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AUG 77 M BRIGGS, W R BUTLER, E P KIEFER N62477-73-C-0359

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The report presents an analysis of the environmental aspects of Ocean Facilities Engineering. The various parameters and phenomena are identified and defined by means of a general breakdown structure that serves to categorize and completely define the interface between a fixed ocean facility and its environment.

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FOREWORD

This report was prepared under Contract No. N62477-73-C-0359, Modification P00008, by the Lockheed Missiles & Space Company, Inc., Sunnyvale, California.

The report presents an analysis of the environmental aspects of Ocean Facilities Engineering. The various parameters and phenomena are identified and defined by means of a general breakdown structure that serves to categorize and completely define the interface between a fixed ocean facility and its environment.

This report was prepared for the Department of the Navy, Chesapeake Division, Naval Facilities Engineering Command, Washington, D. C. Key personnel involved in its preparation were M. Briggs, W. R. Butler, E. P. Kiefer, and P. T. Waterman, all of LMSC. Acknowledgment is also made for the specialized contributions from numerous personnel within the Ocean Systems organization of LMSC's Research and Development Division

CONTENTS

INTRODUCTION

SCOPE

The environmental aspects data are based on a generic breakdown structure which is a comprehensive portrayal of the most significant environmental factors that Ocean Facilities Engineering (OFE) must address during the lifetime of a facility. The breakdown structure is applicable to all naval fixed ocean facilities.

CONTENT AND ORGANIZATION

This report contains a numerical listing of the Breakdown Structure that lists the number of title of each element and subelement, a presentation of the Breakdown Structure units with supporting narrative in numerical order, and a bibliography of source documents. A glossary of terms is included, although many terms are defined within the narrative. The Environmental Aspects (EV) Breakdown Structure is inserted in an envelope preceding the inside back cover, and may be removed and referred to while reading the report.

The narrative descriptions are arranged in the same numerical order as the listing and each description is given the same identifying number as in the listing. Each description starts with a definition (DEFN) which is followed by comments on Interrelationships (INTER) and Influences (INFL) where these are applicable.

Ocean Facilities Engineering - A systematic application of existing engineering and scientific knowledge to the design, construction, and maintenance of naval fixed ocean facilities.

OFE Function - Characteristic actions performed in the OFE process. Each function is briefly described and interrelationships are identified. Functions are indentured and identified from top down so that subfunctions are recognized as part of larger functions. Functions are arranged in sequence, in so far as possible, so that actions can be traced through the breakdown structure.

Naval Fixed Ocean Facility - An installation mounted on structures erected on the ocean floor or suspended above the ocean floor by means of a mooring system.

Facility Life Cycle - The order of actions in the life of a facility: First, the facility is conceived in the form of requirements and conceptual designs, then it is defined in detail designs and plans, after which it is constructed and put into operation. When its mission has been fulfilled the facility is recovered for use elsewhere, for storage, or for salvage.

Breakdown Structure - The division of a subject into generic categories arranged in a hierarchical structure which serves to completely analyze and define the subject. Each category is subdivided into one or more levels of elements with each element being generically related to and defined by the collection of elements appearing at the level below it.

Methods of Measurement (MEAS) - Where applicable, this subheading is introduced under an environmental aspect topic. It provides a statement of the type(s) of instrumentation available and applicable to the taking of the measurement, the technique of measuring or sampling, or the method of operation.

Methods of Calculation (CALC) - This subheading is also introduced as necessary to present calculation methods. It is used variously to present formulas and define terms, to discuss how a specific parameter is determined, or to show how required design information is obtained from measurements taken from samples.

INSTRUCTIONS FOR THE READER

The Breakdown Structure has been amplified by supporting narrative that identifies and defines EV elements. Each element (EV aspect) is identified as a bullet under each unit (box) within the Breakdown Structure. A unique number for reference purposes is assigned each bulleted item. This number appears in the numerical listing and in the narrative description. The narrative for each numbered element includes a definition and a discussion of its interrelationship with other environmental aspects in the breakdown structure. Tabs are provided for each major section.

EV-000 ENVIRONMENTAL ASPECTS

For purposes of this breakdown, environmental aspects have been categorized into three main environments: (1) Atmospheric, (2) Ocean, and (3) Seafloor. In addition, two environmental interfaces have also been broken down separately: (1) Sea/Seafloor, and (2) Air/Sea/Land.

The approach/philosophy taken in developing this breakdown is to l[illegible] those environmental aspects that have a significant influence on the site selection, environmental loads for design purposes, and potential detrimental impacts on the desired performance of the ocean facility. The direction taken was to clearly call out those parameters that are quantified for use in design equations and those that are quantified and/or qualified for use in making qualitative assessments.

The environment affects all aspects of the ocean facility. It provides forcing loads on the structural members, affects life expectancy of payloads, limits types of materials relative to the severity of the respective environments, and at times can modify the effective mission of the facility.

While the breakdown is expressed in terms of the environmental conditions of concern to a fixed ocean facility (FOF) designer, it must be borne in mind that the influence of a facility on the local environment is an equally important consideration. The first level breakdown structure for the Environmental Aspects category is presented in Fig. EV-000-1.

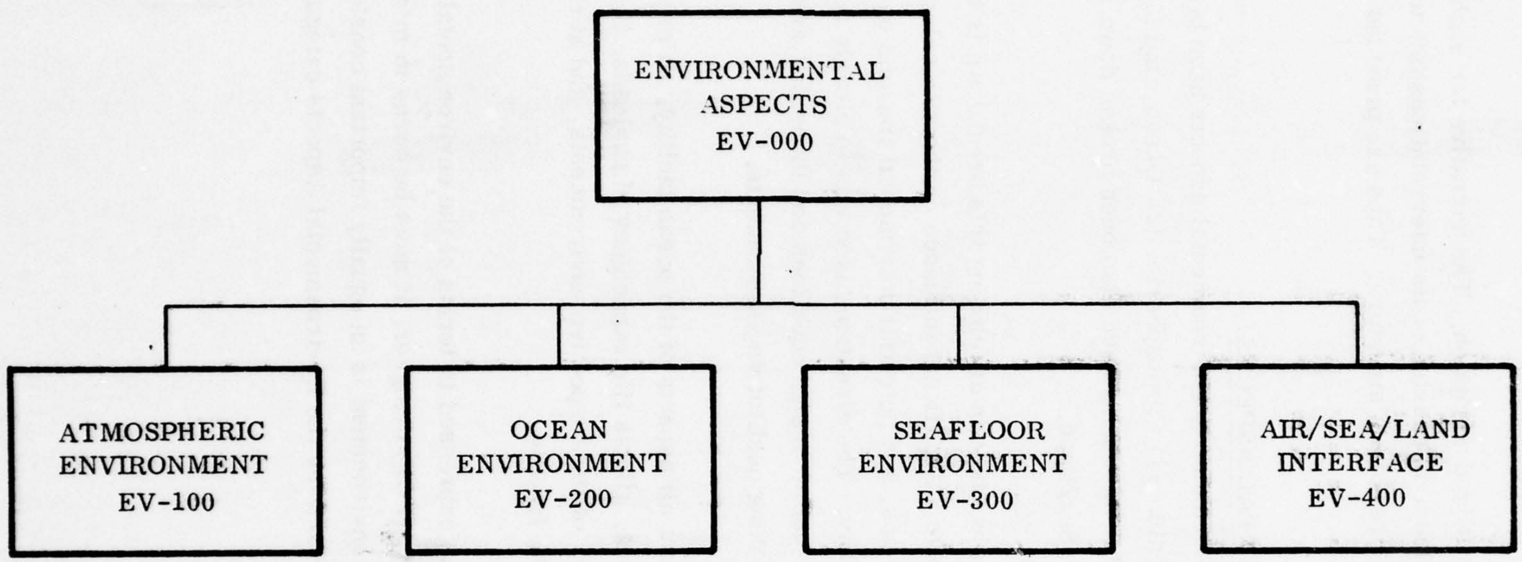

Fig. EV-000-1 Environmental Aspects – Breakdown Structure

NUMERICAL LISTING
OF
ENVIRONMENTAL ASPECTS
BREAKDOWN STRUCTURE
(EV-100)

EV			ELEMENT	
000	ENVIRONMENTAS ASPECTS			
	100	ATMOSPHERIC ENVIRONMENT		
		101	PHYSICAL PROPERTIES	
			101.1	Temperature Variation
			101.2	Humidity
			101.3	Composition
			101.4	Pressure Variation
		102	WINDS	
			102.1	Speed
			102.2	Direction
			102.3	Duration and Fetch
			102.4	Percent Frequency
			102.5	Recurrence Interval
			102.6	Forces
			102.7	Chill Factor
		103	PRECIPITATION	
			103.1	Types
			103.2	Quantities
			103.3	Duration
			103.4	Percent Frequency
			103.5	Recurrence Interval
		104	VISIBILITY	
			104.1	Distance
			104.2	Restrictions
		105	METEOROLOGICAL PHENOMENA	
			105.1	Hurricanes
			105.2	Waterspouts/Cyclones
			105.3	Thunderstorms
			105.4	Lightning
			105.5	Design Storm Conditions

NUMERICAL LISTING OF ENVIRONMENTAL ASPECTS BREAKDOWN STRUCTURE (EV-200)

EV				ELEMENT
000	ENVIRONMENTAL ASPECTS			
	200	OCEAN ENVIRONMENT		
		201	PHYSICAL AND CHEMICAL PROPERTIES	
			201.1	Chemical
			201.2	Optical
			201.3	Electromagnetic
			201.4	Mechanical
			201.5	Acoustic
			201.6	Thermodynamic
		202	CURRENTS	
			202.1	Types
			202.2	Stratification
			202.3	Direction
			202.4	Speed
			202.5	Turbulence
			202.6	Coherence
			202.7	Variation
			202.8	Spectrum
			202.9	Vortex Shedding
		203	INTERNAL WAVES	
			203.1	Deep Interface
			203.2	Shallow Interface
		204	BIOLOGICAL ASPECTS	
			204.1	Effects of Marine Biota
			204.2	Variation
		205	CORROSION ASPECTS	
			205.1	Types

NUMERICAL LISTING
OF
ENVIRONMENTAL ASPECTS
BREAKDOWN STRUCTURE
(EV-300)

EV				ELEMENT
000				ENVIRONMENTAL ASPECTS
	300			SEAFLOOR ENVIRONMENT
		301		BOTTOM TOPOGRAPHY
			301.1	Surface Gradient
			301.2	Surface Roughness
			301.3	Lateral Continuity/Variation
			301.4	Topographic Effects
		302		SUBBOTTOM GEOLOGIC STRUCTURE
			302.1	Composition
			302.2	Stratification
			302.3	Spatial Continuity/Variation
			302.4	Rock Protusion
			302.5	Discontinuities
		303		GEOMORPHOLOGY
			303.1	Origin/Courses of Geologic Formations
			303.2	Active Geomorphology During Facility Life
		304		GEOTECHNICAL PROPERTIES
			304.1	Soil
			304.2	Rock
		305		GEOPHYSICAL PROPERTIES
			305.1	Gravitational Anomalies
			305.2	Magnetic Anomalies
			305.3	Conductivity/Resistivity
			305.4	Acoustic
		306		SEISMIC ACTIVITY
		307		BIOLOGICAL ASPECTS/BURROWING

NUMERICAL LISTING
OF
ENVIRONMENTAL ASPECTS
BREAKDOWN STRUCTURE
(EV-300)

EV				ELEMENT
000	ENVIRONMENTAL ASPECTS			
	300	SEAFLOOR ENVIRONMENT		
		308	SEAFLOOR/FOUNDATION INTERACTION	
			308.1	Foundation Settlement Parameters
			308.2	Foundation Failure Parameters
		309	SEA/SEAFLOOR INTERFACE	
			309.1	Scouring
			309.2	Accretion
			309.3	Turbidity Currents

NUMERICAL LISTING OF ENVIRONMENTAL ASPECTS BREAKDOWN STRUCTURE (EV-400)

EV	ELEMENT		
000	ENVIRONMENTAL ASPECTS		
400	AIR/SEA/LAND INTERFACE		
401	SURFACE WAVES (DEEP WATER)		
		401.1	Types
		401.2	Speed
		401.3	Direction
		401.4	Dispersion
		401.5	Mass Transport/Inertia
		401.6	Characteristics
		401.7	Spray
		401.8	Breaking Height
		401.9	Wave Loading Analysis
		401.10	Wave Prediction Methods for Design of FOFs
402	WAVES (SHALLOW/RESTRICTED WATERS)		
		402.1	Breakers/Surf
403	SEA ICE		
		403.1	Types
		403.2	Statistics of Occurrence
		403.3	Speed
		403.4	Direction
		403.5	Composition
		403.6	Formation
		403.7	Icing
		403.8	Ice Forces
404	LITTORAL TRANSPORT		
405	EROSION		
406	RIVER DISCHARGE		

NUMERICAL LISTING
OF
ENVIRONMENTAL ASPECTS
BREAKDOWN STRUCTURE
(EV-400)

EV			ELEMENT	
000	ENVIRONMENTAL ASPECTS			
	400	AIR/SEA/LAND INTERFACE		
		407	SEA LEVEL VARIATION	
			407.1	Storm Surges
			407.2	Tides
			407.3	Tsunami
			407.4	Seiches
			407.5	Wave Setup
		408	SHORE CHARACTERISTICS	
			408.1	Beach Topography
			408.2	Beach Geology

EV-100 ATMOSPHERIC ENVIRONMENT

DEFN - The atmospheric environment is characterized by those properties which deal with phenomena in the atmosphere at and above the air-sea interface which should be considered in the design of FOFs.

The organization of the subject matter of this section is shown in Fig. EV-100-1.

INTER - The atmospheric and ocean environments are interrelated. For example, Water Temperature (EV-201.6.3) has a stabilizing effect on the air temperature (EV-201.6.3), and Winds (EV-102) cause waves to form and develop on the ocean surface (EV-401 and EV-402), dependent on duration and fetch length.

INFL - Wind loads (EV-102), Precipitation loads (EV-103), Humidity (EV-101.2), Atmospheric Visibility (EV-104), and Lightning (EV-105.4) can affect the structural design, protection considerations, recovery, and mission success of the FOF. The effect of the facility on the atmospheric environment depends on the nature of the facility.

EV-101 PHYSICAL PROPERTIES

DEFN - The physical properties of the atmosphere are defined as:

- Temperature variation
- Humidity
- Composition
- Pressure variation

INTER - The atmospheric environment is influenced by interrelationships in physical properties as, for example, the thermodynamic relation between Temperature and Pressure (EV-101.1 and EV-101.4). The Physical Properties (EV-101) are related also to other atmospheric phenomena such as Pressure Variation (EV-101.4) and Winds (EV-102), Temperature Variation (EV-101.1), Relative Humidity (EV-101.2) and Precipitation (EV-103); Composition (EV-101.3) and Visibility (EV-104); Physical Properties (EV-101) and Meteorological Phenomena (EV-105).

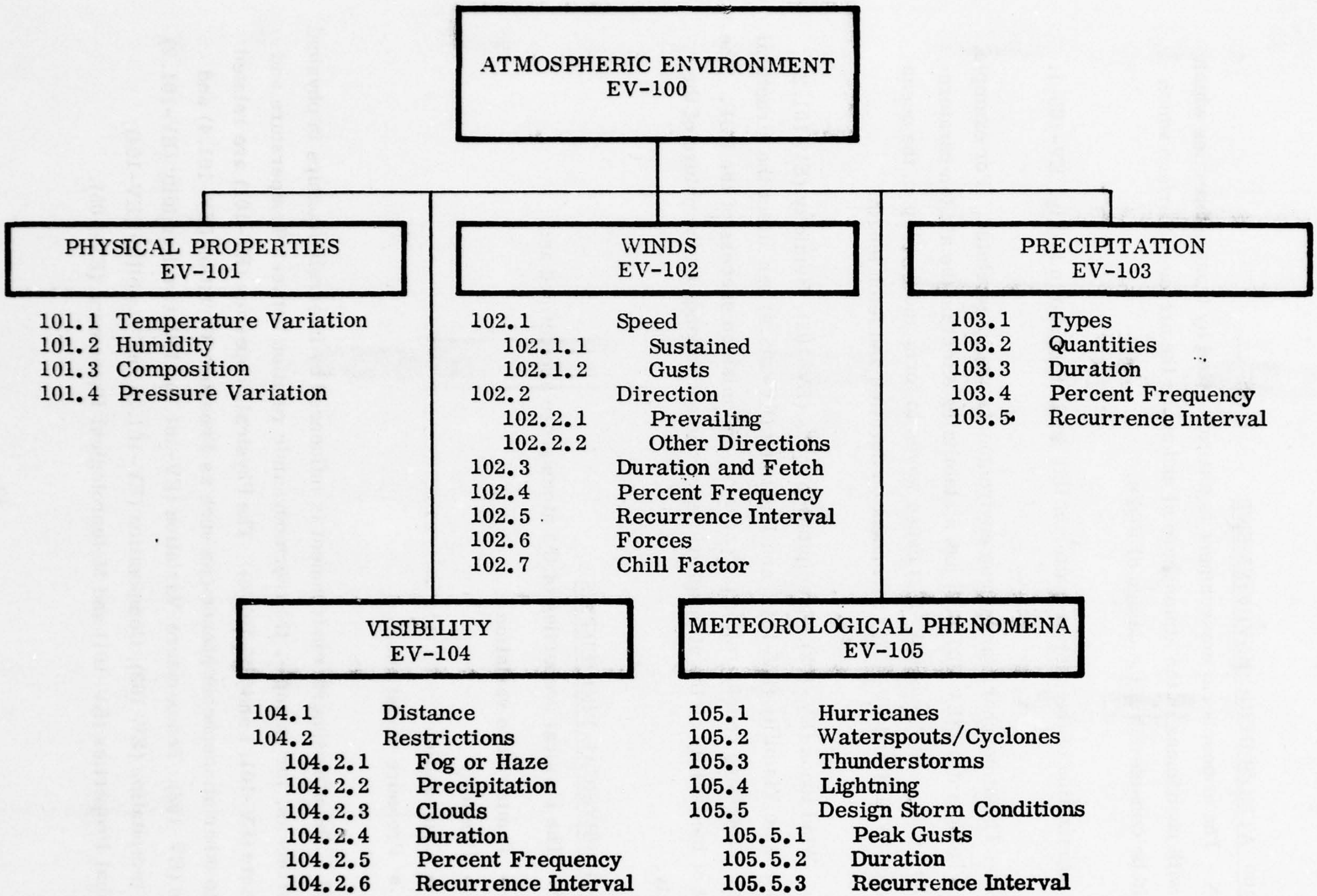

Fig. EV-100-1 Atmospheric Environment – Breakdown Structure

INFL - Structures above the sea surface may be influenced by the physical properties of the atmosphere such as temperature and relative humidity which, for instance, may dictate anticorrosion measures.

EV-101.1 Temperature Variation

DEFN - Atmospheric temperature (T) is the measure of heat in the atmosphere, in units of °C.

INTER - The range, frequency of occurrence, and duration of temperature varies considerably with season, location, time of day, Cloudiness (EV-104.2.3), Storm Conditions (EV-105.1, 105.3), and solar radiation reaching the sea surface. Temperature affects the generation and formation of Winds (EV-102), storms, Precipitation (EV-103), and Sea Ice (EV-403).

INFL - Atmospheric temperature normally has little direct effect on the structural requirements of a FOF. A facility could affect the local temperature and an analysis prior to FOF go-ahead should be accomplished to confirm degree of any detrimental effects. Any corrective action if necessary can then be considered in design of the FOF. In areas of extreme temperature variations, such as the polar regions, the effect can be major.

MEAS - Atmospheric temperature is measured in units of degrees fahrenheit or centigrade by a mercury thermometer.

EV-101.2 Humidity

DEFN - Humidity is a measure of the amount of water vapor in the atmosphere and is measured in percent of saturation. Vapor capacity increases with increasing temperature and decreasing atmospheric pressure. Humidity can be expressed in several ways. Relative humidity is the ratio of observed moisture content to saturated content at a specific temperature. Specific humidity is the amount of water vapor in one kilogram of air. The dew-point temperature is the temperature that the air must be cooled to at constant pressure in order to become saturated (100% relative humidity).

It is measured with a dew-point hygrometer. Vapor pressure is the partial pressure of the water vapor in the air.

INTER - Clouds (EV-104. 2. 3) and Fog (EV-104. 2. 1) form as a result of condensation of saturated water vapor.

INFL - Humidity does not impose specific structural requirements on the FOF but determines protection considerations in the atmospheric zone. It may affect design considerations relative to impaired visibility. Instrumentation necessary for completion of mission requirements can be affected by the corrosive atmospheric environment.

CALC - Relative humidity is determined by using a psychrometer (hygrometer) to measure the temperature differential caused by evaporative cooling of a wet-bulb as compared to a dry-bulb thermometer. The two temperatures are then referenced to standard humidity tables which give *relative humidity* values. This is expressed as a percentage of saturated moisture content at the ambient temperature.

EV-101. 3 Composition

DEFN - The composition of the atmosphere consists of nitrogen, oxygen, argon, and carbon dioxide, neon, methane, and other traces. Table EV-100-1 shows the percent by volume of these constituents in dry air (devoid of water vapor) near sea level (Ref. 1). Water vapor, however, is by far the most important gas as it affects surface climate. Latent heat is released in the atmosphere as water vapor condenses to form clouds. Water vapor concentration ranges from zero to over 4 percent by volume, and usually varies between 0. 1 and 1 percent.

Ozone, sulfur dioxide, ammonia, and carbon monoxide are also present in trace amounts (see Ref. 1). These conditions may vary significantly near centers of human activity which may emit aerosols, dust, carbon, etc.

Table EV-100-1

CHEMICAL COMPOSITION OF THE ATMOSPHERE
PERCENT BY VOLUME IN DRY AIR

Constituent	Percent by Volume
Nitrogen (N_2)	78.084
Oxygen (O_2)	20.948
Argon (A)	0.934
Carbon Dioxide (CO_2)	0.0314
Neon (Ne)	1.8×10^{-3}
Helium (He)	5.24×10^{-4}
Methane (CH_4)	2×10^{-4}
Krypton (Kr)	1.14×10^{-4}
Hydrogen (H_2)	5×10^{-5}
Nitrous Oxide (N_2O)	5×10^{-5}
Xenon (Xe)	8.7×10^{-6}

INTER - Atmospheric composition affects the Relative Humidity (EV-101.2) due to the presence of water vapor (EV-104.2.1, EV-104.2.2, and EV-104.2.3). The pressure variation (EV-101.4) is a function of the constituent gases comprising the atmosphere.

INFL - The effect of the atmospheric composition on fixed ocean facilities is relatively minor compared with the ocean environment. Corrosive aspects of water vapor (humidity) must be considered in the selection of construction materials. Corrosive chemical smog near cities should also be considered.

MEAS - Atmospheric composition is measured by gaseous chemical analysis.

EV-101.4 Pressure Variation

DEFN - Atmospheric pressure (P) is the force per unit area exerted by the earth's atmosphere.

INTER - Atmospheric pressure is most important as it relates to storm conditions, particularly Hurricanes (EV-105.1) and Thunderstorms (EV-105.3).

INFL - Atmospheric pressure has little direct effect on the structural requirements of a FOF.

MEAS - Atmospheric pressure is measured by microbarograph, aneroid barometer, or mercury barometer and is expressed in millibars, atmospheres, or kilograms per square meter or per square centimeter.

EV-102 WINDS

DEFN - Wind is a stream of air flowing over the ocean due to horizontal pressure gradients and the rotation of the earth. These pressure gradients are produced by temperature differences which create density differences in the atmosphere. Wind loads are produced due to frictional or drag effects of this air flow.

INTER - Wind is the primary driving force behind the generation of ocean waves and surface and near-surface currents (EV-202, 203, 401 and 601). Kinetic energy from wind is transferred into wave and current energy which interacts with the FOF. Generally, increases in Wind Speed (EV-102.1), fetch length (EV-401.1), and Wind Direction (EV-102.3) produce increases in wave height and current strengths. Wind speed, fetch length, and wind duration are used in the Sverdrup-Monk-Bretschneider method (Ref. 2) of calculating significant wave heights and periods (EV-401.10.1).

INFL - Wind loads can be a major design consideration in the construction of a FOF if it is placed or transported close to the sea/air interface. Large facilities can disrupt local wind patterns. Structures above the sea surface will be affected by winds.

EV-102.1 Speed

DEFN - The average or mean wind velocity ($\bar{U}_{10}$) is the average value obtained from measurements taken over a specified period of time at standard anemometer height (10 m). Generally, wind velocities vary with time and location.

A vertical wind velocity profile (see Fig. EV-100-2) is the distribution of wind velocity as a function of distance above the surface. The logarithmic law (Prandtl-von Karman law) or the power law is used to define the vertical distribution of the wind speed. The equations defining the logarithmic law wind velocity distribution U_{10}/U_* and friction layer Z_o are:

$$\frac{U_{10}}{U_*} = \frac{1}{k} \ln \frac{10}{Z_o}$$

$$Z_o = Z \exp\left(- k/\sqrt{C_D}\right)$$

where

U_{10} = wind speed at 10 m elevation, knots

U_* = friction velocity, knots

k = von-Karman constant, 0.4

Z_o = friction layer length 3.8×10^{-4} m for light winds, 3.0×10^{-3} m for strong winds

U_C = elevation above water surface, m

C_D = drag coefficient, 1.49×10^{-3} for light winds, 2.37×10^{-3} for strong winds .

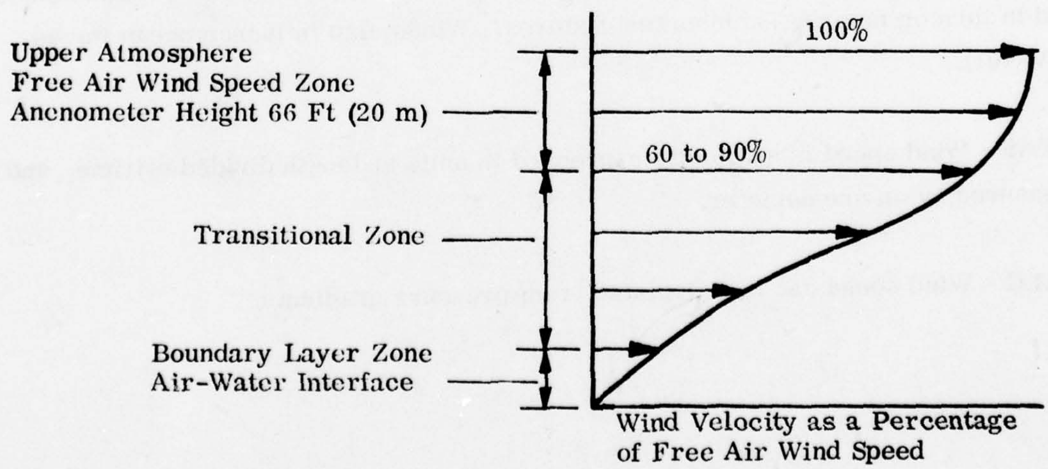

Fig. EV-100-2 Vertical Wind Velocity Profile

The equation defining the power law wind velocity distribution is

$$\frac{U_z}{U_{10}} = \left(\frac{Z}{10}\right)^{1/7}$$

where,

U_z = wind speed at elevation Z above free surface

INTER - The vertical wind velocity profile is affected by atmospheric stability, air turbulence, atmospheric temperature profile (EV-101.1), and sea roughness (EV-401). The mean surface wind speed is a function of the mean free air wind speed. It is generally 60 to 75 percent of the free air value. This free air value is determined from atmospheric pressure measurements as plotted on synoptic weather charts. The mean free air wind speed is calculated using geostrophic wind or gradient wind theory, depending on the amount of curvature of the air particle trajectories.

The relation between average wind speed and sea conditions (EV-401, 402) and the Beaufort scale can be found in the Weather Bureau Observing Handbook No. 1. Wind speed affects atmospheric visibility (EV-104) and sea surface waves (EV-401, 402).

INFL - Wind speed produces a load on any structure which extends above the surface, and in turn on mooring or mounting fixtures. Winds also influence ocean waves (EV-401).

MEAS - Wind speed is a velocity expressed in units of length divided by time, and is measured by an anemometer.

CALC - Wind speed can be calculated from pressure gradients.

EV-102.1.1 Sustained

DEFN - A sustained wind is one that blows in a reasonably constant direction for a considerable period of time. Sustained winds tend to blow along the isobars (lines of equal pressure) rather than across them, from high pressure to low pressure, although the latter behavior is observed when there are violent pressure differences. Essentially this results from the fact that the earth is a moving coordinate system, with an angular rotation about the polar axis. As seen from the local coordinate system, the air mass experiences a fictitious acceleration (called the Coriolis force) amounting in vector notation to $2\vec{\omega} \times \vec{v}_r$, where $\vec{\omega}$ is the angular velocity of the earth's spin and $\vec{v}_r$ is the vector velocity of the air mass relative to the surface of the earth. (Numerical value = $2\,\omega\, v_r \sin\lambda$; λ = latitude.) This Coriolis force cancels the pressure gradient, giving a resultant velocity along the isobars. In the Northern hemisphere such winds are called "geostrophic" and tend to flow counter-clockwise around a low pressure center and clockwise around a high. This leads to Buys Ballot's Law, discovered empirically by a 19th century Dutch meteorologist, which says that if you stand with the geostrophic wind at your back, the low pressure is to your left. This condition is reversed in the Southern hemisphere.

In the case of "gradient" winds, there is a component of velocity across the isobars, and such winds tend to cross the isobars toward the low pressure area at angles of 10 to 20 deg. The gradient wind is thus stronger than the geostrophic wind around high-pressure areas and weaker around low-pressure areas.

EV-102.1.2 Gusts

DEFN - Wind gusts are turbulence phenomena which may be either horizontal, vertical, or a combination of both. Horizontal gusts (blowing parallel to the ground) are of greater consequence than vertical gusts in the first 30 m above the air-sea interface. Vertical gusts (blowing perpendicular to the ground) are important at elevations of 30 m and higher. The gust period is $2\pi/g$ times the speed of the gust, where g is the acceleration due to gravity. Energy is added by each gust to waves in existence, producing short-crested waves.

Gustiness is a function of the gust factor F . Gust factor G_z/U_z is the ratio of the gust speed to the sustained wind speed U_z at the same elevation z . The gust speed G_z is determined by applying the gust factor to the sustained wind speed. Gust factors vary very little with mean wind speeds. They do, however, vary as a function of elevation above the surface. The decrease in gust factor as elevation increases is given by the following equation where a typical range is 1.0 to 1.6.

$$F_z = F_{10}\left(\frac{z}{10}\right)^{-5/84} = \frac{G_z}{U_z}$$

where,

F_z = gust factor at elevation z

F_{10} = gust factor at 10 m elevation

z = elevation above the surface, m

G_z = gust speed at elevation z , km per hr

U_z = wind speed at elevation z , km per hr

INTER - The peak gust velocity G_z increases as the gust duration decreases. The gust duration of vertical gusts is generally only one-third that of horizontal gusts.

INFL - Wind gusts must be considered for design calculations of maximum wind loading.

EV-102.2 Direction

DEFN - The wind direction is given according to the compass heading of a wind vane corresponding to the direction from which the wind blows. Generally, wind direction varies with time and location.

INTER - Wind direction can be from any azimuthal heading near the earth surface. Wind direction is affected by atmospheric Pressure Variations (EV-101.4).

INFL - Prevailing wind direction could affect alignment of facilities and influences Surfaces Waves (EV-401).

MEAS - Wind direction is expressed in degrees azimuth and is measured with a wind vane.

EV-102.2.1 Prevailing

DEFN - The prevailing wind direction is that direction from which the wind blows more often than from any other during a standard unit of time. Prevailing wind direction may be relatively constant (e.g., trade winds); may vary by season of the year; or may vary with time of day as, for example, day and night, off- and on-shore winds. Prevailing wind direction may or may not correlate with wind velocity.

INTER - The existence of a prevailing wind direction affects structure orientation and design load conditions.

EV-102.2.2 Other Directions

DEFN - In some locations there may be no true prevailing wind and the wind direction at any given time may be the result of nearby atmospheric pressure variations. In gusty winds the direction is likely to change over wide angles. Wind direction changes may occur abruptly with the passing of a storm front.

EV-102.3 Duration and Fetch

DEFN - The wind duration is defined as the length of time t that the wind blows in nearly the same direction over the generating area or fetch. It is measured in hours and can range from one hour to over 100 hours.

The fetch length or fetch is the horizontal distance over which a wind with a reasonably constant velocity and direction blows generating "sea" waves. It is measured in units of nautical miles or statute miles and has a range of 1.6 km to over 1600 km.

In the determination of fetch length, wind speed is assumed constant if variations do not exceed 10 km per hr from the mean. However, wind speed variations of as little as 1 km per hr actually affect results. The wind direction variations must not exceed 30 deg from the mean. A deviation exceeding 45 deg seriously affects results. Fetch limits are delineated by curvature or spreading of isobars, a shift in wind direction, or a discontinuity at a weather front.

INTER - The determination of fetch length is a very subjective process. Since this length together with duration greatly affects the resultant significant wave height and period predicted (EV-401), caution must be exercised in delineating the fetch.

INFL - The length of time that wind blows in a given direction has an affect on ocean surface waves (EV-401).

EV-102.4 Percent Frequency

DEFN - The percent frequency of winds is the percent of the time that the wind blows. This can be calculated for various conditions:

- Winds of any velocity and direction vs. no wind
- Winds of any velocity from a given direction
- Winds of a given velocity from any direction
- Winds of specified velocities and directions

CALC - Percent frequency is calculated from measured wind velocities and/or directions over a standard unit of time. This can be expressed as a distribution of categories of wind speed and/or direction vs. percentage of a standard unit of time.

EV-102.5 Recurrence Interval

DEFN - Recurrence interval is the time between succeeding occurrences of events in the same category. In the case of winds this could be time between winds of certain velocity categories and/or from various directions; and/or for certain durations.

INTER - The recurrence interval of wind speeds, directions, or duration is affected by other properties of the atmospheric environment (EV-100), as, for example, the extent, location, and persistence of Pressure Variations (EV-101.4).

INFL - The recurrence interval determines how often a phenomenon, such as winds of a certain velocity, can be expected during the life of a structure.

CALC - The recurrence interval can be determined from measurements of parameters such as speed, direction, and duration associated with the phenomenon, and may be presented diagramatically as shown by Fig. EV-100-3.

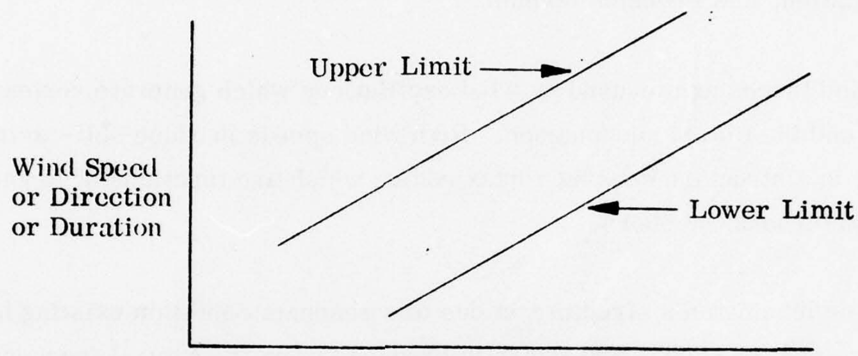

Fig. EV-100-3 Recurrence Interval

EV-102.6 Forces

DEFN - Wind forces are the frictional forces exerted on a structure by the wind due to induced pressure differentials around the structure. A lift force, which is a force normal to the wind, can also develop. Wind forces can generate steady-state, unsteady-state, and dynamic wind loadings on a structure. An equation for the steady-state wind force (see Ref. 3) is

$$F = 0.0113 \, V_{10}^2 \, C_s \, A$$

where,

F = wind force, Newtons (N)

V_{10} = sustained wind velocity at 10 m elevation. km/hr

C_s = Shape coefficient

Beams = 1.5

Sides of buildings = 1.5

Cylindrical sections = 1.0

A = projected area, m^2

The shape coefficient which incorporates drag is a function of object shape, roughness, orientation, and Reynolds number.

