CHAPTER 132

SPECTRAL RESPONSE OF HARBOR RESONATOR CONFIGURATIONS

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ABSTRACT

An outline is given of methods devised recently by the author to predict the spectral response of rectangular resonators, and to improve the response of resonators generally A simple small scale acoustic model of the ocean-resonator-harbor configuration was developed and is described The acoustic "ocean" is effectively decoupled from the rest of the system by means of sound absorbent material placed along the "infinite" boundaries, and standard audio-frequency equipment is used The results demonstrate that the open end contraction for rectangular resonators may not differ significantly from the contraction for resonators of similar geometry placed in a semi-infinite (or effectively decoupled) wave channel, at least if the wavelengths are not smaller than the width of the harbor entrance channel

INTRODUCTION

It is desirable to design harbor entrances to eliminate (as far as possible) those bandwidths in the incident wave spectra that cause difficulties such as range action, high mooring forces, unreasonable wave impact, wave overtopping and drift of littoral sediments into the harbor In many problems these difficulties are functionally related to approximately the second (or higher) power of the wave height, and hence any reduction in the incident wave height will produce real benefits

Resonators placed at the harbor entrance can be tuned to radiate back into the ocean those frequency bandwidths considered to be harmful without hindering navigation[1] Readers are cautioned against using the blanket quarter-wavelength recommendation[2,3,4], the initial design should accord with the fact that the tuning of individual resonators is considerably dependent on the width of the harbor entrance channel[5,6] Readers should also note that resonators are not effective

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for wavelengths smaller than the width of the harbor entrance channel Hence this paper relates to incident wavelengths that exceed the horizontal distance between the leading edges of symmetrically opposed rectangular resonators

The transmitted and reflected spectra can be predicted for given geometry and incident spectra, assuming a linear system[7], and this procedure is outlined below Certain innovations[8] that both broaden the tuning of the resonators and decrease the cost of construction are also briefly described in this paper An acoustic model has been devised[6] and this is used to check the ocean-resonator-harbor coupling The results of the latter tests constitute the major contribution of this paper

SPECTRAL RESPONSE

The method devised for computing the spectral response of individual rectangular resonators is based on experimental results It is usual to plot frequency response curves in the frequency domain[9] but in this study observed transmissivity and reflectivity were plotted against the tuning parameter d/L (i e , in the ka domain) For details of the wave measurement and wave analysis procedure, readers are referred to earlier publications[10,11] The geometrical conditions for distinct resonance are summarised in fig 1

Approximate rectilinear apexes were fitted into the ka domain resonance curves, and the resulting maxima and minima are summarised in fig 2 The tuning parameter bandwidths at the half resonant values were measured and found to be reasonably constant for various values of W/L The information is summarized in fig 3 Sufficient data are available in these three figures to allow the computation of the spectral response of any rectangular resonator to given incident spectra, *but only for the first resonant mode*

Briefly, the procedure is to transform the incident spectrum into an amplitude/wavelength relationship for the particular harbor entrance The dimensions of the resonator are chosen such that distinct resonance obtains for the dominant wavelength, using fig 1 For discrete wavelengths the ratios W/L, w/L and d/L are calculated The resonant tuning parameter is obtained from fig 1, and the resonance curves "reconstructed" graphically or digitally using figs 2 and 3 Values of transmissivity and reflectivity are then interpolated for various tuning parameters

Finally, the incident spectra are transformed using these values Two examples are presented elsewhere[7], and it is shown that a standard quarter-wavelength resonator may reflect *only one quarter of the peak energy*, nearly all of which is reflected by a resonator designed according to fig 1

