EDDY MAKING PART . (-) :  0.0033
  LIFT MOMENT PART . (-) :  0.0000
  BILGE KEEL PART .. (-) :  0.0000

(NON)LINEAR DAMPING COEFFICIENTS:
  Kappa-1 .......... (-) :  0.0001
  Kappa-2 .......... (-) :  0.0394


NATURAL HEAVE AT ZERO FORWARD SPEED
-----------------------------------

NATURAL HEAVE PERIOD  (s) :  11.542
NATURAL FREQUENCY   (r/s) :   0.544


NATURAL PITCH AT ZERO FORWARD SPEED
-----------------------------------

NATURAL PITCH PERIOD  (s) :  10.633
NATURAL FREQUENCY   (r/s) :   0.591


San Diego class tanker motions with  spring              Execution: 18-04-1994 / 18:44
SEAWAY-4.12

FREQUENCY CHARACTERISTICS OF BASIC MOTIONS       FORWARD SPEED =  0.00 kn
------------------------------------------       WAVE DIRECTION =  +180 deg off stern

 WAVE  SQRT   ENC    ...SURGE...   ...SWAY....   ...HEAVE...   ...ROLL....   ...PITCH...
....YAW....   ADDED RESISTANCES
 FREQ SL/WL  FREQ    AMPL PHASE    AMPL PHASE    AMPL PHASE    AMPL PHASE
AMPL PHASE    AMPL PHASE  GER/BEU    BOESE
```

```
 (r/s)  (-) (r/s)   (m/m) (deg)   (m/m) (deg)   (m/m) (deg)  (deg/m) (deg)  (deg/m) (deg)  (deg/m) (deg)
(kN/m2)  (kN/m2)
 0.200 0.452 0.200    1.023  90.4    0.000  90.0    0.950 359.6    0.000  85.1    0.255 266.9    0.000
180.2   1.71E-01 -8.37E-01
 0.233 0.510 0.233    0.909  90.8    0.000  90.0    0.918 359.5    0.000  83.2    0.319 265.8    0.000
180.6   5.43E-01 -8.74E-01
 0.267 0.574 0.267    0.814  91.5    0.000  89.6    0.869 359.3    0.000  79.7    0.389 264.5    0.000
184.2   1.71E+00 -3.11E-01
 0.300 0.641 0.300    0.720  92.6    0.000  90.3    0.797 359.2    0.000 257.6    0.461 262.7    0.000
177.7   5.03E+00  2.34E+00
 0.333 0.710 0.333    0.616  94.6    0.000  90.0    0.701 359.2    0.000 251.5    0.526 260.4    0.000
178.8   1.33E+01  1.06E+01
 0.367 0.780 0.367    0.499  97.7    0.000  89.7    0.577 359.9    0.000 241.3    0.571 257.5    0.000
179.0   3.11E+01  2.86E+01
 0.400 0.851 0.400    0.373 102.7    0.000  89.2    0.430   2.5    0.000 211.6    0.585 253.8    0.000
179.1   6.38E+01  6.00E+01
 0.433 0.922 0.433    0.248 111.9    0.000  88.2    0.272  11.9    0.000 113.2    0.556 249.1    0.000
179.0   1.15E+02  1.03E+02
 0.467 0.993 0.467    0.140 132.1    0.000  83.1    0.159  49.3    0.000  78.8    0.477 242.5    0.000
178.7   1.79E+02  1.50E+02
 0.500 1.064 0.500    0.087 183.3    0.000 351.8    0.217  96.6    0.000  64.9    0.344 233.6    0.000
178.4   2.51E+02  1.76E+02
 0.533 1.135 0.533    0.110 231.1    0.000 278.6    0.324 100.9    0.000  52.6    0.168 216.9    0.000
178.0   3.22E+02  1.70E+02
 0.567 1.206 0.567    0.138 252.3    0.000 273.3    0.335  88.6    0.000  37.8    0.064  80.1    0.000
179.3   3.72E+02  1.18E+02
 0.600 1.277 0.600    0.140 265.8    0.000 272.8    0.242  72.3    0.000  19.7    0.222  25.3    0.000
345.4   4.07E+02  9.00E+01
 0.633 1.347 0.633    0.116 279.7    0.000 274.5    0.101  43.7    0.000 356.5    0.265 357.2    0.000
354.4   4.15E+02  1.52E+02
 0.667 1.418 0.667    0.077 302.5    0.000 282.2    0.049 275.4    0.000 328.6    0.182 329.8    0.000
355.4   3.85E+02  1.41E+02
 0.700 1.489 0.700    0.051 348.4    0.000   1.6    0.100 233.2    0.000 300.0    0.066 281.3    0.000
356.9   3.58E+02  3.96E+01
 0.733 1.560 0.733    0.054  37.6    0.000  69.8    0.095 217.4    0.000 273.5    0.068 176.3    0.000
3.4   3.58E+02 -1.01E+01
 0.767 1.631 0.767    0.058  66.9    0.000  80.6    0.056 203.1    0.000 248.9    0.098 147.6    0.000
54.4   3.47E+02  1.66E+01
 0.800 1.702 0.800    0.049  93.3    0.000  92.0    0.015 156.6    0.000 223.5    0.082 134.2    0.000
146.6   3.10E+02  4.28E+01
 0.833 1.773 0.833    0.035 131.9    0.000 126.1    0.025  48.8    0.000 194.5    0.039 121.5    0.000
159.2   2.75E+02  2.60E+01
 0.867 1.844 0.867    0.030 183.1    0.000 207.1    0.032  34.6    0.000 159.7    0.008 354.4    0.000
169.6   2.60E+02  2.82E+00
 0.900 1.915 0.900    0.030 224.1    0.000 235.8    0.022  29.7    0.000 125.5    0.030 310.6    0.000
217.1   2.52E+02  6.47E+00
 0.933 1.986 0.933    0.024 263.0    0.000 254.8    0.005  32.3    0.000  98.1    0.030 305.5    0.000
306.8   2.35E+02  1.53E+01
 0.967 2.057 0.967    0.019 315.6    0.000 319.4    0.007 200.2    0.000  74.7    0.014 308.6    0.000
322.7   2.23E+02  7.97E+00
 1.000 2.128 1.000    0.018   5.4    0.000  30.7    0.010 204.9    0.000  44.9    0.005  87.7    0.000
337.3   2.17E+02  1.44E+00
 1.033 2.198 1.033    0.015  48.8    0.000  48.3    0.005 221.0    0.000 348.0    0.013 108.4    0.000
103.0   2.10E+02  4.83E+00
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 1.067 2.269 1.067   0.011 108.8   0.000  76.5   0.003 325.1   0.000 295.0   0.009 119.0   0.000
130.1   2.04E+02  4.14E+00
 1.100 2.340 1.100   0.011 165.6   0.000 203.8   0.004   0.6   0.000 266.4   0.003 210.0   0.000
136.4   2.00E+02  7.40E-01
 1.133 2.411 1.133   0.009 211.3   0.000 219.0   0.002  27.0   0.000 232.4   0.006 267.1   0.000
281.7   1.97E+02  2.18E+00
 1.167 2.482 1.167   0.007 283.8   0.000 230.4   0.002 143.3   0.000 132.0   0.004 284.5   0.000
307.9   1.91E+02  1.84E+00
 1.200 2.553 1.200   0.008 340.9   0.000  31.5   0.003 171.8   0.000  83.9   0.002  32.2   0.000
307.0   1.90E+02  4.09E-01
 1.233 2.624 1.233   0.005  32.2   0.000  36.1   0.001 204.3   0.000  46.8   0.004  79.7   0.000
144.1   1.88E+02  1.35E+00
 1.267 2.695 1.267   0.005 120.7   0.000  28.4   0.001 328.3   0.000 305.4   0.002 102.4   0.000
129.0   1.85E+02  6.50E-01
 1.300 2.766 1.300   0.005 168.5   0.000 220.6   0.001 354.4   0.000 256.0   0.001 230.7   0.000
117.8   1.83E+02  3.75E-01
 1.333 2.837 1.333   0.003 242.9   0.000 214.2   0.000  55.0   0.000 207.1   0.002 264.2   0.000
323.8   1.81E+02  6.63E-01
 1.367 2.908 1.367   0.004 324.6   0.000  83.0   0.001 162.7   0.000 106.0   0.001 300.8   0.000
306.8   1.79E+02  1.38E-01
 1.400 2.979 1.400   0.003  17.7   0.000  39.9   0.001 187.2   0.000  65.0   0.001  80.6   0.000
253.6   1.77E+02  2.84E-01
 1.433 3.049 1.433   0.003 112.5   0.000  21.2   0.000 334.8   0.000 325.2   0.001 106.0   0.000
133.9   1.75E+02  9.79E-02
 1.467 3.120 1.467   0.003 180.5   0.000 225.2   0.001  10.2   0.000 252.0   0.000 230.9   0.000
111.8   1.74E+02  7.78E-02
 1.500 3.191 1.500   0.002 259.5   0.000 208.0   0.000  40.4   0.000 199.2   0.001 290.7   0.000
323.4   1.71E+02 -2.55E-03
 1.533 3.262 1.533   0.002 339.0   0.000  56.9   0.000 194.5   0.000  71.0   0.000 317.9   0.000
297.1   1.69E+02  5.15E-02
 1.567 3.333 1.567   0.002  67.4   0.000  28.6   0.000 202.9   0.000  32.4   0.001 107.3   0.000
164.8   1.67E+02 -4.85E-02
 1.600 3.404 1.600   0.002 135.3   0.000 269.1   0.000  13.2   0.000 255.2   0.001 116.1   0.000
118.6   1.65E+02  3.92E-02
 1.633 3.475 1.633   0.002 240.4   0.000 208.4   0.000   7.9   0.000 213.3   0.001 287.2   0.000
16.0   1.63E+02 -6.96E-02
 1.667 3.546 1.667   0.001 309.0   0.000 119.8   0.000 209.1   0.000  75.8   0.001 280.8   0.000
298.0   1.61E+02  3.21E-02
 1.700 3.617 1.700   0.005 221.1   0.000  26.5   0.000 184.2   0.000  28.9   0.000 121.4   0.000
209.2   1.58E+02 -5.55E-02


San Diego class tanker motions with  spring                    Execution: 18-04-1994 / 18:44
SEAWAY-4.12

FREQUENCY CHARACTERISTICS OF MOTIONS POINTS       FORWARD SPEED =  0.00 kn
--------------------------------------------     WAVE DIRECTION = +180 deg off stern
POINT NR =     01
X-APP    = 278.000 m
Y-CL     =   0.000 m
Z-BL     =  10.000 m

                 ............ABSOLUTE MOTIONS............   ..REL MOT..
 WAVE  SQRT   ENC     .....X.....    .....Y.....    .....Z.....    .....Z.....
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```
 FREQ SL/WL  FREQ    AMPL PHASE    AMPL PHASE    AMPL PHASE    AMPL PHASE
(r/s)  (-) (r/s)  (m/m) (deg)  (m/m) (deg)  (m/m) (deg)  (m/m) (deg)
0.200 0.452 0.200  1.053  90.3  0.000 120.3  1.138  30.4  0.193 188.7
0.233 0.510 0.233  0.947  90.6  0.000 125.6  1.207  36.4  0.300 190.6
0.267 0.574 0.267  0.860  91.1  0.000 122.6  1.293  42.4  0.454 192.7
0.300 0.641 0.300  0.774  91.9  0.000 148.6  1.389  47.9  0.664 194.9
0.333 0.710 0.333  0.677  93.3  0.000 151.3  1.479  52.4  0.934 197.3
0.367 0.780 0.367  0.563  95.3  0.000 156.1  1.534  55.9  1.241 200.0
0.400 0.851 0.400  0.435  98.3  0.000 161.1  1.527  58.3  1.551 203.0
0.433 0.922 0.433  0.300 103.3  0.000 166.0  1.434  59.9  1.809 206.6
0.467 0.993 0.467  0.168 113.7  0.000 171.2  1.242  60.8  1.950 211.2
0.500 1.064 0.500  0.069 156.1  0.000 177.3  0.954  62.5  1.903 218.1
0.533 1.135 0.533  0.091 234.2  0.000 186.9  0.600  65.9  1.659 229.0
0.567 1.206 0.567  0.146 252.7  0.000 212.9  0.190  95.2  1.204 250.5
0.600 1.277 0.600  0.155 257.3  0.000 293.1  0.385 178.0  1.154 298.6
0.633 1.347 0.633  0.113 264.0  0.000 331.6  0.539 169.4  1.555 323.2
0.667 1.418 0.667  0.059 292.8  0.000 345.3  0.388 155.7  1.486 338.0
0.700 1.489 0.700  0.049 357.0  0.000 355.7  0.112 143.0  1.096   8.1
0.733 1.560 0.733  0.061  32.6  0.000  13.5  0.104 319.5  1.011  58.0
0.767 1.631 0.767  0.058  55.5  0.000  68.9  0.196 314.0  1.194  97.3
0.800 1.702 0.800  0.042  84.6  0.000 132.8  0.174 312.4  1.230 129.1
0.833 1.773 0.833  0.030 133.4  0.000 155.8  0.085 317.6  1.098 166.7
0.867 1.844 0.867  0.031 182.8  0.000 175.5  0.022  66.0  1.025 214.0
0.900 1.915 0.900  0.030 217.1  0.000 222.3  0.068 112.0  1.079 260.9
0.933 1.986 0.933  0.022 256.5  0.000 294.4  0.069 121.1  1.096 304.4
0.967 2.057 0.967  0.017 316.2  0.000 324.2  0.034 140.4  1.041 351.6
1.000 2.128 1.000  0.018   3.5  0.000 353.7  0.019 239.0  1.026  43.4
1.033 2.198 1.033  0.014  43.7  0.000  76.5  0.031 279.5  1.045  95.0
1.067 2.269 1.067  0.010 107.7  0.000 124.7  0.022 302.2  1.030 147.4
1.100 2.340 1.100  0.011 164.4  0.000 150.1  0.010  17.7  1.016 203.2
1.133 2.411 1.133  0.009 207.2  0.000 238.3  0.016  79.8  1.024 260.1
1.167 2.482 1.167  0.006 283.7  0.000 299.9  0.012 110.3  1.016 318.1
1.200 2.553 1.200  0.008 339.7  0.000 321.6  0.006 195.9  1.010  18.7
1.233 2.624 1.233  0.005  28.4  0.000  75.3  0.009 253.9  1.014  80.6
1.267 2.695 1.267  0.005 121.7  0.000 124.1  0.006 291.3  1.008 144.0
1.300 2.766 1.300  0.005 167.0  0.000 142.9  0.004  33.0  1.006 209.5
1.333 2.837 1.333  0.003 241.0  0.000 291.3  0.005  82.0  1.008 276.4
1.367 2.908 1.367  0.004 325.1  0.000 309.8  0.002 134.6  1.004 345.1
1.400 2.979 1.400  0.003  15.6  0.000 355.9  0.003 246.7  1.005  55.6
1.433 3.049 1.433  0.002 112.9  0.000 124.9  0.003 290.1  1.004 127.5
1.467 3.120 1.467  0.003 180.1  0.000 134.9  0.001  29.1  1.002 201.4
1.500 3.191 1.500  0.002 257.9  0.000 300.4  0.002 107.1  1.004 276.9
1.533 3.262 1.533  0.002 339.5  0.000 307.2  0.001 157.8  1.002 353.9
1.567 3.333 1.567  0.002  65.8  0.000 116.7  0.002 277.6  1.003  72.9
1.600 3.404 1.600  0.002 136.1  0.000 122.4  0.001 311.1  1.002 153.3
1.633 3.475 1.633  0.002 238.8  0.000 308.2  0.001  89.9  1.002 235.7
1.667 3.546 1.667  0.001 310.4  0.000 298.9  0.001 111.3  1.002 319.5
1.700 3.617 1.700  0.005 221.6  0.000 223.0  0.001 272.4  1.001  45.2
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San Diego class tanker motions with  spring            Execution: 18-04-1994 / 18:44
SEAWAY-4.12

