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DRAG TESTS ON PIPE-TIRE FLOATING BREAKWATERS

by Craig T. Bishop

Canada

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ABSTRACT

Drag tests on 1:12 scale models of Pipe-Tire floating breakwaters have been performed in a towing tank. Results of these tests provide guidelines for the selection of a suitable tow boat for towing this type of breakwater and for the estimation of mooring forces exerted by unidirectional currents on Pipe-Tire floating breakwaters.

SOMMAIRE

On a procédé dans un bassin d'essai à des tests de résistance de modèles de brise-lames flottants, à l'échelle de 1/12, faits de tuyaux et de pneus. Les résultats de ces tests fournissent des lignes directrices en vue du choix d'un remorqueur convenable pour tirer ce type de brise-lames et de l'évaluation des forces exercées par les courants unidirectionnels sur les brise-lames amarrés.

MANAGEMENT PERSPECTIVE

This report compliments available data and the manual on the design of floating tire breakwaters. The tests reported provide a means to compute the towing forces when moving the breakwater. In addition, the tests provide a method to estimate forces on breakwaters moored in tidal current areas. The design data will be incorporated in the final design manual.

T. Milne Dick
Chief, Hydraulics Division
December 18, 1981

PERSPECTIVE - GESTION

Le présent rapport complète les données disponibles et le manuel de conception de brise-lames flottants. Les tests ont fourni un moyen de calculer la force de traction au cours du déplacement du brise-lames. En outre, ils offrent une méthode d'estimation des forces auxquelles sont soumis les brise-lames amarrés dans les zones exposées aux courants de marées. Les données de conception seront ajoutées à la dernière édition du manuel.

T. Milne Dick
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Le 18 décembre 1981

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1.0 INTRODUCTION

The purpose of this study was to determine the drag force exerted on Pipe-Tire floating breakwaters as a function of towing velocity. Information concerning the drag force is of interest to those who tow this type of breakwater (from construction site to moorage or from moorage to winter storage location) as well as for analytical purposes (e.g. Harms, 1979). Furthermore, the information enables the estimation of mooring forces exerted on this type of breakwater by a unidirectional current such as a tidal or river current.

2.0 TEST FACILITIES

Tests were conducted in the 122 m long x 5 m wide x 2.7 m deep towing tank in the Hydraulics Laboratory of the National Water Research Institute. The Pipe-Tire breakwater models were made from 8.5 cm diameter tires and 4 cm diameter aluminum pipes; a schematic of a Pipe-Tire breakwater section is shown in Figure 1.

A wooden frame was attached to the underside of the towing carriage and two cantilevered strain gauges were mounted on the frame. The floating tire breakwater models were connected to the strain gauges by 0.81 mm diameter steel wire. The forces exerted on the strain gauges could be considered horizontal as the towing wires were 100 cm long and the wires were connected to the gauges at an elevation of only 10 cm above the water surface. The strain gauges were connected to an oscillographic chart recorder. The test configuration is illustrated in Figure 2.