Unsteady wind forces are induced by wind oscillations which generate vortex formations and the flutter phenomenon. High wind speeds produce self-excited oscillations in a structure causing vortex eddies which are functions of Reynolds numbers and Strouhal numbers.

Dynamic wind loading on a structure is due to a resonant condition existing between the structure and the wind. Resonance is produced when the natural frequency of the structure coincides with a frequency of the wind possessing considerable energy.

INTER - Wind forces combine with wave forces to produce the total force of weather on the FOF.

INFL - Offshore structures are designed to sustain the effects of static and dynamic wind loading interaction.

EV-102.7 Chill Factor

DEFN - A chill factor is used to adjust ambient air temperature to an effective lower temperature due to the increased heat dissipation effect of wind. As the wind velocity and the humidity (to a lesser extent) increase, the chill factor increases. Standard curves are available which give the effective temperature as a function of ambient air temperature, wind velocity, and humidity.

INTER - Chill factor is of most importance when personnel are involved since the body's metabolism is affected directly by the wind. Equipment which generates heat is affected to a lesser extent -- essentially only by the increased rate at which winds dissipate the heat generated.

INFL - In the design of electrical and electronic equipments and in their packaging and installation, the chill factor should be considered from the standpoint of rate of dissipation of the heat generated.

EV-103 PRECIPITATION

DEFN - Precipitation consists of rain, snow, sleet, hail, and their modifications and is customarily measured in inches per hour. A load occurs due to the additional weight of water, snow, or ice on the structure due to the precipitation. Precipitation intensity-duration-frequency curves are available from the U. S. Weather Bureau. They have a general form as illustrated in Fig. EV-100-4.

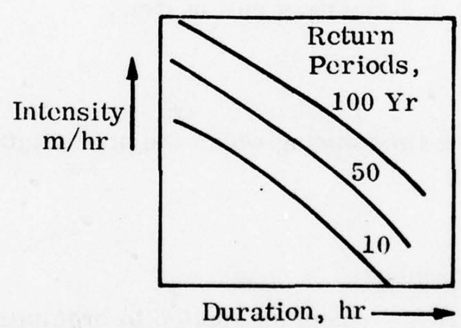

Fig. EV-100-4 Precipitation

These graphs show the probability of occurrence of a particular storm with precipitation of an intensity in millimeters per hour and duration of hours. Precipitation is measured using a rain or snow gauge.

INTER - Precipitation is a function of season, Atmospheric Temperature (EV-101), and location. It affects sea water Salinity (EV-201.1.1) and Sea Ice formation (EV-403).

INFL - The amount of precipitation falling in a site area affects the design of a surface facility. The maximum storm conditions that could prevail dictate design requirements for adequate loading support, drainage, and safety. The amount and form of precipitation which adheres to a structure affects the wind load (EV-102.1) on the structure.

MEAS - Precipitation is ordinarily measured in units of length and time using a scale and timing device in the form of a rain or snow gauge.

EV-103.1 Types

DEFN - Precipitation may occur as hail, mist, rain, sleet, or snow, or mixtures of these.

EV-103.2 Quantities

DEFN - The quantity of precipitation is the amount reaching the surface of the earth at a specified location in a standard unit of time.

EV-103.3 Duration

DEFN - Duration is the time during which the precipitation falls to the surface of the earth.

EV-103.4 Percent Frequency

DEFN - Same as EV-102.4 except as applied to precipitation instead of wind.

EV-103.5 Recurrence Interval

DEFN - Same as EV-102.5 except applied to precipitation instead of wind.

EV-104 VISIBILITY

DEFN - Visibility is a measure of the horizontal distance at which one can recognize a specified object through the atmosphere without the aid of optical instruments. It is measured in units of length.

INTER - Precipitation (EV-103) and Winds (EV-102) affect visibility.

INFL - Structures above the sea surface must be made detectable for relocation and for navigational safety.

EV-104.1 Distance

DEFN - Distance (visibility) is the straight line separation between an object and an observer who can recognize the object.

EV-104.2 Restrictions

DEFN - Fog, haze, smoke, precipitation, clouds, and darkness restrict visibility.

EV-104.2.1 Fog or Haze

DEFN - Fog is a low-level stratus cloud of suspended water particles which reduces visibility to less than 1000 m. Fog is classified into five main types which are (1) radiation, (2) advection, (3) upslope, (4) frontal, and (5) convergent.

Haze consists of fine particulate matter and/or salt spray, and reduces visibility.

INTER - Dissipation of fog is a function of solar heating, wind increase (EV-102.1), or movement of a new cold air mass.

EV-104.2.2 Precipitation

DEFN - See EV-103.

INFL - Visibility decreases as precipitation (as defined in EV-103) intensity increases.

EV-104.2.3 Clouds

DEFN - Clouds are the condensation of water vapor around nuclei of salt particles, ice crystals, and/or smoke and other particles suspended in the atmosphere. The water or ice in a cloud occupies only a relatively small volume of the total opaque image of the cloud. Ten general types of clouds may form and are divisible into four groups of (1) high, (2) medium, (3) low, and (4) clouds with vertical development.

EV-104.2.4 Duration

DEFN - Duration is the time during which visibility conditions fall between specified limits.

MEAS - Duration of visibility in various categories is measured in units of time and length.

EV-104.2.5 Percent Frequency

DEFN - Same as EV-102.4 except applied to visibility instead of wind.

EV-104.2.6 Recurrence Interval

DEFN - Same as EV-102.5 except applied to visibility instead of wind.

EV-105 METEOROLOGICAL PHENOMENA

DEFN - Meteorological phenomena are those atmospheric events which must be considered in the design, construction, and maintenance of fixed ocean facilities. They include such occurrences as hurricanes, waterspouts/cyclones, thunderstorms, lightning, and peak gusts. In addition, the duration and recurrence interval for these extreme events at a particular site are significant.

INTER - Meteorological phenomena are a direct consequence of atmospheric Physical Properties (EV-101), Winds (EV-102), Precipitation (EV-103), and Visibility (EV-104).

INFL - Hurricanes, waterspouts, thunderstorms, lightning, and peak gusts affect the structural design, protection considerations, recovery, and mission success of a fixed ocean facility.

EV-105.1 Hurricanes

DEFN - A hurricane is an intense tropical cyclone in which winds tend to spiral inward toward an eye of low pressure, with maximum surface wind velocities that equal or exceed 121 km per hr (Ref. 4). Other names associated with this type of storm are typhoon and cyclone. Hurricanes are not known to occur within 10 deg of the equator.

In hurricanes and other tropical storms (wind speed ≥ 121 km per hr), the wind velocity and direction changes with both location and time. Thus, a fully arisen sea state never occurs and a fetch with constant wind speed is small. The wave field consists of locally generated "seas" and "swell" from other areas. Bretschneider (Ref. 4) proposed a mathematical model describing the deep-water significant wave height and period at the point of maximum wind generated by a hurricane under steady-state conditions. This allows the significant wave height at any point of the hurricane to be determined graphically once the significant wave height at the point of maximum wind (H_o) is known.

As hurricane waves travel from deep water across the continental shelf into shallower water, the combined effects of bottom friction, refraction, shoaling, continued wind action, and forward speed of the hurricane must be taken into account. In order to do this, effective fetch F_e is calculated in conjunction with the shoaling coefficient K_s, a friction loss parameter A, and a friction factor K_f in successive interactive calculations. Examples of this procedure are given in Ref. 4.

INTER - Hurricanes affect wind speed and direction (EV-102.2), atmospheric pressure (EV-101.4), Precipitation (EV-103), wave height and period (EV-401.6), and fetch (EV-401.1).

INFL - Design wave conditions for a fixed ocean facility should be based on a standard project hurricane (SPH), a probable maximum hurricane (PMH), or a design hurricane.

The deep-water significant wave height, period, and direction are necessary for calculation of maximum wave loadings for design considerations of deep-water structures.

The effect of shallow water on hurricane waves is to alter the significant wave height and period due to the decreased water depth.

MEAS - See EV-101, 102, 103 and 104.

EV-105.2 Waterspouts/Cyclones

DEFN - Waterspouts or whirlwinds are marine counterparts to land-based tornadoes. The strength or violence of a waterspout is a function of the magnitude of the center core pressure drop. The more violent spouts may have an extremely low pressure center (down to 500 mb), associated winds of 370 km per hr, and forward speeds of 45 km per hr or more. There is some question about whether or not these vortex cells suck up water from the ocean's surface into their cores or the moisture present is due to normal atmospheric humidity (see Ref. 1).

INTER - Waterspouts are usually associated with Thunderstorms (EV-105.3) that form in either cold frontal squalls or tropical storms such as hurricanes or typhoons (EV-105.1). Fair-weather weaker waterspouts may form due to convective storms, as many as 30 appearing in a single day.

INFL - Waterspouts have been observed in the Gulf of Mexico, the Florida Atlantic Coast, the Southwest Coastal area, and the North Atlantic. Thus, fixed ocean facilities that are placed in tropical and subtropical waters should incorporate provisions to withstand the high winds associated with waterspouts.

MEAS - See EV-105.1.

EV-105.3 Thunderstorms

DEFN - Thunderstorms are usually associated with movement of cold fronts or other atmospheric instability. A line of vertically developed clouds, cumulonimbus, forms as the result of an overturning of air layers in order to achieve a more stable density stratification.

Thunderstorms are convective storms which rotate about a vertical axis in a cyclonic fashion similar to large-scale cyclones. They obtain their energy from the release of latent heat due to the condensation of water vapor in the rising air currents. They usually measure a few miles in both horizontal and vertical directions and extend from the ground to upwards of 18,000 m. The greater the vertical extent, the greater the energy of the storm. The great stability of the lower stratosphere is the limiting factor in this upward growth.

Thunderstorms are usually of short duration, lasting only 2 hours or so. A period of calm usually follows passage of a thunderstorm. However, this may be followed by renewed storms. Usually the most violent storm systems of winter in the mid-latitudes persist for no longer than 2 or 3 days.

In the summertime, thunderstorms may occur during very warm and humid weather, which is not associated with the passage of a front.

INTER - Thunderstorms invariably produce strong gusty winds (EV-102), extreme turbulence, very strong vertical currents at higher altitudes, violent wind direction shifts (EV-102.2), rapid drops in temperature (EV-101.1), heavy precipitation (EV-103) including snow and hail, and thunder and lightning (EV-105.4).

INFL - As the carrier of gusty winds, heavy precipitation, and lightning, a thunderstorm is a meteorological phenomenon which must be considered in the design of a fixed ocean facility.

EV-105.4 Lightning

DEFN - Lightning is a transient, high-current, electrical discharge due to electric fields in the atmosphere. The lightning flash is composed of component strokes consisting of leader strokes and return strokes. The duration of these strokes is of the order of microseconds, and the flash duration as a whole rarely lasts longer than a second. The time interval between strokes is usually less than 100 milliseconds.

The first stroke is usually branched due to the uneven distributions of point charge in the air. It is also composed of discrete, intermittent steps which cause it to be referred to as a stepped leader. This leader stroke leaves an ionized channel (5 to 20 cm) between the negatively charged cloud formation and the positively charged sea surface. A return stroke forms on the surface carrying positive charge up the channel to neutralize the negative charge. Subsequent dart leaders and corresponding return strokes may continue to form. Peak currents in the return strokes vary from a few to several hundred kA. The highest recorded value was 345 kA. There are other forms of lightning referred to as bead, fork, heat, sheet, ribbon, and ball.

INTER - Lightning is usually associated with Thunderstorms (EV-105.3) and cumulonimbus Clouds (EV-104.2.3). There is some evidence that it precipitates the heavy downpour of thunderstorms by discharging mutually repelling charges on water particles within a cloud, allowing them to coalesce into larger raindrops. Thunder accompanies lightning due to the formation of sound waves from shock waves as a result of the intense heating and expansion of the ionized channel in the air.

INFL - Lightning flashes can occur from cloud to cloud, cloud to air, and totally within a cloud. The lightning flashes from the thunderclouds (cumulonimbus clouds) to the surface are the most concern since electrocution, electrical shorts, fire, and explosion may result. Protection for structures usually consists of a vertical grounded conductor or lightning rod which produces a zone of protection bounded by an imaginary 45-deg conical surface with a radius equivalent to the height of the rod. Electrical transmission lines are protected by earth wires, lightning arrestors, and spark gaps.

CALC - Coulomb's inverse square law and the theory of electrical images are used to calculate the electric field produced at ground level by a charge in a thundercloud.

EV-105.5 Design Storm Conditions

DEFN - Design storm conditions are defined as those which may be expected to occur with a specified frequency during the life of the structure and are usually the most severe conditions that a structure is expected to weather. The design wind speed is calculated using one or more of the following statistical methods: Beard Method, the Gumbel's Standard Skewed Distribution, and the Weibull Distribution Function. The gust speed is then obtained by applying the gust factor. Wind speeds and their corresponding directions are presented in the form of recurrence interval or probability of occurrence graphs. The recurrence interval is defined as the time in years required for a particular event to occur (Ref. 5). The wind data can be obtained from actual site measurements or from wind hindcasts from historical meteorological weather maps. Storms are commonly referred to as "ten year storms" or "one hundred year storms."

INTER - Design storm conditions interrelate with Wind Speeds (EV-102.1), Wind Directions (EV-102.2) and Recurrence Intervals (EV-105.5.3).

EV-105.5.1 Peak Gusts

DEFN - See EV-102.1.2.

EV-105.5.2 Duration

DEFN - Duration is the length of time an event occurs. The time can be measured in hours or days.

INFL - Generally, the longer the duration the greater the possibility of structural damage to the facility.

EV-105.5.3 Recurrence Interval

DEFN - A recurrence interval (as related to meteorological phenomena) or probability of occurrence graph is a statistical tool illustrating the return period in years of a particular maximum design storm event.

INTER - Recurrence intervals are usually associated with the maximum winds (EV-102) and waves (EV-401, 402) that would accompany a maximum storm event (EV-105) such as a hurricane. Data can be obtained from actual site measurements or from hindcasts of historical meterological weather maps.

INFL - A recurrence interval is a factor that must be known to establish realistic criteria for structural design purposes.

CALC - The return period in years of a particular event is plotted along the abscissa versus a design parameter of the particular event such as wind speed or wave height (see Fig. EV-100-5).

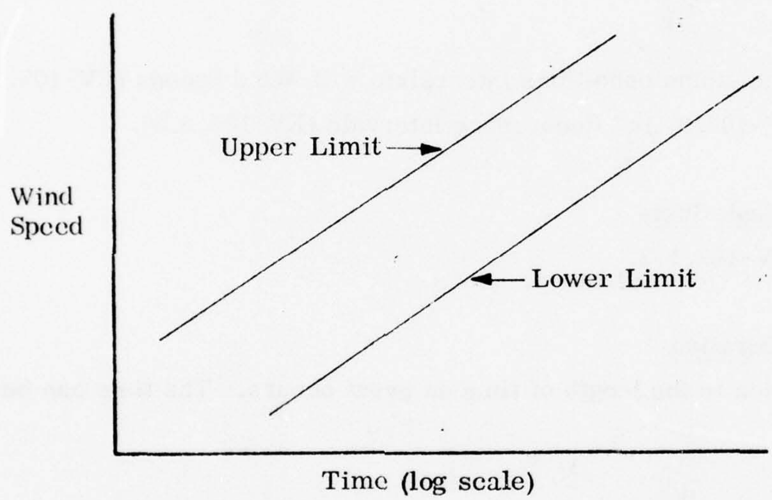

Fig. EV-100-5 Recurrence Interval

EV-200 OCEAN ENVIRONMENT

DEFN - Oceanographic parameters are those parameters or phenomena pertaining to the environment of the ocean below the air-sea interface and above the ocean bottom. These parameters include Physical and Chemical Properties (EV-201), Currents (EV-202), Internal Waves (EV-203), Biological Aspects (EV-204), and Corrosion Aspects (EV-205).

The breakdown structure for the ocean environment is shown as Fig. EV-200-1.

INTER - The physical and chemical properties of the sea affect the Biological Aspects (EV-204) and Corrosion Aspects (EV-205) of the ocean environment.

INFL - Oceanographic parameters affect design, construction, protection, installation, recovery, and mission success.

EV-201 PHYSICAL AND CHEMICAL PROPERTIES

DEFN - Physical and chemical properties of sea water include: chemical, optical, electromagnetic, mechanical, acoustic, and thermodynamic.

INTER - The Chemical (EV-201.1), Mechanical (EV-201.4), and Thermodynamic (EV-201.6) properties affect the Optical (EV-201.3), Electromagnetic (EV-201.3), and Acoustic (EV-201.5) properties of the ocean environment. Major effects of these factors on design of the FOF are likely to be corrosion and biological fouling.

INFL - An understanding of these properties is necessary for proper design, construction, and installation of a FOF. Satisfactory performance of mission requirements also depends on these properties.

EV-201.1 Chemical

DEFN - Sea water consists of 96.5 percent water and 3.5 percent dissolved materials. These dissolved materials are mostly an ionic dispersion of salts, with a minor part consisting of colloids and suspensions.

OCEAN ENVIRONMENT
EV-200

PHYSICAL/CHEMICAL PROPERTIES
EV-201

- 201.1 Chemical
  - 201.1.1 Salinity
  - 201.1.2 Trace Elements
- 201.2 Optical
  - 201.2.1 Turbidity
  - 201.2.2 Extinction
  - 201.2.3 Refraction
  - 201.2.4 Reflection
  - 201.2.5 Solar Radiation
- 201.3 Electromagnetic
  - 201.3.1 Conductivity
- 201.4 Mechanical
  - 201.4.1 Viscosity
  - 201.4.2 Compressibility
  - 201.4.3 Surface Tension
  - 201.4.4 Density and Pressure
- 201.5 Acoustic
  - 201.5.1 Sound Velocity
  - 201.5.2 Sound Absorption
  - 201.5.3 Sound Refraction/Reflection
  - 201.5.4 Sound Scattering/Distortion
  - 201.5.5 Sound Pressure
  - 201.5.6 Ambient Noise
- 201.6 Thermodynamic
  - 201.6.1 Seasonal Variations
  - 201.6.2 Depth Variations
  - 201.6.3 Water Temperature
  - 201.6.4 Thermoclines

CURRENTS
EV-202

- 202.1 Types
  - 202.1.1 Tidal
  - 202.1.2 Inertial
  - 202.1.3 Baroclinic vs. Barotropic
  - 202.1.4 Wind Driven
- 202.2 Stratification
  - 202.2.1 Surface Forces
  - 202.2.2 Mid-Depth Forces
  - 202.2.3 Bottom Forces
  - 202.2.4 Current Drag
- 202.3 *Direction*
- 202.4 Speed
- 202.5 Turbulence
- 202.6 Coherence
- 202.7 Variation
  - 202.7.1 Seasonal
  - 202.7.2 Fluctuations
  - 202.7.3 Decay
- 202.8 Spectrum
- 202.9 Vortex Shedding

INTERNAL WAVES
EV-203

- 203.1 Deep Interface
- 203.2 Shallow Interface

BIOLOGICAL ASPECTS
EV-204

- 204.1 Effects of Marine Biota
  - 204.1.1 Fouling
  - 204.1.2 Fishbite
  - 204.1.3 Boring
  - 204.1.4 Biodeterioration
- 204.2 Variation
  - 204.2.1 Seasonal
  - 204.2.2 Daily
  - 204.2.3 Depth

CORROSION ASPECTS
EV-205

- 205.1 Types

Fig. EV-200-1 Ocean Environment – Breakdown Structure

Water is a chemically simple substance consisting of two hydrogen atoms joined with one oxygen atom. This dipole configuration results in a large dielectric constant which, in turn, results in the great dissolving or associative power of sea water.

Sea water has two unique characteristics – its pH, and the amount of dissolved oxygen.

The pH of sea water is a function of temperature, salinity, photosynthesis and respiration, deposition of carbonate ions, and gaseous exchange with the atmosphere. It usually has a range of 7.8 to 8.3 in the surface water, decreases through a deep-water decomposition zone, and increases slightly in the bottom waters to 7.2 to 7.9. A high value of 9.0 can occur if a high photosynthesis activity is present.

The amount of dissolved oxygen in the ocean waters is a function of temperature and salinity and varies from 5 to 10 ml per liter. Oxygen is extracted from the water by marine life as well as during oxidation for decomposition and corrosion.

INTER - The unique nature of water is responsible for the change in Density (EV-201.4.4) with Temperature (EV-201.6.3), which leads to the formation of the less dense tetrahedral structure of Sea Ice (EV-403) as the density maximum is reached. It also affects the meteorological processes (EV-105) by acting as a great heat sink due to the high specific heat capacity of water. The high Surface Tension (EV-201.4.3) of sea water is responsible for the initial generation of Waves (EV-401) by Winds (EV-102).

INFL - Sea water composition affects the type of materials that may be used in the ocean environment due to its inherent corrosive aspects particularly at the ocean/atmosphere interface.

EV-201.1.1 Salinity

DEFN - Salinity is a measure of the number of grams of dissolved salts in a kilogram (kg) of sea water. The average is $35^{o}/_{oo}$ (expressed as parts per thousand or per mille). The typical range is 33 to $38^{o}/_{oo}$. High values are usually 43 to $45^{o}/_{oo}$, and low values are 0.5 to $1^{o}/_{oo}$. The major components are the cations (sodium, potassium, magnesium, calcium, and strontium) and the anions (chlorine, bromine, fluorine, sulphate, bicarbonate, and boric acid). The major composition of sea water for a total salinity of $35^{o}/_{oo}$ is listed in Table EV-200-1.

Table EV-200-1

MAJOR COMPOSITION OF SEA WATER FOR A TOTAL SALINITY OF $35^{o}/_{oo}$ (Ref. 5)

Cations	gr/kg	Milli-equivalents per kg	Anions	gr/kg	Milli-equivalents per kg
Sodium	10.752	467.56	Chlorine	19.345	545.59
Potassium	0.39	9.98	Bromine	0.066	0.83
Magnesium	1.295	106.50	Flurine	0.0013	0.07
Calcium	0.416	20.76	Sulphate	2.701	56.23
Strontium	0.013	0.30	Bicarbonate	0.145	-
	Total	605.10		Total	602.72

The major salts in sea water of $35^{o}/_{oo}$ and 20°C are given in Table EV-200-2.

Table EV-200-2

MAIN COMPONENTS OF SEA WATER IN THE FORM OF SALTS PER CUBIC METER OF SEA WATER OF $35^{o}/_{oo}$ SALINITY AND 20°C) (Ref. 5)

Component	Weight (kg)
$NaCl$	28.014
$MgCl_2$	3.812
$MgSO_4$	1.752
$CaSO_4$	1.283
K_2SO_4	0.816
$CaCO_3$	0.122
KBr	0.101
$SrSO_4$	0.028
H_2BO_3	0.028

INTER - Salinity is affected by evaporation, Precipitation (EV-103), ice formation (EV-403) or melting, and Currents (EV-202), and it in turn affects many oceanographic parameters. Among these are:

- Sea Water Density (EV-201.4.4)
- Sea Water Viscosity (EV-201.4.1)
- Sea Water Thermal Expansion (EV-201.6.3)
- Sea Water Compressibility (EV-201.4.2)
- Sea Water Electrical Conductivity (EV-201.3.1)
- Sea Water Electrical Permittivity (EV-201.3.2)
- Light Extinction in Sea Water (EV-201.2.2)
- Light Refraction in Sea Water (EV-201.3.2)
- Sound Velocity in Sea Water (EV-201.5.1)
- Sound Refraction in Sea Water (EV-201.5.3)
- Sound Absorption in Sea Water (EV-201.5.2)
- Sea Water Surface Tension (EV-201.4.3)

INFL - Salinity determines the corrosive potential of the oceanic environment on fixed ocean facilities.

MEAS - Salinity (S) is usually measured as a function of chlorinity (Cl) or alkalinity (A) and is determined by instrumentation which electrically measures conductivity or resistivity. The relationship between salinity and chlorinity is

$$S^{o}/_{oo} = 0.030 + 1.8050 \, Cl^{o}/_{oo}$$

The relationship between alkalinity, salinity, and chlorinity as derived from conductivity measurements is

$$A = 0.068 \, S^{o}/_{oo} = 0.123 \, Cl^{o}/_{oo}$$

CALC - The refractive index of sea water decreases with decreasing salinity and increasing temperature. This relationship is used to determine salinity by means of refractometer measurements of sea water. Salinity may be calculated also from conductivity measurements.

EV-201.1.2 Trace Elements

DEFN - See EV-201.1.1.

EV-201.2 Optical

DEFN - Optical properties of sea water are those properties which determine the propagation, extinction, and refraction/reflection of natural light from the sun and the sky and artificial light in the ocean. Parameters affecting optical properties of sea water are turbidity, extinction, refraction, and reflection.

INTER - The optical properties of sea water are interrelated with other properties as, for example, its electrical permittivity.

INFL - Practical applications of sea water optical properties are manifested in underwater visibility, photography, and television.

MEAS - Optical properties are determined using beam transmittance meters, scatterance meters, irradiance meters, and radiance meters. (See EV-201.2.1, EV-201.2.2, EV-201.2.3 and EV-201.2.4.)

EV-201.2.1 Turbidity

DEFN - Turbidity is a characteristic of the optical property of sea water which causes light to be scattered and absorbed rather than transmitted through the sea water. Turbidity in water is caused by the presence of suspended matter such as clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms.

INTER - The introduction of a structure in the marine environment may change the turbidity due to a change in the amount of particulates (EV-201. 1) and a change in water flow patterns (EV-202). Also, a decrease in turbidity could increase biological activity (EV-204) around the structure.

INFL - Turbidity inhibits vision by man and the performance of the submersible optical instruments and TV cameras that may be involved during construction and maintenance.

MEAS - An index of the degree of turbidity can be determined with an alpha meter.

EV-201. 2. 2 Extinction

DEFN - A beam of light passing through sea water is gradually weakened in intensity. This reduction in intensity is called extinction. It is caused by absorption of light in the sea water and by scattering of light by both the water itself and by suspended particles in the water. The extinction is characterized in practice by an extinction coefficient k which is dependent upon the wavelength of light and upon the clarity of the water. It varies from about 0. 016 per meter at 50μ wavelength in pure sea water to 0. 05 per meter in turbid coastal water. Detailed measurements of the extinction coefficient over the whole spectral region from ultra violet to infrared have been made and published by a number of investigators (Ref. 6).

INTER - Turbidity (EV-201. 2. 1) has a large effect on the magnitude of the extinction coefficient. The extinction coefficient is large when turbidity is high. Salinity (EV-201. 1. 1) has an affect on the magnitude of the extinction coefficient of 1 to 2 percent.

INFL - The extinction of light in sea water causes sunlight penetrating the water to undergo changes in intensity and spectral content. The long (infrared) and short waves (ultra violet) are filtered out almost at once, so that the light soon takes on a bluish-green color. The remaining light is greenish in pure sea water and yellowish-green in turbid water. Radiation from the sun incident in the surface of clear sea water falls to less than 1.5 percent of its intensity at the surface on passage to a depth of 100 meters. The effect is greater in turbid water.

MEAS - The reduction in light intensity is measured with photoelectric sensors, while extinction coefficients are measured with accurately filtered spectrobolometric sensors.

CALC - The magnitude of the extinction coefficient determines the intensity of light after passage through the water of a distance x by the formula

$$I_x = I_o e^{-kx}$$

where,

I_x - light intensity at depth or distance x
I_o = initial light intensity at surface or source
k = extinction coefficient as a function of a particular wavelength, typical values range from 0.05 to 0.75 m^{-1}
x = depth below surface or distance from source, m

EV-201.2.3 Refraction

DEFN - Refraction is the bending of light rays that occurs upon their passing through the air-sea interface. The amount of bending is determined by Snell's law, which states that the sine of the angle of incidence is equal to the product of the index of refraction and the sine of the angle of refraction. Figure EV-200-2 is an illustration of Snell's law.

INFL - Refraction affects the transmission of light across the air-sea interface by bending light rays and distorting images. Refraction must be considered in the design of lenses and the application of underwater imaging equipment such as cameras and TV.

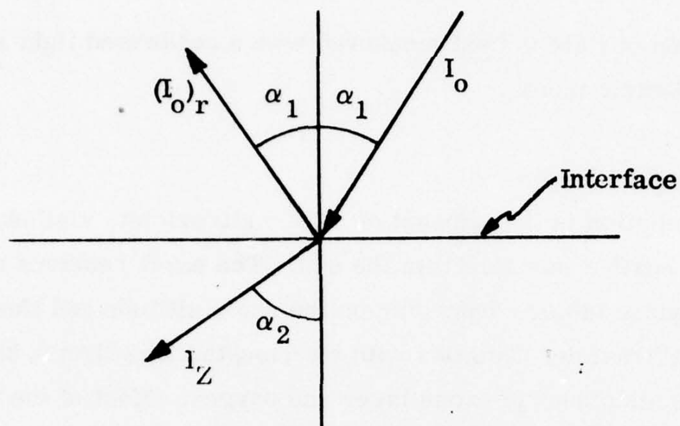

Fig. EV-200-2 Light Refraction and Reflection in the Ocean

INTER - Refraction relates weakly to the chemical properties of sea water (EV-201. 1).

MEAS - The refractive index of water is measured by means of an optical refractometer.

EV-201. 2. 4 Reflection

DEFN - Light waves are reflected as well as refracted at the air-sea interface. The amount of reflection depends upon the angle of incidence and scale of roughness of the sea surface. Light reflection is a function of the sun's altitude for natural light and also a function of sea state. Reflection at a surface is illustrated by Fig. EV-200-2.

INTER - Reflection affects viewing conditions both above and under the surface of the sea. Reflection effects must be considered in the design of lenses and the application of undersea viewing equipment, lights, and photography.

INFL - Reflection relates weakly to the chemical properties of sea water (EV-201. 1) and to Surface Waves (EV-401).

MEAS - Reflection of light is best measured with a calibrated light source and a sensitive photoelectric meter.

EV-201.2.5 Solar Radiation

DEFN - Solar radiation is that amount of light – ultraviolet, visible, and infrared – that reaches the earth's surface from the sun. The earth receives an average of 1 kilowatt per square meter, depending on the sun's altitude and the distance between sun and earth. Ultraviolet radiation with wavelengths less than 0.29μ is completely attenuated by the atmospheric ozone layer and oxygen. Most of the visible light frequencies are reduced very little in passing through the atmosphere. The greatest amount of reduction and selective absorption is in the infrared region of light frequencies.

CALC - Solar radiation is measured in units of microns (μ) equivalent to 10^{-4} centimeters. Other units of measurement and their relationships are given below.

1 micron (μ) = 10^{-4} cm

1 millimicron ($m\mu$) = 10^{-7} cm

1 angstrom (Å) = 10^{-8} cm

The wavelengths of the three parts of the solar radiation spectrum are

ultraviolet	$< 0.36\mu$
visible	0.36 to 0.78μ
infrared	$> 0.76\mu$

INTER - The total short-wave solar radiation (I_O) reaching the sea surface is composed of direct radiation (I_S) and diffuse radiation (I_D). The ratio between these two components varies considerably according to the sun's altitude, cloudiness conditions (EV-104.2.3), and turbidity of the atmosphere (EV-104).

Solar radiation affects the albedo of the sea surface. The albedo of the sea surface (R) is a measure of its total reflectivity and is a function of the ratios of direct, diffuse, and back radiation reaching the sea surface. The back radiation is that part of the underlight which is refracted back through the air-water interface. In addition to the factors mentioned above, the albedo is a function of the Turbidity (EV-201.2.1) of the water.

INFL - Visual measurement techniques are influenced by the amount and characteristics of solar radiation reaching the ocean.

EV-201.3 Electromagnetic

DEFN - The electromagnetic properties of sea water consist of its conductivity, permittivity, and permeability; magnetic fields may be present also.

INTER - The electromagnetic properties of sea water may be affected by its Chemical (EV-201.1) and Thermodynamic (EV-201.6) properties, and in turn can affect its Optical (EV-201.2) properties and Corrosion Aspects (EV-205).

INFL - Electrical properties, through their influence on corrosive effects, restrict the choice of materials usable in ocean structures.

EV-201.3.1 Conductivity

DEFN - The electrical conductivity of sea water is characterized by the water's ability to conduct electrical currents. The average conductivity of sea water is about 4 mho/m, and the conductivity may vary from 2 mho/m to 5 mho/m depending on temperature and salinity.

INTER - Conductivity relates to Salinity (EV-201.1) and Trace Elements (EV-201.2) since conductivity is a direct function of these chemical constituents. It also relates as a weak function which affects Optical Refraction (EV-201.2.3) and Sound Velocity (EV-201.5.1).

INFL - The determination of salinity in sea water can be accomplished by means of measurement of conductivity, which enters into the computation of salinity. As a practical design consideration, conductivity affects the grounding and leakage currents of submarine cables and electrical apparatus.

MEAS - Conductivity of sea water is measured by means of an electrical conductivity bridge, or by an inductor that uses water as a one-turn coupling between the primary and secondary of a transformer.

EV-201.4 Mechanical

DEFN - The mechanical properties of sea water include viscosity, compressability, surface tension, density, and pressure.

INTER - The mechanical properties of water are directly related to other physical and chemical properties and interrelate with wave generation by wind forces (EV-401), acoustic propagation (EV-201.5), and the characteristics of current flow (EV-202).

INFL - Wind-driven waves and surface currents are influenced by the viscosity, density, and surface tension through the effects of wind stress on the surface and eddy coefficients in horizontal flow fields. The velocity of sound and the propagation of sound are strongly influenced by compressability and density, as well as other physical and chemical properties of sea water.

MEAS - Measurement of the mechanical properties of sea water is discussed separately below.

EV-201.4.1 Viscosity

DEFN - In fluids in motion there is a shear stress that is proportional to the velocity gradient. The proportionality factor is a measure of viscosity.

INTER - The coefficient of viscosity is a function of Water Temperature (EV-201.6.3) but is little affected by Salinity (EV-201.1.1). Viscosity interrelates with wind stress surface currents (EV-202.1.4) and waves (EV-401.)

INFL - While the coefficient of molecular viscosity is essentially constant, eddy viscosity varies with both stratification of density and the speed of flow. This affects the shear stress in the water caused by currents and the typically turbulent flow. Because eddy viscosity is large compared with molecular viscosity, the latter has little importance in dynamic processes in the sea.

MEAS - The determination of horizontal eddy coefficients is obtained from the rate of spread of dye markers or clusters of floats.

EV-201.4.2 Compressibility

DEFN - Compressibility is the rate of change of volume with respect to pressure per unit volume. The coefficient of compressibility K is defined by

$$K = -\frac{1}{V}\frac{\Delta V}{\Delta P}$$

where,

K = coefficient of compressibility
V = sample volume, m^3
ΔV = change in volume, m^3
ΔP = change in pressure, kg/m^2

The velocity of sound is inversely proportional to the square root of compressibility. In high-intensity sound pressure fields, the variation in compressibility causes non-linear effects in sound propagation.

INTER - Compressibility decreases with increases in Pressure (EV-201.4.4), Water Temperature (EV-201.6.3), and Salinity (EV-201.1.1).

EV-201.4.3 Surface Tension

DEFN - Surface tension is a property of all liquids resulting from molecular forces. It causes the liquid to approach minimum volume for a given surface area and is displayed in the characteristic form of liquid drops, capillary action, and certain properties of floating bodies. In water, the surface tension is dependent upon the temperature and salinity.

