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WAVES IN SHIP TANKS

PART 3: A RESONANT WAVE ABSORBER (U)

D K Fryer

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PART 3: A RESONANT WAVE ABSORBER (U)

BY

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Contents

WAVES IN SHIP TANKS
PART 3: A RESONANT WAVE ABSORBER

By D K Fryer

1. INTRODUCTION

A formal design method for seakeeping experiments was developed in Part 1 of this series of reports on waves in ship tanks. By application of this method, it was shown that the accuracy and duration of a test run is controlled by the reflection coefficient of the beach to the longest waves present in the test spectrum. This is because the longest waves travel fastest, and it is their reflections which first contaminate the incident wavetrain. The beach reflection coefficient to shorter waves has little effect on accuracy or test duration because, by suitable timing of the introduction of each frequency to the wavemaker, the short-period reflections can be delayed until after the test has been terminated.

Conventional beaches in ship tanks and wave flumes are designed to slow, steepen, and hence break the incident waves. They are therefore most effective for the fairly short, steep, waves which occur at or near the peak of the incident spectrum, and very ineffective for the long, low, waves which travel fastest. As an example, measurements of the reflection coefficient of the original beach at ARE(Haslar) No 1 Ship Tank are shown in Figure 1. It was an effective absorber for both regular and random waves at frequencies above 0.5 Hz (corresponding to a wavelength of about 6 metres), but a very ineffective absorber at lower frequencies. It was also, generally, less effective as an absorber of random waves than of regular waves, and the regular wave reflection coefficient showed a strong dependence on wave amplitude. Because of these characteristics, it was considered impractical to scale the original beach until the required characteristics were achieved. The steepness of the sloping beach elements would need to be scaled in proportion of the ratio of the steepness of the long waves which it was required to absorb to the steepness of the short waves which the original beach was able to absorb effectively. This would result in an unreasonably long, cumbersome, structure.

The requirement of low reflection coefficient over a limited range of frequencies, with "don't care" performance outside this range suggested the use of some sort of resonant structure to absorb the waves. If, in addition, the resonator could be simply tuned, the frequency of maximum absorption could be optimised for any given wave spectrum which was to be generated in the ship tank. A further benefit was also envisaged if a tuneable resonant abosrber could be developed. The absorber could be tuned to absorb the waves generated by a moving ship model in calm-water experiments, thus reducing the waiting time between test runs - necessary to allow the surface to calm down after being disturbed.

2. PRELIMINARY STUDIES

A literature survey and some model tests on candidate resonant absorbers was commissioned from Portsmouth Polytechnic (Reference 1). These demonstrated the potential of a system consisting of two porous screens mounted transversely across the tank at distances of $\lambda o/2$ and $\lambda o/4$ from the reflecting end wall of the tank (λo is the wavelength at which maximum absorption is required). At resonance, a standing wave forms with antinodes at the end wall and the $\lambda o/2$ screen, and a node (where the vertical movement of the surface is a minimum) at the $\lambda o/4$ screen.

A low-porosity screen at the $\lambda o/4$ position causes little reflection because the vertical movement is very small, but can absorb energy by friction as the water flows horizontally backwards and forwards through the screen. The $\lambda o/2$ screen was tested at the same porosity (15 per cent) and at a higher porosity (25 per cent) than the $\lambda o/4$ screen, and it was concluded that the higher porosity produced better results - the bandwidth over which effective absorption occured was slightly greater.

The Portsmouth Polytechnic tests were done at approximately 1/10 scale relative to No 1 Ship Tank at ARE(Haslar), and because both inertial and dissipative effects were involved, it was not clear how the design should be scaled up to a full-size absorber.

3. FULL-SCALE TESTS

a. The Full-Size Porous Screens

Three screens were constructed from vertical wooden slats 45 mm x 25 mm in cross-section. The slats were screwed to frames which could be mounted transversely across the ship tank, and extended from the floor to a height well above the still-water surface.

In two cases, the slats were spaced to provide 15 per cent porosity after allowing for the additional blockage caused by the supporting framework. This required 10 mm separation between slats. In the third case, the spacing provided 25 per cent porosity after allowing for blockage caused by the framework. This required 20 mm separation between slats.