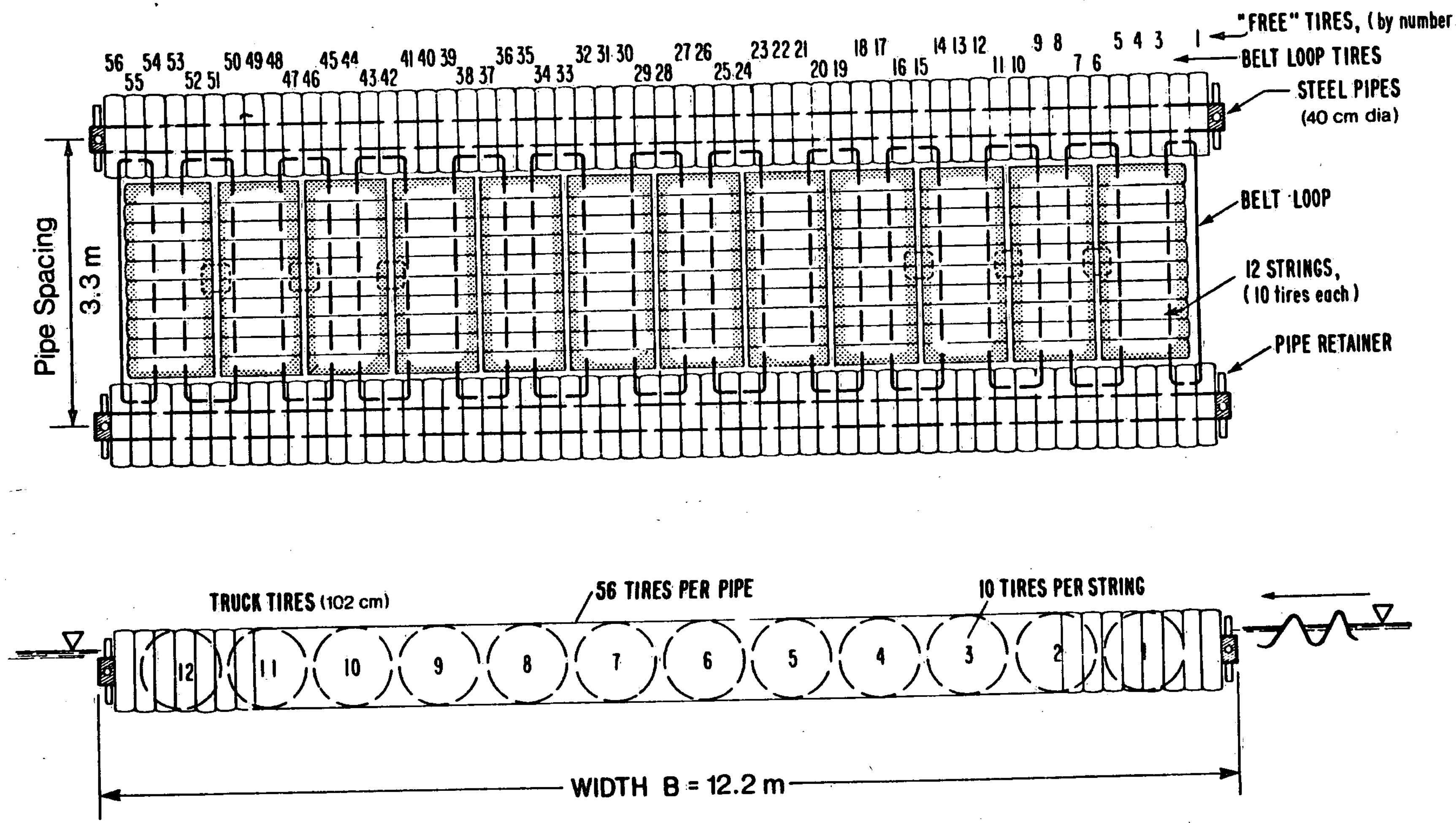

Figure 1 Views of a PT-breakwater section (after Harms and Westerink, 1980)

