

CHAPTER 196

WAVE-INDUCED EFFECTS IN A COOLING WATER BASIN

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Introduction

Wave-induced effects have been observed in a model of the cooling water intake basin of the Pacific Gas and Electric Company's Diablo Canyon Nuclear Power Plant. This model, built to an undistorted scale of 1:45, was constructed initially to study the design for the repair of the terminus region of the West breakwater damaged in storms of January 28, 1981. It was decided by PG&E to investigate, in the same model, the forces due to waves acting on two air intake structures for the auxiliary saltwater pumps and the pressures on the external and the internal walls and the ceiling of the cooling water intake structure located in the man-made cooling water intake basin. During the course of the experiments it was noticed that the mean water level in the breakwater enclosed basin changed as a function of the incident wave characteristics. This allowed waves to overtop the cooling water intake structure which, without the change in mean water level, would not have occurred. It is this difference between the mean water level and the still water level inside the cooling water basin, defined as ponding, which will be reported herein.

Diskin, et al. (1970) investigated this effect behind low and submerged permeable breakwaters in a two-dimensional wave tank model. As was mentioned by them, in normal breakwater tests it is a common practice to provide some means of communication between the seaward and shoreward side of the breakwater so that precisely this mean water level change due to overtopping of the structure does not occur. For their experiments the change in mean level varied from about 5% of the deep water wave height to 32% of the deep water wave height depending upon the submergence of the breakwater crest; the smallest change corresponded to the largest depth over the breakwater crest.

This effect was discussed by Dalrymple and Dean (1971), and they proposed an analytical model based on the conservation of mass. The estimated inflow was equated to an estimate of the return flow over and through the permeable structure. Some limited agreement with the results of Diskin, et al. (1970) were shown.

Seelig (1983) presents the results of laboratory experiments conducted to investigate reef-lagoon system hydraulics. The laboratory tests were two-dimensional wave flume experiments, and indicated that there could be a significant increase in the mean water level within the lagoon due to a seaward reef. Again, these experiments were two-dimensional.

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The study described here, which is an investigation in a three-dimensional undistorted hydraulic model, is in a sense a more realistic model of the actual dynamics of time-varying storage than the two-dimensional experiments summarized above. Due to complexities associated with the three dimensionality, no attempt has been made to develop a detailed analytical model to describe the observed differences between the still water level and the mean water level denoted here as ponding. Therefore, certain of the data obtained in the course of this experimental program will be presented here and discussed in terms of their physical significance without an attempt at a more general development. Somewhat different definitions of ponding are used for the regular and the irregular wave experiments; these will be defined clearly as the pertinent results are presented.

Experimental Equipment

Figure 1 shows the boundaries of the wave basin which was used and the bathymetric contours in the 1:45 undistorted hydraulic model. The highly contorted bottom contours were accurately represented in the model. The cooling water intake basin is seen in the upper right-hand portion of this figure with the two breakwaters (the West and East) forming the boundaries of the protected basin. The breakwaters are built on rock formations which themselves tend to form natural seaward boundaries to the basin.

Wave guides and the wavemaker plate are shown arranged for waves approaching approximately from the west. Numerical methods were used to refract waves from deep water to the depth of approximately 100 ft where the wavemakers are located. (In this paper all dimensions will be given in prototype units.) The wavemaker was divided into five segments, each driven by a programmable hydraulic system from one function generator; the units were portable and could be aligned to correspond to different wave approach directions.

The original breakwaters were constructed with tribars as their outer armor protection and with a concrete cap with a crest elevation of +20 ft MLLW. A detailed description of the model and the breakwaters is presented by Lillevang, et al. (1984). Two different crest elevations were used in these experiments: +20 ft MLLW and 0 ft MLLW. The latter represented an extreme case where the crest of each breakwater was assumed to have been degraded uniformly to MLLW by storm waves. A third case was tested without breakwaters; certainly an extremely conservative condition.

Both regular and irregular waves were used in these experiments. For periodic waves the cnoidal wave generation procedure presented by Goring and Raichlen (1980) was used. To minimize disturbances and provide more permanent waves in the limited space available, a procedure was developed always to begin the wave machine trajectory at a position which corresponded to a zero plate velocity.

Capacitance wave gages, which could be calibrated remotely, were located throughout the model; the locations are indicated by letter in Figure 1. Waves were not measured at all locations simultaneously.

