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INVESTIGATION OF THE EFFECTS OF BIO-FOULING ON THE PERFORMANCE OF A TETHERED FLOAT BREAKWATER

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INTRODUCTION:

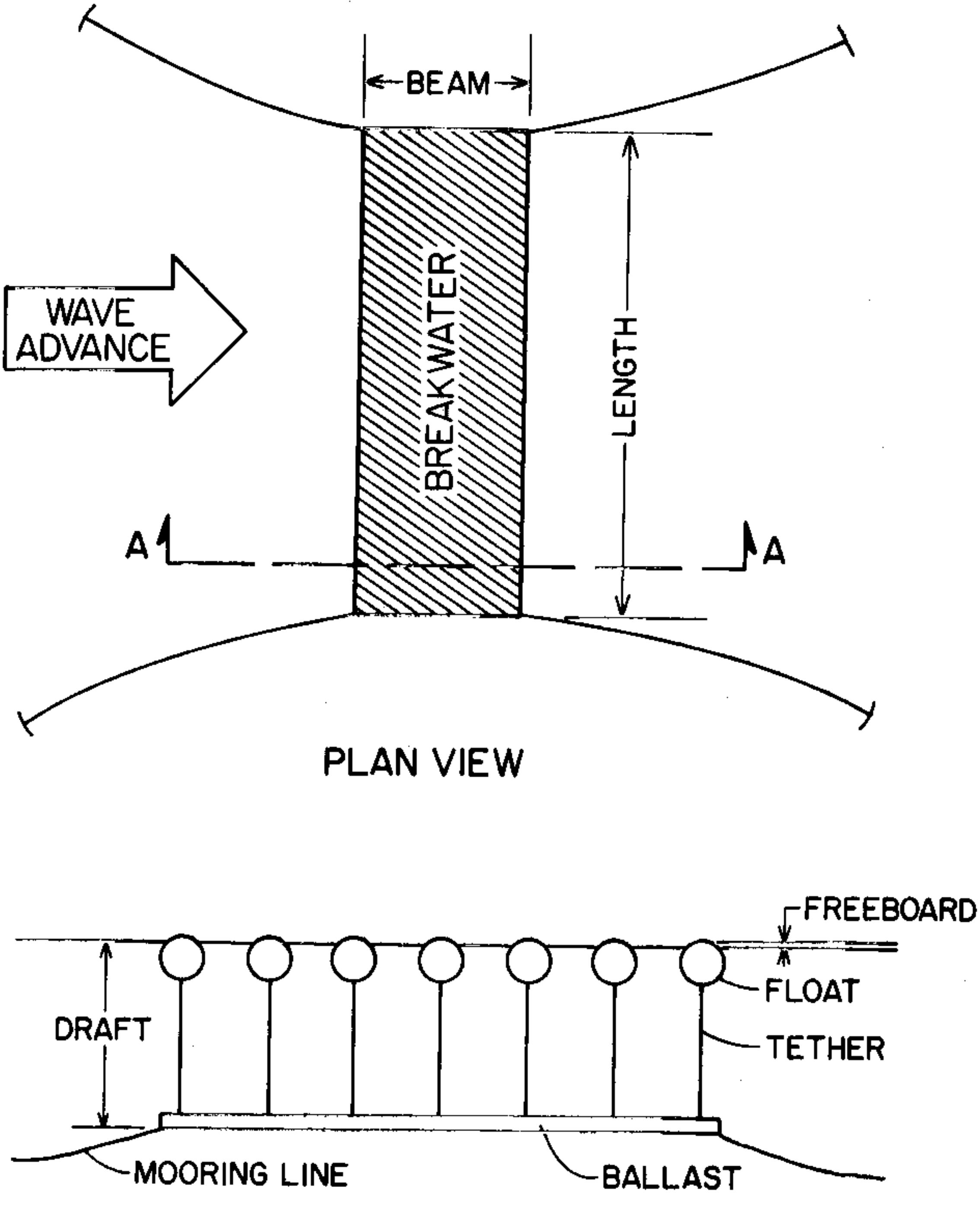
The frontispiece of this report shows a portion of an experimental tethered float breakwater installed in San Diego Harbor under the joint sponsorship of the California Department of Navigation and Ocean Development and the U.S. Navy. The installation is a "marina scale" breakwater, suitable for protection from short period, fetch-limited wind waves and wakes from boats or ships. The geometry is shown in Figure 1. The performance analysis of this breakwater is being performed under a University of California Sea Grant project, with matching funds from DNOD.

