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EXPERIMENTAL STUDY OF A PERMEABLE SLOPING WAVE ABSORBER

by Vahid Chegini

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Title

EXPERIMENTAL STUDY OF A PERMEABLE SLOPING WAVE ABSORBER

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Supplementary Notes

The work reported was carried out and published under the direction of the Director of the Water Research Laboratory.

Abstract

Wave absorbers are used in wave basins to minimise the reflected wave height from the boundaries of the basin.

This report presents the results of a series of laboratory tests on a permeable sloping absorber made of artificial horse hair material. The experiments were carried out in the 0.9 m wide wave flume of the Water Research Laboratory of the University of New South Wales (WRL).

The experimental results indicated that the employed absorber can be as effective as a beach absorber made of sand or gravel materials. The best performance of the absorber, as was anticipated, was obtained for the nimimumsurface slope of the structure. With this slope the coefficient of wave reflection was generally less than 6% for incident wave steepness (! ^ H sub i ^/ L ^ !) ranging from 0.01 to 0.10.

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ABSTRACT

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The experimental results indicated that the employed absorber can be as effective as a beach absorber made of sand or gravel materials. The best performance of the absorber, as was anticipated, was obtained for the minimum surface slope of the structure. With this slope the coefficient of wave reflection was generally less than 6% for incident wave steepness (H_i / L) ranging from 0.01 to 0.10.

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CONTENTS

ABSTRACT i
CONTENTS ii
LIST OF PHOTOGRAPHS iii
LIST OF FIGURES iii
LIST OF SYMBOLS iv
1.0 INTRODUCTION 1
1.1 The Scope of The Study 1
1.2 Summary of Previous Investigations on Beach Type Absorbers 1
2.0 LABORATORY TESTS 5
2.1 The Absorber Characteristics 5
2.1.1 Permeability and porosity of the artificial horse hair 5
2.2 Experimental Facilities 6
2.2.1 Wave flume 6
2.2.2 Instrumentation and data acquisition 6
2.3 Data Analysis 6
2.4 The Wave and The Absorber Parameters 7
3.0 EXPERIMENTAL RESULTS 8
3.1 Discussions 8
3.2 Conclusions 9
REFERENCES 10
APPENDIX

LIST OF PHOTOGRAPHS

Photo No.	Description
1	The permeable sloping absorber after installation
2	The permeable sloping absorber during the tests
3	View of the permeable sloping absorber installed in the shallow water part of the wave flume
4	Breaking of waves on the wave absorber
5	Breaking of waves in front of the wave absorber

LIST OF FIGURES

Figure No.	Description
1	Head losses through artificial horse hair
2	Layout of WRL wave flume
3	Wave reflection coefficient as a function of incident wave steepness, for $S = 0.10$
4	Wave reflection coefficient as a function of incident wave steepness, for $S = 0.15$
5	Wave reflection coefficient as a function of incident wave steepness, for $S = 0.20$
6	Effect of the absorber slope upon the coefficient of wave reflection
7	Wave reflection coefficient as a function of surf similarity parameter
8	Illustrative comparison between the results of the present study and the data from Herbich (1956) for crushed rock absorbers

LIST OF SYMBOLS

Symbols	Description	Units
0	Subscript: Deepwater	-
a	Wave amplitude	m
a	Linear Forchheimer coefficient	$(m/s)^{-1}$
b	Non-linear Forchheimer coefficient	$(m/s)^{-2}$
b / a^2	Non - Darcy flow parameter	-
C	Coefficient of non-linear effective hydraulic conductivity	m / s
h	Water depth, also: Hydraulic head	m
H	Wave height	m
i	Subscript: Incident	-
I	Hydraulic gradient	-
K_r	Coefficient of wave reflection	-
l	Absorber length, also: Distance in direction of flow	m
L	Wave length	m
m	Empirically determined coefficient in equation (8)	-
n	Empirically determined coefficient in equation (8)	-
r	Subscript: Reflected	-
S	Absorber slope	-
T	Wave period	s
V	Flow velocity	m / s
α	Empirically determined coefficient in equations (4) and (5)	-
β	Empirically determined coefficient in equations (4) and (5)	-
γ	Coefficient of Miche's formula	-
θ	Angle of the absorber slope with the horizontal	rad
ξ	Surf similarity parameter	-

1.0 INTRODUCTION

1.1 The Scope of The Study

Wave absorbers are used for dissipation of wave energy at the end of a wave flume or along the rigid boundaries of a wave basin. Normally, for the beach absorbers, the length required to provide sufficient dissipation of the wave energy is at least one wave-length from the basin wall. It is desirable that the reflection coefficient which is defined as the ratio of the reflected wave height to the incident wave height ($K_r = H_r / H_i$) be less that 5%.

According to the research of Ouellet and Datta (1986), the most commonly wave absorbers used in laboratories throughout the world are sand, gravel, stone or concrete beaches. The slopes of these absorbers are usually 1:10.

During '1993 an experimental study was conducted in the Water Research Laboratory of the University of New South Wales (WRL), upon the design of wave filters and wave absorbers composed of perforated plates. To attenuate the energy of transmitted waves through the wave filters, a permeable sloping absorber made of artificial horse hair was erected at the shallow water part of the 0.9m wide wave flume of WRL. The efficiency of the sloped end absorber was examined by measuring the incident and reflected waves seaward of the absorber.

1.2 Summary of Previous Investigations on Beach Type Absorbers

Miche (1951) suggested a technique for prediction of wave reflection from an impermeable sloping beach. He showed analytically that the maximum steepness of waves in deepwater, which will be totally reflected, δ_m, is:

$$\delta_m = \left(\frac{H_0}{L_0}\right)_{critical} = \left(\frac{2\theta}{\pi}\right)^{1/2} \frac{\sin^2\theta}{\pi} \qquad (1)$$

where:

H_0 deepwater wave height

L_0 deepwater wave length

θ angle of the structure slope with the horizontal in radians

Ursell, Dean and Yu (1960) illustrated that predictions using Miche's approach may be conservative by a factor of two.

One of the considered boundary conditions by Miche was the assumption of zero normal velocity at the surface of the structure (i.e. an impermeable installation). To consider the roughness and permeability of the barrier, he introduced an empirically determined coefficient, γ, which was a function of the porosity and the roughness of the slope and independent of θ. The reflection coefficient of an impermeable rough slope (e.g. a revetment), or a permeable surface (such as a beach or a rubble mound breakwater), may be expressed in the following form:

$$K_r = \frac{H_r}{H_i} = \gamma\left(\frac{H_0}{L_0}\right)_{critical} / \left(\frac{H_0}{L_0}\right)_{actual} \tag{2}$$

γ for a permeable surface is less than for an impermeable slope of considerable roughness. This parameter can only be estimated empirically or by direct measurement.

Schoemaker and Thijsse (1949), Healy (1953), Greslou and Mahe (1954) and Moraes (1970) studied the performance of impermeable wave absorbers experimentally.

The Beach Erosion Board (1949) reported data on the reflective specifics of different simple structures. These data were based on experiments made with solitary waves. It was concluded that:

- More efficient absorption is obtained with porosities of 60 to 80 percent.

- Using a porous rock wall bounded by vertical walls and backed by open water, the maximum absorption was obtained for $l / h > 2.5$, where l is the length of the absorber and h is the water depth.

Straub, Bowers and Herbich (1958) carried out some experiments on the following structures: *i)* permeable material consisting of corrugated wire mesh with a porosity of about 93 percent, *ii)* absorbers of gravel, crushed rock and perforated plates, *iii)* absorbers composed of transverse square rods, spaced to produce a porosity of about 70 percent, and *iv)* impermeable surfaces.

They used the values of wave steepness (H_i / L) ranging from 0.005 to 0.08 and relative depth (h / L) ranging from 0.10 to 1.65. Some results of the study are summarised as follows:

- Absorber length is minimised when the absorber is made of high permeable materials like wire mesh screens.

- Crushed rock beaches with low surface slopes, narrow size gradation and high porosity could be as effective as the wire mesh absorbers.

- For constant slope, K_r decreases with increasing wave steepness.

- For constant wave steepness, K_r decreases as the slope decreases.

- Computed γ factor for crushed rock absorbers in Miche's formulae was 0.11 (for $H / L = 0.01$) to 0.19 (for $H / L = 0.07$). Also calculated γ parameter for wire mesh absorber with a surface slope of 15 degree was 0.09 (for $H / L = 0.01$) to 0.19 (for $H / L = 0.07$).

Goda and Ippen (1963) performed a series of experiments on vertical wire mesh screens aligned normally to the direction of wave propagation. To attenuate the transmitted wave energy through the main vertical absorber, they used a small absorber of the permeable sloping beach type placed at the end of the channel. This absorber was composed of 40 sheets of galvanised wire mesh screen. The porosity of the absorber, which was backed by an aluminium plate was 92 percent. Goda et. al. reported that the measured coefficients of reflection were generally less than 7 percent.

Lean (1967) presented a theoretical approach to determine the coefficient of reflection of waves from three shapes of permeable wave absorbers (i.e. with parabolic, triangular and rectangular cross sections), when the resistance coefficient of the absorber material is known. He used the linearized long waves theory to analyse the behaviour of these absorbers. Lean indicated that :

- The minimum required length of the absorber to reduce the coefficient of reflection below 10% is about $1/2$ to $3/4$ of the wave length.

- The absorber of constant slope with length of $l/2$ is as efficient as the absorber of constant depth with length of l. However, by increasing the length of the absorbers, their efficiency becomes close to one another.

- Some savings in the length of the absorber can be accomplished with using parabolic beaches.