STATISTICS OF BASIC MOTIONS                FORWARD SPEED =  0.00 kn
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-----------------------------          WAVE DIRECTION = +180 deg off stern

...........SEA...........      ......................SIGNIFICANT VALUES OF BASIC
MOTIONS.......................        MEAN ADDED
....INPUT... .CALCULATED.   ...SURGE...   ....SWAY...   ...HEAVE...   ....ROLL...   ...PITCH...
....YAW....     RESISTANCE
HEIGHT  PER HEIGHT  PER    AMPL  PER   AMPL  PER   AMPL  PER   AMPL  PER
AMPL  PER   AMPL  PER  GER/BEU  BOESE
 (m)  (s)   (m)  (s)    (m)  (s)   (m)  (s)   (m)  (s)  (deg)  (s)  (deg)  (s)  (deg)  (s)    (kN)
(kN)
 4.76 12.00   4.75 12.16    0.76 17.20   0.00  7.66   0.91 16.35   0.00 10.99   1.00 15.25   0.00
10.32    536.1   242.7
 6.06 13.00   6.05 13.14    1.18 18.22   0.00 18.23   1.37 17.54   0.00 22.02   1.35 15.85   0.00
15.87    717.1   344.9
 7.53 14.00   7.52 14.12    1.71 19.17   0.00 19.14   1.95 18.59   0.00 22.61   1.73 16.41   0.00
16.45    906.9   454.8
 8.84 15.00   8.83 15.10    2.27 20.09   0.00 20.03   2.55 19.55   0.00 22.91   2.04 16.94   0.00
17.02   1021.4   527.2


San Diego class tanker motions with  spring                  Execution: 18-04-1994 / 18:44
SEAWAY-4.12

STATISTICS OF MOTIONS IN POINTS               FORWARD SPEED =  0.00 kn
--------------------------------              WAVE DIRECTION = +180 deg off stern
POINT NR =     01
X-APP   = 278.000 m
Y-CL    =   0.000 m
Z-BL    =  10.000 m
                 ..........................................SIGNIFICANT VALUES
OF.............................................
                 ..........DISPLACEMENTS..........     ..........VELOCITIES............
..........ACCELERATIONS..........
.....SEA....      ....X....  ....Y....  ....Z....     ....X....  ....Y....  ....Z....     ....X....  ....Y....  ....Z....
HEIGHT  PER      AMPL  PER  AMPL  PER  AMPL  PER     AMPL  PER  AMPL  PER  AMPL
PER     AMPL  PER   AMPL  PER   AMPL  PER
 (m)  (s)      (m)  (s)   (m)  (s)   (m)  (s)     (m/s)  (s)  (m/s)  (s)  (m/s)  (s)    (m/s2)  (s)  (m/s2)  (s)
(m/s2)  (s)
 4.76 12.00      0.85 17.2   0.00 15.5   2.67 15.4     0.32 16.2   0.00 10.3   1.10 14.7     0.11 12.7
0.00 6.28   0.48 13.8
 6.06 13.00      1.30 18.1   0.00 16.3   3.65 16.1     0.46 17.1   0.00 15.3   1.44 15.2     0.14 13.0
0.00 6.28   0.60 14.3
 7.53 14.00      1.88 19.0   0.00 17.0   4.73 16.8     0.63 18.0   0.00 15.9   1.80 15.7     0.16 13.3
0.00 9.25   0.73 14.7
 8.84 15.00      2.47 19.9   0.00 17.8   5.69 17.4     0.79 18.7   0.00 16.5   2.09 16.2     0.17 13.5
0.00 16.1   0.82 15.1

               ........VERTICAL RELATIVE MOTIONS........   ...SLAMMING DEFINED BY...
               ..SIGNIFICANT VALUES OF...    .EXCEEDING.    ....BOW EMERGENCE AND....
.....SEA....     DISPLACEMENT   .VELOCITY.   ...Z-BL...   .VELOCITY.   .PRESSURE.
HEIGHT  PER      AMPL  PER     AMPL  PER    PROB  NR/H    PROB  NR/H    PROB  NR/H
 (m)  (s)       (m)  (s)   (m/s)  (s)     (%) (1/h)    (%) (1/h)    (%) (1/h)
 4.76 12.00      3.54 12.58    5.03 13.08     0.0   0.0     0.0   0.0     0.0   0.1
 6.06 13.00      4.34 13.05    6.15 13.39     0.1   0.2     0.0   0.0     0.3   2.4
```

```
7.53 14.00      5.12 13.44    7.19 13.62    0.5   1.5     0.0  0.0      1.5  11.9
8.84 15.00      5.65 13.77    7.85 13.79    1.3   3.6     0.0  0.0      3.2  24.6
```

San Diego Light Ship Environment Input File

```
    4.12
San Diego class tanker (light ship) motions with spring
     +1        +1        0        +1        0
    6.098     0.000     0.000    304.878  1.025E+00
   123456       1         6        +5        0
      1
     0.0
      1
    180.0
    2.500       1      0.200     1.700   0.033333
    1.474
  +16.800    +20.981    69.750     69.750
      0
      3
    5.000
     0.0    61.250   105.000
      0
      1
   278.00      0.0       0.0
    20.4      0.0       0.0
     -1
   278.000    0.000     10.000
      6
     +2
    3.00    12.00
    4.00    13.00
    5.00    14.00
    3.50    12.50
    4.50    13.50
    2.00    11.00
      0
*** End of file ***
```

San Diego Light Ship Output File

```
################################
# Program: SEAWAY                          Journee #
#                                          #
# STRIPTHEORY CALCULATIONS OF MOTIONS AND LOADS IN A SEAWAY #
#                                          #
#               Release 4.12                 #
#               (31-07-1993)                 #
################################

User: University of California, Berkeley, U.S.A.
INPUT DATA
~~~~~~~~~~

San Diego class tanker (light ship) motions with spring
```

```
PRINT-CODE INPUT DATA .............. KPR(1) :     1
PRINT-CODE GEOMETRIC DATA .......... KPR(2) :     1
PRINT-CODE HYDRODYNAMIC COEFFICIENTS KPR(3) :     0
PRINT-CODE FREQUENCY CHARACTERISTICS KPR(4) :     1
PRINT-CODE SPECTRAL DATA ........... KPR(5) :     0

ACTUAL MIDSHIP DRAFT ................ DRAFT :  6.098 m
ACTUAL TRIM BY STERN ................. TRIM :  0.000 m
DUMMY VALUE, FOR THE TIME BEING ...... DIST :  0.000

WATER DEPTH ......................... DEPTH :  304.9 m
DENSITY OF WATER ...................... RHO :  1.025 ton/m3

DEGREES OF FREEDOM CODE ............... MOT : 123456
VERSION-CODE OF STRIP THEORY METHOD ... KTH :     1
NUMBER OF TERMS IN POTENTIAL SERIES .. MSER :     6
CODE OF USED 2-D APPROXIMATION ....... KCOF :     5
NUMBER OF "FREE-CHOICE" SECTIONS ...... NFR :     0

NUMBER OF FORWARD SPEEDS ............... NV :     1
FORWARD SPEEDS (kn) ................ VK(NV) :  0.00

NUMBER OF WAVE DIRECTIONS ............. NWD :     1
WAVE DIRECTIONS (deg off stern) WAVDIR(NWD) : 180.0

MAX. FREQ. OF ENCOUNTER IN SERIES . FREQMAX :  2.500 rad/sec   (range =  0.000 -  3.125
rad/sec)
CODE FOR WAVE FREQUENCY INPUT ....... KOMEG :     1
MINIMUM CIRCULAR WAVE FREQUENCY ..... OMMIN :  0.200 rad/sec
MAXIMUM CIRCULAR WAVE FREQUENCY ..... OMMAX :  1.700 rad/sec
INCREMENT IN WAVE FREQUENCIES ....... OMINC :  0.033 rad/sec

WAVE AMPLITUDE FOR LINEARISATION ... WAVAMP :  1.474 m


INPUT DATA (continued)
----------------------
BASE LINE TO CENTRE OF GRAVITY ... +GKGM=KG : 16.800 m

MASS-GYRADIUS k-xx ................. GYR(1) : 20.981 m
MASS-GYRADIUS k-yy ................. GYR(2) : 69.750 m
MASS-GYRADIUS k-zz ................. GYR(3) : 69.750 m

NUMBER OF LOAD-CALCULATION SECTIONS .. NBTM :     0

CODE OF ROLL DAMPING INPUT ............ KRD :     3
AVERAGE ROLL AMPLITUDE ............. ROLAMP :  5.000 deg
HEIGHT OF BILGE KEEL .................. HBK :  0.000 m
DISTANCE OF A.P.P. TO AFT END B.K. ... XBKA :  61.25 m
DISTANCE OF A.P.P. TO FORWARD END B.K. XBKF : 105.00 m

CODE OF ANTI-ROLLING DEVICES ......... KARD :     0

NUMBER OF LINEAR SPRINGS ............. NCAB :     1
```

```
COORDINATES AND LINEAR SPRING COEFFICIENTS :278.000   0.000   0.000  2.040E+01
0.000E-01  0.000E-01

NUMBER OF DISCRETE POINTS ............ NPTS :    -1
COORDINATES OF POINTS (m) .. PTSXYZ(NPTS,3) : 278.00  0.00  10.00

NUMBER OF SEA STATES ................. NSEA :    6
CODE OF IRREGULAR SEA DESCRIPTION .... KSEA :    2
WAVE HEIGHTS (m) HW(K) / PERIODS (s) TW(K) :  3.00  12.00
                                  4.00  13.00
                                  5.00  14.00
                                  3.50  12.50
                                  4.50  13.50
                                  2.00  11.00

INPUT-CODE OF CRITERA FOR SHIPMOTIONS  KRIT :    0


San Diego class tanker motions with  spring                Execution: 18-04-1994 , 18:53
SEAWAY-4.12

GEOMETRICAL HULLFORM DATA
~~~~~~~~~~~~~~~~~~~~~~~~~

ACTUAL MIDSHIP DRAFT (T) ................ :  6.098 m
ACTUAL TRIM BY STERN .................... :  0.000 m

LENGTH BETWEEN PERPENDICULARS (Lpp) ...... : 278.892 m
REAR SECTION TO A.P.P. .................. :   6.706 m

WATERLINE : LENGTH (Lwl) ................ : 285.598 m
     BEAM (B) .................... :  50.596 m
     AREA ........................ :   11676 m2
     AREA COEFFICIENT (Lpp) ....... :  0.8274
     AREA COEFFICIENT (Lwl) ....... :  0.8080
     CENTROID TO A.P.P. .......... : 150.548 m   (+11.102 m or +3.98 % Lpp/2)
     CENTROID TO REAR SECTION ..... : 157.254 m   (+14.455 m or +5.06 % Lwl/2)

DISPLACEMENT : VOLUME .................... :   68354 m3
     BLOCKCOEFFICIENT (Lpp) .... :  0.7944
     BLOCKCOEFFICIENT (Lwl) .... :  0.7757
     CENTROID TO A.P.P. ........ : 150.967 m   (+11.521 m or +4.13 % Lpp/2)
     CENTROID TO REAR SECTION .. : 157.673 m   (+14.874 m or +5.21 % Lwl/2)
     CENTROID TO WATERLINE ..... :   2.984 m
     CENTROID TO KEELLINE ...... :   3.114 m
     MIDSHIP SECTION COEFFICIENT :  0.9911
     LONG. PRISMATIC COEFFICIENT :  0.8015
     VERT. PRISMATIC COEFFICIENT :  0.9600
     RATIO Lpp/B ............... :   5.512
     RATIO Lwl/B ............... :   5.645
     RATIO B/T ................. :   8.297
     WETTED SURFACE HULL ....... :   13934 m2
```

```
STABILITY PARAMETERS
--------------------

KB ............ :   3.114 m
KG ............ :  16.800 m
BM-TRANSVERSE . :  32.494 m
GM-TRANSVERSE . :  18.808 m
BM-LONGITUDINAL : 792.786 m
GM-LONGITUDINAL : 779.100 m


San Diego class tanker motions with  spring                Execution: 18-04-1994 , 18:53
SEAWAY-4.12