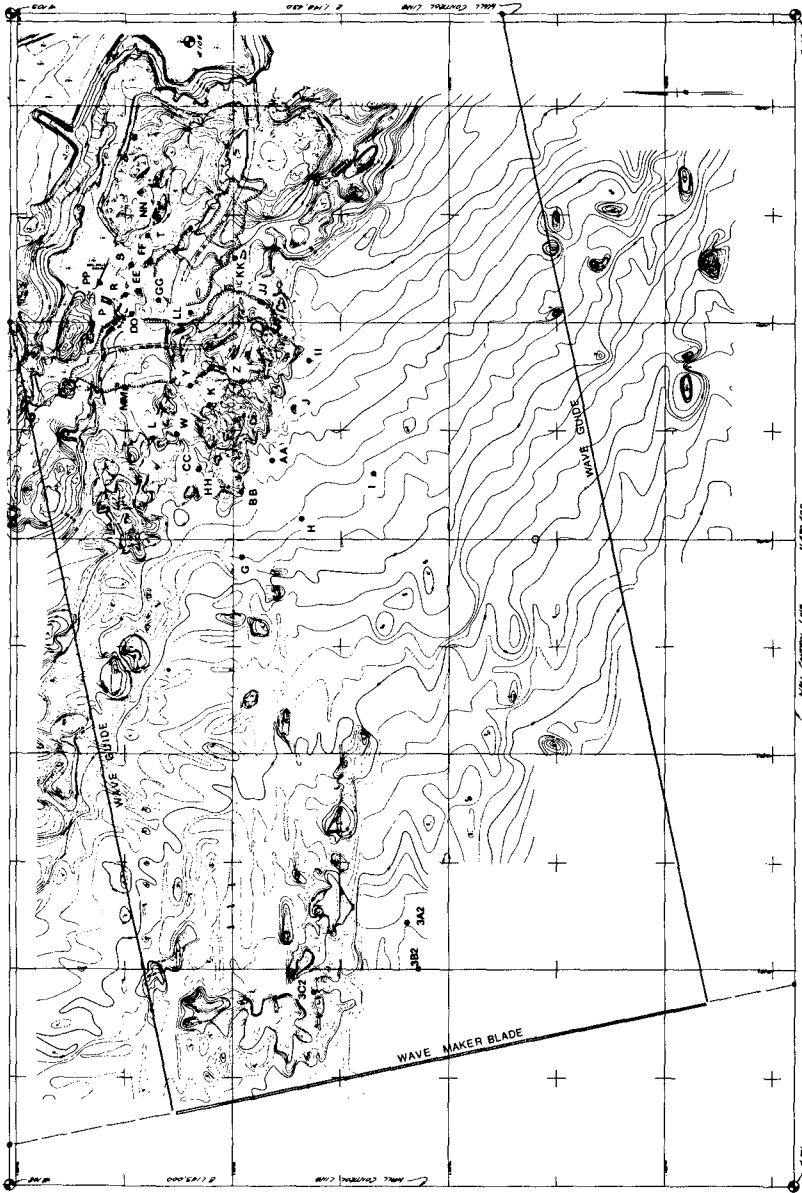


Figure 1 Wavemaker Placement in the Model Basin and Location for Probes, Waves from the West.

The three locations which will be referred to herein are those indicated as: 3B2 near the wave machine, and R and S in front of the cooling water intake structure inside of the cooling water intake basin. (The latter are each located approximately 100 ft seaward of the intake structure and spaced 150 ft apart.) The wave gage at location 3A2 was used with that at 3B2 to define approximately the reflectivity of the breakwater system in the model using a method presented by Goda and Suzuki (1976).

Irregular waves were generated using the wave plate transfer function determined experimentally and spectra defined by either off-shore measurements or hindcasting procedures. The method of Goda (1970) was used to transform a spectrum into its harmonic components from which the wave machine trajectory was defined. For the irregular waves discussed herein the wave machine trajectory was determined from a wave spectrum measured on January 28, 1981 at 1800 hrs GMT by the National Oceanic and Atmospheric Administration (NOAA) Buoy 46011 located 18.6 nautical miles southwest of the Diablo Canyon Nuclear Power Plant.

Presentation and Discussion of Results

In this section results will be presented from the experiments conducted with both regular and irregular waves. An example of wave records taken at locations 3B2 near the wave machine and R and S inside the intake basin are presented in Figure 2 for an azimuth direction at the wave machines of 258°. The upper portion of the figure shows cnoidal waves with a period of 12 seconds and a height of approximately 40 ft near the wave machine; the water surface time histories at R and S are shown in the lower part. The breakwater crest for these experiments was degraded to 0 ft MLLW. The effects of wave breaking and overtopping of the structure are evident at stations R and S, and it is noted that the mean level is different from the still water level. As mentioned earlier, the difference between the mean level and the still water level (which is indicated on the figures by a line extending across the figure) for these periodic waves is termed "ponding". Referring back to Figure 1 it is seen that, for this three-dimensional arrangement, in addition to the return flow over and through the permeable breakwaters there is the return flow through the entrance of the basin. This unsteady flow back through the entrance would be defined by the time varying ponding level.

In Figure 3 the variation in the difference between the mean level and the still water level within the basin, denoted as Δ , is shown as a function of offshore wave height. The ponding level was obtained by taking the time average between the second and the sixth waves in the train such as that shown in Figure 2. These figures present data at positions R and S for different breakwater crest elevations (BRKWTR ELEV.), water depths (W.S. ELEV.), wave periods, and incident wave directions (AZIMUTH). (The extreme still water level of +17 ft MLLW was based on the simultaneous occurrence of an extreme high astronomical tide, storm tide, and tsunami.) It is interesting to see, especially at location R, there is a general trend of increasing ponding elevation with offshore wave height with little effect of direction or depth; at S there appears to be more of an influence of both direction and depth. The ponding elevation measured is approximately 10% of the offshore

