FORMATION OF LARGE-AMPLITUDE WAVE GROUPS IN AN EXPERIMENTAL MODEL BASIN

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ABSTRACT

Experiments were performed to generate groups of large-amplitude waves in irregular seas in an experimental model basin. Measurements included both point and wave-field topology data. The process was deterministic in nature, such that a large-amplitude wave group occurred in the model basin at a predictable and repeatable location and time. Generation of asymmetric large-amplitude wave groups in an experimental basin is the first step in the development of an experimental test technique that ensures a model will be exposed to multiple realistic extreme wave events during a test run. This technique will enable improved evaluation of the performance of ships or offshore structures in severe sea conditions, reduce the necessary testing time in the basin, enhanced V&V for numerical tools, and more accurately represent a full-scale seaway where a ship may be at risk for encountering extreme events.

Keywords: *wave groups, extreme seas, rare events, model testing, dynamic stability, verification and validation (V&V)*

1. INTRODUCTION

The largest waves and wave groups in a seaway represent the most challenging environmental conditions for a surface ship (Kjeldsen, 1984), and provide critical considerations for dynamic stability, slamming and secondary loads, and ultimate structural strength in ship design. Capsizing or severe stability events may result from several initial rare events, including single unusually high, steep, and possibly breaking waves and groups of large waves.

Although not as well documented as single large wave events, eye-witness accounts have been made of ship experiencing wave groups, typically consisting of three large waves (Schuman, 1980; Buckley, 1983, 2005; Smith, 2006). These large-amplitude wave groups are often formed in developing seaways or by intersecting storms (Buckley, 1983; Toffoli, et al., 2004; Onorato, et al., 2006). The maritime accident investigation of the *Norwegian Dawn* indicated that the vessel had encountered three large waves in succession (NTSB, 2005; Broad, 2006).

A statistical comparison between regular wave groups and large-amplitude wave groups showed that the largest wave is typically accompanied by two or three large waves and the probability of the largest wave occurring in a group is higher than for regular large waves (Goda, 1976). Additional characteristics of large-amplitude wave groups include the group period being longer than for regular wave groups. The narrowing of the spectral bandwith for a seaway results in an increase in wave groupiness (Su, et al. 1982; Su, 1986; Yu & Liu, 1990). This spectral narrowing often occurs in a fetch-limited growing sea (Longuet-

Higgins, 1976), where large-amplitude wave groups would most likely occur.

Su (1986) suggested that a wave group with one or more extremely large waves would provide a better environmental design scenario than a single extreme wave or a regular wave group. Philips (1994) also expressed the need to develop a spatially-temporally defined extreme wave group in for ship design. To predict rare response events, wave groups can present a scenario of higher probability for extreme response than a single large-amplitude wave. The "problem of rarity" is encountered when the time between events is long compared to the wave period (Belenky, et al., 2008). For both experiments and simulations, deterministic groups of large-amplitude waves can be applied to overcome the problem of rarity by inducing realistic severe conditions for large roll motions, stability failure, or structural failure at a known time and location.

Tools have been developed for ship design where wave groups are used to induce a specific ship motion response. This approach was discussed by Blocki (1980) and Tikka & Paulling (1990) to study parametric roll, using wave groups to induce parametric excitation. Additional studies of the applications of wave groups to parametric roll response have been made by Boukhanovsky & Degtyarev (1996) and Spyrou (2004). Alford has used a design wave train method to produce a desired motion response (Alford, et al., 2006, 2007; Alford, 2008). Themelis & Spyrou (2007, 2008) deterministically predicted the required critical wave groups to induce instability for a ship. Then the probability of encountering one of these critical wave groups was computed for a given route and duration. Using this critical wave group method, instabilities were assessed including synchronous and parametric resonance, as well as pure loss of stability. A technique to identify "worst sea" and "best sea" conditions for an offshore floating structure was applied by Fernandes, et al. (2008). This technique used both envelope and autocorrelation function approaches to determine the highest and smallest wave groups from a spectrum.

