Sources of Data

Ideally, the proposed program of calculations would require complete voyage loading diagrams for many voyages of each ship, plus detailed hydrostatic data, including Bonjean curves. The hydrostatic properties are always made available to the ship owner by the designer or shipyard, and voyage loading diagrams of one kind or another are in common use by ships' operating personnel. However, the availability and adequacy of such loading diagrams or tables for the purpose of calculating bending moments varies considerably among different operators.

In many cases, especially for tankers and ore carriers in ballasted condition, loading data are not sufficiently detailed to permit accurate assessment of bending moments. The total amount of ballast is usually recorded, but its actual distribution is left to the judgment of the ship's officers, who are not required to record the quantities allocated to each ballast tank. Nor are records of ballast shifts at sea during tank cleaning operations retained. Therefore, significant variations in still water bending moment (SWBM) may actually occur which cannot be calculated from recorded voyage data. To a lesser degree there are similar omissions of certain items in the loaded conditions as well, usually for items whose influence on bending moment is small. By contrast, rather complete loading information was obtained for a containership for both outbound and inbound voyages.

Calculations Made to Date

The number of voyages for which loading information (complete or not) were obtained is as follows:

Containership *New Orleans* (Seattle - Alaska)

59 outbound voyages }
60 inbound voyages } SWBM's could be calculated.

Tanker *Esso Malaysia*

2 loaded voyages }
1 ballasted departure } SWBM's could be calculated.

Ore carrier *Fotini L.*

5 loaded voyages - incomplete data, but SWBM could be estimated.
7 ballasted voyages - data too incomplete to estimate SWBM.

Because of the paucity of reliable data on actual voyages of the latter two vessels, their loading manuals were consulted for "standard" loading conditions. The still water bending moments in these standard conditions were therefore included in the results discussed below. Since these loading conditions were intended for the guidance of shipboard personnel, they should be representative of actual practice.

Techniques and Results

As a first step toward a statistical description of the still water bending moments (SWBM's), histograms have been prepared showing the frequency of occurrence of different values of SWBM's for outbound and inbound (or ballasted) voyages. The "maxima"plotted in the histograms are the maximum values along the length of the ship, which generally occur near, but not necessarily exactly at, amidships. The many-peaked ore carrier bending moment curves required special treatment, as described below. Additional actual voyage data would be required if we were to proceed any further in the analysis of the tanker and ore carrier. Special notes regarding the methods used in the calculations follow.

Containership New Orleans. The owner furnished detailed calculations of midship bending moments in static L/20 wave profiles, hogging and sagging, for the actual cargo loading conditions of 59 outbound (Seattle to Anchorage) and 60 inbound (Anchorage to Seattle) voyages. Two modifications were made to the calculations furnished in order to arrive at the SWBM's:

1) The still water bending moment was approximated as the mean of the static wave bending moments in hog and sag, and was determined to be either hogging or sagging.

2) The resulting approximate SWBM was adjusted because the consumables (fuel and fresh water) assumed in the wave BM calculations were "burned out" for the outbound voyages and "full" for the inbound voyages, rather than the conditions actually listed for the given voyages. Actual tankages were therefore substituted in the calculations to adjust them to actual conditions. Results of the adjusted SWBM calculations are shown in Fig. 4.

Tanker Esso Malaysia. Two loaded voyages and one ballasted condition were available, the SWBM's having been calculated by the owner using his own computer program. Sufficient data to do the same for other runs were not obtainable. The other three load and three ballast conditions indicated in Figure 5 are "standard" conditions from the loading manual. Each standard condition represents either a departure or arrival condition, whichever has the larger SWBM.

Ore ship Fotini L. All SWBM's plotted in Figure 6 are from the loading manual, since available data on actual voyage loadings were insufficient to calculate actual SWBM's. When the vessel carried heavy ore in holds 1, 3, 5, 7, and 9, with the remaining holds empty, the bending moment curve has many peaks, the highest peak often occurring relatively far from amidships. Instead of one, there are several maxima in these cases. The upper plot of Fig. 3 shows the value of the highest peaks of the SWBM curves occurring within the midship 20% of length. The lower plot shows the highest peaks occurring within the midship 40% of length. It is seen that in a number of cases the peak value occurring outside of the midship 20% of length is higher than that within. In other cases, there are no significant peaks at all within the midship 20% of length.

