CHAPTER 160

SWASH ZONE WAVE CHARACTERISTICS FROM SUPERTANK

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ABSTRACT

Measured values of shoreline wave setup and shoreline wave heights are summarized from the SUPERTANK Laboratory Data Collection Project. Water surface elevation time-series in the swash zone were measured by capacitance wave gages that were partially buried in the sand beach. As a result, wave measurements were obtained on the actively eroding/accreting beach-face where little data has traditionally been available. Results presented in this paper include examples of wave transformation across the entire beach profile. Mean water level and wave height conditions at the still water shoreline are then summarized for 19 sets of random wave conditions tested during the first two weeks of the SUPERTANK Project.

INTRODUCTION

Despite recent progress in the study of wave transformation across the surf zone, relatively little is known about wave properties near the shoreline or in the swash zone. Most measurements of wave transformation have focussed on the incipient breakpoint and the mid to outer surf zone where there is sufficient water depth to operate various surface-piercing or bottom-mounted wave gages. Wave measurements in the swash zone are generally more difficult to make and, as a result, are not as widely available. One approach used to measure waves in the swash zone has involved remote time-lapse photography of the time-varying runup, e.g. Holman and Sallenger (1985). Another approach, used to record time-series of water surface elevations at specific locations across the swash zone, has involved filming waves as they propagate past reference stakes driven into the beach-face, e.g. Carlson (1984). In contrast, Waddell (1973) and Sonu et al. (1974) present some of the only data available based on use of electronic surface-piercing wave gages to record time-series of water surface elevations in the swash zone.

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In this paper, some results of extensive swash zone wave measurements are presented from the SUPERTANK Laboratory Data Collection Project. As part of the SUPERTANK Project, twenty-six wave gages were used to document wave transformation across a sandy beach profile in a large wave tank. Of these, ten capacitance-based wave gages were specifically designed to measure wave transformation in the inner surf zone and swash zone where the beach face was intermittently submerged and exposed. The objective of this paper is to present results of these measurements for wave setup and for wave heights in the swash zone. Examples are first shown for wave transformation across the entire profile; then, values measured at the still water shoreline are discussed as a way of summarizing the extensive swash zone measurements.

DESCRIPTION OF EXPERIMENTS

The SUPERTANK Laboratory Data Collection Project took place during the summer of 1991 in the in the large wave tank at Oregon State University. The tank is 104 m long and 3.6 m wide. A sand beach with a median grain size of 0.22 mm was placed in the tank with an "equilibrium" form (concave-upward) having a length of about 75 m and a maximum water depth of 3.05 m. A total of 66 different wave conditions, 70 percent using irregular waves, were then tested over almost 129 hours of wave action during the seven-week long project. In general, wave heights ranged from 0.2 to 1.0 meters and wave periods ranged from 3 to 8 seconds. A thorough documentation of the entire SUPERTANK project is given by Kraus and Smith (1994) while a review of the wave transformation measurements is presented by Kriebel and Smith (1994).

Mean water levels and wave transformation measurements were obtained using 26 wave gages between the wavemaker and the runup limit on the sand beach. Of these, 16 resistance wire wave gages were used to record wave properties between the wavemaker and the mid surf zone while 10 capacitance wave gages were used in the inner surf zone and swash zone. The resistance gages were separated at 3.7 meter intervals while the capacitance gages were spaced at 0.9 to 1.8 meter intervals to obtain better resolution in the swash zone. One capacitance gages was normally located close to the still water shoreline, which evolved from run to run as the beach eroded or accreted.

As illustrated in Figure 1, the capacitance wave gages consisted of a single loop of Teflon-insulated 20-gauge copper wire which was lightly twisted so that both ends of the wire were attached to one terminal at the base of a PVC electronics housing. The electronics housing was attached to a stainless steel support frame that was then attached to the side wall of the wave tank. The bottom of the sensing wire loop was attached to the support frame by a non-conductive rubber band in order to maintain a constant tension in the sensing wire. Sensing wires with lengths of 0.91 to 1.83 meters were used.

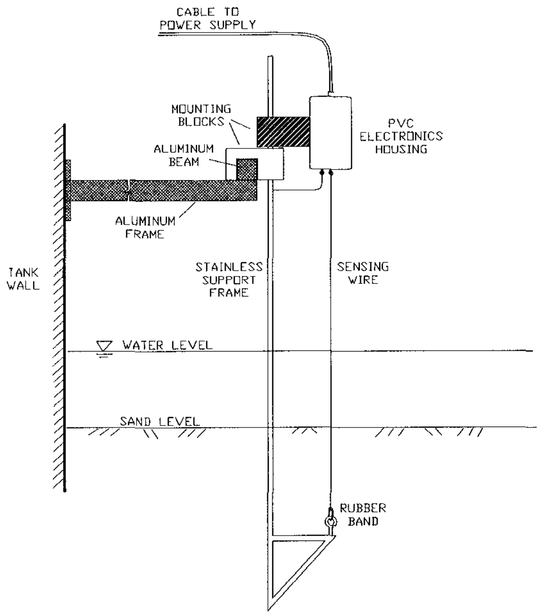

Figure 1. Illustration of capacitance wave gage used in the SUPERTANK Project.