However, theoretical and numerical models to assess surface ship dynamic stability performance, specifically in severe seas, are not yet fully mature. For the near future, model experiments may continue to be the primary method to evaluate surface ship dynamic stability in severe waves. However, once simulation tools are fully developed, model experiments will remain a necessary method to Verify and Validate (V&V) numerical predictions (AIAA, 1998). An important consideration for validation is the accuracy of comparison between the numerical and experimental realizations of these rare events.

Model experiments to assess dynamic stability and secondary loads and slamming performance are currently performed using two methods, testing in regular waves or irregular waves. Regular wave testing can be problematic because of the lack of realism, and also may result in an overly conservative assessment of stability and structural performance. A regular wave train can be considered a wave group of infinite length (IMO, 2005). Irregular wave testing can be difficult because very long run times are needed to ensure extreme events with low probability of occurrence are realized, including large waves or wave groups. Because of the temporal and spatial limitations of the basin, it is impractical to ensure the extreme events are realized.

2. THEORY

The first approach to reduce the number of required tests for regular wave seakeeping was the transient wave technique, developed analytically by Davis & Zarnick (1964). At the David Taylor Model Basin, Davis & Zarnick, and Gersten & Johnson (1969) applied the transient wave technique to regular wave model experiments for heave and pitch, at zero and forward speed. These tests demonstrated a potential reduction of the total necessary testing time by an order of magnitude. The transient wave technique was also applied to model testing in Japan (Takezawa & Takekawa, 1976; Takezawa & Hirayama, 1976) and was used in numerical simulations (Cointe, et al., 1988).

Clauss & Bergmann (1986), Clauss & Kuehnlein (1994, 1995), and Matos, et al. (2005) used a technique, forming a transient wave with Gaussian wave-packets, to excite model ships and offshore structures in an experimental basin. To generate desired deterministic wave sequences in an experimental basin, singular extreme waves were embedded in irregular seas with a linear wave theory "first approach," and then optimized using a fully nonlinear approach (Clauss, 2000, 2002, 2008; Clauss & Schmittner, 2005; Hennig, et al., 2006; Hennig, 2008).

One irregular seaway that has been used often for dynamic stability testing at the David Taylor Model Basin is Hurricane Camille. This storm is typical of a developing seaway and is known for groups of very steep waves. A series of dynamic stability model experiments were performed in both regular and irregular seas with DTMB Model 5514, a common naval combatant flared-type hull form (Hayden, et al., 2006). However, realizations of the most severe wave conditions in an irregular seaway require long time durations and are not repeatable.

To determine ultimate strength and primary bending moments for a ship a design wave formulation consisting of a single large-amplitude wave is typically used. To assess secondary structural loads, such as slamming, two techniques are used: drop tests and pressure panel measurements. While more accurate, pressure panel measurements are also the most difficult. Their usefulness depends on the size and location of the pressure panel, the time-duration of the test to ensure the desired number of slamming events, and the location of the slamming impact on the hull corresponding to the location of the pressure panel. Chen & Milburn (1987) demonstrated analytically that wave groups can have a significant effect on the dynamic response of offshore structures. However, loads predictions have been shown to vary widely, depending on the wave kinematics model employed for the evaluation (Sclavounos, 2005; Stansberg, et al., 2008).

Groups of asymmetric large-amplitude waves have been observed in nature, but are difficult to produce experimentally. Experimental techniques using wave-packet methods have been shown to generate symmetric wave groups often of heights, H_s, $2H_s$, H_s (Clauss, 2002; Clauss, et al., 2007) with shallow troughs, but have difficulty producing asymmetric wave groups. Although previous work has shown the wave-packet technique to be successful for generating single large-amplitude waves or symmetric wave groups and embedding single large-amplitude waves into irregular seas, more realistic conditions are necessary to determine the most severe ship response.

