CHAPTER 8

INVESTIGATION OF SEICHE ACTIVITY IN WEST COAST HARBORS

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INTRODUCTION

The seiche activity in several West Coast harbors has been investigated during the past two years. This investigation has been oriented mainly as an experimental problem in which a new oceanographic instrument, the solion infrasonic hydrophone,[1] is used to detect bottom pressure fluctuations over a range of 5 sec to 1800 sec periods.

A limited theoretical consideration of this problem is presented in an attempt to correlate the seiche phenomenon to the harbor geometry.

The data presented in this paper are for San Diego Bay and Long Beach Harbor. These data were recorded on magnetic tape and returned to the laboratory for analysis. This analysis consists of prewhitening the data with bandpass filters and then computing the power spectra by the method of Blackman and Tukey.[2,3]

A short discussion is presented to relate the use of this type of data to the study of two harbor engineering problems, ship mooring and close quarter navigation.

RECORDING INSTRUMENT

The bottom pressure fluctuations were detected with a solion infrasonic hydrophone.[4] This hydrophone consists of a hydroacoustic high-pass filter in combination with a solion linear differential pressure transducer. The linear response of the hydrophone is in excess of 200:1 (46 dB) and the pressure threshold is comparable to other bottom pressure transducers.[5] Stability of the solion is excellent over long periods of time.

The hydrophone bandpass is relatively flat, with -3 dB period response points at approximately 5 sec and 800 sec periods. Falloff beyond the -3 dB points approaches -6 dB per octave. The output signals of the hydrophone, which are proportional to the pressure signal, were recorded on magnetic tape for analysis over the range of 5 sec to 1800 sec periods.[6] All of the pressure recordings were of 6 to 8 hours duration.

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DATA

Bottom pressure fluctuations were recorded at three locations in San Diego Bay, California. Figure 1 shows the location at which the recordings were made in relation to the open sea. It does not, however, show that part of the bay which extends to the southeast and terminates in broad mud flats. The pertinent environmental conditions that existed during each recording period is given in Table I.

Bottom pressure fluctuations were measured at two locations in the area of San Pedro Bay, California. The recording locations were in the Long Beach Middle Harbor and the Long Beach Outer Harbor. A map of the San Pedro Bay area is shown in Fig. 2. Table II gives the pertinent environmental conditions that existed during each recording period.

ANALYSIS TECHNIQUE

The frequency analysis of a time series such as an ocean wave record can readily be accomplished by computing its power spectrum. The practical computation of the power spectrum of such a time series is given in detail by Blackman and Tukey.[7] This method of computing power spectra has been applied to surface wave records by Pierson and Marks and to bottom pressure records by Timme and Stinson.[8]

This method of attack is based upon Weiner's theorem,[9] which states that the auto-covariance function of a time series X(t) is the Fourier transform of its smoothed power spectrum. If we define the auto-covariance function by the relation

$$C(\tau) = \lim_{T\to\infty} 1/T \int_{-T/2}^{T/2} X(t) \cdot X(t+\tau)\, dt \,, \qquad (1)$$

where τ is a time delay, then it is related to the smoothed power spectrum P(f) by the relation

$$C(\tau) = \int_{-\infty}^{+\infty} P(f)\, e^{2\pi i f\tau}\, df \,, \qquad (2)$$

where

$$P(f) = \lim_{T\to\infty} 1/T \left| \int_{-T/2}^{T/2} X(t)\, e^{-2\pi i f t}\, dt \right|^2 . \qquad (3)$$

The auto-correlation function will be designated as the normalized auto-covariance function, given as

$$\phi(\tau) = C(\tau) / C(o) \,. \qquad (4)$$

Table I. Environmental Conditions During Bottom Pressure Measurements

Location	Date	Water Depth(ft)	Wind Speed(mph)	Wind Direction	Sea State
Pier Alpha	23 Apr 1960	40	5-15 Gusty	Northwest	1
	24 Jan 1961	40	Calm	--	0-1
	25 Oct 1961	40	Calm	--	0-1
Ballast Point	28 Apr 1960	45	10-20 Gusty	East	1-2
	25 Jan 1961	45	Calm	--	0-1
	26 Oct 1961	45	0-10	Northwest	1
Broadway Street Pier	27 Apr 1960	36	5-10	Northeast changing to Southwest	1
	27 Oct 1961	36	0-10	Southwest	1

