Kobe Harbor Quaywall

Part 3
COASTAL STRUCTURES AND RELATED PROBLEMS

Kobe Harbor Breakwater

CHAPTER 45

WAVE AGITATION IN BAYS AND HARBORS-METHODS OF MEASUREMENT AND ANALYSIS*

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ABSTRACT

Practical and effective methods for the measurement of and the determination of the type and the mode of wave action in a semi-enclosed basin are investigated. Pressure gages and flow meters are considered as instruments available for such measurement. The combination and arrangement of these instruments as well as the use of power spectral and cross spectral analyses as the basic means of data reduction are discussed. A special attention is given to the problem of estimating the contributions from the progressive and from the standing modes of oscillation separately. Significance of such estimation on engineering planning is briefly discussed. Examples are given.

INTRODUCTION

An investigation of surging in harbors has a relatively long history of which excellent reviews are found in the articles by B. W. Wilson[1)], J. H. Carr[2)], and R. L. Wiegel[3)].

There is, however, a renewal of interest in this subject in recent years, which is due to the facts that;

i) the trends toward the fuller utilization of the waterfront areas in the harbor by reducing the beaches not in immediate use for shipping and toward the better protection of the navigational facilities by increasing the length of protective structures has made it difficult for the wave energy to dissipate once it enters the semi-enclosed basin of a harbor,

ii) the popularity and the increased size of the small craft harbors have made it necessary for coastal engineers to give priority to protecting the small crafts from the damaging action of waves of periods much less than the usual period of surging in harbors for large-sized vessels,[4),5)]

and

iii) the introduction of the container cargoes as a means of ocean transportation has resulted in the requirement of extremely calm waters in the vicinity of the piers with container handling facilities since any small movement of vessels during the loading and unloading operations there critically affects the economy of the operation.

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The problem that will be discussed here in particular is how we can find out, with efficiency in time and cost, the patterns with which the waters in the semi-enclosed basins such as bays and harbors are oscillating. Such information is essential in locating a new berthing facility and in determining the mooring arrangement along with the plan of new and/or reinforced protection and development of navigation facilities for bays and harbors. Such information is also useful in interpreting the gage record of response of bay waters to external disturbances such as tsunamis and storm surges[6].

It is well established that the motion of waters in a semi-enclosed basin is complex even in case of a basin of simple geometry such as a rectangular or circular shape if there is any asymmetry regarding the entrance or the direction of the incoming waves. To establish a fairly complete picture of the complex patterns of oscillation in the harbor for the varying inputs coming through the entrance requires the analysis of the simultaneous records of wave action obtained at more than a few gaging stations instead of that of a single record from a single station or of records from more than one station but without any preconceived scheme of correlation. The time and cost involved in such a project could become enormous and therefore to set up the effective plan of measurement is a matter of vital importance to the success of the project.

TYPICAL SITUATIONS

Consider the simplest case of a typical basin of a rectangular shape with an opening to the ocean as illustrated in Fig. 1. There are two possible modes of standing wave oscillation in the basin, one being the oscillation whose axis is parallel to the longer axis of the basin and the other parallel to the shorter axis of the basin, which might be designated here as longitudinal and lateral modes of oscillation, respectively. In addition to such standing wave oscillation we may have progressive waves directly coming into the basin through the opening (or if we consider that the standing wave is a superposition of progressive waves and of retrogressive waves, we should say that we have a system of waves, with progressive waves dominating over retrogressive ones.).

Thus when we measure the variation of water surface elevation at a point, say station A, in the basin, the recorded variation could consist of a system of waves, progressive and retrogressive as well as longitudinal and lateral. The analysis of the record of water surface movement at station A, therefore, gives only a limited scope of information. It gives the energy-frequency relationship of the agitation that prevails at the station but it does not provide information on how the agitation there is related to the agitation elsewhere in the basin, which we need in preparing or deciding on a plan to create new or improve existing berthing and navigation facilities and/or protective structures.

The task can be accomplished by employing a set of gages, placed at a few selected points in the basin, such as at Stations E and F or A, B and G in Fig. 1. In addition to measuring the water surface elevation, the measurement of orbital velocity of the particle motion associated with the wave agitation could produce results of equal significance.

