CHAPTER 18

AN EXPERIMENTAL STUDY OF HARBOUR RESONANCE PHENOMENA

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An extensive series of experiments has been carried out at the laboratory in order to study rectangular harbour oscillation excited by incident long waves. Attention is focused on the effect of head loss entrance on resonant response attenuation. A "gross" quadratic hydraulic head loss coefficient is defined and information about it, resulting from tests, is provided. Experimental conditions used in this piece of work seem to be realistic under suitable scaling for Northern Spain harbours.

Introduction

It is a well known fact that long period waves induce harbour oscillations and can cause severe problems to moored ships: breakage of mooring lines, hazards in berthing and cargo handling and possibly an eventual leaving of the berth, damaged fenders and so on.

Resonance of harbours has attracted the attention of researchers and has been successfully studied by means of both mathematical and physical models including the cases of inviscid and real fluid. If real fluid effects are ignored a narrowing of the harbour entrance leads to an enhancement in harbour surging ("harbour paradox", Miles and Munk (1961)).

Previous studies have shown the importance of frictional loss at the harbour entrance (Fukuuchi and Ito (1966), Ito (1970), Horikawa and Nishimura (1970), etc) and the effectiveness of energy dissipation due to friction at the bottom, Kostense et al (1986), in order to influence the peak amplitude, particularly at the first mode of resonance.

This piece of work, where abstraction is made about the long wave origin, includes results, analysis and comparison of different test carried out at the laboratory on two rectangular harbour models excited by incident regular long waves. Attention is focused on

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definition, evaluation and providing some information about a quadratic hydraulic "gross" head loss coefficient by using, under some special experimental conditions, a significant reference velocity.

Although numerical models predict the natural frequencies and the corresponding oscillation modes there is an increasing need for realistic values of amplitudes and as a consequence more experimental information is also needed about head loss or friction coefficient values.

Other previous experimental works (Horikawa and 'ishimura (1970), Lee (1971), Lee and Raichlen (1972), iiles and Lee (1975), etc.) considered the case of a total reflective coast. In this study, the imposed conditions ignore the reflected waves from the coast in the same way as a harbour with breakwaters protruding seaward from a dissipative beach. This hypothesis was used by Iribarren (1958) studying the resonance phenomena in the Spanish Basque Country harbours.

Although the first mode of resonance has only been tested the proposed "gross" coefficient could be relied on to apply to Helmholtz or pumping mode.

Lee (1971) and (1972) provides a comprehensive summary about experimental research in this field.

Some experimental works aimed at solving real problems have been carried out by different researchers: Wegell and Sorensen (1980), etc.

Remarks about the theory

a) Effect of a sudden constriction. Usual approach.

From continuity, energy and momentum equations applied between two sections at each side of a sudden constriction, outside the eddy zone, we may write:

$$\Delta\eta = \frac{K}{2g} u|u| + \frac{L}{g}\frac{\partial u}{\partial t} \qquad (1)$$

Mei (1983), where

$\Delta\eta$ = free surface elevation difference
u = velocity
k = head loss coefficient
L = length coefficient

If apparent inertia term is neglected equation (1) becomes:

$$\Delta\eta = \frac{K}{2g} u|u| \qquad (2)$$

The quadratic friction term makes the problem non linear and the so-called equivalent linearization may be applied if the response is dominated by the first harmonic:

$\Delta\eta = C\,u$ (3)
C = equivalent friction coefficient

Ito (1970) and Horikawa and Nishimura (1970) developed a theoretical model which incorporated formula (2) by using an estimated constant K proved to be reliable from Ofunato Bay results against tsunami.

b) Located head loss

In non-oscillatory flows the head loss at a sudden constriction may be written:

$$\Delta H = K \frac{V^2}{2g}$$

where
ΔH = head loss (specific energy difference)
V = reference velocity
K = coefficient attached to V

K = K (Re, geometry)
Re = flow Reynolds number
if the flow is highly turbulent
K = K (geometry)

In highly turbulent oscillatory flows:

K = K (geometry, oscillatory, Strouhal or Keulegan - Carpenter, etc., flow numbers)

Proposed analysis

The present analysis, aimed at yielding reasonable global predictions, is rather different from the usual ones and can be formulated as following:

Assuming that ΔH is the water surface elevation difference, with and without constriction at the entrance, at the back wall section inside the rectangular harbour, we may write:

$$\Delta H = K \frac{V^2}{2g} \qquad (5)$$

under the hypothesis that head loss balances at the harbour entrance the joint effect of surface elevation, radiation and reflection difference. Measuring ΔH and taking an appropiate and significant reference velocity V, a "gross" quadratic head loss coefficient K, can be estimated, which is indicative of constriction effectiveness and useful to practical applications.

- K estimation

Let : a = the outside amplitude ($a=h/2$; h=long wave height)

f_o= the amplification factor at resonance without constriction

f_i= the amplification factor at resonance with constriction i

The amplification factor is defined as the ratio of the maximum wave height ocurring in the harbour model to the wave height measured outside. For the first mode of resonance, the maximum wave height occurred along the back wall of the model. (f_o and f_i are referred to maximum amplitude inside the harbour).

Thus: $\Delta H = f_o\, a - fi\, a = (f_o - f_i)\, a$

putting $v = \sqrt{2gf_i a}$ (from Bernouilli/Torricelli law)

and invoking (6), we have:

$$K = \frac{f_o}{f_i} - 1$$

Bearing in mind that the amplification factor is a function of amplitude and other variables.

The effectiveness of constriction can also be simply evaluated by means of:

$$E = \frac{(f_o - f_i)a}{f_o a} = 1 - \frac{f_i}{f_o} = 1 - \frac{1}{K} \qquad (8)$$

Experimental apparatus

A series of experiments, aimed at f and K evaluation, was conducted at the laboratory in a rectangular wave basin o.5 m deep, 5 m. wide and 18 m. long. The hydraulic piston wave generator was located at one end of the basin.

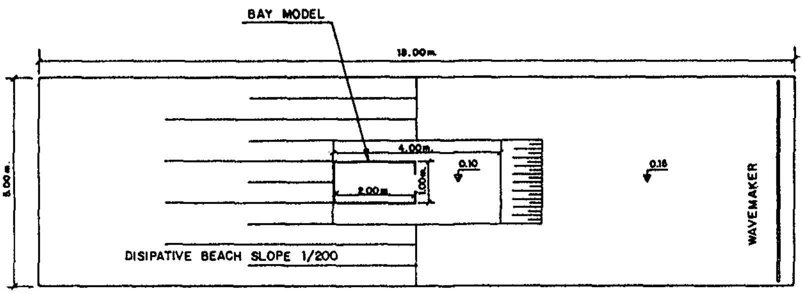

Fig. 1.- Wave basin. Plan view

A 5:1000 beach was built opposite the wavemaker in order to minimize wave reflections. Regular waves were generated with amplitudes (height) between 3 and 8 mm. and frequencies in the range 0.150-0,05 Hz. Two rectangular harbour models were used:

- Model A (2m. long, 1m. wide, 0.1m. deep)
- Model B (2m. long, 0.5 m. wide, 0.1m. deep)

Constrictions at the model entrance were made by using sharp edge elements as breakwaters. Effective wave absorbers (coconut fiber blankets and metallic wire filters) were placed to minimize reflections. Water surface levels were recorded, inside and outside the harbour basin model, when resonance had reached stationary conditions, by using resistive gauges placed to provide information about different conditions (open sea without model, standing waves, partially reflected waves, etc.).

Flow Reynolds number values guaranteed turbulence development in the models. Long wave requirements were fulfilled.

Extrapolation to real conditions is assumed to be made by using Froude similarity, without or with slight scale distortion

Results and analysis

Figures 2 to 5, similar to those of other authors, summarize some results corresponding to the present experiments in the case of centered entrance.