Table II. Environmental Conditions During Bottom Pressure Measurements

Location	Date	Water Depth(ft)	Wind Speed(mph)	Wind Direction	Sea State
Middle Harbor	23 Aug 1960	45	6-15 Gusty	Southwest	1
	17 Jan 1961	45	Calm	--	Storm the previous week off coast of Northern California
	23 Oct 1961	45	Calm	--	0
Outer Harbor	25 Aug 1960	40	5-15	Southeast	1
	19 Jan 1961	40	10-15 Gusty	North	Storm the previous week off coast of Northern California

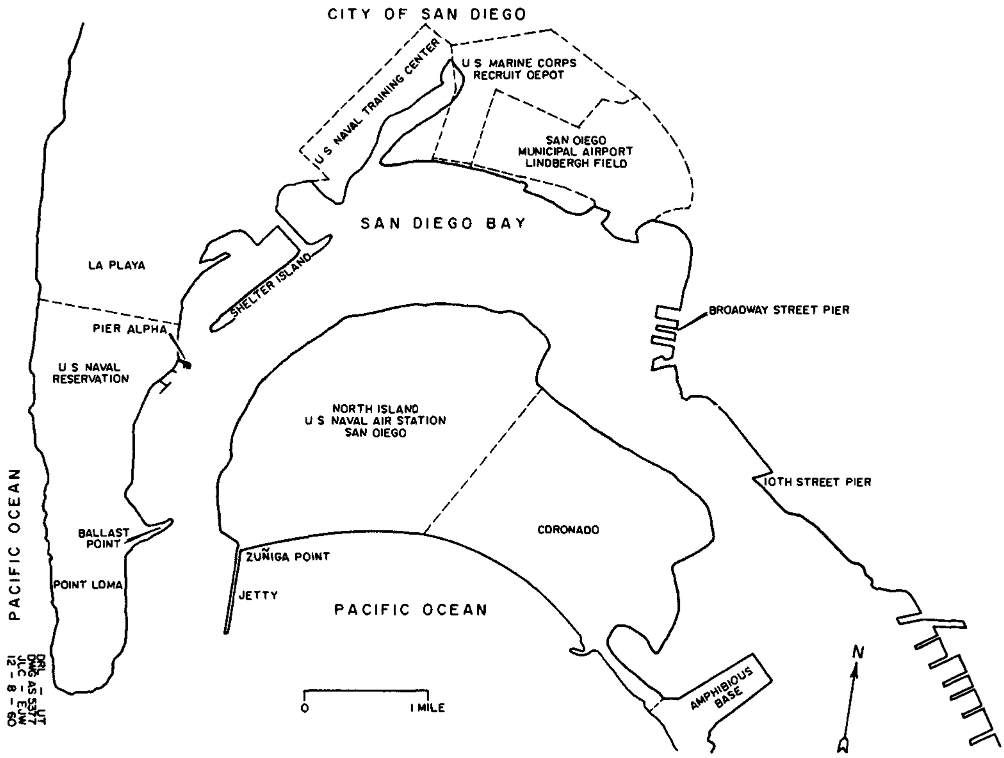

Fig. 1. Map of San Diego Bay.