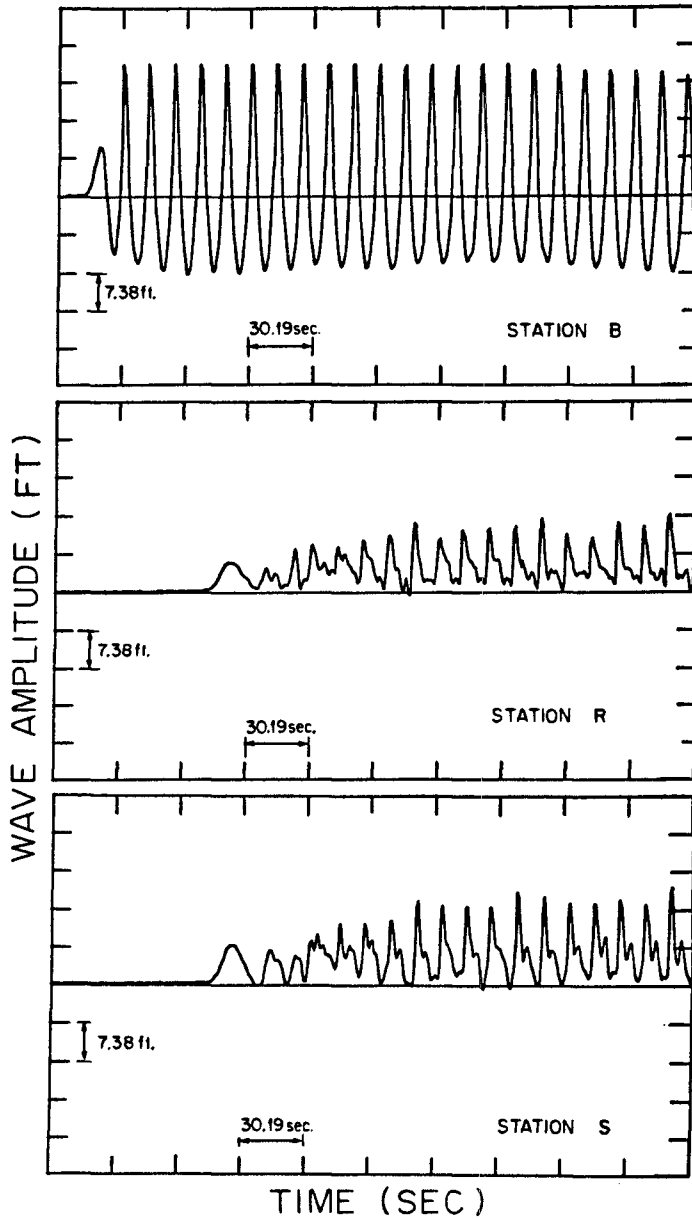


Figure 2 Water Surface Time History Near Wave Machine and at Locations R and S.

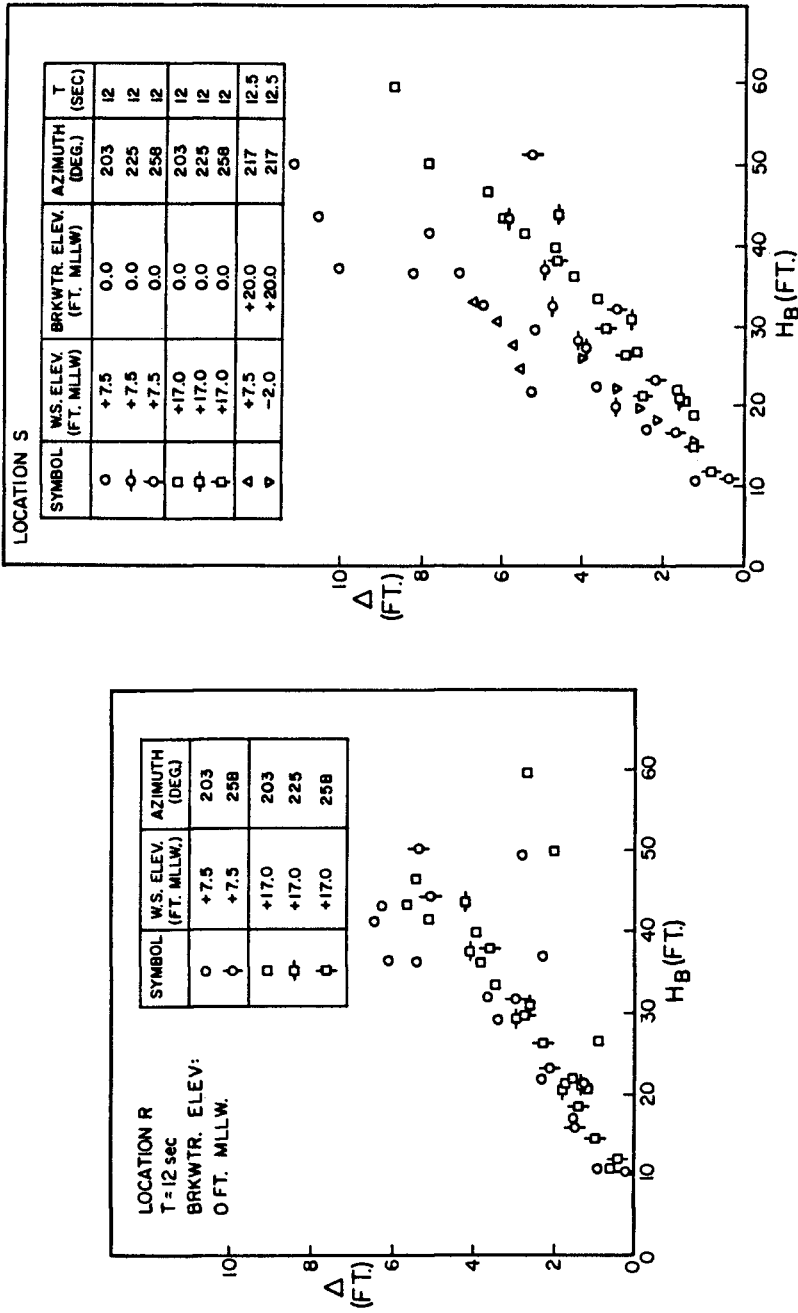


Figure 3 Variation of Ponding at Locations R and S with Offshore Wave Height.