Because the emphasis of this study was on the generation of asymmetric groups of large-amplitude waves, an alternative method was considered. To generate groups of large-amplitude waves with characteristics similar to those observed from full-scale ocean measurements, a method using linear superposition of a series of finite regular waves was examined. Superposition can be utilized to combine wave-trains of different periods, amplitudes, and number of cycles into larger or smaller amplitude waves, by either constructive or destructive interference. This technique is referred to below as the finite-wave linear superposition method.

2.1 Wave Group Formation

The finite-wave linear superposition method employs the interaction between sequential finite length regular wave-trains of different amplitude and frequency. For a given finite wave-train, consideration of the wave amplitude, period, and number of cycles enabled the different finite regular waves to superpose as a group of large-amplitude waves at a desired, repeatable location in the basin. For this investigation, it was determined that wave-trains consisting of four segments were sufficient to produce groups of three waves, similar to those observed in full-scale ocean measurements.

Linear wave theory was applied to produce regular wave-trains which were calculated to coalesce at a determined concentration position, x_a. The wave-maker signals for wave generation were determined using the following equations:

$$t_n = t_0 + \frac{T_n}{4} - T_n\left(Cyc_n - 1\right) \tag{1}$$

$$V(t) = H_n \cos\left[\frac{2\pi\left(t - t_n - \frac{T_n}{4}\right)}{T_n}\right] \tag{2}$$

$$t_P = \frac{x_a}{c_{Gn}} + \frac{T_n}{4} \tag{3}$$

$$c_{Gn} = \frac{d\omega}{dk} = \frac{gT_n}{4\pi} \tag{4}$$

$$s = \frac{H}{\lambda} \tag{5}$$

$$\lambda = \frac{g}{2\pi} T_n^{\,2} \tag{6}$$

where t_n is the start time for the *nth* regular wave-train, *V(t)* is the voltage signal input used for the *nth* wave-train at time, *t*, t_p is the time for the *nth* wave-train to reach the intended point, x_a, and c_{Gn} is the deep-water group velocity of the *nth* wave-train, and λ and *s* are the wavelength and wave steepness, respectively. T_n is the period of the *n*th wave-train in seconds, H_n is the amplitude of wave-maker flap motion for the *n*th wave-train, Cyc_n is the number of cycles of the *n*th wave-train, and t_0 is the zero time before waves start in seconds. Local g is $9.80100\ \mathrm{m/s^2} \pm 0.0004$.

2.2 Wave Groups in Irregular Seas

Asymmetric groups of large-amplitude waves were generated using the finite-wave linear superposition method and then embedded into two scaled irregular sea spectra, a 30th scale Bretschneider sea state 8 (H_s=38.1 cm, T_m=3.0 s) and two Hurricane Camille spectra, a 30th scale (H_s=40.64 cm, T_m=2.45 s) and a 46th scale (H_s=26.16 cm, T_m=1.96 s).

To embed the wave groups, the wave-maker control signal used to generate the wave group was inserted into the control signal to generate the desired scaled irregular seaway. Discontinuities between the initial signal for the seaway, the wave group signal, and the signal for the continuation of the seaway were manually removed. Then a time-series realization of the seaway with the embedded wave group was generated and examined.

3. EXPERIMENTAL METHOD AND TEST PROCEDURES

Experiments were conducted in the Maneuvering and Seakeeping (MASK) basin at NSWCCD to investigate the feasibility of producing large-amplitude wave groups in an experimental basin. The first experiment consisted of producing several combinations of finite regular waves with varying parameters, including amplitude, frequency, and signal duration. A second experiment was conducted to embed large-amplitude wave groups, obtained through finite regular wave superposition, in two scaled long-crested irregular seaways: a Bretschneider sea state 8 spectrum and a Hurricane Camille spectrum. The scales chosen are representative of typical model scale ratios used for dynamic stability and structural loads evaluation.

