CHAPTER 152

LABORATORY STUDY ON PERVIOUS CORE BREAKWATERS

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ABSTRACT

Effects of permeable core layer installed in trapezoidal and rectangular breakwaters have been studied experimentally and analytically. As the materials for armour and core use of the lattice composed of circular cylinders was made in addition to rocks. Perforated plates were also applied as a kind of very thin core.

Expermental results show that the reflected wave heights from breakwater could be reduced considerably by locating the core layer shoreward within it while core thickness controls the transmitted wave heights in the protected water area. Harmonic analysis about the water surface in lattice armour reveals that the second harmonic waves take a pattern of standing wave distribution having a node at the seaward face of breakwater. Thin perforated plates work successfully for reducing the transmitted wave heights when they are installed at the rear face of breakwater.

An analytical approach to predict the transmission and the reflection coefficients is applied for the present experimental data and shown to be useful.

INTRODUCTION

It is well understood by coastal engineers that pervious breakwaters bring less seaward reflective wave energy and wave run-up than impervious ones do, as observed in several laboratory and field experiments.

However they have disadvantage of allowing shoreward wave energy penetration which results in the transmitted waves behind it.

In order to obtain less transmitted wave energy without precluding the merits stated, for instance, a rubble-mound breakwater usually has a permeable core layer which has less permeability compared with armour ones, or it is said to be composed of pervious multi-layers. Effects of hydraulic characteristics of pervious cores on wave transmission and reflection have not been known despite their importance in functional design of pervious breakwaters. The present study deals with fundamental effects of pervious cores installed within porous breakwaters based on experiments on model breakwaters as well as analytical approach.

EXPERIMENTAL FACILITIES AND PROCEDURE

Experiments were performed on horizontal bottom in a wave channel of 18.5 meter long, 0.4 meter wide and 1.0 meter deep. Waves were generated with a regular and flap type generator. Parallel wire wave gages were used to measure water surface fluctuations. Fig. 1 presents arrangement of experimental equipments.

Cross sectional configulations of model breakwaters were of rectangular and trapezoid as shown in Fig. 2.

Photo. 1 Trapezoidal Breakwater Made of Lattice (No Core)

Table 1 Hydraulic Coefficients of Breakwater Materials

		Porosity λ (%)	Diameter D (cm)	Turbulent Coefficient C_3	(Turbulent Frictional Slope)/ V^2 $\left(\frac{\Delta h}{\ell}\right)_t \cdot \frac{1}{V^2}$, ($sec^2 \cdot m^{-2}$)
Armour	Lattice (ϕ34)	60.7	3.4	0.11	2.0
	Rock A	44.8	3.8	0.4	30.0
Core	Lattice (ϕ11)	60.7	1.1	0.11	6.0
	Rock C	43.0	2.9	0.3	36.0

Three kinds of the core thickness tested were 13, 20 and 26 cm for the core location at center of breakwaters. With thickness of 20 cm, the core location was varied in three ways, i.e., the front, center and rear, respectively. Distance between the center core and the front or the rear cores was 20 cm. Main armour material of