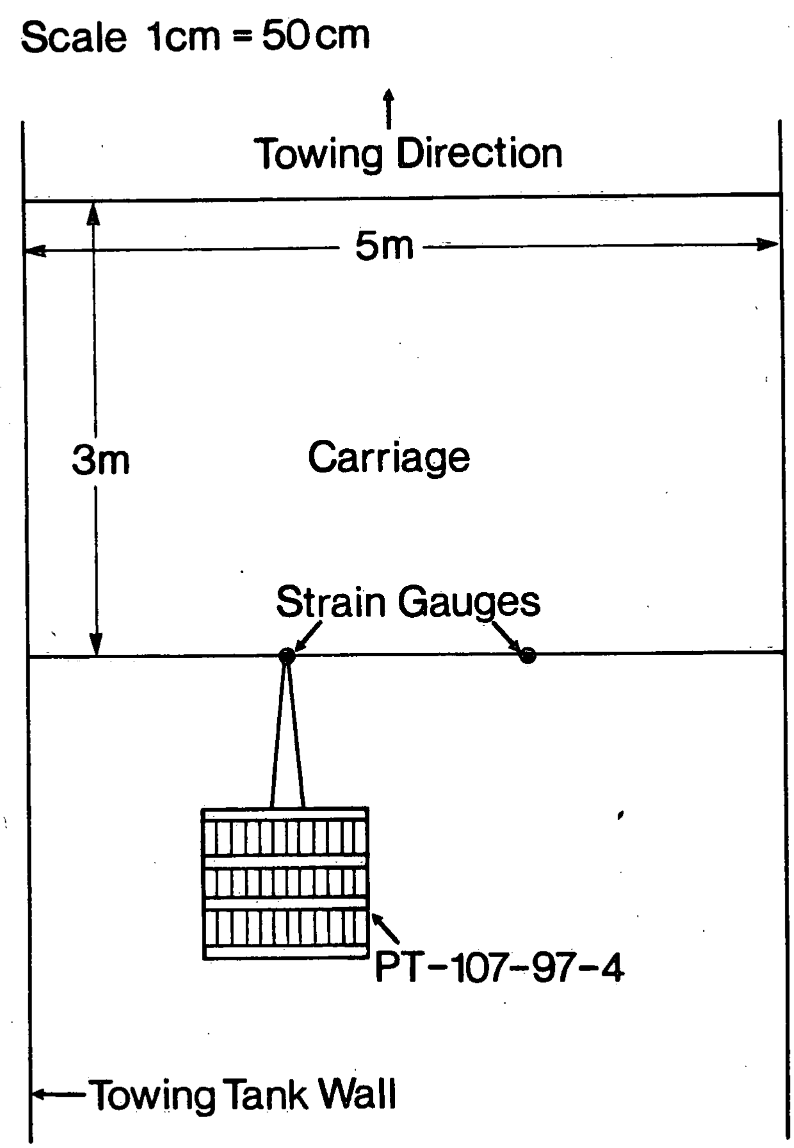

Figure 2 Test Configuration

3.0 TEST PROCEDURE

The strain gauges were calibrated elsewhere by applying known static loads and recording the voltage output on an oscillographic chart recorder. Pre and post test calibration results were virtually identical.

The test procedure consisted of the following:

- Placing one or two models in the towing tank.
- Connecting model(s) to the strain gauge(s). Both of the wider models (PT-165-60-2, PT-184-107-7) were connected to both strain gauges.
- Turning on the chart recorder.
- Towing the models, gradually increasing the speed to a preselected speed. After the drag forces were observed to be steady, the towing speed was gradually increased to the next chosen speed, and so on.

The drag coefficient C_D is defined as

$$C_D = \frac{D_f}{\rho A \frac{U^2}{2}}$$

where	D_f	=	drag force
	ρ	=	density of water
	A	=	cross-sectional area of the model normal to the towing direction
	U	=	towing speed

The towing speed was read from the control panel on board the towing carriage. The cross-sectional area of a model was calculated as the product of the tire diameter and the breakwater width (normal to the towing direction).

The Froude number F_r was calculated as

$$F_r = \frac{U^2}{g D}$$

where	g	=	gravitational acceleration
	D	=	tire's outside diameter

Typical prototype car and truck tires have outside diameters of 0.6 and 1.0 m respectively. Realistic prototype towing speeds would be from 0 to 1 m/s, giving values of F_r less than 0.17. The model breakwaters were tested over a range of F_r from 0 to 1.

Pipe-Tire breakwater models are designated by the notation

PT - XX - YY - Z

where	XX	=	width (cm) normal to the towing direction
	YY	=	lengt (cm) in the towing direction = ℓ
	Z	=	number of pipes in the model

4.0 RESULTS

In a prototype towing situation, a Pipe-Tire breakwater would be towed with the pipes oriented to the towing direction. Results of tests in this configuration are summarized in Table 1 and Figure 3. Two interesting trends can be seen in Figure 3. First, the drag coefficient exhibits only a weak trend to increase with ℓ/D (compare results of PT-107-155-6 and PT-107-184-7 to other PT-107 results) at least for $4.7 \leq \ell/D \leq 21.6$. Second, at low Froude numbers, less than about 0.4, C_D increases only weakly with F_r. For most prototype towing situations ($0 \leq F_r \leq 0.17$) the drag coefficient can be estimated at 0.6.

At rest, the breakwater models float with the waterline at the top of the pipes, meaning that the tires are roughly 80 percent submerged. The leading pipe submerges more and more with increasing towing speed, and becomes fully submerged at a speed of 0.6 m/s (F_r=0.43). This increasing submergence of the leading tire-armoured pipe causes the effective frontal area of the breakwater model to increase. It would seem, therefore, that the mild increase in C_D as F_r increases from 0 to about 0.4 is due mainly to the gradual increase in effective frontal area of the breakwater. For values of F_r greater than about 0.4, C_D increases more strongly with F_r as the effective frontal area continues to increase and the flow pattern over the submerged leading pipe becomes more turbulent.

Model drag tests on a rectangular barge reported by Hoerner (1965, p. 11-6) show a drag coefficient of 0.90 as the Froude number approaches zero. This coefficient was calculated using the statically submerged frontal area of the barge. After multiplying by 0.80 so as to be comparable to this study's calculations (total frontal area at rest), the Hoerner result is shown in Figure 3. It compares well with the present results and, as expected, is slightly greater than the drag coefficients for the more porous Pipe-Tire breakwaters at small values of F_r.

