parameters, the peak-to-trough mean height, the mean zero-crossing period and the mean-crest period. Other parameters, such as the significant wave height, or the spectral width parameter can be approximated from the above measured parameters.

Strip chart wave data, though basically suitable for any type of further analysis, are in practice rather expensive to transfer to the frequency domain. However, in order to extract maximum information out of such records a spectral analysis should be performed in order that the results can be given in a form representing the distribution of wave energy of the irregular wave components over frequency, i.e., an energy spectrum. This constitutes the ideal form of wave data presentation, for ideally if one is to predict the performance of a ship under certain environmental conditions the actual spectrum, or a family of spectra representing different possible wave heights at that location, should be used.

Very few sources of wave records reduced to spectrum form are available in quantities adequate for statistical sampling. The main source of data is (66) and (68). The former is a biased sample of 460 records selected from the North Atlantic weather stations representing mostly fully-developed storm conditions. The latter constitutes a sample of 307 records all taken at one station at midday over a period of 12 years, using a stratified sampling procedure. These records were selected at Webb Institute from National Institute of Oceanography (Great Britain) records, with the assistance of Professor Pierson of New York University, and were spectrum analyzed by the National Research Council (Canada). Correlation of results with Beaufort No. and other analyses are being carried out currently at Webb Institute.

An area for which more measured wave data are needed is the North Pacific. It is hoped that several projects now under way will produce some useful data. Other sources of ocean wave spectra are Scott (69), Fukuda (70), and Yamanouchi (71).

An additional parameter often associated with spectra is the normalized average period slope parameter, K. The value of K is an indication of the deviation of the actual average period of the spectrum from that of a fully developed Pierson-Moskowitz spectrum and was originally introduced in (72). By defining K, as well as the significant wave height and period, some further indication as to the nature of a spectrum is provided. A typical distribution of K values against wave height was recently given in (73) based on 307 records collected at Station INDIA in the North Atlantic.

A limited amount of data has been obtained by means of a buoy measuring wave slope (74). Analysis of the records permitted the determination of directional spectra that give the distribution of wave component directions as well as frequencies.

It must be recognized that shoaling water has a significant effect on wave patterns. The waves tend to become steeper as they travel in from deep to shallow water. Although this effect is noticeable only in water depths of magnitude comparable to wave length, there are a number of ocean areas where the effect is significant for large, modern ships. Of particular importance is the continental shelf at the entrance to the English Channel. In general, the relatively shallow waters of the North Sea, Irish Sea and English Channel are characterized by short, steep seas. Some wave data including representative spectra are available from British sources (75)(76).

Wave Observations

A much more common way of describing the world oceans, because of its relative simplicity and low cost, is by means of the observed heights and periods of the waves and their frequency of occurrence. Both the wave height and period can be estimated to varying degrees of accuracy by seagoing peronnnel. The most reliable data of this type are those available in reports of trained observers on board weather ships, as well as at various permanent weather stations around the world.

However, the most common source of observed data is the reports of various ships sailing throughout the world's oceans. The most comprehensive such collection of data is given in (77), which covers most of the ocean areas. Other sources are (78)(79)(80)(81)(82)(83)(84). Similar, more localized tables are available for specific areas of interest such as the Great Lakes (85), Cape of Good Hope, (86) etc. The information is usually given in tabular form showing the probability of occurrence of the various possible combinations of wave height and period. An alternative form of presentation is by means of a histogram.

Figure 8 gives a comparison of the results given by various sources, mostly for the North Atlantic. Local data for the vicinity of the Cape of Good Hope is also included, in order to show how a local condition may differ from commonly used data. This ocean area is of considerable interest because large tankers regularly traverse it between the Persian Gulf and Europe, and long, heavy swells are known to occur there at times. More data are needed, but the new information helps to round out the picture.

The interpretation of observed wave height and period in terms of the significant wave height and the average period is not easy. It has been found, however, that for the untrained observer a simple approximate relation between the observed wave height H_v and the significant wave height $H_{1/3}$ can be established (87). Similar relationships can also be established for trained observers. When wave records are available it is customary to refer to the period as the average zero-crossing period.

Mathematical Formulations for Spectra

In order to make use of observed wave data for predicting ship motions or wave-induced loads, it is essential to make use of some idealized spectrum formulation. The description of the sea by means of two basic observed characteristics, i.e., wave height and period, can be achieved by means of a mathematical expression of the spectrum in terms of these two parameters. The basic parameters are mathematically defined in terms of the area under the spectrum and the moments of the area. Several such formulations are available, and the most common one is usually referred to as the ISSC spectrum formulation (88).