The capacitance wave gages were partially buried in the sand beach and could record the wave uprush and downrush as well as the saturated sand bed elevation if the bed was exposed in between successive swash events. Water surface elevations and wave heights were measured relative to either: (1) the still water level if the gage was located seaward of the still water shoreline where the sand bed was not exposed at the beginning of the test, or (2) the wet sand surface if the gage was located landward of the still water shoreline where the sand bed was exposed at the start of the test. As a result, the mean wave setup on the exposed beach-face was measured as the increase in the mean (time-averaged) water level above the initial sand bed elevation at the start of the test.

After the mean water level was identified and removed from the wave record, the remaining time-series was subjected to low and high-pass filtering with a filter cut-off at one-half of the peak wave frequency of the target wave spectrum input into the wavemaker. Following this filtering, three time series were available for subsequent analysis: (1) the original or total wave record, (2) the high-frequency wave record containing the wavemaker frequencies and higher harmonic components, and (3) the low-frequency wave record containing wave group and tank seiching frequencies.

Wave heights were determined for each of these three time-series based on both time-domain and frequency-domain analyses. Standard zero-crossing analysis was used to define statistical wave height parameters such as H_{RMS}, $H_{1/3}$, $H_{1/10}$, and H_{MAX}. In the swash zone, these wave heights were determined as the vertical height between each wave crest and the exposed sand bed. Standard spectral analysis was then performed to define the zero-moment wave height. Once again, three values were determined as H_{MO}, H_{MOL}, and H_{MOH} based on the total, low, and high frequency wave records respectively. Based on the filtering, conservation of wave energy requires that the relationship between the various zero-moment wave heights be given as $H_{MO} = (H_{MOL}{}^2+H_{MOH}{}^2)^{1/2}$.

EXAMPLES OF WAVE HEIGHT TRANSFORMATION

Selected results showing typical beach profiles from the SUPERTANK Project are shown in Figure 2, while examples of dimensionless wave transformation across these beach profiles are shown in Figures 3, 4, and 5.

Beach profiles in the SUPERTANK Project varied continuously in response to the incident wave conditions. The initial profile, depicted in Figure 2a, was placed in a concave-upward shape in accordance with equilibrium beach profile concepts. As the experiments proceeded, the initial shoreline receded, the beach face steepened, a bar developed offshore, and the surf zone widened, as illustrated in Figure 2b. This profile is typical of conditions following erosive wave conditions. The profile in Figure 2c is then typical of conditions following accretionary wave conditions in which the bar-trough system was smoothed.

In Figures 3, 4, and 5, dimensionless mean water levels and dimensionless wave heights are plotted against the dimensionless "depth" across the profile. Seaward of the still water shoreline, the initial water depth is considered positive. Landward of the still water shoreline, the "depth" is considered negative when the initial sand bed elevations are above the still water level. The reason for using this format is that the wave transformation can then be shown continuously across the surf zone, to the still water shoreline (depth equal to zero), and across the swash zone to the runup limit. In all cases, the local "depth" is normalized by the significant wave height H_{MOo}, measured in 3.05 m of water at the first wave gage nearest the wavemaker.

Results shown in Figures 3 through 5 were obtained from tests using irregular waves having three values of wave steepness, H_{MOo}/L_o, equal to 0.005, 0.01, and 0.04, all for TMA spectra having a peak enhancement factor of 3.3. The first case, with the lowest steepness, had a significant wave height, H_{MOo}, equal to 0.5 m and a peak period, T_p, of 8 seconds. The second case then had H_{MOo} = 0.64 m and T_p = 6 seconds, while the third case had H_{MOo} = 0.57 m and T_p = 3 seconds. The beach profile in each case was similar to that shown in Figure 2b, although conditions at the end of tests with the lowest steepness were more similar to those in Figure 2c.