Steel trusses were mounted across the rails on either side of the tank to support the tops of two screens, the bottoms of the screens being located by wedges hammered into the small gap between the screen and the tank floor. Initially a 15 per cent screen was mounted on the truss nearest the end of the tank, and the 25 per cent screen was mounted on the other truss. It was intended later to substitute the second 15 per cent screen, for the 25 per cent one, to test the effect of this, but - as will be described later - an alternative and more productive use for the second 15 per cent screen was discovered during the tests.

b. Tests on a Two-Screen Absorber

For the first series of tests, the 25 per cent porous screen was mounted 4.36 m from the end of the tank and the 15 per cent screen was mounted 2.18 m from the end, as illustrated in Figure 2. This configuration was expected to provide resonant absorption for a wavelength of 8.72 m. Had the tank floor been level in the region occupied by the resonator, this would have corresponded to a frequency of 0.4 Hz approximately. However, because of the shallowing of the tank caused by the flight of steps near the end wall, the actual resonant frequency was expected to be lower, although it was not possible to predict by how much.

Figure 3 shows the results obtained with this configuration in both regular and random waves. There is clear evidence of a minimum reflection coefficient at about 0.3 Hz, and the performance is markedly better than the original beach at this frequency. At lower frequencies, the new beach was better at frequencies down to almost 0.1 Hz; where the wavelength is so long compared with the depth of the tank, that the validity of any experiment designed to model deep-water conditions would be very questionable. At higher frequencies, the new beach is better up to about 0.45 Hz, above which there were signs of resonant reflection rather than absorption.

c. Interpretation of the Performance of the Two-Screen Absorber

Interpretation of the results was complicated by the presence of depth changes within the resonator, but it was postulated that the performance was governed by the principles illustrated in Figure 4. The situation in (B) corresponds to the minimum reflection coefficient when the node of the standing wave set up in the resonator coincides with the inner (15 per cent) screen, ie when the screens are at $^{\lambda o}/_{4}$ and $^{\lambda o}/_{2}$ metres from the end of the tank. If this is the case, then the high reflection coefficients at very low frequencies correspond with situations where the node is at or beyond the 25 per cent screen as shown in (A). It follows that the resonant reflection which occured at about 0.5 Hz must correspond with the situation shown in (C), where conditions at the end wall and the two screens are very similar to the conditions in (A), although conditions are not similar elsewhere in the resonator.

Since the resonant absorption was so pronounced in (B) when the node was located at the position of the 15 per cent screen, the placing of a second 15 per cent screen at the position of the node in (C) was examined.

d. Tests on a Three-Screen Absorber

The ideal arrangements for a three-screen abosrber would have the screens placed at distance ratios of $1 : \frac{1}{2} : \frac{1}{3}$ from the end wall of the ship tank. With the first two screens in their original positions, the third screen would need to be placed 1.45 m from the end wall, or 0.73 m behind the second screen. This was not practically realisable because of obstruction by the steel trusses which were necessary to support the tops of the screens. It was however possible to set the screens 1.5 m, 2.1 m and 4.2 m from the end of the tank, giving approximately the required separation ratio, with minimal change of resonant frequency.

The results obtained with this configuration are shown in Figure 5. The resonant reflection at 0.5 Hz was markedly reduced but also (somewhat surprisingly) the minimum reflection coefficient was even lower than for the two-screen configuration. The performance was so much better than that of the original beach that it was decided to adopt the three-screen configuration.

4. TRANSVERSE MODES

One disadvantage of the test absorber was that, because all parts of the structure were vertical and mounted transversely across the tank, it provided little suppression of energy which leaked into transverse modes of oscillation of the water surface. Unfortunately, the structure also assisted the leakage of energy from longitudinal to transverse modes by flexing under the oscillatory loads which were imposed on it. During the tests, it was found that the only transverse mode which actually became a problem was at 0.5 Hz where the wavelength equalled the width of the tank. The oscillation was set up with antinodes at the sides and centre of the tank and nodes one-quarter of the tank width from each side.

The success of the 15 per cent screens placed transversely at nodes in the longitudinal standing waves suggests that similar screens should be placed longitudinally at nodes in the transverse standing waves. If, in addition, the longitudinal screens were used to support the transverse ones, a strong, stiff cage-like structure would be produced. The greater stiffness would result in less flexure and hence lower leakage of energy into the transverse modes, and the longitudinal screens would absorb most of the leakage which took place.

The longitudinal screens would need to be at least half the longest wavelength ever generated in the ship tank to accommodate the full range of adjustment of the transverse screens.

5. CALM WATER EXPERIMENTS

The resonant absorber could in principle be set up to absorb waves generated by moving models in calm water (ie the ship's surface wake). In this case, the screen separation would need to be adjusted for maximum absorption of waves having the same celerity as the ship model's forward speed. Because speed changes occur frequently in this type of test programme, adjustment of the beach needs to be easy and quick.