INTER - Surface tension is reduced by Water Temperature (EV-201.6.3) and increased by Salinity (EV-201.1.1). Impurities always lead to a reduction in surface tension.

INFL - Surface tension is of minor importance in the generation of waves by wind stress. Surface tension is of considerable importance in the rise of water in small-bore tubes and the wetting of surface at the air-water interface. Surface tension affects the rate at which liquids penetrate a porous material such as wood or concrete (capilliary action).

MEAS - Surface tension is measured in the laboratory by means of a clean platinum frame and a chemical balance.

EV-201.4.4 Density and Pressure

DEFN - Density is the mass of a given volume. Due to its salt content, sea water is denser than pure water by about 2.5 percent but the density depends on salinity, temperature, and pressure. Pressure is the force per unit area in a fluid, exerted equally in all directions. The magnitude of pressure in the ocean depends on depth.

INTER - Sound velocity (EV-305.4) is a function of density and, therefore, of pressure, since density varies as a function of pressure. The density of sea water interrelates with wind stress resulting from the friction of air moving over the surface of the water, causing Wind-Driven Currents (EV-202.1.4) and Waves (EV-401). Pressure increases with depth and interrelates with Thermodynamic (EV-201.6) properties of water.

INFL - Sound velocity is inversely proportional to the square root of density and varies with depth due to the effect of pressure. Pressure affects the heat capacity of sea water, causing a reduction in heat capacity as pressure increases. Pressure influences the design of submarine hulls and pressure vessels because pressure increases linearly with depth.

MEAS - The usual method for determining density is by calculation from temperature, salinity, and pressure. It can also be determined from measurement of the index of refraction. Pressure is measured by means of a calibrated pressure gauge. Pressure is not constant everywhere at the same depth, mainly as a consequence of the non-uniform properties of sea water, particularly in regard to temperature and salinity.

EV-201.5 Acoustic

DEFN - Acoustic properties are those characteristics of sea water which affect the production, transmission, reception, and utilization of mechanical energy in the form of pressure variations known as underwater sound.

INTER - Acoustic properties of sea water are changed by three major effects – Temperature (EV-201.6.3), Pressure (EV-201.4.4), and Salinity (EV-201.1.1).

INFL - Acoustic properties are important in the design of subsea instrumentation and sensors for probing the ocean depths, locating objects, investigating seafloor sediments, and communication.

EV-201.5.1 Sound Velocity

DEFN - Sound velocity in sea water (C) is the rate of travel of sound waves and has units of meters per second (m/sec). A typical sound velocity in sea water is found to be 1463.0 m/sec.

INTER - Sound velocity is dependent on Water Temperature (EV-201.6.3), depth (pressure) (EV-201.4.4), and Salinity (EV-201.1.1). These dependencies are illustrated in Figs. EV-200-4, -5 and -6. Sound velocity increases with temperature at about 4.5 m/sec/°C, with depth at 1.70 m/sec/100 m, and with salinity at 1.3 m/sec/ one-thousandth part increase in salinity.

Near the surface salinity and temperature are controlling factors, and the velocity decreases as these factors decrease. Below approximately 1500 m, pressure begins to be the controlling factor and the velocity increases with depth.

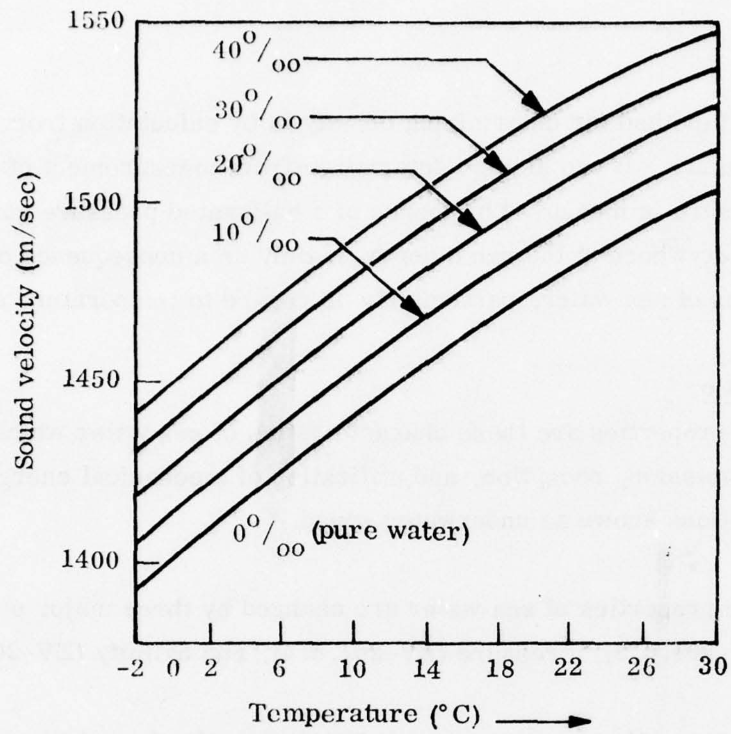

Fig. EV-200-4 Sound Velocity vs. Temperature (P = 1 Atm)
(From Ref. 6)

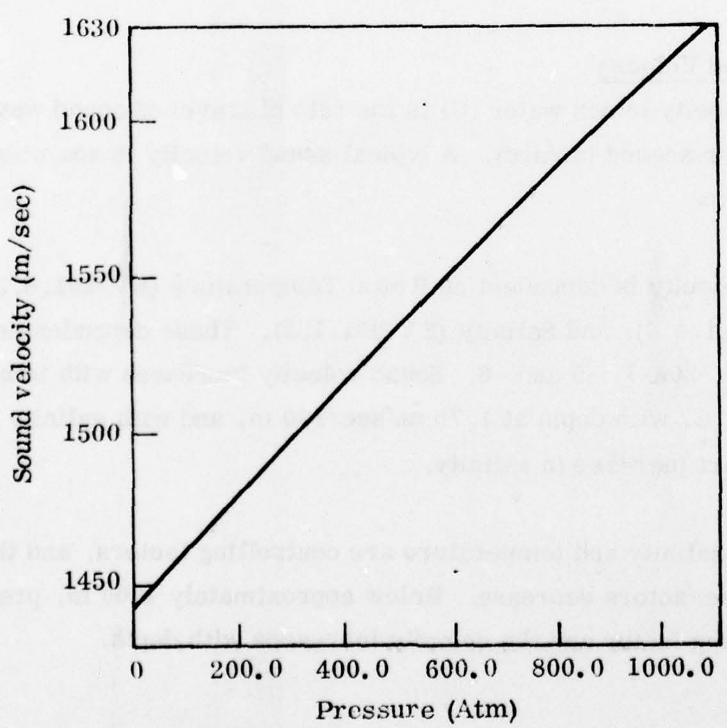

Fig. EV-200-5 Sound Velocity vs. Pressure (S = 35°/oo, T = 0°C)
(From Ref. 6)

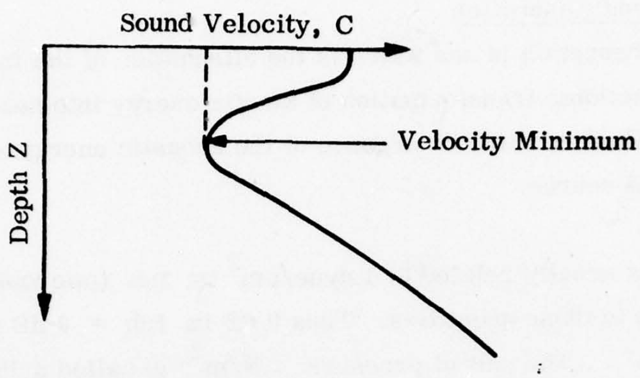

Fig. EV-200-6 Sound-Velocity/Depth Profile

INFL - The variation of sound velocity as a function of temperature, salinity, and pressure is an important phenomenon that must be considered when utilizing acoustic instrumentation.

MEAS - Sound velocity varies from 1450 to 1570 m/sec and can be measured with a sound velocimeter or bathythermographs.

CALC - Sound velocity as a function of temperature, depth, and salinity can be calculated from a set of empirical tables such as Wilson's Tables or the following empirical formula:

$$C = 1449 + 4.6\,t - 0.055\,t^2 + 0.0003\,t^3 + (1.39 - 0.012\,t)(s - 35) + 0.017d$$

where,

- C = sound velocity, m/sec
- t = temperature, °C
- s = salinity, $^o/_{oo}$
- d = depth of measurement, m

EV-201.5.2 Sound Absorption

DEFN - Sound absorption in sea water is the attenuation of the intensity I of sound energy due to frictional transformation of kinetic energy into heat as a result of the viscosity of the fluid, and the divergence of the acoustic energy as a function of the distance from the source.

Sound intensity is usually related to 1 dyne/cm^2 or $1\mu b$ (microbar) and given in decibels relative to those quantities. Thus 0 dB re $1\mu b$ = 0 dB re 1 dyne/cm^2 = -20 dB re 1 N/m^2 . The unit of pressure 1 N/m^2 is called a Pascal, and a common measure of sound intensity is dB relative to $1\mu Pa$. Thus 0 dB re $1\mu b$ is equal to 100 dB re 1μ Pa. (N = Newton, the mks unit of force.)

Low-frequency or long-wavelength sound travels further than high-frequency or short-wavelength sound because it is absorbed less. However, high-frequency sound gives better resolution for echo sounding purposes.

Actual absorption in sea water is somewhat less than predicted by the previous equations due to the scattering effects of dissolved gas or air bubbles in the environment and plant and animal particles.

INTER - Sound absorption is influenced by the sea water molecular Viscosity (EV-201.4.1), Sound Velocity (EV-201.5.1) in sea water, the sea water Density (EV-201.4.4), and the chosen operational frequency.

INFL - Sound absorption must be considered in selecting instrumentation with a frequency that is compatible with the requirements of a particular task.

MEAS - Measurements of sound absorption have been made several ways, the most common being the transmission of sinusoidal pulses transmitted in sea water between two calibrated hydrophones separated by a known distance. An alternate approach is to measure the local salinity and water temperature and calculate the attenuation coefficient as given in the following paragraph.

CALC - The equation defining sound intensity is

$$I = I_o e^{-\alpha x}$$

where,

I = sound intensity at a distance x from the source

I_o = initial sound intensity at the source

e = base of natural logarithm, 2.718

α = absorption coefficient, m^{-1}

x = geometric distance from source, m

The absorption coefficient is a measure of the absorption qualities of sea water, and has been defined by Stokes as

$$\alpha = \frac{16\pi^2\mu}{3\lambda^2\rho C} = \frac{16\pi^2\mu}{3\rho C^3} f^2$$

where,

α = absorption coefficient, m^{-1}

π = 3.1416

μ = dynamic coefficient of molecular viscosity, kg - sec/m^2

λ = wavelength, m

C = propagation velocity of sound, m/sec

ρ = sea water density, kg/m^3

f = operating frequency

The following equation was developed by Schulkin and Marsh (Ref. 7) from a large data set for frequencies between 2 and 25 kHz.

$$\alpha = \frac{1.86 \times 10^{-2} S F_T F^2}{F_T^2 + F^2} + \frac{2.68 \times 10^{-2} F^2}{F_T} \text{ dB/kyd}$$

where,

S = salinity $^o/_{oo}$

F = operation frequency in kHz

F_T = $21.9 \times 10^6/(T)$

T = temperature in degree Kelvin (above absolute zero)

EV-201.5.3 Sound Refraction/Reflection

DEFN - Sound refraction is the bending of propagation paths of sound in the ocean caused by variations in the temperature, salinity, and pressure in the water. Reflection is the turning back of propagated sound at the air-sea interface, by the sea floor, or by an object in the water. Refraction and reflection are governed by Snell's laws. Compare with light refraction and reflection (EV-201.2.3 and EV-201.2.4).

INTER - The refraction of sound in the ocean is caused by changes in the velocity of sound in the vertical water column through which the sound is propagating. Reflection is caused by differences in the specific acoustic impedance between water and air at the air-sea interface, between water and the soil at the bottom, and between water and given objects in the water.

INFL - The refraction of sound is a critical factor in the propagation of sound over long distances in the deep ocean. Refraction and reflection influence the propagation of sound due to air-surface reflection, bottom reflection, and refraction of the propagated wave. Reflection is the basis for detection and ranging by means of sonar.

MEAS - Refraction is determined from the sound velocity profile in the water column. The coefficient of reflection at a surface can be measured as the ratio of reflected sound intensity to the incident sound intensity.

EV-201.5.4 Sound Wave Scattering/Distortion

DEFN - Sound wave scattering (reverberation) is the diffusion of sound by discontinuities in the ocean. It is accomplished by the sea surface, ocean floor, and suspended objects in the ocean, which usually have dimensions smaller than the wavelength of the impinging sound.

INTER - The sea surface loss is a function of sound frequency and wave Height (EV-401.6.1). The bottom-scattering effects are due to the grazing angle and the acoustic frequency reflecting off the seafloor microrelief. Suspended objects include those that are solid or gaseous, living and nonliving. Air bubbles, marine organisms, and other suspended particles are the main source of sound scattering from suspended objects. The effects of air bubbles are quite complex due to compression and resonance phenomena. The phenomenon of the deep scattering layer (DSL) is caused by the marine organisms.

INFL - Reverberation or ringing due to the scattering of sound waves from rough objects back towards the source greatly affects sonar. Distortion of sound waves is caused by overlapping of arrivals. Electronic resolution by timing or directivity is required to reduce the problem.

MEAS - Measurements of sound wave scattering/distortion can be made by using an active source to excite the in situ discontinuities and analyzing the received/recorded signal. These measurements generally will have to be taken over an extended period of time in the desired area and the rms value determined because reverberation levels change with time and place.

EV-201.5.5 Sound Pressure

Shock waves are pressure pulses produced by underwater explosions and characterized by an initial sharp rise in pressure, an exponential decay, then followed by successively smaller pulses caused by the pressure oscillations created by the gas bubbles.

INTER - Sound pressure depends upon water Density (EV-201.4.4) and velocity of sound (EV-201.5.1).

INFL - An understanding of sound pressure in sea water is basic to an understanding of sound propagation in the ocean.

The pressure due to the shock wave resulting from explosions underwater may be significant in terms of ocean engineering considerations. For example, the sound pressure due to 1 lb of TNT at a distance of 1 meter is approximately 4.8×10^7 N/m^2 and decays exponentially with a time constant of about 100μsec. The characteristics of the pulse vary with depth and with distance from the explosion (see Ref. 8).

MEAS - The sound pressure is measured in terms of $dynes/cm^2$ which is 1μb, where the quantity $1\mu b = 10^{-6}$ bar. In mks units 1 $dyne/cm^2$ is equal to 10^{-1} Newton/ $meter^2$.

CALC - Given an acoustic intensity I, the rms acoustic pressure P is given by

$$P = \sqrt{I \rho C}$$

where,

- I = sound intensity
- ρ = density, kg/m^3
- C = velocity of sound, m/sec

EV-201.5.6 Ambient Noise

DEFN - Ambient noise is the naturally occurring background noise in the ocean environment due to barometric and thermal variations, marine life, sea state, machinery (shipping, subsea operations, etc.), and seismic disturbances. Typical ambient noise levels are given in Ref. 5.

Pressure/temperature variations of the fine microstructures of the ocean produce ambient noise. Marine life noise is produced by invertebrates, fish, and marine mammals in the ocean. These effects include altering the signal-to-noise ratio, emitting false signals, and attenuating and reverberating sound signals due to their acoustically opaque bodies.

Sea surface conditions and the sea state affect the reflection and refraction of sound from the air-sea interface. Rain noise and sea surface noise due to waves usually predominates in the deep ocean. The frequency of this noise ranges from 100 Hz to 50 kHz and increases with sea state. Knudsen curves can be used to approximate this increase.

Seismic noise originates from subsea seismic disturbances such as earthquakes, landslides, and volcanic eruptions.

Acoustic noise can be generated due to vortex shedding in the wake created behind a cylinder or cable in a transverse fluid flow.

INTER - Ambient noise in the sea is affected by Pressure (EV-201.4.4) and Water Temperature (EV-201.6.3) variations, sea state (EV-401), Meteorological Phenomena (EV-105), and Biological Aspects (EV-204).

INFL - In general, ambient noise levels are not significant except in terms of the design of sonar systems for use in shallow water and passive acoustic surveillance systems.

Low frequency (< 1.0 kHz) ambient noise levels produced by sea state conditions (rain and waves) are high and will generally hamper underwater acoustic work.

MEAS - Measurements of ambient noise are made by taking quantitative data at the desired site, using sonar. These data are analyzed over time and frequencies of interest to obtain an ambient noise level for the site.

EV-201.6 Thermodynamic

DEFN - The thermodynamic properties of sea water include depth variations and seasonal water temperature variations and adiabatic effects such as potential temperatures (Ref. 9).

EV-201.6.1 Seasonal Variations

DEFN - Seasonal variations are the changes in the thermodynamic properties, depth (pressure), and temperature, of the ocean environment with the season of the year.

INTER - The seasonal variations in thermodynamic properties affect the ocean's Optical (EV-201.2), Electromagnetic (EV-201.3), Acoustic (EV-201.5) properties, Currents (EV-202), Biological Aspects (EV-204), Corrosion Aspects (EV-205), and Ice (EV-403), and are affected by certain atmospheric parameters (EV-100).

INFL - Seasonal variations of thermodynamic properties must be considered in the design of facilities.

EV-201.6.2 Depth Variations

DEFN - Thermodynamic factors, pressure, and temperature vary as a function of depth.

Inter-pressure (EV-201.4.4) increases with depth; temperature (EV-201.6.3) decreases with depth from the surface to about 1000 meters and then is fairly constant at greater depths.

INFL - The depth at which a structure is placed exerts major influence on design.

MEAS - Measurements of pressure and temperature are made at various intervals of depth to provide characteristic curves.

EV-201.6.3 Water Temperature

DEFN - Temperature (T) in the ocean is measured in degrees centigrade (°C) and varies with location and time. The temperature range is relatively small in the open ocean having values of -1.8° to 30 °C. Below approximately 1000 m it remains fairly constant, ranging from about 4° to 12 °C.

INTER - Temperature affects most properties in the ocean including:

- Sea Water Density (EV-201.4.4)
- Sea Water Compressibility (EV-201.4.2)
- Sound Velocity in Sea Water (EV-201.5.1)
- Sound Refraction in Sea Water (EV-201.5.3)
- Sound Absorption in Sea Water (EV-201.5.2)
- Sea Water Molecular Viscosity (EV-201.4.1)
- Sea Water Surface Tension (EV-201.4.3)
- Electrical Conductivity of Sea Water (EV-201.3.1)
- Light Refraction/Reflection in Sea Water (EV-201.2.3 and EV-201.2.4)
- Light Extinction in Sea Water (EV-201.2.5)
- Growth of Sea Ice (EV-402)

INFL - Sea water temperature has little effect on a FOF due to the relatively minor range of values, but is of greater consequence for instrumentation measurements.

MEAS - Temperature in the ocean can be measured with reversing thermometers, bathythermographs, or thermistors. A reversing thermometer measures the in-situ temperature of one point in space and time by the collection and retrieval of a water sample from depth. The instrument is lowered, a collecting bulb flips over trapping a water sample, and the temperature of the sample is read at the surface. The in-situ temperature is different from the temperature read on the surface due to the expansion of sea water.

A bathythermograph gives continuous temperature readings to 0.1°C accuracy. The temperature is related to the vapor pressure changes of the liquid xylene as a function of temperature.

Thermistors are the most widely used temperature measurement devices today.

CALC - Temperature is electronically measured using solid-state semiconductors with a resistance which is related to temperature by an equation of the form

$$R = A e^{B/T}$$

where,

R	=	semiconductor resistance in ohms
A&B	=	constants which are characteristic of the semiconductor material
e	=	base of natural logarithm, 2.718
T	=	temperature in °C

This relationship is shown in Fig. EV-200-7. Thermistors equilibrate almost instantaneously, thereby enabling continuous readings. Resolution is typically 0.001°C or better.

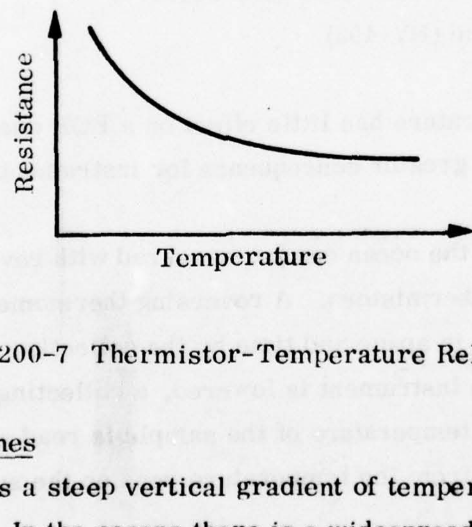

Fig. EV-200-7 Thermistor-Temperature Relationship

EV-201.6.4 Thermoclines

DEFN - A thermocline is a steep vertical gradient of temperature in an otherwise gently graded sounding. In the oceans there is a widespread permanent thermocline that comes and goes with the seasons referred to as a "seasonal theomocline" (Ref. 9).

INTER - Internal waves may be generated at a thermocline.

INFL - Temperature-depth profiles and seasonal thermocline structures affect the basic thermohaline circulation in the world's oceans. This phenomenon could provide a source of energy if suitable structure/systems are placed in the ocean to take advantage of the known temperature gradients.

EV-202 CURRENTS

DEFN - An ocean current is an identifiable water mass, moving with respect to the ocean as a whole. Surface currents develop as a result of wind forces on the surface. The mechanism by which the wind exerts force on the surface is complex. The ocean's response to this force is influenced by a number of factors including frictional interaction, rotation of the earth, the presence of continental barriers, and the properties of the water itself.

Ocean currents in the deep ocean below the thermocline or pynocline are called mid-depth or deep-water currents.

Bottom currents are local movements of the water across the ocean floor. Along the continental shelf and in submarine canyons turbidity currents, caused by submarine landslides, are the fastest currents known. In at least one instance, a turbidity current was calculated to have traveled at 50 knots down the continental shelf off eastern Canada.

INTER - Meteorological Phenomena (EV-105) and the Atmospheric Environment (EV-100) contribute directly to ocean currents. For the ocean engineer, data pertaining to current velocities and distributions (EV-202.4) are used to determine environmental loading.

Technical data concerning mid-depth currents are rare and the coverage of the ocean areas relative to measurements is very limited. Measurements in the vicinity of any planned FOF will be required.

Bottom current measurements should be made in the general area of a planned FOF. Geologic information (EV-300) should be evaluated to provide useful data on the probable occurrence of Turbidity Currents (EV-309.3).

INFL - Ocean currents affect forces on ocean structures, anchor lines, drifting of surface and submarine craft, and influence the conduct of operations at sea.

Forces due to mid-depth and bottom currents must be considered in the design of structures that extend into deep water.

MEAS - Currents are measured in units of length and time by a current meter.

CALC - The presence of the earth's magnetic field in moving water causes weak electric currents in the water which offer a means of calculating the velocity of ocean currents.

EV-202.1 Types

DEFN - Ocean currents are (1) wind driven, (2) density gradient driven, and (3) tidal or planetary body driven. These effects are found to work together to develop the many types and the unique characteristics of the ocean currents found in the world.

EV-202.1.1 Tidal

DEFN - Tidal currents represent the motion of water in progressive or standing tidal waves which on coasts and islands are recognized by the rise and fall of the tide. Tidal currents are different in character in different areas. Complications may arise because of the configuration of the coast, and the tidal currents may attain great velocities in straits or sounds. Current speed and direction continuously change and the current completes one rotation with each tidal period.

INTER - Tidal currents are the response of the oceans to the gravitational pull of the moon and, to a lesser extent, the sun. They are affected by the ocean water depth and width, and the shape of the shoreline.

INFL - Tidal currents are generally weak, being of the order of half a knot or less in the open ocean. However, in shallow water (< 200 m) and particularly in enclosed bays or narrow sounds, the currents can be of the order of 10 to 18 km per hr.

EV-202.1.2 Inertial

DEFN - Inertial motion is caused whenever a water particle moves in a curved path in such a way that centripetal acceleration due to the deflecting force of the earth's rotation is balanced by the centrifugal force of the paths curvature. Inertial motion on the earth is therefore anticyclonic (clockwise) in the Northern Hemisphere and cyclonic (counterclockwise) in the Southern Hemisphere, and closes a path having a rotational period of one half-pendulum day. Inertial motion generally takes on a spiral configuration due to the latitude term in the Coriolis component.

INTER - Meteorological Phenomena (EV-105) and ocean Currents (EV-202) contribute to the initiation of inertial currents. These currents generally are found in the upper few hundred meters of the ocean and are caused by a sudden impulse which generates a fluid motion and then allows the induced circulation system to coast without further interference.

INFL - Inertial currents will have an affect on floating surface facilities although in a minor way only. The current velocities are usually much less than 1 knot.

MEAS - Inertial currents can be measured in direction and rate by monitoring a floating buoy over a period of several days. The buoy must have a directional stabilizer or a drogue that will cause it to indicate the relative direction of the current at any time, which rotates through 360 deg.

EV-202.1.3 Baroclinic vs. Barotropic

DEFN - The Stratification (EV-202.2) or layering of the water in the volume of the ocean may take two different forms – barotropic or baroclinic. Barotropic defines an ocean layering in which the pressure surfaces (isobaric) and the density surfaces (isopycual) are parallel to each other, and these in turn can be parallel to the ocean surface. When the pressure surfaces and density surfaces are parallel to the geopotential surfaces, a barotropic ocean exists with no motion; and when these two surfaces are not parallel to the geopotential surfaces, a geostrophic flow occurs. Baroclinic defines an ocean layering in which the pressure surfaces are inclined (not parallel) to the density surfaces. One, both, or neither of these surfaces may be parallel to the geopotential surfaces. A baroclinic ocean is always in motion; however, this motion is generally contained in the upper 1/2 to 1 kilometer of the water.

INTER - Meteorological Phenomena (EV-105) and Winds (EV-102) can disturb a barotropic ocean; however, the period of readjustment usually takes no more than 12 to 14 days before a state of equilibrium is reestablished. A baroclinic structure is usually regional and the pressure surface and density surface inequalities are usually maintained by persistent external influences, such as Meteorological Phenomena (EV-105), Physical Properties (EV-101.1 and EV-101.4), Winds (EV-102), and Precipitation (EV-103).

INFL - Barotropic and baroclinic ocean surfaces affect forces on ocean structures, anchor lines, drifting of surface and subsurface craft, and influence the conduct and approach to operations at sea.

MEAS - To determine whether there is a barotropic or baroclinic ocean, several vertical samples of pressure, temperature, and salinity can be taken over a several square mile area and the data reduced.

EV-202.1.4 Wind Driven

DEFN - Surface currents develop as a result of wind stress on the surface. The mechanism by which the wind exerts force on the surface is complex. The ocean's response to this force is complicated by a number of factors including frictional interaction, rotation of the earth, the presence of continental barriers, and the properties of the water itself.

INTER - The Atmospheric Environment (EV-100) contributes in a direct way to ocean currents. For the ocean engineer, current data pertaining to velocities and distributions are used to determine environmental loading.

INFL - Ocean currents affect forces on ocean structures, anchor lines, drifting of surface and submarine craft, and influence the conduct of operations at sea.

MEAS - Direction and rate of wind-driven currents can be measured by monitoring a subsurface buoy or using colored dye and noting the relationship in the direction of the wind and the current.

EV-202.2 Stratification

DEFN - Stratification occurs in the ocean mainly through the influence of gravity and buoyancy forces. This stratification generally is horizontal, but can have large waves in it due to local conditions. The tendency is for the dense parcels of water to sink, and for the less dense parcels of water to rise toward the surface. For instance a stable stratified water column may often be cooler at the bottom than the top. It may also be fresher at the bottom.

INTER - Temperature (EV-101.1), Precipitation (EV-103), Chemical (EV-201), and Sea Ice (EV-403) have a combined effect on the local ocean stratification. The oceans generally have a steep vertical temperature gradient called a thermocline, which is located from 100 to 1000 meters deep, and is mostly unaffected by the annual seasonal cycle. In addition, there may be locally controlled steepening gradients of salinity (halochines) and density (pycnochines). These steepening gradients can cause ocean currents to form and to channel or bound existing currents.

INFL - The stratification within the ocean, particularly to depths down to 1200 meters, can affect the design and operation of ocean structures and submarine craft, and can influence the conduct of operations at sea.

MEAS - Measurements can be made using Nansen bottles, or equivalent, or the expendable bathythermographs.

EV-202.2.1 Surface Forces

DEFN - Surface forces caused by the motions of water, whether waves or currents, are mainly due to drag. The force on a floating body is denoted by "drifting force." The combination of ocean currents and wave-particle velocity can result in a substantial increase in wave force. The drag force due to current alone is given by

$$F_D = C_D A \rho V^2/2$$

where C_D is the drag coefficient, which for a given body varies as a function of the Reynolds number, A is the cross-section area, ρ is the mass density, and V is the current velocity. In some instances, depending upon the shape and orientation of the body, lift forces will also be generated. Thus,

$$F_L = C_L A \rho V^2/2$$

where C_L is the coefficient of lift. In the case of long cylindrical members the lift force may be significant and can contribute to lateral oscillations with respect to the axis of the cylinder due to Vortex Shedding (EV-202.9).

When current and wave forces act together the resulting drag force is

$$F_D = C_D A (V + U)^2$$

where V + U is the vector sum of the current velocity and the horizontal orbital wave-particle velocity.

INTER - Current forces are proportional to the square of the Current Speed (EV-202.4). Structural shape is a major factor in the magnitude of current forces.

INFL - Dynamic loads on any FOF will be determined by forces resulting from ocean currents as well as waves and wind.

EV-202.2.2 Mid-Depth Forces

DEFN - Forces caused by mid-depth currents are chiefly the result of drag. The current magnitude and direction must be known. Turbulent eddies having frequencies near the natural frequency can excite resonances.

EV-202.2.3 Bottom Forces

DEFN - Forces due to bottom currents in the abyssal plains will be minor and of little significance to design. On the other hand, turbidity currents are a very significant factor in determining force, because it is not only the transport of water that is involved but also the transport of solid matter. Thus the forces due to turbidity currents may be extremely large.

INFL - Turbidity currents may bury or deposit sediments unequally on bottom installations such as foundations or submarine cables.

EV-202.2.4 Current Drag

DEFN - Current drag is the lateral load induced on a structure due to passage of a submarine current through and around the structure. Suitable drag coefficients for the structure must be obtained and current velocities determined from either past history or present measurements. In lieu of accurate current profile measurements, a design velocity value of 0.70 m/sec for deep-water foundations (>130 m) and 1.55 m/sec for shallow foundations represents a conservative design assumption.

INTER - The effect of the current drag is to induce eccentricity into the foundation loading as well as lateral load. Note that for shallow water foundations, wave surge drag will have a similar effect.

EV-202.3 Direction

DEFN - In the Northern hemisphere the wind drift at the surface is directed 45 deg to the right of the wind. For positions below the surface, the current speed decreases with depth and varies in direction in the form of a logarithmic spiral. The Ekman theory, based only on frictional forces and Coriolis forces, and with the assumption that the eddy viscosity is constant, explains these observations. See Figure EV-200-8.

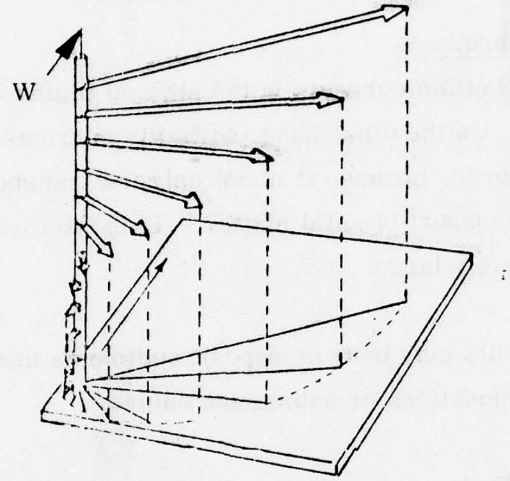

Fig. EV-200-8 Schematic Diagram of a Wind Current in Deep Water - W Indicates Wind Direction

INTER - The principal interrelationships are with Meterological Phenomena (EV-105) and environmental loading. Measurements of current in the deep ocean in the vicinity of of a planned FOF are important to the calculation of forces on the structure. Bottom current measurements should be made in the general area of a planned FOF. Geologic information should be evaluated to provide useful data on the probable occurrence of turbidity currents.

INFL - Forces on marine structures exposed to the surface elements are due to wind, waves, and current. Surface currents cause drifting of surface buoys, ships, and other craft. The forces on structures arising from currents are mainly due to drag.

MEAS - The direction of currents can be determined/measured by monitoring a subsurface buoy, by using colored dye, or by current meters.

EV-202.4 Speed

DEFN - Current speed is the velocity of the local water mass relative to the ocean as a whole. Wind forces over the ocean exert a stress on the water surface which causes a shallow wind drift. This transport of water alters the density distribution and leads to corresponding currents. Experiments have shown that the speed of the surface drift is about 1/20 of the wind speed. For positions below the surface, the current speed decreases with depth. In general, the surface currents in the deep ocean average 0.4 to 0.6 km per hr with variations up to 1.3 km per hr. While measurements of periodic current variation in the deep ocean are very limited, it appears that rotary currents with the period of the semidiurnal tide (12.5 hr), and to a much lesser degree, the diurnal tide (25 hr) are superimposed on the mean flow. Time variations of current related to the inertial period have also appeared in some records of current measurements. The known ocean streams, such as the Gulf Stream and the Kuroshio Current, may reach speeds up to 10 km per hr. Other known currents such as the Canary Current and the California Current are relatively slow. The mean speed in the California Current, for example, is about 0.6 km per hr. Most of the transport of this current is distributed over a band within 1000 km of the coast and in a surface layer about 305 m thick.

In general, deep ocean currents are highest in the surface mixed layer above the thermocline (layer of maximum vertical change in temperature) or pycocline (layer of maximum vertical change in density, generally coincident with the thermocline).

Sufficient data are not available to adequately define the mid-ocean currents for precise engineering design. However, it is feasible to summarize supporting data as follows:

a. A constant component of current magnitude representing no transport is about 0.2 km per hr.
b. A variable component representing the effect of internal waves and inertial effects which changes both in depth and time is also about 0.2 km per hr.
c. The total current in an eddy field at a given location over scales of days may produce magnitudes equal to or greater than 0.4 km per hr.
d. Vertical velocities that may equal or exceed 0.2 km per hr are associated with internal waves and tidal frequencies.

Known bottom current magnitudes do not exceed 0.2 km per hr over relatively smooth abyssal plains. The mean value of these currents is 0.07 to 0.11 km per hr with minor variations in direction, probably due to tidal effects.

INTER - The principal interrelationships are with Meterological Phenomena (EV-105) and environmental loading. Measurements of current in the deep ocean in the vicinity of a planned FOF are important to the calculation of forces on the structure. Geologic information should be evaluated to provide useful data on the probable occurrence of turbidity currents.

INFL - Forces on marine structures exposed to the surface elements are due to wind, waves, and current. Surface currents cause drifting of surface buoys, ships, and other craft. The forces on structures arising from currents are mainly due to drag.

MEAS - The speed of currents can be measured by monitoring a subsurface buoy, using colored dye, and by various electromechanical devices (servonious rotors, etc.)

EV-202.5 Turbulence

DEFN - Turbulent flow results when inertia forces are predominant over viscous forces. Most flows in the ocean are turbulent, occurring at all depths and on many scales. Turbulent flows tend to change their shape with the passage of time and with distance from the initial point of disturbance (dispersion and diffusion).

