RESONANCE IN SOUTH AFRICAN HARBOURS

by

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1. INTRODUCTION

The geographic situation of Southern Africa, and the associated climate of the South Atlantic Ocean, cause the harbours on the west and south coasts of South Africa to be subjected to resonance or range action caused by long-period 50 s to 300 s waves.

Since the construction of Duncan Dock in Table Bay in 1940, Table Bay harbour has become a classical example of resonance. Range action in the harbour has been studied extensively in the past and extensive physical model studies were undertaken to optimise the layout of the Schoeman Dock, construction of which was completed in 1976.

In 1976 South African Railways and Harbours (now South African Transport Services) commissioned the Coastal Engineering and Hydraulics Division of the National Research Institute for Oceanology to optimise plans for future extensions to Table Bay harbour. As a preliminary study, the advantages and disadvantages of all existing methods of simulating resonance were reviewed. For this investigation it was decided to adapt an existing "finite-difference" numerical model developed by Leendertse (1967).

Prototype long-wave data were gathered in Table Bay and at a later stage at the cooling water intake basin of the Koeberg Nuclear Power Station. These data were used to calibrate the numerical model and an attempt was made to find a correlation between long waves and short wind waves in order to determine the frequency of occurrence of long waves.

A method was also developed to incorporate a range of frequencies in one model-run instead of single wave input conditions. This resulted in a considerable reduction of expense and time.

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This resonance study method was used extensively in the Table Bay study and it has also been applied to investigations of alterations and proposed extensions on resonance in other South African harbours (ref. Section 5).

2. PROTOTYPE LONG-WAVE DATA ACQUISITION

2.1 Instruments

Pressure transducers housed in Teflon cannisters were used. The cannisters were attached to galvanized stands on the sea bottom or fixed to permanent harbour structures such as quay walls. Waterproof cables connected the transducers to the recorders which were installed in lockable containers accessible under all weather conditions. These instruments satisfied the following requirements:

(a) Record fluctuations of periods 30 s to 300 s at a sampling rate of 1,0 s.

(b) Automatic switch-on every 12 hours for a 50 min record.

(c) The recorders could be switched to a continuous mode during resonane conditions.

(d) The recorders were synchronised for the determination of the response beween different locations.

2.2 Sampling

It was necessary to obtain an entrance recording so as to be able to determine the response of the locations inside the harbour to that at the entrance. It was necessary that this recorder should be as far outside the harbour as practicable in order that a "clean" input record could be obtained without the influence of the harbour response and the reflections.

At both Table Bay and Koeberg harbour recorders were installed at the heads of the main breakwaters. In Table Bay six recorders were used inside the harbour and in Koeberg three recorders were used.

Records were obtained in Table Bay for a period of six months during 1978. Recording in Koeberg started in April 1981 and will continue until April 1983.

2.3 Analysis

Data analyses were done with the aid of Butterworth digital filters, computation of spectral densities by the autocovariance method and the determination of responses with direct spectra-to-spectra relations and the cross-spectral analysis method. Details of the analytical methods are described by Botes (1980).

A flow diagram of the data analysis exercise is schematized in Figure 2.