For each pair of values for wave height and period a spectrum is defined in terms of the spectral ordinates at discrete values of the frequency, ω. Hence, for a matrix of wave heights and periods a family of spectra can be obtained for which the probability of occurrence of each spectrum can be defined and applied as a weighting factor. Though the mathematical formulations do not completely describe the variability of spectral shape, they can be used for long-term predictions of bending moments with reasonably satisfactory results (10).

Wind Parameter

In the absence of any of the above information, i.e., the actual spectra or observed wave heights and periods, the only way to describe the sea is by means of the wind speed, which can be considered to be the single most important factor in generating waves. It is apparent that wind speed alone is not adequate for an exact description of the sea, since other factors such as duration, fetch, tempera-

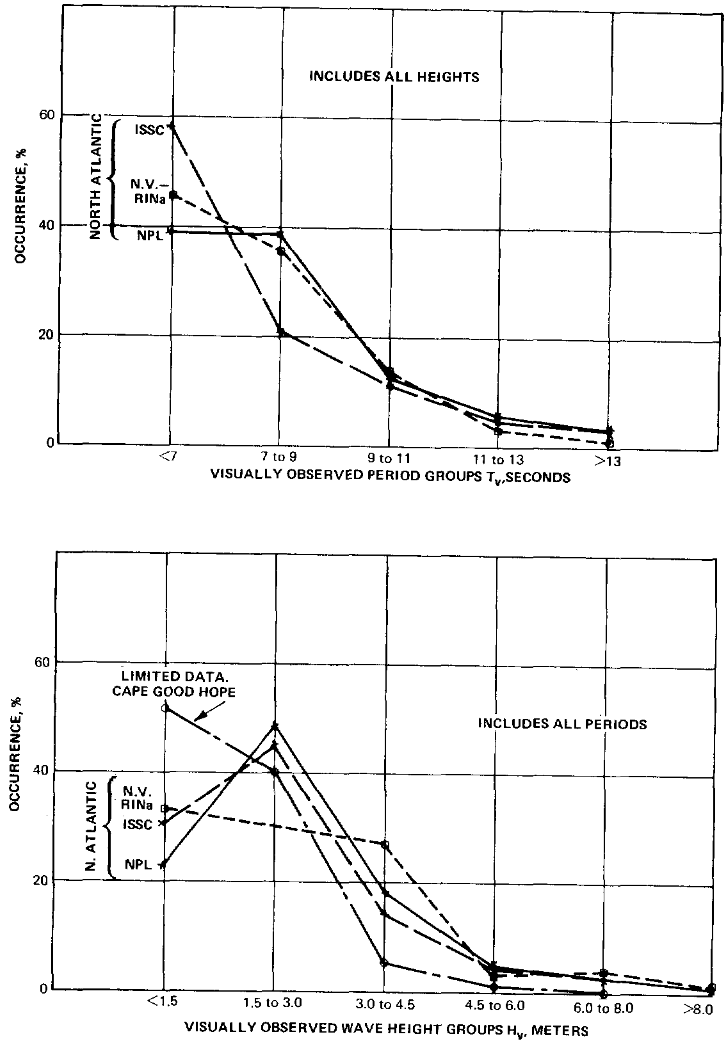


FIGURE 8 - Comparison of Wave Statistics:
Observed Periods and Heights

tures, etc., are important. However, wind speed or Beaufort No. is a relatively easy parameter to measure and is commonly available in most weather charts. Relations between wind speed and wave height have been suggested in several references such as (69)(71). It is always meaningful to relate the wind speed to a mean significant wave height, so long as the standard deviation is also given. One should realize, however, that in lakes or gulfs such data are less meaningful because of the limited fetch conditions which prevail.

The relationship between wind speed and wave period is much less significant and not so easy to define. However, if the significant wave height is available some typical relationships between it and the wave period can be given for specific ocean zones.

FUTURE DEVELOPMENTS

The short survey presented here indicates that a great deal of progress has been made in recent years in the theory of ship behavior in waves, and a variety of computer programs is available to apply this theory to specific problems. However, these programs are only partly coordinated, and only a beginning has been made in showing how different programs can be combined for design use in the area of wave loads. It is felt that further work should be done in documenting, evaluating and improving individual programs, in comparing results in specific cases -- among programs, and between programs and experimental results -- and in determining how different programs can best be combined for various problems and for different types of ships.

An overall view of the problem of determining wave loads discloses that experimental and theoretical aspects have been brought to an advanced stage of development, but that the biggest gap is in our knowledge of ocean waves. Actual wave records that can be subjected to spectral analysis are available for only a limited number of locations on only a few routes, leaving a great uncertainty regarding all of the major trade routes of the world. The collection of more wave records is believed to be of primary importance.