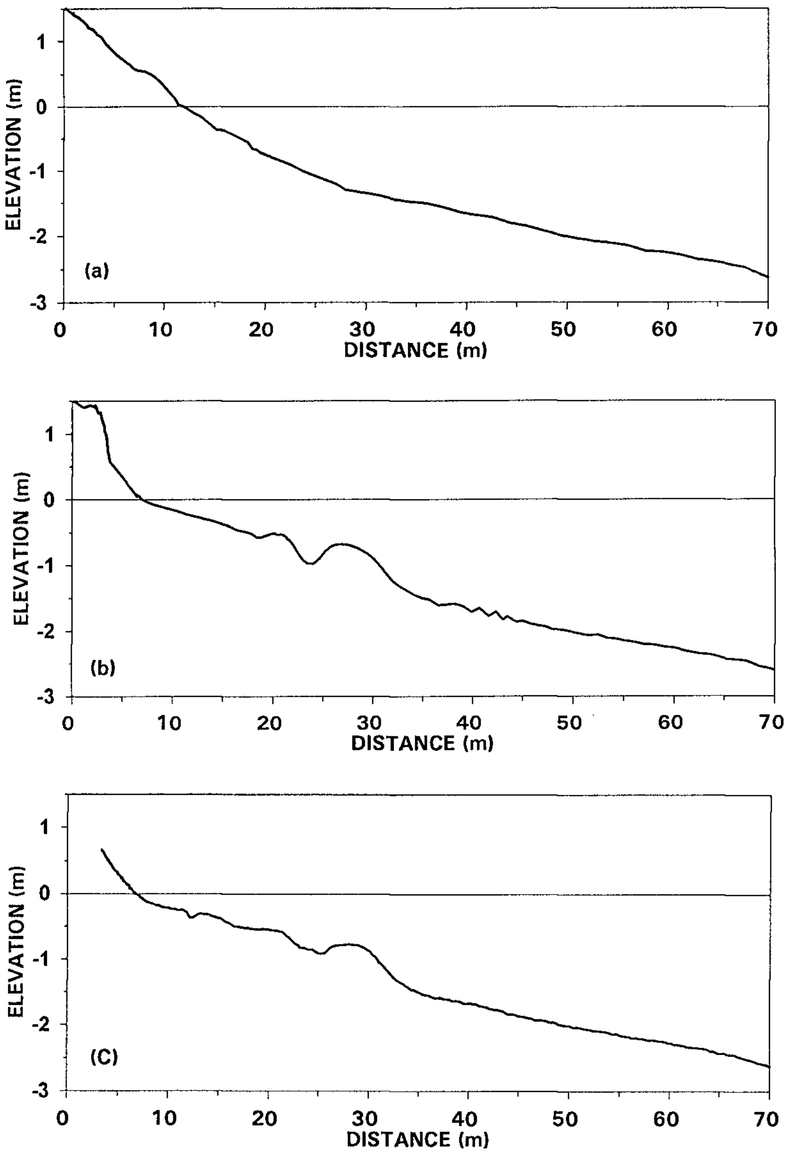

Figure 2. Typical beach profiles: (a) initial profile, (b) profile after erosive wave conditions, and (c) profile after constructive wave conditions.

Figure 3 shows the normalized wave setup and setdown, defined as ratio of the local mean water level, *S*, to the offshore significant wave height. For the three values of wave steepness, the setdown seaward of the breakpoint is fairly consistent, reaching a maximum of 3 to 5 percent of the incident significant wave height. Setup inside the surf zone and in the swash zone is a much stronger function of wave steepness. The maximum setup near the shoreline ranges between 10 and 20 percent of the incident significant wave height and is larger for the lower steepness waves.

Figure 4a shows the normalized total wave heights, defined as ratio of the local zero-moment wave height relative to the value measured offshore near the wavemaker. For the highest steepness, wave heights decrease slightly between the wavemaker and the dominant breakpoint (at a relative depth of about 1.4) due to the selective breaking of the largest waves in the spectrum. Waves then continue to diminish across the surf and swash zones to the runup limit where the relative depth is -0.75. For the lower steepness wave conditions, significant wave heights increase by more than 20 percent between the wave maker and the dominant breakpoint due to shoaling effects. Throughout the surf and swash zones, these lower steepness waves produce greater relative wave heights. At the still water shoreline, wave heights are still about 40 to 60 percent of the offshore values and is largest for the smallest wave steepness.

Figure 4b and 4c then show the normalized wave heights for the high and low frequency portions of the wave spectrum respectively. In the offshore region, the low-frequency wave heights are found to be fairly small (0.1 to 0.2 H_{MOo}) and the high frequency waves are dominant. Near the shoreline and in the swash zone, however, the low frequency wave heights are generally the same magnitude, or larger than, the high frequency wave heights. In the three cases shown, high-frequency wave heights at the shoreline are only about 20 to 50 percent of the offshore zero-moment wave height while the low frequency wave heights are 25 to 35 percent of the offshore height. For the two cases with the highest wave steepness, low-frequency wave components have more energy than high-frequency wave components in the vicinity of the shoreline.

Based on visual observations and on spectral analysis, these low-frequency motions are mostly coherent standing waves. Unlike the high-frequency waves in Figure 4b, which are mainly progressive and which show large gradients in the swash zone due to breaking, the low-frequency waves in Figure 4c exhibit these gradients due to the presence of a reflected wave antinode at the sloping shoreline. These low-frequency waves experience strong growth between the breakpoint and the shoreline and may be the result of forced incident wave groups, long-wave generation by the moving breakpoint, and/or long-wave generation by swash zone wave interactions, all augmented by tank seiching and re-reflection of long waves by the wavemaker. The wavemaker was operated with reflection-compensation to absorb reflected waves at the dominant wave frequency but not at these long-wave frequencies.