If the absorber is installed at the opposite end of the tank from the wavemaker, then it would be necessary to conduct calm-water experiments with the model running towards the beach. This would minimise the time necessary for the water surface to settle between test runs, but is opposite to current practice and would require modifications to the carriage speed control and braking systems.

However, the transverse screens need to be removable to allow access to the docks, so there is no reason why absorbers should not be mounted at both ends of the tank. For seakeeping experiments, the transverse screens would then be removed from the absorber nearest the wavemaker.

6. A PRACTICAL DESIGN

A satisfactory arrangement would be to mount longitudinal screns 8 m long, one quarter of the tank width from each side. The three transverse screens would span between the tank sides and the longitudinal screens, so that the widest transverse screen would only be half the width of the tank.

However, this would obstruct access to the end docks of the ship tank. To avoid this, the longitudinal screens could be mounted slightly nearer the centre-line of the tank, as shown in Figure 6. The height of the dock gates and the dividing walls needs to be increased slightly, because waveheights at antinodes in the resonator are higher than the waveheights elsewhere in the tank.

In Figure 6, $L_1 : L_2 : L_3$ are variable whilst maintaining the ratio $1 : 1/2 : 1/3$, with L_1 having a maximum value of 8 m and a minimum value of 1 m. The transverse screens must be removable to allow access to the docks, but the longitudinal screens can be permanent.

An identical structure could be mounted in front of the wavemaker at the other end of the tank.

7. CONCLUSIONS

A practical design of resonant wave absorber has been developed. The design meets the requirements necessary for accurate seakeeping experiments: viz low reflection coefficient for long-period waves. Furthermore, the absorber is tuneable so that the wave period corresponding to minimum reflection coefficient can be optimised for tests in different seastates.

The design provides access to the end docks of the ship tank.

It can also be used to minimise the time necessary between ship test runs in calm water, by tuning the absorber to selectively absorb the waves generated by the moving model.

8. ACKNOWLEDGEMENTS

The assistance of the drawing office, workshops and facilities group at ARE(Haslar) in designing, constructing, installing and testing both the original and the prototype new absorber are gratefully acknowledged.

Many of the experiments were supervised by Mr S Miles of the Experiment Techniques Group, who also plotted the results provided in this report.

The random wave tests on the original beach (Reference 2), and the software used for the random wave tests on the new absorber, were provided by Dr P Hawkes of Hydraulics Research Ltd.

The new absorber is a very large structure, and full-scale tests would not have been possible on a range of candidate designs. The author is particularly indebeted to Mr J Mitchell of Portsmouth Polytechnic, whose efforts limited the full-scale work to the testing of a minimum number of alternative configurations.