Tests were also conducted by towing the Pipe-Tire breakwater models with the pipes parallel to the towing direction. This is similar to the real life oscillatory flow situation in which the direction of wave approach is parallel to the pipes in a Pipe-Tire breakwater. Results are given in Table 2 and Figure 4. As F_r increases, the leading tire-strings deflect inward and downward in an arc-like manner thereby increasing the breakwater's effective frontal area. This increase in effective frontal area leads to much higher values of C_D than for

TABLE 1. Drag Test Results for PT-Breakwaters with Pipes Normal to the Towing Direction

U (m/s)	$\frac{U^2}{gD}$	PT-40-94-4 D_f (N)	PT-40-94-4 C_D	PT-160-65-2 D_f (N)	PT-160-65-2 C_D	PT-107-40-2 D_f (N)	PT-107-40-2 C_D	PT-107-68-3 D_f (N)	PT-107-68-3 C_D	PT-107-97-4 D_f (N)	PT-107-97-4 C_D	PT-107-126-5 D_f (N)	PT-107-126-5 C_D	PT-107-155-6 D_f (N)	PT-107-155-6 C_D	PT-107-184-7 D_f (N)	PT-107-184-7 C_D
0.2	0.0480			1.04	0.38	0.93	0.51	1.04	0.57	1.04	0.57	1.04	0.57	1.04	0.57	1.04	0.57
0.3	0.108	1.15	0.75	2.30	0.38	2.08	0.51	2.60	0.63	2.08	0.51	2.08	0.51	2.60	0.64	2.60	0.63
0.4	0.192			4.42	0.41	3.38	0.46	4.16	0.57	4.16	0.57	4.16	0.57	4.68	0.65	5.20	0.71
0.5	0.300	3.64	0.86	8.32	0.49	6.24	0.55	6.50	0.57	6.76	0.60	6.76	0.60	7.80	0.68	8.32	0.73
0.6	0.432			21.8	0.89	13.0	0.79	12.7	0.78	12.7	0.78	12.0	0.73	12.0	0.73	14.6	0.89
0.7	0.588			35.4	1.06	19.8	0.89	20.8	0.93	19.8	0.88	19.8	0.88	21.3	0.96	22.4	1.00
0.75	0.675	10.4	1.09														
0.8	0.768			49.9	1.15	30.2	1.04	31.7	1.09	29.4	1.01	31.7	1.09	30.2	1.04	32.2	1.11
0.9	0.971			67.6	1.23	41.6	1.13	45.8	1.24	44.7	1.21	44.7	1.21				
1.0	1.200	19.2	1.13	89.9	1.32												
1.25	1.874	32.8	1.23														

