THE DEAD SEA
The Lake and Its Setting

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10. WIND WAVES ON THE DEAD SEA

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There is very little documented information on wind waves on the Dead Sea. The information we have was contributed by Neve and Emery (1967), and they were obtained by visual observations. In general, they report a diurnal cycle during which the sea is calm and mirror-like until about 1000 hours. They followed by a gradual intensification of the wave field, which reaches its peak at about 1500 hours and then dies out to become calm again at about 2000 hours. According to their report, northerly storms in the autumn, winter, and spring produce higher waves, which reached a maximum height of 1.1 m, a length of 10 m, and a period of a few seconds. They compared the wave field on the Dead Sea to that on Lake Kinneret, where, for similar wind but much shorter fetches, waves of 2 m high and even 3 m high were reported. Neve and Emery (1967) attribute this paradox to the higher density of the Dead Sea.

Direct wave measurements of the Dead Sea were taken, for the first time from October 1962 to January 1983. These measurements were taken by the Israel Oceanographic and Limnological Research Ltd. (IOLR) and are the subject of the present investigation. Subsequent wave, wind, and current data are presented in Sires et al. (chapter 9, this volume).

DATA ACQUISITION AND ANALYSIS

Wave heights were measured with an Environmental Devices Corporation (ENDECO) buoy deployed in 45 m of water, about 3.5 km east of the mouth of the Mishmar River (Fig. 10-1). The buoy measured vertical accelerations induced by the waves, integrated the measurements twice, and transmitted the resulting wave heights as they were recorded. The buoy did not measure wave directions. The accuracy and characteristics of the ENDECO wave-measuring buoy are described in Middle (1967). The resolution and accuracy of the measurements were 26 cm. The buoy did not respond significantly to waves of less than 10 cm in height; therefore, our resolution of calm seas included waves of up to 10 cm high. The response of the buoy to waves with periods of 3.3 to 14.3 s did not affect the measurement of the wave height.

For waves with periods of less than 3.3 s, wave amplitudes were attenuated. The attenuation was as much as 7 dB (that is, 50%) for 1 s-wave periods, and as much as 12 dB (that is, 75%) for 1-s wave periods. The attenuation was corrected according to tables provided by the manufacturer. However, our estimates indicate that the contribution of waves shorter than 2 s was insignificant. The buoy response also attenuated the amplitudes of waves with periods longer than 14 s. However, this is irrelevant because, as we will show, such waves could not possibly develop on the Dead Sea.

We carried out two series of wave measurements. During the first series, October 19, 1982, to January 4, 1983, the analog data from the ENDECO buoy were recorded for 5 minutes every 4 hours. From February 1983 to November 1983, the data from this buoy were recorded for 10 minutes every hour. The length of the record and the intervals between records were a compromise determined by the minimum length and time interval required for a reasonable analysis versus the capability of the available recording instrument (the analog paper recorder being far more sensitive than the digitized magnetic tape).

As far as the analog data are concerned, the diurnal distribution of the measurements, the length of each record, and, perhaps more importantly, the length of the entire series are not suitable for sophisticated statistical analysis. However, the data were also analyzed using a filter of the wave climate in the Dead Sea. Moreover, there are gaps in the recordings resulting from power failures on shore at the recording station. Far more data were collected during the series of digital measurements; however, we were still plagued by power failures and transmission errors. Unfortunately, some of the power failures occurred during storms, when wave development was particularly interesting.

Some of the transmission errors resulted in wave records that were observed for the Dead Sea were taken, for the first time from October 1962 to January 1983. These measurements were taken by the Israel Oceanographic and Limnological Research Ltd. (IOLR) and are the subject of the present investigation. Subsequent wave, wind, and current data are presented in Sires et al. (chapter 9, this volume).

Figure 10-1 Location of the wave buoy off the Mishmar River bed and the meteorological station on En Gedi.

The data reduction was analyzed according to Tucker (1963) and also Draper, 1966, 1976). The following parameters were determined for each record: the exact duration of the record in seconds, Nw, the number of crests, Nc, the number of zero crossings; Hc, the sum of the highest crest and the lowest trough; Hs, the sum of the second highest crest and the second lowest trough; and Tc = Nc/N1, the mean zero crossing period. Hs / Tc is the mean crest period. We assume that the Dead Sea wave heights, like open sea wave heights, are Rayleigh distributed, the measured parameters can provide us with some of the statistical characteristics of the wave field (Longuet-Higgins, 1952) and, in particular, permit the computation of the significant wave height, Hs (or H50 as it is named sometimes), for each of the wave records. The significant wave height and the significant wave period are defined as the "average age height and period of the one-third highest waves" (Tucker, 1963, p. 30).

Another computed parameter is the spectral width, c = 1

\[ \frac{H_s}{N_c\cdot N_1} \]  

This is a measure of the range of frequencies present relative to the mean wave frequency, and it controls the shape of the probability distribution of the height of the wave crest (Tucker, 1963). Draper (1963, p. 30) describes the significance of this parameter as follows:

If the wave components cover a wide range of frequencies, the long waves will carry short waves on top of them and there will be many more crests than zero crossings, so that Tc will be much smaller than Tc and v will be nearly one. If, on the
RESULTS

Analog Measurements

The significant wave heights, $H_s$, are given in Table 10-1, where the gaps indicate missing data and 0 indicates calm seas.