Battjes (1974) used data from Moraes (1970) to extend an equation for the prediction of the reflection coefficient from smooth slopes. This equation is applicable for breaking waves and is conservative for non-breaking (surging) waves. He recommended the reflection coefficient to be calculated from the following equation :

$$K_r = 0.1\xi^2 \qquad (3)$$

where ξ is the surf similarity parameter , $\xi = S / \sqrt{H_i / L_0}$ and $S = \tan\theta$

Chesnutt and Galvin (1974) and Chesnutt (1978) carried out extensive laboratory tests on the reflection characteristics of sand beaches. They showed that K_r can be predicted as follows :

$$K_r = \frac{\alpha\xi^2}{\xi^2 + \beta} \tag{4}$$

so that α and β are empirically determined coefficients. They suggested β = 5.5 and α = 1 gives an upper bound for K_r and α = 0.5 gives the average value of the reflection coefficient.

Madsen and White (1976) measured reflection coefficients on smooth and rough steep-sloped structures which were subjected to non-breaking waves. They developed a model based on their experimental data which predicted the coefficients of reflection on rough slopes.

Ahrens (1980) made some tests on overtopped and non overtopped plane smooth slopes to measure the irregular wave reflection coefficients of these structures (Seeling and Ahrens, 1981)

Seelig and Ahrens (1981) presented a report on estimation of wave reflection and energy dissipation coefficients for beaches, revetments and breakwaters. They reanalysed the data collected from a number of published sources and also conducted some laboratory experiments to increase the number of available data. They proposed that the reflection coefficient of smooth slopes be predicted from one of the following equations, whichever is smaller.

$$K_r = \frac{\alpha\xi^2}{\xi^2 + \beta}$$
$$K_r = \alpha \tanh(0.1\xi^2) \tag{5}$$

where α and β are empirical coefficients to be evaluated from the laboratory data. For slopes with cotθ ≤ 6 the suggested values for α and β are 1.0 and 5.5, respectively.

2.0 LABORATORY TESTS

2.1 The Absorber Characteristics

The permeable sloping absorber was composed of two 20 mm thick layers of artificial horse hair (with the commercial name of Scotch Bright) that was covered by two weld mesh screens. The absorber was installed near the end of the wave flume. A rolled wire mesh wave absorber was placed at the end of the flume to eventually absorb any energy passing the sloping permeable absorber.

The support structure for the absorber was made of $40 \times 40 \times 1.9$ mm Dexion framing. The spacing in the down slope and cross slope directions of the support was 300 and 88 centimeters, respectively. A frame was placed on the top of the side walls of the flume to alter the slope of the absorber by means of a pulley and a cable system connected to it.

Photos (1) to (3) illustrate the wave absorber.

2.1.1 Permeability and porosity of the artificial horse hair

A sample of the artificial horse hair was confined in a test tube of 60 mm diameter to measure the permeability of the material. Water pressure head was applied to the sample by a water column supplied by the constant head tank of WRL.

The test results are plotted in figure (1). These results show that there is a non-linear relationship between the hydraulic gradient (I) and the flow velocity (V) . This relationship can be expressed in the form of Forchheimer's equation, i. e.:

$$I = aV + bV^2 \tag{6}$$

$$a = 6.6, \quad b = 46.5 \tag{6a}$$

or:

$$a = 6.6, \quad b / a^2 = 1.07 \tag{6b}$$

so that:

I	hydraulic gradient
V	flow velocity
a & b	linear and non-linear Forchheimer coefficients, respectively
b / a^2	non - Darcy flow parameter (Cox, 1976; Dudgeon, 1984)

The coefficient of non-linear effective hydraulic conductivity is defined as (Cox, 1976):

$$C = 1/[a/2 + \sqrt{a^2/4 + b|\partial h/\partial l|}] \tag{7}$$

where:

$\lvert\partial h/\partial l\rvert$	absolute hydraulic gradient
h	hydraulic head
l	distance in direction of flow

For instance, when $I = 1$ & 3 the coefficient of non-linear effective hydraulic conductivity of the artificial horse hair are calculated to be 9×10^{-2} & 6.4×10^{-2} m/s for water at 20° C, respectively.

The porosity of the horse hair was 94 percent.

2.2 Experimental Facilities

2.2.1 Wave flume

The experiments were undertaken in the 0.9 m wide, 1.75 m deep, 50 m long wave flume of WRL (fig. 2). This wave flume is equipped by a 40 kw hydraulic piston type wave maker capable of generating waves up to 25 cm height and with periods of between 0.5 and 3 seconds.

2.2.2 Instrumentation and data acquisition

Wave profiles were measured by two fixed capacitive-wire wave probes located in the deep water part of the flume. The distance between the probes was 40 cm. Lotus-Measure Software was employed to transfer the collected data to a Portable Microcomputer. Two channels of data were recorded simultaneously at a sampling rate of 50 samples per second each channel.

2.3 Data Analysis

Fourier analysis was used to evaluate the wave amplitude of the fundamental frequency. The reflection coefficients were calculated from the "two probes technique" reported by Thornton and Calhoun (1972).

2.4 The Wave and The Absorber Parameters

All the tests were carried out in water at a depth of 0.8 m. The wave periods were 1.14, 1.25, 1.50, 1.75, 2.00, 2.15, 2.25 and 2.50 seconds ($h / L = 0.125$ to 0.4). The reflection coefficient was measured for waves with steepness ratios (H_i / L) ranging from 0.003 to 0.10. Absorbers at slopes of 0.1, 0.15 and 0.2 were tested.

3.0 EXPERIMENTAL RESULTS

3.1 Discussions

_a_) Effect of wave steepness

Figures (3) to (5) illustrate the effect of wave steepness on the reflection coefficient for S = 0.1, 0.15 and 0.2, respectively. As can be observed from the figures, for a constant slope the coefficient of wave reflection decreases with increasing H_i /L . This may be partially explained by the breaking of the high-steepness waves on the absorber (Photos 4 & 5).

The best fit equation to the collected data may be expressed as the following general relationship:

$$K_r = m(H_i / L)^{-n} \tag{8}$$

so that m and n can be determined from figure (6).

_b_) Slope effect

Figure (6) demonstrates the effect of surface slope upon the coefficient of wave reflection.

The best performance of the absorber was obtained for the minimum slope of the structure, S = 0.1. With this slope K_r was generally less than 6% for the wave steepness ranging from 0.01 to 0.1.

_c_) Comparison of the results with the data from Herbich (1956)

Variation of the reflection coefficient as a function of the surf similarity parameter is depicted in figure (7). Referring to this figure, the reflection coefficient may be obtained from the following formula:

$$K_r = 0.01\ (1.1 + 1.93\ \xi + 0.7\ \xi^2) \tag{9}$$

Figure (8) shows a comparison between the results of the present study and the laboratory data reported by Herbich (1956) for crushed rock absorbers. The slopes of crushed rock absorbers were 0.15 and 0.22; the dot curve in figure (8) is the best exponential curve passed through the crushed rock absorbers data.

This figure shows that the employed absorber can dissipate the wave energy as well as crushed-rock absorbers. However, the artificial horse hair sloping permeable absorber has the following advantages:

i) Its slope may be altered very easily and quickly.

ii) It is light and can be installed simply.

iii) When a wave flume with glass walls is used, the risk of damage to the glass walls that may be caused by gravel absorber installations is overcome.

The details of experimental results are tabulated in Appendix.

3.2 Conclusions

The experimental study has indicated that :

(1) The reflection coefficient depends on the wave steepness and the slope of the absorber. This coefficient varies directly as a function of the absorber slope and varies inversely as a function of the wave steepness.

(2) The relative depth had no significant effect on the reflection coefficient for the h / L values ranging from 0.125 to 0.4 experienced in the tests.

(3) The permeable sloping absorber made of artificial horse hair can be as effective as crushed-rock absorbers and provides a light and practical solution to reflection, in either laboratory flumes or basins.

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Photo 1 - The permeable sloping absorber after installation