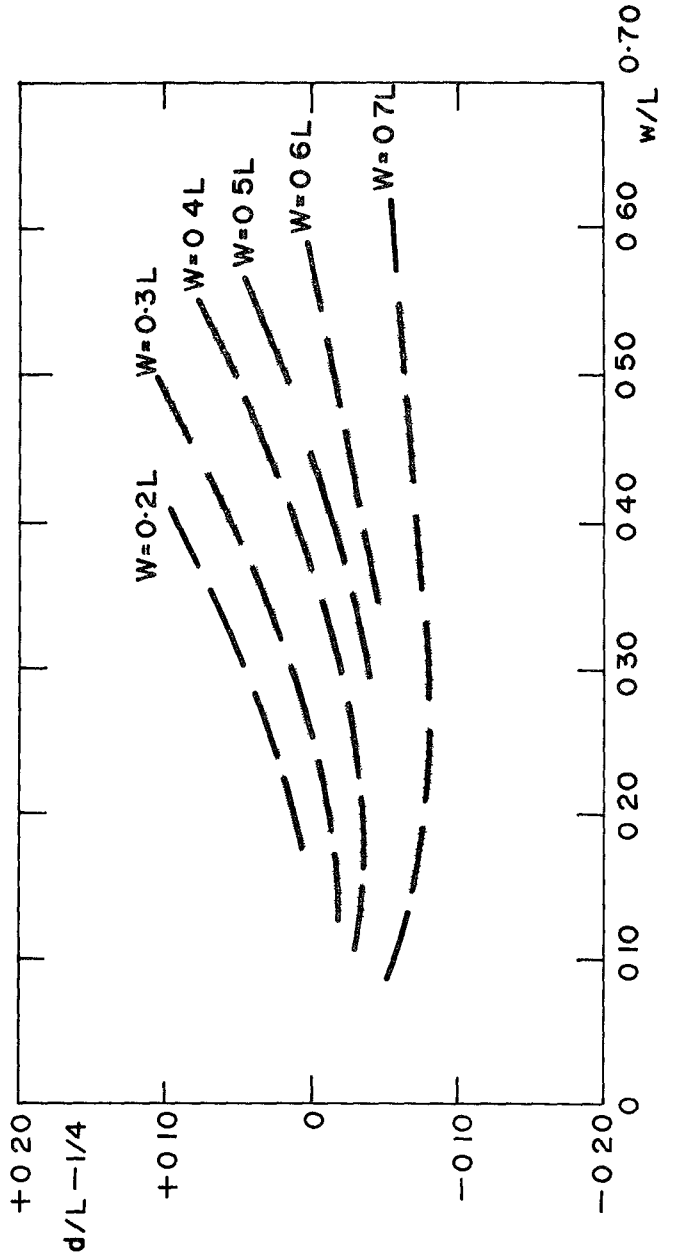

FIG 1 GEOMETRY FOR FIRST RESONANT MODE

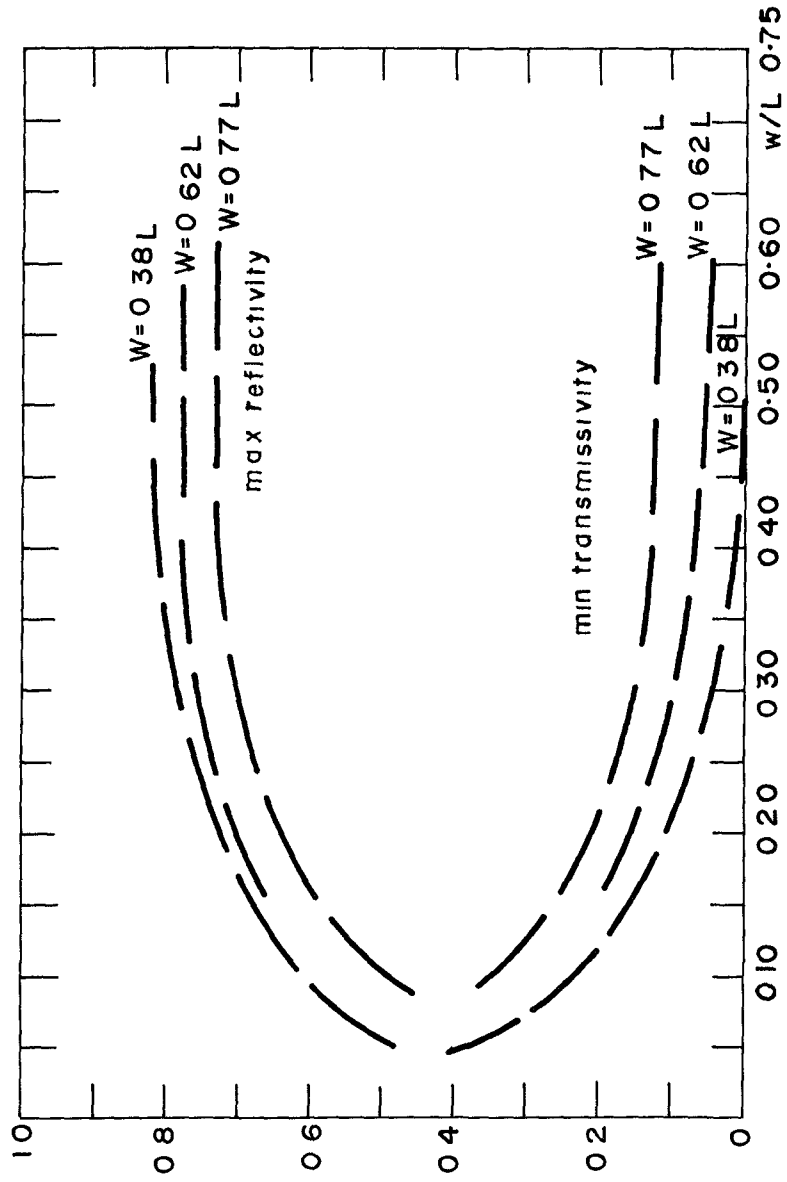

FIG. 2 RESONANT MAXIMA AND MINIMA

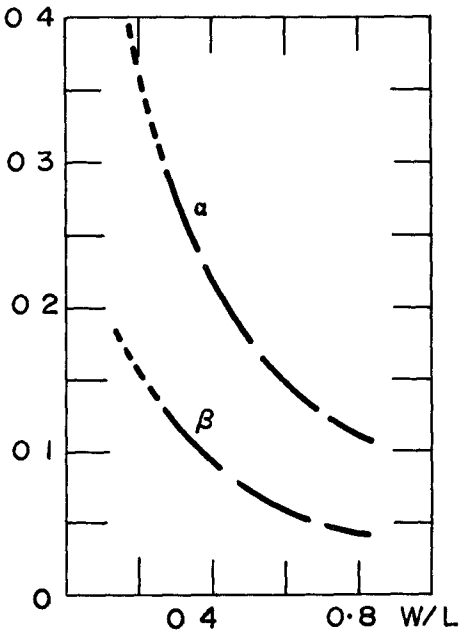

FIG. 3 TUNING PARAMETER BANDWIDTH AT HALF RESONANT VALUE

TWO INNOVATIONS

Experiments were performed on

(a) variable distances between three resonators in a battery configuration, and
(b) non-uniform depths in a resonator/harbor entrance area

Triple Resonator Batteries

Rayleigh[12] recommended that the ratio of the fundamental periods of the individual resonators in a battery configuration should be 1 $\sqrt{2}$ In this study resonators were constructed from 3/4 inch thick "perspex", geometries are shown in fig 4

Reflectivity and transmissivity were measured at points approximately one wavelength upstream and downstream of the battery respectively In these tests the water depth was held constant, and wavelengths were systematically varied

The results showed resonant peaks at those individual resonator frequencies obtained in earlier tests on single resonators, as is to be expected Hence fig 1 can be used to predict the response of battery configurations superimpose the equation (a straight line) for each battery geometry (e g w/L = 1 61 d/L) on fig 1 and scan the line for the location such that the harbor entrance and resonator geometry satisfy the geometrical conditions for resonance This identifies the tuning parameter for resonance, and performance can be estimated using the same computational procedure for spectral response described above

By increasing the distances between the resonators, the water mass in the entrance channel contiguous with the leading edges of two adjacent resonators is brought into the system response This effectively broadens the overall tuning of the battery configuration and hence improves the spectral performance of the battery Because of the end-contractions, the distance should be significant, e g commensurate with resonator dimensions, and chosen by careful *ad hoc* model tests (acoustic models preferably)