It is tentatively concluded that for containerships a single distribution curve for still water bending moments can be established in design for a particular service. In the case of bulk carriers, two distribution curves are usually required -- one for loaded and one for ballast condition.

CLASSIFICATION SOCIETY LIMITS

It should be noted that although classification societies do not in general base hull girder strength standards on a direct addition of still water and wave bending moments, still water moments are taken into account.

For example, the current Rules for Building and Classing Steel Vessels of the American Bureau of Shipping, 1972, require an increase in deck section modulus if the maximum still-water bending moment in the governing loaded or ballasted condition is greater than

$$s\ c\ f\ B\ (C_b + 0.5)$$

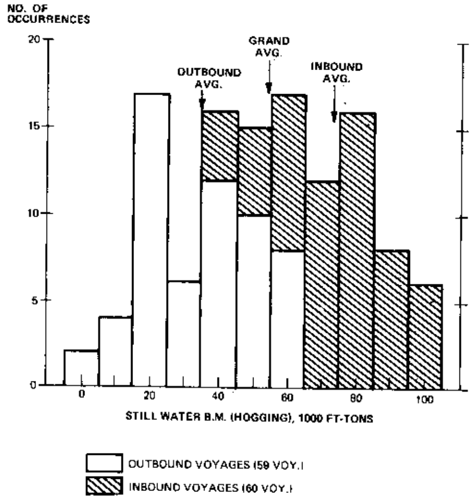

FIGURE 4 - Histogram of Still-Water Bending Moments Containership *NEW ORLEANS*

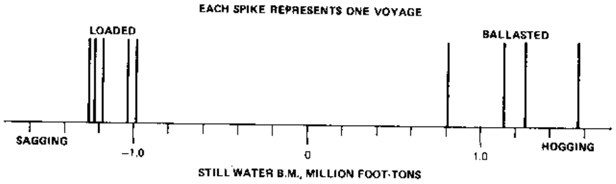

FIGURE 5 - Typical Still-Water Bending Moments, Tanker *ESSO MALAYSIA*

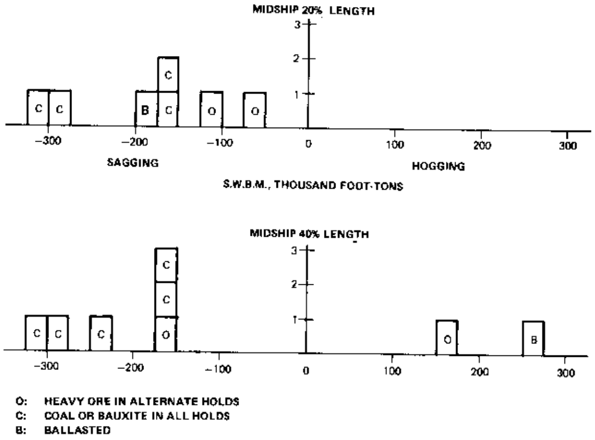

FIGURE 6 - Typical Still-Water Bending Moments, Ore Carrier, *FOTINI L.* Each box represents one voyage

where s and f are coefficients depending on length (see below), B is breadth in ft., C_b is block coefficient (not less than 0.68), and c = 1.00, except for oil carriers, where it is 1.03.

Length, ft.	f	s for oil carriers	s for others
600	594	3.78	4.25
800	1175	3.78	4.25
1000	1921	3.90	4.38

The trend of still water bending moments with ship length on the basis of the above is shown in Fig. 7.

INSTRUMENTS

Our study of still water loadings showed that in many ships a wide range of bending moments can be experienced in service. Hence, a shipboard instrument for quickly calculating still water bending moments can be an important adjunct to safe ship operation. A recommendation is made by Lloyd's Register: "In order to guard against high stresses being imposed through an unsatisfactory cargo or ballast loading, the Society recommends that an approved instrument or other means of determining the suitability of loading be placed on board" (35).

Various instruments of this type are available, as discussed at the beginning of this chapter.