During the first few months of operation, the floats were allowed to accumulate a considerable coverage of marine flora. Approximately 10 percent of the floats had been treated with an anti-fouling paint and these showed no growth. Performance observations were hampered by adverse wind conditions that resulted in the breakwater being on a lee shore during most of this period. However, some data were obtained under the initial unfouled condition and again prior to cleaning the floats. This provided an opportunity to test a theoretical model for the performance alterations caused by bio-fouling.

THEORY:

A simple model for the accumulation of marine organisms was adopted:

Boat wake attenuation through a section of a Tethered Float Breakwater, San Diego Bay.



DEFINITION SKETCH – TETHERED FLOAT BREAKWATER

FIGURE 1

1. All growth is considered to be neutrally buoyant.
2. The growth is assumed to be evenly disposed about the float.
3. The fouled float is assumed to behave hydrodynamically as though it were a reasonable smooth sphere of appropriately increased diameter and density.

This model was verified in two ways:

a) Following Seymour (1974), the horizontal excursion of a single tethered float in response to regular waves was predicted analytically for both the clean and the fouled states and compared with measured values from laboratory experiments.

b) Using the approach presented in Seymour and Isaacs (1974), the reduction in incident wave energy by a tethered float breakwater in real waves was estimated analytically for each configuration and compared with actual field measurements of performance.

The linearized equation of motion for the float in response to regular sinusoidal waves is solved in Seymour (1974) to produce the transfer function, H(f), relating float horizontal excursion to the wave-induced horizontal motion of the water at the depth of the center of the float.

$$H(f) = \frac{(D')^2 \omega^4 + (C^* \omega)^2}{(B - M\omega^2)^2 + (C^* \omega)^2} \qquad (1)$$

