CHAPTER 112

TRANSMISSION OF REGULAR WAVES PAST FLOATING PLATES

by

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ABSTRACT

Theoretical solutions for the transmission beyond and reflection of waves from fixed and floating plates are based upon linear wave theory, as put forth by John (1949), and Stoker (1957), according to which the flow is irrotational, the fluid is incompressible and frictionless, and the waves are of small amplitude. The resulting theoretical relations are rather complicated, and furthermore, it is assumed that the water depth is very small in comparison to the wave length.

Wave transmissions beyond floating horizontal plates are studied in a laboratory wave flume. Regular (harmonic) waves of different heights and periods are generated. The experiments are carried out over a range of wave heights from 0.21 to 8.17 cm (0.007 to 0.268 ft), and wave periods from 0.60 to 4.00 seconds in water depth of 15.2, 30.5, and 45.7 cm (0.5, 1.0 and 1.5 ft). Floating plates of 61, 91 and 122 cm (2, 3 and 4 ft) long were used.

From the analyses of regular waves it was found that: (1) the transmission coefficients, H_T/H_I, obtained from the experiments are usually less than those obtained from the theory. This is due to the energy dissipation by the plate, which is not considered in the theory. (2) John's (1949) theory predicts the transmission coefficients, H_T/H_I, reasonably well for a floating plywood plate, moored to the bottom and under the action of non-breaking incident waves of finite amplitude. (3) a floating plate is less effective in damping the incident waves than a fixed plate of the same length.

INTRODUCTION

Floating horizontal plates are being constructed as breakwaters. When waves meet a horizontal plate, part of the wave energy is reflected by the plate, part of it is transmitted beyond the plate, part is transformed into flow energy as water flowing over the plate, and part of it is absorbed by the plate and its supports. Earlier experiments by Wiegel et al. (1962), Wiegel (1964), Chen and Wiegel (1970), and others with horizontal objects showed that transmitted waves are of complicated form.

John (1949) and Stoker (1957) have theoretically determined the transmission of wave energy from a fixed or floating plate by considering a boundary value problem of a potential flow. Stoker (1957) derived an approximate theory for freely floating and fixed obstacles in shallow water. While Stoker's theory is rather useful for the fixed plate problem, it is too involved a theory for the present problem. In the study by Stoker (1957, p.448) on floating elastic breakwaters, it was indicated that the wave reflection and transmission is an irregular function of wave length, L, and the structure length, λ. In this theoretical study the wave energy was either transmitted or reflected, i.e. no energy dissipation was considered. The theory is derived from the exact hydro-dynamical linear theory for gravity water waves of small surface amplitude by making the simplifying assumption that the wave length, L, is sufficiently large compared with the depth, d, of the water such that the ratio L/d is of the order eight to ten. In fact it is possible to formulate a mathematical theory without making such a restrictive assumption regarding the ratio of wave length to depth; for example, a theory has been worked out by John (1949) for floating rigid bodies having simple harmonic motions, but no solutions could be found in the case of interest in practice.

John (1949) investigated theoretically the effect of an infinitely thin floating cylinder on an incoming wave and derived the reflection coefficient as:

$$C_R = \frac{H_R}{H_I} = \frac{(\pi D/L)^5}{45\left[\left(1-.4\left(\frac{\pi D}{L}\right)^2\right)^2 + \left(\frac{\pi D}{L}\right)^2\left(1-\frac{(\pi D/L)^2}{15}\right)^2\right]^{1/2}} \times \frac{1}{\left[\left(1-\frac{(\pi D/L)^2}{3}\right) + \left(\frac{\pi D}{L}\right)^2\right]^{1/2}} \quad (1)$$

where D is the diameter of the cylinder at the still water line. Furthermore, the transmission coefficient, H_T/H_I, can be obtained by using the law of conservation of energy, $(H_T/H_I)^2 + (H_R/H_I)^2 = 1$. Reflection coefficients for a floating cylinder obtained by using Eq.1 are smaller than reflection coefficients for a fixed cylinder of the same diameter, see John (1949).