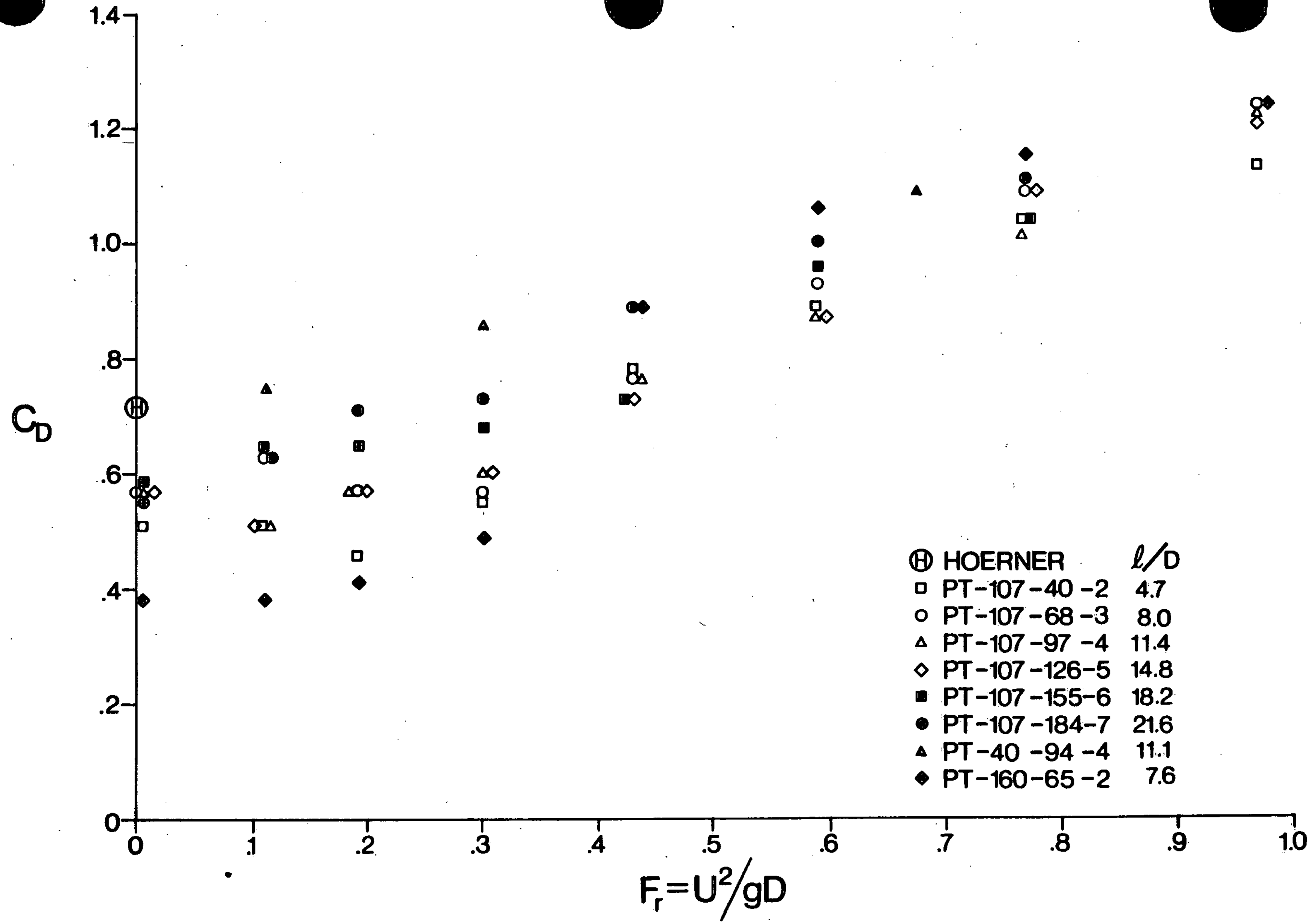

Figure 3 Results of drag tests for pipe-tire breakwaters towed with pipes normal to towing direction.

TABLE 2. Drag Test Results for PT-Breakwaters with Pipes Parallel to Towing Direction

U (m/s)	$\frac{U^2}{gD}$	PT-40-107-2		PT-65-160-2		PT-184-107-7	
		D_f (N)	C_D	D_f (N)	C_D	D_f (N)	C_D
0.2	0.0480					1.56	0.50
0.3	0.108	1.09	0.71	1.82	0.73	4.42	0.63
0.4	0.192					9.36	0.75
0.5	0.300	3.12	0.73	10.4	1.51	16.1	0.82
0.75	0.675	10.4	1.09	30.2	1.94		
0.85	0.866			41.6	2.08		
1.0	1.200	25.2	1.48				
1.25	1.874	44.7	1.68				