INTER - Among the causes of turbulence are Surface Waves (EV-401), Internal Waves (EV-203), and Tides (EV-407.2). Wind stresses (EV-102) create waves that generate turbulence. Turbulence and mixing occur both in the horizontal plane in the form of eddies and gyres and in the vertical plane in the form of overturning circulations caused by the thermal differences (EV-201.6) in the ocean and evaporation-precipitation influences (EV-103). The rate of horizontal turbulence is larger than that in the vertical plane due to the lower stability of the horizontal plane in relation to the vertical. Internal waves are generated due to nonlinear vertical density gradients produced by temperature and salinity differences created by surface heating and cooling. Tidal currents generate transient eddies, which are important inputs to internal wave systems.

INFL - Turbulence is an important concept in understanding the nature of Turbidity Currents (EV-309.3) and their effects on bottom supported structures. It is also necessary for an understanding of current measurement instruments to determine the microstructure of ocean currents, including dispersion and diffusion effects.

CALC - The concepts of eddy viscosity, mixing length, and Reynolds number are used to describe turbulence. The eddy viscosity is an inherent characteristic of fluid motion and is much larger than molecular viscosity. It is a proportionality constant relating Reynolds stresses to velocities of mean fluid motion. The mixing length is the average distance in which eddies in a turbulent flow may travel before mixing with the ambient fluid. Reynolds number is a nondimensional value that characterizes the ratio of inertia terms to viscous force terms. Above a certain critical value, turbulence occurs.

EV-202.6 Coherence

DEFN - Coherence of ocean currents concerns the vertical and horizontal correlation of current motion at a particular site. Ocean currents show a great variability in magnitude and direction in both the horizontal and vertical directions. Because of this variability, a vertical velocity shear develops at the discontinuity layer or boundary between the current flows.

CALC - On a global scale, the oceans can be divided into a warm water sphere and a cold water sphere. These two spheres are separated by a thermocline or discontinuity layer in the density stratification.

INTER - Coherence is a function of the seasonal variability of surface Winds (EV-102), and the seasonal and depthwise variations of sea water Temperature (EV-201.6.1 and EV-201.6.2) and Salinity (EV-201.1.1).

INFL - Vertical current shears affect the design of cable and mooring systems for fixed ocean facilities.

EV-202.7 Variation

DEFN - Variation is the amount or rate of change in speed and direction of ocean currents with time, season, depth, and location.

INFL - Variations in the speed and direction of ocean currents should be important to the design and mission success of Fixed Ocean Facilities, particularly suspended cable structures.

EV-202.7.1 Seasonal

DEFN - Excepting the known ocean streams the surface currents are generally governed by the prevailing wind. The mean speed varies little throughout the year. In certain areas of the ocean, summer and winter conditions differ according to the weather. For example, in the North Atlantic, the surface currents in winter are variable in magnitude and direction, while in the summer the currents are generally NNW at 0.6 to 1.1 km per hr.

Average mid-depth currents are believed to be approximately 0.2 kt and they are variable in depth and time. Mid-ocean currents are little affected by the seasons. In deep-ocean areas free from known streams and topographical features, bottom currents seldom exceed 0.2 km per hr. The bottom currents are little affected by the seasons except along the continental shelf and in shallow seas.

INFL - Forces on marine structures exposed to the surface elements are due to wind, waves, and current. Surface currents cause drifting of surface buoys, ships, and other craft.

EV-202.7.2 Fluctuation

DEFN - Fluctuation refers to the response of current speed and direction to changes in environmental factors with depth, time, and location.

INTER - Tidal (EV-202. 1. 1), Inertial (EV-202. 1. 2), Baroclinic and Barotropic (EV-202. 1. 3), and Wind Driven (EV-202. 1. 4) currents all vary from location to location and with time at any given location. Location variations occur due to coastal configurations, geographic latitude, water depth, physical/chemical properties of the sea water, and physical properties of the atmosphere.

EV-202. 7. 3 Decay

DEFN - Decay is the decrease in current speed or magnitude with time.

INTER - Inertial Currents (EV-202. 1. 2) are influenced by decay as they are analogous to swell in surface waves being no longer subject to a disturbing force. Baroclinic and Barotropic Currents (EV-202. 1. 3) experience some decay as they reach equilibrium if the disturbing conditions are not maintained.

EV-202. 8 Spectrum

DEFN - Spectrum refers to the distribution of kinetic energy among the component oscillations of current motion as indicated by period or frequency. This is also known as a power spectrum.

INFL - In this way, the important components of the observed current motion can be identified according to their frequencies for use in design of a moored structure.

CALC - Power spectra are calculated based on current measurements made by current meters moored in the deep ocean. Frequency or period versus relative kinetic energy are plotted on log-linear graphs, or log-log graphs.

EV-202. 9 Vortex Shedding

DEFN - In certain flow speeds periodic forces are produced by the shedding of vortices. This effect is very marked in cylinder and other symmetrical shapes in a given range of Reynolds numbers and Strouhal numbers.

Vortex shedding produces a lateral vibration effect on cylinders, cables, and other symmetrical shapes in a current flow if the frequency of vortex shedding, as given by the Strouhal number, approaches the resonant frequency of the structure. At these resonant frequencies, self-excited and forced transverse vibrations produce such phenomena as cable strumming and flutter, which affect structural dynamics and underwater acoustics.

In general, the energy in bottom currents in the abyssal plains is too small to cause vortex shedding.

INTER - Current magnitudes (EV-202.4) must be taken into account in design.

INFL - Vortex shedding may cause oscillations if the vortex shedding frequency is close to natural frequencies of the structure (See, for example, EV-202.7). Vortex shedding due to currents in the deep ocean is especially important in the design of suspended cables and symmetrical structures. The vortex shedding frequency should be kept away from all natural frequencies of the structure to avoid dynamic effects and possible resonances.

EV-203 INTERNAL WAVES

DEFN - Internal waves are subsurface waves which form at depth as a result of a density discontinuity within the ocean, water flow over the bottom topography, atmospheric disturbances, tidal forces, and shear flow. The density discontinuity can be rather sharp as in an oceanic thermocline, or varying continuously with depth. The profile is best represented by a progressive wave form.

The period of internal waves can vary from 20 minutes to tidal frequencies. The lower limit, an inertial frequency, is a function of latitude and the upper limit, and Vaisala frequency, is a function of water depth.

The amplitude is usually greatest at the discontinuity for a sharp interface, and in the interior of the fluid for a continuously varying density stratification. The height of internal waves in deep water may be as much as a hundred meters. However, they are normally only 6. 10 to 15. 24 meters high in the main thermocline.

The speed of an internal wave is of the order of 0. 2 to 1. 1 km per hr in shallow water. Equations for this velocity are available (See Ref. 10).

Sea surface slicks – which are regions of long, narrow bands of surface current convergence consisting of accumulations of natural oils halfway between a crest and a following trough – are often manifestations of internal waves. The slick is dependent on wind, organic matter in the water, and the internal wave height, period, and depth. The position and motion of internal waves can thus be charted by observing these slicks.

INTER - Internal waves can be generated in a shallow or a deep interface and are usually associated with Thermoclines (EV-201. 6. 4).

INFL - Internal waves are less a factor in design of ocean structures than surface waves as very little energy is required to cause large internal oscillations. Internal waves can generate mid-depth inertia currents and are an important source of turbulence and mixing in the ocean.

MEAS - Internal waves can be measured by direct or indirect methods. The direct methods utilize instruments (such as swallow floats) to measure the vertical density differences. The indirect methods measure the vertical oscillations of temperature and/or salinity with vertical strings of thermistor beads or isotherm followers.

EV-203. 1 Deep Interface

DEFN - A deep interface is one that is closer to the sea floor than to the sea surface. The phase between the layers of a two-layer density system can be in phase or 180 deg out of phase. The maximum turbulence will be under the trough as the water is funneled through the construction. The maximum water flow will be opposite to the direction of propagation.

INFL - Internal waves can move sediment even in deep water, thus affecting foundation design.

EV-203.2 Shallow Interface

DEFN - A shallow interface is one that is closer to the sea surface than to the sea floor. Water flow over the crests of the internal waves is increased if they are near the surface due to funneling of the water through the constriction.

INTER - A thermocline is a common discontinuity surface at which internal waves may occur.

INFL - Turbulence and ripple marks at the sea surface are due to the funneling of water over the constriction between the crest of the internal waves and the surface.

EV-204 BIOLOGICAL ASPECTS

DEFN - The biological/ecological interaction is the effect of the structure on the biological community and on the total ecological environment, and the corresponding effects of these elements upon the structure.

INTER - The marine environment can degrade the structure through Corrosion (EV-205) attack, Biofouling (EV-204.1.1) and Fishbite (EV-204.1.2). The presence of structures can degrade the environment by changing water flow patterns (EV-202), which may eventually affect the characteristics of the ocean bottom (EV-301). These changes can have adverse ecological effects on the marine environment. A reduction in light will reduce photosynthesis. A change in water flow patterns can cause silting over the bottom, swelling marine life. The structure must be protected from corrosion and biofouling, which can increase hydrodynamic drag and reduce structural strength.

INFL - The OFE must consider the interaction of the marine environment and the structures to be placed in that marine environment to ensure that neither is adversely affected. In order that this be accomplished, he must understand the problems of corrosion, biofouling, fishbite and pollution of the environment by solid and liquid matter, temperature change, and radiation leakage.

EV-204.1 Effects of Marine Biota

DEFN - The effects of marine biota are the effects of the fauna and flora of a particular ocean environment. They include the effects of marine Fouling (EV-204.1.1), Fishbite (EV-204.1.2), marine Boring (EV-204.1.3) and Biodeterioration (EV-204.1.4).

EV-204.1.1 Fouling

DEFN - Marine fouling (or biofouling), as it pertains to fixed ocean facilities, results from the attachment and growth of marine plants and animals on surfaces of the structure.

Although barnacles, mussels, and seaweed are the most serious forms of foulants, over 2,000 different species may be involved. The problems created by fouling are not due to the initial fouling populations as much as they are caused by the secondary communities or organisms which are attracted to and forage on these initial populations. This type of fouling problem is known as the "oasis or halo" effect.

INTER - Marine biofouling occurs throughout the oceans from the surface to the deepest depths, but is most pronounced in near-shore, warm (>15°C), surface waters. The presence and amount of light (EV-201.2) is the key element contributing to the magnitude of biofouling activity. Fouling by marine organisms has been found on structures placed in the deep ocean (700 to >10,000 m) but the extent of fouling is a very small fraction of that which occurs in surface waters (EV-400) where photosynthesis is possible.

Control of fouling can be accomplished by intermittent surface temperature increases, above ambient water temperature, very low water salinity for extended periods of time, biocides in antifouling coatings which prevent shell development and inhibit nutrition, and increases in current flows over the protected surface to prevent initial attachment.

INFL - Very few materials are free from fouling when immersed in the ocean. Fouling on structural members can cause increased loading from waves and currents due to the increased diameter and drag coefficient. Localized crevice corrosion (pitting) may occur as a galvanic cell is created due to the fouling. Loss of buoyancy can occur due to the increased weight. Hydrophones, cameras, and other instrumentation can be adversely affected due to acoustical impedance and visibility changes. Fouling of cables may attract carnivores with an increased incidence of fishbite and resulting cable damage or severance.

MEAS - Rates and amounts of fouling in a particular ocean environment are determined by immersing test samples of material for extended periods of time.

EV-204. 1. 2 Fishbite

DEFN - Fishbite is the biting or otherwise attacking of underwater cable and synthetic cordage by carnivores such as sharks, whales, swordfish, crabs, and squid. Damage associated with these attacks usually results in abrasion and/or severance.

INTER - In any surface or subsurface mooring using synthetic lines, the possibility of fishbite damage must be considered. Moorings utilizing synthetic fibers are frequently damaged by fishbite in the upper 1500 meters. It has been postulated that Fouling (EV-204. 1. 1) of underwater cables attracts the carnivorous fish to the cable.

INFL - Fishbite damage can be minimized if wire rope is substituted in the moorings where the damage is expected to occur and where system requirements and performance allow. Fishbite can have a direct effect on the effectiveness of a suspended cable structure, and should be considered during the construction phase when it may be of most concern.

MEAS - Measurement of fishbite has been historically accomplished by after-the-fact failure inspection. Recently, some tests have been conducted off Bermuda using various types of suspended cables in order to determine cause and deterrents. As many as 8. 5 fishbites per day have been recorded.

EV-204. 1. 3 Boring

DEFN - Boring is the excavating of tunnels, holes, or depressions in wood, concrete, mortar, rock, and metal by abrasive chewing, or chemical action of marine invertebrates such as shipworms (Teredo), wood gribbles (L imnoria), and stone borers (Pholadidae). Several other phyla of borers include sponges, annelids, and arthropods.

INTER - Control of borers is best accomplished by protective coatings containing enzyme poisons which neutralize the conversion of cellulose to sugar in the boring invertebrate.

INFL - Proper material and protective coating selection is necessary to ensure mission protection and success.

MEAS - Measurement of boring activity and protection involves immersion of test samples for a specified length of time. Analysis of the effectiveness of a particular material or coating is determined upon removal.

EV-204. 1. 4 Biodeterioration

DEFN - Biodeterioration is the resultant loss in form or function of a structure and its structural elements due to marine fouling and boring.

INTER - Biodeterioration is the resultant damage caused by marine Fouling (EV-204. 1. 1) and Boring (EV-204. 1. 3). Deterioration or degradation of material placed in the marine environment occurs at all depths (EV-201. 6. 2). Attachment of organisms induce changes in pH and oxygen concentration (EV-201. 1. 2) which can result in crevice corrosion and/or stress corrosion cracking. The attachment of organisms (EV-204. 1. 1) to mooring lines can induce fishbite damage (EV-204. 1. 2) where the fish feed on the attached organisms.

INTL - Loss of electrical and electromechanical cables is a classical problem that is often related to biodeterioration in combination with corrosion.

EV-204.2 Variation

DEFN - Variation is the seasonal, daily, and depthwise variation of marine biotic effects on materials in the ocean environment.

INTER - Sunlight and water temperature are the key elements controlling the variation of marine biotic effects such as marine Fouling (EV-204.1.1), Fishbite (EV-204.1.2), and Boring (EV-204.1.3). In addition, the geographical location has been found to be an important condition for the occurrence of Fishbite (EV-204.1.2).

INFL - The variation of marine biotic affects will have a qualitative effect on the design of the structure and the site selection.

EV-204.2.1 Seasonal

DEFN - The seasonal variation of marine biotic effects concerns the change in fouling, fishbite, or boring activity as a function of the seasons.

INTER - Fishbite (EV-204.1.2) activity has been found to be most prevalent during the summer season. Current variation with season (EV-202.7.1) can affect the activity of marine foulers and borers.

MEAS - Measurement of seasonal variations involves immersion of test specimens and evaluation for specific seasonal intervals.

EV-204.2.2 Daily

DEFN - The daily variation of marine biotic effects concerns the change in fouling, fishbite, and boring activity from day-to-day.

INTER - Marine fouling occurs during the daylight hours when sunlight for plant and animal growth is available. Not much additional information on the daily variation of marine fouling, boring, and fishbite is available.

INFL - Daily variations are of little concern to FOF designers.

EV-204.2.3 Depth

DEFN - Marine biotic effects vary as a function of depth.

INTER - Marine fouling occurs throughout the oceans from the surface to the deepest depths but is most pronounced in near-shore, warm (>15°C), surface waters (euphotic zone). The presence and amount of light is the key element contributing to the magnitude of fouling activity. Fouling by marine organisms has been found on structures placed in the deep ocean (700 to >10,000 m), but the extent of fouling there is a very small fraction of that which occurs in surface waters where photosynthesis is possible.

Moorings utilizing synthetic fibers are frequently damaged by fishbite in the upper 1500 meters. In tests conducted near Bermuda, the majority of bites occurred between 600 and 1200 meters with the peak of activity between 900 and 1000 (see Ref. 11).

EV-205 CORROSION ASPECTS

DEFN - Corrosion is the deterioration of metals and alloys by electrochemical reaction with the marine environment. There are various forms of corrosion. These include general or uniform attack typical of that which occurs on carbon and low alloy steels, galvanic attack, and localized attack such as pitting and crevice corrosion. Other forms of localized attack are de-zincification, de-aluminification, exfoliation, and stress corrosion cracking. All forms of corrosion can occur in the marine atmospheric zone, the splash zone, and the submerged zone. Metals and alloys can be ranked according to potential in a galvanic series. Generally, two different metals connected to each other and placed in a marine environment will experience corrosion. The more electro-negative metal (the more active metal) will act as an anode and corrode due to oxidation; whereas, the other metal will act as a cathode and will not corrode (the corresponding reduction reaction). In order to protect the anodic metal it should be (1) large in relative surface area, (2) thicker then required to withstand the corrosion, (3) noncritical, and/or (4) provided cathodic protection. Cathodic protection utilizes a sacrificial anode (more electro-negative than the metals to be protected) which is designed to corrode in place of the other anodic metals. Another type of cathodic protection is the impressed-current method in which direct current, on the order of 0.5 to 2.5 mA/m^2 for steel structures, is used.

INTER - Corrosion may occur in all areas of the marine structure. Normally, a marine structure is divided into three zones — atmospheric, splash, and submerged. Protection is best afforded by paint systems and galvanizing in the atmospheric zone; by extra material thickness, noncorrosive metal wrap, and protective coatings in the splash zone; and cathodic protection with sacrificial anodes or impressed current in the submerged zone.

INFL - The resistance or lack of resistance of materials to marine corrosion must be understood so that failure due to corrosion attack can be prevented. This understanding will lead to the proper selection of materials and protection methods.

EV-205.1 Types

DEFN - Types of marine corrosion include pitting, crevice corrosion, selective removal of zinc or aluminum, stress-corrosion cracking, and layer corrosion (exfoliation).

Many metals and alloys owe their good corrosion resistance to the formation of a thin, adherent oxide film over the metal surface which isolates the metal from the corrosion process. Degradation of this film can change the electrochemical potential, the active/passive area relationship, and the corrosion process in many materials. Many natural forces are at work to destroy this film so most metals require a ready availability of oxygen and a certain amount of self-repair. Oxygen for film repair is provided more effectively for those structures in moving water.

Pitting is a localized form of corrosion in which small depressions are created in the anodic metal surface. Crevice corrosion is another localized form of attack in which metal parts in a crevice, lacking an adequate supply of oxygen to repair a damaged oxide film, corrode. The oxide-protected area external to the crevice actually acts as the cathode.

Removal of zinc or aluminum from an alloy arises from the selective corrosion of one component of an alloy such as zinc in high-zinc brass, or aluminum in other alloys. A residue of other uncorroded components is left. Stress-corrosion cracking occurs due to simultaneous exposure of an alloy to a corrosive environment and tensile stress. This stress may be due to loads, welding, or heat treatment. Stress-corrosion cracking is believed to be thermally activated. Corrosion fatigue is another form of stress-corrosion cracking which differs only in that loads are applied which are pulsating rather than constant. Hydrogen embrittlement is commonly observed in heat-treated high-strength steel. Layer corrosion or exfoliation occurs in certain alloys such as 7000-series aluminum in sheet or plate form, which tend to corrode in planes parallel to the rolling plane.

INTER - Corrosion such as crevice corrosion and pitting may occur due to marine Fouling (EV-204. 1. 1). A galvanic cell due to the growth of anaerobic bacteria and other microorganisms between the base of the barnacle and the metal surface may bring about a change in the pH of the water in this pocket, thereby creating an electrical current.

INFL - Material corrosion must be well understood by the ocean structure designer to ensure that appropriate materials and protection systems are selected to meet prescribed performance standards.

MEAS - Measurement of these types of corrosion is accomplished by analysis of test specimens immersed in an ocean environment for specified lengths of time.

EV-300 SEAFLOOR ENVIRONMENT

DEFN - The seafloor environmental aspects that impact an ocean facility include minimally: (1) a quantitative portrayal of seafloor surface characteristics, (2) delineation of subbottom characteristics, (3) a qualitative/quantitative assessment of relative activeness of geomorphological forces, (4) quantification of geotechnical engineering properties of the seafloor, and (5) an assessment of the potential for biological and seismic activity. The breakdown structure for Seafloor Environment is presented as Fig. EV-300-1.

INTER - Seafloor characteristics are interrelated with other environmental aspects. They are molded by both the atmospheric (EV-100) and ocean (EV-200) environments. Some of the sediments of the ocean are derived from terrestrial soils and rocks which are carried to the ocean by winds. Winds transport soil particles and icebergs raft rocks miles out to sea. The biota (EV-204) of the oceans contribute their remains to the sediments in the form of falling particulate matter. The chemistry (EV-201.1) of the ocean contributes authigenic ("born-on-the-spot") soils or precipitates from the water mass. The dynamic interface of the coastal zone results in atmospheric and oceanic environmental forces combining to cause transport of terrestrial materials to the seafloor through onshore, offshore, and littoral sediment transport (EV-404). The forces in the dynamic interface zone also cause continuous reworking of the sediments of that zone. Gravitational and seismic forces (EV-306) cause the terrestrial sediments on the continental margins to move into the deep ocean basins, resulting in mixing and stratification of terrestrial and pelagic sediments, depending on the frequency of occurrence of these movements.

INFL - The seafloor environment influences site selection, foundation selection, and foundation performance relative to the mission of an ocean facility and the permissible movement and life expectancy of the foundation units.

EV-301 BOTTOM TOPOGRAPHY

DEFN - Bottom topography refers to the general configuration of the bottom surface including its relief and the position of its natural features. These features include seamounts, submarines, canyons, ridges, slide debris, extent of abyssal plains, etc. The topographic data provide measures of surface gradients and roughness.

SEAFLOOR ENVIRONMENT
EV-300

BOTTOM TOPOGRAPHY
EV-301

301.1 Surface Gradient
301.2 Surface Roughness
301.3 Lateral Continuity/Variation
301.4 Topographic Effects

SUBBOTTOM GEOLOGIC STRUCTURE
EV-302

302.1 Composition
302.2 Stratification
302.3 Spatial Continuity/Variation
302.4 Rock Protrusion
302.5 Discontinuities
302.5.1 Fractures
302.5.1.1 Faults
302.5.1.2 Joints
302.5.1.3 Fissures
3.2.5.1.4 Bedding Planes
302.5.2 Orientation
302.5.3 Extent

GEOMORPHOLOGY
EV-303

303.1 Origin/Courses of Geologic Formations
303.2 Active Geomorphology During Facility Life

GEOTECHNICAL PROPERTIES
EV-304

304.1 Soil
304.1.1 Classification
304.1.2 Composition/Mineralogy/ $CaCO_3$
304.1.3 Shear Strength (Sediment, Soil)
304.1.4 Sensitivity
304.1.5 Bulk Unit Weight
304.1.6 Consolidation
304.1.7 Atterberg Limits
304.1.8 Water Content
304.1.9 Porosity
304.1.10 Void Ratio
304.1.11 Specific Gravity
304.1.12 Permeability
304.1.13 Viscoelastic/Creep Characteristics
304.1.14 Dynamic Characteristics
304.1.15 Adhesion
304.1.16 Friction
304.1.17 Wave Induced Liquefaction
304.2 Rock
304.2.1 Shear Strength (Rock)
304.2.1.1 Competent Rock
304.2.1.2 Discontinuity
304.2.2 Compressive Strength
304.2.3 Deformation Characteristics
304.2.3.1 Stress/Strain
304.2.3.2 Poisson's Ratio
304.2.4 Seepage Characteristics/ Permeability
304.2.5 Density
304.2.6 Water Content

GEOPHYSICAL PROPERTIES
EV-305

305.1 Gravitational Anomalies
305.2 Magnetic Anomalies
305.3 Conductivity/Resistivity
305.4 Acoustic

SEISMIC ACTIVITY
EV-306

BIOLOGICAL ASPECTS/BURROWING
EV-307

SEAFLOOR/FOUNDATION INTERACTIONS EV-308

308.1 Foundation Settlement Parameters
308.1.1 Immediate Settlement
308.1.2 Long-Term Settlement
308.1.3 Differential Settlement
308.2 Foundation Failure Parameters
308.2.1 Bearing Capacity Instability
308.2.2 Rotational Instability
308.2.3 Lateral Instability
308.2.4 Uplift
308.2.5 Breakout

SEA/SEAFLOOR INTERFACE
EV-309

309.1 Scouring
309.2 Accretion
309.3 Turbidity Currents

Fig. EV-300-1 Seafloor Environment – Breakdown Structure

INTER - Bottom topography relates directly to the Geomorphology (EV-303) of an area and helps define Subbottom Geologic Structure (EV-302). The topography helps to locate areas of possible Seismic Activity (EV-306).

INFL - In general, bottom topography dictates the placement of foundations.

MEAS - Topography is obtained through surveys using high-resolution fathometers.

EV-301.1 Surface Gradient

DEFN - The surface gradient is the degree of inclination or rate of ascent/descent of an inclined part of the ocean bottom with respect to the horizontal, i.e., the slope.

INTER - Surface gradients relate directly to Geomorphology (EV-303) and may indicate the extent of features of Subbottom Geological Structure (EV-302). Shear Strength (EV-304.1.3) of soils on steep slopes may be inferred from the gradient.

INFL - Surface gradients may control the placement of a foundation and in any case will dictate the foundation geometry. The existence of steep slopes of sedimentary material may indicate the possibility of slope instability and should be avoided for foundation emplacement.

MEAS - Surface gradients generally need not be measured directly but can be calculated from topography collected by high-resolution fathometers.

EV-301.2 Surface Roughness

DEFN - Surface roughness or micro-topography is the identification of small features such as bed-rock outcrops, pebbles and cobbles, ripples, scour marks, small reefs (organic), and subaqueous sand dunes.

INTER - Surface roughness features are related to Geomorphology (EV-303) and Subbottom Geologic Structure (EV-302).

INFL - The presence of surface roughness features may dictate the local placement of foundation structures.

MEAS - Surface roughness features are determined from bottom photographs and high-resolution echo sounding.

EV-301.3 Lateral Continuity/Variation

DEFN - Lateral continuity and variation refer to the extent or limit to which bottom topographic areas extend before pronounced demarcations in contour or gradient occur. An example of this would be the extent of the continental shelf before the surface achieves sufficient gradient to become a continental slope.

INTER - Lateral continuity and variation define limits of bottom geomorphological features (EV-303).

INFL - The lateral continuity or variation in topographic features affect foundation placement only generally.

MEAS - Extent of lateral continuity is inferred from topographic surveys.

EV-301.4 Topographic Effects

DEFN - Topographic effects on underwater structures result from the specific shape of the sea bottom where the structure is to be placed. As on land, it is necessary to take into account the loads induced by the slope and to investigate slope stability.

INFL - The most apparent topographic feature is an inclined slope on which the foundation rests. The inclination of the site (unless preleveled) induces lateral load components which must be accounted for in the facility design. A less obvious effect of the inclined slope is the tendency for underconsolidated cohesive material to develop downslope forces in excess of downslope shear resistance. The result of this net downslope force is a submarine slump (slope instability) of generally a large area which would eliminate most structures situated thereon.

EV-302 SUBBOTTOM GEOLOGIC STRUCTURE

DEFN - Subbottom geologic structure is the delineation of all features contributing to the makeup of the seafloor. These include:

- **Composition (Types of Materials)**
- **Stratification (Vertical Variation)**
- **Spatial Continuity (Horizontal Variation)**
- **Rock Protrusions**
- **Discontinuities**

INTER - Subbottom geologic structure strongly influences the Bottom Topography (EV-301) and Geomorphology (EV-303).

INFL - In general, as the number, complexity, and variations of subbottom geologic structures increase, foundation analysis becomes increasingly more difficult and less accurate.

MEAS - This information is obtained through seismic profiling techniques and sediment core operations.

EV-302.1 Composition

DEFN - The composition of the ocean subbottom is dictated by tectonic (structural) forces and sedimentation. The constituents are (1) rock assembled by tectonic forces and (2) soil deposited by sedimentation. Due to the random and highly complex nature of earth movements, seismic activity, and sedimentation parameters, the composition of the bottom is varied and nonuniform in the mixtures of rock and soil. For this reason generalities concerning the structural geology and apparent sediments of areas under consideration for foundations should be avoided.

INTER - The constituents of composition of the subbottom are Rock (EV-304.2) and Soil (EV-304.1). The composition contributes to the Geomorphology (EV-303) of the subbottom.

INFL - Composition of the subbottom contributes to the determination of the kind, shape, and placement of foundation structures.

EV-302.2 Stratification

DEFN - Stratification is the formation, accumulation, or deposition of material in layers. It may be produced by the differences in texture hardness, cohesion, cementation, color, internal structure, and mineralogic or lithologic composition.

INTER - Subbottom stratification directly affects the extent to which Geotechnical Properties (EV-304) can be considered uniform. Similarly, Geophysical Properties (EV-305) can be expected to change and Seismic Activity (EV-306) may cause excessive slippage along the bedding planes.

INFL - Stratification may dictate the extent to which pile foundations must be driven to achieve the required vertical and lateral resistance. Evidence of weak shearing bonds between layers may require foundation redesign if high lateral loads are anticipated.

MEAS - Stratification is best determined from examination of core samples.

EV-302.3 Spatial Continuity/Variation

DEFN - Spatial continuity and variation refer to the limits to which subbottom geological masses extend before changes in material occur.

INTER - Spatial continuity and variation define limits of geomorphological features (EV-303).

INFL - Spatial continuity and variations in subbottom geologic features affect foundation placement only generally. An exception to this is where a mass limit is defined by a fault, in which case foundation placement on or near the fault should be avoided.

MEAS - The extent of subbottom masses and locations of mass limits are determined from seismic measurements, core sampling, and topographic maps.

EV-302.4 Rock Protrusion

DEFN - Rock protrusions refer to the injecting of a solid (nonflowing) rock into differing material by tectonic forces. The protrusion may extend up into ocean bottom sediments or may extend above the ocean bottom.

INTER - Rock protrusions are part of the Geomorphology (EV-303) of the ocean bottom.

INFL - Subsurface rock protrusions can affect foundation placement to the extent that pile foundations may reach refusal before sufficient pile resistance to lateral loads has been developed. The placement of a foundation on a rock protrusion will require drilling and anchoring techniques different than the more common placement on sediments. Investigation of the rock protrusion for soundness and load-carrying capability is mandatory.

MEAS - Apparent rock protrusion are identified by topographic maps and descriptions. Subsurface rock protrusions must be identified by seismic interpretation, cores, etc.

EV-302.5 Discontinuities

DEFN - Discontinuities are defined as any sudden or radical change in either depth or physical properties of materials constituting the seafloor. Discontinuities in subbottom rock structure may be masked by sediment layers. Discontinuities may be typically fractures, faults, joints, fissures, and bedding planes.

INTER - Discontinuities contribute to Bottom Topography (EV-301), Geomorphology (EV-303), and may be determined by geophysical property measurements (EV-305). They may be due to Seismic Activity (EV-306). (See also EV-302.2, EV-302.3.)

INFL - Discontinuities generally affect the selection of foundation sites. They should be avoided.

MEAS - Subbottom profiling and inferential measuring techniques (acoustic, gravity, etc.) are used to define the extent, direction, inclination, and depth of discontinuities.

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EV-302.5.1 Fractures

DEFN - Rock fractures can be defined as any break in a mass of rock. Fracturing is caused by stress levels developed within the rock mass which are greater than the strength of the rock. Fractures may take the form of faults, joints, cracks, fissures, folds, etc. An instance of massive sea bottom fracturing is given by mid-ocean ridge structures.

INTER - Fractures contribute to the overall Geomorphology (EV-303) and Bottom Topography (EV-301) of the seafloor.

INFL - Fractures influence the selection of foundation sites and they should be avoided where possible due to possibilities of relative movement along the fracture.

MEAS - Fractures are measured by subbottom profiling and inferential measuring devices (acoustic, gravitational, etc.). Descriptions, extents, and directions of fractures are necessary data for definition.

EV-302.5.1.1 Faults

DEFN - If the rock mass on each side of a fracture indicates that there has been displacement (horizontal or vertical or both) along the plane of fracture, the plane is classified as a fault. Such displacements may be barely noticeable or may be several thousand feet or miles in extent. When several faults occur in close proximity, the resulting zone of broken rock is called a shear or fault zone.

INTER - Faults contribute to the general Geomorphology (EV-303) and Bottom Topography (EV-301) of the seafloor. Faults are usually the result of Seismic Activity (EV-306), occuring in connection with the movement of continental plates (plate tectonics).

INFL - The construction of structural foundations on or near a fault should be avoided due to possibilities of relative motion and high lateral loadings.

MEAS - Faults are described by their extent, depth, direction, and inclination. These descriptions are determined by subbottom profiling techniques.

EV-302.5.1.2 Joints

DEFN - When a series of fractures are more or less continuous and seem to form well-defined patterns bearing a relation to each other or to other elements of a rock mass, the fractures then may be described as joints.

INTER - Joints contribute to the Geomorphology (EV-303) of an area by their delineation of the form and apparent texture of a rock mass. Joints will have a definite relation either with Bedding (EV-302.5.1.4) or with Faults (EV-302.5.1.1). Jointing is caused by the development of tensiles stresses (EV-304.2.3) in the rock mass by shrinkage due to (1) temperature drop, (2) a loss of moisture, or both.

INFL - Jointing generally influences the foundation of structures as it contributes to the general seafloor environment and geomorphology. Foundation structures should not be built over or on joints due to the possibility of relative motion along the joints.

MEAS - Measurements of jointing is indicated by the direction of the plane containing the joint. "Strike" is the direction of contour lines on the surface of the rock mass and "dip" is the maximum slope of the surface.

EV-302.5.1.3 Fissures

DEFN - Fissures are fracture surfaces or a crack in rock along which there is a distinct separation. The fissure is often filled with mineral-bearing matter but may also be vented.

INTER - Fissures contribute to overall Bottom Topography (EV-301) and Geomorphology (EV-303). In the case of vented fissures, the vent may be evidence of volcanic or seismic activity.

INFL - Fissures should be avoided for placement of foundation structures because of the probability of motion, venting, or the presence of unconsolidated material in the fissure.

EV-302.5.1.4 Bedding Planes

DEFN - Bedding planes are the division planes supporting the individual layers, beds, or strata in sedimentary or stratified rock. While sediment deposition and formation of the planes occur in a horizontal position, succeeding earth movements may cause the planes to incline or even become vertical.

INTER - Bedding planes contribute to overall Bottom Topography (EV-301) and Geomorphology (EV-303) of the area.

INFL - The nature of bedding planes is such that they are susceptible to shearing deformations along the plane. In the selection of a foundation site, eliminate any foundation positioning on inclined planes or if the foundation will be subjected to any loading parallel to the bedding plane.

EV-302.5.2 Orientation

DEFN - The orientation of discontinuities refers to the directions describing their locations. These directions are referenced to a given set of control axes — generally true north and horizontal. Further orientation of discontinuities may describe the angles (dip and strike) of their planes.

INTER - Orientation of discontinuities is a result of tectonic forces determining the Geomorphology (EV-303) of the area.

INFL - Orientation of discontinuities affects foundation placement generally.

MEAS - Orientation is determined from topographic maps, core samples, and acoustic measurements.

EV-302.5.3 Extent

DEFN - The extent of discontinuities refers to its length, width, and depth, and provides data for geological surveys.

INTER - The extent of discontinuities is a result of tectonic forces determining the Geomorphology (EV-303) of the area.

INFL - The extent of discontinuities affects foundation placement only generally.

MEAS - The extent of discontinuities is determined from topographic and geologic survey maps, core samples, and acoustic measurements.

EV-303 GEOMORPHOLOGY

DEFN - Submarine geomorphology is concerned with the study of the forms and forming processes of topographic features such as ocean deeps, basins, continental terraces, ridges, troughs, submarine valleys, and submarine volcanic slopes. The blanketing effect of sedimentation is likewise a geomorphological phenomenon.