Wiegel (1964, p.142) studied in a model basin the effects of periodic waves on a plastic bag 3.05 m by 3.05 m by 10 cm thick (10 ft by 10 ft by 4 inch) filled with water. It was seen that a bag twice the wave length should be fairly effective as a breakwater. In another study by Wiegel et al. (1962) six bags were lashed side by side to form a 7.31 m by 6.10 m by 1.22 m deep (24 ft by 20 ft by 4 ft) breakwater. The bags were moored in San Francisco Bay and filled with Bay water. The bags were subjected to wind waves with periods 1 to 2 seconds and heights 15 to 46 cm (0.5 to 1.5 ft). Energy spectrums of the incident and transmitted waves were obtained; it was concluded that the hovering breakwater is effective for damping the incident waves.

Other experiments with floating objects such as pontoon type breakwaters, floating tires, etc. were carried out by Homma et al. (1964), Kamel et al. (1968) and Kato et al. (1969). Recently Wen and Shinozuka (1972) considered a large floating plate to represent a future offshore airport and formulated its response to random incoming waves.

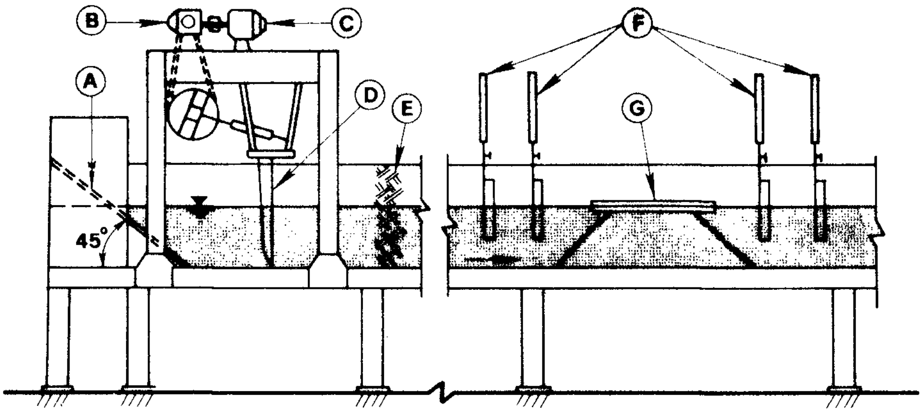
Floating breakwaters are designed to have larger natural periods of roll, pitch, and heave than the expected wave periods. Furthermore, Chen and Wiegel (1970) report that to obtain a long natural period, the floating breakwaters should have a large mass but small elasticity.

Floating breakwaters compared to fixed breakwaters are simple in fabrication and placement. Their size depends on the wave length, wave height, direction of waves, and degree of protection required at the leeward side. However, there is one important problem in connection with the design of floating breakwaters, that is the forces exerted on the mooring lines. The wave forces exerted on the mooring lines are very complicated and at times considerable (see Wilson and Garbaccio, 1969; Tudor, 1968). Therefore, the application of the floating breakwater is limited to smaller bodies of water (see Frederiksen, 1971). However, they may be used in oceans for small chop during short construction operations or cargo handling.

The present investigation concerns itself with the prediction of the wave energy before and after a floating plate. Tests were carried out with regular waves having different wave heights and periods.

THE EXPERIMENT

The wave flume was of uniform cross section, 0.61 m (2 ft) wide, 0.61 m (2 ft) deep, and 20.58 m (67.5 ft) long. It is shown in Fig.1. The flume is constructed with a steel and aluminum frame; the sides are made of glass. Two energy absorbers built with four thin perforated aluminum sheets were placed at both ends of the flume. These sheets, separeted by 6 mm (1/4-inch) spacers, are bolted to an 8 mm (5/16-inch) aluminum impermeable plate. The downstream absorber is inclined at 15° to the horizontal, whereas the upstream absorber (A), located behind the wave generator, is inclined at 45°. To conduct tests with regular



A. Upstream Absorber
B: Hydraulic Transmission
C: Motor
D: Wave Generator Paddle
E: Wire Mesh Filter
F: Wave Gages
G: Plate (Marine Plywood 3/16 inch thick)

Fig. 1 Experimental Set-Up for Regular Wave (not to scale)

waves, a paddle type wave generator (D) was installed at one end of the wave flume. A wire mesh filter (E) was put in front of the generator paddle to smooth the generated waves and to absorb reflected wave energy from the generator paddle.