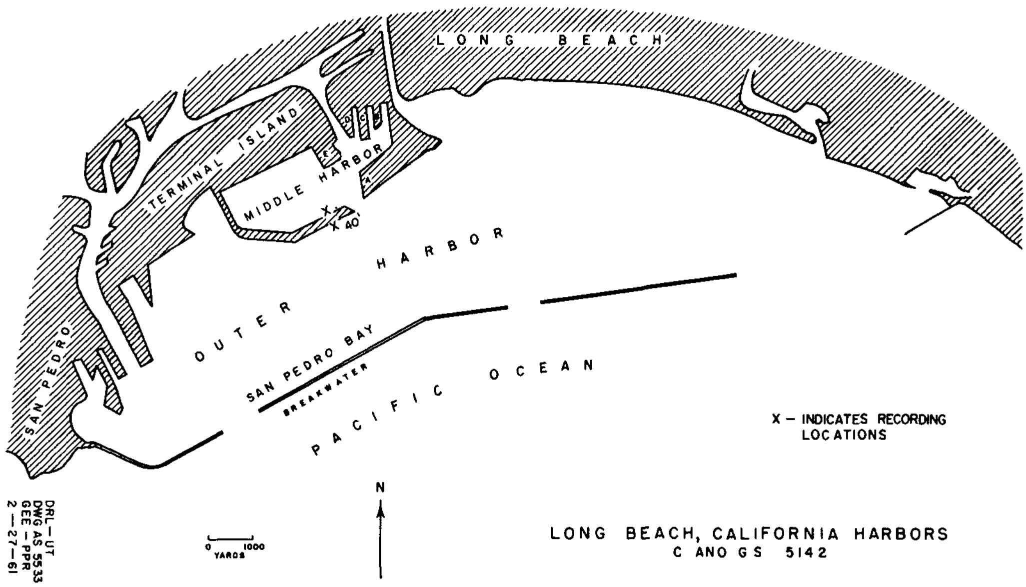

Fig. 2. Map of Long Beach Harbors and San Pedro Bay.

The recorded pressure data were brought back to the laboratory for pre-processing with the low frequency analyzer, which consists mainly of a set of eight octave bandpass analog filters.[9] This method of pre-whitening the data was chosen, since the length of the record is limited, to give greater resolution in the final power spectrum.

A set of power spectral estimates was computed for the resulting noise record from each filter. The power spectral estimates corresponding to the frequencies between the -3 dB points for each filter were combined to give a reasonable estimate of the power spectrum over the entire range of interest. Since the number of data points varies for each filter band, the maximum and minimum 80 percent confidence intervals, based upon the chi square distribution, are indicated on each figure.

In this paper, the magnitude of the power density is presented only as relative values. This was felt acceptable since all of the interpretation will be made on the frequency or period content of the spectra.

DISCUSSION

The seiche of a harbor can be excited by various mechanisms. Sudden changes in barometric pressure, a change in the wind, or seismic activity is capable of exciting standing wave oscillations in basins. One of the main mechanisms for exciting seiche activity in harbors, however, is the motion of external waves at the harbor mouth. These driving forces could be wave motions generated either at sea or in a closely coupled, partially enclosed body of water. External waves can excite both resonant and nonresonant types of motion. For resonant motions there does not exist a velocity component normal to the plane of the harbor entrance, whereas the nonresonant motion is directly affected by a normal velocity component other than zero at the entrance. McNown has completed model studies of various harbors with idealized shapes which verify that both types of motions can exist.[10]

The seiche in the harbor will appear as a periodic signal in the bottom pressure background recordings. This periodic signal may readily be detected by the method of power spectra analysis. A periodic signal will appear as a peak in the spectra, with the period corresponding to this peak being the period of the signal. If there are several different modes of the seiche present in the time series, then each mode will appear as a spectral peak at the period characterizing that mode of oscillation.

An examination of the spectra presented shows that the period content of each harbor is approximately constant regardless of the time of year and the different environmental conditions. It is assumed, therefore, that the spectra are a representation of the true background conditions in each harbor.

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SAN DIEGO BAY

From the spectra analysis of the bottom pressure data recorded at Pier Alpha (Fig. 3) and Ballast Point (Fig. 4) the power density of swell activity is shown by a prominent peak at 15 sec. The magnitude of this peak has diminished considerably in the spectrum at Broadway Pier (Fig. 5). This is to be expected since Broadway Pier is further removed from the ocean or the driving force than either Pier Alpha or Ballast Point. A prominent peak in the spectra for Broadway Pier, which appears in the 6.5 sec region, probably corresponds to local wind-generated wave activity.