References

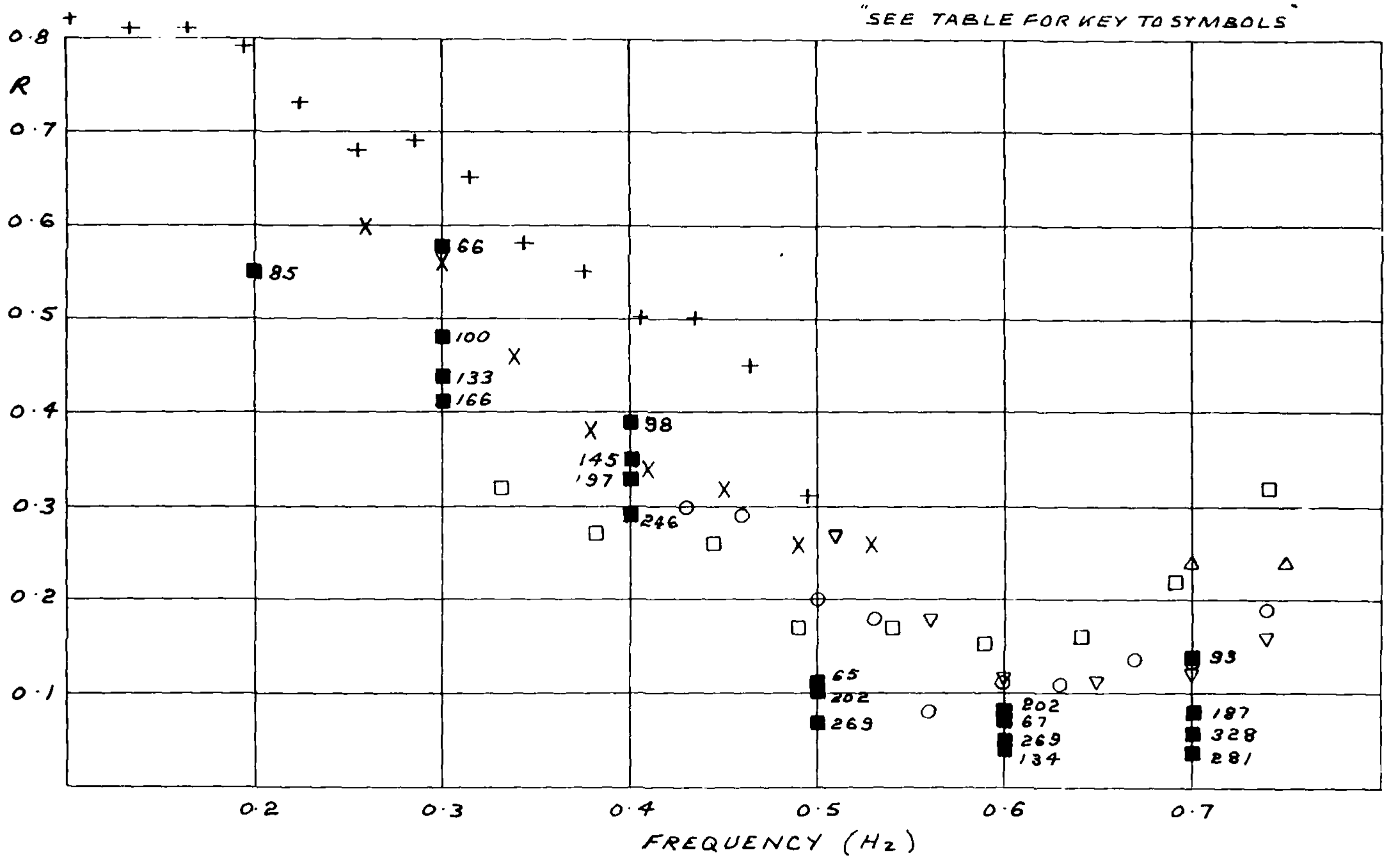
1. Mitchell, J E. A Study of Wave Absorbers for ARE(Haslar) Department of Civil Engineering, Portsmouth Polytechnic. October 1987.

2. Hawkes, P. ARE(Haslar) No 1 Tank - Measurement of Reflection and Transfer Coefficients. Report No EX1660. Hydraulics Research Ltd, Wallingford, Oxon. January 1987.

Table

SUMMARY OF TEST CONDITIONS

Symbol on Graphs	Spectrum	Hs (mm)	fm (Hz)
▣ (Hs)	Regular Wave	given in brackets	
Δ	Pierson-Moskowitz	41	0.966
∇	Pierson-Moskowitz	76	0.714
o	Pierson-Moskowitz	129	0.547
□	Pierson-Moskowitz	229	0.410
X	Pierson-Moskowitz	387	0.316
+	Band-limited white noise	38	0.03-0.48



"SEE TABLE FOR KEY TO SYMBOLS"