SECTIONAL HULLFORM DATA
-----------------------

STATION  X-APP  HALF  HALF  DRAFT   AREA  AREA   KB   BO WETTED
 NUMBER        CL-CL  WIDTH               COEFF        LENGTH
  (-)    (m)   (m)   (m)   (m)    (m2)    (-)   (m)   (m)   (m)
 -6.71  -6.706  0.000  0.003  0.003   0.0000 0.7500 6.097 0.001  0.009
 -3.66  -3.658  0.000  0.003  0.003   0.0000 0.7500 6.097 0.001  0.009
 -0.61  -0.610  0.000  0.003  0.003   0.0000 0.7500 6.097 0.001  0.009
  0.50   2.438  0.000  0.003  0.003   0.0000 0.7500 6.097 0.001  0.009
  1.00   5.486  0.000  0.003  0.003   0.0000 0.7500 6.097 0.001  0.009
  2.00   8.534  0.000  0.003  0.003   0.0000 0.7500 6.097 0.001  0.009
  3.00  12.192  0.000  1.441  6.098  11.9976 0.6825 3.738 2.360 12.694
  4.00  18.136  0.000  4.837  6.098  46.6412 0.7906 3.389 2.709 17.625
  5.00  24.232  0.000  8.016  6.098  80.9939 0.8285 3.304 2.794 23.183
  6.00  34.900  0.000 13.320  6.098 138.5482 0.8528 3.247 2.851 32.687
  7.00  45.568  0.000 17.992  6.098 191.0340 0.8706 3.218 2.880 41.506
  8.00  59.284  0.000 22.502  6.098 250.4236 0.9125 3.173 2.925 50.882
  9.00  73.000  0.000 24.877  6.098 289.3329 0.9536 3.123 2.975 57.119
 10.00  86.716  0.000 25.298  6.098 304.2029 0.9860 3.081 3.017 60.122
 11.00 100.432  0.000 25.298  6.098 305.7981 0.9911 3.072 3.026 60.647
 12.00 127.864  0.000 25.298  6.098 305.7981 0.9911 3.072 3.026 60.647
 13.00 155.296  0.000 25.298  6.098 305.7981 0.9911 3.072 3.026 60.647
 14.00 182.728  0.000 25.298  6.098 305.7981 0.9911 3.072 3.026 60.647
 15.00 210.160  0.000 25.298  6.098 305.5416 0.9903 3.074 3.024 60.607
 16.00 223.876  0.000 25.295  6.098 303.8590 0.9850 3.085 3.013 60.047
 17.00 237.592  0.000 24.912  6.098 292.7500 0.9635 3.117 2.981 57.684
 18.00 249.022  0.000 22.965  6.098 262.1276 0.9359 3.160 2.938 52.595
 19.00 260.452  0.000 18.592  6.098 199.7755 0.8811 3.247 2.851 42.707
 19.50 266.852  0.000 14.457  6.098 146.7948 0.8325 3.338 2.760 34.120
 19.60 272.948  0.000  9.196  5.793  79.2156 0.7435 3.656 2.442 23.210
 19.70 275.971  0.000  6.024  4.422  41.0068 0.7697 4.160 1.938 16.207
 19.80 278.892  0.000  0.003  0.003   0.0000 0.7500 6.097 0.001  0.009


San Diego class tanker motions with  spring                Execution: 18-04-1994 / 18:53
SEAWAY-4.12

TWO-PARAMETER LEWIS CONFORMAL MAPPING COEFFICIENTS
-------------------------------------------------
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```
STATION  X-APP  HALF  DRAFT  AREA   M(S)  A(-1)   A(1)   A(3)   RMS
HULLFORM REMARKS WITH REGARD
 NUMBER        WIDTH       COEFF                                TO LEWIS
CONFORMAL MAPPING
  (-)    (m)   (m)   (m)   (-)    (m)    (-)    (-)    (-)    (m)
 -6.71  -6.706  0.003  0.003 0.7500  0.0025 +1.0000 +0.0000 +0.0225   0.001
CONVENTIONAL
 -3.66  -3.658  0.003  0.003 0.7500  0.0025 +1.0000 +0.0000 +0.0225   0.001
CONVENTIONAL
 -0.61  -0.610  0.003  0.003 0.7500  0.0025 +1.0000 +0.0000 +0.0225   0.001
CONVENTIONAL
  0.50   2.438  0.003  0.003 0.7500  0.0025 +1.0000 +0.0000 +0.0225   0.001
CONVENTIONAL
  1.00   5.486  0.003  0.003 0.7500  0.0025 +1.0000 +0.0000 +0.0225   0.001
CONVENTIONAL
  2.00   8.534  0.003  0.003 0.7500  0.0025 +1.0000 +0.0000 +0.0225   0.001
CONVENTIONAL
  3.00  12.192  1.441  6.098 0.6825  3.6227 +1.0000 -0.6427 +0.0406   0.058
CONVENTIONAL
  4.00  18.136  4.837  6.098 0.7906  5.4855 +1.0000 -0.1149 -0.0033  0.193
CONVENTIONAL
  5.00  24.232  8.016  6.098 0.8285  7.2523 +1.0000 +0.1322 -0.0270  0.302
CONVENTIONAL
  6.00  34.900 13.320  6.098 0.8528  10.0827 +1.0000 +0.3581 -0.0371   0.382
CONVENTIONAL
  7.00  45.568 17.992  6.098 0.8706  12.5611 +1.0000 +0.4734 -0.0411   0.411
CONVENTIONAL
  8.00  59.284 22.502  6.098 0.9125  15.1240 +1.0000 +0.5423 -0.0545   0.263   TUNNELED
  9.00  73.000 24.877  6.098 0.9536  16.6193 +1.0000 +0.5650 -0.0681   0.175   TUNNELED
 10.00  86.716 25.298  6.098 0.9860  17.0732 +1.0000 +0.5623 -0.0805   0.373   TUNNELED
 11.00 100.432 25.298  6.098 0.9911  17.1126 +1.0000 +0.5610 -0.0827   0.431   TUNNELED
 12.00 127.864 25.298  6.098 0.9911  17.1126 +1.0000 +0.5610 -0.0827   0.431   TUNNELED
 13.00 155.296 25.298  6.098 0.9911  17.1126 +1.0000 +0.5610 -0.0827   0.431   TUNNELED
 14.00 182.728 25.298  6.098 0.9911  17.1126 +1.0000 +0.5610 -0.0827   0.431   TUNNELED
 15.00 210.160 25.298  6.098 0.9903  17.1062 +1.0000 +0.5612 -0.0823   0.426   TUNNELED
 16.00 223.876 25.295  6.098 0.9850  17.0641 +1.0000 +0.5625 -0.0801   0.368   TUNNELED
 17.00 237.592 24.912  6.098 0.9635  16.7098 +1.0000 +0.5630 -0.0721   0.191   TUNNELED
 18.00 249.022 22.965  6.098 0.9359  15.5225 +1.0000 +0.5433 -0.0638   0.094   TUNNELED
 19.00 260.452 18.592  6.098 0.8811  12.9321 +1.0000 +0.4830 -0.0454   0.261
CONVENTIONAL
 19.50 266.852 14.457  6.098 0.8325  10.5419 +1.0000 +0.3965 -0.0251   0.244
CONVENTIONAL
 19.60 272.948  9.196  5.793 0.7435   7.3094 +1.0000 +0.2328 +0.0253   0.132
CONVENTIONAL
 19.70 275.971  6.024  4.422 0.7697   5.1725 +1.0000 +0.1548 +0.0097   0.138
CONVENTIONAL            19.80 278.892  0.003  0.003 0.7500  0.0025 +1.0000 +0.0000
+0.0225   0.001    CONVENTIONAL


San Diego class tanker motions with  spring                    Execution: 18-04-1994 / 18:53
SEAWAY-4.12