where $$M = C_m M_w + M_s$$

$$C^* = \rho\frac{A}{2} U_O C_D$$

$$B = \frac{g}{L} (M_w - M_s)$$

$$D' = M_w (1 + C_m)$$

and U_o = linearizing characteristic velocity = $\frac{8}{3\pi}$ ωa

a = amplitude of horizontal water motion

$\omega = 2\pi f$ = radian frequency

M_w = mass of water displaced by the float

M_s = float mass

A = cross sectional area of the float

ρ = density of water

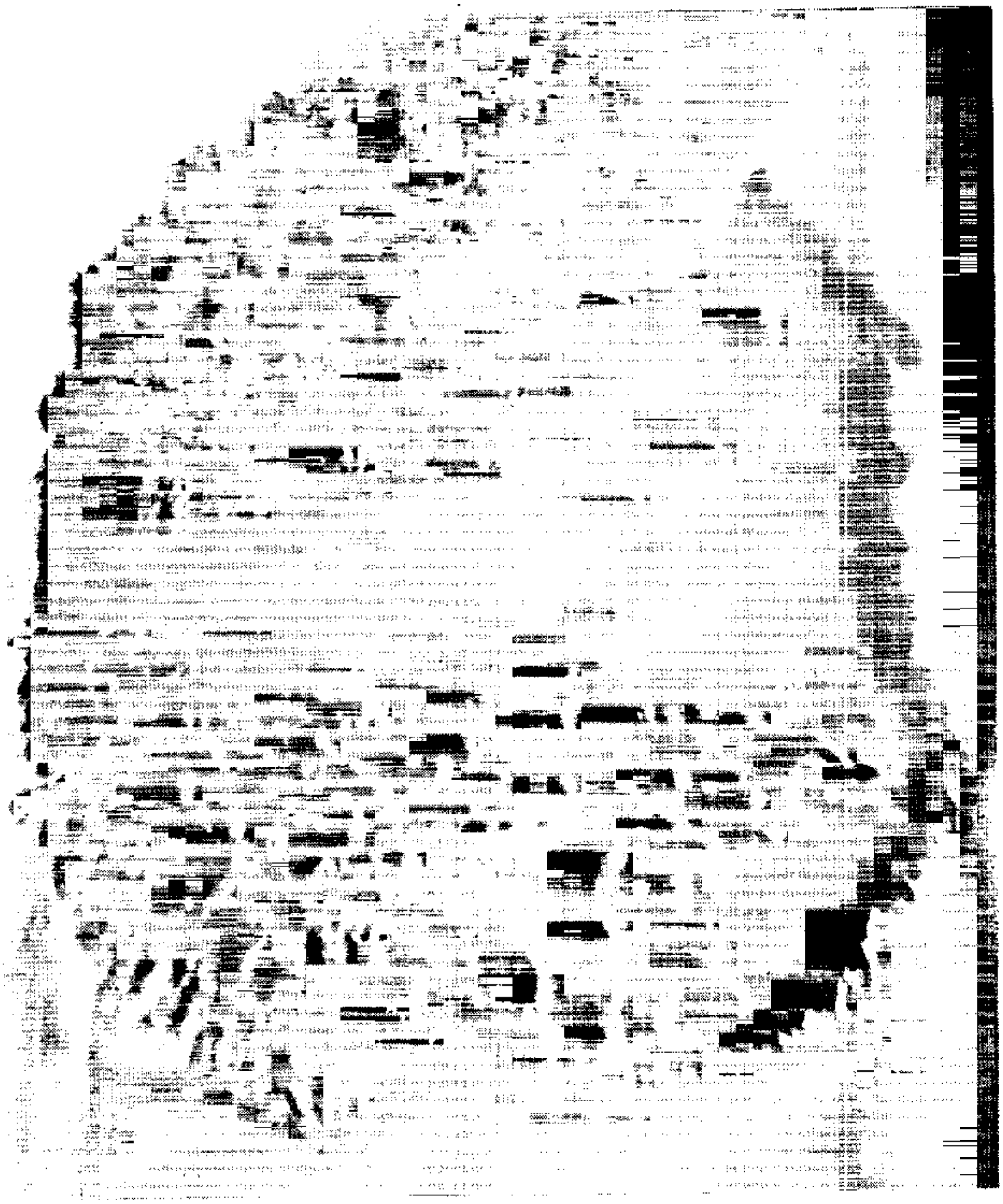
g = gravitational constant

L = effective tether length

C_D = average drag coefficient

C_M = average added mass coefficient

Seymour (1974) also shows that equation (1) can be used to predict the response fo the float to wide band random waves with the substitution of the characteristic velocity, $U = \frac{g}{3\sqrt{\pi}} \sigma_r$, where σ_r is the standard deviation of the relative velocity. Seymour and Isaacs (1974) describes the method for an iterative solution for σ_r with a



FLOAT FOULED BY TUNICATES
AND ALGAE.