INSTRUMENT

The measurement of water level variation can be made by using a pressure gage, a step-type gage or a float-type water level recorder. Among these, the pressure gage is probably the most versatile instrument for the present purpose. In case a fixed station record over an extended period of time is desired the other types of wave gages may be equally useful or better. In general the depth of water where the gage is to be placed is more than 30 ft and the wave period of interest is larger than 7 or 8 seconds. The lower limit of the height of waves that should be measured depends on their frequency range but very often the waves of height as small as an inch may have to be recorded.

The measurement of the orbital velocity of water particle movement may be made by an electromagnetic flow meter[7)] or a sonic flow meter[8)]. The reason why the conventional type of current meters used in hydrological and oceanographical surveys may not be used is that most of them do not produce the continuous record of high resolution and sensitivity required for the present purpose.

The two types of gages mentioned are also subject to limitation at the present time. The first one is not free from operational and directional instability and the second one has problems in the size and the cost of the gage. It is desired that the further improvement would eliminate these difficulties in the near future.

The advantage of using a pressure gage is that it directly detects the movement of the water surface while that of using a flow meter is that the directional properties of the waves are obtained from the latter. One reason why the simultaneous use of those two gages may be of special advantage is that for the standing wave the orbital velocity is the maximum where the water surface movement is the minimum and vice versa.

The recording may be made either in digital or in analogue form. In case the cross-spectral analysis is to be required it is desirable to employ a multi-channel digital recorder.

PRINCIPLES OF ANALYSIS

On the premises that the data collected by these instruments are subjected to spectral and cross-spectral analysis two basic means of calculation are outlined in the following.

First consider the combination of a pressure gage and a flow meter which were placed at the same location where the wave system consists of progressive and retrogressive waves and the axis of the flow meter is parallel to the direction of wave propagation. Thus the basic expressions for water surface elevation, z, dynamic pressure, P and orbital velocity, U are given in the following:

$$\eta(t) = \eta_p(t) + \eta_r(t) = \int \left\{ A_p(\sigma) + A_r(\sigma) \right\} e^{i\sigma t} d\sigma \tag{1}$$

$$P(t) = \int K_p(\sigma) \left\{ A_p(\sigma) + A_r(\sigma) \right\} e^{i\sigma t} d\sigma \tag{2}$$

$$U(t) = \int K_U(\sigma) \left\{ A_p(\sigma) - A_r(\sigma) \right\} e^{i\sigma t} d\sigma \tag{3}$$

where

σ : frequency

p : subscript for progressive waves

r : subscript for retrogressive waves

K_P : pressure response factor $= \rho g \dfrac{\cosh k(d+z)}{\cosh kd}$

K_U : velocity amplitude ratio $= \dfrac{\sigma \cosh k(d+z)}{\sinh kd}$

k : wave number $= \dfrac{\sigma^2}{g} \coth kd$

d : depth of water

From these we can calculate the spectra for the progressive and for the retrogressive waves by the use of the following relationships;

$$A_p(\sigma) = \frac{1}{2} \left\{ \frac{1}{K_p(\sigma)} \int P(t) e^{-i\sigma t} dt + \frac{1}{K_U(\sigma)} \int U(t) e^{-i\sigma t} dt \right\} \tag{4}$$

$$A_r(\sigma) = \frac{1}{2} \left\{ \frac{1}{K_p(\sigma)} \int P(t) e^{-i\sigma t} dt - \frac{1}{K_U(\sigma)} \int U(t) e^{-i\sigma t} dt \right\}. \tag{5}$$

By calculating the spectra of pressure variation and of the variation of the orbital velocity, then, we are able to estimate the contribution to the total energy of agitation, of the progressive waves relative to that of the retrogressive waves.