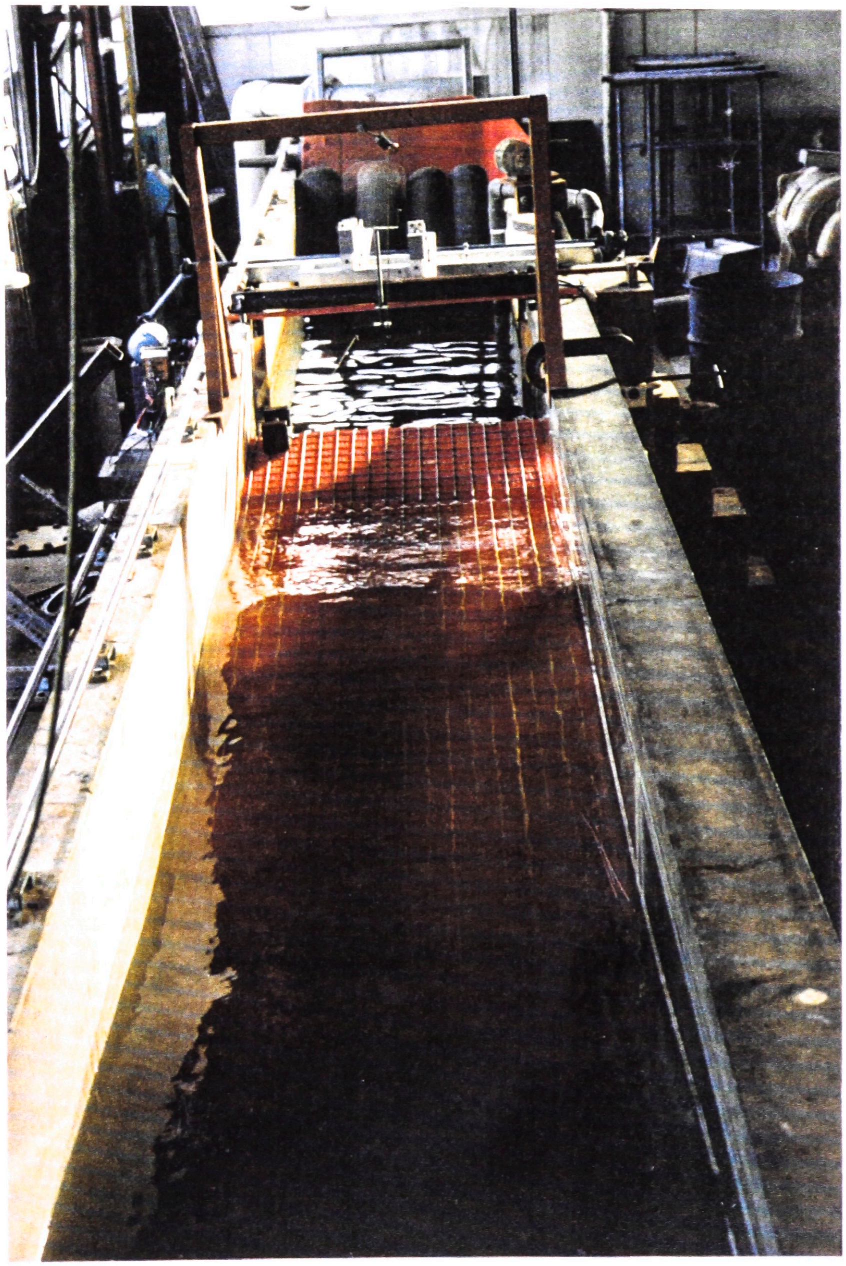

Photo 2 - The permeable sloping absorber during the tests

Photo 3 - View of the permeable sloping absorber installed in the shallow water part of the wave flume