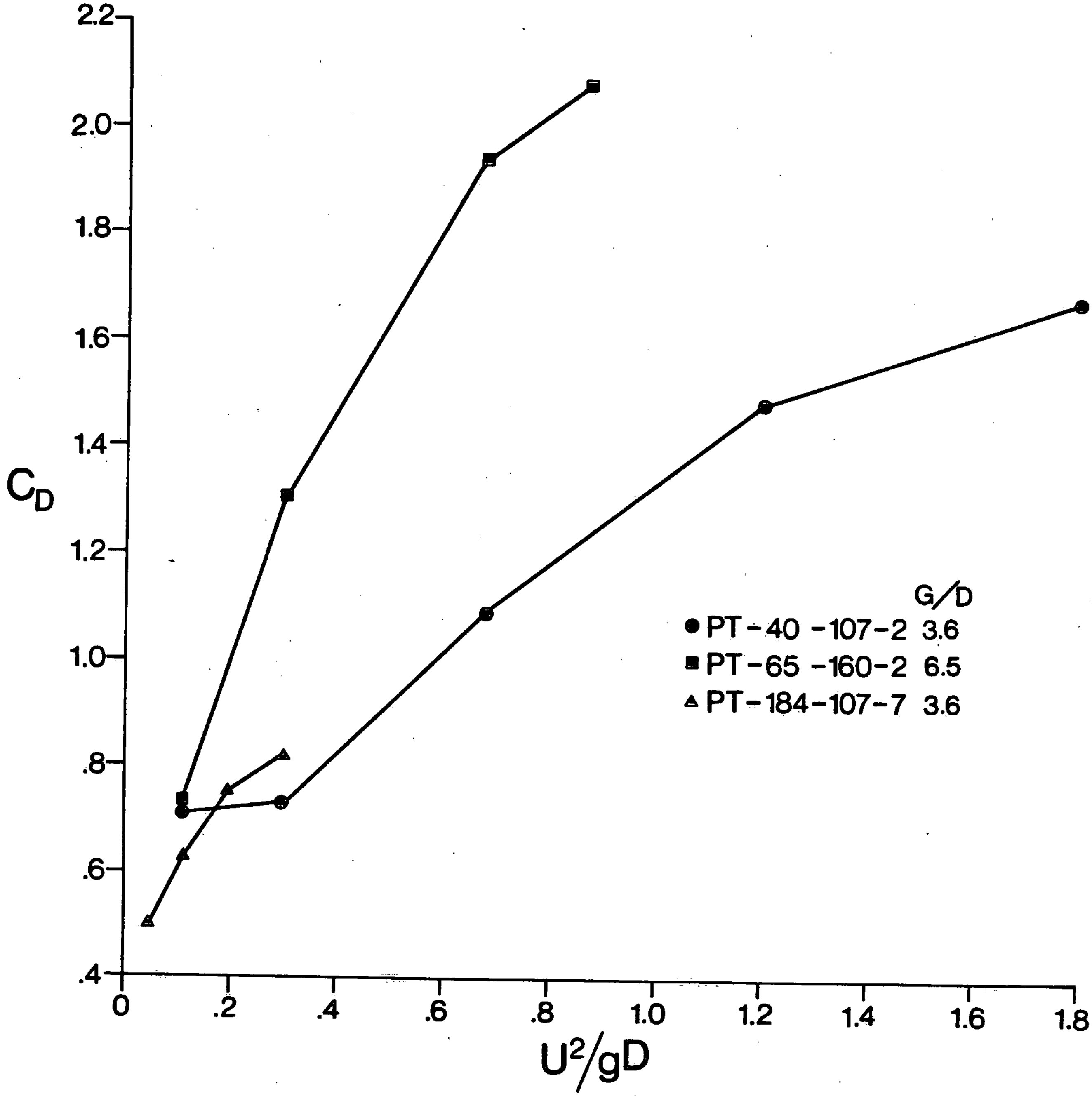

Figure 4 Results of drag tests for pipe-tire breakwaters towed with pipes parallel to towing direction.

breakwaters towed with the pipes normal to the towing direction at comparable values of F_r.

The drag coefficient also increases with increasing pipe spacing, G, as shown in Figure 4 where the results for the PT-65-160-2 model, with G/D=6.5, are much greater than those of the other two models with G/D=3.6. This trend can also be attributed to the effective frontal area increasing with an increase in the pipe spacing.

It is a well-known fact (Harms, 1979; Bishop, 1980; Harms et al, 1981) that the wave attenuation of a Pipe-Tire breakwater improves with increasing wave steepness. The leading tire-strings have been observed to deflect considerably (in an oscillatory manner) when under attack by short, steep waves. Also, the maximum orbital velocity of a water particle in a wave increases with increasing wave steepness (airy wave theory). Thus, both the effective frontal area and maximum orbital velocity tend to increase with increasing wave steepness, thereby producing relatively high values of F_r and C_D. Other things being equal, large values of C_D should enhance wave energy dissipation.

5.0 INERTIAL FORCES

The force required to overcome inertia in accelerating a floating breakwater at rest to a steady speed is

$$F_i = C_m M \, dU/dt$$

where C_m = hydrodynamic-mass coefficient
M = mass of fluid displaced by FTB

Knowledge of the inertial force is important in selecting a boat to tow the FTB from one site to another, as well as for analytical purposes. The values of F_{peak} and dt were estimated from the chart recordings. A typical chart recording is shown in Figure 5. Values of C_m were estimated using an average value of the accelerating force, 0.5 (F_{peak} $-D_f$), over dt. Results are given in Table 3. The values of C_m range from 0.99 to 1.51, averaging about 1.35.