Non-Uniform Depths

In the experiments on non-uniform depths an artificial invert was inserted into a single resonator, as depicted in fig 5 The still water depth and wavelength were held constant and the resonator planform was varied systematically (by gradually retracting the rear wall outwards) Reflectivity and transmissivity were measured as in early tests[1]

The results indicated a reduced efficiency for resonators of comparatively small still water depth, but less upstream agitation

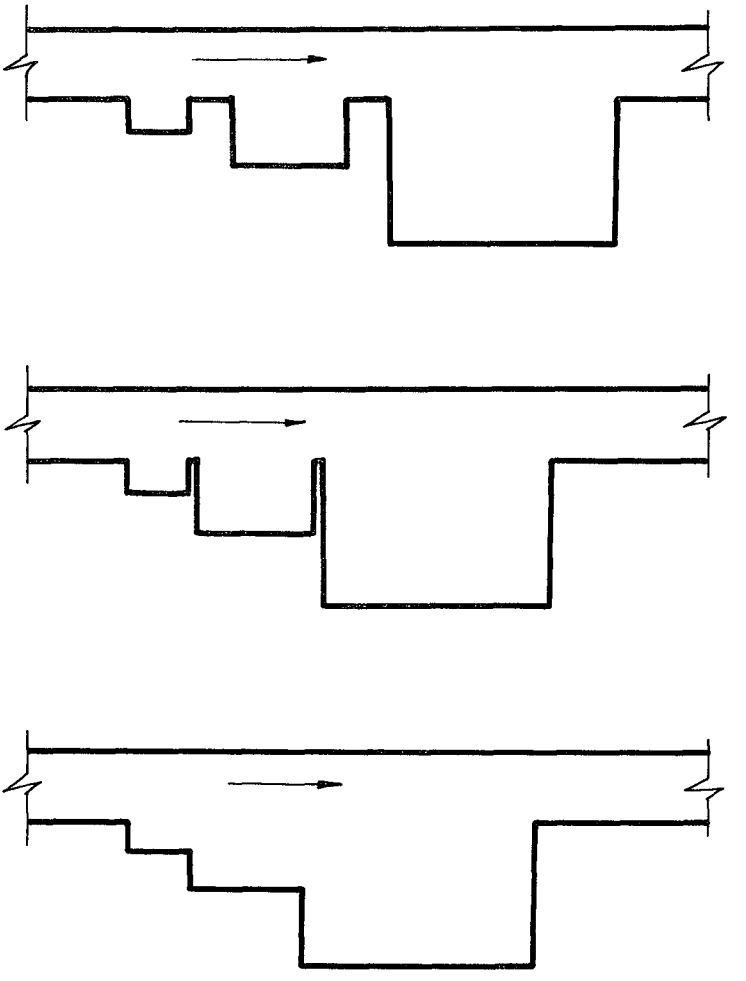

FIG 4 BATTERY GEOMETRIES EXAMINED

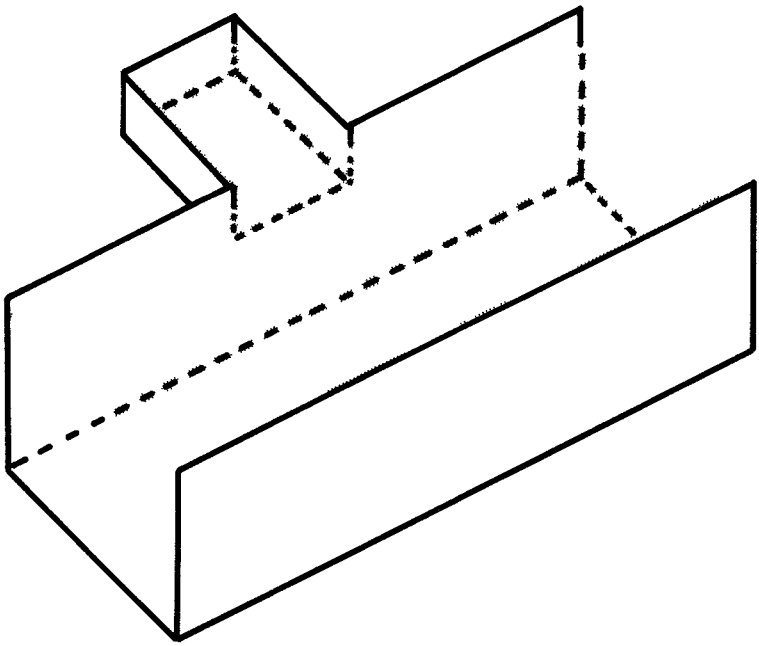

FIG. 5 NON—UNIFORM DEPTHS

(reflectivity) was associated with given transmissivity

It was found that the length of the resonator could easily be halved, if the still water depth in the resonator is reduced to a fraction of the harbor entrance channel depth, a point of considerable practical significance However, tidal ranges will detune the resonator, the effect being related to the proportional reduction in depth and to the actual tidal range

THE ACOUSTIC MODEL

An acoustic model evidently has certain advantages over a hydraulic model wave generation and absorption are easier, the fluid does not have to be isolated, wavelengths are generally shorter, and measuring equipment, speed and accuracy are generally better