The second is for the case of two wave gages (or flow meters) placed at a distance D apart along the orthogonal of the wave propagation. Suppose that only the progressive waves are present in the system, travelling from gage #1 to gage #2. Then the variation of the water surface elevation is expressed in the following:

$$\left.\begin{aligned} z_{p_1}(t) &= \int A_p(\sigma)\, e^{i\sigma t}\, d\sigma \\ z_{p_2}(t) &= \int A_p(\sigma)\, e^{i(\sigma t - kD)}\, d\sigma \end{aligned}\right\} \qquad (6)$$

The cross spectral analysis of these two records then should give the following phase relationship:

$$\theta(\sigma) = k(\sigma)\, D \qquad (7)$$

In case only the retrogressive waves are present the sign of $\theta(\sigma)$ is reversed and in the case of the mixture of two wave systems the phase should assume an intermediate value. The relationship is illustrated in Fig. 2, where the curves I and II represent, respectively, the pure progressive waves and the pure retrogressive waves while the line III represents the case of perfect standing waves for the entire frequency range (which is quite improbable in nature) and the curve IV represents the case of the mixture of the two.

The problem becomes more complicated when we have to admit that there exists wave action whose axis of motion is perpendicular to the longitudinal axis of the basin (lateral mode). In general we can assume that all of the disturbance in the lateral mode is in the form of standing waves. It is therefore not impossible to get the estimate of the energy frequency relationship for this mode of wave action separately from that for the longitudinal mode by analyzing a record of a flow meter placed parallel to the lateral axis of the basin. Then by subtracting the contribution from this source to the total energy of disturbance the energy frequency relationship for the longitudinal mode of wave action could also be derived provided that an additional simultaneous record or records of wave action measured for this purpose (this could be a record of the second flow meter placed exactly in the same location as the first one with its axis parallel to the longitudinal direction, or could be a record from a pressure gage located at the same or at some other point in the basin) is available.

EXAMPLES FROM HONOLULU HARBOR

In Figs. 3 through 5 are shown the results of analysis of wave gage (pressure sensors) records collected in conjunction with the oceanographic investigation of the container fasilities for the port of Honolulu[9]. The spectral density relationship shown in Fig. 3 is what is normally measured in connection with the investigation of surging in harbors. It indicates that there is energy of disturbance over almost the entire frequency range considered that may contribute to the movement of vessels moored in this area. In Figures 4 and 5 the phase relationship between the records from two gaging stations along the pier parallel to the direction of wave propagation is shown. The coherence is high enough (99% level of significance at the value of coherence equal to 0.3) to justify the discussion on the phase relationship between them. The dotted line in the Figure stands for the phase relationship for the system of progressive waves. The measured results closely follow this relationship, indicating the major source of disturbance there is the progressive waves coming through the seaward opening of the harbor and not the standing waves. This information, supplemented by additional case study under different environmental conditions, would definitely be of value in selecting a plan of improving the harbor.

DISCUSSIONS

The past practice on this subject is that usually the wave agitation is measured by a single wave gage (either a pressure gage or a water level recorder) and a few peaks in the spectral density curve are detected by means of harmonic analyses. This could be an effective and the simplest method of approach under certain conditions but in general the patterns of wave action derived by this procedure is inadequate and often misleading. Although in this paper only a few of the possibilities are discussed it is obvious that the combined use of a pressure gage and a flow meter or the use of appropriate arrays could lead to an improved picture of the patterns of wave action in a harbor. The choice of an individual scheme of measurement depends very much on the availability of the type and the number of transducers, the type of information required and the geometry of the basin.

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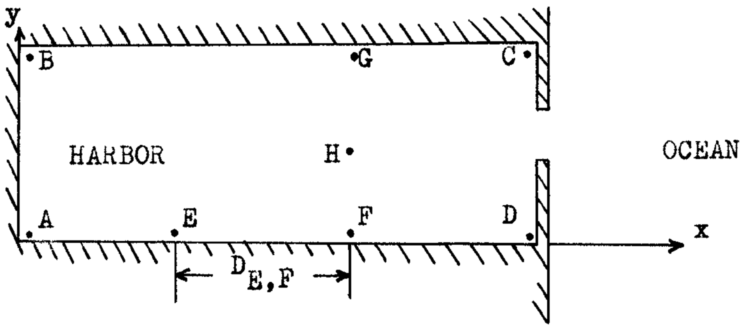

Fig. 1. Typical Basin.