All of the spectra show a prominent peak in the region of 1300-1500 sec. This is attributed to a seiche propagating along the length of the harbor, since this spectral peak does not vary its period appreciably with location.

The spectra of the bottom pressure data recorded at Pier Alpha show a prominent peak in the 160-170 sec region. This is attributed to a transverse seiche in the vicinity of Pier Alpha. There are various other peaks in the spectra that have not been accounted for at this time.

The characteristics of a seiche have been shown to be directly dependent upon the geometry of the containing basin.[11] For a rectangular basin with both ends either closed or open, the period is given by the relation

$$T_m = 2L/\left[m\sqrt{gh}\right], \quad m = 1,2,3,\ldots, \tag{5}$$

where L is the length and h the depth of the basin. For a rectangular basin with one end closed and one end open, Eq. (5) becomes

$$T_m = 4L/\left[m\sqrt{gh}\right], \quad m = 1,3,5,\ldots. \tag{6}$$

If a two-dimensional consideration is made of a rectangular basin, the relation for the period is

$$T_{m,n} = 2(gh)^{-1/2}\left[m^2/L^2 + n^2/B^2\right]^{-1/2}, \quad \begin{matrix} m = 0,1,2,\ldots, \\ n = 0,1,2,\ldots, \end{matrix} \tag{7}$$

where B is the width of the basin.

Equations (5) and (6) were used to calculate the possible modes of the longitudinal oscillations for San Diego Bay. The results of these calculations are given in Table III.

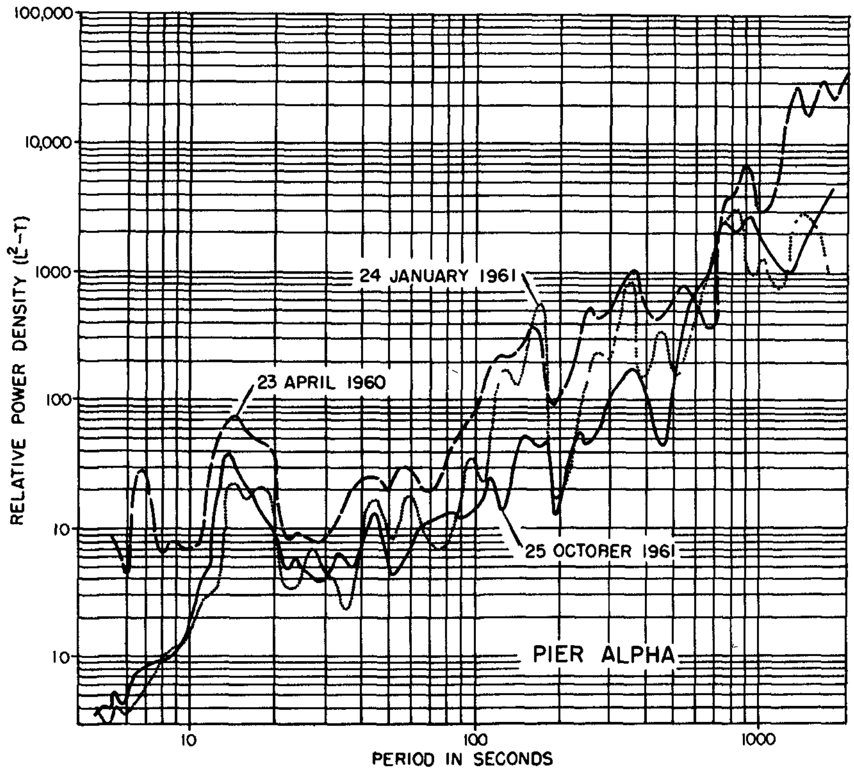

Fig. 3. Relative power spectra for Pier Alpha, San Diego Bay.