V. DYNAMIC LOADS

INTRODUCTION

Dynamic hull loads may be classed as:

a) steady-state,
b) transient.

Steady-state dynamic loads are the result of such exciting systems as propeller-hull interaction, machinery-hull transmission and seaway component excitation of hull girder response, as in "springing." Transient dynamic loads result from forward bottom slamming, bow flare immersion and submergence, carrying green seas aboard and wave impacts on structural members during rough sea operation.

The transient loadings will be considered first. There are a multitude of possibilities for such transient loadings, and the generated impacts on the ship's exposed surfaces often result in structural damage of considerable severity. The impact loadings are generally most severe in the forward portions of a ship's structure where relative velocities between ship and sea are highest. These impact loads arise from the short-time exchange of momentum between ship and sea, and the damage results when the local elastic energy absorption capability is inadequate. Energy absorbed locally is distributed through the structure in the form of dynamic response, "whipping," etc., and dissipated through damping, structurally, by cargo, etc. The question of concern is what loading is to be used in design. There are as yet no established criteria for assessing structural loadings arising from impacts of the sea on ship structure. Consequently, a real need exists for the documentation of resulting damages and the conditions leading thereto, so that future evaluations of probable loads would be possible.

Unlike quasi-static bending moments, dynamic loads acting on the hull girder cannot be considered independently of the structural response of the hull. In the first place, the dynamic magnification factor depends on the natural hull frequency as well as the nature and duration of the exciting force. Secondly, the response depends on the damping, which involves structural as well as hydrodynamic terms. Thirdly, the extreme structural response of the hull which is of particular interest -- plastic buckling or permanent set -- requires time and the absorption of large amounts of energy. As mentioned in Chapter II, the duration of a slam load may be too short to cause buckling of a ship's deck or bottom amidships. This is probably not true, however, of the longer-duration flare-immersion type of slamming which in some ships may contribute significantly to hull girder damage or failure.

Hence, the capability of the structure to withstand a dynamic load or stress may be increased by some factor which is dependent on the rate of application and duration of the load, as well as on the structural properties of the hull. Pending resolution of this structural design problem, it is important that techniques for determining and specifying the magnitude, duration and rate of application of the dynamic loads be dealt with. The problem of phase relationships between dynamic and static loads will be discussed in Chapter VI.

SHIPPED WATER

Consider first the miscellaneous loadings arising from taking aboard green seas over the forecastle, poop and even at boat deck levels and higher. Such loads have resulted in the shearing off and washing away of outfit items, deck houses and bulwarks. More seriously, hatch covers have been stove-in, fo'c'sle decks collapse and deck cargoes torn free of their lashings and washed overboard (89). There are no known published evaluations of the sea forces associated with these actions, though classification societies and cargo survey bureaus have revised scantling, stowage and other requirements on the basis of reported damage. Most loadings of this type are sufficiently random in occurrence, both in time and space, that their importance is primarily local, even though the hull girder may on occasion be excited in a manner which will superimpose significant stress variations upon those arising from static and quasi-static hull girder flexural, torsional and shear loads. Better documentation of shipping water damages and evaluation of the loadings that cause them would allow assessment of such loads for purposes of setting criteria.

Loading of the hull girder as well as local structure resulting from bow submergence into oncoming waves can cause, in addition to severe local damage, significant dynamic loading of the hull girder and generate structural response of such magnitude and duration that the stress generated can significantly augment the levels experienced in main structural elements of the ship. The problem of green seas impacting the ship and being carried over the bow has received attention by investigators in Europe, the U.S.A. and Japan (90). Hoffman and Maclean (91) have shown that in order to predict the event, knowing the ship's relative motion operators and the sea condition is sufficient. Kawakami (92) has shown that carrying green seas over the bow can generate whipping stresses equal in magnitude to as muc as 40%-70% of the sagging bending moment in regular waves. Thus, the prediction of the event and the magnitude of the loading response of the hull girder appear amenable to treatment by combined experimental and theoretical means. There has been, however, no full-scale confirmation of experimental findings, or vice versa. Consequently, there is not at present an established procedure for evaluating the magnitude and frequency of hull loading resulting from carrying green seas aboard at the ship's bow. Though experimental work by Kawakami (92) showed that full-scale fore deck loadings of 40-70 lb/in^2 could be experienced, generalization of these finding has not yet been attempted.

In view of the fact that these loadings can result in the generation of signif cant hull girder responses which are of sufficient duration to cause superposition on the quasi-static loading of the structure, it is recommended that further work b carried out in this area with a view to establishing full-scale experience and combined experimental-theoretical clarification for design.