N-PARAMETER CLOSE-FIT CONFORMAL MAPPING COEFFICIENTS
```

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

STATION    M(S)  A(-1)   A(1)    A(3)    A(5)    A(7)    A(9)   A(11)   A(13)   A(15)   A(17)
A(19)    RMS
  (-)     (m)    (-)     (-)     (-)     (-)     (-)     (-)     (-)     (-)     (-)     (-)     (-)    (m)
 -6.71  +0.0031 +1.0000 -0.0203 -0.1787 +0.0203 +0.0000 +0.0000 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.000
 -3.66  +0.0031 +1.0000 -0.0203 -0.1787 +0.0203 +0.0000 +0.0000 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.000
 -0.61  +0.0031 +1.0000 -0.0203 -0.1787 +0.0203 +0.0000 +0.0000 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.000
  0.50  +0.0031 +1.0000 -0.0203 -0.1787 +0.0203 +0.0000 +0.0000 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.000
  1.00  +0.0031 +1.0000 -0.0203 -0.1787 +0.0203 +0.0000 +0.0000 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.000
  2.00  +0.0031 +1.0000 -0.0203 -0.1787 +0.0203 +0.0000 +0.0000 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.000
  3.00  +3.6242 +1.0000 -0.6402 +0.0375 -0.0163 +0.0027 +0.0142 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.042
  4.00  +5.5354 +1.0000 -0.1510 -0.0205 +0.0189 +0.0062 +0.0182 +0.0021 +0.0000 +0.0000
+0.0000 +0.0000   0.058
  5.00  +7.2825 +1.0000 +0.0834 -0.0375 +0.0238 +0.0089 +0.0077 -0.0024 +0.0168 +0.0000
+0.0000 +0.0000   0.056
  6.00 +10.0017 +1.0000 +0.3218 -0.0483 +0.0322 +0.0190 +0.0070 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.053
  7.00 +12.4274 +1.0000 +0.4446 -0.0507 +0.0291 +0.0199 +0.0048 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.032
  8.00 +15.0270 +1.0000 +0.5285 -0.0641 +0.0125 +0.0158 +0.0048 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.031
  9.00 +16.6765 +1.0000 +0.5642 -0.0801 -0.0060 +0.0088 +0.0048 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.030
 10.00 +17.3566 +1.0000 +0.5742 -0.0933 -0.0218 -0.0022 +0.0007 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.027
 11.00 +17.4423 +1.0000 +0.5746 -0.0964 -0.0250 -0.0036 +0.0008 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.033
 12.00 +17.4423 +1.0000 +0.5746 -0.0964 -0.0250 -0.0036 +0.0008 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.033
 13.00 +17.4423 +1.0000 +0.5746 -0.0964 -0.0250 -0.0036 +0.0008 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.033
 14.00 +17.4423 +1.0000 +0.5746 -0.0964 -0.0250 -0.0036 +0.0008 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.033
 15.00 +17.4306 +1.0000 +0.5750 -0.0954 -0.0247 -0.0040 +0.0005 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.031
 16.00 +17.3371 +1.0000 +0.5745 -0.0917 -0.0212 -0.0029 +0.0003 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.034
 17.00 +16.8167 +1.0000 +0.5671 -0.0813 -0.0093 +0.0033 +0.0015 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.034
 18.00 +15.5149 +1.0000 +0.5406 -0.0700 +0.0013 +0.0066 +0.0017 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.019
 19.00 +12.8671 +1.0000 +0.4610 -0.0430 +0.0117 +0.0024 +0.0128 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.097
 19.50 +10.4680 +1.0000 +0.3717 -0.0216 +0.0164 +0.0034 +0.0111 +0.0000 +0.0000 +0.0000
+0.0000 +0.0000   0.067
```

```
 19.60  +7.2776  +1.0000  +0.2124  +0.0228  +0.0125  +0.0069  +0.0089  +0.0000  +0.0000  +0.0000
+0.0000  +0.0000   0.027
 19.70  +5.1174  +1.0000  +0.1274  +0.0222  +0.0155  -0.0017  +0.0136  +0.0000  +0.0000  +0.0000
+0.0000  +0.0000   0.031
 19.80  +0.0031  +1.0000  -0.0203  -0.1787  +0.0203  +0.0000  +0.0000  +0.0000  +0.0000  +0.0000
+0.0000  +0.0000   0.000
```

```
San Diego class tanker motions with  spring                  Execution: 18-04-1994 / 18:53
SEAWAY-4.12

NATURAL ROLL AND COEFFICIENTS AT FIXED AMPLITUDE
------------------------------------------------

FORWARD SHIP SPEED . (kn) :     0.00
MEAN ROLL AMPLITUDE (deg) :    5.000

NATURAL ROLL PERIOD . (s) :   11.922
NATURAL FREQUENCY . (r/s) :    0.527

LINEAR EQUIVALENT GM  (m) :   18.858

MASS. k-phi-phi ..... (m) :   25.802
COMPONENTS k-phi-phi:
  SOLID MASS PART .. (m) :   20.981
  2-D POTENTIAL PART (m) :   15.018

DAMPING. kappa ...... (-) :   0.0261
COMPONENTS kappa:
  2-D POTENTIAL PART (-) :   0.0227
  SPEED EFFECT PART  (-) :   0.0000
  SKIN FRICTION PART (-) :   0.0003
  EDDY MAKING PART . (-) :   0.0031
  LIFT MOMENT PART . (-) :   0.0000
  BILGE KEEL PART .. (-) :   0.0000

(NON)LINEAR DAMPING COEFFICIENTS:
  Kappa-1 .......... (-) :   0.0002
  Kappa-2 .......... (-) :   0.0371


NATURAL HEAVE AT ZERO FORWARD SPEED
-----------------------------------

NATURAL HEAVE PERIOD  (s) :   9.211
NATURAL FREQUENCY   (r/s) :   0.682


NATURAL PITCH AT ZERO FORWARD SPEED
-----------------------------------

NATURAL PITCH PERIOD  (s) :   8.825
```

```
NATURAL FREQUENCY  (r/s) :   0.712


San Diego class tanker motions with  spring                    Execution: 18-04-1994 / 18:53
SEAWAY-4.12

FREQUENCY CHARACTERISTICS OF BASIC MOTIONS        FORWARD SPEED =  0.00 kn
------------------------------------------        WAVE DIRECTION =  +180 deg off stern

 WAVE  SQRT   ENC    ...SURGE...    ...SWAY....    ...HEAVE...    ...ROLL....    ...PITCH...
....YAW....   ADDED RESISTANCES
 FREQ SL/WL  FREQ     AMPL PHASE     AMPL PHASE     AMPL PHASE     AMPL PHASE
AMPL PHASE     AMPL PHASE   GER/BEU     BOESE
 (r/s)  (-) (r/s)   (m/m) (deg)   (m/m) (deg)   (m/m) (deg)  (deg/m) (deg)  (deg/m) (deg)  (deg/m) (deg)
(kN/m2)  (kN/m2)
 0.200 0.452 0.200    1.064  90.1    0.000  90.0    0.953 359.9    0.000  91.1    0.257 269.4    0.000
179.0   6.46E-02 -1.67E-01
 0.233 0.510 0.233    0.956  90.2    0.000  90.0    0.924 359.9    0.000  91.5    0.321 269.2    0.000
178.8   2.59E-01  1.52E-03
 0.267 0.574 0.267    0.870  90.5    0.000  90.1    0.880 359.9    0.000  91.8    0.394 268.9    0.000
178.5   9.61E-01  4.11E-01
 0.300 0.641 0.300    0.785  90.8    0.000  90.1    0.816 359.9    0.000  92.1    0.470 268.6    0.000
178.3   3.22E+00  1.37E+00
 0.333 0.710 0.333    0.690  91.5    0.000  90.2    0.729   0.2    0.000  92.3    0.540 268.2    0.000
178.0   9.50E+00  3.48E+00
 0.367 0.780 0.367    0.578  92.5    0.000  90.4    0.619   0.7    0.000  92.2    0.594 267.8    0.000
177.7   2.49E+01  7.08E+00
 0.400 0.851 0.400    0.450  94.0    0.000  90.4    0.489   1.9    0.000  91.5    0.622 267.5    0.000
177.4   5.73E+01  1.21E+01
 0.433 0.922 0.433    0.312  96.7    0.000  90.2    0.345   4.8    0.000  89.3    0.614 267.3    0.000
177.3   1.17E+02  1.71E+01
 0.467 0.993 0.467    0.175 102.8    0.000  87.5    0.198  13.1    0.000  83.3    0.562 267.5    0.000
177.3   2.13E+02  1.98E+01
 0.500 1.064 0.500    0.057 131.7    0.000  66.8    0.080  50.0    0.000  64.6    0.466 268.8    0.000
177.7   3.49E+02  1.65E+01
 0.533 1.135 0.533    0.070 242.2    0.000 240.0    0.100 131.6    0.000 280.9    0.335 272.7    0.000
183.1   5.14E+02  8.15E+00
 0.567 1.206 0.567    0.135 260.3    0.000 254.2    0.168 151.6    0.000 152.1    0.188 285.7    0.000
185.7   6.79E+02  2.11E+00
 0.600 1.277 0.600    0.164 266.7    0.000 273.3    0.195 159.4    0.000 125.8    0.095 340.0    0.000
224.6   8.21E+02  9.53E+00
 0.633 1.347 0.633    0.154 272.1    0.000 285.7    0.177 167.7    0.000 114.8    0.146  36.1    0.000
334.6   9.23E+02  3.39E+01
 0.667 1.418 0.667    0.112 280.0    0.000 303.3    0.132 184.3    0.000 105.0    0.197  52.1    0.000
346.2   9.93E+02  5.85E+01
 0.700 1.489 0.700    0.057 300.4    0.000 334.3    0.099 218.4    0.000  88.7    0.192  62.9    0.000
354.1   1.06E+03  5.65E+01
 0.733 1.560 0.733    0.032  20.6    0.000  12.7    0.099 254.4    0.000  34.9    0.148  82.0    0.000
10.9   1.15E+03  2.58E+01
 0.767 1.631 0.767    0.057  67.9    0.000  44.5    0.098 277.7    0.000 321.2    0.116 117.5    0.000
63.3   1.27E+03  5.66E+00
 0.800 1.702 0.800    0.066  84.5    0.000  92.1    0.080 301.5    0.000 299.7    0.115 152.4    0.000
112.6   1.36E+03  2.34E+01
```

```
 0.833 1.773 0.833   0.051 101.5   0.000 167.9   0.062 337.5   0.000 286.6   0.107 177.3   0.000
129.4   1.41E+03  4.82E+01
 0.867 1.844 0.867   0.028 140.7   0.000 192.5   0.058  15.2   0.000 269.9   0.081 207.6   0.000
148.4   1.42E+03  4.07E+01
 0.900 1.915 0.900   0.027 211.1   0.000 200.9   0.052  44.0   0.000 201.1   0.067 251.8   0.000
271.5   1.44E+03  1.73E+01
 0.933 1.986 0.933   0.032 246.2   0.000 205.1   0.038  76.8   0.000 128.4   0.067 289.0   0.000
293.3   1.48E+03  1.34E+01
 0.967 2.057 0.967   0.025 276.4   0.000  24.1   0.028 125.3   0.000 114.6   0.055 318.1   0.000
297.5   1.49E+03  2.14E+01
 1.000 2.128 1.000   0.017 336.5   0.000  27.5   0.027 168.4   0.000 110.3   0.036   0.5   0.000
305.0   1.48E+03  1.73E+01
 1.033 2.198 1.033   0.020  33.4   0.000  32.0   0.021 202.4   0.000 114.2   0.033  58.0   0.000
109.0   1.46E+03  8.17E+00
 1.067 2.269 1.067   0.017  66.7   0.000  54.1   0.013 255.2   0.000 269.6   0.032  95.5   0.000
115.5   1.44E+03  8.10E+00
 1.100 2.340 1.100   0.009 124.4   0.000 187.3   0.013 318.0   0.000 295.8   0.021 132.7   0.000
127.3   1.42E+03  8.46E+00
 1.133 2.411 1.133   0.012 199.7   0.000 209.7   0.012 353.4   0.000 320.2   0.015 204.3   0.000
228.5   1.38E+03  4.13E+00
 1.167 2.482 1.167   0.012 233.8   0.000 247.9   0.007  38.4   0.000 344.2   0.017 257.1   0.000
275.5   1.34E+03  3.38E+00
 1.200 2.553 1.200   0.007 291.0   0.000 320.2   0.006 130.5   0.000 353.7   0.013 294.7   0.000
303.4   1.29E+03  4.15E+00
 1.233 2.624 1.233   0.009  10.0   0.000 357.7   0.007 174.5   0.000 228.1   0.008   6.1   0.000
43.6   1.24E+03  2.09E+00
 1.267 2.695 1.267   0.008  52.8   0.000  97.0   0.004 220.2   0.000 198.8   0.009  71.3   0.000
75.2   1.19E+03  1.78E+00
 1.300 2.766 1.300   0.005 125.4   0.000 149.4   0.003 300.4   0.000 191.0   0.007 121.7   0.000
117.9   1.14E+03  2.12E+00
 1.333 2.837 1.333   0.007 191.9   0.000 168.6   0.003   2.5   0.000 138.0   0.006 189.6   0.000
242.8   1.09E+03  1.06E+00
 1.367 2.908 1.367   0.005 251.4   0.000 323.7   0.003  67.0   0.000  52.3   0.005 246.3   0.000
259.5   1.03E+03  1.00E+00
 1.400 2.979 1.400   0.005 337.0   0.000 347.3   0.002 120.9   0.000  58.3   0.003 329.2   0.000
26.7   9.80E+02  7.96E-01
 1.433 3.049 1.433   0.004  26.6   0.000  48.4   0.001 200.6   0.000 141.0   0.004  28.8   0.000
70.0   9.28E+02  5.34E-01
 1.467 3.120 1.467   0.003 142.1   0.000 147.7   0.002 282.3   0.000 213.9   0.002  82.8   0.000
120.1   8.80E+02  4.94E-01
 1.500 3.191 1.500   0.005 188.0   0.000 195.8   0.001 327.4   0.000 294.9   0.002 196.0   0.000
225.7   8.30E+02  2.93E-01
 1.533 3.262 1.533   0.002 269.4   0.000 294.9   0.001  83.2   0.000 339.2   0.002 244.2   0.000
262.4   7.82E+02  4.05E-01
 1.567 3.333 1.567   0.004 359.8   0.000 336.4   0.001 138.1   0.000  33.1   0.001 348.1   0.000
20.6   7.39E+02  2.18E-01
 1.600 3.404 1.600   0.003  49.0   0.000  95.4   0.001 240.2   0.000 146.2   0.002  46.8   0.000
55.4   6.96E+02  2.70E-01
 1.633 3.475 1.633   0.003 172.4   0.000 133.2   0.001 294.4   0.000 182.7   0.001 149.7   0.000
179.6   6.54E+02  1.78E-01
 1.667 3.546 1.667   0.003 230.0   0.000 257.2   0.000  40.3   0.000 314.4   0.001 204.0   0.000
219.5   6.15E+02  1.89E-01
 1.700 3.617 1.700   0.002 345.3   0.000 304.1   0.001 110.3   0.000 338.6   0.001 292.8   0.000
343.8   5.80E+02  1.16E-01
```

```
San Diego class tanker motions with  spring                    Execution: 18-04-1994 / 18:53
SEAWAY-4.12

FREQUENCY CHARACTERISTICS OF MOTIONS POINTS      FORWARD SPEED =  0.00 kn
-------------------------------------------   WAVE DIRECTION = +180 deg off stern
POINT NR =      01
X-APP    = 278.000 m
Y-CL     =   0.000 m
Z-BL     =  10.000 m

                   ...........ABSOLUTE MOTIONS............  ..REL MOT..
 WAVE  SQRT  ENC   .....X.....   .....Y.....   .....Z.....   .....Z.....
 FREQ SL/WL  FREQ   AMPL PHASE    AMPL PHASE    AMPL PHASE    AMPL PHASE    AMPL PHASE
(r/s)  (-) (r/s)  (m/m) (deg)   (m/m) (deg)   (m/m) (deg)   (m/m) (deg)
0.200 0.452 0.200  1.094  90.1  0.000 118.0  1.114  30.6  0.152 191.0
0.233 0.510 0.233  0.994  90.2  0.000 123.9  1.173  37.2  0.237 193.4
0.267 0.574 0.267  0.917  90.4  0.000 130.1  1.250  44.2  0.360 196.1
0.300 0.641 0.300  0.841  90.7  0.000 136.2  1.337  51.0  0.529 199.1
0.333 0.710 0.333  0.754  91.2  0.000 141.7  1.423  57.4  0.744 202.5
0.367 0.780 0.367  0.648  91.9  0.000 146.6  1.484  63.2  0.995 206.3
0.400 0.851 0.400  0.523  93.1  0.000 150.8  1.499  68.5  1.257 210.8
0.433 0.922 0.433  0.384  95.0  0.000 154.0  1.446  73.6  1.496 216.1
0.467 0.993 0.467  0.240  98.6  0.000 156.1  1.313  79.2  1.665 222.6
0.500 1.064 0.500  0.105 110.6  0.000 154.1  1.097  86.2  1.719 231.1
0.533 1.135 0.533  0.042 213.1  0.000 209.5  0.822  97.1  1.632 243.0
0.567 1.206 0.567  0.115 255.5  0.000 189.3  0.548 118.4  1.430 261.1
0.600 1.277 0.600  0.161 262.8  0.000 218.6  0.407 159.7  1.233 289.0
0.633 1.347 0.633  0.164 267.1  0.000 326.0  0.461 199.4  1.211 324.6
0.667 1.418 0.667  0.129 272.3  0.000 345.7  0.534 221.6  1.354 357.0
0.700 1.489 0.700  0.072 285.0  0.000 356.6  0.517 238.4  1.465  24.5
0.733 1.560 0.733  0.028 347.3  0.000  12.7  0.427 260.2  1.447  53.2
0.767 1.631 0.767  0.050  55.7  0.000  50.0  0.351 292.0  1.387  87.1
0.800 1.702 0.800  0.062  72.7  0.000 107.4  0.327 325.2  1.381 123.9
0.833 1.773 0.833  0.050  87.2  0.000 141.3  0.296 353.2  1.374 160.4
0.867 1.844 0.867  0.026 120.7  0.000 174.4  0.237  24.6  1.313 199.2
0.900 1.915 0.900  0.021 197.1  0.000 236.5  0.196  64.7  1.263 241.9
0.933 1.986 0.933  0.027 234.8  0.000 281.4  0.181 102.6  1.246 285.8
0.967 2.057 0.967  0.021 264.4  0.000 305.8  0:150 135.7  1.199 330.5
1.000 2.128 1.000  0.013 328.6  0.000 354.2  0.108 177.5  1.139  19.1
1.033 2.198 1.033  0.016  27.8  0.000  81.8  0.091 230.2  1.120  70.0
1.067 2.269 1.067  0.014  59.1  0.000 109.5  0.084 272.4  1.104 121.2
1.100 2.340 1.100  0.007 121.3  0.000 139.3  0.061 313.9  1.065 174.8
1.133 2.411 1.133  0.010 198.9  0.000 226.3  0.044  15.9  1.052 231.2
1.167 2.482 1.167  0.010 229.3  0.000 273.9  0.044  71.7  1.052 288.0
1.200 2.553 1.200  0.006 290.0  0.000 310.2  0.034 117.3  1.033 346.6
1.233 2.624 1.233  0.008  10.5  0.000  31.1  0.024 182.8  1.026  47.5
1.267 2.695 1.267  0.007  50.1  0.000  81.5  0.024 245.8  1.026 109.4
1.300 2.766 1.300  0.005 126.1  0.000 139.2  0.019 301.4  1.018 173.0
1.333 2.837 1.333  0.006 192.1  0.000 228.4  0.016   8.2  1.016 238.4
1.367 2.908 1.367  0.004 252.1  0.000 270.3  0.013  66.4  1.011 305.3
1.400 2.979 1.400  0.005 337.7  0.000  11.7  0.010 142.3  1.009  14.1
1.433 3.049 1.433  0.004  26.3  0.000  68.9  0.010 207.8  1.009  84.1
```

```
 1.467 3.120 1.467   0.003 145.9   0.000 133.1   0.006 268.5   1.004 156.1
 1.500 3.191 1.500   0.004 187.5   0.000 222.6   0.006   6.9   1.007 229.7
 1.533 3.262 1.533   0.001 273.3   0.000 274.8   0.005  67.4   1.005 304.7
 1.567 3.333 1.567   0.004   0.3   0.000  11.1   0.004 161.1   1.005  21.5
 1.600 3.404 1.600   0.002  49.2   0.000  66.2   0.004 229.1   1.004  99.8
 1.633 3.475 1.633   0.003 173.6   0.000 164.9   0.003 321.0   1.004 179.9
 1.667 3.546 1.667   0.003 231.7   0.000 227.3   0.004  25.6   1.003 261.5
 1.700 3.617 1.700   0.002 347.0   0.000 327.4   0.002 111.9   1.002 344.9
```

```
San Diego class tanker motions with  spring                     Execution: 18-04-1994 / 18:53
SEAWAY-4.12

STATISTICS OF BASIC MOTIONS                      FORWARD SPEED =  0.00 kn
~~~~~~~~~~~~~~~~~~~~~~~~~~~                   WAVE DIRECTION =  +180 deg off stem