INTER - Geomorphology is interrelated directly with Bottom Topography (EV-301) and depends upon Subbottom Geologic Structure (EV-302) for delineation. The forms of topographic features are dictated by the material comprising them and their Geotechnical Properties (EV-304). Geophysical Properties (EV-305) may govern the topographic forms and Seismic Activity (EV-306) and Biological Aspects (EV-307) may contribute to altering existing forms.

INFL - Geomorphology generally influences the foundations of structures as it dictates the seafloor environment upon which the structure will be founded. It further determines the extent to which changes in the seafloor material or form will occur during the life of the structure.

MEAS - Geomorphological studies are compiled from data secured from core samples, soundings, bottom and subbottom profiling, and the history of similar geologic phenomena.

EV-303.1 Origin/Courses of Geologic Formations

DEFN - The origin and courses of geologic formations define the limits (or extents) and directions of differing formations. Differences identified may be those of properties, constitutive material, degree of weathering, extent of sedimentation, etc.

EV-302.2 Active Geomorphology During Facility Life

DEFN - Active geomorphology refers to any geomorphological process such as sedimentation, erosion, faulting due to tectonic forces, seismic activity, etc., which may affect structure function and life.

INFL - While most geomorphological processes are of extremely long duration, investigation of these processes and recent evidence of them may influence foundation design:

- Excessive sediment rates may cause interference with equipment.
- Excessive sediment rates may indicate consolidation and the build up of material on a slope which is susceptible to turbidity currents, slope instabilities, or slides.
- Erosion may cause removal of support material.
- Evidence of seismic activity may indicate tendencies for movement, shock loadings, etc.

EV-304 GEOTECHNICAL PROPERTIES

DEFN - Geotechnical properties of soil and rock are those properties used to predict the response of soil to applied load/deformation and for the design of foundations and anchors. Geotechnical properties are generally divided into index and engineering properties. Index properties are those measured quantities that are used primarily to identify soil type. Engineering properties are measured quantities that are used in design equations to predict the response of soil to applied loads or deformation.

INTER - The geotechnical properties relate to the Geomorphology (EV-303) and geology (EV-302) of the subbottom since the properties will vary depending on the manner in which the sediments were deposited, the length of time the sediments have been in their present site, and the diagenesis and consolidation that has occurred since the initial deposition of the sediment.

INFL - Geotechnical properties influence the design of foundations and anchors. They qualitatively influence the site selection decision process.

MEAS - These properties are measured through the use of in-situ tests, tests on samples taken from the seafloor, and remote sensing devices.

EV-304.1 Soil

DEFN - Soil is a natural aggregate comprised of mineral grains, interstitual waters, gas, and deposited biogenic material. Soils are not man-made materials that have had the benefit of quality control for consistency and production within specified bounds. Soils in nature tend to be stratified, heterogenous, and nonisotropic in their response to loadings.

INTER - Soils differ from Rock (EV-304.2) to the extent that they are the products of rock weathering and deposition of biogenic material. Seafloor soils have some features not common to terrestial soils: (1) some seafloor soils have a high content of animal skelectal remains, i.e., the calcareous and siliceous oozes; and (2) some soils have a high content of authigenic material, i.e., solid formed by chemical precipitation from the water media.

INFL - Soils have a one-to-one influence on foundation and/or anchor design since they provide the final reaction to any loads applied to the ocean facility.

EV-304.1.1 Classification

DEFN - Sediments can be described or classified by various methods including their origin, their given size characteristics, or their physical and mineralogical properties. For engineering purposes, classification by grain size analysis is often used. Classification is also made on the basis of the cohesive or cohesionless properties. Cohesive sediments are those in which interparticle forces are significant (clays).

INTER AND INFL - Classification is reflected in the description of the Shear Strength (EV-304.1.3) of soils in which the cohesive and cohesionless components are identifiable and separate. Consolidation (EV-304.1.6) is most often a problem in cohesive material. Atterburg Limits (EV-304.1.7) are specifically designed for handling material with a preponderance of cohesive soil. Cohesion (EV-304.1.15) is a property of cohesive material, while Friction (EV-304.1.16) is predominantly a cohesionless soil property. The differences by which soils are classified are determined by the Subbottom Geologic Structure (EV-302) and geomorphological processes (EV-303).

MEAS - Classification of soils by grain size is accomplished by sieve analysis for particles larger than 0.06 mm and by hydrometer analysis for smaller particles. Grain size scales classify sediments on the basis of size as sand, silt, clay, or combination.

EV-304.1.2 Composition/Minerology/$CaCO_3$

DEFN - Sediments may be classified by their composition, which is for the most part a measure of the relative amounts of minerals and carbonates present in a given sample. Sediments of the deep sea are principally oxidized materials of continental origin and minerals elaborated from the sea water itself. These are the red clays. Organisms in the sea produce skeletons of silica or calcium carbonate. The silicious skeletons are fairly insoluble and are additive to the deep sea sediments. Calcium carbonate skeletons survive down to about 3,500 meters and then go rapidly into solution. Hence, carbonaceous sediments are restricted to shelves, continental slopes, swales, and seamounts.

INTER - Sediment composition is dictated by both Atmospheric (EV-100) and Ocean (EV-200) environments.

INFL - The composition of sea floor sediments affects all geotechnical properties which, in turn dictate foundation and site selection, and foundation performance.

MEAS - Chemical analyses provide constituent breakdowns of compounds, elements, minerals, etc., comprising sediments.

EV-304.1.3 Shear Strength (Sediment, Soil)

DEFN - Shear strength of seafloor sediments specifies the ability of the material to resist shear deformation. Shear strengths are dependent on many factors including the sediments' index properties, electrochemical and mechanical interparticle forces, and constraints on mode of failure and stress system during testing.

INTER - The shear strength property relates generally to the other geotechnical soil properties, e.g., shear strength generally will decrease with increasing Water Content (EV-304.1.8) and increase with increasing Bulk Unit Weight (EV-304.1.5). The static shear strength value is the usual reference when considering Viscoelastic (EV-304.1.13) and Dynamic (EV-304.1.14) strength properties. The latter are generally expressed as a percentage of the static strength.

INFL - Shear strength values are used in soil engineering design equations for the determination of the bearing capacity of footings, pile capacity, slope stability, and holding capacity of anchors. Shear strength values therefore influence the final foundation/anchor selection and site selection for an FOF.

MEAS - Shear strength of soils can be determined by several laboratory tests on samples taken from the seafloor, in-situ field tests, and by approximate correlation with the other sediment properties. The four most widely used laboratory shear tests are vane shear, direct shear, triaxial, and unconfined compression. Two commonly used in-situ tests include the field vane shear and cone penetrometer tests.

EV-304.1.4 Sensitivity

DEFN - Sensitivity of soil is defined as the ratio of the shear strength of an undisturbed soil sample to the shear strength of the same soil in a completely remolded state. It represents the ability of remolded material to resist shearing deformations. It is applicable to clay soils and clay-silt mixtures, but has no significance in granular noncohesive material. Sensitivities up to 10 are not uncommon.

INTER - Sensitivity relates directly to the Shear Strength (EV-304.1.3) of cohesive soil; hence, interrelationships described in EV-304.1 apply here.

INFL - Sensitivity values applied to shear strength values in design equations may appreciably reduce the usable shear strength values, thereby increasing foundation area requirements, number of piles, and decrease the designated holding power of the anchors. It should be recognized that complete remolding of foundation soil is rarely accomplished; hence, use of disturbed shear strengths in design computations builds in a safety factor. Further, the thixotropic character of cohesive soils dictates a regain in shear strength, but usually not to its original shear strength value.

MEAS - Sensitivity measurements are made using the same equipment as for Shear Strength (EV-304.1.3) with the addition of some manner of device for total remolding of the same soil prior to remeasuring.

EV-304.1.5 Bulk Unit Weight

DEFN - The unit weight of the sediment is defined as the weight of sediment plus the water per unit volume. It depends on the unit weight of the solid constituents, the porosity of the soil, and the degree of saturation. For marine sediments, 100 percent saturation is usually assumed.

INTER - The bulk unit weight of a soil sample is dependent upon the Geomorphology (EV-303) of any area as it dictates the type of soil grain material (EV-304.1.2) and its Specific Gravity (EV-304.1.11) in situ. Unit weights of clay soils are affected by the degree of Consolidation (EV-304.1.6); high unit weights imply low Porosities (EV-304.1.9), Void Ratios (EV-304.1.10), and Water Content (EV-304.1.8).

INFL - Bulk unit weight values enter into all design equations for the bearing capacity of foundations, the lateral resistance of piles, and the holding capacity of anchors. As such they influence the final foundation and anchor selection for fixed ocean structures.

CALC - Bulk unit weight may be computed as follows:

The unit weight of the dry soil (0% saturation):

$$\gamma_d = (1 - \eta)\gamma_s \quad \text{(in g/cm}^3 \text{ or lb/ft}^3\text{)}$$

and of the saturated soil (100% saturation):

$$\gamma = (1 - \eta)\gamma_s + \eta\gamma_w. \quad \text{(in g/cm}^3 \text{ or lb/ft}^3\text{)}$$

where,

γ_s = average unit weight of solid constituents (g/cm^3)

γ_w = unit weight of water (g/cm^3)

EV-304.1.6 Consolidation

DEFN - Consolidation is defined as the amount of volume compression sustained by a soil under a superimposed loading. It generally refers to clay soils in which the superimposed loading is transferred from the pore water system to the soil grain system, which then moves into the void system or simply compresses. It is time dependent as the water must proceed through the small intricate void system of the clay, usually at a slow rate (permeability). Consolidation of cohesionless soils is usually instantaneous because permeability is very high.

INTER - Consolidation relates directly to Void Ratio (EV-304.1.10) as a measure of the volume into which soil particles will migrate. Permeability (EV-304.1.12) governs the rate at which pore water will escape to allow particle movements. Bulk Unit Weight (EV-304.1.5) affects consolidation indirectly as the weight of overburden in the compressible stratum. Consolidation of a large compressible area due to sediment deposited as overburden will affect Bottom Topography (EV-301) and Geomorphology (EV-303).

INFL - Consolidation characteristics affect the final position a foundation will assume when placed on compressible stratum. Nonsymmetric loading of foundations will cause nonuniform consolidation under a loaded area, which may result in tilt of the foundation. Disproportionate loadings on individual footings may cause differential settlement of the footings, which can induce large stresses in the primary structure.

MEAS - Consolidation characteristics are determined from consolidometer tests on compressible soil samples. Data from these tests are presented as pressure (stress) vs. amount of consolidation (strain) and amount of consolidation as a function of time.

EV-304.1.7 Atterberg Limits

DEFN - Atterberg limits are results from laboratory tests to determine arbitrary water content of remolded soil samples.

(a) Liquid limit: The limit at which the soil is on the verge of being a viscous liquid.

(b) Plastic limit: The stage at which the soil is on the verge of being nonplastic.

(c) Plasticity index: The difference between the liquid limit and plastic limit, i.e., the range of water content at which the soil is plastic.

INTER - Atterberg limits are indicator tests which help to define the type of soil tested (EV-304.1.1) and how it will behave over ranges of moisture content (EV-304.1.8). Empirical approximations have been devised for relating the liquid limit to the coefficient of Consolidation (EV-304.1.6 and EV-304.1.14) with a large degree of success.

INFL - Atterberg limits influence foundation design only as identifiers of soil type and their possible behavior patterns.

MEAS - Atterberg limits are determined from standard ASTM test procedures.

EV-304.1.8) Water Content

DEFN - Water content (w) of soil is defined as the ratio, in percent, of the weight of water in a given sediment mass (W_w) to the weight of the ovendry soil particles (W_s). In marine sediments, determination of water content must include a correction for the salt content in the water.

INTER - Water content relates directly to the Bulk Unit Weight (EV-304.1.5) of a sample as it indicates the amount of water contained in the soil void system (EV-304.1.10). Varying water contents are used in determination of Atterberg Limits (EV-304.1.7). Large moisture content gives an indication of the type of Consolidation (EV-304.1.6) that can be anticipated, e.g., large moisture content can mean great compressibility.

INFL - Water content influences foundation designs only generally as an indication of the type of soil to be encountered.

CALD - Moisture content is determined according to ASTM procedures. The equation for determination is

$$(\%) = \frac{\text{wet weight - dry weight}}{\text{dry weight - saltweight}} \times 100$$

EV-304.1.9 Porosity

DEFN - Porosity "n" is defined as the ratio of the volume of voids V_v to the total volume V of a soil mass and is expressed as a percentage. It is assumed in marine soil mechanics that samples are 100 percent saturated and that voids are totally filled with water.

INTER - The porosity (n) of a soil is related directly to the Void Ratio (e) (EV-304.1.10) of a soil by the relationship

$$n = \frac{e}{1 - e}$$

Also, the higher the porosity the lower the Bulk Unit Weight (EV-304.1.5). Similarly large porosities indicate high permeabilities.

INFL - No direct influence on foundation design can be inferred from porosity values.

CALC - $$n(\%) = \frac{\text{volume of salt water}}{\text{wet volume}} \times 100 = \frac{V_v}{V} \times 100$$

EV-304.1.10 Void Ratio

DEFN - Void ratio "e" is defined as the ratio of the volume of voids V_v to the volume of solids V_s. In 100 percent saturated sediments, the volume of voids is equal to the volume of salt water.

INTER - Void ratios relate directly to Porosity (EV-304.1.9) such that the higher the void ratio, the higher the porosity. Void ratios are used as indications of the amount of Consolidation (EV-304.1.6) a soil may undergo and are indicators of the Permeability (EV-304.1.12) of a soil, e.g., the higher the void ratio, the higher the permeability.

INFL - Void ratios help to indicate the amount a foundation may settle.

CALC -

$$e = \frac{\text{volume of salt water}}{\text{dry soil volume}} = \frac{V_v}{V_s}$$

EV-304.1.11 Specific Gravity

DEFN - Specific gravity is defined as the ratio of the unit weight of soil grain particles, excluding voids, to the unit weight of water. It is then a means of expressing the heaviness of a material and is referred to as the "true" specific gravity. "Apparent" specific gravity is defined as the ratio of the dry weight of a unit volume of soil (including voids) to the unit weight of water.

INTER - The specific gravity of the soil grain material directly affects the Bulk Unit Weight (EV-304.1.3).

MEAS - Specific gravity is determined by ASTM test procedures.

CALC -

$$Gs = \gamma_s / \gamma_w$$

where,

γ_s = unit weight of soil particles

γ_w = unit weight of water

EV-304.1.12 Permeability

DEFN - Permeability of a soil is the soil's ability to allow water to pass through its void system. It is represented mathematically as a proportionality constant relating velocity and hydraulic gradient. Clay soils have a low permeability coefficient due to the very small intricate pore network in the soil system.

INTER - Permeability interrelates directly with rate of Consolidation (EV-304.1.6) such that the higher the coefficient of permeability, the faster the consolidation process will proceed.

INFL - Permeability of sea bottom soils enters into computations of consolidation rates of cohesive material under imposed loadings. The permeability further influences the time required for the breakout of foundations from cohesive material, an important aspect if total structures are to be moved or replaced.

MEAS - Permeability measurements are determined from constant head permeameters (coarse grained soils) or falling head permeameters (fine grained soils). Both computations utilize Darcy's Law (Ref. 12). Permeability coefficients have units of velocity, i.e., cm/min, etc.

EV-304.1.13 Viscoelastic/Creep Characteristics

DEFN - Elasticity of a soil material is the behavior under loading wherein compressive loadings cause compression of the soil grain material, and release of the loading allows the material to return to its original condition. The amount of elastic response in soil is usually low because the soil grains tend to migrate and the soil system deforms plastically.

Viscous behavior of soils is characterized by the tendency of the soil to deform under induced shearing loads. It is a time-dependent phenomenon. Release of the shearing load will cause some elastic return of the soil to its original formation.

Creep of soil material is the continuing deformation of the soil system due to a continuous applied loading. Creep rates are usually very small but persistent.

INTER - Material deformation characteristics are the direct result of the geomorphological forces (EV-303) acting on constitutive material derived from Subbottom Geologic Structure (EV-302).

INFL - Initial settlements of structures occur when the soil material compresses elastically. This is usually a small percentage of the total settlement of structures on cohesive material but is a larger percentage of cohesionless settlement. Elastic deformation is recoverable. Imbedment anchors under continuously applied pullout loads have been known to fail due to the creep phenomenon.

MEAS - Elastic properties are determined from unconfined compression and triaxial shear tests. Viscous and creep properties are best determined by testing of the material under modeled (or actual) loading conditions.

EV-304.1.14 Dynamic Characteristics

DEFN - Dynamic characteristics of soils are those affecting the response of soils and structures due to dynamic loadings. They include moduli of elasticity, bulk moduli, sound velocities, Poisson's ratio, damping coefficients, etc. Selection of the type of rheological model for portraying soil response to induced dynamic loading dictates the properties required.

INTER - Dynamic characteristics are determined by the soil type and method of placement (EV-302, EV-303). Void Ratio (EV-304.1.10), Porosity (EV-304.1.9) and Water Content (EV-304.1.8) affect all dynamic properties. Acoustic methods (EV-305.4) of measurement can be used for determining dynamic properties.

INFL - Dynamic characteristics of soils influence the response of foundations due to seismic loading and vibrations. Seismic loadings may induce liquefaction of granular soils causing foundation settlement and failure. Vibrations of foundation structures due to emplaced machinery, cable strumming, and to some extent vibrations induced by wind, wave, and current action can cause particle migration resulting in settlements and possible failure.

MEAS - Dynamic properties can be determined by acoustic measuring devices for in-situ material.

EV-304.1.15 Adhesion

DEFN - Adhesion is the tendency of a cohesive soil to develop a resistance to sliding or penetration due to the "stickiness" of the soil particles to objects placed in the soil. Unlike friction, it is independent of any normal loading on the soil system.

INTER - Adhesion relates directly with the cohesive portion (c) of Shear Strength (EV-304.1.3), e.g., the higher the shear strength, the higher the adhesion. Note that a coefficient of adhesion depends on the adhering surface as well as the cohesive material. Adhesion of clay to concrete will differ from adhesion of the same clay to steel.

INFL - Adhesion is used as the frictional force when computing resistances offered to piles when driven in soft to firm clay. It has a maximum value for the cohesive strength of soil. It can be used for estimating the sliding resistance of flat foundation elements due to gravity on a sloping surface, or their lateral load resistance.

MEAS - Adhesion is usually measured by fluid or laboratory tests in which the force required to extract a specimen of a particular material is measured directly and compared with the measured shear strength. This coefficient of adhesion relates the adhesive force to the shear strength.

EV-304.1.16 Friction

DEFN - Friction is defined as the resistance offered to an object penetrating or sliding on cohesionless soils. It is similar to Adhesion (EV-304.1.15) but depends upon normal loading (overburden pressure) in order to develop resistance. It is usually expressed as

$$f = K\,p\tan\phi$$

where,

f = friction force

K = coefficient (0.4 to 0.7)

p = effective overburden pressure

ϕ = friction angle

INTER - Friction relates directly with the friction component ($\tan \phi$) of Shear Strength (EV-304.1.3), e.g., the higher the shear strength, the higher the friction. As in Adhesion (EV-304.1.15), friction depends on the type of material resisting the soil.

INFL - Friction forces are used when computing resistances offered to piles in granular, noncohesive material.

MEAS - The coefficient of friction K is measured in field or laboratory tests in which the force necessary to extract a material specimen from granular soil under known overburden pressures is measured and compared with the known friction angle (ϕ) of the material.

EV-304.1.17 Wave-Induced Liquefaction

DEFN - Wave-induced liquefaction is a phenomenon in which surface storm waves induce rapid pressure changes in the pore water of a soil system such that flow out of the void system (permeability) is hindered and the pressure is transmitted to the soil grains.

INFL - This transfer of pressure to the soil grain system may destroy particle bonds or internal friction resulting in a "liquid" or fluid soil. Foundations designed to bear on intrinsically high shear strength soils are suddenly cast into a fluid (negligible shear strength) medium. The results can be catastrophic because the sustaining loads on the structure can cause overturning, sinkage, sliding, etc.

EV-304.2 Rock

DEFN - Rock is a naturally formed aggregate or mass of mineral matter, whether or not coherent, constituting an essential part of the earth's crust. It is generally considered by engineers to signify firm, coherent, or consolidated substances that cannot be excavated by manual methods only. Seafloor rock may be of igneous origin wherein molten material has cooled and extruded, or may be of sedimentary origin.

INTER - The presence of rock as a founding material is the result of geomorphological processes (EV-303) acting on Subbottom Geological Structure (EV-302).

INFL - Rock has a direct influence on foundation and/or anchor design since it provides the final reaction to any loads applied to or generated by ocean facilities.

EV-304.2.1 Shear Strength (Rock)

DEFN - The shear strength of rock specifies the ability of the material to resist shearing deformations. This resistance is specified by two parameters — cohesion and friction angle. The shear strength (τ) is expressed by the Coulomb equation

$$\tau = c + p \tan \phi$$

where,

c = cohesion
ϕ = angle of shearing resistance
p = pressure on shear surface

The shear strength of sedimentary rocks is strongly dependent upon its cementing agent, while the shear strength of igneous and metamorphic type rocks is influenced more by grain size, crystallinity, constituent material, and method of formation.

INTER - The shear strength property relates generally to other geotechnical properties, e.g., shear strength decreases with increasing Water Content (EV-304.2.6), and increases with increasing Density (EV-304.2.5) and Compressive Strength (EV-304.2.2).

INFL - Shear strength values may be used in design formulas for determining the bearing capacity of rocks as well as determining the holding power of anchors that have been drilled and/or grouted in rock.

MEAS - Shear strength measurements are made on core samples removed from the site under consideration. Shear strength values are determined from triaxial shear tests or unconfined compression tests.

EV-304.2.1.1 Competent Rock

DEFN - Competent rock is a volume or rock which under a specific set of conditions is able to support a tectonic force. Such a volume may be competent or incompetent a number of times in its history depending upon the environmental condition, degree and time of fracturing, etc. In strength theory, competent rock is capable of supporting a given bearing or bending load without failing.

INTER - Competent rock is dependent upon its Composition (EV-302.1) and Stratification (EV-302.2) for its inherent strength. Discontinuities (EV-302.5) may qualify rock as incompetent.

INFL - Competent rock will usually provide sufficient strength capabilities for foundations.

MEAS - The competency of rock can be determined by shear tests and unconfined compression tests.

EV-304.2.1.2 Discontinuity

DEFN - Discontinuity is defined as (1) a surface separating two unrelated groups of rocks is a fault; or (2) any interruption in sedimentation, whatever its cause or length, usually a manifestation of nondeposition and accompanying erosion is an unconformity break.

INTER - Discontinuities in rock specimens are the result of their Composition (EV-302.1), Stratification (EV-302.2), and Discontinuities (EV-302.5) in the overall Subbottom Geologic Structure (EV-302).

INFL - Discontinuities in rock strata may reduce the effective shear resistance of the rock by the presence of weak or easily deformed strata. Sharp local discontinuities (cracks, folds, etc.) will produce stress concentrations when loaded, which may lead to fracture of the foundation material.

MEAS - Discontinuities in rock specimens subjected to shear testing can be found visually.

EV-304.2.2 Compressive Strength

DEFN - The compression strength of rocks refers to the ability to resist compressive loadings. This compressive resistance acts simultaneously with the shearing resistance of the material. Compressive strength is a function of the material itself, grain size, cementing agent, method of formation, and most important, the lateral support offered by surrounding material. Unconfined compression testing of rock samples provide a "no support" condition and is directly related to the shear strength of the material.

INTER - Compressive strength relates generally to other geotechnical properties, e.g., compressive strength increases with (1) decreasing Water Content (EV-304.2.6), (2) increasing Density (EV-304.2.5), (3) increasing Shear Strength (EV-304.2.1), (4) increasing modulus of elasticity (EV-304.2.3.1).

INFL - Compressive strength values are used in design formulas for determining the "bearing value" of foundation rock. Usually the allowable "bearing value" is specified with a large factor of safety. The compressive strength then dictates the structure foundation design for FOF structures founded on rock.

MEAS - Compressive strengths are determined from triaxial compressive tests and unconfined compression tests.

EV-304.2.3 Deformation Characteristics

DEFN - The deformations (short of fracture) of rock foundations under imposed loadings may be due to several measurable characteristics. These may be elastic, plastic, shearing, or creep. Elastic and plastic deformations generally occur instantaneously with load application, but only the elastic portion is recoverable when the load is released. Shearing deformations may occur along bedding planes and may be elastic or plastic. Creep deformation is a time-dependent phenomenon during which permanent plastic flow of the material occurs. Sandstones and lava rock are particularly susceptible to plastic flow as they possess considerable cohesion and a small angle of internal friction.

INTER - Deformation characteristics are the result of determinations of Stress/Strain (EV-304.2.3.1) characteristics and Poisson's Ratio (EV-304.2.3.2). They are indirectly affected by Density (EV-304.2.5) and Water Content (EV-304.2.6).

INFL - Deformation characteristics must enter into computations for the structural design of foundations of rock if the foundation and primary structure are rigid frames that may be susceptible to high stresses caused by small relative deformations of the founding material. Rock anchoring devices may be influenced by the deformations of the surrounding rock, and may pull out under steady creep of the material.

MEAS - Deformation characteristics are determined from stress/strain tests.

EV-304.2.3.1 Stress/Strain

DEFN - Stress/strain characteristics of rock are typified by initial elastic response and subsequent plastic flow to failure. The ratio of stress to strain in the elastic range of stresses is the modulus of elasticity (E) which varies from 800 ksi for sandstones to 12,000 ksi for slates. Moduli may vary for differing directions in rocks due to the anisotropic nature of the material. Moduli may differ in tension and compression, and failure stresses are much lower in tension. Yielding of the material under constant stress may be instantaneous (plastic) or time dependent (creep).

INTER - Stress/strain characteristics and particularly shear strength are affected by Subbottom Geologic Structure (EV-302), Density (EV-304.2.5), and Water Content (EV-304.2.6). No generalization concerning the behavior of "E" due to these interrelationships can be made.

INFL - Stress/strain characteristics are necessary for the design of foundations where loadings may cause excessive deformations and limit the function of the primary structure by displacement or inducing critical stresses.

MEAS - Stress/strain characteristics are determined from unconfined compression tests on cored samples.

EV-304.2.3.2 Poisson's Ratio

DEFN - Poisson's ratio is defined as the ratio of lateral strain to axial strain when load is applied in the axial direction on a material. It is then a ratio of lateral "contraction" to axial "extension" under axial tensile loads. The same definition holds true in axial compression. The anisotropy of some sediments or other rocks may dictate different Poisson's ratios for differing loading directions. Poisson's ratios may vary from 0.1 to 0.3, depending on both material and direction.

INTER - Poisson's ratio is affected by the internal structure of a given material.

INFL - Poisson's ratio enters into computations for determining the resulting stresses induced in a foundation mass by imposed loadings. The variation in value of Poisson's ratio usually has a relatively small effect on engineering predictions (Ref 12).

MEAS - Poisson's ratio is usually determined from unconfined compression tests on cored samples, but may also be determined by sonic means on cored samples.

EV-304.2.4 Seepage Characteristics/Permeability

DEFN - Seepage characteristics of rock are generally confined to porous, sedimentary type rock and reflect the ability of the rock stratum to allow the flow of a fluid or gas under the influence of hydraulic gradient, gravity, or imposed pressure system. The degree of permeability of rock depends upon the size and shape of the pores in the rock, the size and shape of their interconnections, and the extent of the latter.

INTER - Seepage characteristics/permeability are interrelated with the processes forming the rock system or simply the Subbottom Geological Structure (EV-302) and Geomorphology (EV-303).

INFL - The permeability of founding rock structures can affect foundation design if it is known that the load-bearing stratum contains water-filled voids that will carry the load system (and possibly generate stress concentrations) instead of the rock. The transfer of load to the rock strata is dependent on the ability of the void water to escape, e.g., its permeability. The seepage characteristics of founding material in which liquids are to be stored (undersea fuel depots, etc.) requires attention, since the difference in specific gravities of the fluids generates a hydraulic gradient, thereby causing flow.

MEAS - Permeability of rock is determined by ASTM tests. Units are those of velocity (ft/min, cm/min). Seepage flow (Q) is determined by Darcy's Law (EV-304.1.2):

$$Q = kiA$$

where,

k = coefficient of permeability

i = hydraulic gradient

A = pore area

EV-304.2.5 Density

DEFN - The density of rock is specified as its weight per unit volume. The volume usually includes the void system; hence, the density cannot be used directly as a measure of material specific gravity. In ocean bottom masses the void systems are assumed to be full of water (100 percent saturation). Care should be exercised in using density values under water to account for the salt water buoyant effect.

INTER - Densities of rocks are the direct result of the tectonic forces governing the Subbottom Geologic Structure (EV-302) and Geomorphology (EV-303) of the area.

INFL - The density of rock may influence foundation design insofar as it is an indicator of the relative hardness of the material, which will influence drilling and anchoring.

MEAS - Standard ASTM methods are used to determine the density of rock specimens. In-situ densities can be determined by acoustic methods.

EV-304.2.6 Water Content

DEFN - Water content is the amount of water contained in a porous sediment or sedimentary rock and is generally expressed as the ratio of the weight of water (corrected for salt content if present) in the sediment to that of the dried sediment, multiplied by 100.

INTER - Water content relates directly to the Density (EV-304.2.5) of a sample because it indicates the amount of water in the void system.

INFL - Water content influences foundation conditions generally as an indication of the type of rock to be encountered. If, however, moisture is unable to flow from rock or if the seepage is restricted, portions of the imposed foundation load on the rock may transfer directly to the water, resulting in stress concentrations.

CALC - Water content is determined according to ASTM procedures. The equation is the same as for soil Water Content (EV-304.1.8).

EV-305 GEOPHYSICAL PROPERTIES

DEFN - Geophysical properties include gravity, electrical conductivity, magnetic susceptibility, radioactivity, heat flow, and acoustic waves.

INTER - Geophysical properties provide — by direct measurement, deduction, and induction — knowledge concerning Subbottom Geologic Structure (EV-302), Geomorphology (EV-303), and Geotechnical Properties (EV-304), and may give information concerning the probability of Seismic Activity (EV-306).

MEAS - Geophysical properties are measured by instrumentation unique to the property sought, e.g., gravity meters, magnetometers, resistivity potentiometers, radioactive sondes, geochronometers, and acoustic waves.

EV-305.1 Gravitational Anomalies

DEFN - Gravitational anomalies are deviations in magnitude and direction from uniform or regular gravity fields, usually indicating inclusions of differing materials in sea bottom sediments.

INTER - Gravitational anomalies may indicate differences in sea bottom Composition (EV-302.1), Stratification (EV-302.2), Spatial Variation (EV-302.3), Rock Protrusion (EV-302.4), and Discontinuities (EV-302.5). The anomalies may substantiate geomorphological origins (EV-303.1) and activity (EV-303.2).

INFL - Gravitational anomalies may influence site selection for ocean structures due to the possibility of intrusions, etc., affecting deep foundations, as well as when equipment sensitive to gravity variations is to be installed.

MEAS - Gravity measurements are made using a gravimeter, which provides sensitive weight measurements and therefore variations for a known constant mass when moved from place to place.

EV-205.2 Magnetic Anomalies

DEFN - Magnetic anomalies are local variations in space and time from the earth's average magnetic field. The earth's magnetic field strength is weak, decreasing from a high at the magnetic poles to a low at the magnetic equator. The average field of the earth in the Northern Hemisphere is about 50,000 gammas, and varies slowly on a daily basis (diurnal variations). Solar flares and magnetic storms cause fluctuations in the earth's magnetic field strength which are greater during years of maximum sun-spot activity.

INTER - The earth's magnetic field in the water may be utilized to measure ocean Currents (EV-202).

INFL - Magnetic measurements can be carried out in deep water if suitable provision is made to enable instruments to work under high pressure and low temperature (approximately 0 °C). The depth does not affect the measurements except where there are anomalies.

MEAS - Magnetic measure is the gamma which is equivalent to 10^{-5} oersted ($1/400\pi$ amp/m). Magnetic compasses may be used for determination of direction in the ocean at any depth. Fluxmeters and nuclear resonance magnetometers are used for measuring the field magnitude.

EV-305.3 Conductivity/Resistivity

DEFN - Conductivity/resistivity methods are electrical exploration methods in which current is introduced into the ground by two contact electrodes and potential differences are measured between two or more other electrodes. The resistivity curve generated by the traveling electrode is used to determine the nature of the strata penetrated.

MEAS - Measurements are made of potential differences using contact electrodes placed in the ground.

EV-305.4 Acoustic

DEFN - The acoustic properties of rocks and soils are used as identifiers of bottom and subbottom material. More specifically, it is the difference in acoustic velocities of various materials which is used for identification.

INTER - Acoustic methods can be used to define Bottom Topography (EV-301), Subbottom Geologic Structure (EV-302), and provide information about the Geomorphology (EV-303) of the area. Some success has been made in using acoustic methods for prediction of median grain size (EV-304.1.1), Porosity (EV-304.1.9), and density (EV-304.1.5) of soils. Acoustic methods are used for determining Dynamic Characteristics (EV-304.1.14) of soils.

MEAS - Acoustic profiling measurements are made in-situ using sound source systems (sparkers, detonators, etc.) for signal initiation and geophones for signal recovery.

EV-306 SEISMIC ACTIVITY

DEFN - Seismic loading of a structure is due to the accelerations and translations of the ground support due to earthquake or volcanic action.

INTER - Seismic activity is the result of geomorphological processes (EV-303) taking place in Subbottom Geologic Structures (EV-302). Seismic activity is particularly apparent along Discontinuities (EV-302.5). Seismic activity can cause liquification of granular soils (EV-304.1.1) resulting in loss of Shear Strength (EV-304.1.3) and catastrophic failure. Seismic activity is particularly likely along the boundaries of the continental plates (plate teckonics).

INFL - The governing parameter for seismic design of land-based structures is the lateral motion (force) factor. In undersea structure design, however, because the mass of the structure may be several times larger than the submerged buoyant static weight, the vertical component of force can also assume large proportions.

On the sea floor, loads and forces due to seismic accelerations arise from the inertia of the structure (as on land-based structures) and also from the incompressibility, inertia (added mass), and viscosity of the surrounding water. Catastrophic failures are not uncommon in areas of seismic activity.

MEAS - Seismic activity is measured from records of volcanic and earthquake action usually expressed as Richter scale values. Seismic activity may be predicted from geomorphological comparison with known histories of similar areas.

EV-307 BIOLOGICAL ASPECTS/BURROWING

DEFN - Animal undermining refers to the removal of material beneath a foundation due to the burrowing of sea life that may consider the emplaced object a new reef.

INTER - Burrowing has been observed at all depths in some form or other. Coupled with Scouring (EV-309.1), the effect may be to degrade a foundation's lateral load capability and cause overturning.

INFL - Burrowing can be retarded (and possibly totally inhibited) by the addition of deep penetrating "skirts" around the foundation.

MEAS - Predictions of the extent of animal burrowing can only be made by observation at comparable test sites or by observations taken in the area of the proposed site.

EV-308 SEAFLOOR/FOUNDATION INTERACTIONS

DEFN - Foundations necessarily interact with the seafloor environment and are subject to loadings induced by the environment and their response to loading and behavior affected by the environment itself. Examples of this interaction are foundation settlements and foundation failures.

INTER - Foundation/seafloor interactions are a result of foundation loads imposed on the Subbottom Geologic Structure (EV-302). Loading reactions are governed by the Geotechnical Properties (EV-304) of the support material. Loadings can be induced on foundations by Bottom Topography (EV-301) and Seismic Activity (EV-306).

INFL - Foundation loads directly affect the material upon which the structure is founded. The material, in turn, when subjected to the applied load, will affect the behavior of the structure.

MEAS - Seafloor/foundation interactions are measured by the observed behavior of the primary structure and its foundation.