Descriptions of the MASK basin, wake-maker operations for regular and irregular waves, and two wave height measurement systems, the Senix wave gage and Global Laser Rangefinder Profilometry (GLRP) are presented in the following sections.

3.1 Maneuvering and Seakeeping (MASK) Basin

The wave generation experiments were conducted in the Maneuvering and Seakeeping (MASK) basin at NSWCCD (Figure 1). Eight pneumatic wave-maker units are located along the 73 m east side of the basin and thirteen units along the 110 m north side of the basin. The basin is 6 m deep. A 115 m bridge traverses the basin and can be moved to a 45 degree offset from the longitudinal center of the basin. The two perpendicular banks of wave-makers can be operated individually to produce long-crested waves, or simultaneously to generate a bi-directional wave-field. Sloping, perforated, concrete beaches are located on each of the sides of the basin opposite the wave-makers to minimize wave reflections.

For these experiments, the MASK bridge was located in the middle of the basin, parallel to the long bank. Wave data was collected from sonic probes on the bridge were recorded at 20 Hz, after being filtered with fixed 10 Hz low-pass filters. Zeroes were taken at the beginning of each testing session to obtain more accurate test data and to account for small changes in the water level of the basin.

3.2 Wave-maker Operation

For this test, waves were generated from the short bank wave-makers and travel from West to East across the basin, as shown in Figure 1. Two methods were used to control the flow of energy into the wave-field: variation of the blower motor speeds supplying air to the pneumatic domes and variation of the motion amplitude of the flapper valve which controls the air being pumped in and out of the domes. Hydraulic cylinders with a voltage control signal were employed to actuate the flapper valves.

The MASK wave-maker also has a series of lips on each of the pneumatic domes (Figure 2), which can be set in a position of either up or down. The lips can be used to modify high frequency disturbances in the generated wave-field.

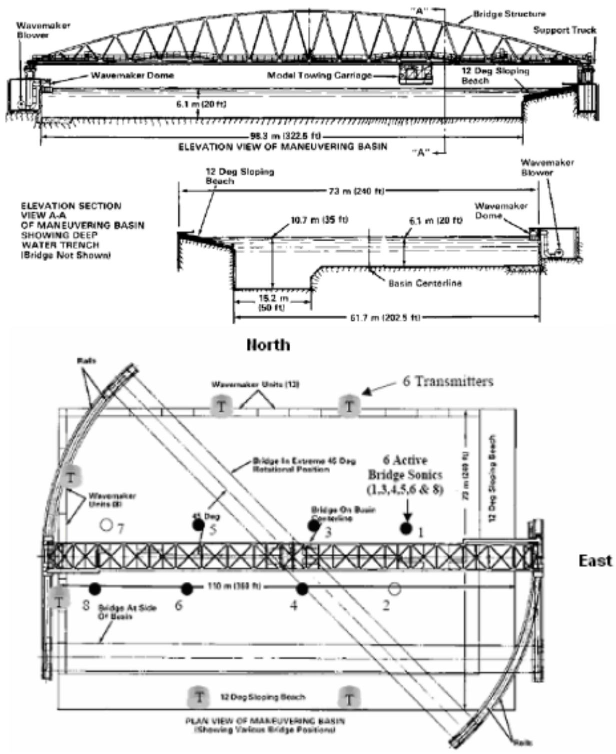

Figure 1. MASK basin with bridge mounted wave probes (1-8).

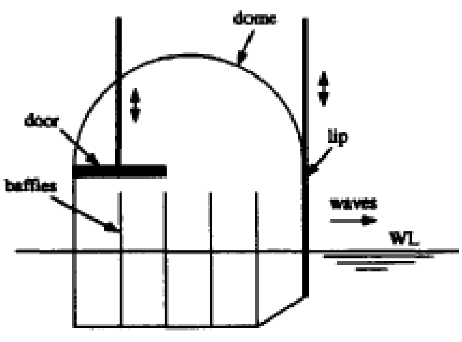

Figure 2. Pneumatic wave-maker domes in the MASK basin.