............SEA...........     ......................SIGNIFICANT VALUES OF BASIC
MOTIONS......................        MEAN ADDED
....INPUT... .CALCULATED.   ...SURGE...  ....SWAY...  ...HEAVE...  ....ROLL...  ...PITCH...
....YAW....     RESISTANCE
HEIGHT  PER HEIGHT  PER    AMPL  PER   AMPL  PER   AMPL  PER   AMPL  PER
AMPL  PER    AMPL  PER  GER/BEU  BOESE
  (m)  (s)    (m)  (s)    (m)  (s)    (m)  (s)    (m)  (s)  (deg)  (s)  (deg)  (s)  (deg)  (s)    (kN)
(kN)
  3.00 12.00    2.99 12.16    0.55 17.10    0.00  6.28    0.59 16.87    0.00 13.33    0.70 14.94    0.00
6.28     470.8    17.1
  4.00 13.00    3.99 13.14    0.88 18.05    0.00  9.49    0.94 17.84    0.00 13.67    0.97 15.52    0.00
7.43     659.5    26.5
  5.00 14.00    4.99 14.12    1.27 18.97    0.00 18.92    1.34 18.75    0.00 14.02    1.24 16.07    0.00
12.25     814.4    35.5
  3.50 12.50    3.49 12.65    0.71 17.58    0.00  6.28    0.76 17.37    0.00 13.50    0.84 15.24    0.00
6.28     568.7    21.8
  4.50 13.50    4.49 13.63    1.07 18.51    0.00 13.93    1.13 18.30    0.00 13.85    1.11 15.80    0.00
9.71     741.6    31.1
  2.00 11.00    1.99 11.19    0.29 16.03    0.00  6.28    0.31 15.76    0.00 12.98    0.43 14.32    0.00
6.28     265.1     8.6
```

```
San Diego class tanker motions with  spring                     Execution: 18-04-1994 / 18:53
SEAWAY-4.12

STATISTICS OF MOTIONS IN POINTS                   FORWARD SPEED =  0.00 kn
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~               WAVE DIRECTION =  +180 deg off stem
POINT NR =      01
X-APP   = 278.000 m
Y-CL    =   0.000 m
Z-BL    =  10.000 m
                    ...........................................SIGNIFICANT VALUES
OF............................................
                    ..........DISPLACEMENTS..........     ...........VELOCITIES............
..........ACCELERATIONS..........
.....SEA....     ....X....  ....Y....   ....Z....      ....X....  ....Y....   ....Z....     ....X....  ....Y....  ....Z....
HEIGHT  PER     AMPL  PER  AMPL  PER  AMPL  PER     AMPL  PER  AMPL  PER  AMPL
PER     AMPL  PER  AMPL  PER  AMPL  PER
```

```
 (m)  (s)      (m) (s)   (m) (s)   (m) (s)    (m/s) (s) (m/s) (s) (m/s) (s)   (m/s2) (s) (m/s2) (s)
(m/s2) (s)
 3.00 12.00      0.62 17.0  0.00 15.6  1.72 15.0     0.23 16.0  0.00 6.28  0.73 14.0     0.06 11.5
0.00 6.28  0.34 12.7
 4.00 13.00      0.98 17.9  0.00 16.3  2.42 15.7     0.35 16.9  0.00 7.87  0.99 14.6     0.08 11.7
0.00 6.28  0.43 13.2
 5.00 14.00      1.40 18.8  0.00 17.0  3.13 16.4     0.47 17.7  0.00 12.6  1.22 15.1     0.09 11.9
0.00 6.28  0.52 13.7
 3.50 12.50      0.79 17.4  0.00 15.9  2.07 15.3     0.29 16.5  0.00 6.28  0.86 14.3     0.07 11.6
0.00 6.28  0.39 13.0
 4.50 13.50      1.18 18.3  0.00 16.6  2.78 16.0     0.41 17.3  0.00 10.1  1.11 14.9     0.08 11.8
0.00 6.28  0.48 13.5
 2.00 11.00      0.33 16.0  0.00 8.62  1.05 14.3     0.13 15.0  0.00 6.28  0.47 13.3     0.04 11.3
0.00 6.28  0.23 12.1

              ........VERTICAL RELATIVE MOTIONS........    ...SLAMMING DEFINED BY...
              ..SIGNIFICANT VALUES OF...  .EXCEEDING.    ....BOW EMERGENCE AND....
.....SEA....    DISPLACEMENT   .VELOCITY.   ....Z-BL...    .VELOCITY.    .PRESSURE.
HEIGHT  PER      AMPL  PER     AMPL  PER     PROB  NR/H     PROB  NR/H    PROB  NR/H
 (m)  (s)      (m)  (s)   (m/s)  (s)     (%) (1/h)     (%) (1/h)     (%) (1/h)
 3.00 12.00      2.02 11.91    2.14 11.55    0.1  0.2     0.0  0.0     0.0  0.0
 4.00 13.00      2.56 12.36    2.68 11.97    1.0  2.9     0.0  0.0     0.0  0.1
 5.00 14.00      3.00 12.74    3.11 12.28    3.4 10.0     0.0  0.0     0.2  1.1
 3.50 12.50      2.30 12.14    2.42 11.77    0.3  1.0     0.0  0.0     0.0  0.0
 4.50 13.50      2.79 12.55    2.91 12.14    2.0  6.0     0.0  0.0     0.1  0.5
 2.00 11.00      1.40 11.36    1.49 10.98    0.0  0.0     0.0  0.0     0.0  0.0
```

Appendix 5 : Calculations of Seismic Motions

Seismic motions were calculated with the use of the PCNSPEC seismic analysis program. The reader is referred to the PCNSPEC manual for a more detailed description of the program. Two input files are required by the program : a ground motion file and a system characteristics file. The characteristics for the SALM system, subjected to 2-, 10-, 100- and 1000-year peak accelerations are given below. The ground motion history is that of the El Centro earthquake, scaled to match the predicted peak ground accelerations.

Input File for 2-year Conditions

```
 SALM SYSTEM, EL CENTRO=2-year quake, damping=0.33
2
 1.00000, 0.3300,-0.0000,  1,  2,  2,  0,   1.00000,,,,
  1, 1,  0.
 0.1000
   7.42
   330.0
12,,,,,
0.02,0, 200
(8f10.0)
0.0287
```

Input File for 10-year Conditions

```
 SALM SYSTEM, EL CENTRO=10-year quake, damping=0.33
2
 1.00000, 0.3300,-0.0000,  1,  2,  2,  0,   1.00000,,,,
  1, 1,  0,
 0.1000
   7.42
   66.0
12,,,,,
0.02,0, 200
(8f10.0)
0.144
```

Input File for 100-year Conditions

```
 SALM SYSTEM, EL CENTRO=100-year quake, damping=0.33
2
 1.00000, 0.3300,-0.0000,  1,  2,  2,  0,   1.00000,,,,
  1, 1,  0,
 0.1000
   7.42
   18.33
12,,,,,
```

```
0.02,0, 200
(8f10.0)
0.517
```

Input File for 1000-year Conditions

```
SALM SYSTEM, EL CENTRO=1000-year quake, w/damping=0.33
2
 1.00000, 0.3300,-0.0000,  1,  2,  2,  1,   1.00000,,,,
  1, 1,  0,
 0.1000
   7.42
   8.25
12,....
0.02,0, 500
(8f10.0)
1.148
```

Input File for Ground Motions

```
  -14   -108   -101    -88    -95   -120   -142   -128
 -110    -85    -85   -131   -176   -194   -162   -144
 -108    -82    -42    -66   -131   -190   -196    -66
   30    141    -49   -128   -144   -203   -260   -325
 -306   -172   -197   -163   -164    -67     25    150
  236    252    336    463    492    419    359    271
  235    339    412    530    639    732    652    599
  400    400     63   -515   -787   -603   -484   -250
  -59    134    308    499    710    995   1219   1529
 1449   1155    935    892    926    839    901    993
 1209    328  -1475  -2066  -1989  -2034  -1816  -1725
-1752  -1753  -1805  -1630  -1347  -1087   -782   -429
  -17    360    785   1164   1598   1960   2412   2729
 3036   3200   3417   2821   2324  -1198  -2373  -1640
-1865  -1095   -753   -173    113    533    895   1186
 1757    576  -2631  -1547  -1729  -1012   -579    237
 -670  -1980  -1641  -1685  -1481  -1231  -1001   -751
 -523   -271    -44    188    -95   -433   -838   -951
 -716   -599   -334   -108    185    420    673    -97
 -372    -40     11    344    565    883   1130   1363
  219    241    683    689   1318   1353   2040   -931
-1308   -692   -546     72    675  -1067  -1488  -1071
-1162   -762   -559   -215   -126   -674   -324   -337
 -109     17    299    488    608    222    -32   -245
   77    211    568    826   1206   1478   1737    421
   29    259    293    -55   -147    143    206    499
  645    957   1128   1447   1629   1945   1856   1984
 1769   1250  -1207   -542   -384   -311  -1118  -1661
-2464  -2025  -1835  -1317   -960   -325    154    816
 1319   1818    -58   -169    285    447    983   1424
 1853   2456   1685  -1380   -999  -1089   -907   -469
-1250  -2111  -1617  -1692  -1306  -1111   -773   -510
 -544  -1200  -1209  -1158  -1145   -717   -546     64
 -804  -1634   -859   -961   -396   -147    319    648
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876	472	198	-27	292	445	785	1033
1352	1606	1861	1281	640	204	314	373
496	235	-84	-168	-113	-229	-248	-157
-69	147	379	579	255	-41	-428	-133
95	230	-129	-50	80	210	380	510
157	-32	-111	5	76	35	-95	-36
-16	38	85	-56	-304	-421	-244	-236
-177	-129	-18	203	-108	-91	-34	-106
-111	-99	-2	73	235	355	705	779
184	-263	-124	-42	159	48	-219	-467
-428	-216	-43	159	320	419	123	-160
-204	-82	-206	-137	-55	53	134	266
232	79	-8	200	435	492	191	92
-22	-21	52	93	255	368	525	541
425	398	559	756	365	411	98	-204
-249	-405	-413	-471	-433	-458	-57	178
-208	-492	-530	-362	-405	-308	-316	-265
-265	-269	-345	-309	-217	-78	87	281
310	358	341	358	287	305	112	214
136	384	-861	-1349	-1342	-1354	-1193	-1042
-829	-651	-444	-258	-60	-91	-182	-147
85	163	50	264	582	867	1200	1695
1111	-1100	-366	-445	-236	-960	-656	-597
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667	132	-95	-520	-827	-1152	-1150	-803
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23	64	-406	-451	-79	168	567	93
-55	44	-123	-282	-437	-352	-255	-111
205	519	854	1144	733	237	-368	-271
-217	-873	-973	-589	-336	77	259	508
361	81	-56	-209	-317	-238	-376	-550
-722	-803	-523	-340	-11	65	-37	-5
-168	-410	-80	79	374	615	665	254
-57	-474	-356	-243	-48	126	379	241
-227	-428	-679	-661	-590	-513	-408	-309
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-473	-333	-199	20	211	432	613	767
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-1246	-1179	-1050	-920	-743	-809	-850	-860
-863	-873	-868	-885	-537	52	215	245
580	314	236	485	589	525	355	197
199	492	343	288	432	239	88	77
-148	-77	-19	75	44	-145	-316	-241
-28	182	426	439	512	466	479	193
222	274	393	504	577	588	822	797
949	345	45	-123	-347	-426	-416	-275
-270	74	428	-231	-387	-83	139	445
27	-697	-796	-251	-135	79	-115	-251
-333	-269	-301	-200	-67	-38	105	296
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-210	-303	-512	-727	-579	-266	-178	40
98	137	221	437	91	-548	-555	-243
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482	783	622	331	-14	-195	-247	-212
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-18	170	-80	5	230	374	601	516
432	344	505	653	683	172	-170	-527
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-335	-218	-12	142	70	-63	-120	-322
-346	-91	73	309	472	603	576	330
-73	-777	-608	-438	-209	31	350	293
121	338	317	254	206	198	174	21
-144	-343	-339	-145	-28	170	-96	-255
-279	-388	-242	-215	-182	-174	-38	-27
-185	-123	87	343	695	910	853	760
513	186	15	-190	-151	-73	21	129
215	24	-124	-329	-519	-708	-579	-462
-307	-145	-9	-180	-318	-465	-391	-345
-316	-435	-491	-475	-420	-361	-277	-258
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205	74	-56	-72	70	106	147	-9
-159	-187	-7	155	105	-115	-302	-309
-95	-58	4	20	50	57	97	134
177	218	261	302	346	386	474	393
238	115	-79	-124	54	27	-250	-566
-630	-591	-413	-68	272	277	-21	-60
-110	-221	-416	-519	-222	30	79	139
171	253	323	391	164	-136	-323	-291
-287	-304	-339	-245	-76	125	376	402
245	156	-40	-153	-289	-316	-111	94
335	576	424	143	-7	-135	-270	-341
-357	-396	-402	-488	-480	-406	-407	-351
-187	-57	44	-19	-72	-169	-115	126
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-44	-288	-384	-492	-428	-416	-276	-52
237	426	604	452	284	126	-54	-275
-423	-175	1	254	481	641	554	413
184	-48	-303	-531	-708	-928	-863	-631
-376	87	309	589	614	385	351	311
246	19	-198	-158	-15	99	286	408
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-555	-446	-8	253	411	644	579	474
384	385	340	357	8	-254	-460	-471
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41	-27	21	44	99	135	94	58
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-530	-701	-323	-52	94	328	478	509