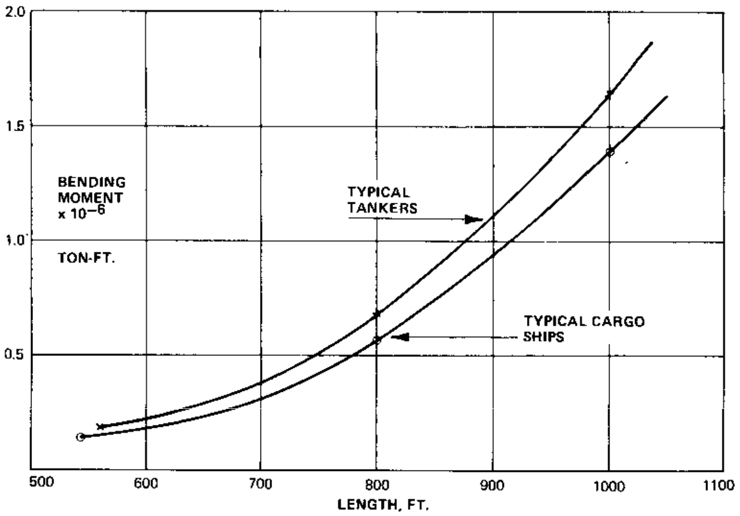

FIGURE 7 - Trends of Still-Water Bending Moment, Maximum Value by ABS Rules (1972) Requiring no Addition to Section Modulus

SHIP'S OWN WAVE

When a ship proceeds at appreciable speed in calm water, as previously noted, a wave pattern is generated which causes the ship's own bending moment. This may be a hogging moment in the case of a full ship pushed to high speed, but in fine, fast ships -- where the effect is most pronounced -- it is a sagging moment created by the bow and stern waves.

Results of systematic model tests by Vossers give the trend of bending moments due to a ship's own wave over a range of block coefficients and speeds (36).

Model tests with destroyers have shown (37) that when waves are encountered the effects of the ship's own wave and of the ocean waves are superimposed with very little interference.

SUMMARY

It has been shown that still water bending moments can readily be calculated by available techniques in the design stage. But relatively little data in statistical form are available for actual service loadings of various ship types, particularly in ballast conditions.

IV. WAVE LOADS

INTRODUCTION

The problem of wave-induced loads on a ship at sea is that of determining successive conditions of dynamic equilibrium of forces and moments acting in and on an elastic body moving in the irregularly disturbed interface of two different media. This problem can be simplified by considering external loads only, on the underwater part of the ship, which is considered to be a rigid body in an ideal fluid. Motions and other ship responses in waves are regarded as linear functions of wave height, and both the irregular waves and the irregular responses can be considered as the sum of many sinusoidal functions. Hence, the analysis begins with the study of harmonic oscillations of a rigid body, moving at forward speed on the surface of an ideal fluid under the action of regular gravity waves.

Though in principle the ship motion problem has been solved for three-dimensional cases (38)(39), the analytical solution is limited to forms such as a sphere or an ellipsoid. In view of this, a less rigorous strip theory solution has been developed which is suitable for long, slender bodies, where each cross section of the ship is considered to be part of an infinitely long cylinder. Hence, a series of individual two-dimensional problems can be solved separately and then combined to give a solution for the ship as a whole. The idea was originally introduced by Korvin-Kroukovsky (40) and has since been endorsed, criticized and improved by many authors (41)(42)(43).

The main drawback of the strip theory is that it neglects the mutual interactions between the various cross sections, which are of particular importance for certain frequency ranges, depending on the size of the body. Hence in waves that are either very long or very short relative to a ship the theoretical justification of strip theory is somewhat questionable. This statement is particularly applicable to lateral motions, since the hydrostatic restoring force is small or non-existent under these circumstances.

In spite of the above reservations, the basic strip theory has been found to be very satisfactory for heave and pitch motions and bending moments in head waves (40), and it is the only suitable method for numerical computation. Modifications have included the use of "close-fit" methods, which have led to a significant improvement in the computation of the sectional added mass and damping coefficients for all but the simplest sections. An additional major contribution to the theory has been the inclusion of all the forward speed terms in the equations of motion in order to satisfy the symmetry relationship proved by Timman and Newman (44). All the modified strip theories developed in the past two to three years (45)(46) have practically identical forward speed terms. Extension of the theory to oblique waves, to lateral motions, torsional moments, and lateral bending moments has also been achieved, as shown in (39)(43). Finally the use of close-fit mapping techniques and strip theory for determining the distribution of pressures over the hull has been demonstrated (47)(48).