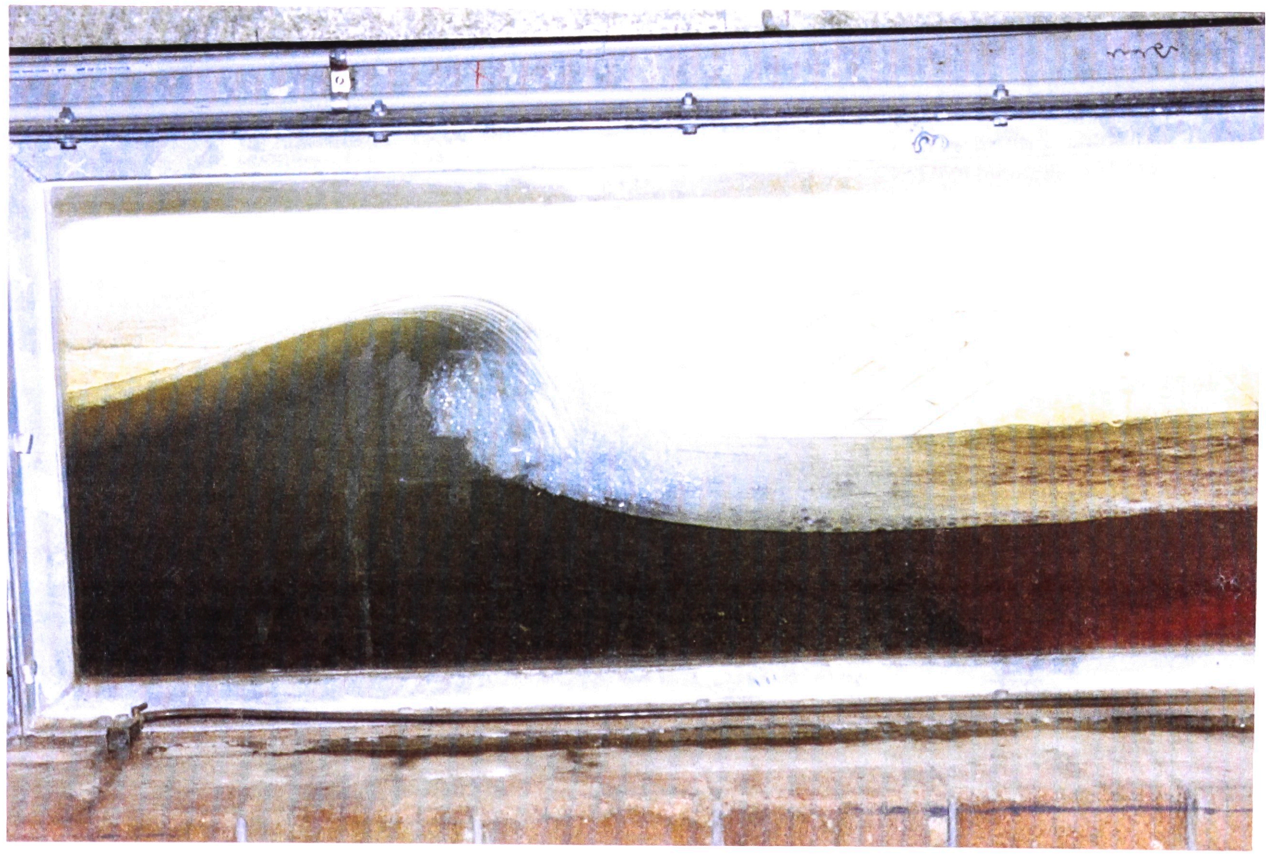

Photo 4 - Breaking of waves on the wave absorber

Photo 5 - Breaking of waves in front of the wave absorber

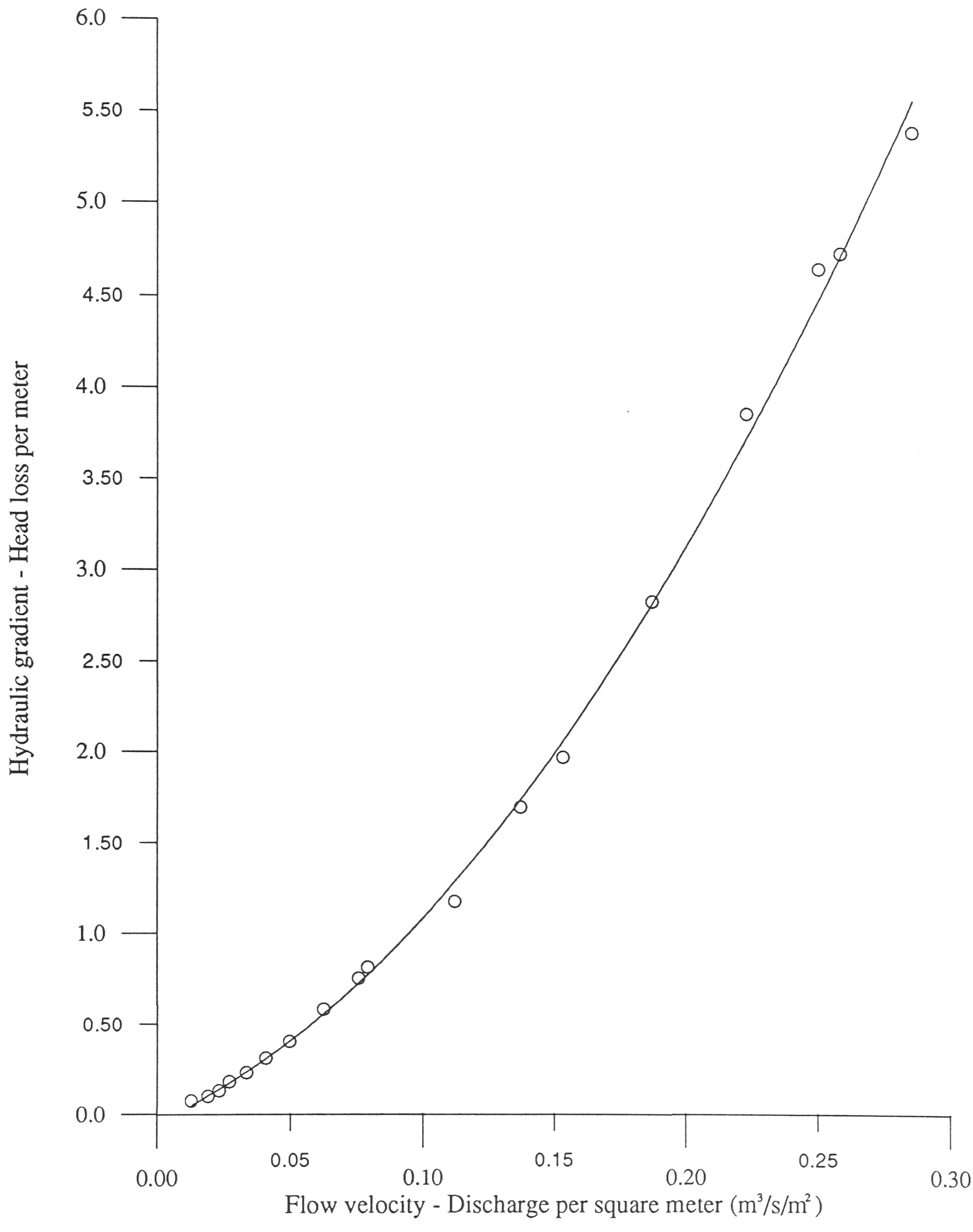

Fig. 1 - Head losses through artificial horse hair

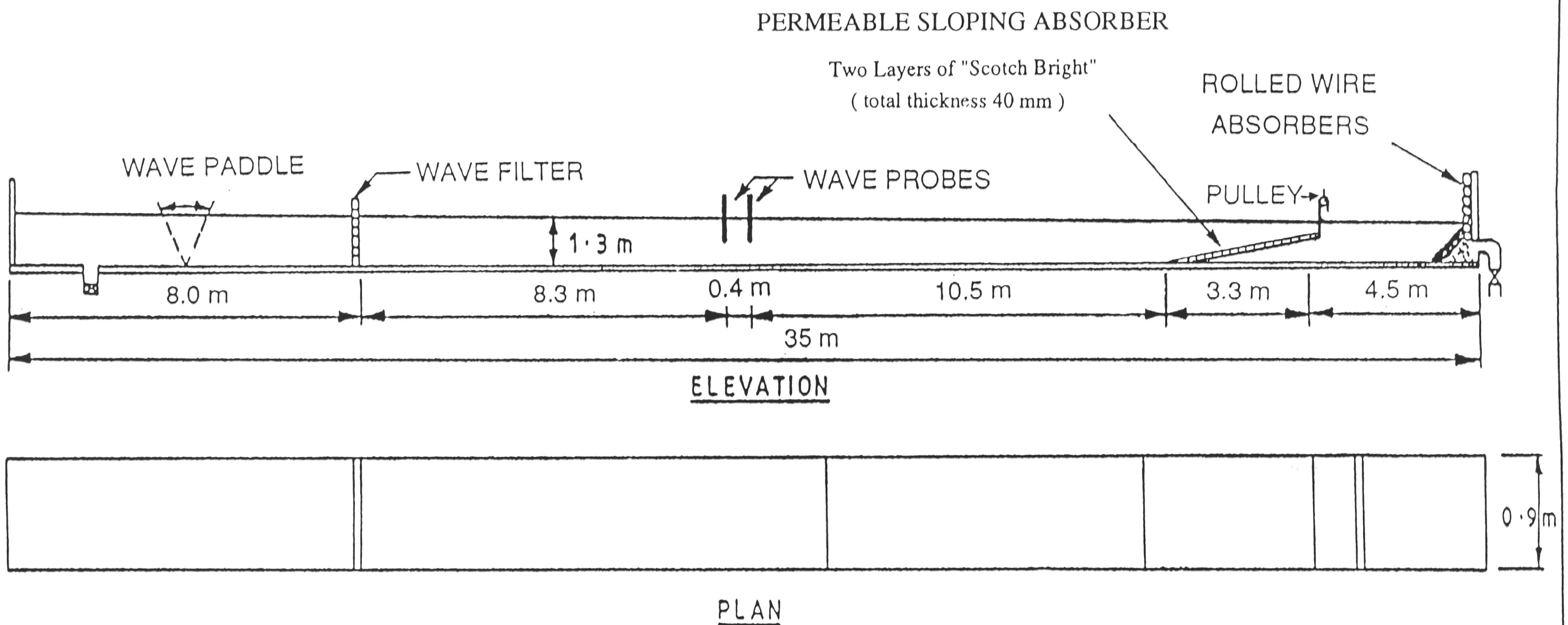

FIGURE (2) - LAYOUT OF THE WAVE FLUME
(NOT TO SCALE - SCHEMATIC ONLY)

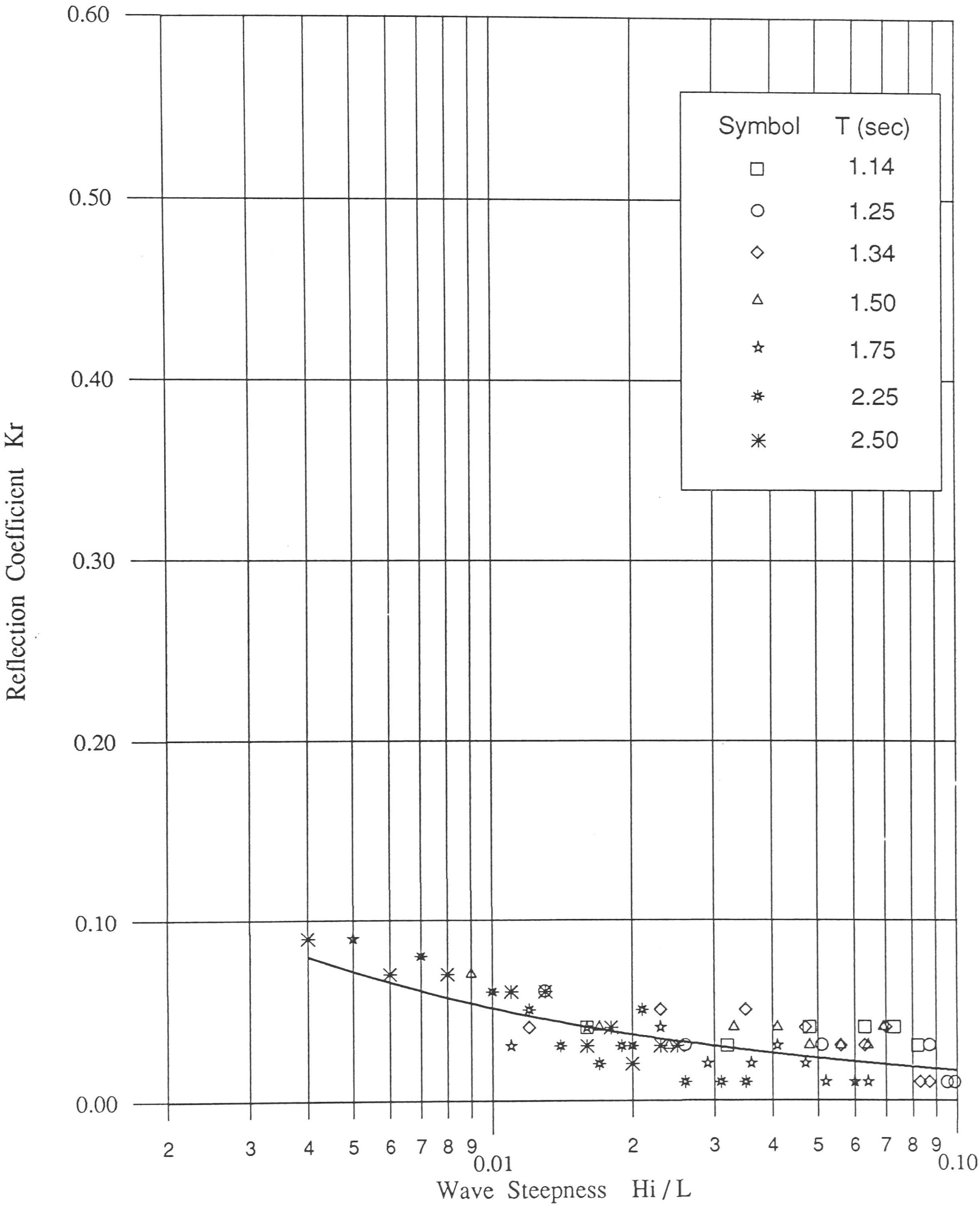

Fig. 3 - Wave reflection coefficient as a function of incident wave steepness, for S = 0.10

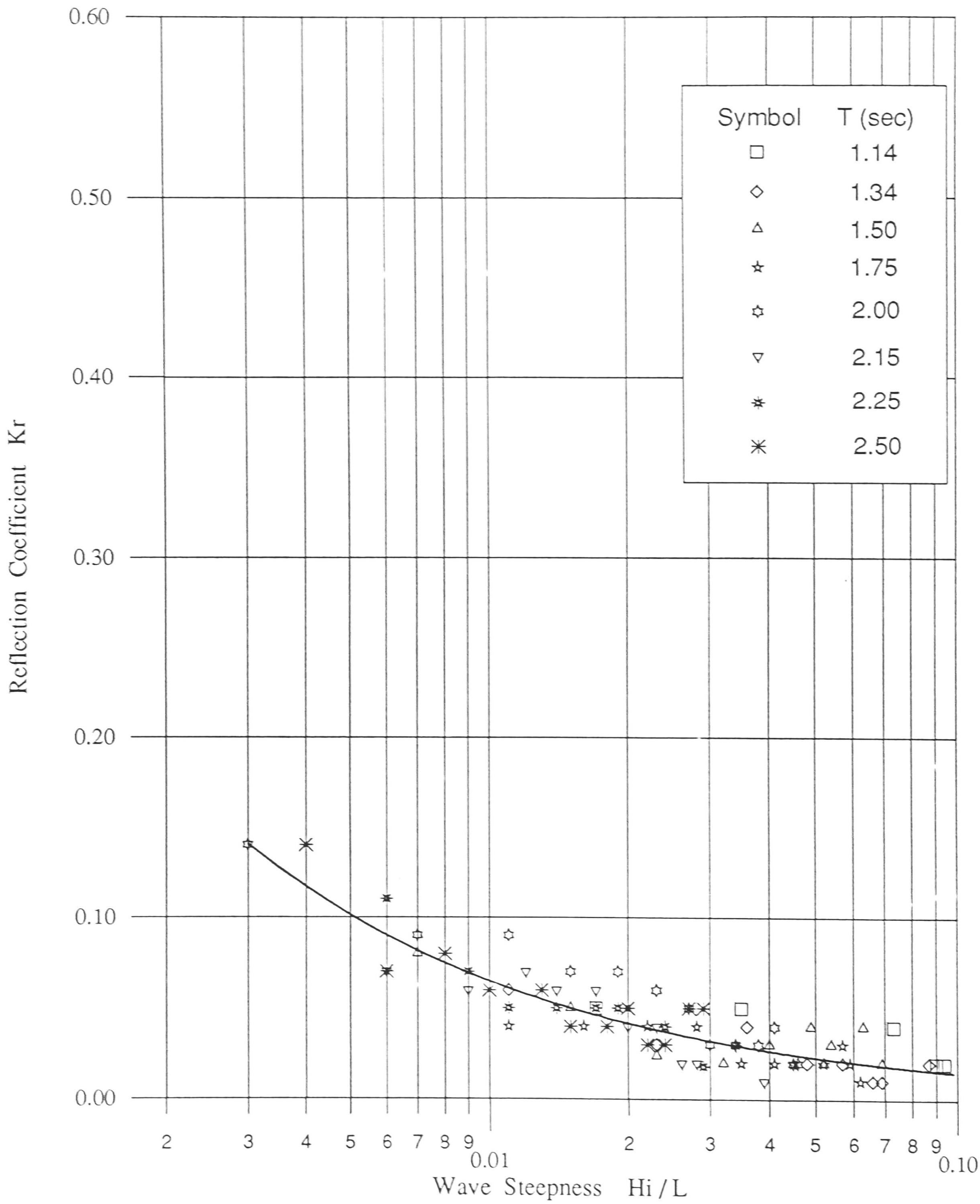

Fig. 4 - Wave reflection coefficient as a function of incident wave steepness, for S = 0.15