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-365	-310	-297	-280	-237	-266	-308	-366
-357	-308	-193	19	196	160	129	140
110	108	92	89	19	-131	-247	-436
-432	-300	-192	-48	97	168	148	173
78	-58	-215	-234	60	262	269	84
-41	-227	-76	31	182	310	479	459
166	-58	-396	-444	-241	-101	217	261
121	8	-168	-382	-566	-781	-619	-256
44	456	783	1103	953	489	122	-387
-846	-1226	-864	-616	-228	150	477	323
248	95	227	338	505	594	519	552
595	617	593	466	158	-77	-230	-303
-329	-364	-490	-660	-723	-784	-846	-566
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594	630	370	217	40	23	-62	-286
-380	-457	-505	-777	-628	-189	189	509
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-859	-468	81	594	823	556	301	-11
-380	-347	-20	180	633	1013	1122	1107
940	805	608	508	206	-201	-572	-1021
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577	562	464	300	107	-4	-33	-69
-101	-201	-188	25	134	243	266	265
155	-19	-95	-216	-167	-120	-64	-129
-163	-193	-242	-236	-175	-124	-185	-265
-323	-336	-454	-430	-334	-213	-69	30
3	-93	-89	-150	-164	-238	-323	-421
-457	-397	-349	-258	-172	-20	156	284
362	354	269	101	-45	-125	-245	-229
-126	-68	18	93	200	286	365	311
181	24	-156	-319	-219	-118	15	153
298	243	136	102	24	-10	-23	-36
-48	-89	-155	-148	-76	0	-20	-148
-225	-374	-365	-251	-164	-14	153	302
393	406	385	329	183	125	70	-1
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-269	-350	-359	-297	-227	18	99	203
256	199	160	107	156	198	242	141
55	-66	-97	-26	16	100	94	39
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-104	-10	55	129	200	199	169	143
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-290	-110	50	132	157	177	195	255
331	328	252	173	45	-85	-190	-229
-304	-277	-227	-174	-121	-126	-129	-80
-26	39	65	55	50	64	126	179
243	307	298	251	216	163	192	234
282	301	196	106	-39	-163	-322	-335
-219	-148	-10	11	-53	-101	-126	-143

-129	-104	-71	-18	33	85	158	239
319	341	318	213	73	9	-15	-47
-75	-121	-156	-116	-56	-6	-3	-3
14	46	72	86	98	124	147	172
200	256	317	287	231	105	-1	-11
-36	-53	-83	-52	-7	37	96	155
205	143	73	21	-22	-70	-100	-75
-54	-29	-15	0	-1	-6	-11	-10
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102	56	6	-40	-98	-96	-46	-7
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-28	-17	-6	-5	-17	-22	-36	-32
-7	14	41	65	63	52	6	-45
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-36	-25	-2	4	36	82	115	70
38	-10	-25	-34	-41	-45	-65	-120
-117	-108	-98	-81	-76	-110	-138	-166
-144	-130	-111	-108	-98	-98	-63	-2
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10	-67	-105	-122	-138	-166	-215	-269
-274	-217	-178	-116	-61	0	54	99
144	187	232	262	255	227	171	127
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-40	-45	-49	-39	-21	-22	-16	-16
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-31	-78	-92	-92	-95	-92	-86	-52
-22	14	38	34	34	29	40	54
67	85	87	77	70	61	75	87
102	111	90	75	53	62	79	97
118	135	105	77	44	12	-21	-42
-68	-87	-120	-159	-198	-233	-258	-270
-278	-287	-278	-270	-258	-251	-219	-173
-129	-109	-105	-95	-91	-72	-59	-40
-23	18	35	42	48	43	43	38
36	32	47	63	85	110	134	160
181	173	168	159	147	108	68	32
9	19	28	40	54	69	95	117
143	143	125	122	124	126	130	133
106	79	46	20	5	-11	-25	-11
18	43	76	103	133	101	62	18
-27	-80	-89	-54	-30	6	12	22
27	32	48	69	89	112	133	140
137	140	135	139	102	30	-32	-63
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-142	-129	-125	-120	-116	-114	-106	-64
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-3	-30	-60	-87	-116	-107	-94	-78
-68	-63	-57	-50	-41	-33	-24	-14
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-202	-213	-198	-173	-135	-65	-14	20
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3	-24	-57	-45	-13	13	33	48
54	58	62	65	69	72	75	77
73	69	64	58	54	48	61	79
96	114	126	139	131	123	114	103
87	72	56	40	24	7	4	8
9	23	42	52	61	72	79	89
95	95	93	89	25	0	-5	-20
-24	-33	-48	-64	-80	-97	-114	-128
-106	-89	-66	-43	-19	-11	-9	-5
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13	-8	-36	-47	-55	-62	-68	-73
-80	-75	-64	-28	5	46	65	60
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21	31	43	49	49	49	48	47
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91	89	87	84	82	80	77	62
47	35	36	34	35	36	32	19
15	14	12	12	11	0	-10	-20
-25	-29	-33	-37	-48	-63	-77	-92
-107	-122	-138	-143	-120	-103	-78	-67
-63	-58	-56	-53	-50	-48	-45	-42
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54	55	63	84	101	84	71	53
33	28	29	28	27	12	-1	-10
-11	-16	-15	-31	-68	-99	-102	-105
-106	-99	-89	-79	-74	-72	-68	-67
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63	41	13	-14	-35	-37	-44	-46
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99	93	86	79	72	63	55	46
38	31	27	21	17	12	7	3
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-47	-53	-48	-43	-38	-25	-9	7
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71	47	27	4	-16	-24	-33	-46
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-67	-66	-66	-64	-56	-50	-43	-34

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  -14      -7      6     16     13     12      8      5
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  -30     -26    -22    -22    -32    -41    -51    -46
  -43     -38    -32    -26    -20    -19    -18    -15
   13      41     67     70     76     78     80     81
   84      78     61     48     31     29     30     32
   35      37     24      7     -8    -28    -35    -22
  -13       1      3      1     -1     -5     -8    -11
  -15     -12     -8     -4      1      5      8      8
    9      10     22     33     46     59     72     79
   62      50     32     16     -4      0     30     52
   87      82     31     -2    -62    -28     58    130
  221     185     94     91     77     90     16    -84
 -200    -148     -7    107     99     48      3    -69
 -107     -15     69    138     67     20     35     90
   86      52     24     16     13    -11    -34    -67
  -54     -20     14     48     97     58    -48   -119
  -95     -60    -24     32     38     14     -1     -7
    6      10     24     13      4     -8    -27    -55
  -84     -93    -61    -36     -2     33     37    -14
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   15      61     73     74     76     73     71     57
   38      21     -2    -33    -64    -68    -51    -54
  -54     -57    -33      0     33     70     96     85
   80      68     75     77     85     61     37      7
   -1       4      5    -10    -29    -46    -69    -65
  -44     -28     -7    -23    -33    -51    -60    -56
  -54     -50    -66    -91   -114   -140   -138   -140
 -121     -96    -74    -46    -34    -42    -45    -55
  -63     -72    -80    -73    -52    -37    -26    -14
```

Output File for 2-year Conditions

```
***********************************************************************************


                   PCNSPEC

                  A PROGRAM
                     BY
                 R. BOROSCHEK


              A MODIFIED VERSION OF
                    NONSPEC
                      BY
                  S. A. MAHIN

                  ASSISTED BY
                  R. HERRERA
```

```
                    J. LIN

                  JULY 10, 1991

NOTE: INPUT FILE WITH FIRST LINE CONTAINING THE WORD "HELP"
    TO OBTAINE INPUT FILE FORMAT
    LIKE pdspec < foo.file
     AND  foo.file : help
***********************************************************************************

****************************************************

SALM SYSTEM, EL CENTRO=2-year quake, w/damping=0.33

****************************************************



ANALYSIS TYPE ........... :              2
  1-SINGLE STRUCTURE
  2-SPECTRUM REPONSE

SYSTEM MASS ............. :          1.00000
SYSTEM DAMPING .......... :            .50000
POST YIELD STIFF FACTOR . :              .00000
ELEMENT TYPE ............ :              1
  1-BILINEAR MODEL
  2-DEGRADING MODEL
PROPERTY PARAMETER ...... :                  2
  1-STIFFNESS
  2-PERIOD
YIELD PARAMETER ......... :                2
  1-YIELD DISPL.
  2-ETA VALUE
  3-TARGET
P-DELTA EFFECT .......... :              0
  0-ONLY POST YIELD
  1-FULL EFFECT
YIELD PARAMETER SCALE ... :            1.00000

NUMBER OF STIFF/PERIODS . :                1
NUMBER OF YIELD DISP/ETA  :                1
COMBINATION OF RESULTS .. :                0
 0-TOTAL COMBINATION
 1-ONE-TO-ONE COMBINATION

MAXIMUM TIME STEP ....... :          .10000

STIFF/PERIOD VALUES :
): 1):          7.4200

YIELD DISPL/ETA/TARGET VALUES :
): 1):        330.0000
```

```
LOAD TYPE .............. :            12

INPUT FUNCTION TIME STEP. :         .02000
INPUT FUNCTION TYPE ..... :   READ OTHERGM
INPUT FUNCTION LENGTH ... :            200

INPUT FUNCTION FORMAT ... :      (8f10.0)

INITIAL VELOCITIY ....... :         .00000

INITIAL DISPLACEMENT .... :         .00000

LOAD FACTOR ............ :          .02870

ELEMENT PROPERTY SUMMARY :

 stiffness    natural       period       yield          yield
              frequency                  displacement   shear

 .717054E+00  .846790E+00  .742000E+01  .451324E+05  .323624E+05


EXECUTION STARTS .........
GROUND MOTION MAXIMA

          ground       ground      ground
       displacement   velocity   acceleration

maximum     .4358E+01   .1094E+02   .9807E+02
time        2.6600      2.1800      2.1200
minimum    -.1379E+01  -.3872E+01  -.7551E+02
time        1.0400      2.9400      2.4400

ENERGY MAXIMA

          input     kinetic   recoverable  hysteretic   damping
          energy    energy      strain       energy      energy
                                energy

maximum    .4701E+02  .7238E+01  .3966E+01  .0000E+00  .4614E+02
time        3.9600     2.6400     2.5800     .0000      3.9800
RELATIVE RESPONSE MAXIMA

          displacement    velocity    acceleration   resistance

maximum        1.5609       6.8683       81.9621        1.1192
time         3.9600       2.9400       2.4400        3.9600
minimum       -3.3261      -9.3652      -91.9137       -2.3850
time         2.5800       2.1800       2.1200        2.5800

ABSOLUTE RESPONSE MAXIMA

          displacement    velocity    acceleration
```

```
maximum       9.1455      3.8048      3.7393
time        2.1800      2.6400      3.9800
minimum      -4.6384     -1.0930      -.8424
time        2.9600      1.0200      1.5400
DUCTILITY FNVELOPES

maximum positive ductility ratio      :   .0000
minimum negative ductility ratio      :  -.0001
cyclic ductility ratio              :  1.0000
accumulative ductility ratio          :  1.0000
normalized hysteretic energy          :   1.0000

RESPONSE ENVELOPES

number of positive yield excursions   :      0
number of negative yield excursions   :      0
number of yield reversals             :    0
number of zero crossings              :     2

residual displacement              : -.1292E-15
EXECUTION ENDS ..........
WRITING RESULTS .........
```

Output File for 10-year Conditions

```
*******************************************************************************


                    PCNSPEC

                   A PROGRAM
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                  R. BOROSCHEK


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                      BY
                  S. A. MAHIN

                  ASSISTED  BY
                   R. HERRERA
                    J. LIN

                 JULY 10, 1991

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    LIKE pdspec < foo.file
    AND  foo.file : help
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```
****************************************************

SALM SYSTEM, EL CENTRO=10-year quake, w/damping=0.33

****************************************************


ANALYSIS TYPE .......... :          2
  1-SINGLE STRUCTURE
  2-SPECTRUM REPONSE

SYSTEM MASS ............ :       1.00000
SYSTEM DAMPING ......... :        .33000
POST YIELD STIFF FACTOR . :          .00000
ELEMENT TYPE ........... :          1
  1-BILINEAR MODEL
  2-DEGRADING MODEL
PROPERTY PARAMETER ...... :            2
  1-STIFFNESS
  2-PERIOD
YIELD PARAMETER ......... :         2
  1-YIELD DISPL
  2-ETA VALUE
  3-TARGET
P-DELTA EFFECT .......... :         0
  0-ONLY POST YIELD
  1-FULL EFFECT
YIELD PARAMETER SCALE ... :          1.00000

NUMBER OF STIFF/PERIODS . :             1
NUMBER OF YIELD DISP/ETA  :             1
COMBINATION OF RESULTS .. :             0
 0-TOTAL COMBINATION
 1-ONE-TO-ONE COMBINATION

MAXIMUM TIME STEP ...... :         .10000

STIFF/PERIOD VALUES :


): 1):        7.4200

YIELD DISPL/ETA/TARGET VALUES :


): 1):       66.0000

LOAD TYPE .............. :          12

INPUT FUNCTION TIME STEP. :          .02000
INPUT FUNCTION TYPE ..... :   READ OTHERGM
INPUT FUNCTION LENGTH ... :           200
```

```
INPUT FUNCTION FORMAT ... :      (8f10.0)

INITIAL VELOCITIY ....... :     .00000

INITIAL DISPLACEMENT .... :      .00000

LOAD FACTOR ............ :      .14400

ELEMENT PROPERTY SUMMARY :

 stiffness   natural      period     yield        yield
          frequency               displacement    shear

 .717054E+00  .846790E+00  .742000E+01  .452897E+05  .324752E+05


EXECUTION STARTS .........
GROUND MOTION MAXIMA

           ground        ground       ground
       displacement   velocity   acceleration

maximum      .2187E+02    .5490E+02    .4920E+03
time         2.6600       2.1800       2.1200
minimum      -.6917E+01   -.1943E+02   -.3789E+03
time         1.0400       2.9400       2.4400

ENERGY MAXIMA

          input      kinetic   recoverable hysteretic   damping
          energy     energy      strain      energy      energy
                                 energy

maximum     .8878E+03  .1310E+03  .1270E+03  .0000E+00  .8530E+03
time        3.9600     2.7200     2.6000      .0000     3.9800
RELATIVE RESPONSE MAXIMA

          displacement    velocity    acceleration   resistance

maximum        7.9294       34.4778      407.0706        5.6858
time         3.9800       2.9400       2.4400        3.9800
minimum       -18.8176      -49.2111     -468.8034      -13.4932
time         2.6000       2.1800       2.1200        2.6000

ABSOLUTE RESPONSE MAXIMA

          displacement     velocity     acceleration

maximum        34.1961       16.1868        18.9277
time         2.1800       2.7200       3.9800
minimum       -16.5668       -4.5784        -3.7553
time         3.7000       1.0600       1.6000
DUCTILITY ENVELOPES
```

```
maximum positive ductility ratio      :    .0002
minimum negative ductility ratio      :   -.0004
cyclic ductility ratio           :   1.0000
accumulative ductility ratio          :   1.0000
normalized hysteretic energy          :    1.0000