FLARE IMMERSION

Slamming of the forward bottom and bow flare surfaces give rise to large loads on the hull girder of sufficiently short duration that high-frequency hull girder dynamic stress variations are generated of such magnitude that they may significantly augment the maximum stress levels experienced by main structural elements. The slam-generated forces developed on the ship forward bottom surfaces are generally the result of high pressures acting over relatively small areas of the flatter bottom plating; significant force duration is generally less than 100 milli-seconds. The forces developed by the immersion of the bow flare are generally the resultant of lower pressures acting on relatively larger surface areas of the hull. The duration of these forces is generally greater, but usually of less than a second with significant magnitude. These latter forces are of importance primarily to vessels with large bow flare, such as some aircraft carriers and some recently designed commercial vessels with large bow flare and overhang.

The generated pressures and resulting forces developed on the bow flare are susceptible to computation on the basis of available theory. The initial effect as the bow flare enters the water is a non-linear addition to the quasi-static wave-induced bending moment. A step-wise evaluation of the exciting force for the calculation of vibratory hull girder response, as discussed below, can be used to compute the initial bow flare immersion effect. The duration of this bending moment is sufficiently long that it should probably be added to the other moments involved in ultimate strength.

The vibratory response or whipping following flare entry can be determined by analog simulation (93)(94) or by deterministic calculation (95)(96). This short-duration response, generally in the fundamental mode, should be considered in relation to fatigue and brittle fracture. However, there are no known published recommendations concerning the magnitude of bow flare-generated forces that should be considered as design loads either for the hull girder or the local structure forward.

The basic theory of impact for a wedge entering the free surface of a fluid is applicable to bow flare load generation. Such theory, developed by Wagner, von Karman, Pabst and others has been modified by Szebehely, Ochi, and others for application to ship forms in which the body is not stopped by the impact. This theory has been the basic ingredient for all the work mentioned above. To use it for the generation of load information, as per Kaplan's program (95)(96), requires a deterministic approach in which a mathematically defined hull is subjected to an irregular wave pattern derived from a sea spectrum of interest. Kaplan's procedure allows the prediction of ship loads on such a basis and, upon repeating the process for a suitable number of sea conditions, a body of load data could be developed for use in a suitable probability model.

The chief drawback seen in the above approach appears to be the fact that sinkage and trim, as well as dynamic bow wave build-up, should be included if reliable bow immersion results are to be expected. These non-linear effects have been identified in experimental work (91) as vital to reliable prediction of flare submergence. The works of Tasaki (97) and Tasai (98) are also useful here. Further development of the theory should be carried out.

It is believed that a part of a rational design criterion would be first the calculation of initial bow-flare immersion bending moment for one or two representative severe head sea conditions, especially if the ship has considerable flare and operates in a deeply loaded condition. An exhaustive statistical study should not be necessary but simply a long enough irregular sea run to determine the highest value in, say, three to four hours.

The problem of phasing of flare-immersion bending moment appears to be much simpler than that of slamming (See Chapter VI). The bending moment (sagging) gradually increases as the flare enters the water and reaches a maximum at or near the time when the wave bending moment is also a maximum in sagging. Hence, the combined effect of wave bending moment and flare immersion can be approximated by adding the *maximum* values *directly*.

Secondly, the vibratory response (whipping) that follows flare immersion should be calculated for ships with large flare by the method developed by Kaplan (96). It is recommended that this approach be developed into a standard procedure for use in relation to design for ultimate strength, fatigue and brittle fracture.

BOTTOM IMPACT

The initial effect of a bottom impact is the generation of large local pressures which may in some cases cause local structural damage. The resulting hull girder response is in the higher modes, as well as the fundamental, and therefore may produce a high initial stress. The whipping that follows will be mainly in the fundamental, since the higher modes are quickly damped.

In respect to loads generated by forward bottom slamming, present capability is restricted to the prediction of peak pressures at a point on the forward bottom centerline of typical hull forms. Based on the work of Ochi (99), the hull form of a ship's forward bottom sections can be assigned coefficients, k, such that for a known impact velocity, V, the peak pressure generated at a section would have a most probable value $p = kV^2$. The coefficients, k, for some typical section shapes have been determined on the basis of regression analysis of 3-dimensional model experiments in waves (100). Using these values, a comparison can be made respecting the slamming propensities of competing hull forms. To do so, the ship response properties must be determined, experimentally or analytically, and the relative velocity spectrum for the critical ship section established. Using this approach, maximum slam-generated pressures in a given sea can be predicted on the basis of probability. Such data may be used for design of local structure if the probability can be prescribed with a satisfactory degree of confidence. Unfortunately, no full-scale assessment of local loading has yet resulted in the establishment of a probability level that could be used as above; a recommendation is made that such be pursued.