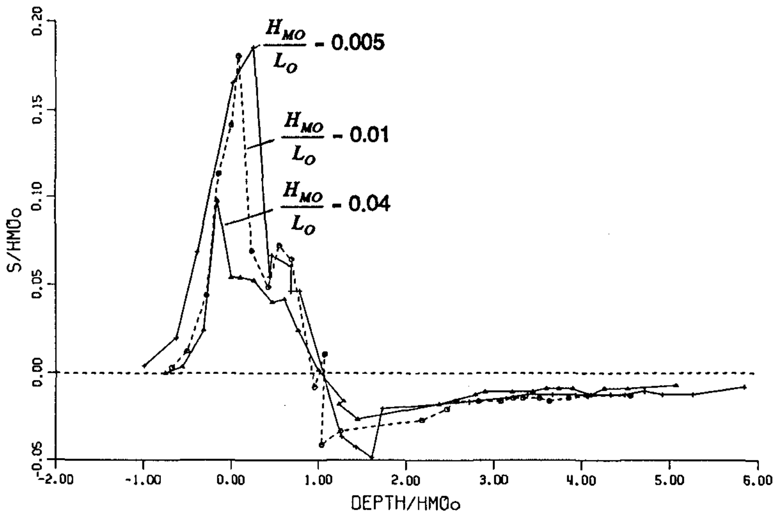

Figure 3. Dimensionless wave setup for three values of random wave steepness.

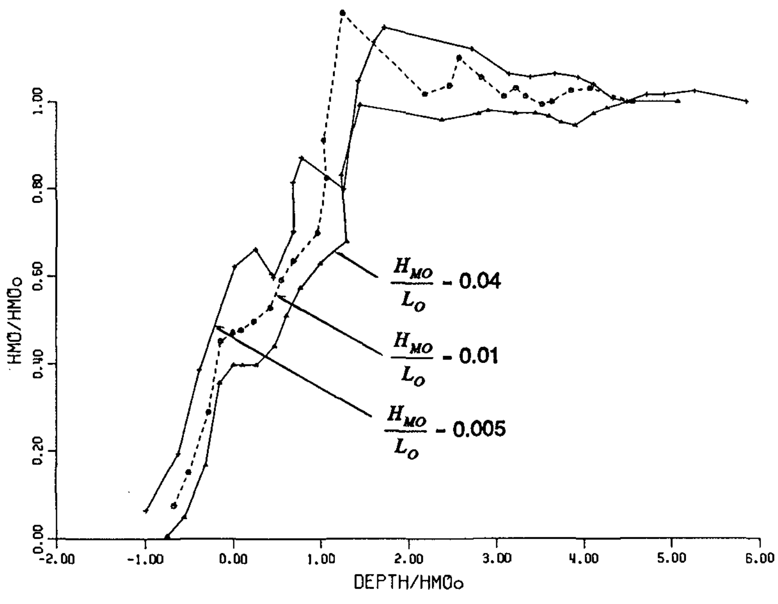

Figure 4. Dimensionless wave heights for three values of wave steepness: (a) based on total or unfiltered wave record

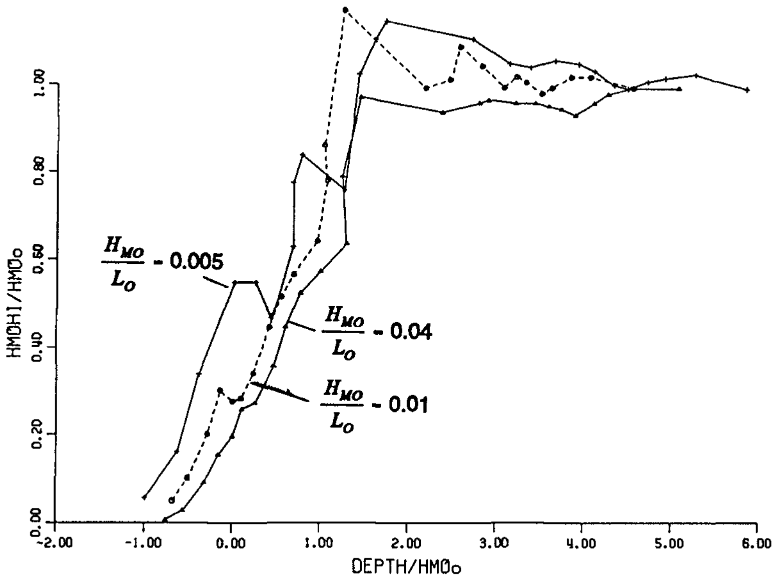

Figure 4. (b) based on high-pass filtering at one-half of the peak frequency.