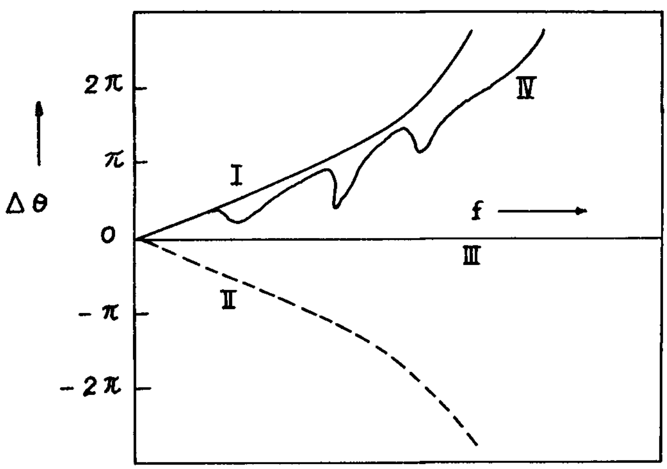

Fig. 2. Illustration ot Phase-Frequencey Relationship.

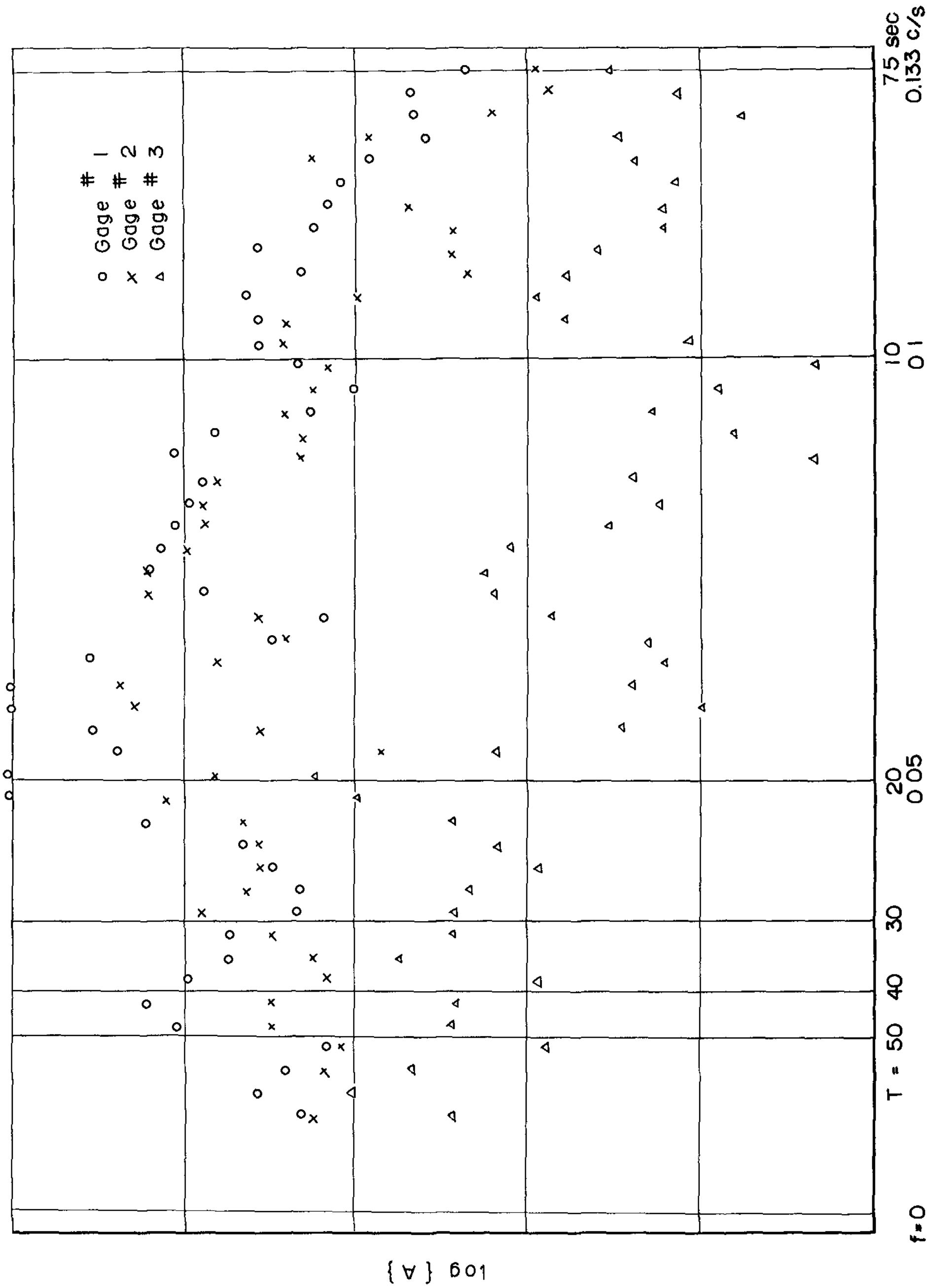