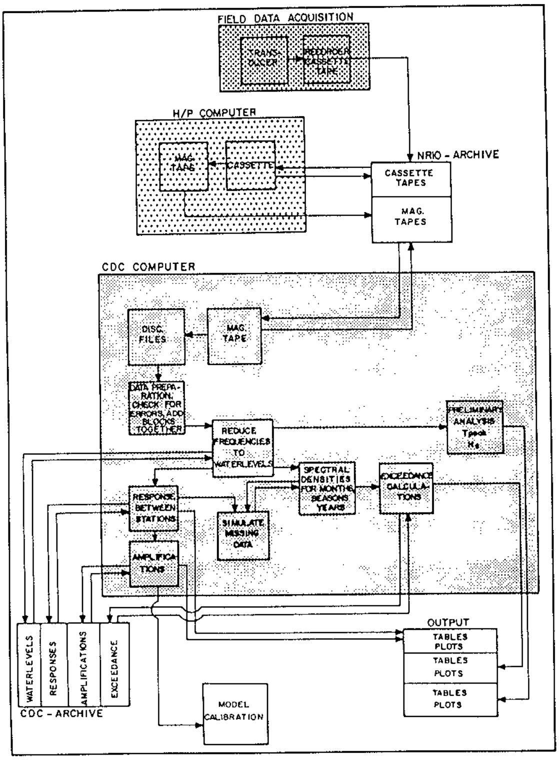

Figure 1 Flow diagram of the data analysis

2.2.1 Preliminary analysis

Raw data are expressed in frequencies and in blocks of 10 minutes each. These data are reduced to water-levels and five blocks joined together form 50 min data blocks. All data are filtered to obtain desired frequency bands and a preliminary spectral analysis is carried out for the qualification of the data and to obtain significant heights and peak periods.

2.2.2 Correlation with short waves

Until now long-wave data have been sampled for specific purposes such as for the calibration of a model. Occurrence figures for long waves in South Africa are virtually non-existent. This and a better knowledge of the origin and generation of long waves are becoming an urgent need.

A waverider is in operation ≈ 3 km from the entrance of Koeberg. An attempt was made to determine whether there is any correlation between increased short waves and long waves. The wave heights during a month were normalised by dividing the measured heights with the mean of the month for the short (1 to 30 s) and long waves (50 to 110 s). These waves were measured independently by means of a waverider and pressure transducer. The relationship between the short and long waves for April and September 1982 is illustrated in Figures 2 and 3.

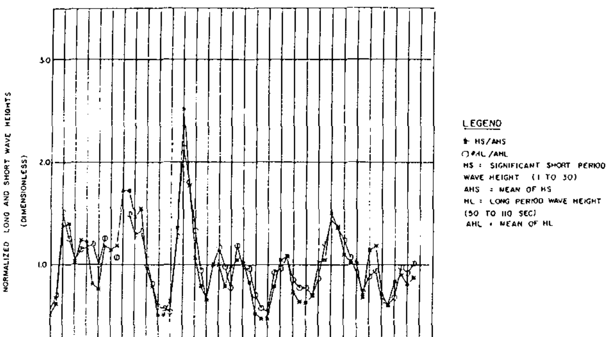

Figure 2 Normalised long and short period wave heights (April 1981)

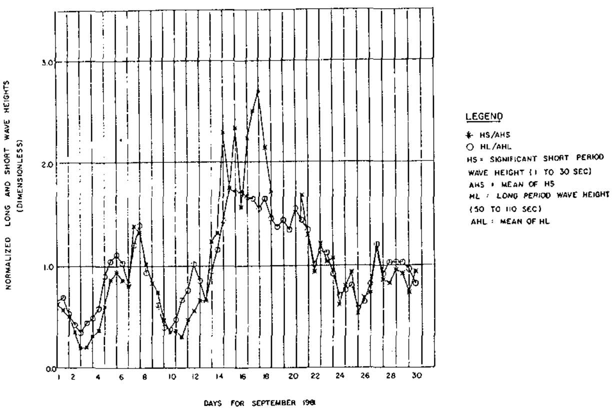

Figure 3 Normalised long and short period wave heights (September 1981)