wave height for this case. For the breakwater crest at 0 ft MLLW but with the still water level at +7.5 ft MLLW significantly more scatter of the data is apparent than for the larger depth over the breakwater. This probably can be attributed to the effects of wave breaking and the relatively small depth over the crest through which the broken waves must propagate before entering the intake basin. It should be realized that the width of the breakwater crest is increased significantly for the degraded condition compared to that for the crest at +20 ft MLLW, since in designing the degraded section the volume of the breakwater between 0 ft MLLW and +20 ft MLLW was placed on the shoreward side of the breakwater. (At a crest elevation of +20 ft MLLW the crest width is 21 ft, about three depths, but for the degraded section it would be about 90 ft or about 12 depths.) For the breakwater with its crest at +20 ft MLLW and for mean water levels at +7.5 ft MLLW and -2 ft MLLW the ponding for the former is somewhat greater than for the latter.

In Figure 4 examples are shown of the ponding as a function of the parameter HL; where H and L represent a wave height and wave length, respectively. (The wave height and wave length are defined from linear wave theory using the incident wave height measured at station B near the wave machine, and based on a depth of 50 ft MLLW plus the indicated "tide" elevation, e.g. for a "tide" of +17 ft MLLW a depth of 67 ft was used in the calculations.) This parameter is proportional to the volume under the crest of a periodic wave. The reason for using HL is that the quantity of water which overtops the breakwater and flows into the cooling water basin must be related to the "crestal" wave volume which would be a measure of the volume of the breaking wave which would be associated with overtopping. This is a relatively unsophisticated approach to the problem, and does not consider the detailed intricacies of both overtopping and return flow as, for example, Dalrymple and Dean (1971) did for a two-dimensional problem. The data shown in Figure 4 correspond to an azimuth approach near the wave machines of 203°, some of these data have been presented earlier in Figure 3. In addition, data corresponding to wave periods of 16 sec and 20 sec also are presented.

Data corresponding to the model without the breakwater in place also are presented in Figure 4. These data are for 10 sec and 16 sec waves approaching from 203° with the water surface elevation (W.S. ELEV.) at +7.5 ft MLLW. Generally, it appears that the ponding trends are similar to the cases with the breakwater enclosed basin. However, for a given crestal volume there is less ponding for this case than for the breakwater enclosed cooling basin with the same water depth. Thus, even though the bottom bathymetry acts to form a natural basin it is no doubt the impediment of the return flow imposed by the breakwaters which causes a larger volume storage (and ponding) in the basin.

Average curves obtained from data such as those presented in Figure 4 for R and S are shown in Figure 5; data corresponding to experiments with several different water surface elevations and for the breakwater crest at +20 ft MLLW and at 0 ft MLLW have been used. For convenience, one of the curves in the upper portion of the figure is presented in the lower part at an expanded scale. It is seen that with the exception of the largest depth with the degraded breakwater, all data are in