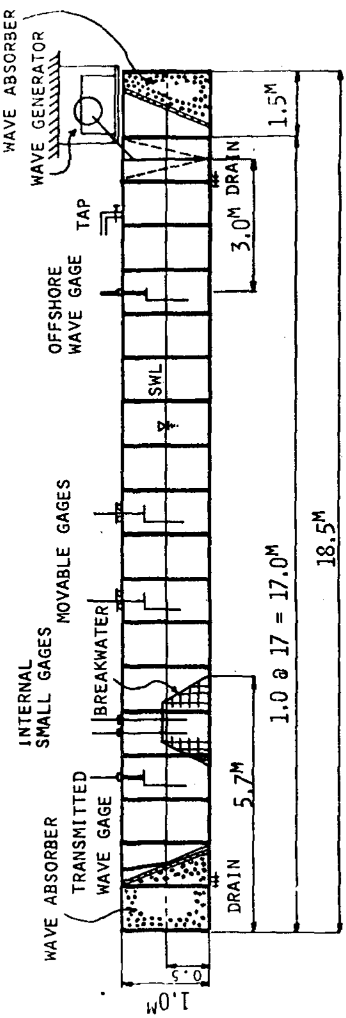

Fig. 1 Arrangement of Experimental Equipment

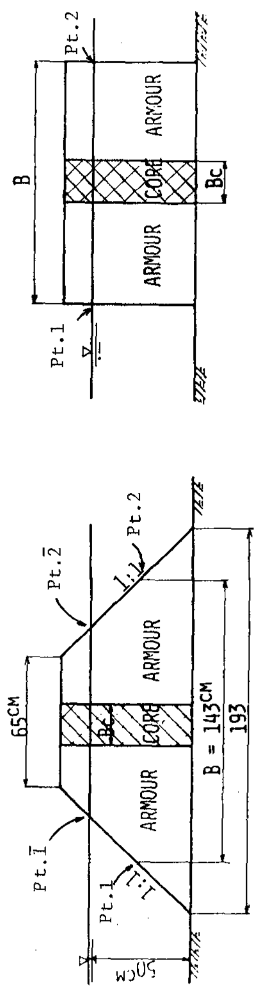

Fig. 2 Cross Section of Model Breakwaters

breakwaters was the lattice of D = 3.4 cm (Photo.1), and the core ones were the another lattice of D = 1.1 cm and the rock of the median diameter (D_m) = 2.9 cm. Hydraulic characteristics of the lattice were discussed in detail previously[1]. Some of the hydraulic properties are cited in Table 1. Coefficient C_3 in the table is of one to turbulent resistance, and is related to the frictional slope as in the following equation.

$$\frac{\Delta h}{\ell} = \frac{V^2}{2g\lambda^5 D}\cdot\left[\frac{C_2}{(DV/\nu)} + C_3\right], \qquad (1)$$

where V, g, ν, and C_2 are steady discharge velocity, acceleration of gravity, kinematic viscosity, and another coefficient for laminar flow resistance, respectively. The turbulent frictional slope, denoted $(\Delta h/\ell)_t$, is defined as that neglecting the laminar term in Eq.1, and is expressed as,

$$\left(\frac{\Delta h}{\ell}\right)_t = \frac{C_3 V^2}{2g\lambda^5 D}. \qquad (2)$$

The ratio of the turbulent frictional slope of the lattice armour to that of core is 1:3 for the lattice core, and it is 1:18 for the rubble core. The ratio for a typical rubble mound breakwater[2] having artificial concrete blocks of λ = 0.5 and C_3 = 0.67 as armour and rock of λ = 0.4 and C_3 = 0.4 as core[1], is 1:15 provided weight of the core unit is 1/200 of the armour one, which is close to 1:18.

Uniformly perforated steel plates were also employed since they were expected to represent one of the thin cores. The plates with circular holes of 1.2 and 2.0 cm in diameter and of porosity of 20 and 34 % were tested. The rock as armour material was used mainly with the plates.

The incident wave height H_I and the reflected one H_R were determined by moving one or two gages to measure amplitudes at loops and nodes, and adding or subtracting the latters to the formers. The transmitted wave height through breakwater H_T was measured at location about one quarter wave length shoreward from the point of the rear face which intersects with the still water surface.

The transmission coefficient and reflection coefficients are defined as H_T/H_I and H_R/H_I, and denoted hereafter K_T and K_R, respectively.

The internal water surface fluctuations of lattice armour were measured by inserting small gages vertically into voids between cylinders. Dimensions of experimental waves were the ranges shown below. while the water depth h was kept constant of 50 cm.

Incident wave heights h = 1 - 10 cm, Wave periods T = 0.7 - 2.2 sec.

RESULTS AND DISCUSSIONS

In the statement followed results about trapezoidal breakwaters will be mainly presented except for the ones with plates. Rectangular breakwaters will be discussed in comparison with the trapezoidal ones in a few sections.