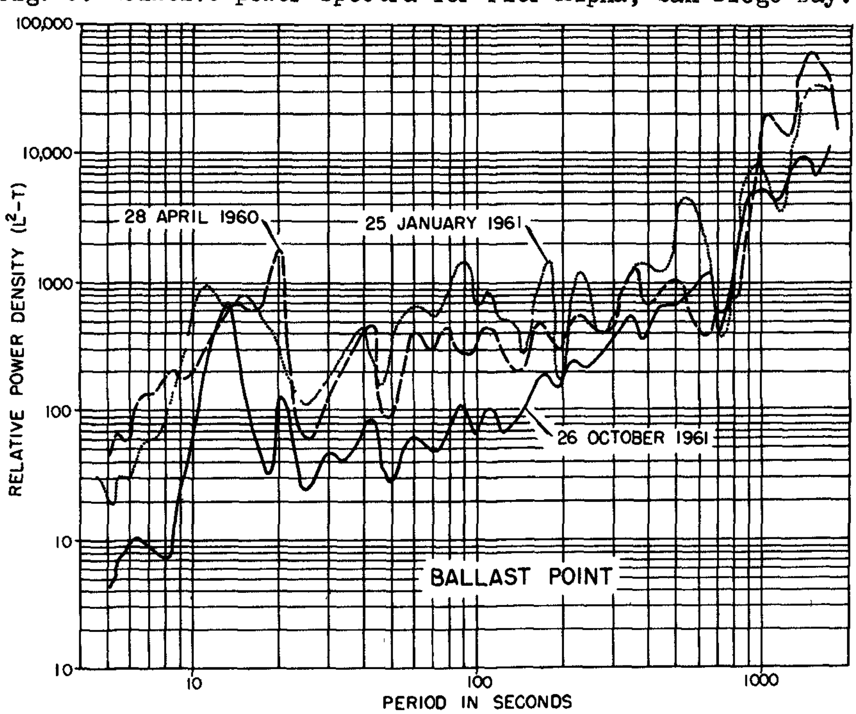

Fig. 4. Relative power spectra for Ballast Point, San Diego Bay.

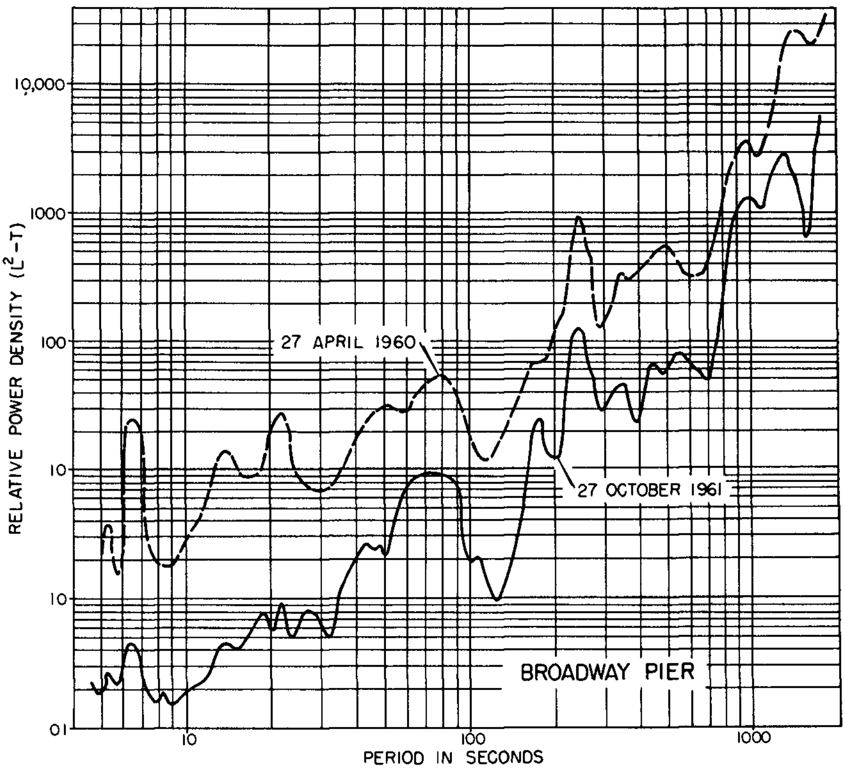

Fig. 5. Relative power spectra for Broadway Pier, San Diego Bay.