FIGURE 2

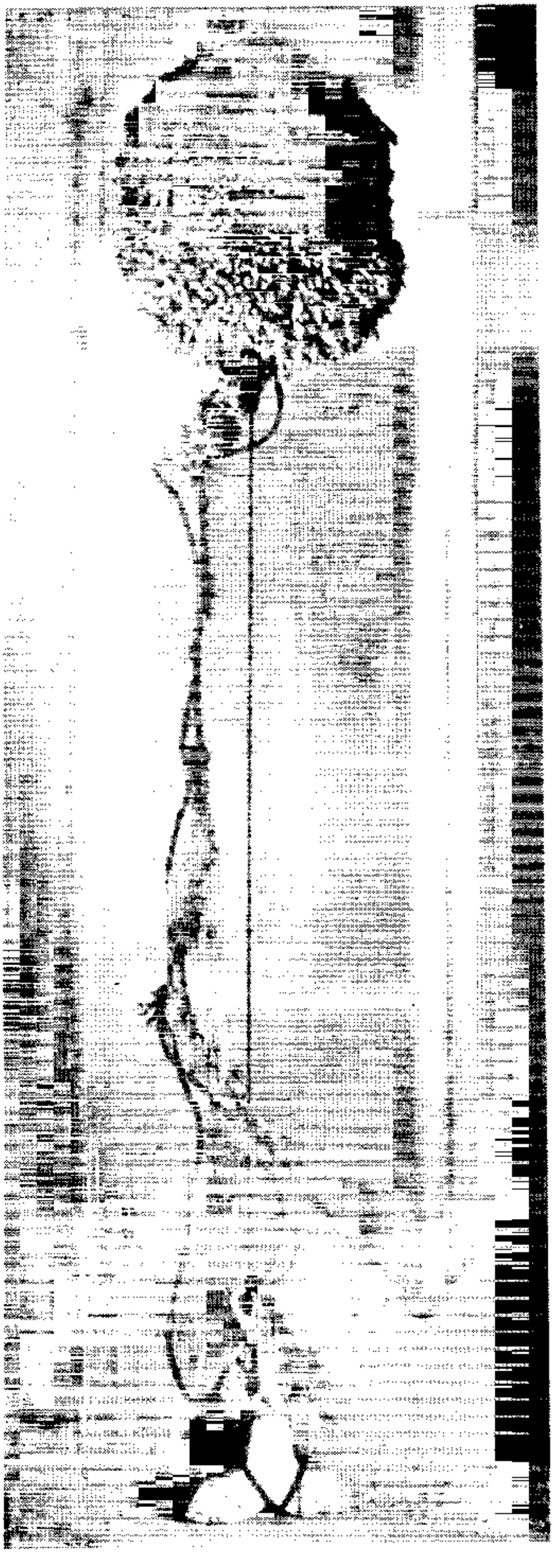
given incident wave spectrum. The dissipative power of the float is shown to be proportional to σ_r^3, allowing the effective prediction of wave attenuation performance for any assemblage of floats. This predictive technique is embodied in a numerical computer program called TFBAN.

LABORATORY INVESTIGATIONS:

A single float and tether, representative of the heaviest fouling, was removed from the breakwater installation in San Diego Bay. The condition of the float is shown in Figure 2. The top of the float is covered by a thin canopy of mixed algal species and the lower portion is dominated by tunicates, a troublesome summertime fouling animal in this region.

A clean float has a diameter of 29.2 cm. A sphere with the same displacement as the fouled float would have a diameter of approximately 36 cm.

The float was anchored in 1.78 m. deep water in a wave channel at the Hydraulics Laboratory, Scripps Institution of Oceanography (SIO) as shown in Figure 3. The float was then subjected to regular narrowband waves. The float excursion was measured optically through a window in the side of the wave channel. The wave height was recorded



FOULED FLOAT IN WAVE CHANNEL.

FIGURE 3

by means of a digital wave staff. The horizontal water particle amplitude, (a), was calculated by linear (Airy) theory from the wave height and frequency. A measured value of H(f) was then obtained by dividing the observed float excursion amplitude by the calculated water excursion amplitude at the center of the float.

The float was then cleaned of all growth and the experiments were repeated. The results of the two series are shown in Table I.