To test the model, earlier experiments on resonators in a water wave channel were reproduced The variable geometry was built up from 3 inch movable timber walls and placed on a glass plate on top of a desk A second glass plate was placed on top of the walls, and a loudspeaker was connected to an oscillator and placed against sponge rubber at the entry to the main duct A microphone was placed against the sponge rubber absorber at the harbor end of the main duct, and was connected through a small pre-amplifier to an oscilloscope By setting the widths of the main entrance duct and of the resonator, and by holding the oscillator frequency constant, the length of the resonator was adjusted until resonance occurred This was monitored by a minimum signal on the oscilloscope

The effect of imperfect sound absorption was checked and found to be unimportant Tests on scale effects were also negative, although these were not exhaustive In addition the effects of sound waves entering the duct along its length were also found to be insignificant The signal-to-noise ratio was easily improved by means of the amplifier on the oscilloscope

The results showed slight differences from those of the water wave experiments Reasonably accurate predictions of harbor resonance modes for frequencies can be obtained in this way, but further development of the method will be necessary if absolute values of harbor amplification are required

OCEAN-RESONATOR-HARBOR COUPLING

Fig 6 shows the experimental apparatus used to examine the coupling problem In this case the model was set up on a reasonably clean office floor, again using 3 inch high timber walls The cover to the ocean domain was supported on 3 inch iron nails Cotton batting (reflectivity about 5%) was arranged along the "infinite"