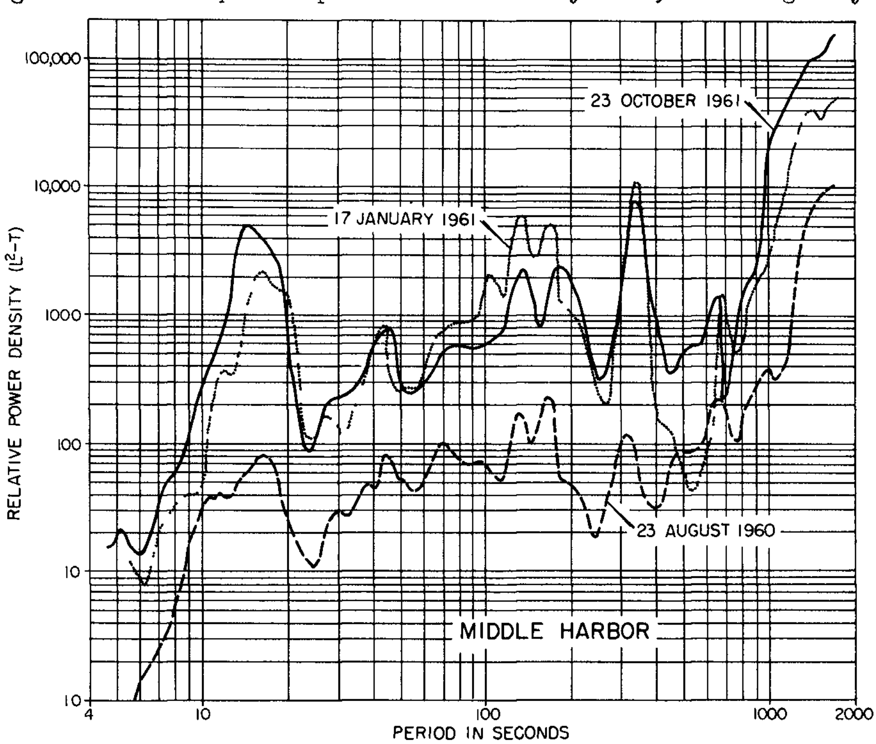

Fig. 6. Relative power spectra for Long Beach Middle Harbor.

Table III. Calculated Periods of Possible Modes of Oscillation Based Upon the Average Length and Depth of San Diego Bay

m	Period given by Eq. (5) in sec	Period given by Eq. (6) in sec	Mode of Oscillation
1	2900	5800	First
2	1450	--	Second
3	966	1933	Third
4	725	--	Fourth
5	580	1160	Fifth

The broad mud flats at the southeast end of the bay will approximate a wave absorber for the long period standing waves associated with this type of oscillation. The standing wave phenomenon would, therefore, be analogous to that taking place in an organ pipe with both ends open. Equation (5) would then govern the longitudinal seiche in the bay, and the peak in the power spectra at 1450 sec could be explained as being due to the second mode or second harmonic seiche activity. This would be an oscillation with a mode of vertical displacement at the entrance to the bay, at the terminating end of the bay, and in the vicinity of the 10th Street Pier. Present analysis does not extend to the 3000 sec period region, and the predicted 2900 sec period oscillation cannot be confirmed.

The spectra of the pressure data recorded at Pier Alpha show a prominent peak in the 160-170 sec region. This may possibly be a local oscillation across the bay in the vicinity of Pier Alpha. Calculations using Eq. (5) have been made by taking various sections across the bay. This gives a mean value for the period of the fundamental mode of the oscillation to be 160 sec.