TABLE I
SINGLE FLOAT RESPONSE EXPERIMENTS

EXPERIMENT NUMBER	WAVE FREQUENCY (hz)	WAVE HEIGHT (cm)	HORIZONTAL AMPLITUDE (cm)	FLOAT CONDITION (cm)	FLOAT AMPLITUDE	MEASURED H(f)
1	0.5	18.16	7.41	foul	18.4	2.48
2	0.9	13.2	3.41	foul	6.34	1.86
3	0.5	18.16	7.41	clean	37.4	5.05
4	0.9	13.2	3.41	clean	16.5	4.83

Values for H(f) were calculated using equation(1)and the simplified model for the fouling described above. The comparison of predicted and measured values was excellent as shown in Table II.

TABLE II
COMPARISON OF CALCULATED AND OBSERVED VALUES OF AMPLITUDE FACTOR H(f)

EXPERIMENT NUMBER	FLOAT CONDITION	H(f) OBSERVED	H(f) CALCULATED
1	foul	2.48	2.48
2	foul	1.86	1.77
3	clean	5.05	5.07
4	clean	4.83	4.84

The values of C_m and C_D assumed in equation (1) were 0.35 for all of the experiments. The fact that agreement was obtained without adjustments of these coefficients verifies that the effect of biofouling is predominately a mass increase. The ability of equation (1) to predict the response of a fouled float assuming only an increase in float diameter and mass gives credibility to the use of the TFBAN program for predicting breakwater performance.

FIELD INVESTIGATIONS:

The major characteristics of the tethered float breakwater installed in San Diego Bay are shown in Table III. The terminology used in this table and elsewhere in the report follows the recommendations of Kowalski (1974).

TABLE III
PRINCIPAL CHARACTERISTICS OF SAN DIEGO BAY BREAKWATER

LENGTH	45.7 m.
BEAM	6.1 m.
FLOAT DIAMETER	29.2 cm.
TETHER LENGTH	1.52 m.
NUMBER OF FLOATS *	836

The performance of the system is monitored by measuring the wave field in front of and behind the breakwater. Resistance type wave gages, mounted on spars pivoted at their anchors, provided the surface elevation time histories. These signals are digitized, mutiplexed and transmitted over leased lines to a computer at SIO for recording and analysis.

The results of two records, one obtained shortly after the breakwater was installed and another with considerable fouling were selected for this investigation. On July 9, 1975, with the floats visually clean to underwater investigation, the wakes of passing destroyers with a peak energy period of 2.5 seconds were recorded. On August 8, 1975, after rapid fouling was observed, a broad spectrum wind generated wave field with peak energy in the range between 4 seconds and 2 seconds period was recorded.

*Reserve buoyancy is provided by 20% of the floats which have a freeboard (see Figure 1) of one half diameter. All other floats have a negative freeboard of one quarter diameter.

The actual measured incident spectra obtained from these records were used in Program TFBAN to predict the exiting spectra for an unfouled breakwater. The results are shown in Table IV. The ratio of the total transmitted energy to the total incident energy is the energy transmission coefficient.

TABLE IV
PREDICTED AND MEASURED PERFORMANCE

RECORD	CONDITION	MEASURED HEIGHT REDUCTION	ENERGY TRANSMISSION COEFFICIENT MEASURED	ENERGY TRANSMISSION COEFFICIENT CALCULATED (unfouled)
1	unfouled	0.45	0.299	0.293
2	fouled	0.33	0.593	0.446

Thus, it can be seen that the analytical model accurately predicts the performance of the clean breakwater but over predicts the fouled system by failing to account for the altered characteristics of the floats. Because of the wide variation in the amount of fouling, and the difficulty of making in situ measurements, it was not possible to make an a priori prediction of the fouled performance. However, the effects of assuming various average amounts of fouling were calculated and the results of this work shows that an average effective radial growth of 1 cm. (2 cm. increase in diameter) results in a predicted increase of the energy transmission coefficient of 0.15, approximately the discrepancy observed. It should be noted that this diameter increase assumes a 100% volumetric efficiency of the growth. In nature, the actual overall thickness of the growth could exceed this considerably. The level of growth that must be assumed to match the observed performance is consistant with observations by one of the authors while diving, with underwater photographs taken close to the time of the reported performance record, and with the laboratory measurements.