The set-up for the floating plate (G) is shown in Fig.1. The mooring of the plate was provided by light chains and hooks. Floating plates of three different sizes were used, having the following length, width, and thickness respectively: 61 by 61 by 0.48 cm (24 by 24 by 3/16 inch), 91 by 61 by 0.48 cm (36 by 24 by 3/16 inch), and 122 by 61 by 0.48 cm (48 by 24 by 3/16 inch).

The wave generator consists of an oscillating plate, hydraulic transmission, and AC electric motor. The generator is capable of producing frequencies in the range of 0 to 5 cps. The speed of the motor could be adjusted to obtain the desired wave period while different wave heights could be obtained through stroke adjustment. The water surface fluctuations were measured by capacitive type wave gages, described by Killen (1956) and Sendil (1973). The signals from the wave gages were recorded on a 6-channel Model BL-520 Brush recorder.

Floating plates were positioned at 13.57 m (44.5 ft) from the upstream end of the flume. The waves were measured at four positions, namely 4.57 m (15 ft) and 6.10 m (20 ft) to the front of the plate and at about 1.22 m (4 ft) and 2.44 m (8 ft) to the rear of the plate.

Table 1 gives a tabulation of the tests; 138 runs were carried out for the floating plate experiments that are given in Şendil (1973, Appendix B).

Table 1
Number of Runs for Different Plate Lengths, λ
(Run No. 379 to 516)

T (sec)	λ=2 ft			λ=3 ft			λ=4 ft		
	d (ft)			d (ft)			d (ft)		
	0.5	1.0	1.5	0.5	1.0	1.5	0.5	1.0	1.5
0.6	4	-	3	5	5	5	5	5	6
1.0	5	5	5	6	6	5	5	5	6
2.0	5	5	5	-	-	-	-	-	-
4.0	4	4	4	4	5	4	3	4	5

The data obtained were analyzed by using the method of dimensional analysis.

Fig.2 shows a definition sketch of the horizontal plate with the incident and transmitted waves progressing in water of constant depth, d. For a horizontal plate interacting with regular waves, the following variables are of importance: (1) Wave parameters -- H_I, incident wave height; H_T, transmitted wave height; L, wave length; T, wave period. (2) Plate parameters -- λ, length of the plate; b, width of the plate;

s, thickness of the plate; ε, roughness of the plate. (3) Flow parameters -- g, gravitational acceleration; U, horizontal component of orbital velocity; d, still water depth; k', roughness of the bottom. (4) Fluid parameters -- ρ, fluid density; μ, fluid viscosity.

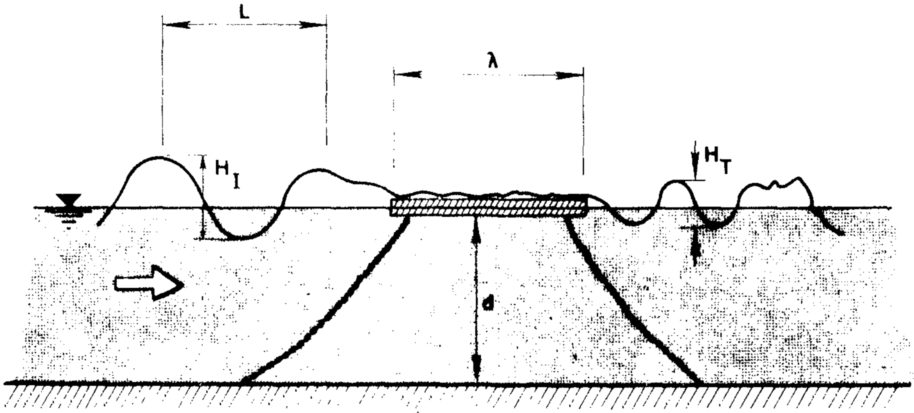


Fig. 2 Definition Sketch for Regular Waves

In the present experiments the roughness of the channel bottom, k', and the roughness of the top and bottom surface of the plate, ε, were held constant. Furthermore, the plate thickness s, was small so that its effect on wave reflections was assumed to be negligible. Then, for the two dimensional (b=1) case of a very wide plate, the variables pertaining to the present problem may be written as

$$f(H_I, H_T, L, T, \lambda, g, U, d, \rho, \mu) = 0 \qquad (2)$$

Grouping these variables into dimensionless parameters yields:

$$\frac{H_T}{H_I} = f\left(\frac{H_I}{L}, \frac{d}{L}, \frac{\lambda}{L}, \frac{U_m T}{\lambda}, Re, Fr\right) \quad (3)$$

where $U_m T/\lambda$ is another form of Keulegan-Carpenter's (1958) period parameter, with U_m as the maximum horizontal component of orbital velocity.