EV-308.1 Foundation Settlement Parameters

DEFN - Foundation settlement parameters are considered to be the modes in which displacements of FOFs occur due to consolidation of the load-bearing soil structure. They include immediate, long-term, and differential settlements.

INTER - Foundation settlement parameters depend directly on the elastic responses (EV-304.1.13), Consolidation (EV-304.1.6) characteristics, and the Shear Strength (EV-304.1.3) of soils. They depend on the Deformation Characteristics (EV-304.2.3) of rock.

INFL - Installation of a FOF on any ocean bottom surface causes an immediate load transfer to the bearing strata. The induced stress on the bearing strata can cause measurable settlements of the FOF (except on a rock or rocklike surface). Some settlement will occur immediately during structure placement. Further settlement may take place as the imposed load/soil stress system equilibrates. In the event that soil characteristics differ under the FOF foundation, or if the FOF loading is eccentric, differential settlement may take place, causing tilting of the structure. Excessive settlements of the FOF (axial and differential), negate its function if (1) equipment becomes buried, (2) excessive loads are placed on the surface anchoring structure, (3) equipment may become misaligned, (4) tilting may be aggravated to an overturning failure, or (5) tilting may expose foundation undersides to facilitate scour, animal burrowing, etc.

EV-308.1.1 Immediate Settlement

DEFN - Immediate settlement occurs as the FOF load is transferred to the soil surface.

INTER - The first part of the displacement occurs as the soil structure compresses elastically (EV-304.1.13). This is usually a small amount and is outweighed by plastic deformation as bearing capacity failure surfaces beneath the structure are generated and the Shear Strength (EV-304.1.3) of the soil is mobilized along these failure surfaces.

EV-308.1.2 Long-Term Settlement

DEFN - Long-term settlement occurs as the soil stress system proceeds to come to some form of equilibrium. In clay soils, this disequilibrium is maintained by excess pressure in the pore water system.

INTER - As the pore water is allowed to permeate through the void system, the load is transferred to the soil grain system causing the grains to migrate away from the load, thus inducing Consolidation (EV-304.1.6) of the material and subsequent settlement of the structure. Settlement may also occur due to the Creep (EV-304.1.13) of the soil grain system due to the imposed load. Creep is independent of the pore pressure system and can occur in cohesionless as well as cohesive soils.

EV-308.1.3 Differential Settlement

DEFN - Differential settlement occurs when a portion of a structure settles more than the rest. The result may be a tilting of the structure or the inducing of large stresses in the primary structure.

INTER - Differential settlement is generally long term; hence, interrelations discussed in EV-308.1.2 are valid.

EV-308.2 Foundation Failure Parameters

DEFN - Foundation failures on the ocean bottom surface can be defined as the inability of a structure to complete its mission satisfactorily due to excessive movement of the structural base. In some instances, a failure mode deemed catastrophic for a particular mission (small angular or spatial displacements that disrupt equipment alignment, spatial orientation, etc.) may be of no consequence to other types of structures whose mission is insensitive to small displacements. In general, however, catastrophic motions of the foundation will negate a mission.

INTER - Foundation failure parameters depend upon elastic responses (EV-304.1.13), Consolidation (EV-304.1.6), characteristics and bearing capacity developed through Shear Strength (EV-304.1.3).

INFL - Driving forces contributing to failure include the structure loads and eccentricities, and environmental loads such as:

- Current drag
- Scour
- Undermining

- Wave-induced forces
- Seismic effects
- Scope (lateral load)
- Scope instability
- Turbidity currents

The failure phenomena instigated by these driving forces are dependent upon the response of the soil structure to these loadings. They include foundation instabilities (bearing capacity, rotational, lateral), uplift, and breakout.

EV-308.2.1 Bearing Capacity Instability

DEFN - Bearing capacity instability is the catastrophic motion of a foundation due to the inability of the soil structure to support the induced loadings along the soil failure surfaces.

INFL - Bearing capacity failures generally occur in purely cohesive material, of which ocean bottom sediments are typical, and rarely in cohesionless material (sands). The failures may be an excessive axial (vertical) displacement of the structure in which the soil rupture surface extends in a symmetric pattern about the footing. More likely, however, is the bearing capacity failure in which the possible downward motion of a foundation is not restrained in any manner, so that the foundation is free to rotate about any one of its edges.

EV-308.2.2 Rotational Instability

DEFN - Rotational instability is the catastrophic angular rotation of a foundation.

INFL - The rotation may be caused by eccentric axial loading of the foundation or imposed lateral loading of the structure above the foundation due to current drag or any other moment development load. Overturning may also be caused by weak soil strength on one side of the foundation, which would permit rotation and subsequent failure.

EV-308.2.3 Lateral Instability

DEFN - Lateral instability is the sideways translation of a foundation.

INFL - Lateral instability may be caused by a lateral loading of the structure, which induces failure loading in the soil structure. It may also occur on slopes where the lateral (downslope) component of the foundation load induces soil failure.

EV-308.2.4 Uplift

DEFN - Uplift failure of a foundation is the release of the vertical restraint retaining foundation/soil-surface contact.

INFL - Uplift may be caused by upward vertical forces induced on the structure by mooring lines, the upward force of wave action on a fixed structure, or currents. In mat or spread footing foundations, it is characterized by the inability of the foundation mass to restrain the load. In pile foundations, the uplift is characterized by the inability of the soil to maintain sufficient friction on the pile surface (negative skin friction) to restrain movement.

EV-308.2.5 Breakout

DEFN - Breakout failure for a foundation can be defined as the inability to release a foundation from a given position.

INTER - Breakout resistance is characterized by the Adhesion (EV-304.1.15) of the soil to the foundation and the development of negative pore pressure (suction) in the lifting operation. It is a problem in cohesive soils only, as the Permeability (EV-304.1.12) of cohesionless soils allows practically free movement of the water in the soil void system to eliminate negative pore pressure.

INFL - FOF mission requirements may be jeopardized if breakout and subsequent movement of a structure is not accomplished.

EV-309 SEA/SEAFLOOR INTERFACE

DEFN - The sea/seafloor interface is the meeting of the ocean environment with the sea floor environment on the sea bottom.

INTER - The Seafloor Environment (EV-300) interacts with the Ocean Environment (EV-200) causing Scouring (EV-309.1), Accretion (EV-309.2), and Turbidity Currents (EV-309.3) at the sea/seafloor interface.

EV-309.1 Scouring

DEFN - Scour is the removal of sediment material around a foundation due to water movement at the structure/soil interface.

INTER - Scour may be enhanced by animal undermining. Scour is dependent on Current Speed (EV-202.4) affecting soil particles (EV-304.1), and can also be induced by storm waves (EV-401) (oscillatory) at depths to 100 m.

INFL - Scouring of materials from a foundation can degrade its capability for withstanding lateral loadings and can increase the probability of failure due to overturning.

MEAS - Visual means are required for determining the extent of scour.

EV-309.2 Accretion

DEFN - Accretion at the sea floor is the gradual addition of new material to the old by sedimentation.

INTER - Accretion directly interrelates with Bottom Topography (EV-301), Subbottom Geologic Structure (EV-302), and Geomorphology (EV-303). The type of material sedimented affects the Geotechnical Properties (EV-304) and Geophysical Properties (EV-305) of the founding material.

INFL - Sediment deposition influences the design of and site selection for foundation structures to the extent that both topographic features and material properties must be considered.

MEAS - Accretion, or sedimentation, is measured in terms of its deposition (centimeters, etc.) per year.

EV-309.3 Turbidity Currents

DEFN - Turbidity currents are soil/water currents in which the soil is carried in suspension by the water resulting in a very dense fluid (up to 2000 kg/m^3).

INTER - Turbidity currents generally occur on seafloor areas having a Surface Gradient (EV-301.1). Stratification (EV-302.2) of sediment layers may create a surface on which unconsolidated sediments are prone to move due to Seismic Activity (EV-306). The unconsolidated sediments have a low Shear Strength (EV-304.1.3).

INFL - The effect of turbidity currents is to drastically change the buoyant weight of any structure to the extent that it may "float" resulting in mission failure. These currents may be triggered by: man-made disturbances such as the screws of a submersible; agitation of the sediments by waves and currents; and a phenomenon similar to slope instability in which a density current is generated rather than a slump.

Turbidity currents are the fastest known currents in the ocean. They can cause severe damage to ocean structures. For example, a high-speed turbidity current caused a sequential series of submarine cable breaks in the North Atlantic off Nova Scotia.

Such currents also make it difficult to operate submersibles due to poor visibility as well as the thruster power that is required to compensate for the strong currents.

EV-400 AIR/SEA/LAND INTERFACE

DEFN - The sea/land interface is the sea bottom across which there is a density change from approximately 2.5 to 1.06 g/cm^3. The air/sea interface is the sea surface where the density change is from about 1.03 to 0.0013 g/cm^3. The interface between the sea surface and land is the coastline. This section discusses the combined interface of the sea bottom, sea surface, and coastline.

The breakdown structure for Air/Sea/Land Interface is presented as Fig. EV-400-1.

INTER - The air/sea interface is molded by the Atmospheric Environment (EV-100) and the Ocean Environment (EV-200). A strong interrelation exists among the Physical Properties (EV-101) of the atmosphere and the imparting of energy by Winds (EV-102) to form Surface Waves (EV-401). Meteorological Phenomena (EV-105) provide enormous amounts of energy which reacts with the sea surface. The Physical and Chemical Properties (EV-201) of the ocean environment in turn affect the creation of surface waves and sea ice. Currents (EV-202) bring colder waters into contact with warmer air, causing some meteorological phenomena.

All phenomena affecting the ocean, the atmosphere, and the land take their origin from the air/sea surface. All the energy absorbed by the ocean or given off by it must pass through these interfaces, and this energy entering or leaving the ocean is the basic cause of all the phenomena and changes of state in the water mass and of near-shore and shoreline changes. (For Seismic Activity see EV-306.)

INFL - The interactions that occur at the air/sea interface influence the structural design, protection considerations, recovery, and mission success of the facility. The site selection is thereby influenced.

Although the phenomena that are observed at the shoreline pose many complex problems for ocean engineering in general, they do not have a major bearing on the design and construction of FOFs, which are generally installed offshore. One important exception is concerned with the frequent need for cable communications with FOFs which must be brought ashore, and therefore must pass through (and survive) the triple interface at the coastline.

AIR/SEA/LAND INTERFACE
EV-400

SURFACE WAVES (DEEP WATER)
EV-401

401.1 Types
- 401.1.1 Sea
  - 401.1.1.1 Gravity Waves
  - 401.1.1.2 Capillary Waves
- 401.1.2 Swell
- 401.1.3 Fetch

401.2 Speed
- 401.2.1 Composite
- 401.2.2 Particle Velocity
- 401.2.3 Particle Dispersion

401.3 Direction

401.4 Dispersion

401.5 Mass Transport/Inertia

401.6 Characteristics
- 401.6.1 Height
- 401.6.2 Period/Length
- 401.6.3 Spectrum

401.7 Spray

401.8 Breaking Height

401.9 Wave Loading Analysis
- 401.9.1 Static Analysis
  - 401.9.1.1 Wave Forces and Moments
  - 401.9.1.2 Subsurface Pressure
  - 401.9.1.3 Hydrodynamic Drag and Inertia Coefficients
- 401.9.2 Dynamic Analysis

401.10 Wave Prediction Methods for Design of FOFs
- 401.10.1 SMB Method

WAVES (SHALLOW/RESTRICTED WATERS)
EV-402

402.1 Breakers/Surf

SEA ICE
EV-403

403.1 Types
- 403.1.1 Drift
- 403.1.2 Icebergs
- 403.1.3 Pack
- 403.1.4 Ice Islands

403.2 Statistics of Occurrence

403.3 Speed

403.4 Direction

403.5 Composition
- 403.5.1 Salinity
- 403.5.2 Density
- 403.5.3 Structure

403.6 Formation

403.7 Icing

403.8 Ice Forces

LITTORAL TRANSPORT
EV-404

EROSION
EV-405

RIVER DISCHARGE
EV-406

SEA LEVEL VARIATION
EV-407

407.1 Storm Surges

407.2 Tides

407.3 Tsunami

407.4 Seiches

407.5 Wave Setup

SHORE CHARACTERISTICS
EV-408

408.1 Beach Topography

408.2 Beach Geology

Fig. EV-400-1 Air/Sea/Land Interface – Breakdown Structure

EV-401 SURFACE WAVES (DEEP WATER)

DEFN - Surface waves in deep water are those waves formed by the transfer of energy from the wind to the water. This transfer of energy is related to (1) dynamic pressure differences feeding energy into the wave as the wind is deflected at the air/sea interface, and (2) moving pressure fluctuations of turbulent wind resonating the water surface into waves. A discussion of surface wave Types (EV-401.1), Speed (EV-401.2), Direction (EV-401.3), Dispersion (EV-401.4), Mass Transport/Inertia (EV-401.5), Characteristics (EV-401.6), Spray (EV-401.7), and Breaking Height (EV-401.8) follows.

INTER - Increases in surface waves usually result from increases in wind Speed (EV-102.1) as well as Duration and Fetch (EV-102.3). Physical and Chemical Properties (EV-201) determine the response of the ocean waters to the wind stress.

INFL - Surface waves are one of the most important sources of loading on FOFs. Wave loads are basically dynamic in nature but can be adequately represented by static analysis. In extremely deep water and where structures are more flexible, a dynamic load analysis must be performed to consider resonance effects. Due to this loading, surface waves influence the structure's design, construction, installation, protection, and foundation (if bottom mounted).

MEAS - Surface waves are measured using optical methods above the surface; accelerometers, wave staffs, and drag force methods at the surface; and pressure and acoustic methods below the surface.

EV-401.1 Types

DEFN - The types of surface waves in deep water are those waves classified as Sea (EV-401.1.1) and Swell (EV-401.1.2). The Fetch (EV-401.1.3) or fetch length and its relationship to seas are also described.

INTER - The Airy Theory, which has a sinusoidal wave form and an oscillatory motion, does not accurately predict actual ocean wave surface profiles and Mass Transport (EV-401.5). The finite amplitude theories of Stokes to the second and higher orders more nearly account for these phenomena and more closely estimate water Particle Velocity (EV-401.2.2) and subsurface pressure. The Stokes second-order surface profile is more peaked at the crest and flatter at the trough, with more than half of the wave Height (EV-401.6.1) above the stillwater level.

Dean's Stream Function theory makes assumptions similar to Stokes' theory and may possibly describe naturally occurring wave phenomena better than other theories. Dean's theory has been applied to the calculation of wave forces and moments. Due to its complexity of series expansion terms, it is presented in tabular and graphical form. Figure EV-400-2 (Ref. 4) shows the regions of validity for the various wave theories. A relative amplitude parameter H/T^2 is plotted versus a relative depth parameter d/gT^2.

INFL - It is important to indicate the particular theory from which wave parameter calculations are based because each theory employs certain simplifying assumptions that can greatly affect the subsequent wave loading computations. Thus, a FOF can be overdesigned or underdesigned depending on the wave theory used.

CALC - In order to adequately represent these types of surface waves, relative depth and relative amplitude criteria are used for determining the validity of a particular mathematical theory. Deepwater conditions imply a relative depth ratio d/L (ratio of water depth d to wavelength L) greater than 0.5, which permits certain simplifying mathematical assumptions. Relative amplitude is the ratio of wave amplitude to wavelength. The two types of theories are the small amplitude (Airy theory) and the finite amplitude theories of Stokes and Dean. Small amplitude theories do not assume linearity. Second and higher order terms are retained.

EV-401.1.1 Sea

DEFN - Sea is defined as those waves in a region where they are being actively generated by wind. They are usually steep waves with a wavelength 10 to 20 times the wave height. As a result of this interaction with the wind, a highly complex sea surface condition develops with individual waves and wavetrains of varying periods and heights moving in many directions. This complexity of waves is known as a wave spectrum. Most of the energy in this spectrum is usually concentrated in a narrow band of frequencies or periods with possibly one wave period being the dominant.

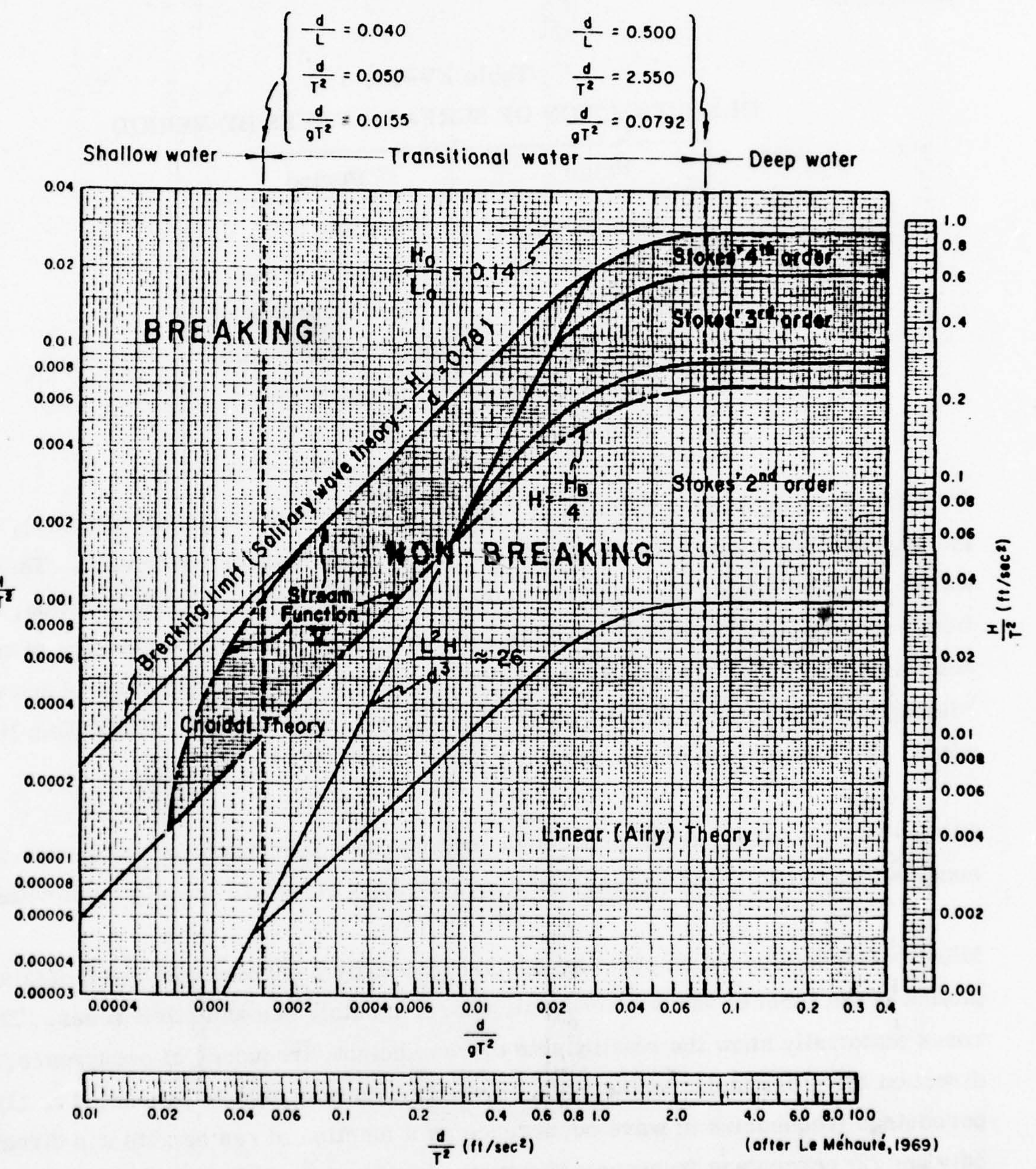

Fig. EV-400-2 Regions of Validity for Various Wave Theories

Table EV-400-1 shows the classification of surface waves by periods. Gravity Waves (EV-401.1.1) and Capillary Waves (EV-401.1.1.2) are discussed in the following paragraphs.

Table EV-400-1

CLASSIFICATION OF SURFACE WAVES BY PERIOD

Name	Period
Capillary	0.1 sec
Ultragravity	0.1 to 1.0 sec
Gravity	1.0 to 30 sec
Infragravity	30 sec to 5 min
Long Period	5 min to 24 hr
Transtidal	24 hr

INTER - Sea waves are a function of Winds (EV-102), the Fetch (EV-401.1.3), and the Physical and Chemical Properties (EV-201) of the ocean environment. These waves increase in size (up to a maximum limit) as the wind velocity, duration, and fetch increase. Surface tension and molecular viscosity affect the creation of surface sea waves and their dissipation. Swell (EV-401.1.2) is a modified form of sea waves. Although seas are under the influence of the disturbing force that causes them (the wind), swell waves are free waves.

INFL - Sea conditions develop in the generating area of an atmospheric disturbance, such as a hurricane, and are the most devastating a structure usually must withstand.

MEAS - Sea data based on observations are generally combined with swell data and plotted in the form of annual, seasonal, and/or monthly sea and swell roses. These roses pictorially show the relationship of wave height, frequency of occurrence, and direction for a particular ocean area. Tabular data may also be presented as (1) percentage frequencies of wave occurrence as a function of sea heights and directions only and (2) percentage frequency of combined sea and swell height versus wave period. Duration data in the form of frequency of occurrence histograms, which illustrate total hours per year that waves in certain wave height groupings occur, may also be included.

CALC - The finite amplitude theories of Stokes and Dean provide the best representation of sea conditions.

EV-401.1.1.1 Gravity Waves

DEFN - Gravity waves, as classified by period, are those surface waves with a period between 1.0 and 30 seconds (see Table EV-400-1) whose velocity of propagation is controlled mainly by gravity. As classified by restoring force, gravity waves would encompass a larger frequency domain (see Fig. EV-400-3).

INTER - Both Sea (EV-401.1.1) and Swell (EV-401.1.2) are forms of gravity waves.

INFL - Gravity waves are the most important in consideration of fixed ocean facility design because they contain the largest amount of wave energy (see Fig. EV-400-3), particularly in the 5- to 15-second period range.

EV-401.1.1.2 Capillary Waves

DEFN - Capillary waves, as classified by period, are those surface waves with a period less than 0.1 second.

INTER - The velocity of propagation of capillary waves is primarily controlled by the Surface Tension (EV-201.4.3) of the sea water. Capillary waves usually have wavelengths less than 2.54 cm. They are often combined with gravity waves as small perturbations on the surface.

INFL - Capillary waves are of negligible importance to structure design.

EV-401.1.2 Swell

DEFN - Swells are those waves that have undergone decay as they move out of their generating area. They have progressed beyond the influence of the generating winds and have a direction essentially the same as they had in the generating area. As they travel they lose height, but maintain their period and wavelength. Wave heights tend to be reduced by 50 percent after traveling 1600 km from the generating area. This attenuation rate continues to increase with increasing distance. As a result, the steep

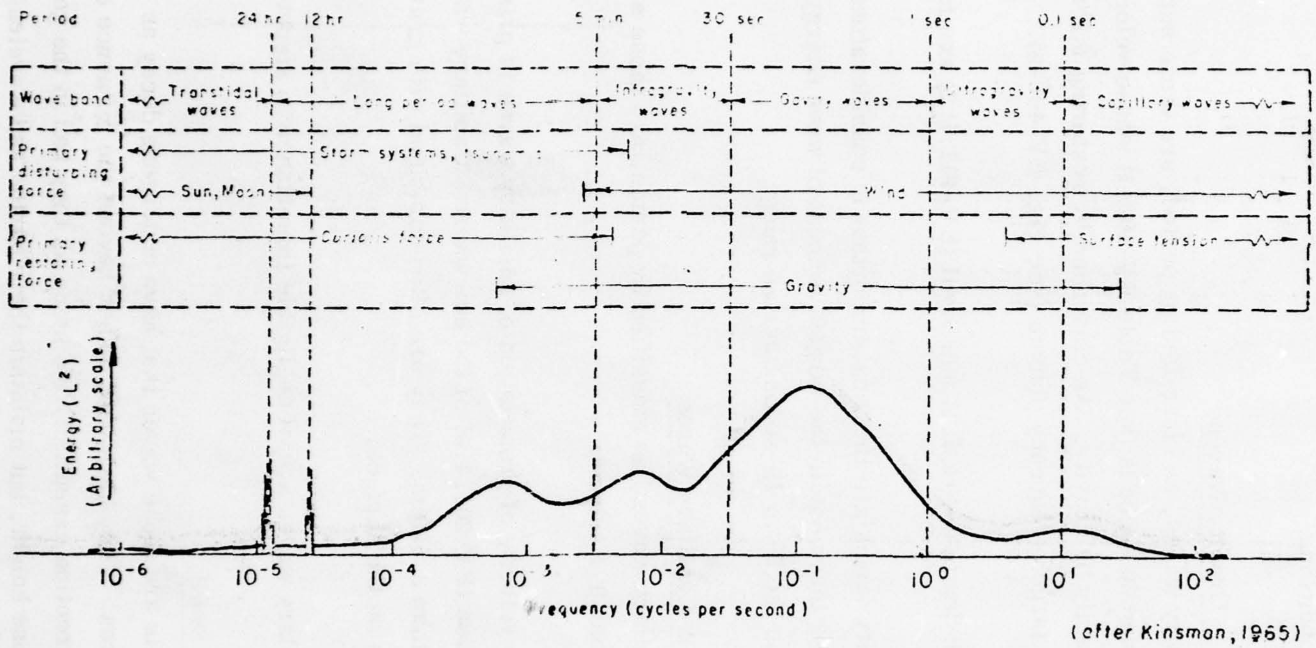

Fig. EV-400-3 Relative Energy Distribution of Ocean Waves vs. Frequency (Ref. 4)

waves originally in the wave spectrum are eliminated and only relatively long, low waves with wavelengths 30 to more than 500 times their wave height remain.

The outstanding characteristics of a swell, as contrasted with a sea, are its low, rounded crests, the comparative smoothness of its surface contours, its great length from crest to crest, and the broad sidewise expanse of its individual crests; its gentleness, in a word, contrasted with the fierceness of the waves that composed the storm sea from which it has developed (Ref. 13).

INTER - Sea (EV-401.1.1) and swell are generally present in the same area at the same time and may obscure one another. Swell characteristically exhibits more regular and longer Period (EV-401.6.2) and has flatter crests than seas (waves within their fetch).

MEAS - Swell data based on shipboard observations or buoy measurement are usually combined with sea data and displayed in the form of annual, seasonal, and/or monthly sea and swell roses. These roses pictorially illustrate the relationship of wave height, frequency of occurrence, and direction. Tabular data presented as percentage frequency of combined sea and swell height versus wave period may also be given. Duration data in the form of frequency of occurrence histograms can be constructed using the frequency of occurrence versus wave height data. These charts illustrate the total hours per year that waves in a certain wave height grouping occur.

CALC - Swell conditions can be closely approximated by linear, small amplitude, Airy theory. Wave energy is propagated according to the group velocity (EV-401.2.1).

EV-401.1.3 Fetch

DEFN - Fetch or fetch length is the horizontal distance over which a wind with a reasonably constant velocity and direction blows generating "sea" waves. It is measured in units of kilometers and has a range of 1.61 km to over 16,093 km.

INTER - The determination of fetch length is a very subjective process. Since this length greatly affects the resultant significant wave Height (EV-401.6.1) and Period (EV-401.6.2) predicted, caution must be exercised in delineating the fetch.

INFL - The fetch influences the size of the wave forecast and the consequential design considerations of the facility.

CALC - In the determination of fetch length, wind speed is assumed constant if variations do not exceed 9 km from the mean. However, wind speed variations of as little as 2 km actually affect results. The wind direction variations must not exceed 30 deg from the mean. A deviation exceeding 45 deg seriously affects results. Fetch limits are delineated by curvature or spreading of isobars, a shift in wind direction, or a discontinuity at a weather front.

EV-401.2 Speed

DEFN - Wave speed or celerity is the velocity of wave propagation, or phase velocity. It has dimensions of length/time.

INTER - Wave speed is a function of wave Period/Length (EV-401.6.2), wave number, and wave angular frequency. The ratio of wave angular frequency to wave number is a form of the Particle Dispersion (EV-401.2.3) relationship.

INFL - Wave speed is used to calculate the wave energy propagation speed or the group velocity (the velocity with which wave energy is propagated in swell).

CALC - According to small amplitude theory, gravity waves in deep water have an equation of the form

$$C_o = \frac{L_o}{T} = \frac{\sigma}{k_o} = \sqrt{\frac{g}{k_o}} = \frac{gT}{2\pi} = 1.56\ T$$

If both gravity and capillary waves are present, the celerity in deep water is

$$C_o = \sqrt{\frac{g}{k_o} + \frac{k\tau}{\rho}}$$

where,

C_o = deep water wave celerity, m/sec

L_o = deep water wavelength, m

T = wave period, sec

σ = wave angular frequency, $2\pi/T$ radians/sec

k_o = wave number, $2\pi/L_o$ m^{-1}

g = gravitational constant 9.81 m/sec^2

τ = surface tension, kg/m

ρ = sea water density, kg/m^3

It is seen that the first term for gravity waves is identical to the gravity wave celerity in the first equation. The second term considers the surface tension effect of the capillary wave.

EV-401.2.1 Composite

DEFN - The composite speed for the purpose of this report is the group velocity as defined by small amplitude theory. The group velocity is the propagation of a wave group characterized by a wave envelope of several superimposed individual waves separated by nodes of zero amplitude. Assuming two individual waves of equal amplitude but different periods, for some values of x at a given t, the wave amplitudes will be in phase and additive; and for some other values of x and t, they will be completely out of phase and cancel each other (Fig. EV-400-4). This velocity is different from the wave celerity or phase velocity of the individual waves. It has dimensions of length/time.

INTER - Wave energy is transported in the direction of the phase velocity but is propagated with the velocity of the group velocity. Waves with longer wavelengths travel faster than waves of shorter wavelengths (EV-401.6.2).

INFL - The interaction of waves on fixed ocean facilities is a function of wave energy and wave energy propagation as determined by the group velocity.

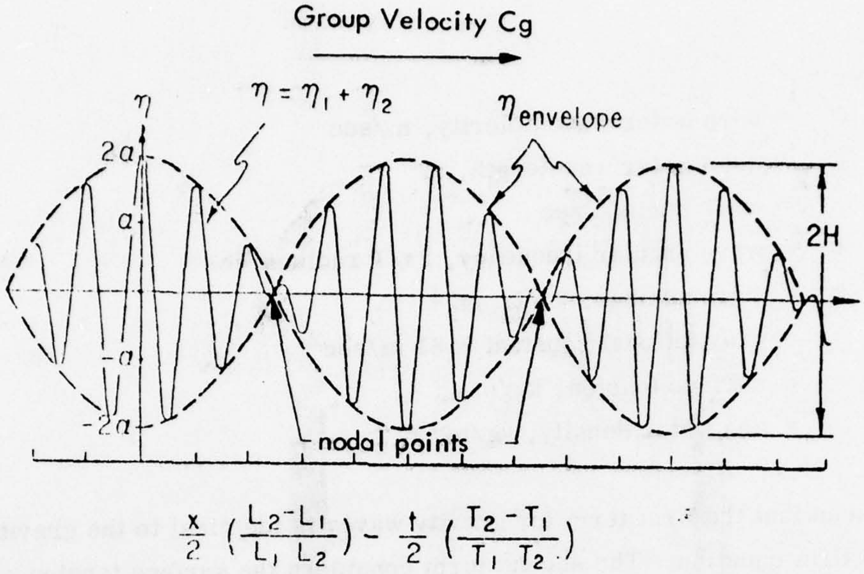

Fig. EV-400-4 Wave Energy Propagation and the Group Velocity Superposition of Two Harmonic Waves of Different Periods

CALC - The equation for the group velocity of gravity waves in deep water, according to small amplitude theory, is

$$C_g = \frac{d\sigma}{dk} = \frac{C_o}{2}$$

where,

C_g = group velocity in deep water, m/sec

C_o = deep water phase velocity, m/sec

$\frac{d\sigma}{dk}$ = change in wave angular frequency with respect to wave number

The group velocity for deep water gravity waves is 1/2 the phase velocity; whereas, for capillary waves, the group velocity is 3/2 the phase velocity.

EV-401.2.2 Particle Velocity

DEFN - The water particle velocities are the space-time average velocities of particle translation in the horizontal and vertical directions. These two components have units of meters per second.

INTER - Particle velocity, particle acceleration, and wave Height (EV-401.6.1) exhibit a temporal relationship which is a function of the particular wave theory selected.

INFL - Wave loadings on offshore structures are computed based on water particle velocities and accelerations that have been calculated based on wave period and height measurements.

MEAS - Wave particle accelerations are recorded using accelerometers.

CALC - The wave accelerations are integrated to obtain wave particle velocity and doubly integrated to obtain wave height. The horizontal and vertical water particle velocities are respectively

$$u = \sigma H e^{-kz} \cos(kx - \sigma t)$$

$$W = \sigma H e^{-kz} \sin(kx - \sigma t)$$

where,

- u = horizontal particle velocity in the x-direction, m/sec
- w = vertical particle velocity in the z-direction, m/sec
- H = wave height, m
- T = wave period, sec
- k = wave number, σ^2/g
- z = vertical distance below the surface, m
- x = horizontal distance in direction of wave propagation, m
- σ = wave angular frequency, $2\pi/T$ radians/sec
- t = time or duration, sec
- g = gravitational constant, 9.81 m/sec^2

In deep water, the horizontal and vertical water particle velocities are equal (see Fig. EV-400-5) and experience an exponential decay with depth below the surface.

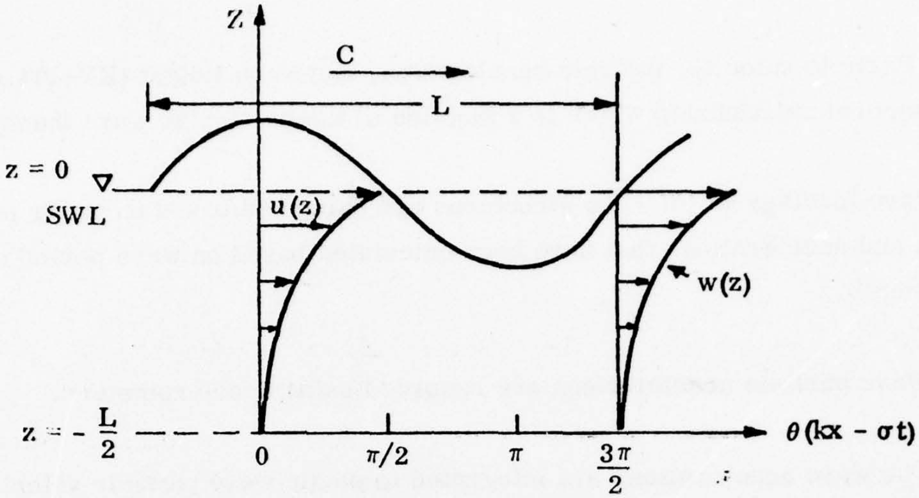

Fig. EV-400-5 Water Particle Velocity Variation with Depth

EV-401.2.3 Particle Dispersion

DEFN - Particle dispersion deals with the dispersion relationship by which the wavelength and wave speed is derived in small amplitude theory.

INTER - Particle dispersion is related to the wave Speed (EV-401.2) and the wave Period/Length (EV-401.6.2).

CALC - The formula for the dispersion relationship in deep water is

$$\sigma^2 = gk$$

which, when divided by the wave number squared, yields the wave speed relationship

$$\frac{\sigma^2}{k_o^2} = C_o^2 = \frac{g}{k_o} = \left(\frac{L_o}{T}\right)^2$$

where,

σ = wave angular frequency, $2\pi/T$ radians/sec

k_o = wave number in deep water, $2\pi/L_o$ m^{-1}

C_o = wave speed in deep water, m/sec

g = gravitational constant, 9.81 m/sec^2

L_o = wavelength in deep water, m

T = wave period, sec

EV-401.3 Direction

DEFN - Wave direction is the direction from which a wave advances. Generally, an eight point compass (N, NE, E, SE, S, SW, W, NW) is sufficient for delineating the wave direction. Wave crests are aligned perpendicular to the wave direction.