Since we are concerned with successive conditions of dynamic equilibrium, it should be noted that a complete solution of the problem of wave loads and bending moments cannot be obtained without first determining the motions.

LOADS IN REGULAR WAVES

Basic Theory

In order to evaluate the state of development of ship motion and load calculation in waves a short analysis of the basic approach of most investigators will first be given. The mathematical formulation of the problem, i.e., a ship advancing at constant mean speed with arbitrary heading into regular sinusoidal waves, can be presented in most general form by defining the velocity potential so as to satisfy the assumptions of the ideal fluid, linearized theory. At this initial stage no strip theory assumption is required. The time-dependent part of the potential can be decomposed into three components representing the potentials due to incident wave, defraction and the mode of motion considered, as in the original theory by Korvin-Kroukovsky (40). However, an additional time-independent term due to steady forward motion of the ship has been added in more recent theories (43).

Once the formulation of the component potentials is completed, the hydrodynamic forces and moments acting on the hull can be determined. Using the Bernoulli equation the pressures in the fluid are defined and expanded in a Taylor series about the undisturbed still water position of the hull. Ignoring steady pressure terms at first,the linearized time-dependent pressure on the hull can be formulated and integrated over the hull surface. The hydrodynamic forces and moments can be obtained in two superposable parts: those associated with a wave passing a restrained ship (excitation) and those acting on a body forced to oscillate in calm water.

In order to obtain a numerical solution the application of strip theory approximations are necessary for the integration of the sectional exciting and motion-related forces over the length of the ship. These sectional forces involve two-dimensional added mass, damping and displacement terms. The speed-dependent coefficients are expressed in terms of a speed-independent variable, which is evaluated by means of strip theory, and of a speed-dependent term which is obtained from a line integral along the waterline as given by Stoke's theorem.

Hence, the main difference between the original strip theory in (40) and the more recent "new" methods is in the formulation of the problem. In (40) the strip theory assumptions were applied in the initial formulation, and the forward speed effect was only introduced in certain terms. In the "new" theories the assumptions with regard to strip theory were made after the general terms for the coefficients in the equations of motion were determined, including the forward speed terms.

In addition to the above, the theory presented in (43) includes end terms in the coefficients associated with the aftermost sections, which are not usually included in the strip theory and are claimed to be important for bluff bodies. These terms are independent of the strip theory assumptions.

Using either the old or the new approach, the formulation of hydrodynamic forces and moments permits the equations of motion to be solved and the amplitudes and phase angles of motion determined. Then the longitudinal distribution of all forces -- including those that are dependent on the motions and forward speed -- can be evaluated and shearing forces and bending moments calculated for any instant in the motion cycle, usually at midship. In general the solutions for two instants of time suffice to determine the amplitudes and phase angles of these quantities.

In general, design calculations, full-scale data collection, and model tests concentrate on conditions amidships. This is a sound procedure, particularly for collecting statistical data on different ships at sea. But some consideration must also be given to the longitudinal distribution of loads (48A). There are two questions to be answered by suitable trial calculations or experiments:

1. Are bending moments ever significantly higher at any other section than midships?
2. Over what ship length do midship bending moment values extend before they begin to taper off significantly?

It is felt that these questions can be answered by a limited number of systematic calculations, using the technique just described, on the basis of regular waves of various lengths, without the need for collection of long-term data or calculation of irregular wave responses.

Computation in Regular Waves

The preceding section treated the overall problem of ship motions, shear forces and bending moments in a seaway, indicating the need for a strip theory solution if numerical computations are required. In the following, the specific computer programs available for the above computations and the theories associated with them will be discussed.

When referring to an available computer program indication will be given of the degree of availability in terms of whether the program is public property or whether it is of proprietary nature.

The two programs in the first category are "SCORES," developed by Oceanics, Inc under SSC Project SR-174, and the MIT program developed under sponsorship of the Maritime Administration. Though the basic equations of motion are identical for the two programs, the scope is somewhat different. SCORES calculates the vertical and lateral motions and loads and torsional moment, while MIT is limited to the vertical longitudinal plane only, but includes additional information such as approximate mean added resistance in waves. SCORES is documented in a recent Ship Structure Committee report (49) and the MIT program in two MIT reports (50)(51).