It is understood that Dr. Ochi is working on a mathematical description of slam loading which attempts to describe the distribution of pressures in both time and space. With such a load definition various procedures are available for calculating the hull girder response and hence the midship slamming stress (101)(102). However, the requisite load definition is not yet available.

Because of the above situation, it is not possible to prescribe at this time a slam loading of the hull girder, due to forward bottom slamming, which should be used in setting design criteria. On the other hand, the problem can be viewed in another light somewhat more positively. Full-scale strain recording on board the S.S. Wolverine State has captured hull girder slam and whipping stress variations experienced during rough sea operations of the vessel. Evaluation of data (103) obtained in various high sea states has shown that the severity of slam response -- *when it occurs -- tends to be somewhat insensitive to sea condition.* This can be explained by noting that though slamming frequency and severity are increasing functions of sea state, sea speed and vessel heading, the latter two are under the control of the ship master who will tend to alter course and speed so as to keep the frequency and severity of such sea loadings within reasonable bounds, according to his experience. Fig. 9 shows histograms of midship slam stress variation for the Wolverine State (103), which can be interpreted in terms of equivalent hull girder bending moment.

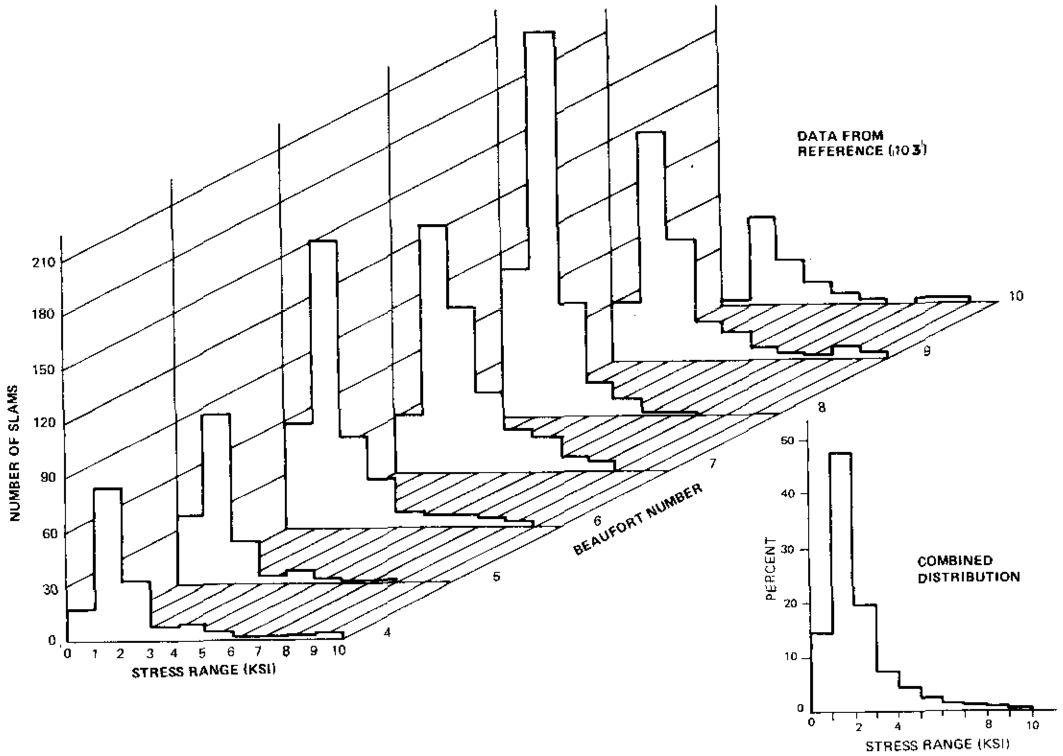


FIGURE 9 - Peak-to-Peak Slam Stress Distributions in Different Weather Conditions, *S.S. WOLVERINE STATE*

Whereas the findings as to the relative level of loading experienced by the S.S. Wolverine State would apply only to that vessel and in its particular trade, it seems apparent that the collection of similar data on a sampling of vessels of other types loaded in different ways should provide a suitable basis for the development of allowances for slam loading of the hull girder. Further, in view of the complexity of the slamming phenomenon, it does not appear that an analytic description of slam loads will be forthcoming in the foreseeable future, and the collection of full-scale slam response data appears to offer the most promise for the establishment of expected hull girder slam loads.