It therefore appears that the analytical model for breakwater performance, suitably modified to account for the biofouling, is capable of predicting performance alteration. Since changes from the design performance are a matter of concern to both the designers and the users of tethered float breakwaters, and since larger float diameters would appear to be affected less by growth, a comparative study of varying float diameters was performed.

STUDY OF DIAMETER EFFECTS:

In general, a given performance level requires an increase in the volume of floats required per foot of length with an increase in float diameter. This provides the smaller floats with an economic advantage in that, within reasonable limits, float and ballast costs (which dominate the total hardware costs) are nearly proportional to float volume. The study was undertaken, then, using a number of breakwater designs each employing a different float diameter but with the same initial (unfouled) total float volume per unit length. Thus, the smaller floats produce lower transmission coefficients in the unfouled, or initial state. The performances, measured by the wave height transmission ratios, were then compared for a number of conditions of fouling. It was assumed that each float size would accumulate an identical thickness of fouling in a given time period. This is a simplified assumption since varying the depth of submergence of the substrate can change the dominant species and therefore the growth rate.

In deepwater applications, such as the San Diego Bay installation, maximum performance is achieved with minimum float density so that the observed performance degradation was anticipated. In shallow water applications (i.e.: shallow water relative to the wave length of the dominant frequencies), with tether length restricted by the available depth, the maximum performance is achieved with float densities which are a large fraction of the density of water. In this study, the initial density was set at the same value used in the deep water case.

In certain of these applications, performance may be expected to be enhanced by fouling. An example of each condition was included in this study. The characteristics of the two classes of breakwaters are shown in Table V.

TABLE V
CHARACTERISTICS OF BREAKWATER DESIGNS IN DIAMETER EFFECTS STUDY

INITIAL FLOAT DIAMETER (m)	NUMBER ROWS OF FLOATS	INITIAL AVG. DENSITY (g/cc)	TETHER LENGTH (m)	
			DEEP	SHALLOW
0.6	69	.06	9.1	2.3
0.9	30	.06	9.1	2.3
1.2	17	.06	9.1	2.3
1.5	11	.06	9.1	2.3

CHARACTERISTICS OF INCIDENT WAVE FIELD

Pierson-Moskowitz Spectrum for 14 knot wind.