Although the basic equations of motion for pitch and heave are identical in both of the above programs, there are slight differences in the coefficients of the equations, as well as in the excitation forces and moments. Both programs are based on coefficients originally derived in (40) and later modified slightly by (41). The only difference in the coefficients is in the restoring force coupling terms which are corrected in the MIT program to account for the fact that the origin of the ship coordinate system is taken at midship rather than at the more conventional location at the center of gravity. The programs are therefore virtually identical for vertical motion and loads when the center of gravity is near midships. It should be noted that the routines used to calculate the two-dimensional added mass and damping coefficients are also identical in both programs and are based on (42).

Note should be made of the fact that the MIT program includes a special routine to handle bulb sections which cannot be properly mapped by the commonly used "Lewis" routine (52). However, both programs lack a general routine to handle any shape, such as can be obtained by "close-fit" techniques. SCORES includes the motion and loads in the lateral plane for which the two-dimensional properties are calculated according to (46).

An additional program available to the public through the NSRDC is the "YF-17." This program is limited to motions in the longitudinal vertical plane and is based on the same equations and coefficients as the above two programs. The main feature of this program is its close-fit subroutine which allows an exact mapping of any required section and therefore is of particular value for ships of non-conventional section shapes. The YF17 is the most advanced available program at NSRDC. A new program based on the theory in (43), which includes ship motions and loads in three dimensions, as well as a new strip theory approach, is not yet available for public use and is now being tested and modified. In the case of certain types of ships, such as Naval destroyers or very full tankers, a combination of elements from two or three of the above programs may prove to yield the best results.

It should be noted that all of the above programs supercede the original Davidson Laboratory program based on the theory in (40). In addition to the latter, several less-known programs, generally not available to the public, also exist. The University of California has a computer program called "SEALOAD" for the calculation of dynamic loads (pressures) at discrete points on the hull of a ship for a range of frequencies, speeds and headings. It is based on motion in the vertical and the lateral directions. A similar program for calculating the transverse as well as longitudinal pressure distribution on the hull due to motion in head seas is available at Webb Institute (47).

The above survey does not include programs presently in use outside the U.S.A., mainly because of lack of information with regard to the details. Such programs exist in Japan (46), Germany (43), the Netherlands (41), Norway (43), and U.S.S.R., but are generally not available for distribution, although specific runs can usually be purchased.

For most of the purposes of this project the SCORES program (Oceanics) is the only suitable one available. Consequently, it has been adapted to the Webb computer facilities, and is now regularly in use. It will be a simple matter to upgrade this program in scope or in detail as new developments appear. Each section is supposed to be amenable to a conformal transformation from which the hydrodynamic coefficients can be derived for vertical and lateral oscillations. The particular coefficients used are:

Vertical oscillations:	Grim (42)
Lateral "	Tasai (46)

The hydrodynamic forces are then obtained for each strip after the motions are calculated. The integration of the difference between hydrodynamic forces and gravity forces yields the shear force and hence the bending moment for a particular position of the wave along the length of the ship. The results for all wave lengths and headings are the response amplitude operators as a function of the wave circular frequency per unit wave height.

Comparison of Theoretical and Experimental Bending Moment

A comprehensive comparison between calculations by program SCORES and model basin test results in regular waves has been made by Oceanics, Inc. (53). Results are presented graphically for the cases listed below, covering a range of wave headings in all cases.

	Load Conditions	Speeds	Bending Moment Vertical	Bending Moment Lateral	Torsion	Shear
Wolverine State (54)	2	2	x	x		
Series 60, Block 0.80 (55)	1	1	x	x	x	x
Series 60, Block 0.70 (36)	1	4	x	x		
T-2 tanker (56)	1	5	x	x	x	

The following conclusions were drawn from the graphical comparisons:

> "The comparison between calculations of vertical and lateral bending moments and the experimental results for the *Wolverine State* indicates generally very good agreement. This holds for both loading conditions, both speeds, and over the range of wave angle and wave length. The experimental results shown for lateral bending moment in head and following seas, where lateral motions and loads should be zero as in the calculations, are regarded as indicative of the possible error, or range of discrepancy, to be expected between calculations and experimental results. These loads are believed to arise in the model tests due to its free-running, but rudder controlled, condition. That is, the model may undergo small lateral motions, with rudder corrections to keep course, which leads to the measured lateral bending moments.
>
> "The comparison for the Series 60, block 0.80 hull for vertical and lateral bending moments indicates excellent agreement, in general ... The agreement for torsional moments is only fair and indicates excessive response at roll resonance conditions. The agreement for the shear forces is quite good, in general, with the exception of some deviation in lateral shear at 110° wave angle. However, the shear forces are generally small at midships, and should really be investigated at the quarter-length points."