Table 10-1  Dead Sea wave measurements: Analog Data (significant wave heights in cm)

<table>
<thead>
<tr>
<th>October 1982 (Time (Hours))</th>
<th>November 1982 (Time (Hours))</th>
<th>December 1982 (Time (Hours))</th>
<th>January 1983 (Time (Hours))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day</td>
<td>00</td>
<td>04</td>
<td>08</td>
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<tr>
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<td>02</td>
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</tr>
</tbody>
</table>

Figure 10-2  Analog data measurements; histogram of significant wave heights ($H_s$)

Figure 10-3  Analog data measurements; histogram of average crest periods ($T_c$). To complete the histogram to 100%, the value for calm seas was included.

Figure 10-4  Analog data measurements; histogram of average zero crossing periods ($T_z$). To complete the histogram to 100%, the value for calm seas was included.

Figure 10-5  Analog data measurements; histogram of spectral width ($\sigma$). To complete the histogram to 100%, the value for calm seas was included.

Figure 10-6  Digital data measurements; histogram of significant wave heights ($H_s$).

Figure 10-7  Digital data measurements; histogram of average crest periods ($T_c$).

Figure 10-8  Digital data measurements; histogram of average zero crossing periods ($T_z$).
A number of factors are not taken into account by either the CERC-SPFM (Coastal Engineering Research Center, 1984) or the LEKNEK (Leenknecht et al., 1982). Such factors include the wave peak frequency, the fetch length, and the fetch depth. In our model, these factors were included in the wave height prediction. We also assumed that the wave height is directly proportional to the fetch length and the fetch depth. However, this assumption may not hold in all cases.

A more accurate prediction of the wave height is achieved by using a combination of the linear and nonlinear models. The linear model is used to predict the wave height for fetch lengths greater than 10 km, while the nonlinear model is used for fetch lengths less than 10 km. The nonlinear model takes into account the effects of the wave height and the fetch depth on the wave height.

The wave height prediction for fetch lengths greater than 10 km is given by the following equation:

\[ H = 0.25 \times F \times D^{0.3} \]

where \( H \) is the wave height in meters, \( F \) is the fetch length in kilometers, and \( D \) is the fetch depth in meters.

The wave height prediction for fetch lengths less than 10 km is given by the following equation:

\[ H = 0.25 \times F^{0.3} \times D \]

In this equation, \( H \) is the wave height in meters, \( F \) is the fetch length in kilometers, and \( D \) is the fetch depth in meters.

The wave height prediction for fetch lengths between 10 and 100 km is given by the following equation:

\[ H = 0.25 \times F^{0.5} \times D^{0.3} \]

In this equation, \( H \) is the wave height in meters, \( F \) is the fetch length in kilometers, and \( D \) is the fetch depth in meters.

In summary, the wave height prediction is a function of the fetch length and the fetch depth. The linear model is used for fetch lengths greater than 10 km, while the nonlinear model is used for fetch lengths less than 10 km. The wave height prediction for fetch lengths between 10 and 100 km is given by a combination of the linear and nonlinear models.

In the future, more accurate predictions of the wave height can be obtained by using a combination of the linear and nonlinear models. This will require more data on the fetch length and the fetch depth. However, the results obtained from the linear and nonlinear models are satisfactory for practical applications.
about 1000 hours, followed by a gradual intensification of the wave field, which reaches its peak by about 1700 hours and then dies out to become calm again at about 2000 hours. It is not clear from their report whether the sea stays calm throughout the night, i.e., between 2000 hours and 1000 hours the following day. The questions is, what is the reason for this periodicity? One obvious periodic driving force could be the sea breeze. New and Emery (1967) report that the winds over the Dead Sea are diurnally periodic: calm in the morning until 1000 hours, increasing to 1500 hours, and dying out by 2000 hours. According to Neumann and Stahlin (1978, p. 53), "One of the outstanding meteorological features of the Jordan Rift in summer is the arrival of a forceful afternoon hours of the Mediterranean sea breeze." Their investigation shows that the Mediterranean sea breeze arrives at Lake Kinneret in the afternoon hours and because of the geography of the region surrounding Lake Kinneret, it is amplified to twice and even two-and-a-half times the velocity near the Mediterranean shores. Thus, the breeze can reach speeds of 10 to 15 m/s and is the driving force behind the daily summer afternoon storms on Lake Kinneret. Weiss et al. (1987), as well as Weiss and Cohen (1988), mention that the high evening air temperatures on the Dead Sea, as well as the wind peaks occurring between 1200 and 1900 hours, are due to the Mediterranean breeze, but present no analysis to demonstrate their statements.

However, as we have seen, although our measurements show that the wave field is diurnally periodic, we observed the calmest seas in the afternoon and the highest seas past midnight at about 0200 hours, contrary to New and Emery (1967). Therefore, we decided to analyze the available wind measurements on the Dead Sea (i.e., November 8, 1983 to August 19, 1984). The data suffer from many gaps, and as a time series, they are not suitable for spectral analysis. A simpler and more superficial approach is to average the wind velocity for every half hour of the day, regardless of the date of the measurement (similar to the procedure we applied to the wave measurements). Our results (Fig. 10-10) show that the wind speed reaches a maximum around midnight and a minimum during the late afternoon hours. Thus the diurnal variations in the wind speed on the Dead Sea do not resemble those reported for Lake Kinneret and, climatologically, fit in with the diurnal wave height as reported herein. The present investigation has indicated a number of discrepancies between the wave field as reported by New and Emery (1967) and our own measurements. Far from trying to belittle the pioneering work of New and Emery (1967), to whom we are deeply indebted, we intend to stress the importance of objective long-term measurements as opposed to sporadic observations. Therefore, we expect that an even longer and more precise series of wave measurements on the Dead Sea may yield different results than those we have presented.

Acknowledgments
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REFERENCES