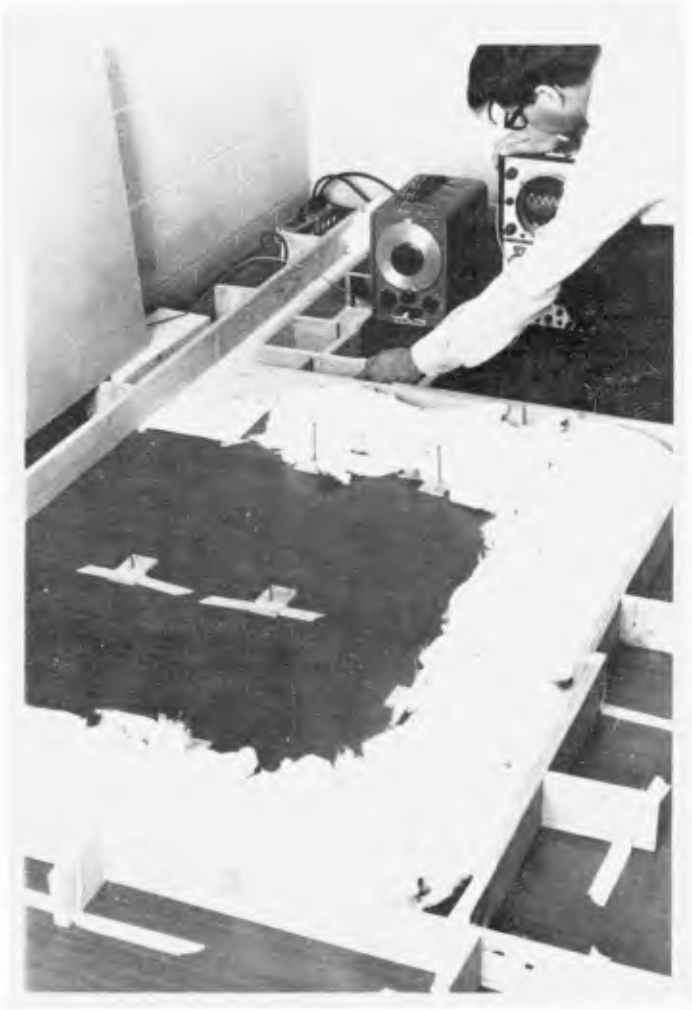

FIG. 6 ACOUSTIC MODEL: OCEAN-RESONATOR-HARBOR

boundaries, and this effectively decoupled the ocean domain Total cost of the model excluding audio equipment was $8 50

Acoustic waves were generated from a virtual point source, and so the ocean domain had to be long enough for the radiating incident waves to achieve an approximately parallel wave front at the harbor entrance It follows that re-reflections from the harbor off the loudspeaker were negligible

The experimental procedure adopted was similar to that above resonance monitored by a minimum acoustic pressure signal in the harbor, and achieved by systematic variation of resonator geometry This method was better than incident wave frequency variation, since system attenuation, transmissivity and reflectivity, parasitic vibrations, and also wave generation and recording were frequency dependent

Geometrical conditions obtained for distinct resonance are presented in fig 7 Results for semi-infinite ocean coupling and semi-infinite wave channel coupling almost coincided, consequently both results could not be plotted on the figure However the ocean coupling curves were slightly flatter, as indicated by the dashed curve

Evidently, then, harbor resonance studies may be carried out at the end of water wave channels (provided that the incident wavelength exceeds the width of the harbor entrance channel) without material loss of accuracy

Further tests on the acoustic model confirmed that resonators should be located at the ocean end of the entrance channel, and at an amplitude antinode in the wave envelope, if the harbor is reflective at the resonator tuning frequency Since partial re-reflections occur off the ocean end of the entrance channel, the downstream harbor and channel oscillations are generally not amplified by resonators For *transparent* frequencies there is no effect and for *opaque* frequencies there is no penetration

CONCLUSIONS

Three figures are presented for estimating the spectral response of individual rectangular resonators, *but only for the first resonant mode* No account is taken of the second resonant mode even though this is important when considering the response of a battery of resonators

Individual resonators in a battery respond in an additive manner, and hence this response can also be predicted The mass of water contiguous with adjacent resonators in the harbor entrance channel can