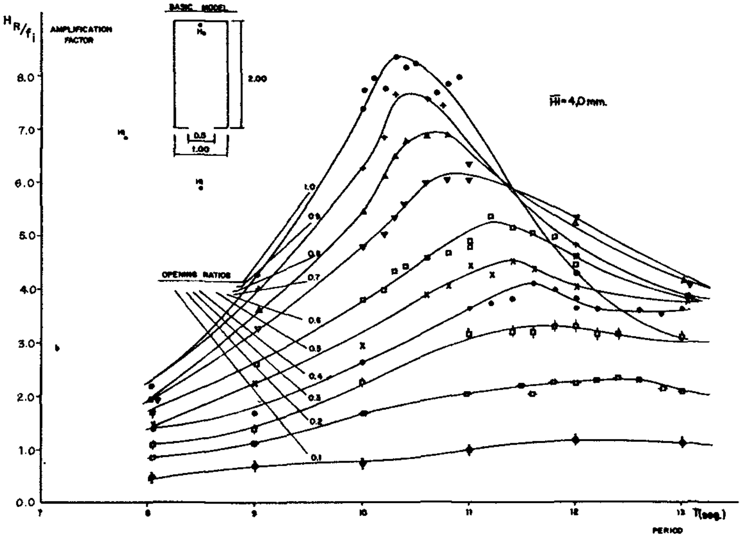

Fig. 2.- f versus T curves. Model A. Pure wave 4mm.

The amplification factor versus period bell-shaped curves, corresponding to several opening ratios, show clearly the peak response attenuation, inside the harbour, due to entrance friction. Separation of horizontal flows at each end of the entrance was very noticeable in the experimental work.

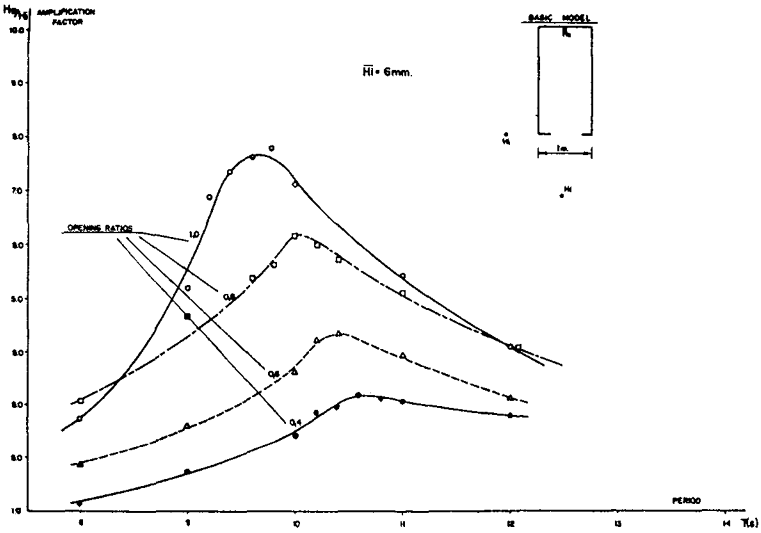

Fig. 3.- f versus T curves. Model A. Pure wave 6mm.

Amplification factor and resonant period depend upon the opening ratio, on harbour and entrance geometries and on oscillatory flow characteristics.

Bell-shaped curve "steepness" depends on the outside amplitude and on the harbour geometry. Small outside amplitudes lead to an increase in curve "steepness", larger ones lead to smoother curves. Note that increasing the amplitude leads to a decrease in f.

In the range of present experimental conditions, nearly fifty percent of peak amplitude reduction inside the harbour can be achieved with fifty percent of entrance aperture ratio.

As was previously pointed out, amplification factor depends upon the harbour geometry. Increasing the harbour ratio (width/length) leads to a decrease in amplification factor and viceversa.

From test results it can be concluded that the reduction of resonant peaks by entrance loss is more pronounced for larger amplitude and narrower entrance.