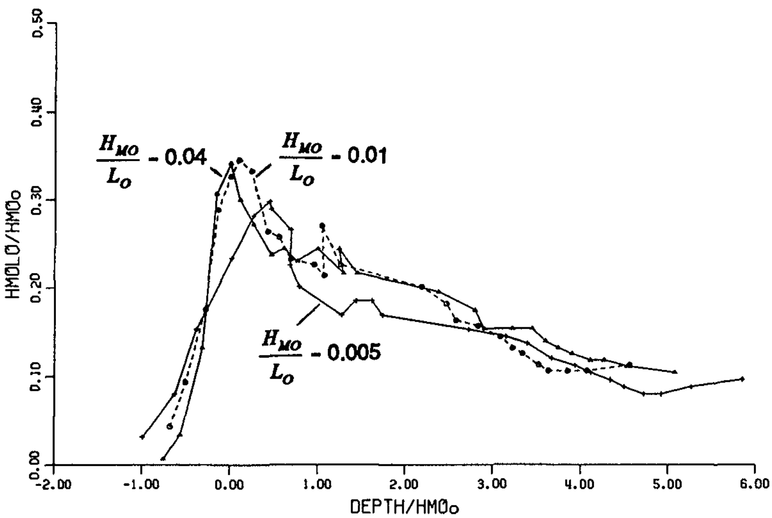

Figure 4. (c) based on low-pass filtering at one-half of the peak frequency.

One interesting result of these measurements is that, despite the effect of the reflective wavemaker boundary, there appears to be a strong correlation between the low-frequency and high-frequency wave heights. Figure 5 shows the ratio between the low- and high-frequency zero-moment wave heights as measured at each wave gage. This ratio is extremely consistent and well-behaved across the entire offshore region from the wavemaker to the mid surf zone. In this region, the ratio of low-to-high frequency wave heights increases from approximately 0.1 near the wavemaker to approximately 0.3 near the bar crest to nearly 0.5 in the inner surf zone. Although there is a slight trend toward increasing ratios for higher values of wave steepness, this ratio is similar for each of the three conditions.

At the shoreline, the ratio of low-to-high frequency wave heights is then a strong function of wave steepness, varying from about 0.5 for the lowest steepness, to about 1.2 for the middle steepness, to about 2.0 for the highest steepness. Thompson and Briggs (1993) considered the same ratio and concluded that the long-wave heights may reach a maximum of about 1.2 times the short-wave heights at the shoreline based on field data from Duck, North Carolina, for conditions where the spectral wave steepness was about 0.01. This seems to be confirmed by the laboratory data, however, the SUPERTANK data suggests that this growth in low-frequency wave components relative to the rapidly decaying high-frequency components depends strongly on the incident wave steepness so that no simple generalization is possible.

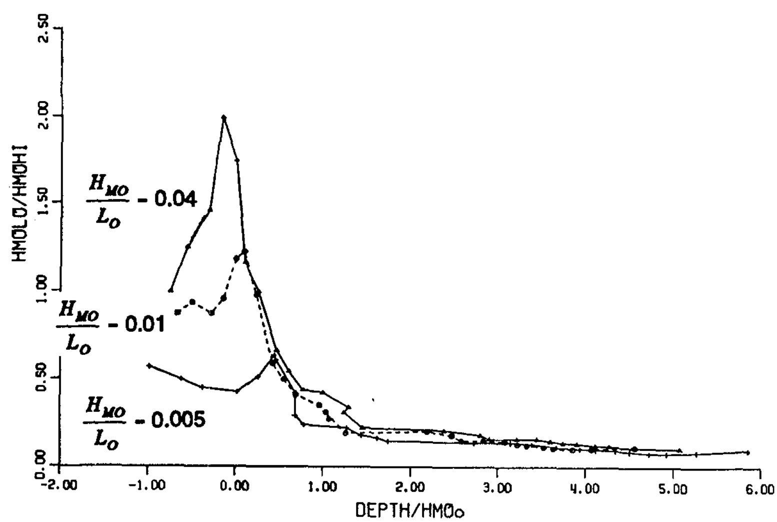

Figure 5. Ratio of locally-measured low-frequency significant wave height to high-frequency significant wave height based on filtering at one-half of the peak frequency.

SUMMARY OF SHORELINE SETUP AND WAVE HEIGHTS

In order to summarize additional data from the SUPERTANK Project, the remainder of this paper will present results of wave setup and wave height parameters measured at the still water shoreline in 19 tests conducted with irregular waves over the first two weeks of the experiment. Figures 6 through 8 show normalized wave setup and zero-crossing wave heights as determined from the total wave record, the high-pass wave record, and the low-pass wave record. Results are based on linear interpolation between wave gages located either side of the still water shoreline. In each figure, values of shoreline setup and wave height are normalized by the offshore zero-moment wave height, $HM0o$, and the normalized results are plotted against the incident wave steepness, $(HM0o/Lo)^{1/2}$.