TABLE 3. Inertial Test Results for PT-Breakwaters

Model	U_1 (m/s)	U_2 (m/s)	dt (s)	$\frac{dU}{dt}$	M (kg)	F_{peak} (N)	D_f (N)	$\frac{(F_{peak}-D_f)}{2M\ dU/dt} = C_m$
Pipes Normal to the Towing Direction								
PT-40-94-4	0	.3	1.0	.3	32	27.6	1.30	1.37
PT-160-65-2	0	.1	1.5	.067	88	17.7	0	1.51
PT-107-40-2	.1	.2	1.0	.1	36	9.10	0.93	1.13
PT-107-68-3	0	.2	1.0	.2	62	37.7	1.56	1.46
PT-107-97-4	0	.2	1.5	.133	89	35.4	2.08	1.50
PT-107-126-5	0	.2	1.5	.133	113	38.0	1.56	1.21
PT-107-155-6	0	.2	1.5	.133	139	49.9	1.56	1.31
PT-107-182-7	0	.2	2.0	.1	166	43.2	1.56	1.26
								1.34 Avg.
Pipes Parallel to the Towing Direction								
PT-40-107-2	0	.3	1.0	.3	36	30.7	1.04	1.37
PT-65-160-2	0	.3	2.0	.15	88	36.4	1.56	1.32
PT-184-107-7	0	.2	1.5	.133	166	62.4	2.08	1.37
								1.35 Avg.