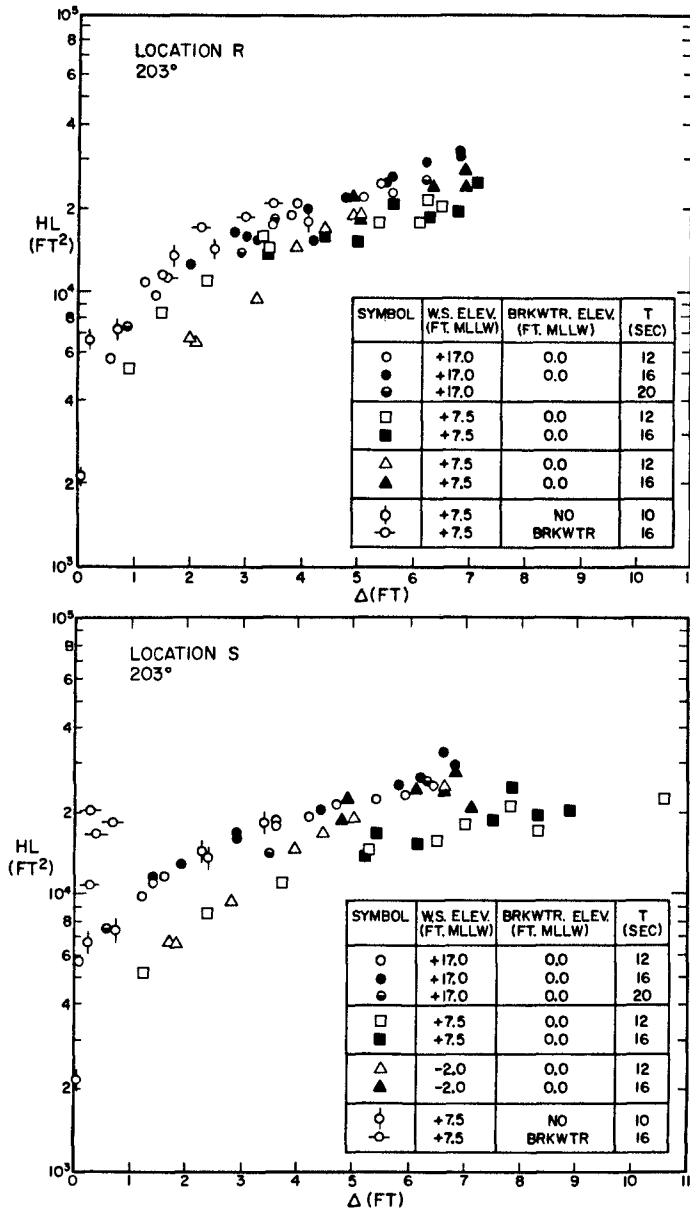


Figure 4 Variation of Ponding at Locations R and S with Wave Crestal Volume Function, HL.

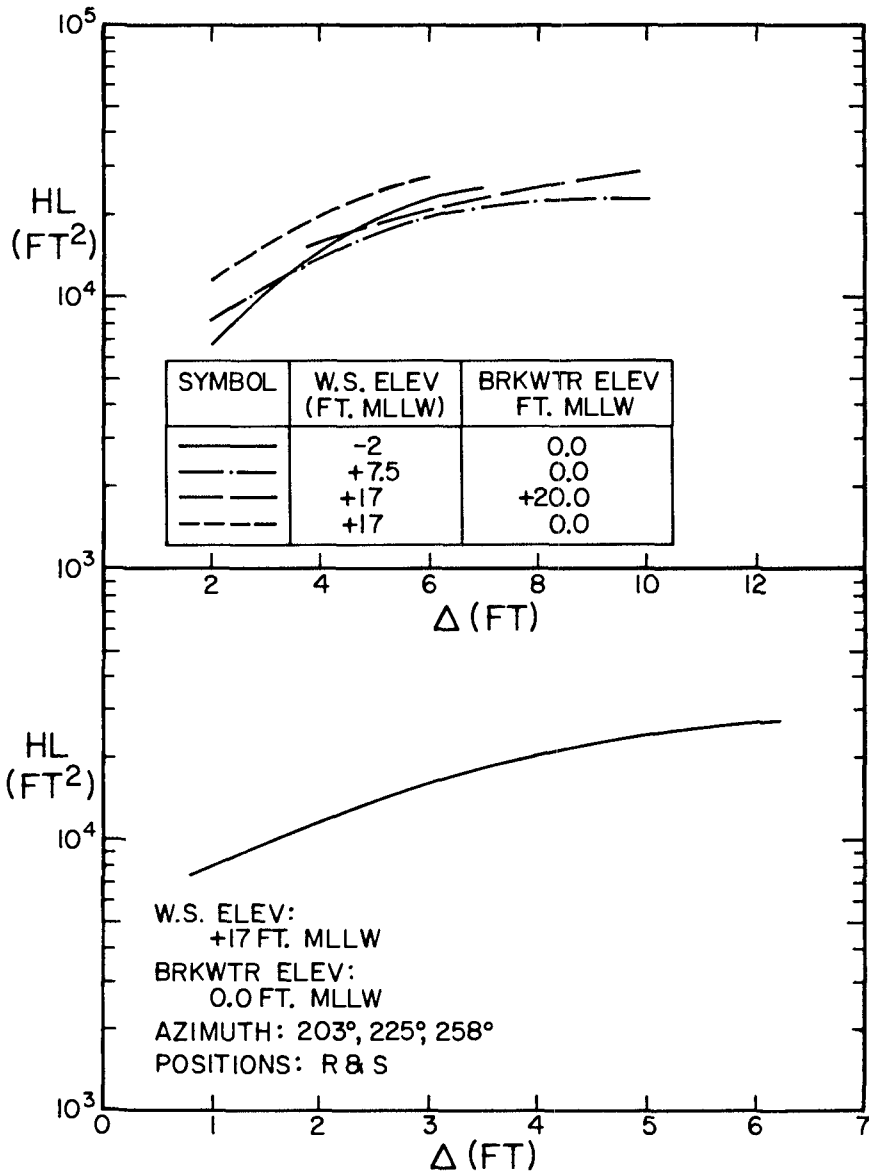


Figure 5 Variation of Average Ponding with Wave Crestal Volume Function, HL.

reasonable agreement when the ponding is presented in terms of the crestal volume parameter.

Experiments were conducted with irregular waves, and data relating to ponding for these cases also are presented. In Figure 6 the water-surface time history near the wave machine is shown for an irregular wave train whose spectral distribution of energy used in constructing the wave machine trajectory was obtained from measurements made by NOAA Buoy No. 46011 on January 28, 1981, at 1800 hrs GMT. (It should be noted that, relative to the still water level, the ordinate is scaled arbitrarily in Figure 6.) The corresponding relatively narrow-band wave spectrum (with the ordinate representing the energy density in units of ft^2/sec) is presented in Figure 7 showing a concentration of energy at a frequency of about 0.06 Hz. The significant wave height as determined from the spectrum is about 28 ft.

In Figure 8 the frequency distribution of wave heights offshore as determined from measurements in the model is presented. The ordinate is the wave height normalized by the significant wave height and the abscissa is the percent by number of waves greater than the indicated height. A Rayleigh distribution is fitted to the data for comparison, and the agreement appears reasonably good except at the extremes, which is as would be expected.