Although the wave-field produced in the MASK basin is not completely uniform (O'Dea & Newman, 2007; Smith, et al., 2007), it can be considered uniform within the region of measurement. The range of experimental parameters used to generate wave groups is shown in Table 1. Detailed wave-maker settings used for the two experiments are detailed in Bassler, et al. (2008).

Table 1. Experimental parameters.

Blower (rpm)	1100, 1300, 1500
Amplitude (V)	± 1.0, 2.0, 6.0, 8.0, 9.0, 9.5
Frequency (Hz)	0.4-3.3
Number of cycles	1-5

For irregular waves, control software produced digital control signal sequences and supplied them to the wave-maker controller through a digital-to analog (D/A) converter. A filtered white noise technique was used to produce the desired wave spectra. The signal was used to actuate the flapper valves, resulting in pressure fluctuations of the wave-maker domes. The wave energy distribution, as a function of the frequency, was adjusted with the driving frequencies for the valve controls.

3.3 Wave Height Measurements

Two wave height measurement systems were used for this investigation. Point data was collected using wave probes and wave-field topology data was collected using Global Laser Rangefinder Profilometry (GLRP).

Wave Probes. The MASK basin contains an array of six non-contact ultrasonic wave probe sensors, Senix Corporation model ULTRA-SR-BP, suspended from the MASK Bridge to measure the generated waves (Figure 1). Locations (*xy*) of the sensors are given in Bassler, et al. (2008). The sensor transmits an ultrasonic wave and measures the time of reflection from the target to calculate the distance. Each wave probe emits a conical sonic beam with a nominal 12-degree total angle. When attempting to measure large, steep waves, the probes can have signal drop-outs or inaccurate measurements due to scattering, which may result in measurement error.

The wave probes were calibrated in-situ, by varying the distance above a measured calm water level in the MASK. Most of the calibration uncertainty is due to the data scatter in the calibration. Contributions from instrument noise and position were quite small by comparison. Because some of the waves measured in the first set of experiments exceeded the initial calibration range of the wave probes, a higher range calibration was performed for the second set of experiments. Because both the normal and higher range calibrations were performed on a flat-plane surface, the accuracy associated with signal drop-outs when attempting to measure steep waves should be considered. However, the influence of wave steepness on signal dropouts for the wave probes is not currently known. Detailed discussion of the calibration results and uncertainty estimates are described in Bassler, et al. (2008).

GLRP. Global Laser Rangefinder Profilometry (GLRP) was developed at NSWCCD to provide the capability for a time-resolved field measurement of wave elevations. GLRP provides a high-rate, three-dimensional mapping of surface waves over a large physical area. The GLRP concept and original prototypes were demonstrated and documented previously, and a fully-functional GLRP system was constructed in the MASK basin (Atsavapranee, et al., 2005; Carneal, et al., 2005a). The GLRP system illuminates the water surface with distinct points using laser diodes and measures vertical fluctuations. The apparent position of each diode is calibrated and recorded on a charge-coupled device (CCD) detector.

The system used for this experiment (Figure 3) consisted of two panels. Each panel has 200 diodes and spans an area of 1.5 m by 3 m, at a spatial resolution of 7.62 cm in each direction. Two CCD cameras, with a frequency of 30 Hz and a resolution of 1392 X 1040 pixels, were mounted on each panel. The platform has a seeding system consisting of two seeding rakes, with three nozzles each, to disperse fluorescent dye across the measurement area. The panels were located near wave probe 5 (Figure 1).

Data processing was accomplished by analysis of the raw data images and locating the diode image in each frame. Information from the calibration process was used to assign the detected diode image to the appropriate calibration curves. The centroid of the detected diode image was determined and the calibration curves were applied to determine the spatial location of each diode in each frame.

Figure 3. GLRP array panel in the MASK basin.