PRESENTATION OF RESULTS

The important parameters obtained from dimensional analysis for the wave transmission beyond a floating plate were expressed by Eq.3. In search for a meaningful relationship, the various arguments in Eq.3 were plotted; this was done by Sendil (1973). The findings are briefly summarized as:

(a) Plotted were the transmitted wave height, H_T, against the incident wave height, H_I, with the relative plate length, λ/L, as parameter for two different d values. It was concluded that H_T, H_I, and λ/L are important parameters.

(b) Plotted were the transmission coefficient, H_T/H_I, against the wave steepness, H_I/L, with the relative plate length, λ/L, as parameter for three different λ values. It was concluded that H_T/H_I, H_I/L and λ/L are important parameters.

(c) Plotted were the transmission coefficient, H_T/H_I, against the Reynolds number, Re, with the relative plate length, λ/L, as parameter for three different λ values. The present experiments showed that the Reynolds number is not an important parameter.

(d) Plotted were the transmission coefficient, H_T/H_I, against the Froude number, Fr, with the relative plate length, λ/L, as parameter for three different λ values. The present experiments showed that the Froude number is not an important parameter.

(e) The transmission coefficient, H_T/H_I, was plotted against the period parameter, $U_m T/\lambda$, with relative depth, d/L, as parameter for three different λ values. The present experiments indicated that, $U_m T/\lambda$ is not an important parameter.

In summary, it is believed that the following parameters play an important role: H_T/H_I, H_I/L, λ/L, and d/L. Eq.3 can now be written as:

$$\frac{H_T}{H_I} = f\left(\frac{H_I}{L}, \frac{\lambda}{L}, \frac{d}{L}\right) \qquad (4)$$

It can be noticed that the significant parameters for the floating plate, given by Eq.4, are the same as the significant parameters for the fixed plate, obtained by Şendil (1973).

A comparison of the floating plate experiments of this study was made with John's (1949) theory (see Eq.1) and is presented in Fig.3. However, it should be pointed out that in John's (1949) theory, the plate length, λ, is represented by the diameter, D, of a flat cylinder. It is believed that this does not present a problem when comparing theory with experiments. The experimental data of Wiegel et al. (1962) and of Wiegel (1964, p.141) are also included. It can be seen from Fig.3 that there is some agreement of the present data with John's (1949) theory.

Wiegel et al.'s (1962) data for a 3.05 m by 3.05 m by 10 cm bag (10 ft by 10 ft by 4 inch) filled with water under pressure also seem to follow the general trend of the theoretical curve of John (1949). Their incident wave heights ranged from 2.80 to 6.70 cm (0.092 to 0.220 ft) and the wave periods ranged from 0.72 to 3.94 seconds.

Experimental data from Wiegel (1964, p.141) for plastic and rubber sheets fall above the theoretical curve, whereas the data for plywood fall below the curve. This indicates that materials of large mass and small elasticity are apparently more effective in damping the waves than materials of small mass and large elasticity. Hence, the plywood damped the waves more effectively than the plastic sheets. The plywood and plastic sheets used by Wiegel (1964) were 152 cm (5 ft) in length, with holes, and subjected to wind generated waves in a water depth of 15.2 cm (0.5 ft).

The relative depth, d/L, was used as parameter in Fig.3. There was no evident dependence of H_T/H_I upon d/L. However, in general, larger d/L ratios are associated with larger λ/L ratios and smaller transmission coefficients, H_T/H_I, whereas smaller d/L ratios are associated with smaller λ/L ratios and larger transmission coefficients, H_T/H_I.

Comparing floating plates with fixed plates (see Şendil, 1973; p.112) it was concluded that a floating plate is less effective in damping the incident waves than a fixed plate of the same length.