The relative power spectra of Broadway Pier (Fig. 5) show a peak at 240 sec. This may be a transverse seiche in the neighborhood of Broadway Pier. By using Eq. (5) the fundamental period of a seiche of this type is found to be 494 sec, with a second harmonic of 247 sec.

LONG BEACH HARBORS

Figure 6 shows the relative power spectra of the bottom pressure data recorded in the middle harbor. There is a peak at 16.5 sec which corresponds to the swell activity in the harbor. There are three other definite peaks at 135 sec, 170 sec, and in the 320 to 340 sec region. All of the spectra show a rising trend around 1500 sec. The spectral peak in the 320 to 340 sec region is the second mode or harmonic of the longitudinal oscillation. This would give a possible fundamental mode of 640 to 680 sec, which also corresponds to a peak in the spectra. The peak in the spectra at 170 sec is probably composed of several modes, the most prominent of which is the fundamental of an oscillation across the width of the basin. The fourth harmonic of the longitudinal mode may also be excited.

Carr has shown by model studies of the middle harbor that the fundamental of the longitudinal oscillation has a period of 720 sec.[12] He found, however, that the resonance of the basin to the second harmonic of 360 sec produces an oscillation of higher amplitude than the fundamental. Carr also measured, from model studies, an oscillation across the harbor with a period of 180 sec. The periods of these oscillations determined by the model studies differ from the periods determined by power spectrum analysis by approximately 10 percent. Experimental errors readily account for this difference.

Calculations of the periods of the possible modes for the middle harbor have been made by using Eqs. (5) and (7). According to this theory, using mean dimensions in Eq. (5), the period of the fundamental mode of the longitudinal seiche is 652 sec. The second harmonic or mode would have a period of 326 sec, and the fourth harmonic or mode would have a period of 163 sec. The calculated period for the fundamental mode of the oscillation across the harbor is 244 sec. If Eq. (7) is used--that is, if the basin is given a two-dimensional consideration--the period $T_{1,2}$ is found to be 185 sec.

The spectra of the middle harbor show a rising trend around the 1500 sec region. This trend also appears in the spectra of the bottom pressure records of the outer harbor (Fig. 7). The period of the third harmonic of a longitudinal seiche in the outer harbor was found, by using Eq. (6), to be 1420 sec. This would give a fundamental mode of 4263 sec, which would be out of the bandpass of the recording hydrophone. The fifth harmonic, as calculated according to this theory, would be 825 sec. This type of motion in the outer harbor would readily account for the peak in the spectra of the middle harbor at 1500 sec.

On examination of the spectra from both harbors, it is seen that several peaks of the same period occur in each. This may be attributed to the nonresonant phenomena stimulated by the waves in the outer harbor. A "second generation" solion infrasonic hydrophone with a flat period response beyond 5000 sec is being constructed to help investigate this phenomenon.

APPLICATION OF RESULTS

The seiche phenomenon that occurs in harbors presents various problems to ship mooring and to close quarter navigation, such as docking. A better knowledge of the spectra of the harbor would give some insight to the solution of such problems.