RESPONSE ENVELOPES

number of positive yield excursions   :        0
number of negative yield excursions   :        0
number of yield reversals            :      0
number of zero crossings             :       2

residual displacement                :  .1019E-15
EXECUTION ENDS ..........
WRITING RESULTS ..........
```

Output File for 100-year Conditions

```
************************************************************************************

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                            S. A. MAHIN

                            ASSISTED  BY
                            R. HERRERA
                              J. LIN

                           JULY 10, 1991

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    LIKE pdspec < foo.file
    AND  foo.file : help
************************************************************************************

*******************************************************

SALM SYSTEM, EL CENTRO=100-year quake, w/damping=0.33

*******************************************************
```

```
ANALYSIS TYPE ........... :            2
  1-SINGLE STRUCTURE
  2-SPECTRUM REPONSE

SYSTEM MASS ............. :        1.00000
SYSTEM DAMPING .......... :         .33000
POST YIELD STIFF FACTOR . :          .00000
ELEMENT TYPE ............ :          1
  1-BILINEAR MODEL
  2-DEGRADING MODEL
PROPERTY PARAMETER ...... :               2
  1-STIFFNESS
  2-PERIOD
YIELD PARAMETER ......... :            2
  1-YIELD DISPL.
  2-ETA VALUE
  3-TARGET
P-DELTA EFFECT .......... :          0
  0-ONLY POST YIELD
  1-FULL EFFECT
YIELD PARAMETER SCALE ... :          1.00000

NUMBER OF STIFF/PERIODS . :               1
NUMBER OF YIELD DISP/ETA  :               1
COMBINATION OF RESULTS .. :               0
 0-TOTAL COMBINATION
 1-ONE-TO-ONE COMBINATION

MAXIMUM TIME STEP ....... :          .10000

STIFF/PERIOD VALUES :

): 1):          7.4200
YIELD DISPL/ETA/TARGET VALUES :

): 1):         18.3300

LOAD TYPE ............... :          12

INPUT FUNCTION TIME STEP. :          .02000
INPUT FUNCTION TYPE ..... :   READ OTHERGM
INPUT FUNCTION LENGTH ... :            200

INPUT FUNCTION FORMAT ... :      (8f10.0)

INITIAL VELOCITIY ....... :      .00000

INITIAL DISPLACEMENT .... :          .00000

LOAD FACTOR ............. :      .51700

ELEMENT PROPERTY SUMMARY :
```

```
 stiffness    natural       period      yield        yield
          frequency               displacement    shear

.717054E+00  .846790E+00  .742000E+01  .451592E+05  .323816E+05


EXECUTION STARTS .........
GROUND MOTION MAXIMA

          ground       ground      ground
       displacement  velocity  acceleration

maximum     .7851E+02    .1971E+03    .1767E+04
time         2.6600       2.1800       2.1200
minimum     -.2484E+02   -.6975E+02   -.1360E+04
time         1.0400       2.9400       2.4400

ENERGY MAXIMA

          input     kinetic   recoverable hysteretic   damping
          energy     energy      strain      energy     energy
                                 energy

maximum    .1144E+05  .1689E+04  .1636E+04  .0000E+00  .1100E+05
time         3.9600     2.7200     2.6000      .0000     3.9800
RELATIVE RESPONSE MAXIMA

          displacement     velocity     acceleration   resistance

maximum        28.4689       123.7848     1461.4964       20.4137
time          3.9800        2.9400        2.4400        3.9800
minimum        -67.5603     -176.6814     -1683.1346      -48.4444
time          2.6000        2.1800        2.1200        2.6000

ABSOLUTE RESPONSE MAXIMA

          displacement     velocity     acceleration

maximum        122.7733       58.1150       67.9558
time          2.1800        2.7200        3.9800
minimum        -59.4794      -16.4377      -13.4825
time          3.7000        1.0600        1.6000
DUCTILITY ENVELOPES

maximum positive ductility ratio      :     .0006
minimum negative ductility ratio      :    -.0015
cyclic ductility ratio            :    1.0000
accumulative ductility ratio         :    1.0000
normalized hysteretic energy          :    1.0000

RESPONSE ENVELOPES

number of positive yield excursions    :        0
number of negative yield excursions    :        0
```

```
number of yield reversals        :    0
number of zero crossings         :    2

residual displacement          : .2422E-14
EXECUTION ENDS ..........
WRITING RESULTS .........
```

Output File for 1000-year Conditions

```
********************************************************************************


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                    NONSPEC
                      BY
                  S. A. MAHIN

                  ASSISTED BY
                  R. HERRERA
                    J. LIN

                JULY 10, 1991

NOTE: INPUT FILE WITH FIRST LINE CONTAINING THE WORD "HELP"
   TO OBTAINE INPUT FILE FORMAT
   LIKE pdspec < foo.file
   AND  foo.file : help
********************************************************************************

******************************************************

SALM SYSTEM, EL CENTRO=1000-year quake, w/damping=0.33

******************************************************



ANALYSIS TYPE .........:            2
  1-SINGLE STRUCTURE
  2-SPECTRUM REPONSE

SYSTEM MASS ............ :        1.00000
SYSTEM DAMPING .......... :         .33000
POST YIELD STIFF FACTOR . :           .00000
ELEMENT TYPE ........... :          1
```

```
  1-BILINEAR MODEL
  2-DEGRADING MODEL
PROPERTY PARAMETER ...... :          2
  1-STIFFNESS
  2-PERIOD
YIELD PARAMETER ......... :        2
  1-YIELD DISPL.
  2-ETA VALUE
  3-TARGET
P-DELTA EFFECT .......... :      1
  0-ONLY POST YIELD
  1-FULL EFFECT
YIELD PARAMETER SCALE ... :        1.00000

NUMBER OF STIFF/PERIODS . :          1
NUMBER OF YIELD DISP/ETA  :          1
COMBINATION OF RESULTS .. :          0
 0-TOTAL COMBINATION
 1-ONE-TO-ONE COMBINATION

MAXIMUM TIME STEP ....... :      .10000

STIFF/PERIOD VALUES :


): 1):        7.4200

YIELD DISPL/ETA/TARGET VALUES :


): 1):        8.2500

LOAD TYPE .............. :       12

INPUT FUNCTION TIME STEP. :       .02000
INPUT FUNCTION TYPE ..... :  READ OTHERGM
INPUT FUNCTION LENGTH ... :        500

INPUT FUNCTION FORMAT ... :     (8f10.0)
INITIAL VELOCITIY ....... :     .00000

INITIAL DISPLACEMENT .... :       .00000

LOAD FACTOR ............ :     1.14800

ELEMENT PROPERTY SUMMARY :

 stiffness   natural     period     yield       yield
            frequency           displacement    shear

.717054E+00  .846790E+00  .742000E+01  .451324E+05  .323624E+05


EXECUTION STARTS .........
```

```
GROUND MOTION MAXIMA

            ground        ground      ground
        displacement   velocity   acceleration

maximum      .5973E+03   .4377E+03   .3923E+04
time        9.9800      2.1800      2.1200
minimum     -.5515E+02  -.2211E+03  -.3020E+04
time        1.0400      5.3800      2.4400

ENERGY MAXIMA

           input      kinetic   recoverable hysteretic   damping
           energy     energy      strain     energy      energy
                                  energy

maximum     .1061E+06  .9876E+04  .8069E+04  .0000E+00  .1026E+06
time        9.2200     8.5800     2.6000      .0000     9.9800
RELATIVE RESPONSE MAXIMA

           displacement    velocity    acceleration   resistance

maximum        63.2153      323.5411     3245.2570       45.3288
time          3.9800       5.3800       2.4400        3.9800
minimum      -150.0178     -392.3216    -3737.4052     -107.5709
time          2.6000       2.1800       2.1200        2.6000

ABSOLUTE RESPONSE MAXIMA

           displacement    velocity    acceleration

maximum        272.6186      140.5419      649.0404
time          2.1800       8.5800       9.9800
minimum      -169.3432     -36.5000      -29.9378
time          5.4000       1.0600       1.6000
DUCTILITY ENVELOPES

maximum positive ductility ratio      :   .0014
minimum negative ductility ratio      :  -.0033
cyclic ductility ratio            :  1.0000
accumulative ductility ratio        :  1.0000
normalized hysteretic energy         :  1.0000

RESPONSE ENVELOPES

number of positive yield excursions   :      0
number of negative yield excursions   :      0
number of yield reversals          :    0
number of zero crossings           :    6