Figure 6 shows results for the normalized wave setup at the shoreline. Results from the SUPERTANK Project appear consistent with other lab and field data in which maximum wave setup at the shoreline is generally in the range of 0.15 to 0.2 times the offshore significant wave height. For example, Greenwood and Osborne (1990) suggest a ratio of 0.19 based on field data from Lake Huron. The SUPERTANK data also show a clear trend toward decreasing wave setup for increasing wave steepness, as also found in the literature. In this case, the wave setup ranges between 0.21 $HM0o$ for the lowest wave steepness tested to about 0.11 $HM0o$ for the highest wave steepness tested.

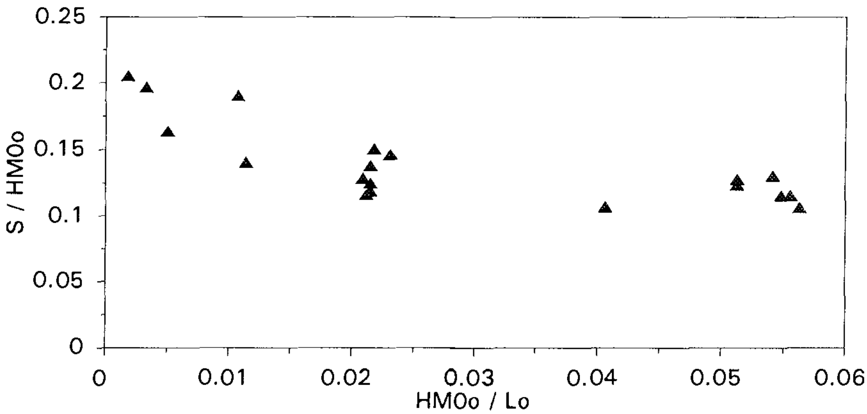

Figure 6. Normalized wave setup at the shoreline from SUPERTANK data.

Figure 7 shows the energy-based zero-moment wave heights at the shoreline, H_{M0s}, relative to the offshore zero-moment wave height, H_{M0o}, as a function of incident wave steepness. Figure 7a shows the total wave height at the shoreline, while Figures 7b and 7c show the high and low frequency wave height components at the shoreline respectively. As shown in Figure 7a, the wave height at the shoreline can vary between about 40 and 80 percent of the offshore value for the extreme wave steepness tested. While these shoreline wave heights decrease as wave steepness increases, there is little variation for values of steepness above 0.02.

The high and low frequency wave heights at the shoreline, shown in Figures 7b and 7c, show opposing functional dependencies on wave steepness. For the lowest values of steepness, low-frequency wave heights are small, about 0.2 H_{M0o}, while high frequency wave heights are dominant, up to 0.7 H_{M0o} or so. As the wave steepness increases, however, low frequency wave heights increase up to about 0.4 H_{M0o} while high frequency wave heights decrease dramatically to about 0.2 H_{M0o}. As a result, for the higher values of steepness, the low frequency wave height components (low frequency energy content) is actually twice as large as the high frequency wave components. A reversal in which wave energy band is dominant occurs at a wave steepness of about 0.01.

As shown in Figure 5, the ratio of low-to-high frequency wave height components is fairly stable across the surf zone but shows large differences in the swash zone. Figure 8 then shows this ratio at the shoreline as a function of wave steepness. As discussed previously, high frequency wave heights dominate for the lowest wave steepness tested and the ratio of low-to-high frequency wave heights is about 0.5 or less. Above a steepness of 0.01, however, the low frequency wave heights dominate the swash zone motions such that the ratio of low-to-high frequency wave heights is greater than unity. While there is significant scatter in the data, the ratio is in the range of 1.5 to 2.0 for the highest values of wave steepness which were highly energetic and highly erosive wave conditions.

At the still water shoreline, there is initially zero water water depth until the mean water level rises due to wave setup. As a result, the ratio of wave height to still water depth at the shoreline is infinite unless wave setup is considered. With wave setup, the ratio of wave height to water depth (setup) is finite and this ratio is shown in Figure 9 for all 19 data sets. As shown, the ratio of total zero-moment wave height to wave setup at the shoreline is in the range of 3 to 4 and is insensitive to wave steepness. In contrast, the ratio of wave height to water depth in the surf zone is commonly assumed to be approximately one. Based on the SUPERTANK data, the significant wave height at the shoreline is given by $H_{M0s} = 3.3\ S$ on average. Consideration of the high and low frequency significant wave heights separately does not produce results that are as well-behaved, but on average the high frequency significant height at the shoreline is 2.0 times the wave setup while the low frequency wave height is 2.5 times the setup.