It is recommended, therefore, that stress (strain) recordings presently in hand for other vessels in other trades be reviewed and analyzed as to the frequency of slamming and the magnitude of slam stresses, and that consideration be given to the gathering of similar data on vessels of more recent design to be reviewed on the same basis. Such data can be used for the time being as a guide in estimating dynamic loads and stresses for new ship designs.

Another aspect of the slam load problem to be considered, if one is to determine the combined effect of slamming and quasi-static wave bending on the hull girder, is the phasing of the slamming loads. The particular instant in the wave bending cycle at which a slam occurs determines the extent to which the slam stress-- and the subsequent whipping stress -- add to the total stress magnitude. A study of this subject has been made, on the basis of Wolverine State stress records, and is reported in Chapter VI. This investigation indicates that the phasing -- as well as the magnitude -- of slam loading can be established empirically for different ship types as a basis for design. However, it also shows that the stresses at impact seldom if ever add significantly to the total bending moment. Of much greater importance is the whipping that follows a slam.

For design purposes, the practical problem of determining the transient dynamic loads reduces to two parts:

(a) The prediction of the probability that slamming will occur (over a period such as a 20-minute record).

(b) The distribution of added stress (or equivalent bending moment) to be expected when slamming and whipping occur.

OBSERVED LOADS AND STRESSES

Available published data on actual slamming pressures recorded on ships at sea and on measured midship slamming stresses are scarce. However, a summary of available information on maximum recorded values is given in the accompanying Table I, compiled from the indicated references.

Reference should also be made to a general survey of slamming by Henry and Bailey (104).

SPRINGING

As mentioned in the Introduction, one type of steady-state dynamic effect is known as "springing." This phenomenon has been noticed particularly in Great Lakes bulk carriers (114), but it has also been reported on ocean-going ships (115)(113). A clue to the origin is given by the fact that the Great Lakes bulk carriers are quite shallow in depth and consequently have unusually long natural periods of vertical hull vibration (2-noded periods of 2 secs. or longer). The apparent explanation is that when the ship is running into comparatively short waves that give resonance with the natural period of vibration, significant vibration is produced. This vibratory respohse may continue over some period of time, gradually fluctuating in magnitude. A corresponding fluctuation in stress amidships is therefore

Table I

MEASURED FULL-SCALE SLAM LOADS AND MIDSHIP STRESSES

	Pressure p.s.i.	Peak-to-trough Midship Slam Stress, kpsi
USCG Cutter	295 local	-
Unimak (105)	86 ave. panel	-
Dutch Destroyer (106)(107)	100+	11.20
Cargo Ship S.S. Westboro (108)	-	1.90
Cargo Ship S.S. Wolverine State Voy. 288	49	2.60
(109) Voy. 277	69	-
(103)		10.00
Bulk carrier Fotini L (110)	-	15.50
Container ship Manchester City (111)	-	5.00
Cargo ship M.V. Jordaens (112)	-	4.50
	19.	2.04
Container ship Flinders Bay (113)	-	15.60

superimposed on the quasi-static wave bending moment. The springing stress appears to have the characteristics of a stochastic process, but one that is essentially independent of the low-frequency wave bending, which -- as previously noted -- is also treated as a stochastic process.

Figure 10 shows a record of midship stress in which both low and high-frequency stresses are present. Also shown are two records in which first the high-frequency stresses have been filtered out and second in which the low-frequency stresses have been filtered out.

The well-developed strip theory of ship motions has been applied to the springing problem (115). Although motions of a springing ship may be very small, the theory provides information on the exciting forces acting on the ship in the short waves that produce springing. Hence, when these forces are applied to the ship as a simple beam the vibratory response can be predicted. Despite the fact that strip theory is not rigorously applicable to such short waves, results for one ocean-going ship were found to agree quite well with full-scale records (115). Further coordination between theory and experiment has been attempted for Great Lakes ships, including model tests where idealized wave conditions can be provided (116). Subsequent tests with a jointed model of the Great Lakes carrier Stewart J. Cort using connecting beams of varying stiffness, show clearly that the springing bending moment increases with hull flexibility.