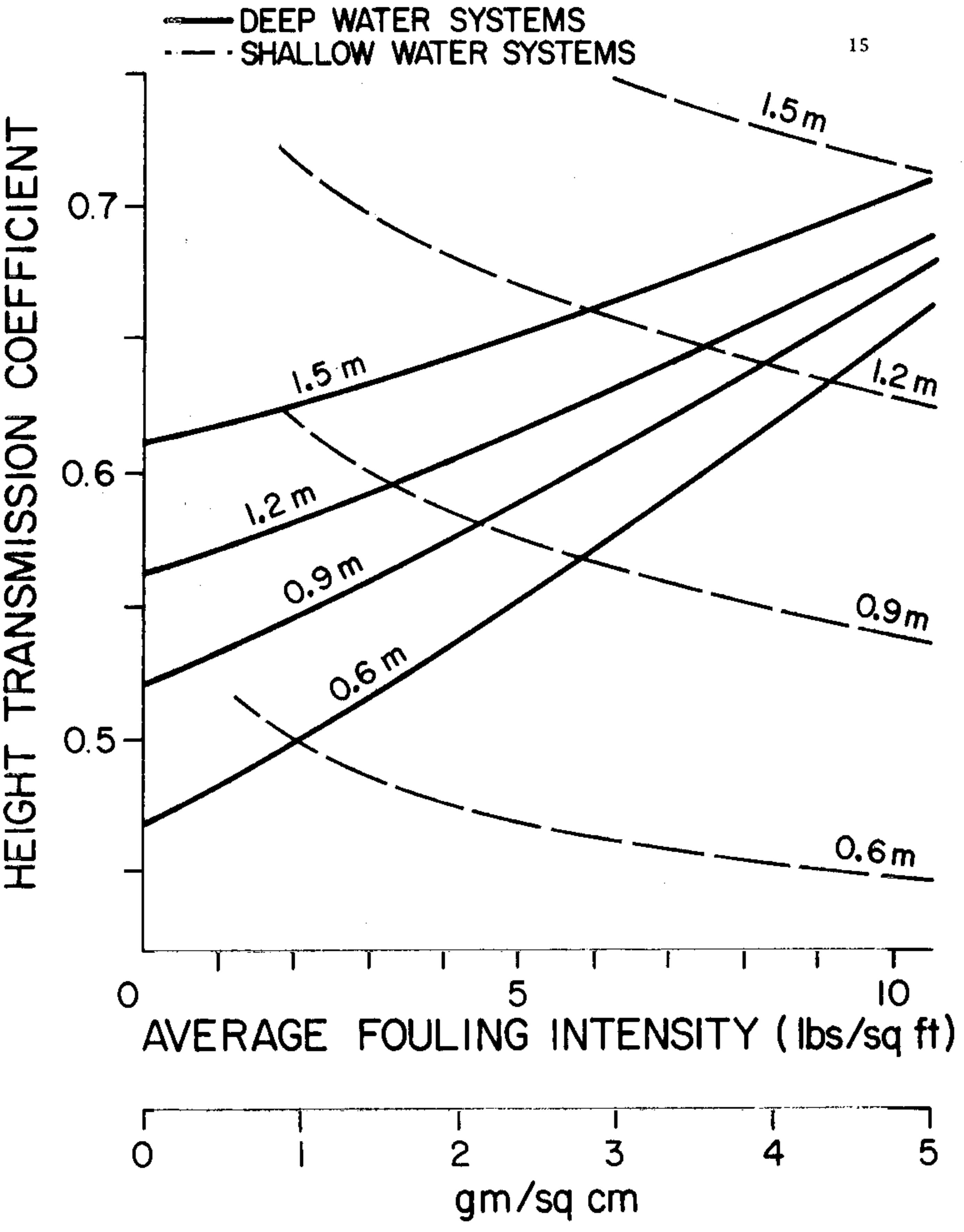
Period of peak energy = 5.4 seconds

Significant wave height = 1.1 m.

Depth, deep water system = 12.2 m.

Depth, shallow water system = 6.1 m.

The performance changes predicted for these designs with various levels of fouling are shown in Figure 4. As anticipated, the deep water designs show a decrease in performance which is more severe in the smaller diameters. The 0.6 m. diameter float would appear to lose its performance advantage relative to the 1.5 m. float at a fouling intensity of about 7.5 gm/sq cm (or cm^2). It should be noted, however, that this is a very heavy canopy of fouling; Approx-



PERFORMANCE CHANGES FROM BIOFOULING AT VARIOUS FLOAT DIAMETERS

FIGURE 4

imately 15 lbs. per square foot and six inches thick at a 50% volumetric efficiency. Very energetic wave climates could make such an accumulation difficult or impossible in may locations.

On the other hand, the performance of the shallow water designs is improved by fouling. Although the 1.5 m. float size improves more rapidly, it would not appear to overcome the performance advantage of the 0.6 m. float at any reasonable fouling intensity.

CONCLUSIONS:

The simplified model of smooth, evenly distributed, neutrally buoyant growth appears to provide for accurate prediction of the changes to the performance of a tethered float breakwater caused by biofouling. The performance of smaller diameter floats is affected less beneficially than that of larger diameter floats. Deep water, long tether, low initial float density systems are degraded by fouling. Shallow water, short tether, high initial float density systems are enhanced by growth.

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