For the Series 60, block 0.70 hull form and the T-2 tanker,

> "In general, the agreement is fairly satisfactory, considering the factors involved in the experimental comparison. With regard to this point, consider the double peak calculated vertical bending moment response for the T-2 tanker at 120° wave heading and 1.65 fps model speed. While the corresponding experimental data do not indicate such a response, similar double peaked responses for vertical bending are confirmed by experimental results for *Wolverine State*, full load and the Series 60, block 0.80 hull. The greater resolution of the test data due to testing at more wavelength conditions for these latter cases tends to produce such results, thereby limiting the utility of the experimental points for the T-2 tanker as a complete measure of bending moment variation" (53).

Bending moment calculations for the Wolverine State carried out by means of Program SCORES are compared with experimental results in (53).

Another available comparison between theory and experiment is for the tanker Universe Ireland (57). Model tests were carried out at the Davidson Laboratory (58) and calculation using a modified SCORES program were made at Webb Institute, both under the sponsorship of the American Bureau of Shipping. Vertical bending moment results for the head seas case in both full-load and ballast conditions indicate excellent agreement between theory and experiment over the range of wave lengths tested. Similarly good results were found for 150°, 30°, and 0° headings, full load.

For the 60° and 120° headings, the comparison is not as good as for the above-mentioned cases. Although similar trends are maintained, the differences in magnitude at some wave lengths are rather large. A possible explanation of the above discrepancies is the variation between the actual and desired heading angle for the free running model in oblique waves. It has been previously shown (59) that deviations of up to 10° in the heading angle can occur for certain wave lengths. This effect will be most pronounced for the 60° and the 120° cases, and any small change in heading angle for these cases may result in a large shift in the response curves, as proved to be the case.

An extensive comparison was made between Series 60 model results obtained at Wageningen and strip theory calculations (60). The vertical bending moment comparisons for head seas covered block coefficients of 0.60, 0.70, and 0.80, and for C_B = 0.70 three values of L/B, three values of L/H, three values of gyradius, four forebody section shapes, and four heading angles (1 case only). Agreement with the basic Korvin-Kroukovsky strip theory was excellent except for some higher speed cases and cases of large gyradius and extreme V forebody.

Extensive comparisons are given by Faltinsen (61) for an 0.80 block coefficient hull for which Wageningen model tests were available (55). Using the basic Korvin-Kroukovsky theory (on which SCORES is based), agreement was good except at 50° and 130° heading angles -- as in the above results for Universe Ireland. However, using the more refined procedure developed by Salvesen, Tuck and Faltinsen (43), vertical bending moment results were good at all angles. The refined theory generally gave better results for vertical shear also.

Since comparisons between model tests and theory showed generally good agreement in vertical bending and shear, the theoretical calculations are believed to be satisfactory for the present stage of development of load criteria, especially when it is remembered that the integration of results over a range of ship-wave headings averages out the result and reduces any errors considerably. But further refinements in SCORES are needed along the line of Salvesen (43) and greater precision in determining lateral bending and torsional moments is needed.

Rudder Forces

Kaplan and Raff point out that "since the lever arm of the rudder forces is large for moments at midships, it appears that rudder forces can significantly affect the lateral bending and torsional moments. To the extent that the use of the rudder affects the overall ship motion response in oblique seas, the vertical bending moment also can be influenced, but to a much smaller degree" (53). Rudder effects are not included in SCORES, but they are taken into account by Grim and Schenzle (62). However, the rudder effect is not separated out so that its relative importance can be assessed. They also included the effect of anti-rolling fins on torsional moment, which produced a significant reduction. It is felt that rudder effect can be neglected insofar as vertical wave bending moments are concerned, but it should be given further attention with reference to lateral bending and torsion.