INTER - In shallow/restricted waters, the wave direction affects the wave refraction and diffraction. These changes in wave crest alignment as they pass from deep water to coastal waters affects the Littoral Transport (EV-404) phenomenon; shoreline Erosion (EV-405); Sea Level Variations (EV-406) due to storm surges, tsunamis, and seiches; and Shore Characteristics (EV-408).

INFL - The predominant direction of wave travel influences the overall design and orientation of the surface structure so as to minimize wave loadings. Site selection is also affected.

MEAS - Measurement of wave direction can be accomplished by the use of two or more wave recorders which simultaneously record wave profiles. A triangular configuration of the recorders is often used. Wave staffs and pressure transducers can be used as the recorders.

EV-401.4 Dispersion

DEFN - Wave dispersion refers to waves in a dispersive medium, a medium where their speed is a function of their wavelength. After leaving the generating area, wave energy is dispersed, spread, dissipated, transferred, and scattered. Thus, wave dispersion by lateral diffraction of wave energy is one of the greatest factors contributing to wave decay.

INTER - Selective attenuation whereby wave energy is spread over a larger and larger area, air resistance by opposing or following Winds (EV-102), and the waves' (EV-401) tendency to overrun Currents (EV-202) are also processes that contribute to decay of Swell (EV-401.1.2).

INFL - Wave dispersion is essential to an understanding of wave decay of swell.

EV-401.5 Mass Transport/Inertia

DEFN - Mass transport velocity $\bar{u}(z)$ according to Stokes theory is the net transfer of water by wave action in the direction of wave travel. This means drift velocity is defined as the distance a particle is displaced during one wave period when divided by the wave period.

INTER - According to laboratory experiments, water Viscosity (EV-201.4.1) has little effect on the mass transport phenomenon in deep water.

INFL - Numerous investigators have found that the vertical distribution of the mass transport velocity is modified so that there is zero net transport of water across a vertical plane.

CALC - According to Stokes theory, the mass transport velocity is

$$\bar{u}(z) = \left(\frac{\pi H}{L}\right)^2 \frac{C}{2} \frac{\cosh 2(kz + kd)}{\sin^2(kd)}$$

where,

$\bar{u}(z)$ = mass transport velocity, m/sec

H = wave height, m

L = wavelength, m

C = wave speed or celerity, m/sec

k = wave number, $2\pi/L$, m^{-1}

z = depth below surface, m

d = water depth, m

EV-401.6 Characteristics

DEFN - Wave characteristics are those wave parameters that are essential for a proper understanding of surface wave phenomena in deep water. Wave theories predict idealized monochromatic waves. In actuality, any wave field consists of waves of variable heights, periods/wavelengths, and spectra. Thus, statistical wave characteristics are used to describe the complex nature of these waves.

EV-401.6.1 Height

DEFN - Wave height is the vertical distance between the top of the crest and the bottom of the trough and is measured in meters.

The significant wave height H_s or $H_{1/3}$ is defined as the average height of the one-third highest waves and has units of meters.

INTER - Wave height is used to define the energy Spectrum (EV-401.6.3) of ocean waves. Specific portions of the total wave energy are contained in specific frequency and directional components. The wavefield may be described by more than one Period (EV-401.6.2) and more than one Direction (EV-401.3) of propagation.

INFL - Wave height, as related to wave amplitude, is one of the primary criteria used in the design of FOFs. Wave loadings (forces and moments) are calculated using design or significant wave heights of a statistical maximum storm event.

MEAS - Wave height and wave amplitude are measured using optical methods above the surface; accelerometers, wave staffs, and drag force methods at the surface; and pressure and acoustic methods below the surface.

The wave height occurring in a sea state have been shown to fit a Rayleigh distribution function (see Fig. EV-400-6). According to this distribution function for the significant wave height, the probability that it will be greater than any arbitrary value is given as a percent based on the root-mean-square height (H_{rms}). The equation for this relationship is:

$$H_s = 1.416\, H_{rms} = 1.598\, \overline{H} = 0.79\, H_{10} = 0.60\, H_1$$

where,

H_s = significant wave height, m

H_{rms} = root-mean-square wave height, m

$\overline{H}$ = average wave height, m

H_{10} = average of highest 10 percent of all waves, m

H_1 = average of highest 1 percent of all waves, m

Good engineering agreement between these parameters was found by Goodnight and Russell (Ref. 4) during experiments in the Gulf of Mexico with wave-gage observations.

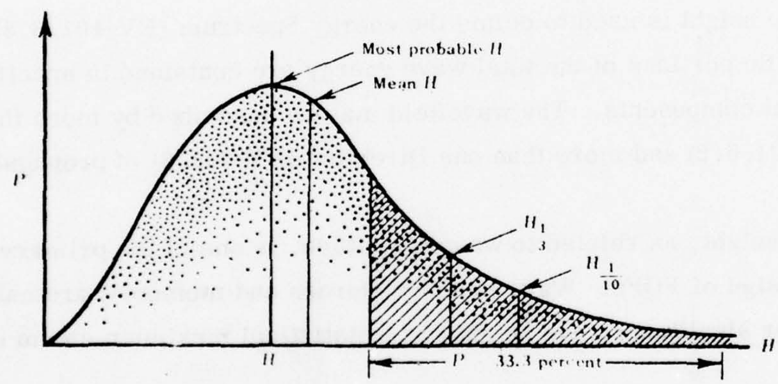

Fig. EV-400-6 Rayleigh Distribution Function For Wave Height Spectrum (Ref. 2)

EV-401.6.2 Period/Length

DEFN - The wave period is a measure of the time interval between successive crests passing a given point. It is a time parameter and has dimensions of seconds, although minutes and hours are sometimes used. The significant wave period is the corresponding average period of the one-third highest waves; the most frequently occurring of the larger, well-defined waves observed.

Wavelength is the horizontal distance between successive wave crests and is usually measured in meters.

INTER - Wave period is the fundamental reference for all wave parameters because it is independent of depth. However, for waves traveling many thousands of miles a gradual decrease in wave period would occur. Wave period is the same for all small amplitude and finite amplitude theories.

Wave period is used in the calculation of the surface profile, the wave length, wave Speed (EV-401.2), wave angular frequency, group velocity (EV-401.2.1), and water Particle Velocity (EV-401.2.2).

Wavelength is used to calculate wave number, relative depth, relative amplitude, Speed (EV-401.2), and water Particle Velocity (EV-401.2.2), as well as the speed of ocean waves.

INFL - Ocean structures are designed so as to minimize wave loadings by maintaining the natural resonant frequency of the structure well below the significant frequency (reciprocal of the significant period) of the waves. The significant frequency is that component frequency of the wave train possessing the largest portion of the total wave energy. The significant period is used in the calculation of wave forces and moments on fixed ocean facilities.

MEAS - Wave period and wavelength are measured by analysis of wave profile records as obtained by wave staffs, visual observation, and pressure transducers.

CALC - The wave period occurring in a sea state has been shown to fit a Rayleigh distribution function (see Fig. EV-400-7).

In deep water, the governing equation for wavelength according to small amplitude theory is

$$L_o = \frac{g T^2}{2\pi} = 1.56 T^2$$

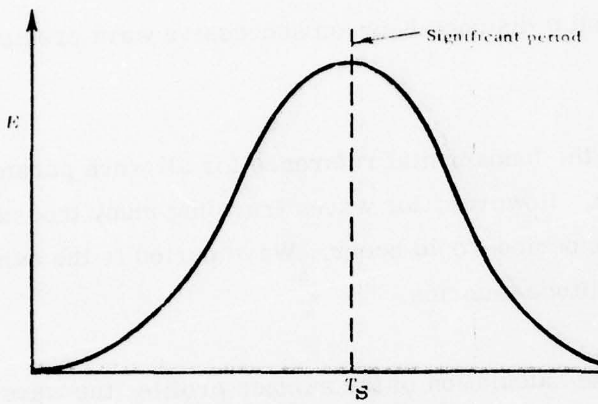

Fig. EV-400-7 Rayleigh Distribution Function For Wave Period Spectrum (Ref. 2)

where,

L_o = deep water wavelength, m

g = gravitational constant, 9.81 m/sec^2

π = 3.1416

T = wave period, sec

EV-401.6.3 Spectrum

DEFN - The wave energy spectrum E(ω) is the summation of fractions of the total wave energy possessed by specific frequency intervals. Recognizing that waves are complex and consist of many components of varying amplitude, the energy spectrum is a means of describing the relative importance of a wave field according to its frequency components. In addition to the energy spectrum, there is a directional wave spectrum, which is a means of calculating the total energy of a wave field based on the individual directional components. Wave energy is scattered in specific frequency interval components, and not all these wave components within a wave field are traveling in the same direction.

INTER - Both the energy spectrum and the directional spectrum are dependent on the wave Period (EV-401.6.2).

INFL - At this time, only advanced wave prediction models are capable of utilizing the directional spectrum concept. Practical engineering applications are not yet available.

CALC - The equation for the wave energy spectrum is obtained by integrating the energy densities over all frequency intervals.

$$\sigma^2 = \int_0^\infty E(\omega)\, d\omega = \frac{1}{2} \sum_{j=1}^{N} a_j^2$$

The total wave energy E is obtained by integrating the directional energy density E (θ,ω) over all directions and frequencies.

$$E = \int_0^{2\pi} \int_0^\infty E(\theta,\omega)\, d\omega\, d\theta$$

where,

σ = standard deviation of the wave record

$E(\omega)$ = wave energy spectrum function

a = wave amplitude of individual wave components

j = index of j^{th} wave component in the wave field

ω = wave components frequency, 1/T sec^{-1}

θ = wave component direction

EV-401.7 Spray

DEFN - Ocean spray is a sheet of droplets of water driven from the tops of waves by the wind. Spray is formed when winds exceed 16 knots.

INTER - Ocean spray is determined by wind Speed (EV-102.1), sea Waves (EV-401 and EV-402), and is a determinant of icing (EV-403.7).

INFL - Ocean spray influences visibility and icing.

MEAS - Ocean spray can be classified empirically from the Beaufort scale of sea state conditions.

Wind Speed/Sea State	Spray
Beaufort 5 to 6	Slight
Beaufort 7 to 8	Moderate
Beaufort > 8	Severe

EV-401.8 Breaking Height

DEFN - The maximum breaking wave steepness is defined as the condition when the water particle velocity at the crest is equal to the wave propagation speed, just before wave breaking occurs.

INTER - The maximum breaking wave height is a function of the wave Period/Length (EV-401.6.2).

INFL - The maximum breaking wave steepness is important for calculating the design height of the main superstructure above the mean water surface of a FOF (if bottom mounted), and determining maximum wave loadings due to breaking and/or nonbreaking waves.

CALC - In deep water, Stokes defined this criteria in terms of the wave steepness (H/L) where

$$\left(\frac{H_b}{L_{o_b}}\right)_{max} = 0.142$$

where,

H_b = wave height at breaking, m

L_{o_b} = wavelength at breaking in deep water, m

Another form of this relationship is

$$\frac{H_b}{T^2} = 0.875$$

where,

T = wave period, sec

The crest angle at maximum breaking was found to be 120 deg.

EV-401.9 Wave Loading Analysis

DEFN - Wave loading analysis is the analysis of the dynamic load effects of ocean waves on FOFs. A static analysis is used to approximate some dynamic effects with horizontal force and moment calculations. A dynamic analysis is employed to analyze the resonance phenomenon due to a dynamic coupling of the structure and the wave.

INTER - Wave loading is a function of sea water Physical and Chemical Properties (EV-201), Wind (EV-102), and fundamental wave parameters (EV-401).

INFL - Wave loading analysis is essential for proper design of a FOF in the ocean environment.

EV-401.9.1 Static Analysis

DEFN - Static analysis is an analysis of dynamic loading effects of offshore structures which can be represented by static concepts.

For rigid offshore structures (i.e., offshore platforms) in deep water an analysis of static wave loading includes forces and moments due to nonbreaking and breaking waves. Vertical cylindrical piles are of primary interest although (1) groups of vertical cylindrical piles, (2) nonvertical cylindrical piles, and (3) noncircular piles can be considered if more sophisticated analysis is required. The wave loading is proportional to an inertia or mass coefficient C_M and a drag coefficient C_D, which are functions of water particle acceleration in an ideal or nonviscous fluid and steady flow (water particle velocity constant) kinetic energy of a real viscous fluid, respectively.

INTER - The static analysis involves calculation of forces and moments, which are functions of sea water Density (EV-201.4.4), water Depth (EV-201.6.2), wave Period (EV-401.6.2), and wave Height (EV-401.6.1).

EV-401.9.1.1 Wave Forces and Moments

DEFN - Wave forces and moments are those forces and moments exerted by waves on the structure due to drag and inertia effects.

INFL - The wave force and moment equations given are based on Dean's Stream-function theory. Because of this theory's more accurate mathematical representation of ocean waves, the design wave loading calculated is more accurate than that predicted by Airy theory.

CALC - Figure EV-400-8 illustrates the variables important in wave loading calculations on a single, rigid, vertical cylindrical pile.

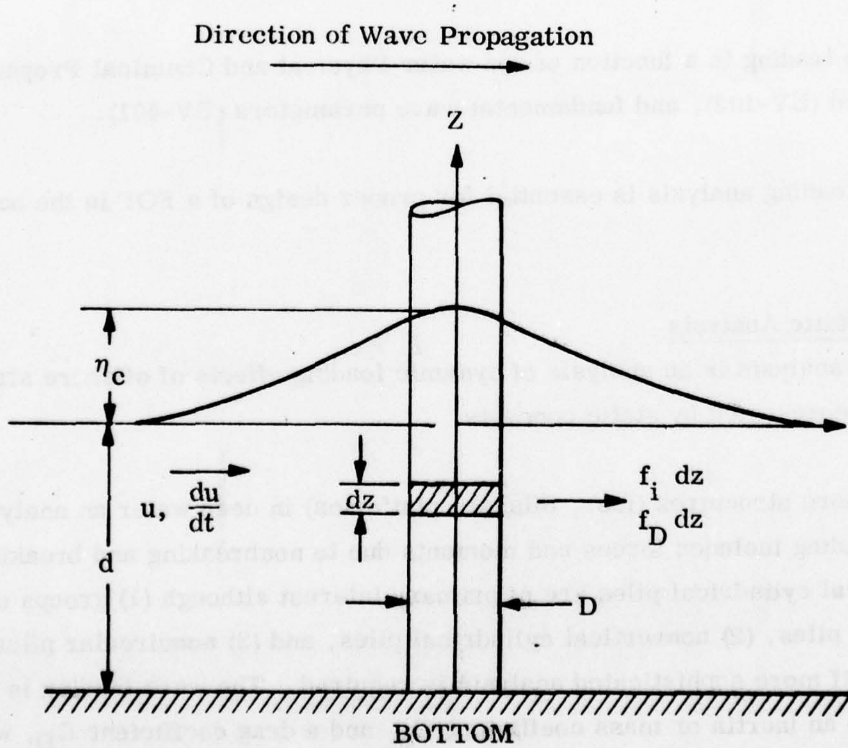

Fig. EV-400-8 Wave Loading on a Single, Rigid, Vertical Cylindrical Pile

The equations for the maximum inertia, drag, and total forces and moments are

$$F_{im} = C_M \rho g \, \pi D^2/4 \;\; H \, K_{im}$$

$$F_{Dm} = C_D \, \rho g/2DH^2 \;\; K_{Dm}$$

$$F_m = \phi_m \, \rho g \;\; C_D \; H^2 \; D$$

$$M_{im} = F_{im} \;\; d \;\; S_{im}$$

$$M_{Dm} = F_{Dm} \;\; d \;\; S_{Dm}$$

$$M_m = \alpha_m \;\; \rho g \;\; C_D \;\; H^2 \;\; D \;\; d$$

where,

F_{im} = maximum horizontal inertial force on a unit length of pile for a given wave, kg

F_{Dm} = maximum horizontal drag force on a unit length of pile for a given wave, kg

F_m = maximum total horizontal force on a unit length of pile for a given wave, kg

M_{im} = maximum inertial moment acting on a pile about the mudline, m-kg

M_{Dm} = maximum drag moment acting on a pile about the mudline, m-kg

M_m = maximum total moment acting on a pile about the mudline, m-kg

C_M = hydrodynamic force coefficient of inertia

C_D = hydrodynamic force coefficient of drag

ρ = density of sea water, kg/m^3

g = gravitational acceleration, 9.81 m/sec^2 .

D = pile diameter, m

H = wave height, m

K_{im} = Dean's stream-function parameter, function of inertial force on pile

K_{Dm} = Dean's stream-function parameter, function of drag force on pile

S_{im} = Dean's stream-function parameter, maximum moment arm of total inertial force on pile

S_{Dm} = Dean's stream-function parameter, maximum moment arm of total drag force on pile

ϕ_m = Dean's stream-function parameter, coefficient for calculation maximum total force on pile

α_m = Dean's stream-function parameter, coefficient for calculation maximum total moment on pile

d = water depth from SWL, m

The following parameters are used for graphical solutions of the above equations (see Ref. 1).

$\frac{H}{gT^2}$ = dimensionless wave steepness

$\frac{d}{gT^2}$ = dimensionless water depth

$\frac{D}{L}$ = relative ratio of pile diameter to wavelength

$\frac{H}{H_b}$ = nonbreaking wave height to breaking wave height, equals one for breaking wave analysis

$W = \frac{C_M D}{C_D H}$ = Dean's stream-function parameter for calculation of maximum force and moment on a pile

EV-401.9.1.2 Subsurface Pressure

DEFN - Subsurface pressure at any point beneath the surface of a wave includes a dynamic component due to wave acceleration and a static component due to hydrostatic pressure. It is usually expressed in kilograms per square centimeter or kilograms per square meter.

The subsurface pressure is defined as:

$$P = \gamma \left[K_p \eta - z \right]$$

where,

P = subsurface pressure, kg/m^2

γ = specific weight, kg/m^3

K_p = pressure response factor

η = surface profile, the displacement of the water surface due to the passage of a wave, m

z = vertical distance below the surface, m

The pressure response factor is given by

$$K_p = e^{kz}$$

where,

k = wave number, $2\pi/L$, m^{-1}

z = vertical distance below the surface, m

The bottom pressure is greater than the hydrostatic pressure under a wave trough and smaller under a wave crest. Figure EV-400-9 illustrates this continuous variation of pressure with phase at a given elevation z beneath the surface.

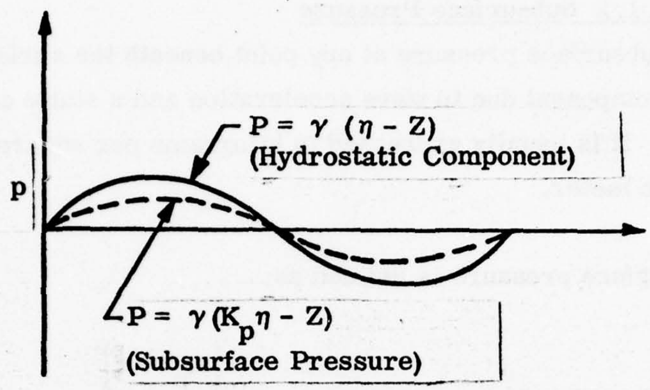

Fig. EV-400-9 Phase Distribution of Subsurface Pressure Head

INTER - Subsurface pressure is a function of a sea water Density (EV-201.4.4) and the surface profile of ocean waves (EV-401).

INFL - Pressure transducers located at a specific depth beneath the surface can be used to measure wave heights and surface profiles from which wave force and moment calculations can be made.

MEAS - Subsurface pressures are measured with pressure transducers placed at various depths.

EV-401.9.1.3 Hydrodynamic Drag and Inertia Coefficients

DEFN - The drag coefficient (C_D) is a factor which considers the effects of pile diameter, roughness, and the Reynolds number (R_e) in the force and moment calculations. A chart illustrating the variation of the drag coefficient in the three ranges of Reynolds number (subcritical, transitional, and supercritical) for steady state conditions can be found in Ref. 4.

INFL - It is important to use an equivalent wave theory for wave force calculations and hydrodynamic coefficient determination. The values given here are only intended as an approximation for preliminary design. More accurate values must be obtained using the theory of Dean or Skjelbria (Ref. 4).

CALC - The equations below define the parameters necessary for estimation of the drag coefficient by this graphical method.

$$R_e = \frac{u_{max} D}{\nu}$$

$$u_{max} = \frac{\pi H}{T}$$

$$\frac{H}{D} > 20$$

where,

R_e = wave Reynolds number

u_{max} = maximum horizontal water particle velocity, m/sec

ν = kinematic viscosity, μ/ρ, m^2/sec

H = wave height, m

T = wave period, sec

H/D = nonbreaking wave-height-to-pile-diameter ratio, expresses amplitude of particle motion to pile diameter, satisfaction of inequality allows use of steady state C_D value, usually satisfied for $R_e > 4 \times 10^4$

Generally, the drag coefficient varies from 0.5 to 1.0. The mass or inertia coefficient C_M is a factor which takes into account the effects of wave acceleration in the force and moment calculations. Based on experimentally determined values (Ref. 1), it is recommended that the inertia or mass coefficient C_M be defined by the following set of equations:

$$C_M = 2.0, \text{ when } R_e < 2.5 \times 10^5$$

$$C_M = 2.5 - \frac{R_e}{5 \times 10^5}, \text{ when } 2.5 \times 10^5 < R_e < 5 \times 10^5$$

$$C_M = 1.5, \text{ when } R_e > 5 \times 10^5$$

The inertia-force component is generally much smaller than the drag-force component in shallow water and of comparable magnitude in deep water.

EV-401.9.2 Dynamic Analysis

DEFN - Dynamic analysis is the investigation of the structure to determine resonance effects and transverse forces due to wave loading. Resonance effects of a rigid offshore structure are important if and when the natural frequency of the structure coincides with a wave frequency possessing significant amounts of energy. Transverse forces or lift forces are due to the downstream shedding of vortices or eddies from a structural member. These forces are laterally oscillatory and perpendicular to both wave direction and the structure axis, and are in addition to static buoyant lift forces. Although the unsteady state nature of these forces is not well understood, some insight can be gained from steady state analysis. For rigid structures, the transverse force is approximately equal to the drag force as an upper limit where a dynamic interaction has not been achieved.

CALC - An equation for the lift force is

$$F_L = C_L \frac{\rho g}{2} D H^2 K_{Dm} \cos 2\theta$$

where,

F_L = lift or transverse force, kg

C_L = lift force coefficient, function of Keulegan-Carpenter number $\overline{U}_{max}$ T/D (See Ref. 3)

$\overline{U}_{max}$ = maximum horizontal velocity averaged over the depth, m/sec

T = wave period, sec

D = diameter of a vertical circular pile, m

ρ = sea water density, kg/m^3

g = gravitational acceleration constant, 9.81 m/sec^2

H = wave height, m

K_{Dm} = Dean's stream-function parameter, function of drag force on pile

θ = phase angle of the lift force, time variation of force

INTER - Fatigue failures can alter and increase the natural structural frequency or period and lead to eventual failures of the structure due to dynamic coupling between the structure and Waves (EV-401).

INFL - Usually, resonance effects of a structure can be avoided if the natural period of the lowest vibrational mode is less than one second because this frequency possesses very little of the total energy of the wave field. In flexible structures in deeper waters with natural design periods of a couple of seconds or more, dynamic response must be considered. Lift forces over four times larger than the drag force have been observed due to dynamic coupling interaction and can add greatly to the total wave loading.

EV-401.10 Wave Prediction Methods for Design of FOFs

DEFN - Wave prediction methods include forecasting and hindcasting procedures. Forecasting is based on predicted meteorological data, whereas hindcasting is based on past meteorological data. The significant wave method of hindcasting of Sverdrup, Munk, and Bretschneider (SMB Method) is a method for calculating significant wave height and period for storm events other than hurricanes. The design of FOFs for maximum storm events includes calculation of significant wave heights and periods for hurricanes according to a mathematical model of Bretschneider. Tsunamis are seismically generated ocean waves of long period which can affect FOFs installed in shallower water locations (see EV-407.3).

INFL - The wave prediction methods listed here are a means of predicting a significant wave Height (EV-401.6.1) and Period (EV-401.6.2) from which to calculate design wave loading due to maximum storm events (EV-105).

EV-401.10.1 SMB Method

DEFN - The SMB method is a hindcasting procedure for calculating the significant wave height and the significant wave period, when a limited amount of time and data are available. The simplifying assumption of a fully arisen sea — a condition in which wind, waves, and turbulence are in equilibrium but which rarely if ever occurs in nature — is made with little loss of accuracy. Charts are available (Ref. 1) which make resolution of the equations relatively simple. The wave pattern developed by this theory may be duration-limited or fetch-limited (quasi-steady-state conditions). The significant wave height and period is limited by the duration and by fetch, respectively, in these two cases.

INTER - The SMB method is a function of the wind Speed (EV-102.1), the length of the Fetch (EV-401.1.3), and the wind Duration (EV-102.3). The significant wave Height (EV-401.6.1) and Period (EV-401.6.2) calculated increases as these input parameters increase.

INFL - This method is very useful in calculating significant wave heights and periods without the use of zero-time predictions of high-speed computer facilities. Little loss in accuracy is sacrificed.

EV-402 WAVES (SHALLOW/RESTRICTED WATER)

DEFN - Shallow-water waves occur in water whose depth is less than 1/20 of the wavelength and include intermediate-depth waves, which occur in water depth greater than 1/20 and less than 1/2 of the wavelength. These are gravity waves having wave periods ranging from 1 to 30 seconds. As these waves approach shore slopes and move across shallow water they reflect, diffract, and refract. These small amplitude waves may move up an estuary with an abrupt steep-front or they may break into a dozen small waves.

INTER - Waves provide an important energy source for forming beaches. They transport bottom materials onshore, offshore, and alongshore, and cause many of the forces to which coastal facilities are subjected. An understanding of surface wave generation and propagation is necessary to understand complex water motion in the nearshore areas of large bodies of water and is essential in the planning and design of structure in shallow, restricted waters.

INFL - The effects of waves are of paramount importance in the field of coastal and ocean engineering. Waves are the major factor in determining the geometry and composition of beaches, and significantly influence planning and design of harbors, waterways, shore protection measures, and ocean facilities and other coastal works.

Surface waves generally derive their energy from the winds. A significant amount of this wave energy is finally dissipated in the nearshore region and on the beaches.

EV-402.1 Breakers/Surf

DEFN - As a wave moves toward shore it collapses or breaks as it reaches shallow water. It breaks when the depth of a gently sloped beach is equal to about 1.28 times the wave height. Waves moving from deep into shoal water continually decrease in length and speed, while the height at first decreases and then increases. Because of this, the waves lose energy due to bottom friction, percolation, and nonrigidity of the bottom.

There are three types of breakers – spilling, plunging, and surging. Spilling breakers are characterized by the appearance of white water at the crest and break gradually. Plunging breakers are characterized by a curling over of the top of the crest and a plunging down of this mass of water. Surging breakers peak up as if to break in the manner of a plunging breaker, but dissipate when the base of the wave surges up the beach.

INTER - Surf changes from moment to moment and beach to beach. The waves are influenced by the bottom and the bottom is changed by the waves. Most surf zones have larger tidal ranges (EV-407.2) and are underlain by shifting sand: their Beach Topography (EV-408.1) is constantly changing.

INFL - Surf provides a taxing environment for cables brought ashore from a bottom mounted or suspended cable structure.

EV-403 SEA ICE

DEFN - Sea ice is the crystalline form of water which forms by the freezing of sea water or the calving of icebergs from glaciers. It is a viscoelastic solid consisting of a three-phase, heterogeneous mixture of ice crystals, liquid brine cells, and precipitated cryohydrates and air bubbles. This section discusses sea ice (1) types, (2) statistics of occurrence, (3) speed, (4) direction, (5) composition, (6) formation, and (7) icing.

INTER - The mechanical and chemical properties of sea ice are functions of sea water Salinity (EV-201.1.1), sea water Temperature (EV-201.6.3) and atmospheric Temperature (EV-101.1), water Depth (EV-201.6.2), hydrostatic Pressure (EV-201.4.4), wind Speed (EV-102.1), wind Direction (EV-102.2), Surface Currents (EV-202), Surface Waves, (EV-401), and snow cover.

INFL - Sea ice presents formidable design problems for the FOF. Ice loadings are a function of ice thickness, strength, and speed of movement. They include horizontal forces and vertical forces. Great pressure can be exerted on structures by ice fields driven by winds and currents. Those structures subject to this type of impact should be capable of resisting pressures of 10 to 12 kg/cm^2 psi on the area exposed (Ref. 4). Foundations should be constructed so as to prevent sliding on the base due to ice forces. Piles must be designed to withstand the lifting effect and added weight effect of ice frozen to them.

EV-403.1 Types

DEFN - Sea ice has been classified according to a number of different systems. Among these are those of the International Meteorological Organization and the U.S. Naval Oceanographic Office.

Six basic types of sea ice have been defined according to stage and method of development. These are new ice, young ice, winter ice, biannual ice, polar ice, and land ice. New ice is ice formed in the initial stages of development. It is days to weeks in age, less than one centimeter in thickness, and has no bending strength. Young ice is newly formed ice in transition from new ice to winter ice. It is very weak and is transparent to gray in color. Winter ice is a progression of young ice in more or less unbroken sheets. It is less than one year in age, grey to grey-white in color, and stronger in bending than young ice. Biannual ice is ice in process of aging through a second winter, takes on a blue to blue-gray color, has major structural discontinuities, but is relatively strong. Polar ice is more than two seasons in age, has undergone considerable exclusion and regeneration of salt, is blue to gray-blue in color, and is exceptionally strong. Finally, land ice is ice that forms on land and calves as some form of iceberg on an island. It is the strongest of all types considered. Table EV-400-2 summarizes the characteristics of these five ice types.

Table EV-400-2

SEA ICE TYPES

Name	Age	Color	Strength	Areal Extent	Thickness
New	Days to weeks	Gray to black	None	-	1 cm
Young	Days to weeks	Gray to transparent	Weak, brittle	-	1 m
Winter	1 yr	Gray to gray-white	Good	-	1 < thick < 2.5 m
Biannual	1 < age < 2 yr	Blue	Very good	-	2.5 to 3 m
Polar	> 1 yr	Steel blue	Excellent	-	4 to 5 m
Land	-	-	Excellent	Square miles	30 to 55 m

EV-403.1.1 Drift

DEFN - Drift ice consists of grease ice and pancake ice which gradually coalesce into the young drift ice sheet. Grease ice is the initial stage of ice formation in the open ocean under wave or current conditions. The surface appears to have a greasy or opaque appearance as vertically oriented thin plates of ice are formed. Gradually, the surface is covered with ice of a thick, soupy consistency, which masks the effects of small waves.

Pancake ice consists of circular flat disks, 30 to 100 cm in diameter, which are formed as a result of the irregular motion of the surface. The freezing has segregated into individual centers from which the freezing expands radially outward. After repeated breaking, pancake ice is frozen together to form the young ice sheet of drift ice.

INTER - Drift ice is basically new ice. Its formation is a function of Air Temperature (EV-101.1) and Water Temperature (EV-201.6.3).

INFL - Drift ice does not have the structural rigidity to be of much concern to fixed ocean facilities.

EV-403.1.2 Icebergs

DEFN - Icebergs are the enormous masses of floating ice which drift with the wind, tide, and currents at up to 32 to 50 km/day. They are the predominant type of floating ice in south polar regions and originate in the shelf ice and glaciers of the Antartic and Arctic continents, respectively. Icebergs break off because of the enormous buoyant forces as the main ice body reaches the water's edge. They vary in size up to 100 meters high above the water, 145 km long, and 40 km wide. Their shape is tabular for Antarctic bergs and irregular for Arctic bergs. The depth of immersion depends on the specific weight of glacier ice and sea water. This depth may be greater than 8 times the height of the iceberg above the water. Hence, icebergs respond more to currents and tides than to wind.

INFL - Icebergs occupy approximately 19 percent of the world's oceans. In the southern hemisphere they have been carried as far north as 44°S. In the northern hemisphere, they reach as low as 36°N. It is important to consider iceberg transit lanes in site selection. Also, in shallow near-shore waters, icebergs can destroy bottom mounted devices and cables.

MEAS - Iceberg characteristics are measured by visual observation and mechanical and chemical testing. Their movements, speed, and direction are charted from observation of position over time by the U.S. Naval Hydrographic Office and U.S. Coast Guard.

EV-403.1.3 Pack

DEFN - Pack ice is formed by the alternate piling up and freezing together of drift ice of different sizes and form. Pressure ridges and hummocks are formed when opposing drifts of pack ice come together. Extremely hard, dense sections of ice are thus formed. The topography of pack ice usually is indicative of the underside. A flat upper surface will be reflected in a smooth bottom surface. A hummocked surface will be compensated by matching protuberances beneath.

INTER - Pack ice is usually considered to be semipermanent ice such as biannual and polar ice. Some broken portions of land ice can be included in this polar ice matrix however.

INFL - Pack ice has sufficient size and strength that ice floes moving past a fixed ocean facility could affect mission performance and success.

MEAS - Monthly, seasonal, and annual measurements of sea ice concentrations, extremes, and polar pack boundaries are made by the U.S. Naval Hydrographic Office based on aerial reconnaissance, land stations, surface ship and submarine observations.

EV-403.1.4 Ice Islands

DEFN - Ice islands are huge masses of floating ice formed by the breaking off of shelf ice. It is believed that seismic forces or sudden changes in barometric pressure generate tides and waves which provide the breaking force. Since 1946, as many as 60 of these islands have been located with most of them originating along the northern coast of Ellesmere Island in the Arctic. Ice islands vary in size up to 780 square kilometers and 75 meters in thickness. Their topography is rolling and relatively uniform extending about 12 meters above the water's surface.

INTER - Ice islands are a form of land ice. Because of their deep draft, their rate of movement is primarily due to ocean Currents (EV-202) rather than Winds (EV-102). As a result they generally drift slower, in the order of 2 kilometers per day, than the surrounding sea ice.

INFL - Because of their size and strength, ice islands can be used as floating stations in place of other facilities if fixed position is not necessary.

MEAS - See Icebergs (EV-402.1.2).

EV-403.2 Statistics of Occurrence

DEFN - The statistics of occurrence of sea ice include many variables. The principle ones are (1) monthly and semimonthly recordings of mean and extreme ice conditions depicting ice limits and concentrations; (2) earliest, latest, and average dates of ice appearance, freeze up, breakup, opening, and complete opening of ice; and (3) seasonal probability of superstructure icing for various locations.

INFL - Pack ice statistics are useful in assessing design considerations of a facility.

CALC - Pack ice statistics are calculated based on data furnished to the U.S. Naval Hydrographic Office and the U.S. Coast Guard by aerial reconnaissance, land stations, and ship and submarine cruises.

EV-403.3 Speed

DEFN - Speed of sea ice is the velocity with which it drifts.

INTER - The drift speed is a function of Current (EV-202) and Winds (EV-102). Icebergs and ice islands are more dependent on the currents, moving with speeds of 32 to 40 km/day for icebergs and 1 km/day for ice islands. Pack ice moves with a speed which is proportional to the wind speed, usually drifting with a speed 1/50 of the wind speed at 2 meters elevation.

INFL - The speed with which sea ice interacts with a fixed ocean facility determines the force the structure must be designed to withstand.

MEAS - The speed is measured in kilometers per hour and is usually at a minimum for most forms of sea ice at the end of winter.