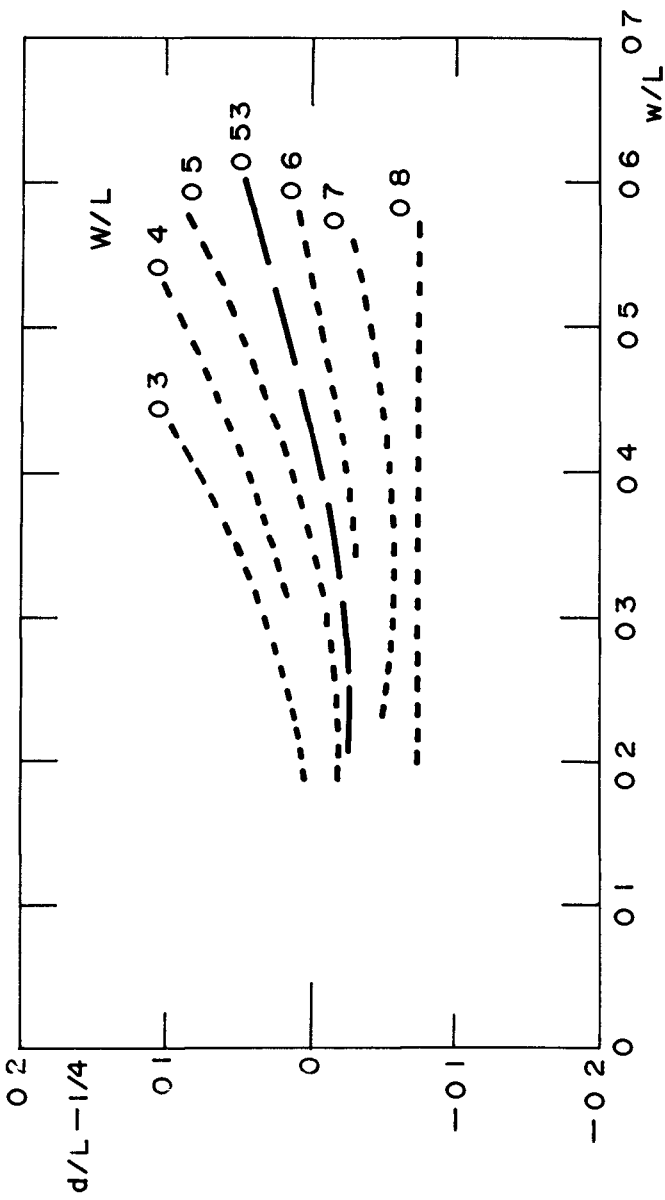

FIG 7 OCEAN—RESONATOR—HARBOR COUPLING

also be incorporated in the system response For this reason the resonators should not be contiguous, if at all possible

Comparatively shallow still water depths in individual resonators detunes the resonator downwards, i e towards smaller frequencies Hence, for a particular tuning, non-uniform depths, with smaller depths in the resonator, result in smaller geometry, and concommitant savings in construction and excavation costs Large tidal amplitudes would effectively detune such systems, however

The acoustic analogy is an extremely fast and cheap method for evaluating eigen frequencies for any harbor planform The method could probably be elaborated for estimation of orbital velocities and even of mooring forces, for uniform water depths in the harbor and harbor entrance No scale effects were detected in the tests reported

An acoustic model was constructed to check the ocean-resonator-harbor coupling *The results indicated that the end-effect does not differ significantly from the contraction for resonators of similar geometry placed in a semi-infinite wave channel, at least for wavelengths greater than the harbor entrance width*

This result validates the experimental results obtained in the wave channel, the method for predicting the spectral response of resonators for a real situation (i e on the edge of a semi-infinite ocean) is evidently reliable to the first order

REFERENCES

1 James, W , "Rectangular Resonators for Harbour Entrances", Chapter 98, Coastal Engineering, A S C E , August 1969, pp 1512 - 1530

2 Valembois, J , "Etude de l'Action d'Ouvrages Resonants sur la Propagation de la Houle" Proc Minnesota Int Hydraulics Conf , Minneapolis 1953, pp 193-200

3 Wiegel, R L , Oceanographical Engineering, Pub Prentice Hall, 1964, p 144

4 Ippen, A T (Ed) Estuary and Coastline Hydrodynamics, pub McGraw Hill, 1966, p 397

5 James, W , "An Experimental Study on End-Effects for Rectangular Resonators", Journal of Fluid Mechanics, in press

6 James, W , "A Desk-top Model of Harbour Resonators", Journal of the Acoustical Society of America, in press

7 James, W , "The Spectral Response of Harbour Resonators", The Institution of Civil Engineers (London), in press

8 James, W , "Two Innovations for Harbour Resonators", A S C E , in press

9 Miles, J , and Munk, W , "Harbor Paradox", Proc A S C E , Vol 87 No WW3, Aug 1961, pp 111-130

10 James, W , "Accurate Wave Measurements in the Presence of Reflections", Jour Instn Water Engrs (London), Vol 23, No 8, Nov 1969

11 James, W , "Resolution of Partial Clapotis", Proc A S C E Vol 96, No WW1, Feb 1970

12 Strutt, J W (Lord Rayleigh), The Theory of Sound, Dover, 2nd Ed 1945, Chap XVI

NOTATION

a = lineal dimension
d = length of resonator
k = wave number
L = incident wavelength
w = width of resonator
W = width of harbor entrance channel
α = reflectivity
β = transmissivity

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