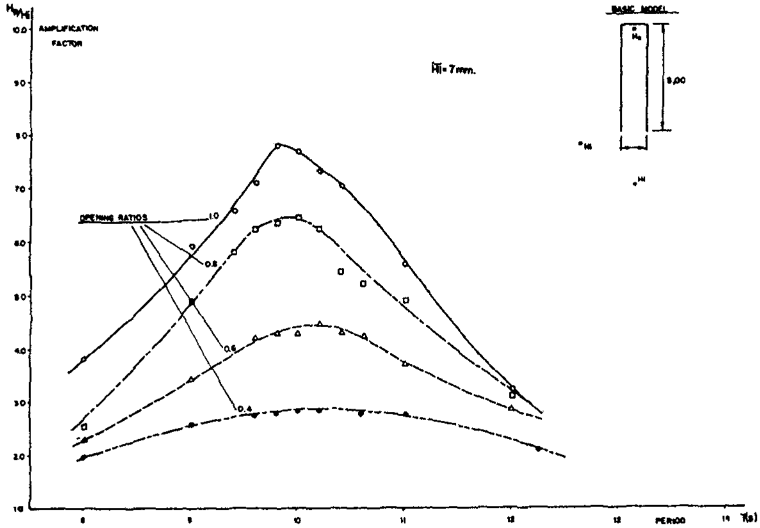

Fig. 4.- f versus T curves. Model B. Pure wave 7 mm.

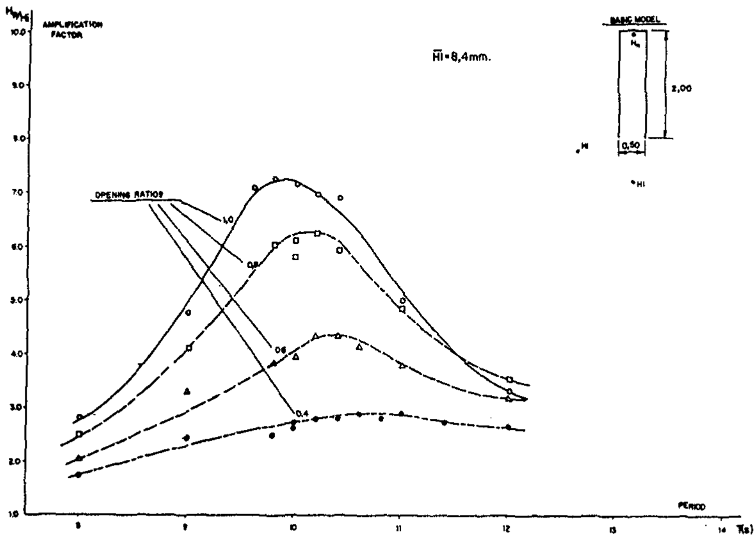

Fig. 5.- f versus T curves. Model B. Pure wave 8mm.

The observed displacement of resonance peak period as a consequence of entrance constriction enables us to find out that it is important to take into account the range of frequencies where head loss is effective, otherwise some kind of harbour paradox may result.

From test data, "gross" head loss coefficient values were estimated by using (6).

Figure 6 shows K values versus opening ratio curves,corresponding to two outside amplitudes considered to be appropiated for Cantábrico sea conditions.

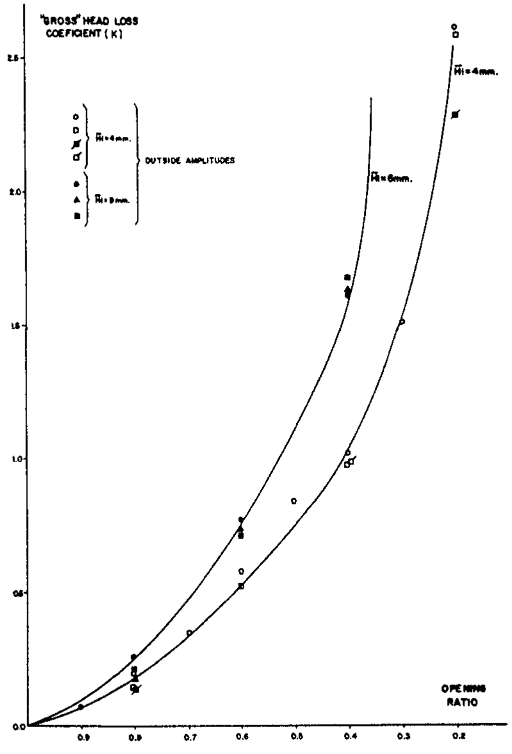

Fig.-6 K versus aperture ratio curves.