As it can be seen in Fig.3, the present data compare favorably with John's (1949) theory for floating plates. However, a further correlation was made by proposing the following relation:

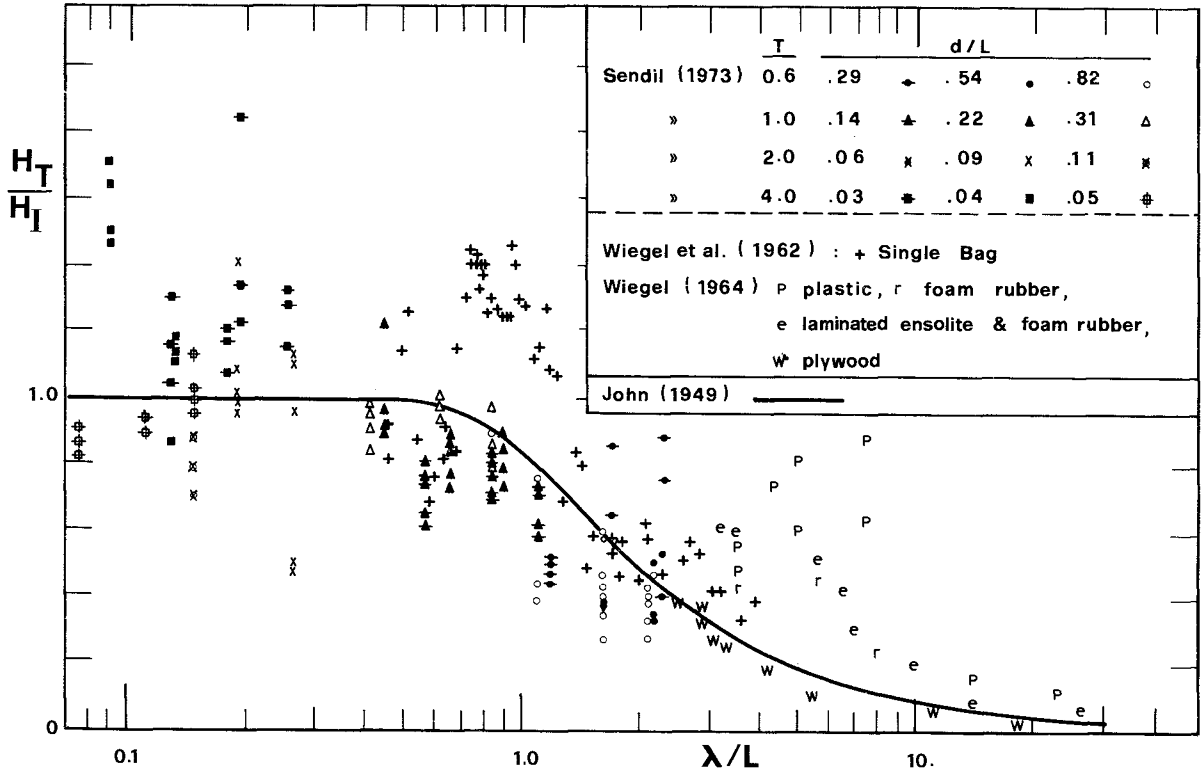


Fig. 3 Transmission Coefficient, H_T/H_I, vs. Relative Plate Length, λ/L; d/L as Parameter (Floating Plate)

$$\frac{H_T}{H_I} = \alpha_1 . C_T \qquad (5)$$

where α_1 is a correction factor depending upon the wave steepness, H_I/L, and C_T is the transmission coefficient from John's (1949) theory, which can be obtained by using Eq.1 and the law of conservation of energy. Values of α_1 are plotted against wave steepness on a logarithmic paper in Fig.4. The plate lengths included in this plot are 61, 91, and 122 cm (2, 3, and 4 ft).

A linear curve is eye-fitted to the plotted points in Fig.4. For a very small wave height, H_I, and/or a very long wave length, L, or for $H_I/L \to 0$, it can be deduced that John's (1949) theory should be valid and hence $\alpha_1 \to 1$. Therefore, α_1 must pass through unity. As it can be seen in Fig.4, there is a very weak relationship between α_1 and H_I/L -- that means the present data and John's (1949) theory agree well, which already was noticed in Fig.3. This in turn indicates that John's theory predicts wave transmission coefficient, H_T/H_I, satisfactorily.