FIG. 1. REFLECTION COEFFICIENT OF ORIGINAL BEACH

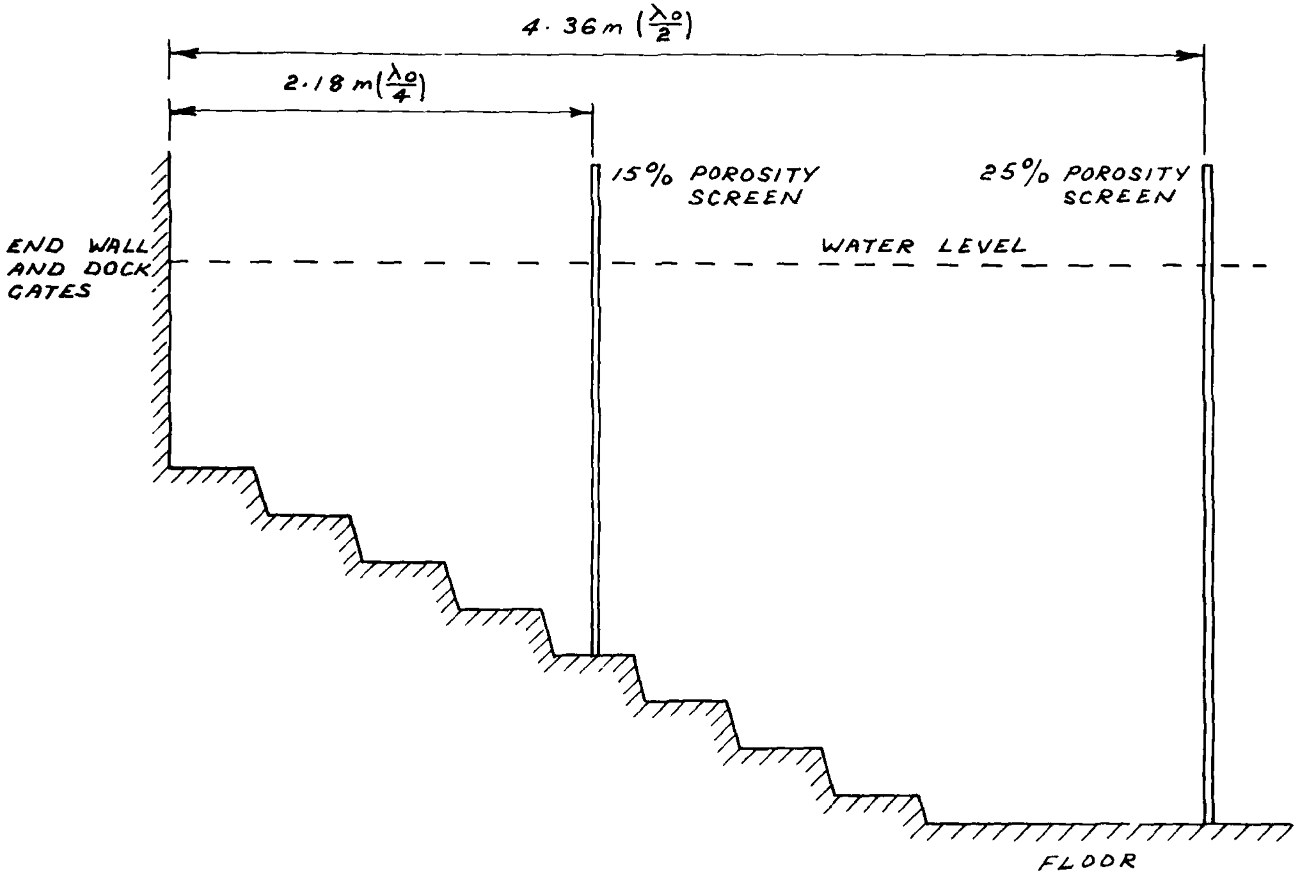


FIG. 2. ELEVATION OF FIRST TEST CONFIGURATION

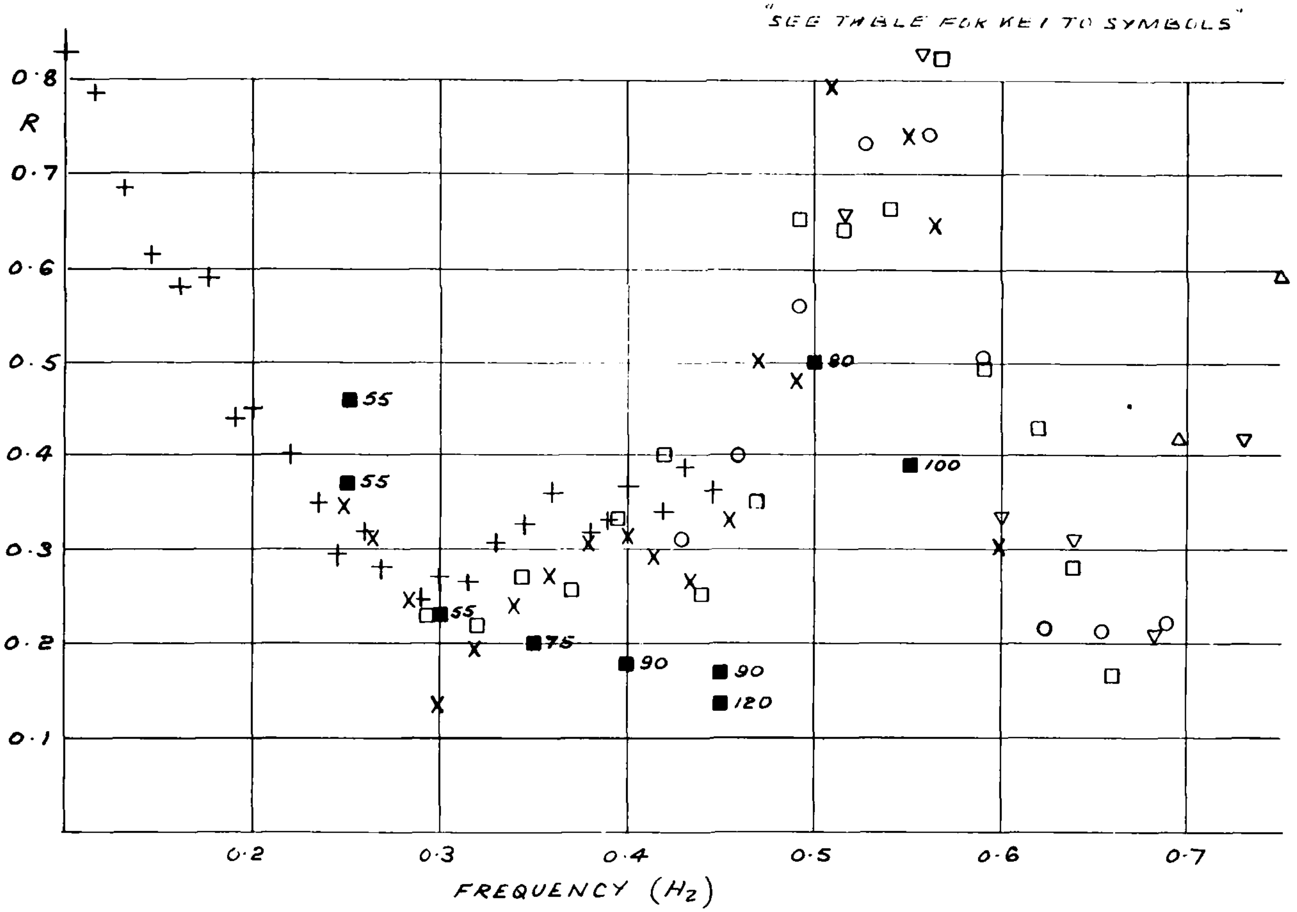


FIG. 3. REFLECTION COEFFICIENT OF 2-SCREEN ABSORBER