The water surface time history measured at position S is shown in Figure 9; the difference between the mean level and the still water level is evident. The corresponding spectrum is presented in Figure 10 showing the modification of the wave spectrum due to the propagation of the waves over the degraded breakwater into the cooling water basin. Wave breaking tends to introduce the higher frequency components seen centered at about 0.15 Hz with a remnant of the original spectrum remaining at a frequency of about 0.045 Hz. A low frequency component, not seen before, appears at a frequency of about 0.02 Hz (50 sec) along with a mean, i.e., a zero frequency component. The latter reflects the direct effect of ponding whereas the former possibly is evidence of a mode of oscillation of the basin which may be excited by the impingement in the basin of breaking waves which overtop the breakwater.

It is interesting to compare Figure 10 with Figure 7. In the latter there is an absence of energy at frequencies less than 0.03 Hz whereas in the former, i.e., the spectrum of waves at location S, energy exists below that frequency. Since it is apparent that the energy below 0.03 Hz is due to the overtopping process, only this energy was retained in investigating ponding in the cooling water basin. This was done by eliminating all harmonic components at frequencies greater than 0.03 Hz; the resultant water surface time history is shown in Figure 11. This is used to determine a frequency distribution of water surface elevation for the filtered water surface time history as well as an average mean level. For irregular waves, where the long period oscillation is easily seen in Figure 11, the ponding is defined from this frequency distribution. It is defined in this way as opposed to evaluating only the mean of the water surface because it is apparent that there is a significant effect of the low frequency "carrier" component on the crest elevation of the wave. It is this elevation

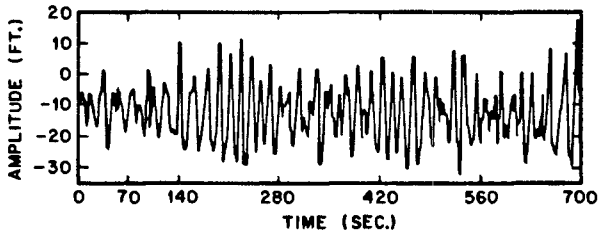


Figure 6 Water Surface Time History Offshore.

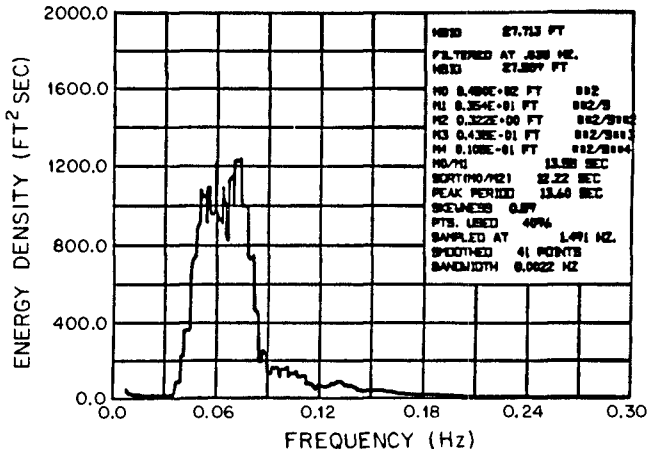


Figure 7 Energy Spectrum Offshore.

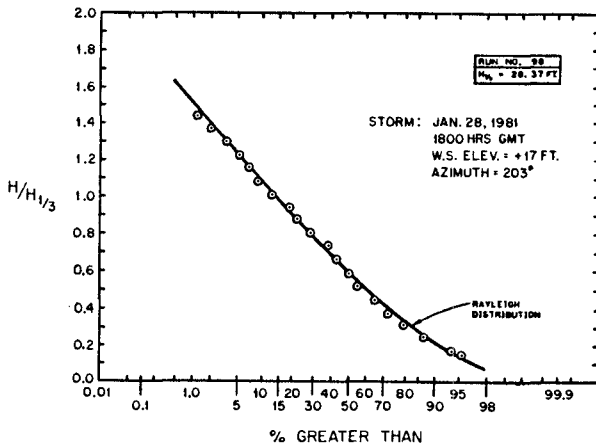


Figure 8 Frequency Distribution of Wave Height Offshore.

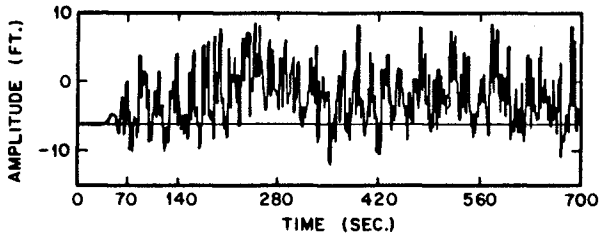


Figure 9 Water Surface Time History at Position S.