A weak relationship between α_1 and H_I/L is again seen when Wiegel et al.'s (1962) data for the 10 ft single bag are plotted; see Fig.5.

In summary, the wave steepness, H_I/L, yields a weak relationship, and the relative depth, d/L, does not yield a detectable relationship with the wave transmission coefficient, H_T/H_I, for floating plates. Therefore, Eq.4 can be written as:

$$\frac{H_T}{H_I} = f\left(\frac{\lambda}{L}\right) \qquad (6)$$

which is made up of the same significant parameters as used in John's (1949) theory.

CONCLUSIONS

The present investigation was concerned with the study of wave height and energy transmitted beyond a floating horizontal plate. Experiments were carried out with regular waves having different heights and periods. The following conclusions may be drawn from the experimental results.

(i) A comparison of Sendil's (1973) data with John's (1949) theory (see Fig.3) showed that the transmission coefficients, H_T/H_I, obtained from the present experiments are in overall agreement with the theoretical values.

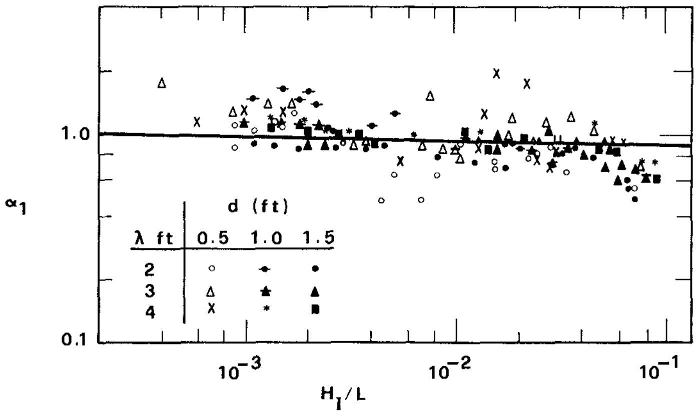


Fig. 4 α_1 vs. H_I/L for Floating Plate

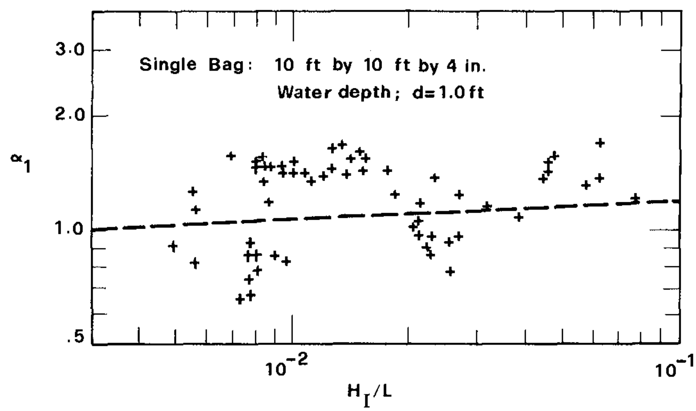


Fig. 5 α_1 vs. H_I/L for Floating Bag

(After Wiegel et al.,1962)

(ii) John's (1949) theory predicts the transmission coefficient, H_T/H_I, -- Eq.1 -- reasonably well for a plywood plate, moored to the bottom and subjected to non-breaking incident waves of finite amplitude.

(iii) A floating plate is less effective in damping the incident waves than a fixed plate of the same length (see Şendil 1973). A floating plate will have an effective damping of the incident waves if its length is several times the incident wave length.

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NOTATIONS

Fr	=	Froude number defined as $U_m/\sqrt{gd}$
g	=	gravitational acceleration
H_I	=	incident wave height
H_R	=	reflected wave height
H_T	=	transmitted wave height
H_R/H_I	=	reflection coefficient
H_T/H_I	=	transmission coefficient
k'	=	roughness of the bottom of the wave flume
L	=	local wave length
L_o	=	deep water wave length
Re	=	plate Reynolds number defined as $(U_m\lambda/\nu)$
s	=	thickness of plate
T	=	wave period
U	=	horizontal component of orbital velocity
U_m	=	maximum horizontal component of orbital velocity
α_1	=	a correction factor, defined by Eq. 5
ε	=	roughness of plate
λ	=	length of plate
μ	=	fluid viscosity
ρ	=	fluid density