Calibration of the GLRP measurement was performed by raising and lowering the GLRP panels to several standoff heights. Images of the laser diode's intersection with the water surface were recorded at each height to simulate vertical motion of the water surface. In addition to calibration of the system in the *z*-coordinate an *xy*-mapping calibration was also performed. Because the camera was at an angle to the water surface, the *xy*-positions of the diodes must be determined as a function of water height. This was accomplished by recording images of a precision machined calibration target at several heights, at a known position in the MASK facility. These images were then de-warped using standard image processing techniques.

The absolute uncertainty of the system was estimated at 3 mm, which represents a relative uncertainty on the order of 0.5% of the full measurement range (Carneal, et al., 2005b, Carneal & Atsavapranee, 2006). Detailed discussion of the GLRP calibration results and uncertainty estimates are presented in Bassler, et al. (2008).

4. EXPERIMENTAL RESULTS

4.1 Wave Group Formation

The influence of the different parameters (Table 1) was examined using thirty-six different wave sequence files and repeatable groups of large-amplitude waves were obtained at fixed locations in the basin, wave probes 3 and 4 (Figure 1).

A representative surface elevation time-history is presented (Figure 4) where the generated wave sequence coalesced to form a group of three waves of successively increasing amplitude. In some cases, the third wave in the group reached a wave height of nearly 0.75 m.

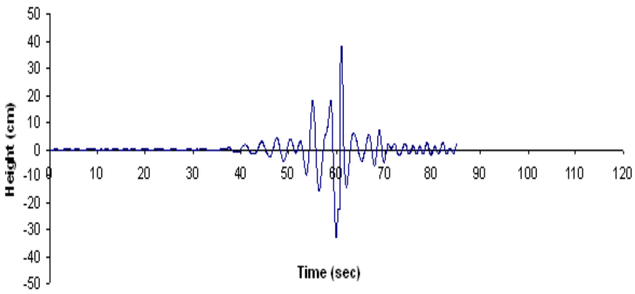

Figure 4. Surface elevation time-history at wave probe 4 of a wave group formed through finite wave superposition.

From the conditions tested, increased wave-maker blower rpm led to an overall increase in the generated wave amplitudes. For the range of parameters tested, a generalized limit for the wave-maker blower rpm was established. For wave cycles with large amplitudes, indicated by large voltage signals, a blower setting of 1300 rpm could not be exceeded without breaking waves occurring. For some cases, reduced signal voltages for the 1st and 4th cycles enabled a blower setting of 1500 rpm to be applied without breaking waves resulting.

Results from the first experiment for wave group formation are shown in Tables 2 and 3. The experimental realization, or run number, the wave height, *h*, the wave length, *λ*, the notional model length, *L*, and the estimated full-scale wave height for a notional model, h_{fs}, are given.

Table 2. Summary of maximum wave height results- probe #3.

Run	h (m)	h/λ	h/L	h_{fs} (m)
15	0.615	0.125	0.157	28.7
7*	0.738	0.143	0.189	34.4
35	0.595	0.111	0.152	27.7
42*	0.678	0.111	0.173	31.6
43	0.606	0.125	0.155	28.2
8*	0.744	0.143	0.190	34.7
51	0.633	0.111	0.162	29.5
5*	0.633	0.111	0.162	29.5
61	0.595	0.125	0.152	27.7
6*	0.705	0.143	0.180	32.9

Table 3. Summary of maximum wave height results- probe #4.

Run[1]	h (m)	h/λ	h/L	h_{fs} (m)[2]
15	0.743	0.100	0.190	34.6
7*	0.739	0.091	0.189	34.4
35	0.722	0.100	0.185	33.6
42*	0.669	0.077	0.0.171	31.2
43	0.706	0.091	0.180	32.9
8*	0.732	0.091	0.187	34.1
51	0.666	0.100	0.170	31.0
5*	0.507	0.100	0.130	23.6
61	0.727	0.111	0.185	33.9
6*	0.672	0.100	0.172	31.3

4.2 Wave Groups in Irregular Seas

The influence of the different parameters (Table 1) was examined using ten different wave sequence files and repeatable groups of large-amplitude waves embedded in an irregular seaway were obtained at fixed locations in the basin, wave probes 3 and 4 (Figure 1). Wave groups were embedded using the process described in section 2.2.