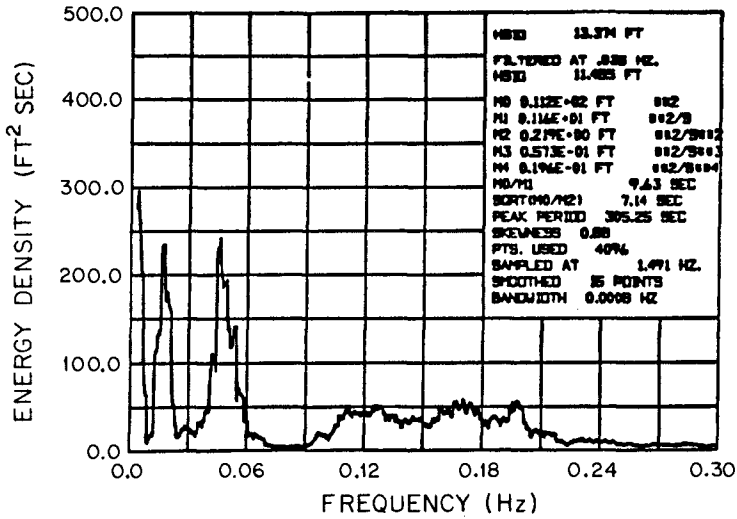


Figure 10 Energy Spectrum at Position S.

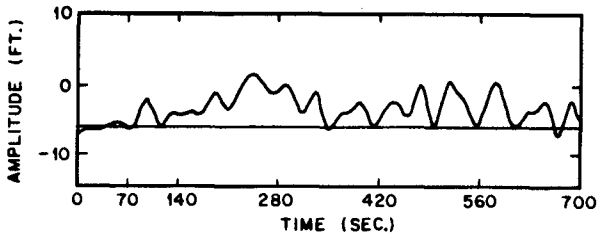


Figure 11 Filtered Water Surface Time History at Location S.

which is most important in the effect of waves in the breakwater protected basin on structures located around its boundary such as the cooling water intake structure. (Data corresponding to the mean alone will be presented also for completeness.)

A typical frequency distribution of the filtered water surface time history is presented in Figure 12. The ordinate is the ponding elevation, i.e., the elevation of the filtered water surface time history relative to the still water level, and the abscissa is the percent by number greater than the indicated elevation. The data shown are for positions R and S for a condition where the tide is -2 ft MLLW with the breakwater degraded such that the crest is at 0 ft MLLW.

Additional data are presented in Figure 13 for several different conditions of still water surface elevation and breakwater crest elevation. In this figure it is observed that the maximum still water surface elevation and the maximum breakwater crest elevation results in the lowest ponding. The maximum ponding occurs for the degraded breakwater with the lower of the two still water levels. If one defines the mean ponding for the irregular wave as the time average of the water surface time history shown in Figure 11 the following values are obtained for experiments 147, 148, and 231: 1.62 ft, 2.6 ft and 1.0 ft, respectively. Thus, there appears to be a somewhat different trend for the irregular wave case as compared to the regular wave results presented in Figure 5; this may be an effect of direction as the waves in experiment 231 are from the south, but those for 147 and 148 are more westerly.

As mentioned earlier, an important effect of the ponding in the cooling water basin is its effect on the elevation of the crest of the wave relative to the still water level. This relates, for example, directly to the overtopping of the cooling water intake structure located along the north boundary of the cooling water basin. Examples of this are shown in Figure 14 for periodic waves for three cases: a still water level of +17 ft MLLW and of -2 ft MLLW with the degraded breakwater and the higher still water level with the breakwater crest at elevation +20 ft MLLW. The ordinate in Figure 14 is the elevation of the crest of the wave in the basin relative to the still water level and the abscissa is the corresponding elevation of the crest of the wave outside of the basin also measured relative to the still water level; a line of equivalence is shown as a solid line in the figure. For 12 sec waves, the distance from the still water level to the crest of the wave at positions R and S appears to be relatively independent of whether the breakwater is at the full elevation of +20 ft MLLW or at 0 ft MLLW for the maximum still water surface elevation (+17 ft MLLW). This indicates, with regard to the elevation of the maximum instantaneous water level in the basin, the effect on the elevation of the wave crest of the elevation of the breakwater crest is small. This means that the effect of ponding must negate to some extent the reduction in wave height due to the increased protection to the cooling water basin afforded by the higher breakwaters.

Conclusions

The following major conclusions can be drawn from this investigation:

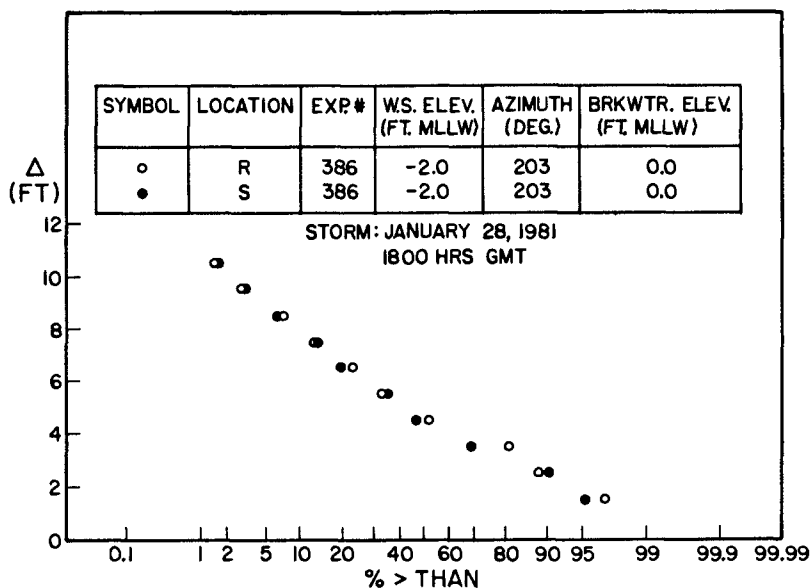


Figure 12 A Frequency Distribution of the Filtered Water Surface Time History.