EV-403.4 Direction

DEFN - The sea ice direction is the direction from which the sea ice is drifting. Pack ice usually drifts at an angle to the wind direction. In the Arctic, the average deviation angle has been found to be about 30 deg to the right of wind direction. The corresponding angle in the Antarctic is approximately 34 deg to the left. This difference in drift direction of sea ice and that of open water to the wind stress is a result of the frictional resistance of the ice. Land ice drift direction is a function of the ocean current direction due to the extremely deep draft of these ice forms.

INTER - The drift direction is a function of the Wind (EV-102.2) and current Direction (EV-202.3).

INFL - Selection of a location for the FOF may be affected by the apparent paths of sea ice drifts, especially for icebergs and ice islands.

MEAS - The direction of sea ice drift is measured by visual observation of subsequent sea ice positions.

EV-403.5 Composition

DEFN - Sea ice composition is the arrangement and disposition of organic molecules, inorganic molecules, and particulate matter in the ice structure. These inclusions affect the ultimate strength and mechanical properties of the sea ice. Organic material comes from the diversity of land and sea life that accumulates in the oceans. Inorganic material consists of the complex solution of salts in ocean water. Particulate matter consists of 50 to 80 percent fine silts, sands, and nonplastic clays; 20 to 50 percent medium to coarse sands; and a small percentage of cobbles and larger rocks.

INTER - Sea ice composition is a function of the ice Salinity (EV-403.5.1), Density (EV-403.5.2), and Structure (EV-403.5.3).

EV-403.5.1 Salinity

DEFN - Salinity of sea ice is a measure of the number of grams of dissolved salts frozen in the ice. The salinity of sea ice is always less than the salinity of the original sea water from which the ice was formed. This is because part of the brine escapes as the ice freezes and solidifies.

A normal range of sea ice salinity is between 3 $^{o}/_{oo}$ and 8 $^{o}/_{oo}$, with a high of 14.59 $^{o}/_{oo}$ for young sea ice. With age, the salinity may decrease to 0.5 $^{o}/_{oo}$ for polar ice.

INTER - The salinity of sea ice is a function of the original Salinity (EV-201.1.1) of sea water, the air Temperature (EV-101.1), the thickness of the ice (EV-403.6), and the Density (EV-403.5.2) of the ice. The air temperature, as it affects the rate of ice formation, causes an increase of salinity of the ice with decreasing air temperature. More brine is trapped in the cavities with a faster freezing process than with a slower process. The salinity of sea ice also decreases with increasing thickness of the ice sheet. This is a function of the vertical salinity distribution of the original sea water. Finally, density of sea ice, as it relates to age of the ice, affects salinity. The older an ice sheet is, the more it has melted and reformed, allowing the cavities to grow and the ice to become more porous. Thus, the salinity of sea ice usually decreases with age or decreasing density.

INFL - Sea ice salinity affects the ultimate strength of the ice.

CALC - An analysis of 1 kg of sea water with a salinity of $35^{o}/_{oo}$ frozen into sea ice has the following composition at -30°C.

Ice crystals	921.9 gr
NaCl crystals	20.2 gr
Na_2SO_4 crystals	3.95 gr
$CaCO_3$ crystals	traces
Remaining brine	43.95 gr
	1000. gr

EV-403.5.2 Density

DEFN - The density of sea ice is its mass per unit volume expressed in grams per cubic centimeter (gr/cc). Seasonal variations of density for five sea ice types are shown in Table EV-400-3 (Ref. 6). These values are approximations for preliminary design purposes and are measured values between -5° to -20°C.

Table EV-400-3

SEASONAL VARIATIONS OF SEA ICE DENSITY

Ice Types	Fall Season	Winter Season
Young	0.85	0.88
Winter	0.88	0.91
Biannual	0.91	0.92
Polar	0.92	0.94
Land	0.94	0.96

INTER - Density of sea ice depends primarily on Salinity (EV-403.5.1) and porosity. These density relationships for several values of salinity and porosity (air content) can be found in Ref. 6 and others.

INFL - Density affects the depth of submergence of sea ice and the weight of the sea ice interacting on a FOF for design loadings.

CALC - The density of fresh water ice at a temperature of 0°C is 0.91676. The density of sea ice is usually smaller than this density although sometimes it may be larger. The maximum density of sea ice was found to be 0.924 at 1.32 meters depth, 14.6 $^{0}/_{00}$ salinity, and -29°C temperature.

EV-403.5.3 Structure

DEFN - Sea ice structure is the arrangement of the crystal lattice of water molecules and interlattice solute and inclusions. As sea water starts to freeze, salt solution is located between layers of ice crystals. Cells form around this solute as more ice forms across the layers of solute. With time the cells interconnect forming tubes which provide drainage and diffusion of the solute until the eutectic temperature is reached below which the solute freezes. Thus, in nature, between 80 and 90 percent of the salt is excluded during the freezing process, leaving a salinity of only 5 to 8 $^{0}/_{00}$.

INTER - Sea ice structure is a function of the temperature of sea ice formation as determined by the Air Temperature (EV-101.1) and Water Temperature (EV-201.6). Sea ice is in a state of constant phase change due to these temperature changes and water Salinity (EV-201.1.1) changes.

INFL - As sea ice is a viscoelastic solid, it follows Hooke's Law behaving as an elastic material until the elastic limit is reached, after which failure occurs due to its small plastic range.

EV-403.6 Formation

DEFN - Sea ice formation or growth is the increase in thickness and areal extent with time. As the ambient temperature is lowered to the freezing point, ice crystals consisting of small spicules of thin platelets form on the surface. Slush forms (grease ice) a thin layer of less than 5 centimeters thickness as the ice crystals accumulate and freeze together. Sludge, consisting of spongy whitish ice lumps a few centimeters across, is an advanced stage of slush. Ice rind forms due to the freezing of slush to an average thickness of less than 5 centimeters. Pancake ice is the final stage of new ice development. It measures 0.3 to 3.0 meters in diameter and less than 5 centimeters in thickness. Young ice, winter ice, biannual ice, and polar ice then forms in progression according to the age of the sea ice.

INTER - A figure illustrating the rate of growth of sea ice (formed at constant freezing temperature and based on the equation below) can be found in Ref. 8. The ice thickness h increases with increasing time and decreasing temperatures (EV-101.1 and EV-201.6.3).

The rates of increase of sea ice formation can be altered considerably if (1) snow cover protects the ice surface and (2) currents beneath the ice sheet cause circulation while the ice is forming.

INFL - Unless adequate design provision is made, the growth of sea ice near a FOF could greatly affect mission fulfillment capabilities.

MEAS - Thickness of ice is measured on a linear scale.

CALC - The rate of growth of an ice cover under natural conditions was investigated by Barnes and Czekanska. The ice thickness was calculated as

$$h + 1 = \sqrt{1 + \frac{2\ell}{\lambda_i \rho_i} Tt}$$

where,

h = ice thickness, cm

ℓ = coefficient of thermal conductivity, cal/cm-sec-°C

λ_i = latent heat of fusion, cal/gr

ρ_i = density of sea ice, gr/cm^3

T = frost temperature at the surface of the ice layer or the temperature difference between the upper and lower boundaries of the ice of thickness h, °C

t = time interval necessary to form the ice layer of thickness h, sec

EV-403.7 Icing

DEFN - Icing is the formation of ice on the superstructure of ocean facilities due to ocean spray.

INTER - Icing is a function of Air Temperature (EV-101.1), wind Speed (EV-102.1), Water Temperature (EV-201.6), and duration of exposure. Whenever the wind speed is equal to or greater than 17 knots and the air temperature is less than or equal to 15.5°C, then icing is possible. Generally, icing severity will vary according to the Beaufort Scale of Sea States as shown in Table EV-400-4.

Table EV-400-4

ICING CONDITIONS AS A FUNCTION OF BEAUFORT SEA STATES

Wind Speed/Sea State	Icing
Beaufort 5 to 6	Slight
Beaufort 7 to 8	Moderate
Beaufort 9+	Extreme

Storms of gale force winds accompanied by freezing temperatures have been observed for as long as 3 days duration and occurring as often as thrice yearly. Icing is limited by the edge of the pack ice since the occurrence of ocean spray is limited.

INFL - Icing can influence loads applied to a fixed ocean facility with a high superstructure and/or shallow draft.

MEAS - Icing is measured by the increase in thickness and weight with time. Accumulations of 2 tons in a 24 hour period have been recorded.

EV-403.8 Ice Forces

DEFN - Ice can exert considerable force on offshore structures. Some of the effects of sea ice on FOFs are listed in Ref. 1. In general, they include horizontal forces and vertical forces. Great pressure can be exerted on structures by ice fields driven by winds and currents. Those structures subject to this type of impact should be capable of resisting pressures of 10 to 12 kg/cm^2 on the area exposed (Ref. 4). Foundations should be constructed so as to prevent sliding on the base due to ice forces. Piles must be designed to withstand the lifting effect and added weight effect of ice frozen to them.

INTER - Ice forces are determined by the Direction (EV-403.4) of sea ice drift, the Density (EV-403.5.2) of sea ice, the Growth (EV-403.6) of sea ice, and the Type (EV-403.1) of sea ice.

INFL - An FOF must be designed to withstand sea ice if such occurrences are likely in the area.

EV-404 LITTORAL TRANSPORT

DEFN - Littoral transport is movement of near-shore sediments by Waves (EV-402) and Currents (EV-202) and is divided into two classes — longshore transport and onshore-offshore transport. Longshore transport is the movement of sediment parallel to the shore and is caused by waves striking the shoreline at an angle. High storm waves will generally move more material per unit time than low waves. However, if low waves occur for longer periods than high waves, they may move more sand. The material moved by longshore transport is called littoral drift.

Onshore-offshore transport is determined primarily by wave steepness, sediment size, and beach slope. In general, high steep waves move material offshore, and low waves of long period or low-steepness waves move material onshore.

INFL - For engineering problems involving littoral transport, the following information is required: (1) the longshore transport condition for the design of groins, jetties, navigation channels, and inlets; (2) the trend of shoreline migration for design of near-shore and onshore structures; (3) the direction and rate of onshore-offshore sediment motion; and (4) the effect of the proposed structure on littoral transport. The sediments transported will influence the design of foundations and the structural loading of near-shore structures.

MEAS - For the measurement of sediment transport, the rate of sand motion and wind and wave action should be correlated. A method for this correlation study is to record wind and waves and to make detailed beach profiles upstream and downstream.

EV-405 EROSION

DEFN - Erosion is the wearing away of land by the action of natural forces and occurs in two primary areas – beaches and cliffs. Beach erosion is the carrying-away of beach material by winds, waves, tidal currents, littoral currents, or by deflation. The most notable rapid rearrangement of beach profile is by storm waves, especially during storm surge, which enables the waves to attack at higher elevations on the beach.

Cliff erosion is caused by (1) hydraulic and pneumatic action, (2) waterborne rock fragments, (3) the abrasion or rubbing together of the fragments in suspension, (4) grinding of the blocks that fall against each other, and (5) corrosion or chemical weathering by salt water and oxygen in the zone just above sea level. In many areas, erosion from cliffs of one area is the principal source of sand for downdrift beaches.

INFT - Groins will prevent or retard the erosion of existing beaches and cliffs, widen an existing beach, or provide a beach where none exists. The magnitude of beach erosion to be expected during severe storms must be predicted and applied to the planning of submarine cable shore terminations.

EV-406 RIVER DISCHARGE

DEFN - River discharge describes the process of sediment transport by rivers and streams to the sea shore. As rivers discharge their sediment loads at the mouth of a river, estuaries and deltas form. An estuary is the wide part of a drowned river mouth that is affected by tides and characterized by salt and fresh water mixing, forming a saline wedge which extends upstream.

INTER - River discharge is a function of the river bed gradient, the water supply, and the material available. If Tides (EV-407.2) dominate the river mouth, then estuaries form. If, however, the river sediment load dominates, deltas are formed. The rate of Littoral Transport (EV-404) determines the net gain or loss of sediment that is transported away from a river mouth.

EV-407 SEA LEVEL VARIATION

DEFN - Water level is the mean elevation of the water when averaged over about a minute to eliminate high frequency oscillations caused by surface gravity waves. Types of water level variations include storm surges, astronomical tides, tsuanamic, switches, and wave setup.

INTER - Climatological variations and secular variations affect water levels over periods ranging from semiannually to many years.

INFL - While simplified prediction systems will not solve all problems, they can be used to indicate probable wave conditions for most design studies. Water levels continuously vary. Variations due to astronomical tides are predictable, and are well documented for many areas. Variations due to meteorological conditions are not as predictable, and are less well documented. These variations should be considered in the design of bottom mounted structures and suspended cable structures in shallow water.

MEAS - Water levels are determined in a stilling well in which inflow and outflow is restricted to eliminate the rapid responses produced by gravity waves.

EV-407.1 Storm Surges

DEFN - When violent storms occur, such as hurricanes across the coast, the sea level rises above the normal tide level. Part of this rise is due to low barometric pressure, but is mostly due to coupled long waves and wind setup (wind tide) (Ref. 14).

INFL - Water-level variations under storm conditions must be estimated in the planning and design of coastal engineering projects. Rises in water levels are of most concern. Abnormal rises in water level in nearshore regions will not only flood low-lying terrain, but provide a base on which high waves can attack the upper part of a beach and penetrate farther inland. With the possible exception of Tsunamis (EV-407.3), the greatest loss of life and property damage is associated with storm surges accompanying Hurricanes (EV-105.1).

INTER - Determination of design water elevations due to the storm surge is a complex problem involving interaction between wind and water, differences in atmospheric pressure, and effects caused by other mechanisms unrelated to the storm. The water-level variations due to a storm surge may depend on several distinct factors: (a) astronomical Tides (EV-407.2), (b) direct Winds (EV-102), (c) atmospheric pressure difference, (d) earth's rotation, (e) rainfall, (f) Surface Waves (EV-401) and associated Wave Setup (EV-407.5), and (g) storm motion effects.

EV-407.2 Tides

DEFN - Tide, or astronomical tide, is a periodic rising and falling of sea level caused by the gravitational attraction of the moon, sun, and other astronomical bodies acting on the rotating earth. The tides follow the moon more closely than they do the sun. The tidal extremes are called high water and low water, the rise is designated as flood, and the fall as ebb. The difference in height between low water and high water is called the tidal range. There are usually two high and two low waters in a tidal or lunar day. The horizontal movements of water are called tidal currents.

Detailed data concerning tidal ranges are published annually in Tide Tables, U.S. Department of Commerce, National Ocean Survey.

INFL - Tides and tidal currents are of considerable importance in the design of FOF structures because of the loads applied and the changes in water level, as well as to the unloading of ships alongside structures.

MEAS - Analysis of the tides at the coast requires regular observations and recording of sea-level variations. Observations of this kind have been gathered for centuries in numerous locations and can be made either by means of a vertical board (tide staff) or more accurately with a tape gauge to eliminate wave effect.

EV-407.3 Tsunami

DEFN - Tsunami is defined as long-period gravity waves generated by such disturbances as earthquakes, landslides, volcano eruptions, and explosions near the sea surface. Tsunamis cross the sea (deep water) as very long waves of small amplitude. Their period is of the order of 1000 seconds; their wavelength may be as much as 240 km; their height, less than one meter in deep water. The slope of the wave front is imperceptible and ships at sea are unaware of their passage. When the tsunami reaches land, its amplitude may be greatly amplified, carrying sea water high above the sea level.

INTER - In general, the tsunami wave amplitudes decrease but the number of individual waves increases with distance from the source region. Tsunami waves may be reflected, refracted, or diffracted by islands, seamounts, submarine ridges, or shores. When tsunami waves reach land, they may be greatly amplified by shoaling, diffraction, convergence, and resonance. The influence of the Bottom Topography (EV-301) and the configuration of the coastline transforms the small amplitude waves of deep water into rampaging monsters.

INFL - Tsunamis are important because of the loss of life and vast property and coastal facility damage that have resulted from large ones. Near-shore FOFs can experience strong wave action from tsunamis.

MEAS - A tsunami wave warning system has been developed by the U. S. Coast and Geodetic survey. Ten seismograph stations around the Pacific rim from the Philippines to Alaska and from Peru to Japan are equipped with automatic alarm systems and visible recorders.

EV-407.4 Seiches

DEFN - Seiches are standing waves of relatively long periods in lakes, canals, bays and along open sea coasts and continue after the forces that start them have ceased to act. Large amplitude standing waves will be generated if the force setting the water basin in motion is periodic and has the same period as the natural period of the basin. The periods of free oscillations are dependent upon the horizontal and vertical dimensions of the basin, the number of nodes of the standing waves, lines where deviation of the free surface from its undisturbed value is zero, and friction.

INTER - Open-sea seiches can be caused by changes in atmospheric pressure and Wind (EV-102) or Tsunamis (EV-407.3).

INFL - One reason for the importance of an understanding of oscillations of harbors and the causative mechanism is that a small vertical motion is accompanied by a relatively large horizontal motion of the water. When the period of horizontal water motion coincides with the natural period of surge, sway, and yaw of a moored ship, a further resonance phenomenon occurs which results in loads due to currents on structures and in a considerable motion of a moored ship, possibly damaging adjacent structures.

EV-407.5 Wave Setup

DEFN - Wave setup is the super-elevation of the mean water level caused by wave action alone. Isolated observations have shown that wave setup does occur in the surf zone on the beach. The wave setup occurs between the zone of breaking waves and the beach, and can be as much as 10 to 20 percent of the incident wave height.

INFL - Wave setup causes an additional rise of water level, having the same effects on FOFs as previously cited water level changes.

EV-408 SHORE CHARACTERISTICS

DEFN - The shore is the narrow strip of land in immediate contact with the sea, including the zone between high and low water levels. Shores may be classified as with or without a beach. A beach is a zone of unconsolidated material that extends landward from the low waterline to the place where there is marked change in material of a physiographic form. Of the 59,436 km of the U. S. coastline, exclusive of Alaska, approximately 33 percent have beaches.

INTER - The shoreline configuration is a function of many factors. Waves (EV-402), Winds (EV-102), Currents (EV-202, 404), and Tides (EV-407.2) provide the main Erosion (EV-405), Littoral Transport (EV-404), and sedimentation mechanisms. Of these, waves are by far the most influential. An incoming wave can be described by its height, period, and direction. A deep water wave, upon entering shallower water, experiences changes in Height (EV-401.6.1) and Direction (EV-401.3) due to refraction, diffraction, shoaling, bottom friction, and percolation. As the wave aligns itself according to the Bottom Topography (EV-301), Littoral Transport currents (EV-404) are initiated. As the wave travels towards shore, the beach is eroded or accreted as a function of the wave steepness (H_0/L_0). Also, the foreshore slope is a function of the wave height; the slope decreases as the wave height increases. Beach profiles are seasonal, eroding during winter storms and prograding during summer calms. Thus, the position of the beach face and the longshore bars is constantly undergoing cyclic change. Storms erode sediment at the rate of 10 to 125 cubic meters per meter of beach face.

Winds (EV-102) transport sand from the beach to build foredunes, which can be used as a sand reservoir during the winter storms. They may also blow sand seaward. Typical rates of wind transport landward range from 2.5 to 25 cubic meters per year per meter of beach and average from 2.5 to 7.5 cubic meters per year per meter of beach.

Currents as generated by waves and winds aid in transporting sediment, particularly the longshore currents, which are the littoral transport mechanism.

Tides act to raise the water level at a beach, thus increasing the amount and elevation of beach sand exposed to wave attack. They are particularly effective during storms. Tidal currents (EV-202.1.1) are most effective near entrances to bays and estuaries in regions of large tidal range.

INFL - A knowledge of shore characteristics, including patterns of littoral transport, is essential if coastal constructions are not to interfere with sediment source and flow patterns.

Shore characteristics may be of importance in selecting sites for cables and pipes to come ashore from FOFs to make connection with land facilities.

EV-408.1 Beach Topography

DEFN - Beach topography describes the typical, two-dimensional, vertical profile of the beach measured perpendicular to the shoreline. Beach profiles extend from the foredunes, cliffs, or mainland out to mean low water (see Fig. EV-400-10). A beach consists of a backshore and a foreshore. The backshore consists of one or more berms, which are nearly flat surfaces, at elevations above the reach of all but storm waves and sloping landward at a slight angle. A crest often bounds the seaward side of a berm at the break in slope and is often the boundary between the backshore and the foreshore. The foreshore, or beach face, is usually the steepest part of the beach and extends from the highest elevation reached by the waves at normal high tide seaward to the low waterline. A nearly horizontal low-tide terrace covered with sand ripples and large bar-and-trough systems extends seaward of the foreshore. Extending seaward of this terrace are the longshore troughs and longshore bars.

INTER - Beach topography is a function of Waves (EV-402), Littoral Transport (EV-404), Tides (EV-407.2), Winds (EV-102), and Beach Geology (EV-408.2). Relative changes in Sea Level (EV-407) affect beach profiles. Generally, submergence leads to erosion or recession of a beach and emergence to progradation. Typical rates of sea level rise on the U. S. coasts average 1 to 2 millimeters per year with values ranging from -13 to 9 millimeters per year.

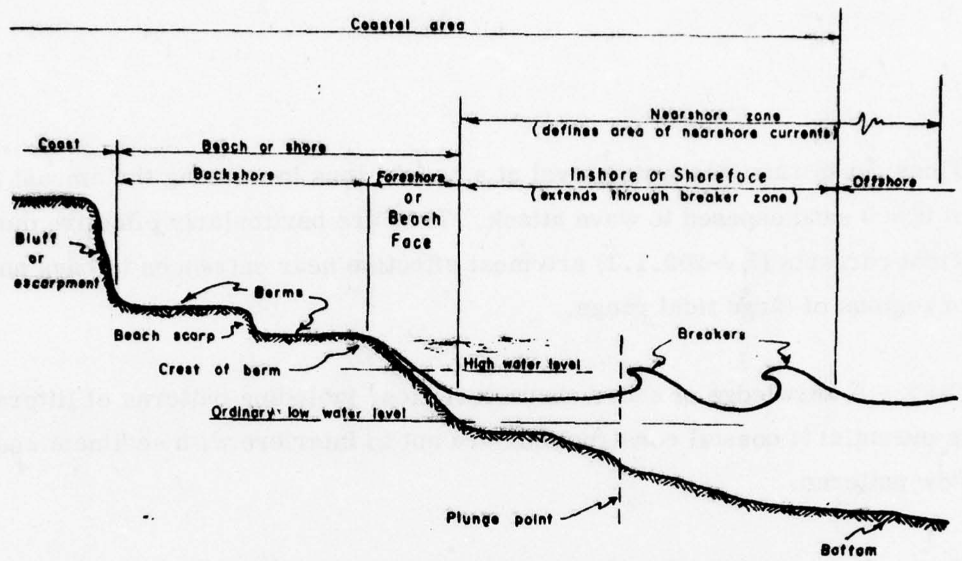

Fig. EV-400-10 Beach Profile-Rated Terms (Ref. 4)

MEAS - Beach topography is measured using standard leveling and taping techniques.

CALC - Sources of beach topography data can be obtained from historical records of the Army Corps of Engineers, the Defense Mapping Agency Hydrographic Center, the United States Geological Survey, National Ocean Survey, and the Defense Mapping Agency Topographic Center.

EV-408.2 Beach Geology

DEFN - Beach geology deals with the geologic features of the beach, in particular the beach structure and formation. Most beaches are composed of fine or coarse unconsolidated sand. Less common compositions include: gravel, shingle, and cobble beaches; mud, silt, and clay beaches; and bedrock and reef beaches. Sand beaches are characterized by the size and shape distribution of the particles, the steepness of the foreshore, and the water content of the sand. Beach sand is usually of terrigenous origin, having quartz as the main mineral with feldspars, micas, and other heavy minerals present.

INTER - The slope of the foreshore is a function of the grain size of the beach deposits. The slope increases as the grain size increases.

INFL - Beach geology influences the shape and engineering properties of a beach.

MEAS - Beach geology is measured by taking sediment samples, borings, or cores along a line perpendicular to the shore. Also, a known weight of dried beach sand can be passed through a succession of sieves of diminishing mesh diameter to determine the sorting and size grades of the beach deposits.

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GLOSSARY

ANISTROPIC - Not isotropic; that is, exhibiting different properties when tested along axes in different directions.

ATTERBERG LIMITS - The indices (LL, PL) of the water content of a sediment at the boundary between the semiliquid and plastic state (liquid limit) and the plastic and the semisolid state (plastic limit).

AUSTENITIC - A face-centered-cubic crystalline structure in steel in which the carbon present is in solution (solid or liquid).

AUTHIGENIC - A term applied to products of chemical and biochemical action which originated in sediments at the time of or after deposition, and before burial and consolidation, such as calcium carbonate or manganese oxide deposition.

BAR - A unit of pressure equal to 1,000,000 dynes per square centimeter. A bar = 100 centibars = 1,000 millibars. A barometric pressure of one bar is sometimes called a C.G.S. atmosphere and is equivalent to a pressure of 29.531 inches of mercury at 0° F, and in latitude 45°.

BATHYMETRY - The measurement of depths of water in oceans, seas, and lakes; also information derived from such measurements.

BEAUFORT SCALE - The scale of wind force devised by Admiral Sir Francis Beaufort in 1895, beginning with dead calm, indicated by 0, and ending with hurricane, indicated by 17. The scale is based on the effect of wind on the surface of the sea. In its original form, it was based on the effects of various wind speeds on the amount of canvas which a full-rigged frigate of the early nineteenth century could carry. Numbers above 12 are an extension of the original scale.

BIOCIDES - An agent used to destroy marine organisms.

CAPILLARY WAVE - A wave whose velocity of propagation is controlled primarily by the surface tension of the liquid in which the wave is traveling. Water waves of length less than about 1 inch are considered capillary waves. Waves longer than 1 inch and shorter than 2 inches are in an indeterminate zone between capillary and gravity waves.

CELERITY - Wave speed.

GLOSSARY (Cont'd)

CENTRAL PRESSURE INDEX (CPI) - The estimated minimum barometric pressure in the eye (approximate center) of a particular hurricane. The CPI is considered the most stable index to intensity of hurricane wind velocities in the periphery of the storm; the highest wind speeds are associated with storms having the lowest CPI.

CONDUCTIVITY - The quality of a material for conducting electrical current. Conductivity is the reciprocal of the specific resistivity, which is numerically equal to the resistance of a homogeneous unit cube of the material with a uniform current. Conductivity is measure in reciprocal ohms per meter, in mks units. the conductivity is measured in mhos/m.

CORIOLIS FORCE - A deflective force caused by the rotation of the earth on its axis. It causes moving bodies to be apparently deflected to the right of their course in the Northern Hemisphere and to the left in the Southern Hemisphere. The magnitude of this deflective force is basically dependent upon the velocity of the moving body and the latitude.

DECAY OF WAVES - The change waves undergo after they leave a generating area (FETCH) and pass through a calm, or region of lighter winds. In the process of decay, the significant wave height decreases and the significant wavelength increases.

DIAGENESIS - The chemical and physical changes that sediments undergo after deposition, comfaction, cementation, recrystallization, and perhaps replacement, which result in lithification.

DISCONTINUITIES - Deformations caused by rupture rather than material flow.

EUPHOTIC ZONE - The shallow surface zone of sea water into which sunlight penetrates and influences the production of organic nutrients.

FAULT - A fracture in the earth's crust along which there are displacements of the sides relative to one another.

FETCH - Horizontal distance over which the wind blows with reasonably constant velocity and direction (see also MINIMUM FETCH).

FLOC (FLOCCULATION) - A condition in which the attractive forces from electrostatic charges causes agglomeration of the particles.

FORMAZEN TURBIDITY UNIT - A measure of turbidity based on calibration of the Jackson Turbidimeter with various dilutions of a solution containing 1 gm of Hydrozine Sulphate and 10 gm of Hexamethylenetetramine.

GLOSSARY (Cont'd)

GENERATING AREA - In wave forecasting, the continuous area of water surface over which the wind blows in nearly a constant direction. Sometimes used synonymously with FETCH LENGTH.

GEOMORPHOLOGY - That branch of geography and geology which deals with the form of the earth, the general configuration of the earth's surface, and the changes that occur in the evolution of land forms.

GEOSTROPHIC WIND - The velocity of the wind in the free atmosphere attained when blowing under the conditions of complete balance of forces, i.e., the pressure force due to the pressure gradient and the Coriolis force.

GRADIENT WIND - The wind velocity necessary to balance the pressure gradient. The true wind above the friction layer is approximately equal to the gradient wind.

GRAZING ANGLE - The angle that the sound ray path forms with the reflecting surface; usually applies to sound rays reflected from the bottom. Conventionally, the angle is measured from the horizontal.

GYRES - A 'closed' circulatory system in the ocean, largely geostrophic in origin.

HYPOTHETICAL HURRICANE ("HYPO-HURRICANE") - A representation of a hurricane, with specified characteristics, that is assumed to occur in a particular study area, following a specified path and timing sequence.

HYDROGRAPH - An instrument which makes a continuous record of humidity.

INDEX OF REFRACTION - The index of refraction of water is the ratio of the velocity of light in free space to the velocity of light in water and is equal to the square root of the permittivity.

IGNEOUS - A condition produced by the action of fire; specifically, formed by volcanic action or great heat; as, igneous rock.

INTERNAL WAVES - Waves that occur within a fluid whose density changes with depth, either abruptly at a sharp surface of discontinuity (an interface) or gradually. Their amplitude is greatest at the density discontinuity or, in the case of a gradual density change, somewhere in the interior of the fluid and not at the free upper surface where the surface waves have their maximum amplitude.

INTERSTITIAL WATER - Water contained in the pore spaces between the grains in rock and sediments.

GLOSSARY (Cont'd)

ISOBARS - On a weather map, lines of equal barometric pressure.

ISOTHERMS - On a weather map, lines of equal temperature.

JACKSON TURBIDIMETER - An instrument used to define the scale of measurement of turbidity in water samples (Jackson Turbidity Units) by measuring the height of the water column at which a candle flame image changes to a uniform disc of light.

JOINTS - Fractures in rock along which no applicable movement has occurred.

LITHOLOGIC - Pertaining to physical characteristics of rocks and sediments.

MASS TRANSPORT - The net transfer of water by wave action in the direction of wave travel.

METAMORPHISM - Change in the structure of rocks under pressure, heat, chemical action, etc.

MICRORELIEF - The texture of the seafloor as opposed to its topography.

MINIMUM FETCH - The least distance in which steady state wave conditions will develop for a wind of given speed blowing a given duration of time.

MIXED TIDE - A type of tide in which the presence of a diurnal wave is conspicuous by a large inequality in either the high- or low-water heights with two high waters and two low waters usually occurring each tidal day. In strictness, all tides are mixed, but the name is usually applied without definite limits to the tide intermediate to those predominantly semidiurnal and those predominantly diurnal.

PELAGIC; PELAGIC DIVISION - A primary division of the sea which includes the whole mass of water. The division is made up of the neritic province which includes water shallower than 100 fathoms and the ocean province which includes water deeper than 100 fathoms.

PERMEABILITY - Permeability is an intrinsic property of all natural materials, metals, composites, and fluids which determines the susceptability of the materials to magnetization. The absolute permeability of sea water is identical to that of free space, i.e., 1.257×10^{-6} henrys/m in mks units.

PERMITTIVITY - Permittivity is an intrinsic property of matter which determines the susceptibility of the material to electric polarization. The absolute value of the permittivity ϵ in most materials is a function of temperature, pressure, conductivity, and frequency. ϵ_o, the absolute value of permittivity in vacuum, is a constant, equal to 8.85×10^{-12} farads/m in mks units. In water the relative permittivity $\epsilon_r \, \epsilon/\epsilon_o$ varies visible light spectrum.

PROBABLE MAXIMUM WATER LEVEL - A hypothetical water level (exclusive of wave runup from normal wind-generated waves) that might result from the most severe combination of hydrometeorological, geoseismic and other geophysical factors that is considered reasonably possible in the region involved, with each of these factors considered as affecting the locality in a maximum manner. It is a water level with virtually no risk of being exceeded.

PSYCHROMETER - An instrument for measuring humidity.

PYNOCLINE - Vertical density gradient in the ocean, thought to be related to diffusion of heat and upward motion of cool water from the ocean depths.

RAY PATH - The energy associated with a point on a wave front that moves along an imaginary line known as a ray path.

REYNOLDS NUMBER - A ratio between inertia forces and viscous forces characteristic of the condition of flow about a body, given by $R = V\ell/v$ where V = velocity of flow, ℓ = characteristic length of the body, and v = kinematic viscosity.

RHEOLOGY - The study of the flow of materials, particularly the plastic flow of solids.

RICHTER MAGNITUDE SCALE - A quantity which represents the total energy released by an earthquake, as contrasted to "intensity", which describes its effects at a particular place. The Richter Magnitude Scale ranges numerically from near 0 to about 8.5. The smallest shocks felt have a magnitude of 1.5, which represents an energy release of about 10^{11} ergs.

SAVONIUS ROTOR - A current sensor which uses an impeller mounted on a vertical axis so that the stream velocity passing through the impeller produces torque; a particular form of impeller wheel used in the current sensor.

SEAMOUNT - Submarine mountain rising more than 500 fathoms above the ocean floor.

SEA STATE - Description of the sea surface with regard to wave action. Also called state of sea.

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SHOALING COEFFICIENT - The ratio of the height of a wave in water of any depth to its height in deep water with the effects of refraction, friction, and percolation eliminated. Sometimes SHOALING FACTOR or DEPTH FACTOR.

SLIDE SCARPS - Cliff or steep slope created or uncovered by a slide.

SMB METHOD - Sverdrup-Munk-Bretschneider method of calculating significant wave heights and periods.

STROUHAL NUMBER - A dimensionless number defining the ratio of the frequency of periodic velocity, given by $S = Nd/V$

where N = frequency of vortex oscillations, d = diameter of cylinder, V = velocity of flow.

SUBMARINE CANYONS - Steep, valley-like submarine depression up to 10 miles wide and 1,000 fathoms deep.

SWALLOW FLOATS - Neutrally buoyant floats equipped to emit acoustic signals at regular intervals, used in measurement of drift velocity.

SWELL - Wind-generated waves that have traveled out of their generating area. Swell characteristically exhibits a more regular and longer period, and has flatter crests than waves within their fetch (seas).

SYNOPTIC CHART - A weather map, inasmuch as it depicts a synopsis of meteorological conditions over a large area at a given moment.

TECTONICS - The study of the origin and development of the broad structural features of the earth.

THERMOHALINE CIRCULATION - An overturning circulation process maintained by the influence of the sun and evaporation, and occurring as a direct result of water density gradients due to temperature and salinity differentials.

TRANSITIONAL ZONE (TRANSITIONAL WATER) - In regard to progressive gravity waves, water whose depth is less than 1/2 but more than 1/25 the wavelength. Often called shallow water.

VAISALA FREQUENCY - The upper limit on stable frequency of internal waves in the ocean; a function of density, wave speed in the ocean, and acceleration due to gravity.

VARIABILITY OF WAVES - (1) the variation of heights and periods between individual waves within a wave train. (Wave trains are not composed of waves of equal height and period, but rather of heights and periods which vary in a statistical manner.) (2) The variation in direction of propagation of waves leaving the generating area. (3) The variation in height along the crest, usually called "variation along the wave".

WAVE GROUP - A series of waves in which the wave direction, wave length, and wave height vary only slightly.

WAVE SPECTRUM - In ocean wave studies, a graph, table, or mathematical equation showing the distribution of wave energy as a function of wave frequency. The spectrum may be based on observations or theoretical considerations. Several forms of graphical display are widely used.

WIND SETUP - (1) The vertical rise in the stillwater level on the leeward side of a body of water caused by wind stresses on the surface of the water. (2) The difference in stillwater levels on the windward and the leeward sides of a body of water caused by wind stresses on the surface of the water. (3) Synonymous with WIND TIDE and STORM SURGE. STORM SURGE is usually reserved for use on the ocean floor and large bodies of water. WIND SETUP is usually reserved for use on reservoirs and smaller bodies of water.