Representative surface elevation time-histories for wave groups in irregular seas are shown in Figures 5 and 6. The first measurement (run 14), at wave probe 4, shows a wave group embedded in a 30th scale Bretschneider sea state 8 (Figure 5). The second measurement (run 41) at wave probe 3, shows a wave group embedded in a 46th scale Hurricane Camille seaway (Figure 6). GLRP measurement of a wave group embedded in a 30th scale Bretschneider SS8 (run 11) is shown in Figure 7.

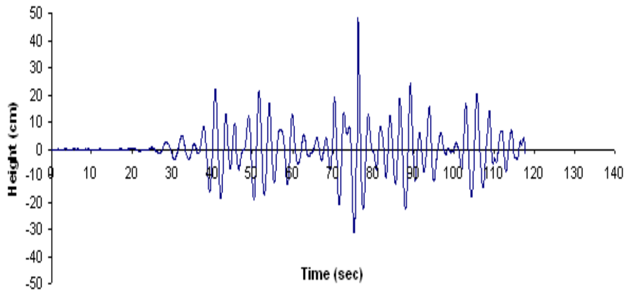

Figure 5. Wave group embedded in an irregular seaway, measured at wave probe 4.

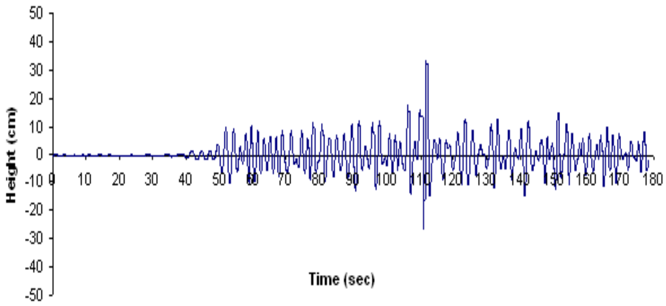

Figure 6. Wave group embedded in an irregular seaway, measured at wave probe 3.

[1] * indicates a repeat run from the first experiment.

[2] For a scale ratio of 46.6.

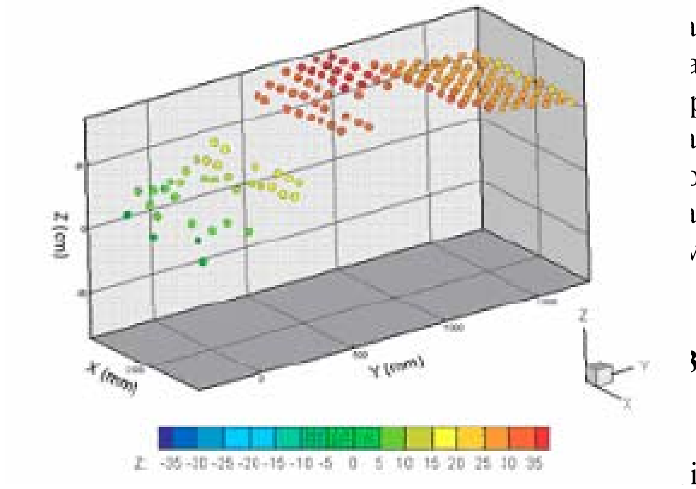

Figure 7. GLRP measurement of a wave group embedded in an irregular seaway.