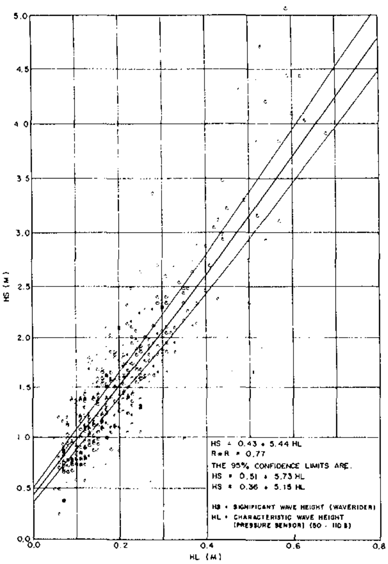

Figure 4 Correlation between long- and short-period wave heights

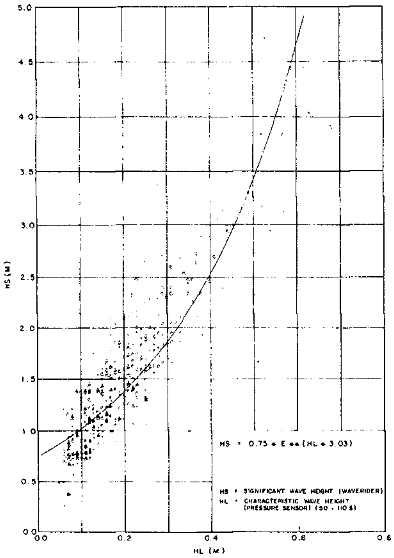

Figure 5 Correlation between long- and short-period wave heights

The height of short-period and long-period waves for 1981 were plotted and the following correlation was determined:

$$HS = 0,43 + 5,44\ HL \quad \text{(Figure 4)}$$
$$(R^2 = 0,77)$$

The 95% confidence limits are:

$$HS = 0,51 + 5,73\ HL$$
$$HS = 0,36 + 5,15\ HL$$

where HS = short period wave height (m) (1 to 30 s)
HL = long period wave height (m) (50 to 110 s).

An exponential fit is even more realistic as the long wave heights will not increase indefinitely (Figure 5).

$$HS = 0,75\ e^{3,03\ HL}$$

An attempt will now be made to find a correlation between the steepness of the short- and long-period waves.

The waverider data can then be used to determine a height and period occurrence of the long-period waves for several years.

2.2.3 Spectral density exceedance curves

In order to be able to obtain an idea of the magnitude of the wave spectra at Koeberg over a period, spectral density exceedance graphs were determined for all recording positions. From these figures it is also clear that each position in the harbour has its own characteristic spectrum as shown in Figures 6 and 7. Figure 8 indicates that the form of the spectra stay the same during calmer conditions.

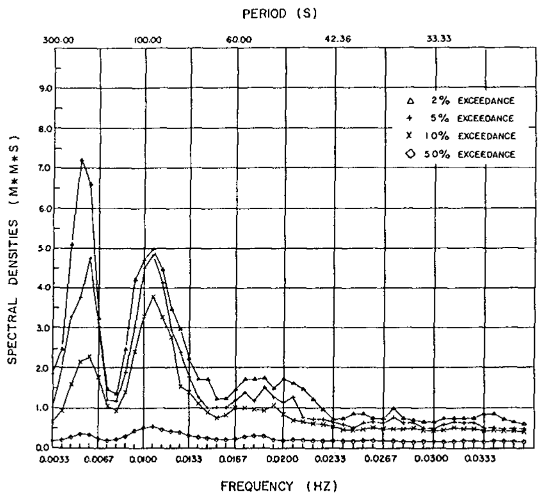

Figure 6 Spectral density exceedances for September 1981 at the entrance of the harbour

2.2.4 Response

The response between two stations is determined by means of a direct spectrum-to-spectrum relation or by means of a cross-spectral analysis technique. Examples of responses between different locations for Koeberg are illustrated in Figures 9 and 10.