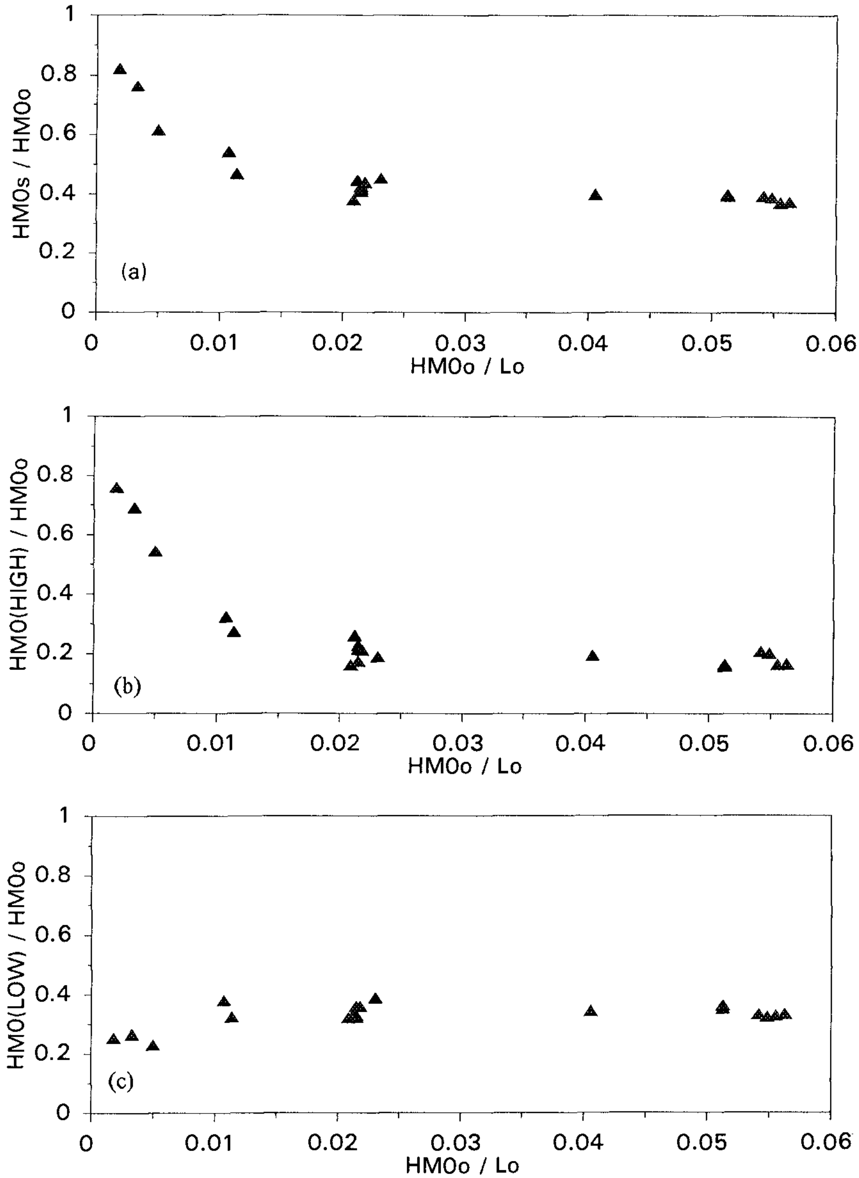

Figure 7. Normalized zero-moment wave heights at the shoreline: (a) total wave height, (b) high-frequency wave height, (c) low-frequency wave height.

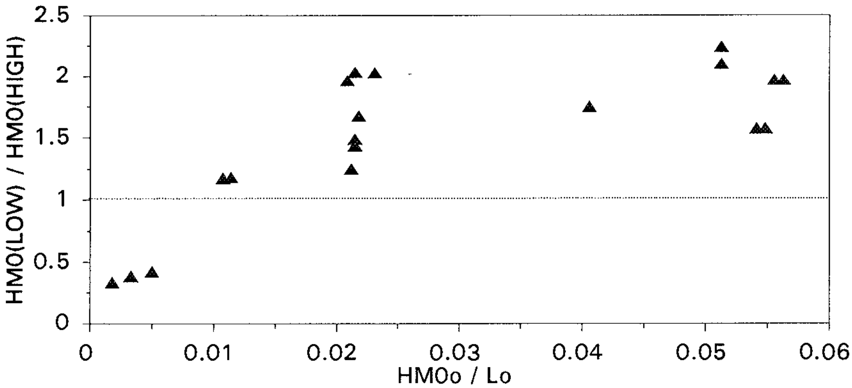

Figure 8. Ratio of low-to-high frequency wave heights at the still water shoreline.