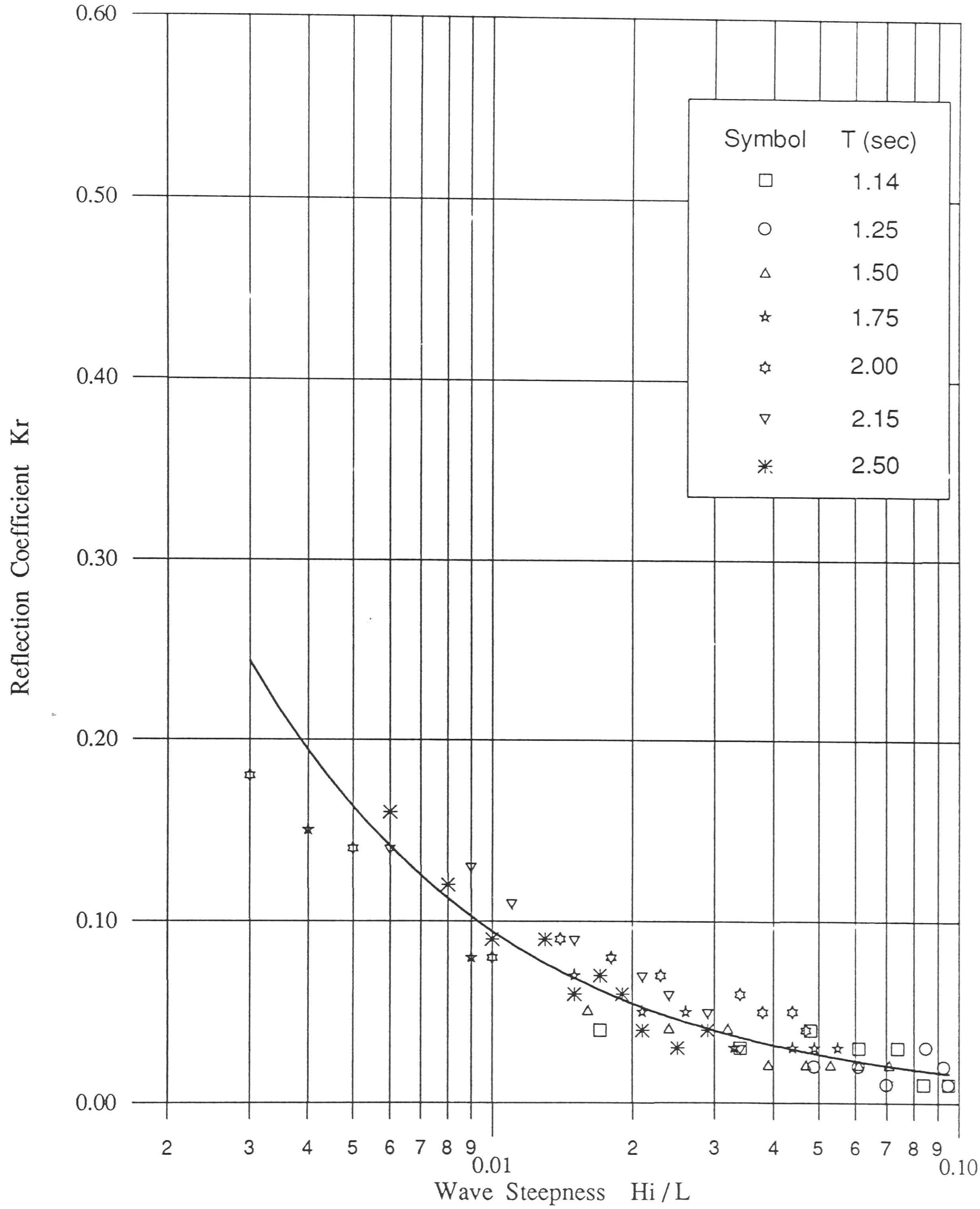

Fig. 5 - Wave reflection coefficient as a function of incident wave steepness, for S = 0.20