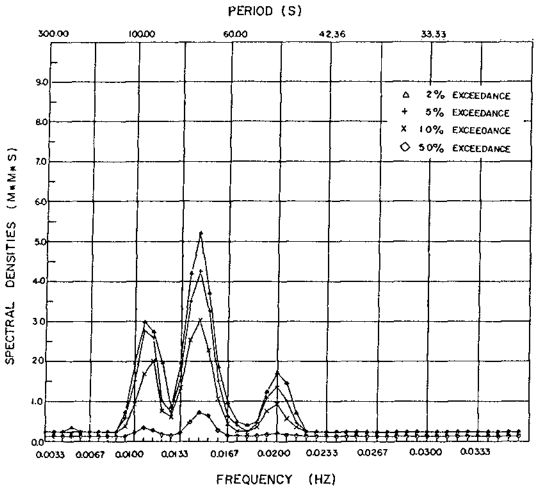

Figure 7 Spectral density exceedances for September 1981 inside the harbour

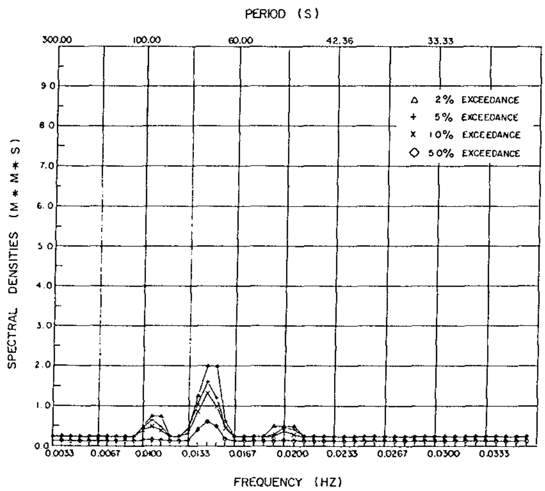

Figure 8 Spectral density exceedances for October 1981 inside the harbour

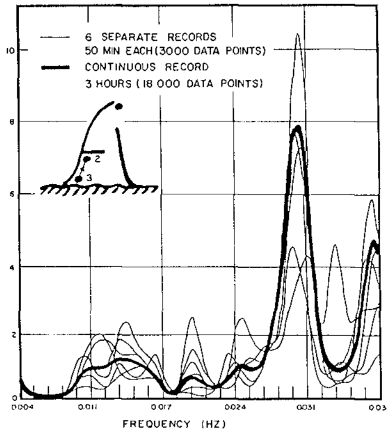

Figure 9 Response between positions 2 and 3

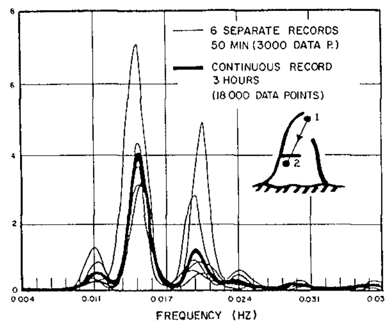

Figure 10 Response between positions 1 and 2

3. NUMERICAL MODEL

3.1 Description

The computations are based on the approximation of the hydrodynamic equations (conservation of mass and momentum equations in terms of the water elevation and the depth average velocity) by using finite-difference techniques. The finite-difference model, originally developed by Leendertse (1967) was adapted to accommodate any harbour layout (Russell and Huizinga, 1978). The modifications include radiative open boundaries which can be applied to any of the model boundaries and permit the passage of reflected waves.

The model area is represented by a two-dimensional grid system; at each grid point the depth and bottom roughness are described and the water velocities and water levels are calculated.

3.2 Input Conditions and Calibration

An input open boundary is installed as the boundary of the model orientated to the dominant wave direction. Originally only single-period sine waves were used as input conditions. During the analysis of data sampled at Table Bay harbour it was found that the average spectrum at the entrance of the harbour was almost flat which could be simulated by the bandpass-filterng of a white noise spectrum as illustrated in Figure 11.

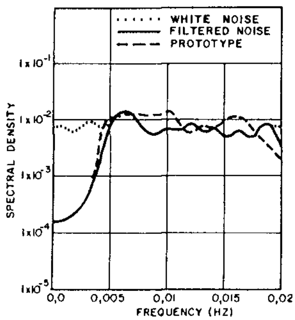

Figure 11 Simulated input spectrum for Table Bay Harbour

With the random noise as input condition, model spectra and model responses between the entrance position and other locations were obtained which were similar to those for the prototype (Figures 12 and 13).