With present experiment results, the "gross" head loss coefficient K proved to be practically independent of harbour geometry, (Width/length) ratio; K strongly depended on the outside amplitude.

In general, K may depend, for highly turbulent flows, on the Strouhal, or Keulegan - Carpenter, number and on geometry of breakwater-tips, not considered in this piece of work.

Fig. 7 correlates amplification factor values under different hypothesis related to measured outside amplitude: open sea or pure wave (basin without harbour model), partially reflected and radiated wave and standing wave with harbour entrance blocked off.

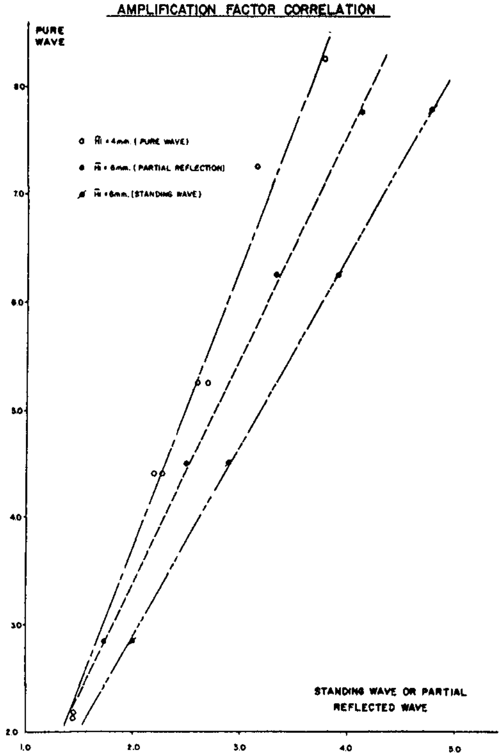

Fig. 7.- f correlations.

From test data, calculations were made in order to evaluate the harbour effective length: distance from the harbour back wall to node of the standing wave near the the harbour mouth. Comparison with theoretical length resulting from asymptotic formulas, for the fundamental mode, enables us to point out that lower opening ratios require severe modifications of f_3, Miles and Munk (1961), function, adequate for inviscid fluid conditions or hypothesis. Asymptotic formula overestimates effective length for lower apertures. A linear approximation fits rather well with test results.

Summary and conclusions

Experiments were conducted at the laboratory in order to measure the importance and effectiveness of friction loss at the harbour entrance. Two rectangular harbour models with several opening ratios were used.

Entrance head loss practically eliminates the first mode (quarter wave mode) of resonance as was pointed out earlier.

A "gross" head loss coefficient K, including the joint effect of reflection, transmission, radiation and friction differences, is defined and evaluated under some special experimental conditions by using a significant reference velocity.

Curves amplification factor versus period or equivalent magnitude, deduced from tests, have shown that it is important to take into account the range or periods where constriction is effective, if not undesirable "harbour paradox" effects may result.

K values, under different assumptions are provided.

K values and bell-shaped curves (f versus T) have shown to be dependent on oscillatory flow characteristics. The influence of oscillatory numbers needs to be investigated.

Basin dimensions, water depth, long wave characteristics and other experimental conditions could be extrapolated to harbours in Northern Spain by using suitable scales.

Research was limited to first mode of resonance; analysis carried out seems to be appropiate to Helmholtz or pumping mode.

f_3, Miles and Munk (1961) function, overestimates effective length for severe constrictions where real fluid effects are important.

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