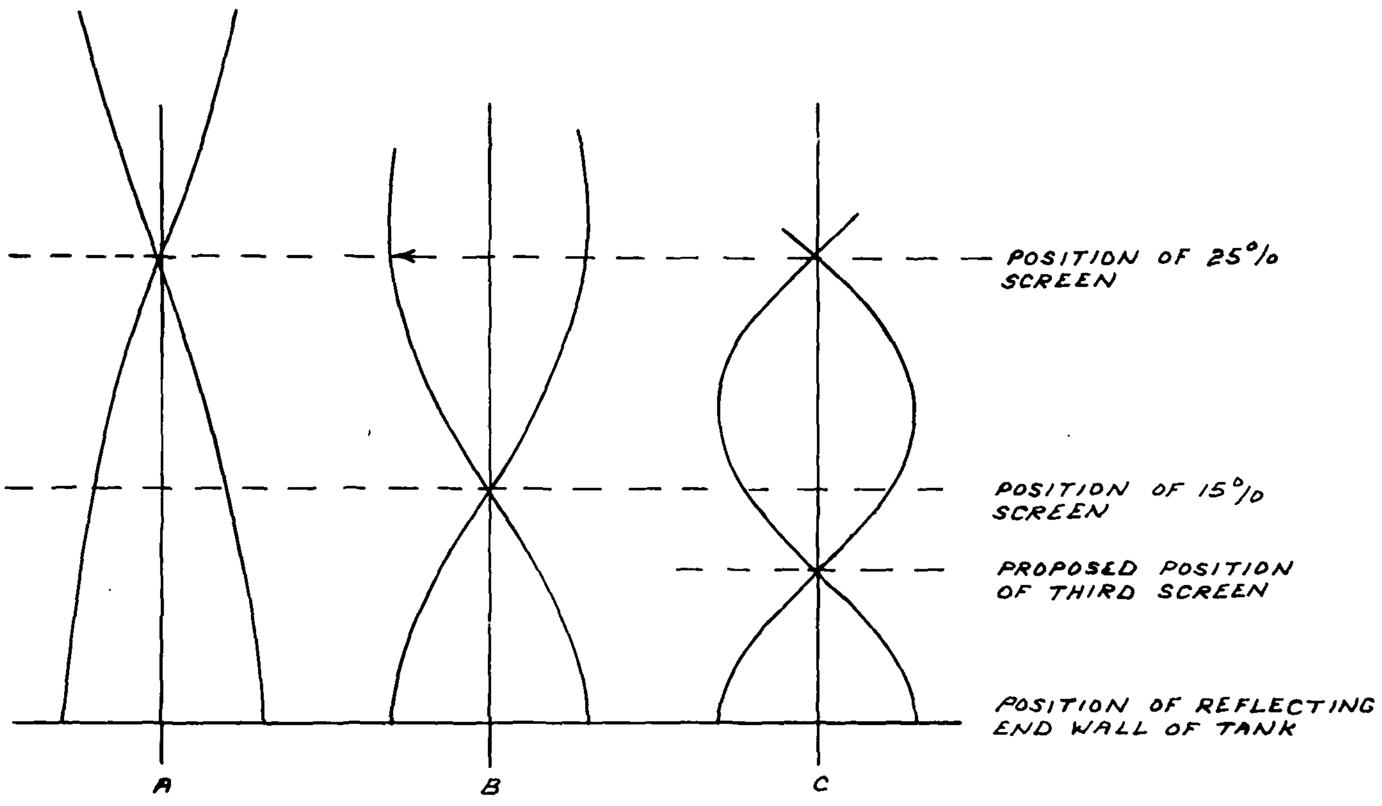


FIG. 4. STANDING WAVES IN RESONATOR

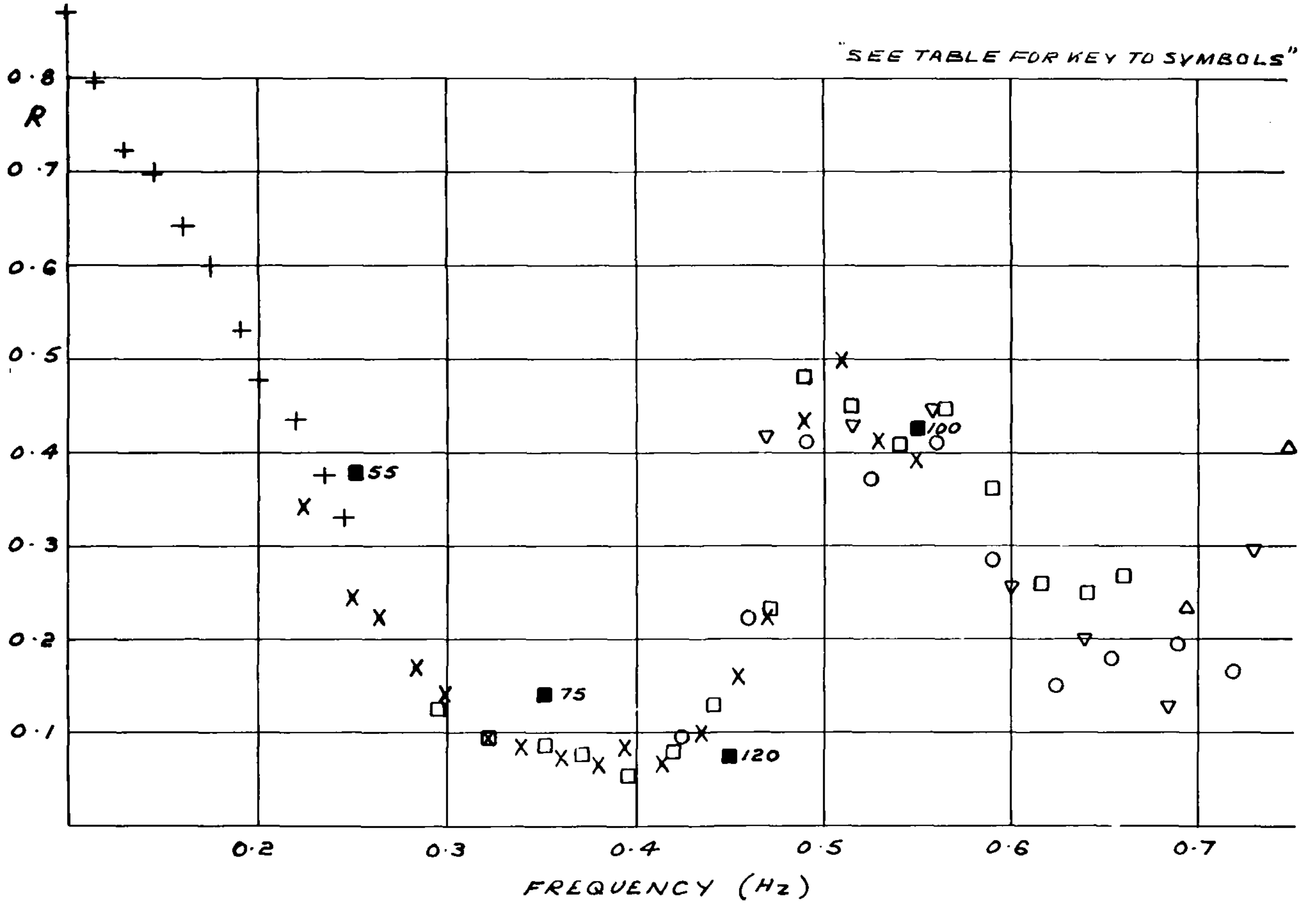


FIG. 5. REFLECTION COEFFICIENT OF 3-SCREEN ABSORBER

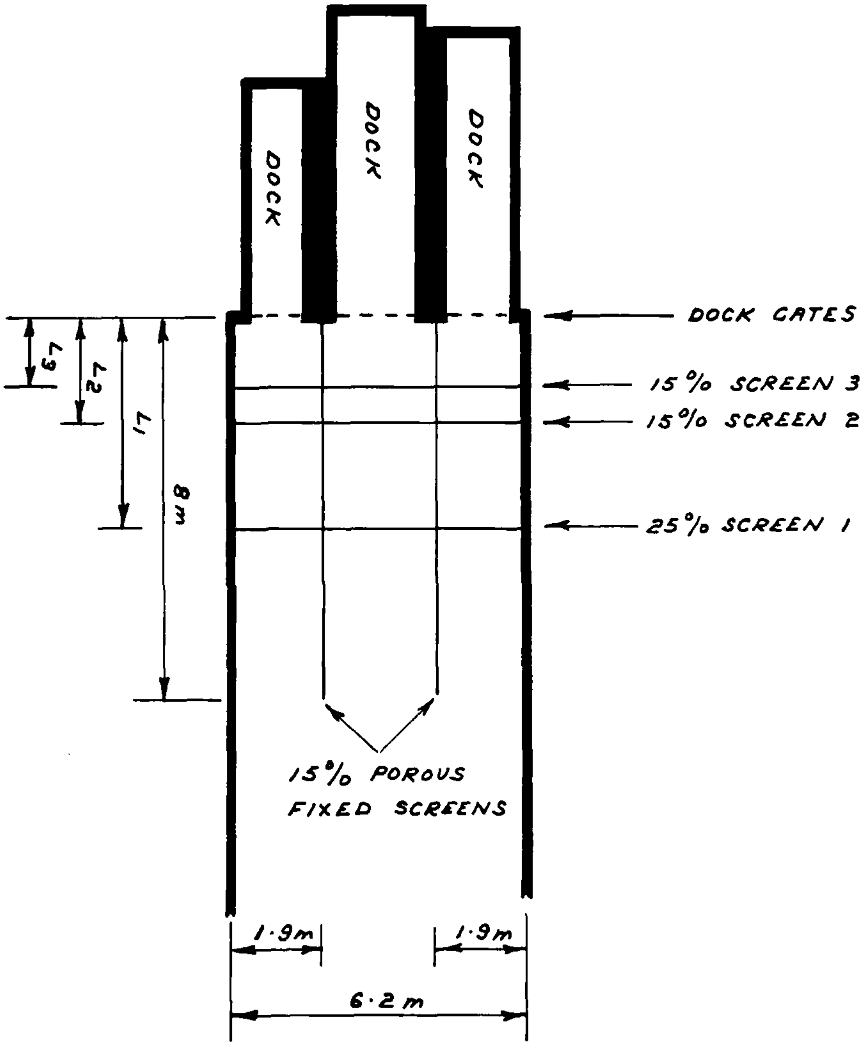


FIG. 6. PLAN VIEW OF FINAL DESIGN OF ABSORBER

Document Control Sheet

(Notes on completion overleaf)

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8. Author 1. Surname, Initials **FRYER D K**	9a. Author 2	9b. Authors 3,4..	10. Date pp ref **7.1989 6**
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Abstract
This memorandum describes a new type of resonant wave absorber for ship tanks. It can be tuned for optimum performance at any prescribed wavelength, and is generally more effective than the sloping, slatted, beach which it replaces. [illegible]