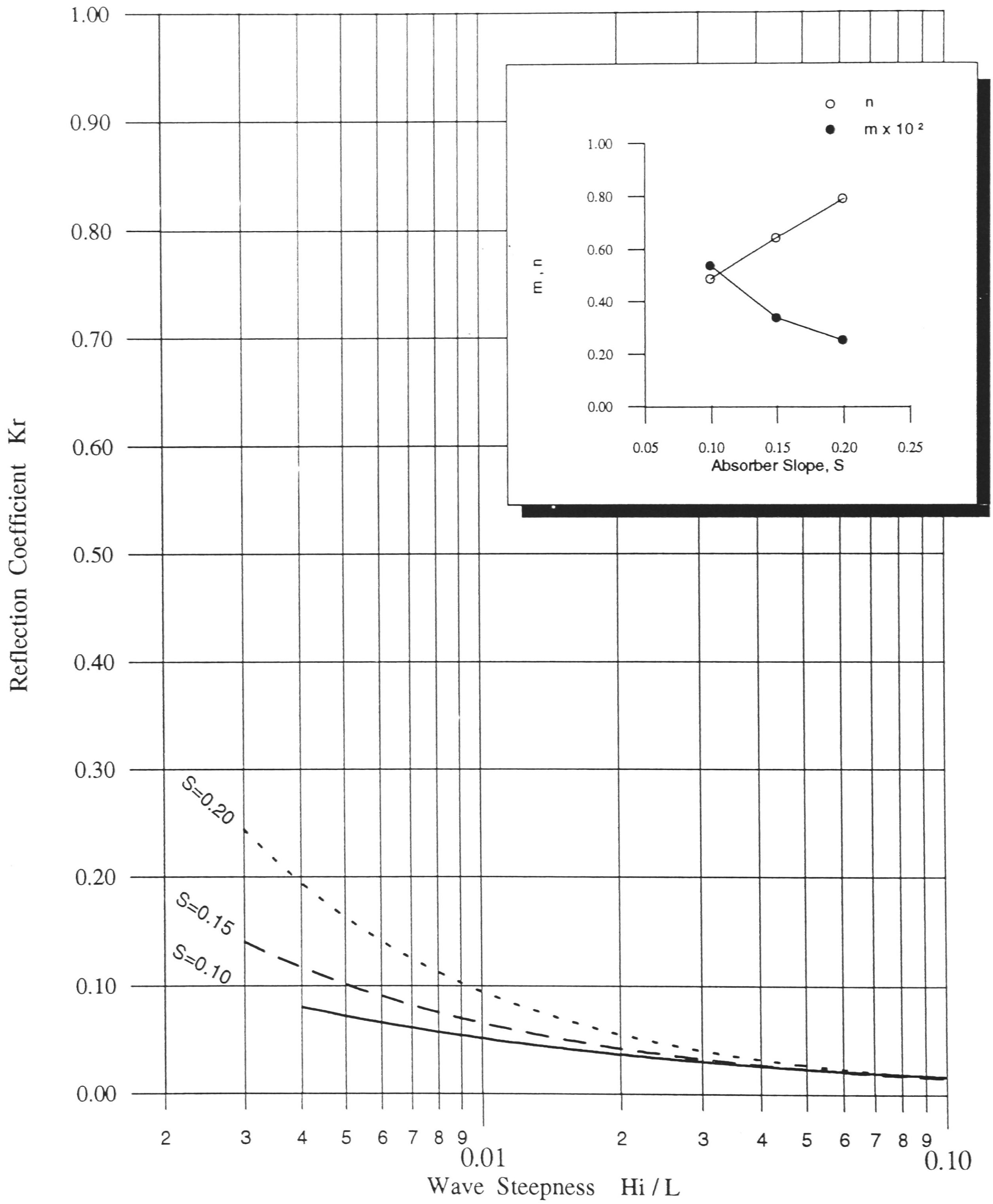

Fig. 6 - Effect of the absorber slope upon the coefficient of wave reflection

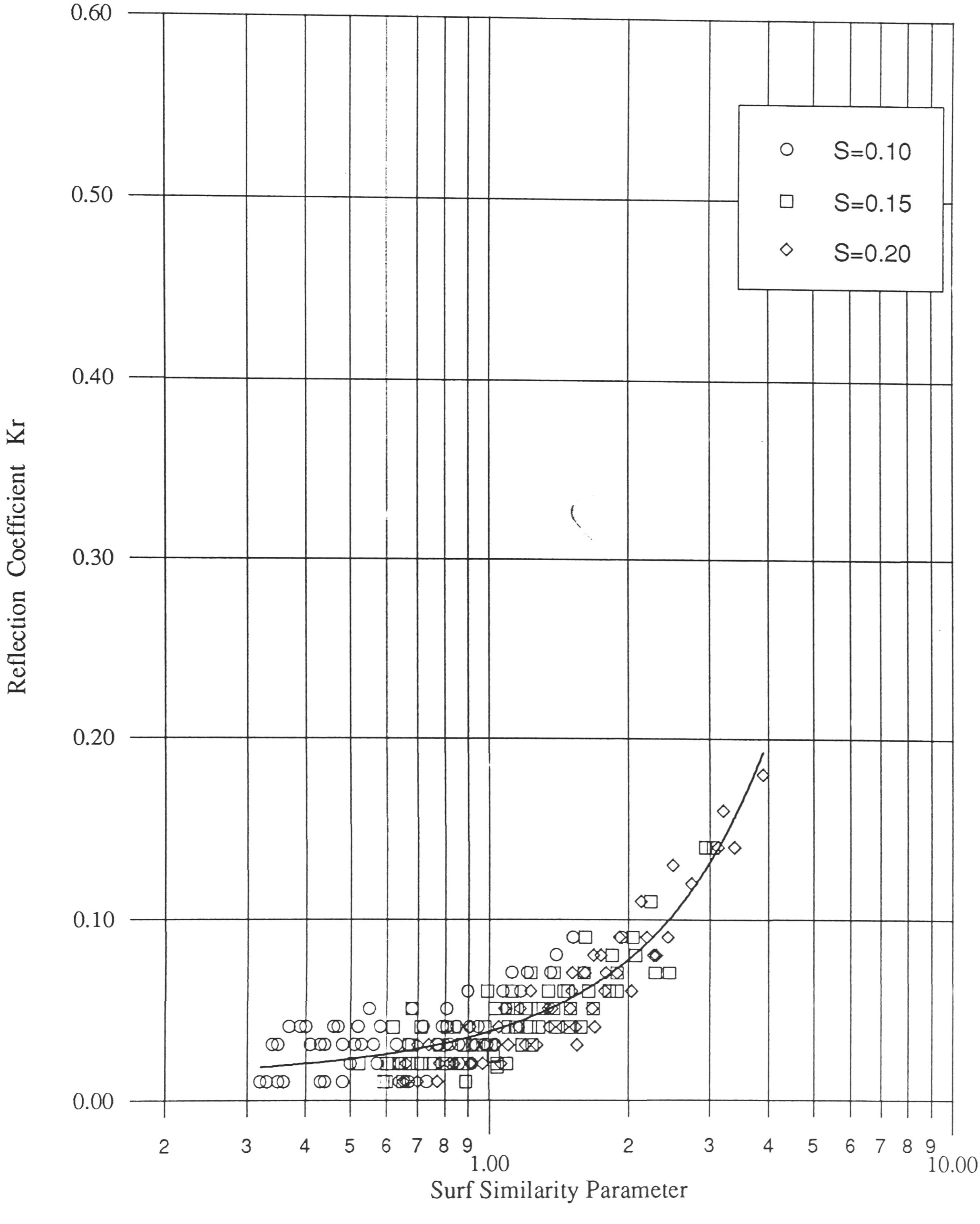

Fig. 7 : Wave reflection coefficient as a function of surf similarity parameter

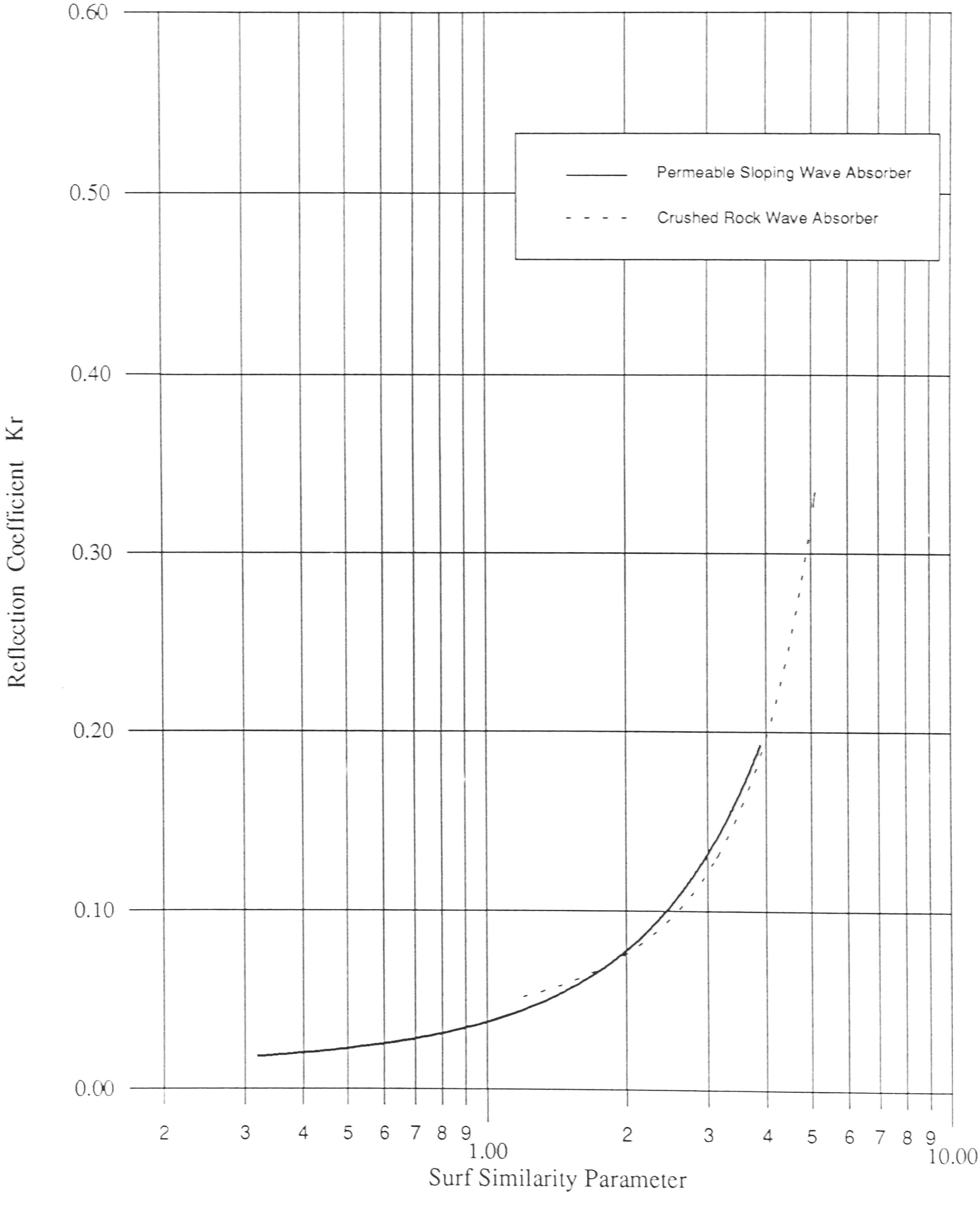

Fig. 8 : Illustrative comparison between the results of the present study and the data from Herbich (1956) for crushed rock absorbers

Appendix

<u>Table A.1</u>

Permeable Sloping Wave Absorber - Tabulated Data

Test No.	*S* (-)	*T* (sec)	*L* (m)	*h/L* (-)	a_i (mm)	a_r (mm)	K_r (-)	*H/L* (mm)	ξ (-)
EA1101	0.10	1.14	2.00	0.399	16.32	0.58	0.04	0.016	0.79
EA1103	0.10	1.14	2.00	0.399	32.22	0.89	0.03	0.032	0.56
EA1104	0.10	1.14	2.00	0.399	47.91	1.83	0.04	0.048	0.46
EA1105	0.10	1.14	2.00	0.399	62.62	2.37	0.04	0.063	0.40
EA1106	0.10	1.14	2.00	0.399	72.62	3.19	0.04	0.073	0.37
EA1107	0.10	1.14	2.00	0.399	82.22	2.71	0.03	0.082	0.35
EA1201	0.10	1.25	2.37	0.337	14.90	1.00	0.06	0.013	0.90
EA1203	0.10	1.25	2.37	0.337	30.82	0.99	0.03	0.026	0.63
EA1205	0.10	1.25	2.37	0.337	60.44	1.66	0.03	0.051	0.45
EA1208	0.10	1.25	2.37	0.337	102.66	3.31	0.03	0.087	0.34
EA1209	0.10	1.25	2.37	0.337	112.53	1.07	0.01	0.095	0.33
EA1210	0.10	1.25	2.37	0.337	116.92	0.45	0.01	0.099	0.32
EA1301	0.10	1.34	2.68	0.299	15.41	0.64	0.04	0.012	0.95
EA1303	0.10	1.34	2.68	0.299	30.59	1.56	0.05	0.023	0.68
EA1304	0.10	1.34	2.68	0.299	47.11	2.25	0.05	0.035	0.55
EA1305	0.10	1.34	2.68	0.299	62.59	2.56	0.04	0.047	0.47
EA1306	0.10	1.34	2.68	0.299	74.60	2.51	0.03	0.056	0.43
EA1307	0.10	1.34	2.68	0.299	84.55	2.80	0.03	0.063	0.41
EA1308	0.10	1.34	2.68	0.299	93.15	4.12	0.04	0.070	0.39
EA1310	0.10	1.34	2.68	0.299	110.84	0.51	0.01	0.083	0.36
EA1311	0.10	1.34	2.68	0.299	115.89	0.50	0.01	0.087	0.35
EA1401	0.10	1.50	3.22	0.249	13.93	0.92	0.07	0.009	1.12
EA1403	0.10	1.50	3.22	0.249	26.65	1.11	0.04	0.017	0.81
EA1404	0.10	1.50	3.22	0.249	38.81	0.94	0.03	0.024	0.67
EA1406	0.10	1.50	3.22	0.249	65.50	2.71	0.04	0.041	0.52
EA1407	0.10	1.50	3.22	0.249	77.05	2.45	0.03	0.048	0.48
EA1408	0.10	1.50	3.22	0.249	90.06	2.85	0.03	0.056	0.44
EA1409	0.10	1.50	3.22	0.249	103.16	3.29	0.03	0.064	0.41
EA1410	0.10	1.50	3.22	0.249	110.83	4.18	0.04	0.069	0.40
EA1501	0.10	1.75	4.05	0.198	10.31	0.95	0.09	0.005	1.52
EA1503	0.10	1.75	4.05	0.198	22.38	0.54	0.03	0.011	1.03
EA1504	0.10	1.75	4.05	0.198	33.35	1.38	0.04	0.016	0.85
EA1505	0.10	1.75	4.05	0.198	46.06	2.08	0.04	0.023	0.72
EA1506	0.10	1.75	4.05	0.198	59.09	0.87	0.02	0.029	0.64
EA1507	0.10	1.75	4.05	0.198	72.43	1.47	0.02	0.036	0.57
EA1508	0.10	1.75	4.05	0.198	83.80	3.00	0.03	0.041	0.53
EA1509	0.10	1.75	4.05	0.198	94.75	1.75	0.02	0.047	0.50
EA1510	0.10	1.75	4.05	0.198	105.36	1.04	0.01	0.052	0.48
EA1511	0.10	1.75	4.05	0.198	121.40	1.72	0.02	0.060	0.44
EA1512	0.10	1.75	4.05	0.198	129.61	1.14	0.01	0.064	0.43
EA1804	0.10	2.25	5.63	0.142	20.21	1.78	0.08	0.007	1.40
EA1805	0.10	2.25	5.63	0.142	27.10	1.93	0.06	0.010	1.21