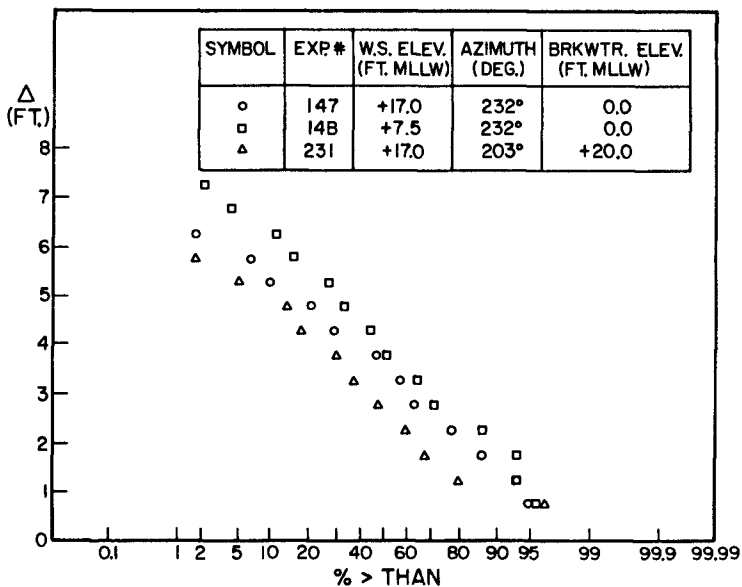


Figure 13 A Frequency Distribution of the Filtered Water Surface Time History.

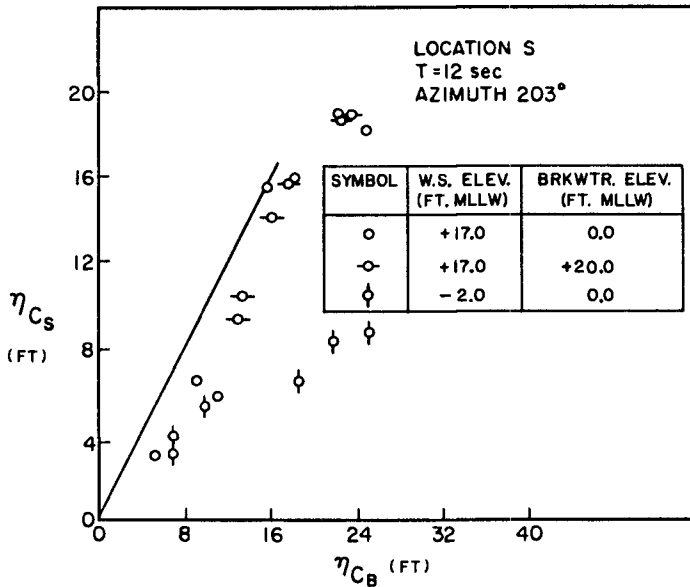
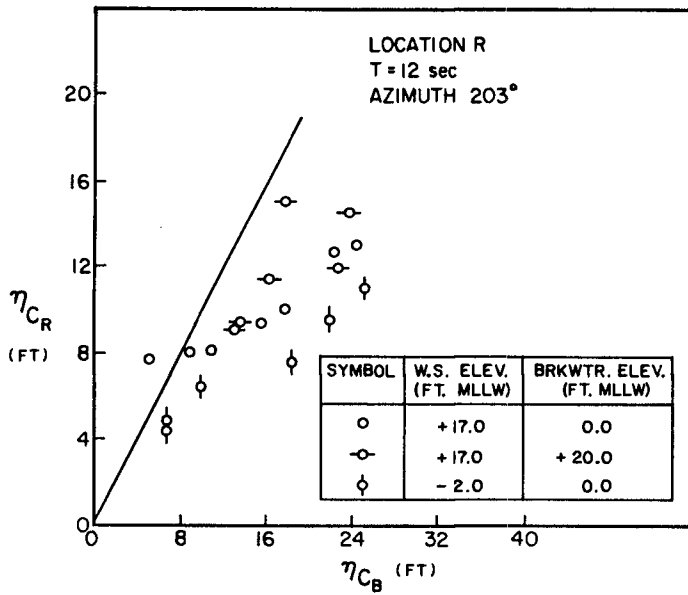


Figure 14 The Variation of the Amplitude of the Crest of the Wave Within the Basin to that Outside.

1. A significant change in the mean water level elevation in the cooling water basin can take place due to the overtopping of the West and East breakwaters. This has been defined in this study as ponding.
2. For regular waves the difference between the mean water level and the still water level can be about 10% of the offshore incident wave height.
3. For regular waves, it appears that the breakwater with its crest at +20 ft MLLW results in larger ponding than when the crest is at 0 ft MLLW.
4. Although the results for periodic waves show a direct dependence of ponding on the wave period, when the data are presented in terms of a measure of the overtopping wave volume, HL, the dependence on wave period is reduced significantly.
5. Irregular wave overtopping of the breakwaters tends to induce oscillations in the cooling water basin and increase the mean water level. Thus, an improvement of wave conditions inside a basin created by breakwaters which may be partially overtopped is, to some extent, reduced by these other wave-induced effects.

Acknowledgement

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