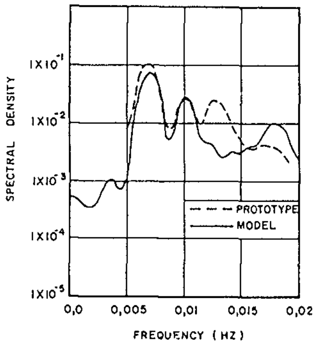

Figure 12 Model and prototype spectral density estimates

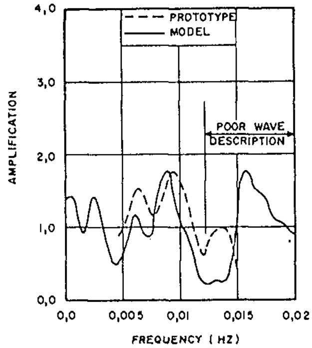

Figure 13 Model and prototype amplifications

This method of using a spectrum as input condition was a considerable improvement on previous studies as one model run accommodates a range of frequencies, instead of numerous expensive and time-consuming tests with single-period sine waves.

After a model run with a spectrum as input condition the frequencies which caused peak amplifications were selected and these were then used as input conditions in order to obtain amplification over the entire model area.

4. APPLICATIONS

4.1 Table Bay Harbour

The study was undertaken in 1976 on behalf of South African Railway and Harbours (South African Transport Services) to optimise plans for future extensions to the harbour. The results of a preliminary investigation have been given elsewhere (CSIR, 1978). Prototype data were recorded during 1978 (CSIR, 1979), after which the model calibration followed (CSIR, 1980a) and the investigations were made of the influence of future extensions (CSIR, 1980b). An example of the amplifications of one of the peak frequencies (93 s) is illustrated in Figure 14.

4.2 Mossel Bay Harbour

A preliminary study was carried out on behalf of the Fisheries Development Corporation of South Africa to determine whether proposed alterations in the harbour would affect the long-wave response of the layout (CSIR, 1980c). The harbour layout and contours with the model grid superimposed on it is illustrated in Figure 15.

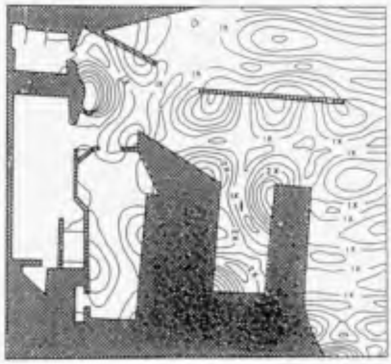

Figure 14 Maximum amplification for a wave period of 93 s (Table Bay Harbour)

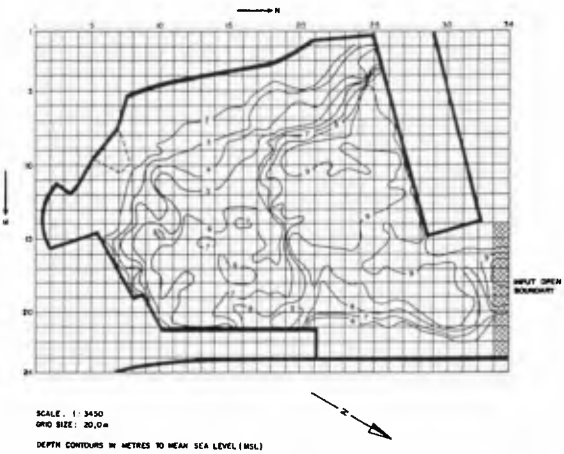

Figure 15 Mossel Bay Harbour layout with model grid superimposed on it

The amplifications of the original layout and a proposed layout for two positions are shown in Figure 16.