Table A.1 - Continued

Permeable Sloping Wave Absorber - Tabulated Data

Test No.	*S* (-)	*T* (sec)	*L* (m)	*h/L* (-)	a_i (mm)	a_r (mm)	K_r (-)	*H/L* (mm)	ξ (-)
EA1806	0.10	2.25	5.63	0.142	33.18	1.49	0.04	0.012	1.09
EA1807	0.10	2.25	5.63	0.142	40.09	1.22	0.03	0.014	0.99
EA1808	0.10	2.25	5.63	0.142	46.76	0.96	0.02	0.017	0.92
EA1809	0.10	2.25	5.63	0.142	53.42	1.49	0.03	0.019	0.86
EA1810	0.10	2.25	5.63	0.142	59.95	2.83	0.05	0.021	0.81
EA1811	0.10	2.25	5.63	0.142	66.46	1.98	0.03	0.024	0.77
EA1812	0.10	2.25	5.63	0.142	73.78	0.35	0.01	0.026	0.73
EA1814	0.10	2.25	5.63	0.142	87.05	0.30	0.01	0.031	0.67
EA1815	0.10	2.25	5.63	0.142	97.28	0.14	0.01	0.035	0.64
EA1903	0.10	2.50	6.40	0.125	13.12	0.98	0.07	0.004	1.93
EA1904	0.10	2.50	6.40	0.125	19.11	1.30	0.07	0.006	1.60
EA1905	0.10	2.50	6.40	0.125	26.42	2.04	0.07	0.008	1.36
EA1906	0.10	2.50	6.40	0.125	35.34	2.00	0.06	0.011	1.17
EA1907	0.10	2.50	6.40	0.125	43.01	2.59	0.06	0.013	1.07
EA1908	0.10	2.50	6.40	0.125	51.24	1.62	0.03	0.016	0.98
EA1909	0.10	2.50	6.40	0.125	58.87	2.50	0.04	0.018	0.91
EA1910	0.10	2.50	6.40	0.125	66.20	1.29	0.02	0.020	0.86
EA1911	0.10	2.50	6.40	0.125	73.15	2.17	0.03	0.023	0.82
EA1913	0.10	2.50	6.40	0.125	79.47	2.48	0.03	0.025	0.78
EA2101	0.15	1.14	2.00	0.399	16.93	0.85	0.05	0.017	1.15
EA2103	0.15	1.14	2.00	0.399	34.89	1.98	0.06	0.035	0.99
EA2106	0.15	1.14	2.00	0.399	73.27	4.25	0.04	0.073	0.60
EA2107	0.15	1.14	2.00	0.399	89.68	1.43	0.02	0.090	0.62
EA2108	0.15	1.14	2.00	0.399	93.81	1.67	0.02	0.094	0.61
EA2109	0.15	1.14	2.00	0.399	97.66	0.72	0.01	0.098	0.59
EA2301	0.15	1.34	2.68	0.299	14.32	0.92	0.06	0.011	1.48
EA2303	0.15	1.34	2.68	0.299	31.14	1.06	0.03	0.023	1.01
EA2304	0.15	1.34	2.68	0.299	48.31	1.69	0.03	0.036	0.81
EA2305	0.15	1.34	2.68	0.299	64.16	1.59	0.02	0.048	0.70
EA2306	0.15	1.34	2.68	0.299	76.51	1.02	0.02	0.057	0.64
EA2308	0.15	1.34	2.68	0.299	92.16	1.32	0.01	0.069	0.59
EA2310	0.15	1.34	2.68	0.299	116.76	2.77	0.02	0.087	0.52
EA2401	0.15	1.50	3.22	0.249	11.62	0.97	0.08	0.007	1.84
EA2403	0.15	1.50	3.22	0.249	24.19	1.26	0.05	0.015	1.28
EA2404	0.15	1.50	3.22	0.249	37.72	0.91	0.03	0.023	1.02
EA2405	0.15	1.50	3.22	0.249	51.52	1.09	0.02	0.032	0.88
EA2406	0.15	1.50	3.22	0.249	64.29	1.79	0.03	0.040	0.78
EA2407	0.15	1.50	3.22	0.249	79.29	3.15	0.04	0.049	0.71
EA2408	0.15	1.50	3.22	0.249	87.68	2.39	0.03	0.054	0.67
EA2409	0.15	1.50	3.22	0.249	101.39	4.35	0.04	0.063	0.62
EA2410	0.15	1.50	3.22	0.249	111.10	2.77	0.02	0.069	0.60
EA2503	0.15	1.75	4.05	0.198	21.43	0.89	0.04	0.011	1.58
EA2504	0.15	1.75	4.05	0.198	32.97	1.48	0.04	0.016	1.28
EA2505	0.15	1.75	4.05	0.198	46.69	1.98	0.04	0.022	1.10
EA2506	0.15	1.75	4.05	0.198	56.36	2.48	0.04	0.028	0.98

Table A.1 - Continued

Permeable Sloping Wave Absorber - Tabulated Data

Test No.	*S* (-)	*T* (sec)	*L* (m)	*h/L* (-)	a_i (mm)	a_r (mm)	K_r (-)	*H/L* (mm)	ξ (-)
EA2507	0.15	1.75	4.05	0.198	70.35	1.08	0.02	0.035	0.87
EA2508	0.15	1.75	4.05	0.198	82.04	1.28	0.02	0.041	0.81
EA2509	0.15	1.75	4.05	0.198	92.01	1.72	0.02	0.045	0.76
EA2510	0.15	1.75	4.05	0.198	106.51	2.11	0.02	0.052	0.71
EA2509	0.15	1.75	4.05	0.198	115.67	3.08	0.03	0.057	0.68
EA2512	0.15	1.75	4.05	0.198	120.09	2.74	0.02	0.059	0.67
EA2513	0.15	1.75	4.05	0.198	125.84	0.66	0.01	0.062	0.65
EA2601	0.15	2.00	4.85	0.165	8.16	1.17	0.14	0.003	2.93
EA2603	0.15	2.00	4.85	0.165	16.94	1.60	0.09	0.007	2.04
EA2604	0.15	2.00	4.85	0.165	26.96	2.48	0.09	0.011	1.61
EA2605	0.15	2.00	4.85	0.165	36.84	2.44	0.07	0.015	1.38
EA2606	0.15	2.00	4.85	0.165	46.32	3.12	0.07	0.019	1.23
EA2607	0.15	2.00	4.85	0.165	56.06	3.51	0.06	0.023	1.12
EA2608	0.15	2.00	4.85	0.165	65.60	3.49	0.05	0.027	1.03
EA2609	0.15	2.00	4.85	0.165	74.05	2.46	0.03	0.030	0.97
EA2610	0.15	2.00	4.85	0.165	82.67	2.30	0.03	0.034	0.92
EA2611	0.15	2.00	4.85	0.165	91.01	2.85	0.03	0.038	0.88
EA2612	0.15	2.00	4.85	0.165	99.24	4.26	0.04	0.041	0.84
EA2613	0.15	2.00	4.85	0.165	108.52	2.15	0.02	0.045	0.80
EA2614	0.15	2.00	4.85	0.165	112.21	1.83	0.02	0.046	0.79
EA2702	0.15	2.15	5.32	0.150	15.62	1.03	0.07	0.006	2.28
EA2703	0.15	2.15	5.32	0.150	22.80	1.47	0.06	0.009	1.89
EA2705	0.15	2.15	5.32	0.150	31.77	2.25	0.07	0.012	1.60
EA2706	0.15	2.15	5.32	0.150	38.55	2.17	0.06	0.014	1.45
EA2707	0.15	2.15	5.32	0.150	45.05	2.99	0.06	0.017	1.34
EA2708	0.15	2.15	5.32	0.150	54.10	2.05	0.04	0.020	1.23
EA2709	0.15	2.15	5.32	0.150	61.48	2.39	0.04	0.023	1.15
EA2710	0.15	2.15	5.32	0.150	68.29	0.99	0.02	0.026	1.09
EA2711	0.15	2.15	5.32	0.150	75.03	1.38	0.02	0.028	1.04
EA2713	0.15	2.15	5.32	0.150	90.97	2.69	0.03	0.034	0.94
EA2715	0.15	2.15	5.32	0.150	102.72	1.29	0.01	0.039	0.89
EA2804	0.15	2.25	5.63	0.142	17.80	1.88	0.10	0.006	2.23
EA2805	0.15	2.25	5.63	0.142	25.02	1.78	0.07	0.009	1.89
EA2806	0.15	2.25	5.63	0.142	32.36	1.52	0.05	0.011	1.68
EA2807	0.15	2.25	5.63	0.142	39.73	1.90	0.05	0.014	1.50
EA2808	0.15	2.25	5.63	0.142	46.99	2.13	0.05	0.017	1.38
EA2809	0.15	2.25	5.63	0.142	54.67	2.59	0.05	0.019	1.28
EA2810	0.15	2.25	5.63	0.142	61.74	2.92	0.05	0.020	1.20
EA2811	0.15	2.25	5.63	0.142	68.57	2.44	0.04	0.024	1.14
EA2813	0.15	2.25	5.63	0.142	82.02	1.48	0.02	0.029	1.04
EA2815	0.15	2.25	5.63	0.142	95.07	3.26	0.03	0.034	0.97
EA2903	0.15	2.50	6.40	0.125	11.80	1.60	0.14	0.004	3.05
EA2904	0.15	2.50	6.40	0.125	18.31	1.13	0.07	0.006	2.45
EA2905	0.15	2.50	6.40	0.125	25.64	2.09	0.08	0.008	2.07
EA2906	0.15	2.50	6.40	0.125	33.05	1.95	0.06	0.010	1.82