Fig. 3. Spectra for October 27, 1965.

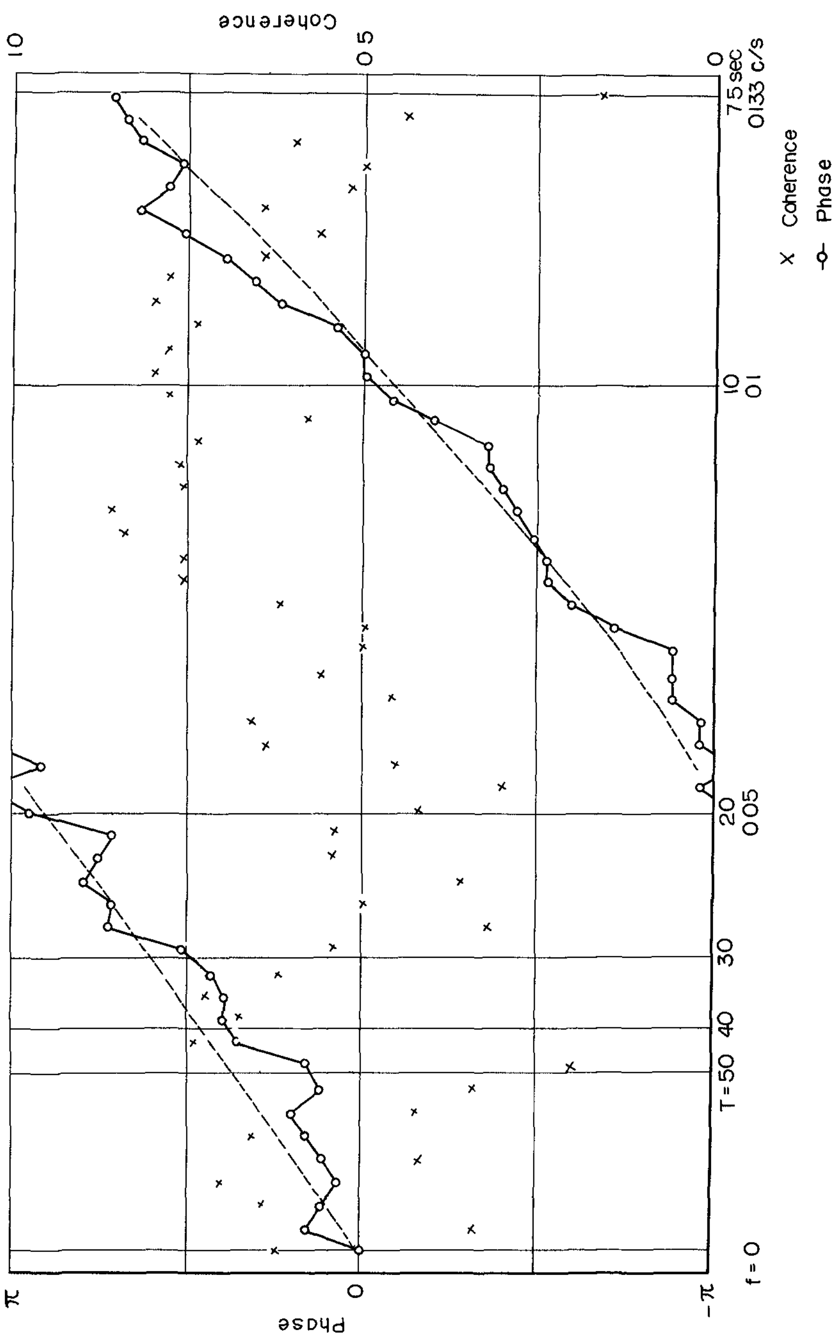

Fig. 4. Coherence and phase for gages #1 & #2, Sept. 23, 1965.