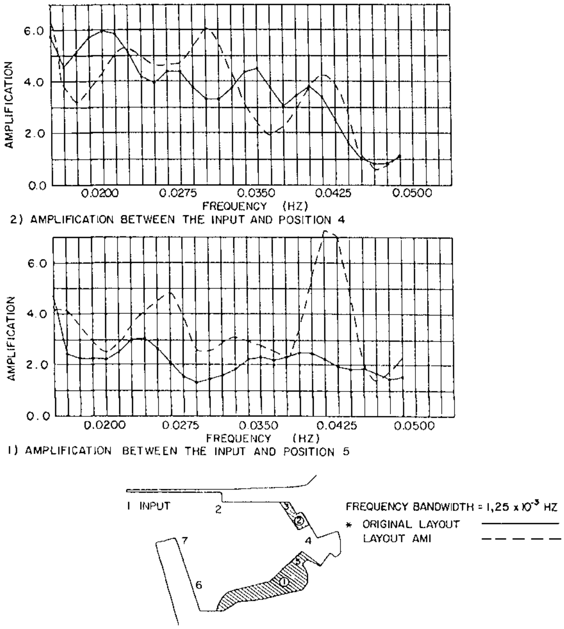

Figure 16 Amplifications for different layouts

4.3 Granger Bay Harbour

A proposed small-craft harbour at Granger Bay (situated next to Table Bay harbour) was tested to determine whether range action will be within the required design criteria for this type of harbour (CSIR, 1981).

Prototype conditions will be similar to Table Bay harbour. The harbour layout with the computational grid superimposed on it is illustrated in Figure 17.

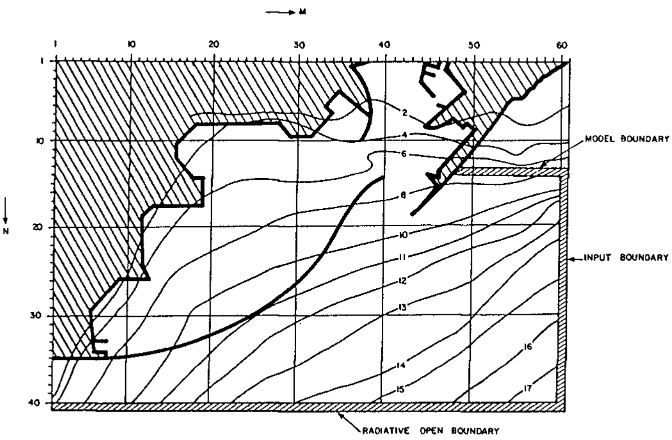

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Figure 17 Granger Bay Harbour layout with the model grid superimposed on it

The maximum amplifications of a 60,0 s sine wave are shown in Figure 18.

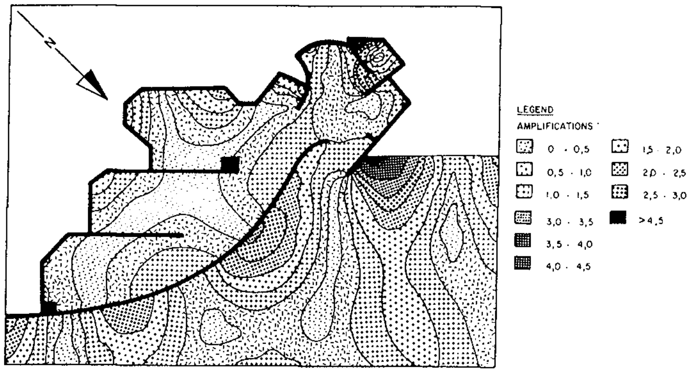

Figure 18 Maximum amplification for a period of 60,0 s

4.4 Koeberg

Prototype long-wave data were sampled at the cooling water intake basin of the Koeberg Nuclear Power Station as part of a post-construction monitoring program in order to determine the occurrence of long waves and the magnitude of the amplifications in the basin. The initial analyses of these data are described in Section 2. The data will also be used for the further verification and refinement of the model techniques and the investigation of the origin and generation of the long waves on the South African west and south coasts.

5. REFERENCES

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