Table A.1 - Continued

Permeable Sloping Wave Absorber - Tabulated Data

Test No.	*S* (-)	*T* (sec)	*L* (m)	*h/L* (-)	a_i (mm)	a_r (mm)	K_r (-)	*H/L* (mm)	ξ (-)
EA2907	0.15	2.50	6.40	0.125	40.90	2.25	0.06	0.013	1.64
EA2908	0.15	2.50	6.40	0.125	48.78	2.02	0.04	0.015	1.50
EA2909	0.15	2.50	6.40	0.125	56.77	2.03	0.04	0.018	1.39
EA2910	0.15	2.50	6.40	0.125	64.11	3.48	0.05	0.020	1.31
EA2911	0.15	2.50	6.40	0.125	70.89	2.28	0.03	0.022	1.24
EA2912	0.15	2.50	6.40	0.125	78.26	2.14	0.03	0.024	1.18
EA2913	0.15	2.50	6.40	0.125	85.25	4.21	0.05	0.027	1.13
EA2914	0.15	2.50	6.40	0.125	91.19	5.25	0.05	0.029	1.10
EA3101	0.20	1.14	2.00	0.399	17.14	0.64	0.04	0.018	1.54
EA3103	0.20	1.14	2.00	0.399	33.76	0.84	0.03	0.034	1.10
EA3104	0.20	1.14	2.00	0.399	48.54	2.24	0.04	0.048	0.91
EA3105	0.20	1.14	2.00	0.399	61.28	2.02	0.03	0.061	0.81
EA3106	0.20	1.14	2.00	0.399	73.68	2.84	0.03	0.074	0.74
EA3107	0.20	1.14	2.00	0.399	83.76	0.61	0.01	0.084	0.70
EA3108	0.20	1.14	2.00	0.399	94.89	0.52	0.01	0.095	0.65
EA3205	0.20	1.25	2.37	0.337	58.13	1.17	0.02	0.049	0.92
EA3206	0.20	1.25	2.37	0.337	72.75	0.71	0.02	0.061	0.82
EA3207	0.20	1.25	2.37	0.337	83.21	0.90	0.01	0.070	0.77
EA3208	0.20	1.25	2.37	0.337	100.25	3.65	0.03	0.085	0.70
EA3209	0.20	1.25	2.37	0.337	110.50	1.81	0.02	0.093	0.66
EA3210	0.20	1.25	2.37	0.337	112.45	0.52	0.01	0.095	0.66
EA3403	0.20	1.50	3.22	0.249	25.17	1.22	0.05	0.016	1.67
EA3404	0.20	1.50	3.22	0.249	38.70	1.54	0.04	0.024	1.35
EA3405	0.20	1.50	3.22	0.249	52.00	2.12	0.04	0.032	1.16
EA3406	0.20	1.50	3.22	0.249	62.91	1.21	0.02	0.039	1.06
EA3407	0.20	1.50	3.22	0.249	75.29	1.75	0.02	0.047	0.97
EA3408	0.20	1.50	3.22	0.249	84.92	1.99	0.02	0.053	0.91
EA3409	0.20	1.50	3.22	0.249	98.96	1.93	0.02	0.061	0.84
EA3410	0.20	1.50	3.22	0.249	114.14	2.32	0.02	0.071	0.78
EA3501	0.20	1.75	4.05	0.198	8.92	1.34	0.15	0.004	3.27
EA3502	0.20	1.75	4.05	0.198	12.66	1.41	0.11	0.006	2.75
EA3503	0.20	1.75	4.05	0.198	18.67	1.54	0.08	0.009	2.26
EA3504	0.20	1.75	4.05	0.198	29.96	2.24	0.07	0.015	1.79
EA3505	0.20	1.75	4.05	0.198	42.24	1.97	0.05	0.021	1.50
EA3506	0.20	1.75	4.05	0.198	53.60	2.65	0.05	0.026	1.34
EA3507	0.20	1.75	4.05	0.198	66.54	2.20	0.03	0.033	1.20
EA3509	0.20	1.75	4.05	0.198	89.88	2.30	0.03	0.044	1.03
EA3510	0.20	1.75	4.05	0.198	99.42	3.19	0.03	0.049	0.98
EA3511	0.20	1.75	4.05	0.198	111.57	3.24	0.03	0.055	0.93
EA3601	0.20	2.00	4.85	0.165	8.26	1.50	0.18	0.003	3.89
EA3602	0.20	2.00	4.85	0.165	10.96	1.54	0.14	0.005	3.38
EA3604	0.20	2.00	4.85	0.165	23.90	1.92	0.08	0.010	2.29
EA3605	0.20	2.00	4.85	0.165	34.27	3.28	0.09	0.014	1.91
EA3606	0.20	2.00	4.85	0.165	44.46	3.95	0.09	0.018	1.68
EA3607	0.20	2.00	4.85	0.165	54.79	4.56	0.07	0.023	1.51

Table A.1 - Continued

Permeable Sloping Wave Absorber - Tabulated Data

Test No.	*S* (-)	*T* (sec)	*L* (m)	*h/L* (-)	a_i (mm)	a_r (mm)	K_r (-)	*H/L* (mm)	ξ (-)
EA3610	0.20	2.00	4.85	0.165	82.44	5.33	0.06	0.034	1.23
EA3611	0.20	2.00	4.85	0.165	91.88	4.92	0.05	0.038	1.17
EA3613	0.20	2.00	4.85	0.165	107.88	6.24	0.06	0.044	1.08
EA3615	0.20	2.00	4.85	0.165	118.99	5.49	0.04	0.047	1.05
EA3702	0.20	2.15	5.32	0.150	10.47	1.10	0.11	0.004	3.71
EA3703	0.20	2.15	5.32	0.150	14.80	2.21	0.15	0.006	3.12
EA3704	0.20	2.15	5.32	0.150	23.29	3.02	0.13	0.009	2.49
EA3705	0.20	2.15	5.32	0.150	31.77	3.52	0.11	0.012	2.13
EA3706	0.20	2.15	5.32	0.150	39.77	3.58	0.09	0.015	1.91
EA3707	0.20	2.15	5.32	0.150	47.80	3.88	0.08	0.018	1.74
EA3708	0.20	2.15	5.32	0.150	55.57	3.63	0.06	0.021	1.61
EA3709	0.20	2.15	5.32	0.150	63.02	3.76	0.06	0.024	1.51
EA3711	0.20	2.15	5.32	0.150	77.25	3.83	0.05	0.029	1.37
EA3713	0.20	2.15	5.32	0.150	89.70	2.72	0.03	0.034	1.27
EA3904	0.20	2.50	6.40	0.125	19.10	3.13	0.16	0.006	3.20
EA3905	0.20	2.50	6.40	0.125	25.96	3.23	0.12	0.008	2.74
EA3906	0.20	2.50	6.40	0.125	32.97	3.07	0.09	0.010	2.43
EA3907	0.20	2.50	6.40	0.125	40.54	3.75	0.09	0.013	2.19
EA3908	0.20	2.50	6.40	0.125	47.19	3.02	0.06	0.015	2.03
EA3909	0.20	2.50	6.40	0.125	54.57	3.85	0.07	0.017	1.89
EA3910	0.20	2.50	6.40	0.125	61.40	3.55	0.06	0.019	1.78
EA3911	0.20	2.50	6.40	0.125	67.97	2.98	0.04	0.021	1.69
EA3913	0.20	2.50	6.40	0.125	81.11	2.42	0.03	0.025	1.55
EA3915	0.20	2.50	6.40	0.125	94.32	4.19	0.04	0.029	1.44

List of variables used in Table A.1 :

S slope of the absorber
T wave period
L wave length
h/L relative water depth
a_i incident wave amplitude
a_r reflected wave amplitude
K_r reflection coefficient
H/L wave steepness
ξ surf similarity parameter