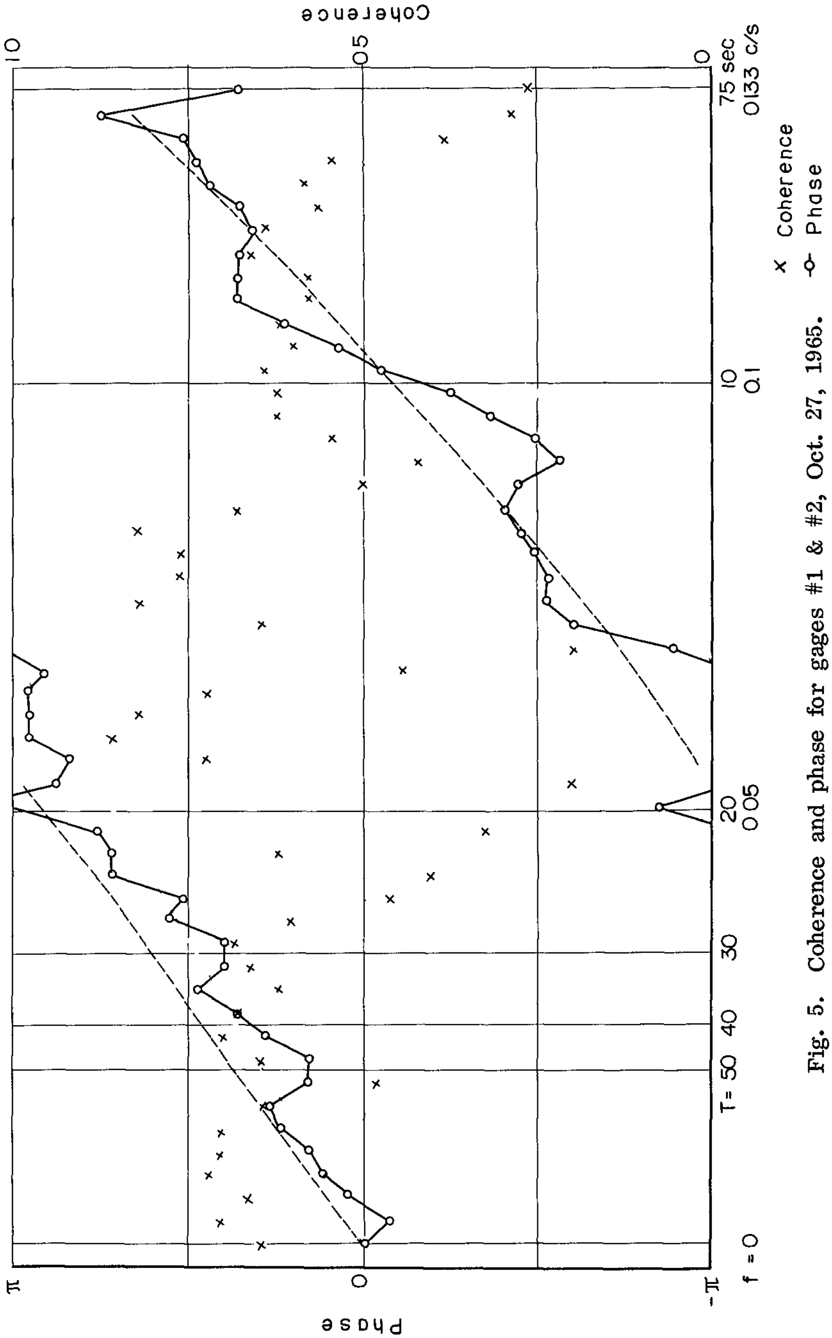

Fig. 5. Coherence and phase for gages #1 & #2, Oct. 27, 1965.