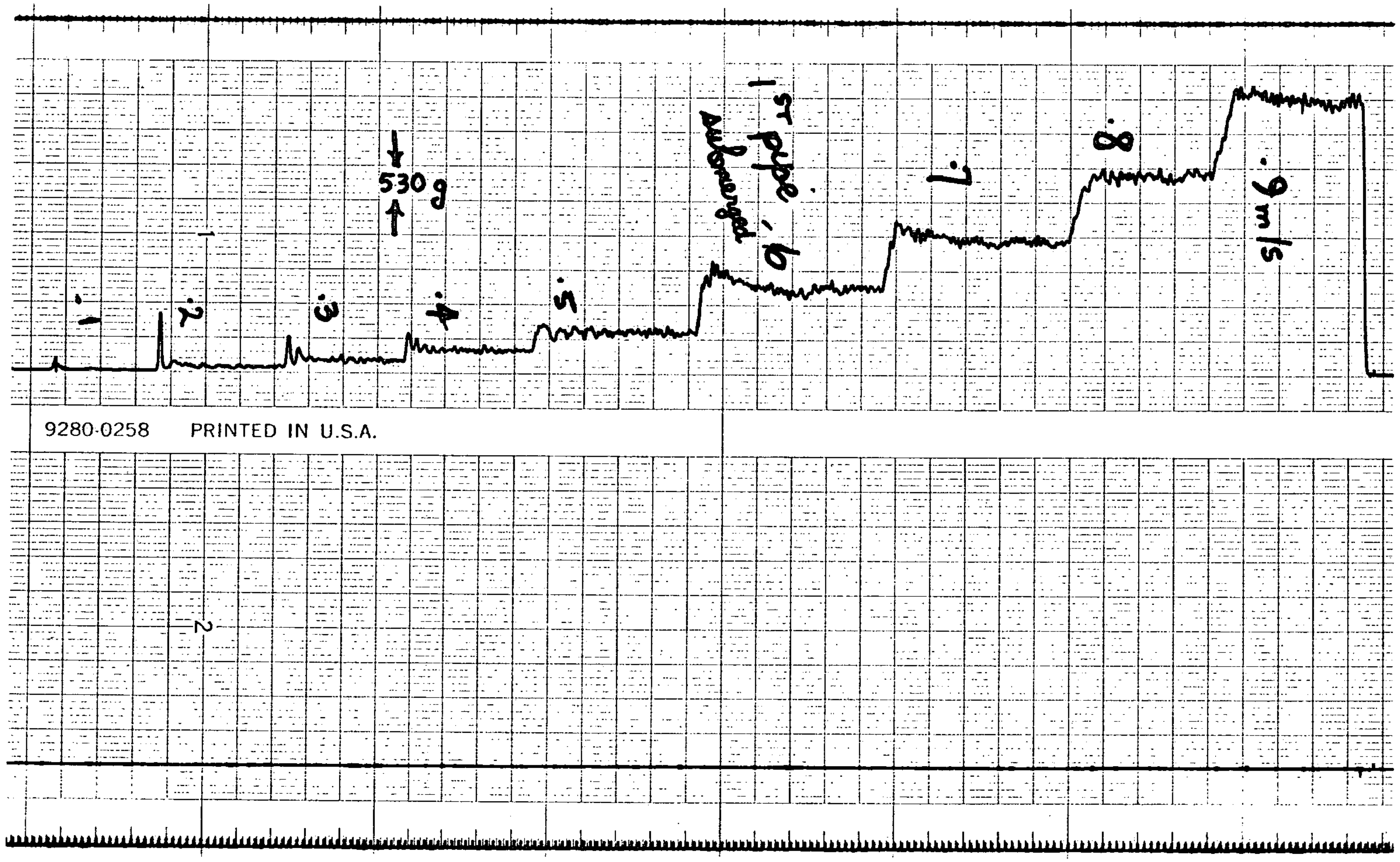

Figure 5 Strain gauge chart recording for PT-107-40-2 test with pipes normal to the towing direction

6.0 PRACTICAL APPLICATION

Suppose a Pipe-Tire breakwater constructed of truck tires, with overall dimensions of 100 m x 12 m x 1 m, is to be towed from one site to another at a speed of 0.5 m/s. Neglecting drag on the tow boat, assuming no currents, and that the tow line is long enough to avoid an opposing current caused by the tow boat's propeller, what force is required to tow the breakwater ? In addition, what mooring force would be exerted on the breakwater by a 2 m/s tidal current acting in a direction parallel to the pipes ?

6.1 Inertial Force

$$F_i = C_m M \frac{dU}{dt}$$

$$C_m \simeq 1.4$$

$$M = 100 \text{ m} \times 12 \text{ m} \times 1 \text{ m} \times 1000 \text{ kg/m}^3 = 1.2 \times 10^6 \text{ kg}$$

$$U = 0.5 \text{ m/s}$$

dt (s)	F_i (N)
5	168 000
10	84 000
15	56 000
30	28 000
60	14 000

Clearly, the inertial force is sensitive to the acceleration of the breakwater.

6.2 Drag Force

$$D_f = C_D \rho A \frac{U^2}{2}$$

$$U^2/gD = 0.025, \text{ so } C_D \simeq 0.6$$

$$D_f = 0.6 \times 1000 \text{ kg/m}^3 \times 12 \text{ m} \times 1 \text{ m} \times \frac{0.5^2}{2}$$

$$= 900 \text{ N}$$

Thus the inertial force is much greater than the drag force. Once a steady towing speed has been attained, the drag force is modest. An opposing current of 0.5 m/s would increase the drag force to 3600 N.

The rated thrust of an inboard or outboard engine can be obtained from the manufacturer. For example, an 80 hp Mercury Marine outboard engine with an 11 inch pitch and 14 inch diameter propellor has a rated thrust of 4670 N (1050 lb) determined in a static test (Mercury Marine Limited, private communication).

6.3 Tidal Current Mooring Force

$$U^2/gD = 2^2/9.81 \times 1 = 0.41$$

From Figure 4 with G/D = 3.6, get $C_D \simeq 0.8$

$$D_f = 0.8 \times 1000 \times 1 \times 1 \times 2^2/2$$
$$= 1600 \text{ N/m}$$

Thus a tidal current of 2 m/s would exert a force of about 1600 N per metre length of breakwater. This can be compared to the force exerted on a Pipe-Tire breakwater by a 1.0 m wave height of about 2900 N per metre length of breakwater (Harms et al, 1981, with water depth $d \gtrsim 4.5$ D and wavelength $L \lesssim 20$ D). In some cases, the mooring forces exerted by currents could govern the design of the breakwater's mooring system.

7.0 CONCLUSIONS

7.1 In a practical towing mode, with the pipes normal to the towing direction, the drag coefficient of a Pipe-Tire floating breakwater increases with the Froude number (mainly because of an increasing effective frontal area due to the submergence of the leading pipe) and increases weakly with the breakwater length. A value of C_D=0.6 can be used for most prototype towing applications ($0 \leq F_r \leq 0.17$).

7.2 In a practical wave attenuating mode, with the pipes parallel to the direction of wave advance, the drag coefficient of a Pipe-Tire floating breakwater increases strongly with increasing Froude number and pipe spacing (mainly because of an increasing effective frontal area due to the deflection of the leading tire-strings).

7.3 In a practical towing situation, the inertial forces induced in accelerating a Pipe-Tire floating breakwater are one or two orders of magnitude larger than the drag forces.

7.4 The results of these drag tests can be useful for design purposes in estimating the mooring forces exerted on a Pipe-Tire floating breakwater by unidirectional currents.

ACKNOWLEDGEMENT

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