Table 4. Summary of maximum wave height results for wave groups in irregular waves-probe #3

Run	Spectrum	h (m)	h/λ	h/L	h_{fs} (m)
11	BS SS8	0.804	0.143	0.205	24.1
14	BS SS8	0.799	0.143	0.204	24.0
21	BS SS8	0.602	0.111	0.153	18.1
22	BS SS8	0.644	0.111	0.164	19.3
24	BS SS8	0.718	0.125	0.184	21.5
26	HC	0.647	0.018	0.165	19.4
27	HC	0.530	0.071	0.136	15.9
30	HC	0.542	0.015	0.139	16.3
41	HC	0.480	0.063	0.123	22.4
43	HC	0.649	0.091	0.165	30.2

Table 5. Summary of maximum wave height results for wave groups in irregular waves-probe #4

Run	Spectrum	h (m)	h/λ	h/L	h_{fs} (m) [3]
11	BS SS8	0.714	0.091	0.183	21.4
14	BS SS8	0.710	0.100	0.182	21.3
21	BS SS8	0.525	0.063	0.134	15.8
22	BS SS8	0.530	0.050	0.136	15.9
24	BS SS8	0.540	0.526	0.138	16.2
26	HC	0.761	0.040	0.195	22.8
27	HC	0.582	0.067	0.149	17.5
30	HC	0.786	0.100	0.201	23.6
41	HC	0.478	0.040	0.122	22.3
43	HC	0.494	0.048	0.126	23.0

[3] For the related scale ratio, R=46.6 for runs 41 and 43, all other runs R=30.

Results from the second experiment, where ive groups were embedded into irregular aways are shown in Tables 4 and 5. The perimental realization, or run number, the ive height, *h*, the wave length, *λ*, the notional odel length, *L*, and the estimated full-scale ive height for a notional model, h_{fs}, are ven.

3 Summary of Experimental Results

The maximum calibrated attained wave ight, as normalized with a nominal representative ship model length (h/L), was 0.205 compared to 0.1 for the typical largest regular wave height to ship model length ratio used for testing. The maximum wave steepness (h/λ) observed was approximately 1/7, approaching the limit for non-breaking waves, compared to a 1/10 wave steepness which is typically the maximum for regular wave testing. The largest estimated full-scale wave height observed was 34.6 m, at a 46.6 scale ratio. Maximum full-scale equivalent wave heights between 20 and 30 m were observed in irregular seaways with the embedded wave groups.

5. APPLICATIONS AND FUTURE WORK

An experimental technique to generate extreme wave groups in irregular seas was demonstrated. This technique may be used to model and evaluate event-driven nonlinear large-amplitude response, such as dynamic stability and wave loads or slamming. This technique is particularly useful in the V&V process for numerical tools.

For further development to address ship response, control of initial conditions for experimental testing must be implemented. Also, experimental measurement of the wave group kinematics is needed to provide important physical insight, necessary for further development of numerical tools.

Further development may result in a standard set of testing conditions which can be used to mitigate the problem of rarity for the evaluation of dynamic stability and wave load events. Standardization will also enable direct comparisons of nonlinear ship response between numerical and experimental realizations for more realistic severe wave environments.

One of the major remaining considerations is how to select the appropriate wave conditions which critical to the ship. Some previous work has demonstrated various methods which may be used to address this consideration (Themelis & Spyrou, 2007, 2008; Alford, 2008).

Further work must also be carried out to determine the probability of occurrence of the wave groups in a region of interest in the ocean. This can be combined with the ship response based on initial conditions to the wave group to evaluate risk.

6. CONCLUSIONS

Experiments were performed to generate groups of large-amplitude waves in irregular seas in an experimental model basin. Measurements included both point and wave-field topology data. The process was deterministic in nature, such that a large-amplitude wave group occurred in the model basin at a predictable and repeatable location and time. Generation of asymmetric large-amplitude wave groups in an experimental basin is the first step in the development of an experimental test technique that ensures a model will be exposed to multiple realistic extreme wave events during a test run. This technique will reduce the necessary testing time in the basin, and more accurately represent a full-scale seaway where a ship or offshore structure may be at risk for encountering extreme events.

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