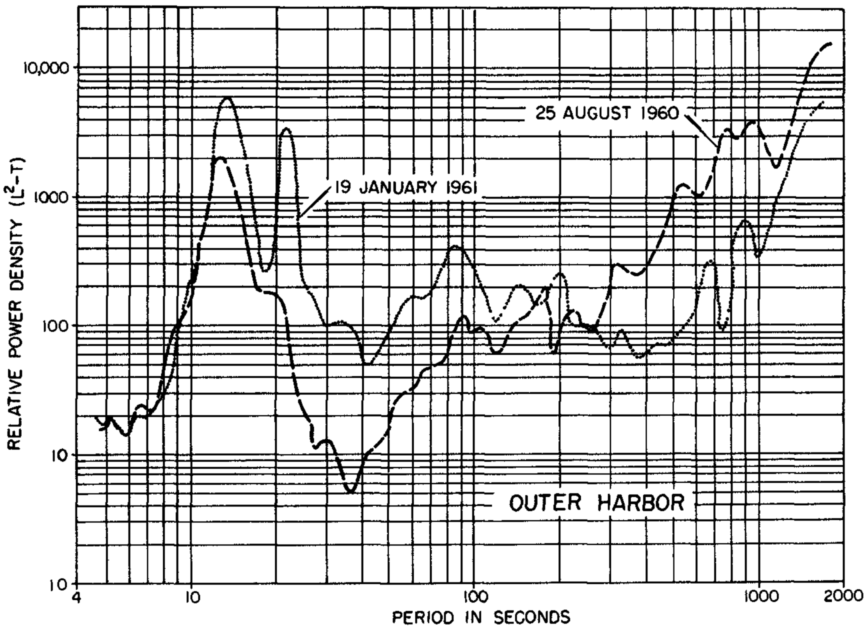

Fig. 7. Relative power spectra for Long Beach outer harbor.

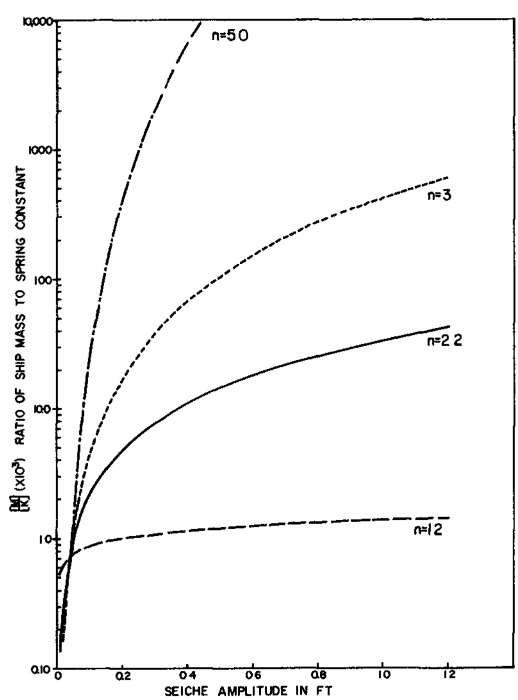

Fig. 8. Relation between the ratio of the mass of the ship to the spring constant and the seiche amplitude for resonant conditions.

The problem of a ship moored in the direction parallel to the dock face has been described by Wilson[13] using the analogy of a spring-mass vibratory system. The resonant period of a moored ship is given by the relation

$$T_n = 2\pi \sqrt{\frac{M}{K}} \left[\frac{MgA^2}{Kd} \right]^{\frac{1-n}{2(n+1)}} \quad (8)$$

where M is the mass of the ship, K is the spring constant for all lines collectively, g is the acceleration due to gravity, d is the depth of the water at the mooring, and n is the numerical exponent expressing the non-linear load-movement behavior of the representative mooring line. When the resonant period of the moored ship corresponds to the fundamental period or one of the harmonic periods of the seiche, then ship damage can occur. Figure 8 shows a graph of the ratio of the ship mass to the spring constant versus the amplitude of the seiche. This family of curves is governed by Eq. (8) at resonant conditions. That is, the period T_n of the ship is chosen to be equal to 170 sec, the period of the transverse seiche at Pier Alpha, San Diego Bay. The value of n may be determined by measurement of the particular ship.[14] One could then determine the resonant spring constant of a given ship for a particular amplitude of the seiche, enabling the ship to be moored in such a manner as to avoid resonance.

The problem of close quarter navigation has been evident at Broadway Pier in San Diego Bay. While docking ships the pilots find that a current will flow in one direction at one time, but in the opposite direction at another time. This may well be due to the long period seiche along the length of the harbor or the shorter period seiche across the bay in the neighborhood of Broadway Pier. A greater knowledge of the spectra of the harbor would allow a prediction of the magnitude and direction of the current during a particular time interval.

ACKNOWLEDGMENTS

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