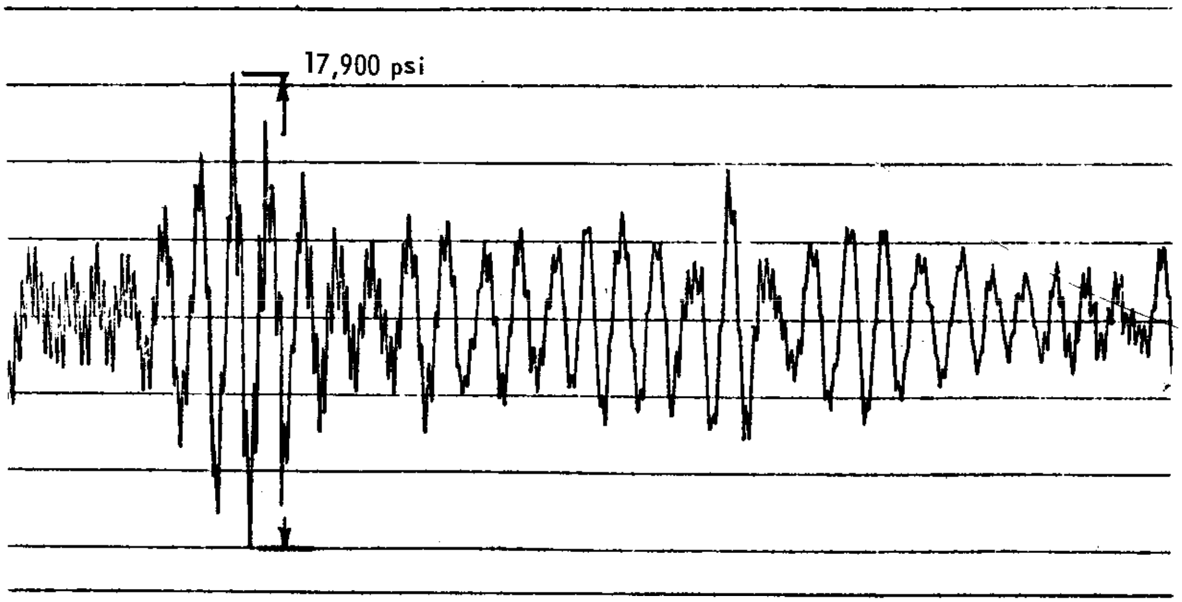
When the above calculation procedures have been tested and revised as necessary, a tool will be available for predicting springing stresses in a new ship design. The remaining problem for incorporating springing into the comprehensive ship hull design criteria is to determine the manner in which springing stresses superimpose on the low-frequency bending. This problem has also been solved in principle (117) on the basis of the assumption that the two stochastic processes are independent. This assumption is illustrated by the records in Fig. 10 which show that high amplitudes of the two types of stress do not occur at the same time.

Further work needs to be done as new information becomes available. Meanwhile, the general cargo ship -- which is the principal subject of the present study -- does not seem to be subject to significant springing effects, and therefore they need not be included in the present criteria.