residual displacement            : .1811E-14
EXECUTION ENDS ..........
WRITING RESULTS .........
```

Appendix 6 : Calculations of Fatigue

The following fatigue calculations are based on the relations given in Chapters 4 and 5. The calculations were carried out with the use of Microsoft Excel spreadsheets, which are reproduced here. Fatigue calculations were done for the tubular riser, wire rope, connections, articulations, and chain components.

Fatigue Reliability : Tubular Riser

Input Parameters, Mean Fatigue Life	
100 year wave height (Hfd, Ho)	*46*
Accumulated Fatigue Dam. (D)	1.00
Wave Period (sec)	*15*
Stress cycles (No)	2.10E+08

S-N m value	*4.38*
Biased K value	*1.50E+12*
Alpha	1.00
Stress range bias	0.80

Out - Mean Fatigue Life	
Mean Fatigue Life (yrs)	98034

Cd	*0.3*
Ck	*0.73*
Cb	*0.5*

Removing Bias from K	
Deviation in K	0.65
Unbiased K (S-N)	5.54E+12

Input Parameters, Stress Range Para.	
Rainflow correction (y(m))	1.00
Average freq of stress (1/yr)	2.10E+06
Epsilon 0	1.00
1+m/eps0	5.38
Gamma (1+m/eps0)	46.69
Largest stress in 100 years	***21.12***

Output	
Omega	1.50E+08

Reliability	
Sigma ln T	1.57
Median T (yrs)	9.80E+04
Service Life (yrs)	*20*
Beta	**5.41**
Probability of Fail	**3.27E-08**

Fatigue Design Stress	
Design Time Period	100
Fatigue Life F.S.	3
Yo	4.55E+09
SfD	63.36
SCF	3.00
Nom. Allow. D Stress	21.12

Fatigue Reliability : Wire Rope

Input Parameters, Mean Fatigue Life	
100 year wave height (Hfd, Ho)	*46*
Accumulated Fatigue Dam. (D)	1.00
Wave Period (sec)	*15*
Stress cycles (No)	2.10E+08

S-N m value	*4.09*
Biased K value	*1.30E+10*
Alpha	1.00
Stress range bias	0.80

Out - Mean Fatigue Life	
Mean Fatigue Life (yrs)	66820

Cd	*0.3*
Ck	*0.73*
Cb	*0.5*

Removing Bias from K	
Deviation in K	0.65
Unbiased K (S-N)	4.80E+10

Input Parameters, Stress Range Para.	
Rainflow correction (y(m))	1.00
Average freq of stress (1/yr)	2.10E+06
Epsilon 0	1.00
1+m/eps0	5.09
Gamma (1+m/eps0)	30.56
Largest stress in 100 years	*7.99*

Output	
Omega	1.79E+06

Reliability	
Sigma ln T	1.53
Median T (yrs)	6.68E+04
Service Life (yrs)	*20*
Beta	**5.31**
Probability of Fail	**5.79E-08**

Fatigue Design Stress	
Design Time Period	100
Fatigue Life F.S.	3
Yo	2.31E+09
SfD	23.96
SCF	3.00
Nom. Allow. D Stress	7.99

Fatigue Reliability : Connections

Input Parameters, Mean Fatigue Life	
100 year wave height (Hfd, Ho)	***46***
Accumulated Fatigue Dam. (D)	1.00
Wave Period (sec)	*15*
Stress cycles (No)	2.10E+08

S-N m value	***3.74***
Biased K value	***1.79E+10***
Alpha	**1.00**
Stress range bias	**0.80**

Out - Mean Fatigue Life	
Mean Fatigue Life (yrs)	42072.49

Cd	*0.3*
Ck	*0.73*
Cb	*0.5*

Removing Bias from K	
Deviation in K	0.65
Unbiased K (S-N)	6.62E+10

Input Parameters, Stress Range Para.	
Rainflow correction (y(m))	1.00
Average freq of stress (1/yr)	2.10E+06
Epsilon 0	1.00
1+m/eps0	4.74
Gamma (1+m/eps0)	18.82
Largest stress in 100 years	***10.11***

Output	
Omega	3.62E+06

Fatigue Design Stress	
Design Time Period	100
Fatigue Life F.S.	3
Yo	1.05E+09
SfD	30.34
SCF	3.00
Nom. Allow. D Stress	10.11

Reliability	
Sigma ln T	1.477313
Median T (yrs)	4.21E+04
Service Life (yrs)	*20*
Beta	**5.18**
Probability of Fail	**1.15E-07**

Fatigue Reliability : Articulations

Input Parameters, Mean Fatigue Life	
100 year wave height (Hfd, Ho)	*46*
Accumulated Fatigue Dam. (D)	1.00
Wave Period (sec)	*15*
Stress cycles (No)	2.10E+08

S-N m value	*3.74*
Biased K value	*1.79E+10*
Alpha	1.00
Stress range bias	0.80

Out - Mean Fatigue Life	
Mean Fatigue Life (yrs)	42072.49

Cd	*0.3*
Ck	*0.73*
Cb	*0.5*

Removing Bias from K	
Deviation in K	0.65
Unbiased K (S-N)	6.62E+10

Input Parameters, Stress Range Para.	
Rainflow correction (y(m))	1.00
Average freq of stress (1/yr)	2.10E+06
Epsilon 0	1.00
1+m/eps0	4.74
Gamma (1+m/eps0)	18.82
Largest stress in 100 years	*10.11*

Output	
Omega	3.62E+06

Reliability	
Sigma ln T	1.477313
Median T (yrs)	4.21E+04
Service Life (yrs)	*20*
Beta	**5.18**
Probability of Fail	**1.15E-07**

Fatigue Design Stress	
Design Time Period	100
Fatigue Life F.S.	3
Yo	1.05E+09
SfD	30.34
SCF	3.00
Nom. Allow. D Stress	10.11

Fatigue Reliability : Chain

Input Parameters, Mean Fatigue Life	
100 year wave height (Hfd, Ho)	*46*
Accumulated Fatigue Dam. (D)	1.00
Wave Period (sec)	*15*
Stress cycles (No)	2.10E+08

S-N m value	*3.36*
Biased K value	*4.60E+09*
Alpha	1.00
Stress range bias	0.80

Out - Mean Fatigue Life	
Mean Fatigue Life (yrs)	25460.46

Cd	*0.3*
Ck	*0.73*
Cb	*0.5*

Removing Bias from K	
Deviation in K	0.65
Unbiased K (S-N)	1.70E+10

Input Parameters, Stress Range Para.	
Rainflow correction (y(m))	1.00
Average freq of stress (1/yr)	2.10E+06
Epsilon 0	1.00
1+m/eps0	4.36
Gamma (1+m/eps0)	11.52
Largest stress in 100 years	***8.23***

Output	
Omega	1.41E+06

Reliability	
Sigma ln T	1.42
Median T (yrs)	2.55E+04
Service Life (yrs)	*20*
Beta	**5.04**
Probability of Fail	**2.43E-07**

Fatigue Design Stress	
Design Time Period	100
Fatigue Life F.S.	*3*
Yo	4.59E+08
SfD	24.68
SCF	3.00
Nom. Allow. D Stress	8.23

Cumulative Annual Probability of Failure

The cumulative annual probabilities of failure are given in Table A.6.1. These values were obtained by varying the service life in the fatigue reliability calculations for chain. The values are plotted in Figure 5.1.

Year	End-of-Year Beta	End-of-Year Probability of Failure
2	6.66	4.46E-10
4	6.17	4.84E-09
6	5.89	1.86E-08
8	5.68	4.71E-08
10	5.53	9.56E-08
12	5.40	1.69E-07
14	5.29	2.72E-07
16	5.20	4.08E-07
18	5.11	5.82E-07
20	5.04	7.98E-07
22	4.97	1.06E-06
24	4.91	1.37E-06
26	4.85	1.73E-06
28	4.80	2.14E-06
30	4.75	2.61E-06

Table A.6.1 : Fatigue Reliability versus Service Life (Chain)

Appendix 7 : Calculations of CALM Line and Anchor Tensions

The calculations of CALM line and anchor tensions were carried out by Wei Ma, and the reader is referred to his report for a detailed discussion of this analysis [Ma, 1994]. A table of Offset versus Line and Anchor Tensions is provided in Table A.7.1..

Offset (ft) (feet)	Steady Force (pounds)	Line Tension (pounds)	Anchor Tension (pounds)
0	0	52907	19537
40	37812	67282	30735
80	78708	88156	47640
120	129952	117780	72652
160	198253	160205	109855
200	293530	222052	165910
240	431631	314840	252353

Table A.7.1 : CALM Offset versus Tension

Appendix 8 : Calculations of SALM Line and Anchor Pile Tensions

The design of the SALM system was carried out using Microsoft Excel spreadsheets, which are reproduced here. The SALM system consists of three major components : the buoy, the anchor leg, and the pile anchor. The anchor leg for this system is composed of three solid risers. The hoses were also examined in this design process. Based on the weight and buoyancy of all system components, a buoy draft could be determined. A pretension was then added by increasing the draft of the buoy. The effectiveness of a pretension at providing restoring force is calculated in the next section.

SALM Component Design

Buoy			
Input		*Output*	
Diameter (ft)	15	Volume (ft^3)	12369.66
Depth (ft)	70	**Weight (LT)**	**47.35**
Steel Volume Ratio (ft^3/ft^3)	0.0175		
Steel Density (kip/ft^3)	0.49		

Top Tubular Riser	*(watertight)*		
Input		*Output*	
Diameter (in)	48	Steel Margin	3.20
Thickness (in)	0.5	Cross-section (in^2)	74.61
Length (ft)	300	Total Volume (ft^3)	3770
Weight/ft (LT/ft)	0.113	Weight (LT)	108.81
Steel Density (kip/ft^3)	0.49	Buoyancy (LT)	107.71
Steel Young's mod (kip/ft^2)	29000	Stiffness (LT/ft)	50.09
		Net Weight (LT)	**1.10**

Middle Tubular	***Riser***	*(watertight)*		
Input			*Output*	
Diameter (in)		48	**Steel Margin**	1.80
Thickness (in)		0.75	**Cross-section (in^2)**	111.33
Length (ft)		350	**Total Volume (ft^3)**	4398
Weight/ft	(LT/ft)	0.169	**Weight (LT)**	106.54
Steel Density (kip/ft^3)		0.49	**Buoyancy (LT)**	125.66
Steel Young's mod (kip/ft^2)		29000	**Stiffness (LT/ft)**	64.06
			Net Weight (LT)	**-19.12**

Lower Tubular Riser		*(watertight)*		
Input			*Output*	
Diameter (in)		48	**Steel Margin**	1.40
Thickness (in)		1	**Cross-section (in^2)**	147.65
Length (ft)		320	**Total Volume (ft^3)**	4021
Weight/ft	(LT/ft)	0.224	**Weight (LT)**	100.48
Steel Density (kip/ft^3)		0.49	**Buoyancy (LT)**	114.89
Steel Young's mod (kip/ft^2)		29000	**Stiffness (LT/ft)**	92.92
			Net Weight (LT)	**-14.40**

Hoses	*(submerged sections only)*			
Input			*Output*	
Outer Diameter (in)		24	**Cross-section (in^2)**	36.91
Thicknes (in)		0.5	**Steel Vol (ft^3)**	281.97
Length (ft)		1100	**Steel Wt (LT)**	15.42
Steel Density (kip/ft^3)		0.49	**Buoyancy (LT)**	8.06
Steel % in Volume		25	**Net Weight (LT)**	**7.36**

Buoyancy refers only to solid hose, not interior

Pile Anchor			
Input		*Output*	
Length (ft)	140	**Weight (LT)**	77
Diameter (ft)	5	**Holding Power (LT)**	2001
Soil U.S.S (ksf)	2.0	**Min.Thickness (in)**	0.84
		Thickness (in)	1.00

SALM System Design

No Pretension in System		*Pretension Added*	
# Hoses	2	*Pretension Force (LT)*	300
Net Weight (LT)	29.66	Tension/tendon (LT)	329.66
Required Buoy Buoyancy (LT)	29.66	Elong : Pretension (ft)	0.000
Buoy Draft (ft)	5.87	Delta Buoy Draft (ft)	59.42
Buoy Freeboard (ft)	64.13	Buoy Draft (ft)	65.29
		Buoy Freeboard (ft)	4.71

With the system characteristics determined, the horizontal environmental force versus the horizontal restoring force could be iterated to find an equilibrium offset position. This procedure is given in the spreadsheets below for the SALM system without a moored tanker for the 2-year, 10-year and 100-year return period conditions. The procedure was also carried out for the SALM system with a connected tanker, for the tanker in both the full-load and lightship conditions. The procedure was then carried out given total offset (steady force offset plus peak oscillating offset), iterating to find forces and tensions based on equilibrium offset.

SALM System, 2-year Return Period Calculations

Elongation	
Tendon Angle (deg)	0.88
Environ. Force (LT)	4.20
Cable Tension (LT)	273.07
Tension/tendon (LT)	273.07
Elongation (offset) (ft)	5.452

Added Buoyancy (with Elongation)	
Tendon Angle (deg)	0.88
Offset (ft)	15.38
Del Draft (ft)	0.12
Del Draft, with Elong. (ft)	-5.33
Added Buoyancy (LT)	-26.93
Added Restoring (LT)	**-0.41**

Pretension Restoring Force	
Tendon Angle (deg)	0.88
Restoring Force (LT)	**4.61**

Output	
Tendon Angle (deg)	0.881
Offset (ft)	**15.38**
Buoy Draft (ft)	59.96
Buoy Freeboard (ft)	10.04
Tension/tendon (LT)	**273.07**
Vertical Stiffness (LT/ft)	50.09

Input / Iteration	
Environ. Force (LT)	*4.2*
Tendon Angle Gss (deg)	***0.88128***
Restoring Force (LT)	4.20
Force Differential	2.69E-08

SALM System, 10-year Return Period Calculations

Elongation	
Tendon Angle (deg)	1.71
Environ. Force (LT)	8.20
Cable Tension (LT)	274.57
Tension/tendon (LT)	274.57
Elongation (offset) (ft)	5.482

Added Buoyancy (with Elongation)	
Tendon Angle (deg)	1.71
Offset (ft)	29.88
Del Draft (ft)	0.45
Del Draft, with Elong. (ft)	-5.04
Added Buoyancy (LT)	-25.43
Added Restoring (LT)	**-0.76**

Pretension Restoring Force	
Tendon Angle (deg)	1.71
Restoring Force (LT)	**8.96**

Output	
Tendon Angle (deg)	1.711
Offset (ft)	**29.88**
Buoy Draft (ft)	60.26
Buoy Freeboard (ft)	9.74
Tension/tendon (LT)	**274.57**
Vertical Stiffness (LT/ft)	50.09

Input / Iteration	
Environ. Force (LT)	*8.2*
Tendon Angle Gss (deg)	***1.71136***
Restoring Force (LT)	8.20
Force Differential	9.33E-09

SALM System, 100-year Return Period Calculations

Elongation	
Tendon Angle (deg)	2.80
Environ. Force (LT)	13.60
Cable Tension (LT)	278.03
Tension/tendon (LT)	278.03
Elongation (offset) (ft)	5.551

Pretension Restoring Force	
Tendon Angle (deg)	2.80
Restoring Force (LT)	**14.67**

Input / Iteration	
Environ. Force (LT)	*13.6*
Tendon Angle Gss (deg)	***2.80383***
Restoring Force (LT)	13.60
Force Differential	4.54E-08

Added Buoyancy (with Elongation)	
Tendon Angle (deg)	**2.80**
Offset (ft)	**48.98**
Del Draft (ft)	**1.20**
Del Draft, with Elong. (ft)	**-4.35**
Added Buoyancy (LT)	**-21.97**
Added Restoring (LT)	**-1.07**

Output	
Tendon Angle (deg)	2.804
Offset (ft)	**48.98**
Buoy Draft (ft)	60.94
Buoy Freeboard (ft)	9.06
Tension/tendon (LT)	**278.03**
Vertical Stiffness (LT/ft)	50.09

Appendix 9 : Approximations to the Standard Normal Distribution

Several formulas have been proposed for approximating the standard normal distribution. A handy form of estimation was necessary in this paper due to the number of iterations run which made use of the standard normal distribution. Two approximations were examined, one by Abramowitz [Melchers, 1987] and one from [Bea, 1990]. These approximations are :

$$\Phi(\beta) = 1 - \left[\frac{1}{\beta(2\pi)^{1/2}}\right]\exp\left[-\frac{1}{2}\beta^2\right] \qquad \text{(Abramowitz)}$$

$$\Phi(\beta) = 1 - 0.475\exp\left(-\beta^{1.6}\right) \qquad \text{(Bea)}$$

The values calculated by the Abramowitz approximation were found to more closely approximate the standard normal distribution for the values of beta encountered in this project, and this approximation was used.

Appendix 10 : Calculations of Reliability

The calculation of reliability was carried out using Microsoft Excel spreadsheets. The relations used in the reliability analysis are detailed in Chapter 5. For the sake of conciseness, only one reliability calculation is presented here for each system, as only the load will vary for calculation of different return periods, and the results for other return periods can be found in Chapter 5.

Calculation of CALM Reliability

CALM Components

	Wire	Chain	Connect.	Anchor
Capacity (LT)	*447*	*321*	*100*	*274*
Variance on Capacity	*0.1*	*0.1*	*0.1*	*0.4*
Natural Log Deviation	0.100	0.100	0.100	0.385
Mean (2-yr) Tension (LT)	*31.70*	*31.70*	*31.70*	*15.6*
Ln Dev. Loading	0.115	0.115	0.115	0.115
Variance, Type II	0.100	0.100	0.100	0.100
Correlation	*0.0*	*0.0*	*0.0*	*0.0*
Beta	18.74	16.39	8.13	7.20
Pf	**1.29E-78**	**1.12E-60**	**2.11E-16**	**3.06E-13**

CALM System

	Number	Individual Beta	Individual Pf
Chain Anchor Legs, Upper	*8*	16.39	**1.12E-60**
Chain Anchor Legs, Lower	*8*	16.39	**1.12E-60**
Wire Rope Anchor Legs	*8*	18.74	**1.29E-78**
Connections	*32*	8.13	**2.11E-16**
Anchors	*8*	7.20	**3.06E-13**

Pf of single leg	
Rho =	0.569429
Pf =	**3.06E-13**
Beta =	8.13

Pf of System (all legs in parallel)	
Beta =	10.3
Pf =	**3.5E-25**

Calculation of Reliability for SALM

SALM Components

	Riser	Joint	Pile
Capacity (LT)	***700***	***600***	***2000***
Variance on Capacity	***0.1***	***0.1***	***0.4***
Natural Log Deviation	0.100	0.100	0.385
Mean (2-yr) Tension (LT)	***283.4***	283.4	283.4
Ln Dev, Loading	0.015	0.015	0.015
Variance in Loading	0.015	0.015	0.015
Variance, Type II	0.100	0.100	0.100
Correlation	***0.0***	0.0	0.0
Beta	6.37	5.28	4.91
Pf	**9.93213E-11**	**6.65106E-08**	**4.8291E-07**

SALM System

	Number	Individual Beta	Individual Pf
Riser	*3*	6.37	**9.93213E-11**
Pile	*1*	4.91	**4.8291E-07**
Joints	*4*	5.28	**6.65106E-08**

Pf of system

Rho =	0.022007
Pf, Storm	4.8291E-07
Beta, Stm	5.16

Appendix 11 : SPMS evaluated by ABS Factors of Safety

The following is a list of single point moorings which have been classed by ABS [Jones, 1992].

Year Installed	Country/Location	System Name
1978	Abu Dhabi	Tropical Lion
1981	United States	Santa Ynez
1981	Phillipines	FPSO II
1981	Thailand	Erawan
1986	Nigeria	FPSO VI
1986	Indonesia	Kakap Natuna
1986	Colombia	Convenas
1988	Yemen	Safer
1989	China	Bo Hai You Yi Hao
1989	China	Nanhai Faxian
1990	China	Chang Qing Hao
1990	Indonesia	Anoa Natuna
1990	China	Ayer Biru
1990	Malaysia	Puteri Dulang
1992	Austrailia	NA
1992	Indonesia	Belida
1992	China	NA

Table A.11.1 : SPMS Evaluated by ABS

APPENDIX 11 : SPMS EVALUATED BY ABS FACTORS OF SAFETY 1