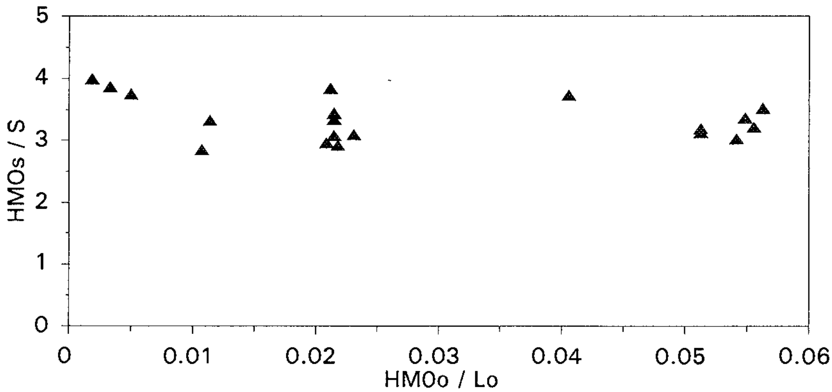

Figure 9. Ratio of significant wave height to mean water depth (setup) at shoreline.

As a final consideration, statistical wave height parameters at the shoreline, obtained from a zero-crossing analysis of the total wave record, are shown in Figure 10. This gives H_{RMS}, $H_{1/3}$, and H_{MAX} measured at the shoreline, all normalized again by the offshore zero-moment wave height. For the lowest values of wave steepness, it is found that statistical wave heights are a strong function of wave steepness. For these conditions, H_{RMS} at the shoreline can be 0.4 to 0.5 times H_{MOo}, $H_{1/3}$ can typically be 0.5 to 0.7 H_{MOo}, and H_{MAX} can typically be 0.7 to 1.1 H_{MOo}. At the other extreme, for the highest values of wave steepness, wave heights are not strong functions of steepness and H_{RMS}, $H_{1/3}$, and H_{MAX} are about 0.2, 0.3, and 0.5 to 0.6 times H_{MOo}, respectively.

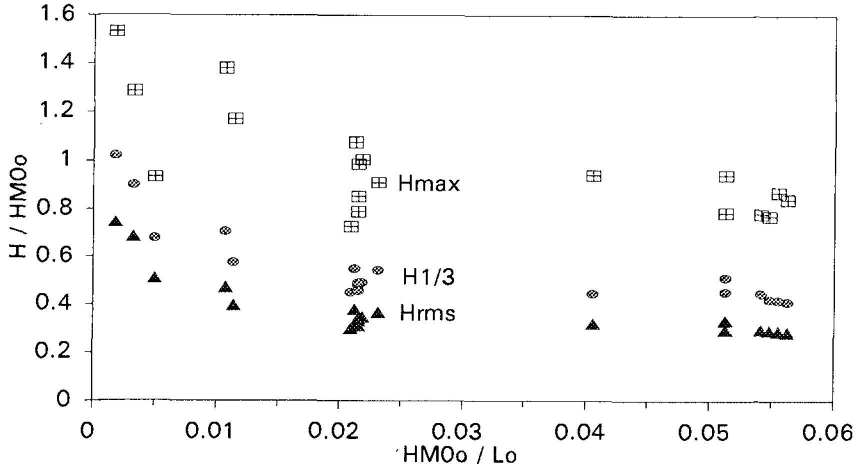

Figure 10. Shoreline wave height parameters based on zero-crossing analysis.

CONCLUSIONS

This paper has presented selected results of wave setup and wave height measurements from the SUPERTANK Data Collection Project. The main objective of the measurements was to document wave transformation across the beach profile at all locations between the wavemaker and the wave runup limit. This required use of capacitance wave gages, partially buried in the sand beach, to document mean water levels and time-varying wave heights in the swash zone where the initial sand bed elevation was above the still water level of the wavetank.

Several examples have been presented of the random wave transformation across the beach profile for various wave steepness conditions. These measurements show that wave properties in the swash zone are well-behaved despite the fact that waves in this region are intermittently occurring bores that do not propagate on a finite water depth. Results are then shown for wave setup and wave heights at the still water shoreline where the initial water depth is zero.

In the analysis, the wave record is filtered into separate low and high frequency components. In the offshore region, the high frequency (incident band) wave components dominate and low frequency components (wave group and tank seiching frequencies) are small. In the inner surf zone and swash zone, the high frequency components diminish due to breaking while the low frequency components grow and reach a maximum amplitude at the still water shoreline.

For low incident wave steepness, the high frequency portion of the wave spectrum, containing the intended peak frequency of the spectrum and higher harmonics, dominates in the swash zone and is usually larger than the long standing waves at the shoreline. In contrast, for high incident wave steepness, the low frequency portion of the spectrum dominates at the shoreline and in the swash zone. While this paper has documented the characteristic heights of these long wave components, it does not address the possible generation mechanisms for these waves.

ACKNOWLEDGEMENTS

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