LOADS IN IRREGULAR WAVES

The extension of regular wave results to short-crested irregular seas, by means of the superposition principle, was accomplished by St. Denis and Pierson (63), on the assumption that both the irregular waves and the ship short-term responses are stationary stochastic processes. The computer calculation of ship response was obtained some time ago, using model test data as inputs (64). In the case of all the above-mentioned computer programs, however, irregular wave capabilities are incomplete. The MIT and YF-17 programs have been extended to long-crested seas as represented by the Pierson-Moskowitz one-parameter sea spectrum family, and statistical response parameters can be computed from which various seakeeping events are determined. The SCORES program has been extended by Oceanics, Inc., to include response to short-crested seas, as well as a limited option for the use of a two-parameter spectrum formulation (dependent on both wave height and period). These are features which are considered to be absolutely essential in order to avoid erroneous results which may be obtained otherwise, such as near-zero longitudinal bending moment in beam seas. Furthermore, it has been previously shown (65) that superposition of responses to irregular waves should not be limited to a single spectrum for each sea condition (i.e., a one-parameter family), but a group of spectra should be used in order that both the mean response and its standard deviation can be determined for each range of wave height. Such programs are available using as input spectra either ordinates of actual spectra obtained for the North Atlantic or tables of probability of occurrence of certain combinations of wave height and period, which are substituted in the ISSC two-parameter spectrum formulations. These programs, designated as WTS 120 and WTS 121, respectively, were recently used to extend the SCORES program at Webb as additional options available to the user.

The present status of wave data will be reviewed in a subsequent section.

In the numerical exmmple given in Chapter IX, the Webb "H-family" of spectra, based on wave spectra from (66), is used in conjunction with WTS 120. For each spectrum the standard spreading function was applied:

$$S(\mu) = \frac{2}{\pi} \cos^2 \mu$$

where μ represents the wave direction angle. The RMS response corresponding to each wave spectrum was obtained from,

$$(RMS)^2 = \int_{-\pi/2}^{\pi/2} \int_0^{\infty} S(\mu) \quad S(\omega) \; | \; R \; (\omega) |^2 \; d\omega \; d\mu$$

Then the mean m_j and standard deviation s_j of RMS values within each wave height group j were determined.

LONG-TERM COMPUTATIONS

The final step of ship loading response calculations is to extend the available calculations for limited periods of time in specific irregular sea conditions to long-term predictions, covering the lifetime of a ship or a fleet of ships. The mathematical model and program WTS 62 were described in detail in (10). The only additional required input to this program is a distribution of sea conditions for the particular ocean area of interest.

The mean m_j and the standard deviation s_j for each wave height group, together with the probability of occurrence of that group p_j, give us the necessary parameters to obtain the long-term distribution:

$$P(x_o) = \sum_{j=1}^{5} p_j \int_0^{x_o}\int_0^{\infty} p(x_o;\ \mathrm{RMS})\ p(\mathrm{RMS};\ m_j,\ s_j)\ d\ \mathrm{RMS}\ dx_o$$

where $p(x_o;\ \mathrm{RMS})$ = Rayleigh distribution of x_o, for a particular value of RMS, and $p(\mathrm{RMS};\ m_j,\ s_j)$ = Normal distribution of RMS. The technique is applied to the shear forces, and to vertical, lateral and combined bending moments.

It is believed that the incorporation of the above programs, and the various modifications to SCORES, have produced the most comprehensive program presently available in this country for use in wave load aspects of ship design.

It should be noted that the long-term probability density function can be expressed as follows:

$$p(x_o) = \sum_{j=1}^{5} p_j \int_0^{\infty} p(x_o;\ \mathrm{RMS})\ p(\mathrm{RMS};\ m_j,\ s_j)\ d\ \mathrm{RMS}$$

This function is of importance for two applications, in particular:

1. For combining with the probability density function for still water bending moment. (See Chapter VIII).
2. For combining with the probability density function for structural capability to determine the probability of failure (31).

The present status of wave data is reviewed in the next section.

WAVE DATA

Wave data available for calculation of bending moments have been obtained in two ways: by actual measurement of the surface elevation over a period time and by observation of wave heights and periods. Each of these sources will be reviewed in turn.

Wave Records

The largest source of data available under the first category is the NIO wave records collected by means of Tucker wave meters on British Weather Ships over the past 18 years in the eastern part of the Atlantic Ocean. The records are available in the form of strip charts. A typical example of one type of analysis which can be performed on such data is given in (67). The analysis is limited to three basic