Wave Groups and Wave Breaking in Random Seas

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LONG-TERM GOALS

To develop an understanding of wave groups and wave breaking in random seas, including the interrelation between the two.

OBJECTIVES

1. Study wave groups and wave breaking, develop a laboratory database using measurements made in the Naval Academy's 380-ft wave/towing tank, and develop appropriate statistical descriptions and theory for the observed phenomena.
2. Investigate influence of laboratory system on measurements.

APPROACH

1. Statistics are derived from laboratory wave records of random seas. Theoretical concepts are established from similarity arguments, general statistical theory, existing theories of wave statistics and wave groups, wave mechanics and extensions to include nonlinear effects.
2. Influence of laboratory system on measurements is examined by varying measurement location in the wave tank, by comparison of results with full-scale ocean data, and by comparison with results from computer simulations.

Participating Individuals

- Dr. D.L. Kriebel, Professor, U.S. Naval Academy. Colleague on research and publications.
- Ms. L.A. Wallendorf, Ocean Engineer, U.S. Naval Academy Hydromechanics Laboratory. Colleague on experimental measurements.

WORK COMPLETED

Wave Groups

Previous work under this project has involved development of wave group statistics from laboratory simulations of Bretschneider and Jonswap seas (Dawson et al., 1991). Statistics have been found to be insensitive to measurement location in the wave tank, provided location changes are limited to regions where the wave spectrum itself does not change appreciably (Wallendorf, 1989). Wave-group statistics

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from the scaled seas have been found to contain significant Stokes nonlinearity, causing increased crest amplitudes and decreased trough amplitudes (Kriebel and Dawson, 1991; Dawson and Kriebel, 1994). Linear theories of wave statistics and wave groups have been extended to include this nonlinearity within the context of Stokes 2nd order theory (Kriebel and Dawson, 1991; 1993). Enhanced group formation in ocean swell has been studied experimentally for comparison purposes (Dawson and Kriebel, 1993).

Wave Breaking

Previous work has also been directed toward the laboratory study of wave breaking in random Jonswap seas and the development of breaking statistics for these seas when different degrees of wave breaking are present (Dawson et al., 1991; 1993). A simple theory for the probability of breaking at a point in narrow-banded seas has been developed. The theory has been extended to describe the distribution of crest amplitudes in severe seas with breaking (Kriebel and Dawson, 1993). Additional work has involved the study of the evolution of wave breaking by use of multiple probe measurements (Kriebel and Dawson, 1994). Breaking is found to occur when waves reach critical crest amplitudes as they run through wave groups, consistent with qualitative observations of others.

Scale Modeling

Additional previous work has been concerned with scale modeling in the laboratory of sea conditions that existed in the Gulf of Mexico during Hurricane Andrew of 1992. The objective has been to determine how well actual sea-state statistics can be determined in laboratory studies. Laboratory results have been compared with those found from full-scale records, kindly supplied by Shell Oil Company. Good agreement was found to exist for basic statistics such as the relative number of high waves observed at a fixed location and the average number of waves in runs of one or more high waves (Dawson et al., 1996). Recent work (FY 98) has involved modeling extreme sea conditions that existed in the Gulf of Mexico during the intense Hurricane Camille of 1969. Laboratory wave records have been made and comparison with full-scale data is in progress, with special emphasis on wave-breaking conditions.

Markov Description

Earlier work has involved a detailed study of the applicability of Markov theory in describing wave-crest statistics (Dawson et al., 1996). The basic assumption in this theory is that waves are statistically correlated only with their immediately preceding neighbor. Comparisons with laboratory and field measurements indicate direct applicability of the theory for waves with crest amplitudes greater than 50% of the significant wave height. More recently, the Markov theory has been extended to describe group structure in random seas, that is, the statistics associated with the occurrences of two or more consecutive high waves (Dawson, 1997). Comparison with laboratory and field data showed good agreement. Additional comparisons with laboratory and computer data have been completed (Dawson, 1998a). Theoretical and experimental studies relating the Markov description to spectral properties of random seas have also been completed (Dawson, 1998b). Recent work (FY98) has been completed on an examination of Markov correlation for the very highest waves in a Jonswap sea (Dawson, 1998c). As a part of this work, the Stokes 2nd order theory for nonlinearity in random seas has been extended to 5th order.

Wave Breaking and Group Statistics

Work is continuing on an experimental study of the effect of wave breaking on group statistics. Recently (FY98), wave measurements have been made for three cases of a scaled Jonswap sea: (1) that with large, but non-breaking waves, (2) that with large waves having moderate wave breaking, and (3) that with large waves having significant breaking. Analysis of wave data with respect to group properties is continuing for this new data set, as well as for measurements reported for FY97.

RESULTS

Results achieved in FY98 include the following:

1. Based on extensive computer simulation of a Jonswap sea, it has been found that no Markov correlation exists for waves having crest amplitudes greater than about 80% of the significant wave height. This is in contrast with the case of waves with crest amplitudes exceeding 50% of the significant wave height, where appreciable correlation exists. The implication is that no biased grouping of the very highest waves exist and that any occurrence of two or more very high waves in a group is strictly a matter of chance for independent events. This result is of importance regarding predictions of the expected highest wave in a sea of finite duration (Dawson, 1998c).

2. Extension of Stokes 2nd order theory for nonlinearity in random seas to 5th order has indicated that, for severe seas, the probability of occurrence of wave crests greater than the significant wave height is somewhat less than predicted by 2nd order theory and that the corresponding probability of occurrence of wave heights greater than twice the significant wave height is somewhat increased over the 2nd order of prediction. Work is continuing on experimental verification of the extended theory.

3. Experimental studies of the effects of wave breaking on group statistics indicate, as a result of wave breaking, that the average number of waves in a group of waves, say N_{DG} is decreased from the non-breaking case, and that the average number of waves between wave groups, say N_{IG} , is increased because of the wave breaking. For example, considering Jonswap seas and wave heights greater than the significant wave height, a non-breaking sea provides values N_{DG} = 2.5 and N_{IG} = 31, while a sea with noticeable breaking provides values of N_{DG} = 2.2 and N_{IG} = 41. These results are, of course, consistent with earlier observations that breaking waves generally occur in groups. They indicate that breaking can reduce the number of waves in a group and reduce the number of groups existing in the sea.

IMPACT/APPLICATIONS

A detailed description of surface-wave statistics and wave breaking is of fundamental importance in understanding the nature of wind-driven sea states. For example, conventional wave statistics provide information on the relative number of high waves expected at a fixed location in a non-breaking random sea, but provide no information on the relative number arriving alone, in groups of two, groups of three, etc. For this refined description, wave-group and wave-breaking statistics are needed. A detailed description of wave statistics and wave breaking is also of importance in understanding hazards to and response of marine systems in heavy seas. Motions of such systems may be acceptable when caused by a single wave, but unacceptably high when caused by two or more successive high waves in a group. Nonlinearity associated with wave-crest statistics and wave groups is also important in forming accurate estimates of deck loading and deck wetting of ships and structures in heavy seas. Breaking of large waves in severe seas can require modification of such estimates.

TRANSITIONS

Increasing applications of wave-crest and wave-group statistics in ocean engineering can be expected in the near future as design methodology is refined to meet the continuing challenge of operating in severe seas.

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