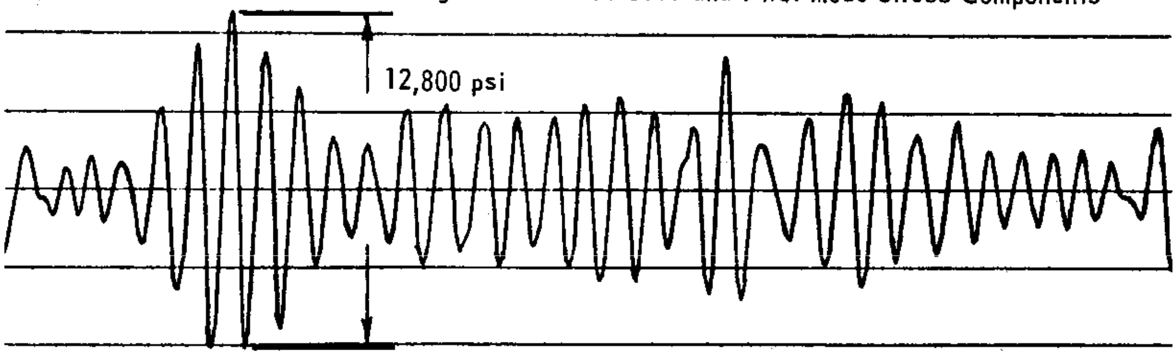
VI. PHASING OF SLAM AND WAVE LOADS

INTRODUCTION

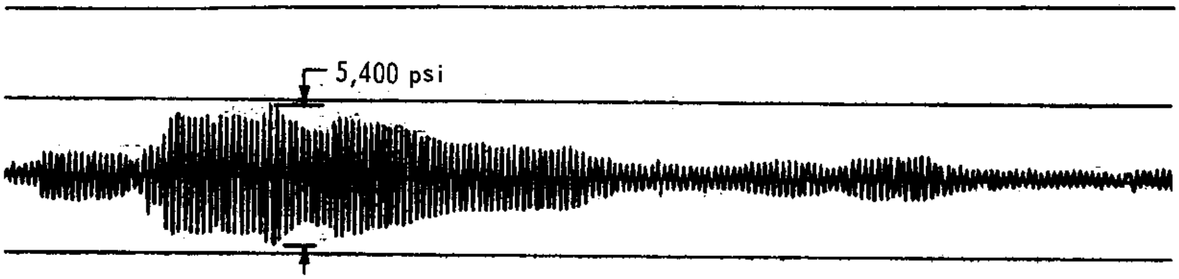
It has been the goal of this project to obtain complete information on all aspects of ship hull loading, particularly loads generated by waves at sea. The first type of load, quasi-static wave-bending moments, has, of course, been focused upon first, and the current state of knowledge is summarized in Chapter IV. Next must be considered the influence of slamming, and whipping after the slam, which are discussed in Chapter V. Finally, in order to determine the combined effect of wave bending and slamming, particularly in reference to brittle fracture, it is necessary to understand the way in which the latter high-frequency load is superimposed on the former. If the slam should occur, for example, when the wave bending moment is near zero, the immediate effect of the slam will not be an increase in the total amplitude of bending moment amidships unless it exceeds the wave bending moment amplitude. On the other hand, if the slam should occur exactly at a peak bending moment it would increase the total by whatever its amplitude might be. Similarly the amount by which the vibratory whipping stress (or equivalent bending moment) following the slam would add onto the subsequent peak of the wave bending moment curve would depend on how rapidly the vibration is damped out.



a) Total Stress Variations Including Both Wave-Induced and First-Mode Stress Components



b) Wave-Induced Stress Variations (Frequency Approx. 0.1 Hz)



c) First-Mode (Springing) Stress Variations (Frequency Approx. 0.70 Hz)

FIGURE 10 - Typical Record of Midship Stress Variation, M.V. *FOTINI L*, Showing Filtered Wave-Induced and Dynamic Stresses (3).

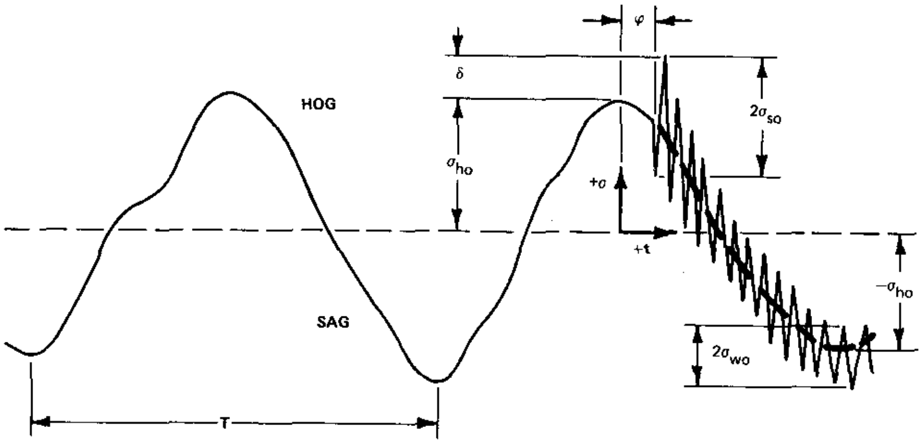
Nothing could be found on this subject in the literature. Hence, it was decided to make a study of the phasing of slam and wave loads for the Wolverine State, since it was possible to obtain stress records of slamming from Teledyne Materials Research, and a reasonably clear picture emerged for this particular ship.

It is realized that is impossible to generalize this result for one ship to apply to all ships, and hence it is believed that similar studies should be made on ships of other types and sizes.

DEFINITIONS

A slam is defined as a transient impact force acting on a ship. We can therefore call the hull girder stress generated by this transient force the slam stress, σ_{so}, by which we mean the first peak (sag) or the second peak (hog) in the slam stress time record. (See Fig. 11). The two-noded hull girder vibration generated by the slam is called whipping. We call the stress generated by this vibration the whipping stress, σ_{wo} . It should be noted that bending moments equivalent to these stresses can be determined for combining with other loads. Wave bending moment is defined as the low-frequency hull girder moment which is experienced at frequencies corresponding to the ship's encounter with the waves in the seaway and produces the wave stress, σ_{ho}.

It should be pointed out here that in this study we are particularly interested in: (a) the second peak of the slam stress time trace -- generally occurring during a hogging wave stress condition -- and (b) the whipping stresses in the subsequent sagging and hogging wave stress conditions. See Fig. 11.



σ_{ho} = WAVE STRESS
σ_{so} = SLAM STRESS
σ_{wo} = WHIPPING STRESS
δ = ADDITIVE PORTION OF σ_{so}
φ = PHASE ANGLE

FIGURE 11 - Definitions of Stresses and Phase Angles Involved in Slamming