1) Comparison of K_T and K_R between No-core and With-core Breakwaters

First of all, function of the core installed in a porous breakwater has beeen investigated. Fig. 3 shows the case of lattice core,

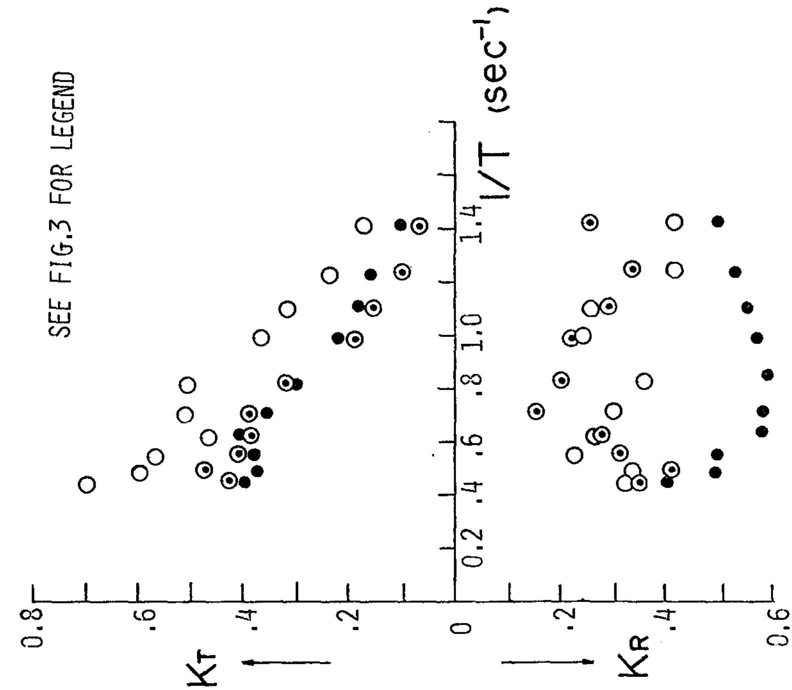

Fig. 4 Effect of Rubble Core on K_T and K_R

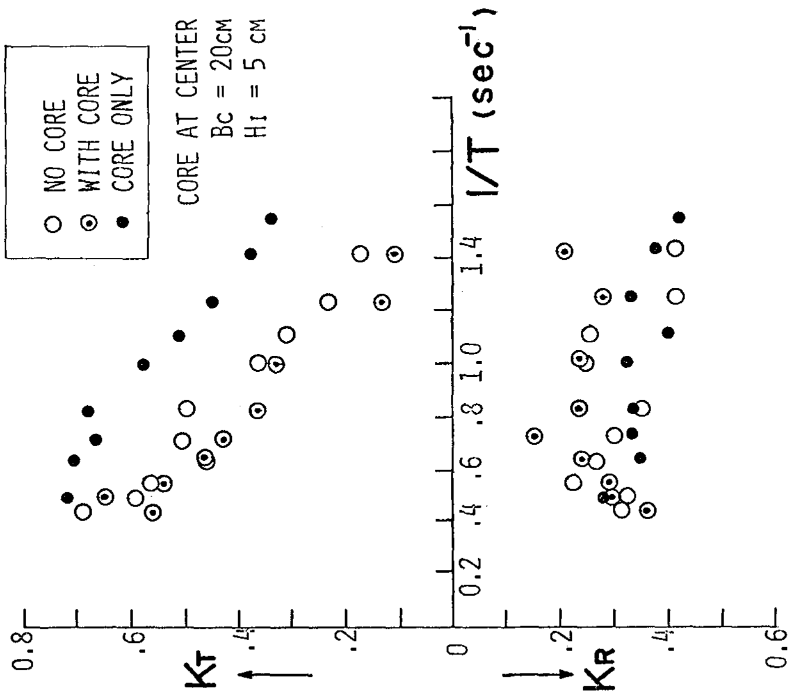

Fig. 3 Effect of Lattice Core on K_T and K_R

in which the ordinate is taken as the transmission coefficient upward and as the reflection coefficient downward, and the abscissa is freqency. K_T of the with-core breakwater is nearly the same as no-core one. In this case the core doesn't work effectively since the frictional slope of the core is only three times that of armour. Fig. 4 presents the case of rubble core, in which K_T of with-core is dominated by the core and almost coincides with that of the case of core layer only. K_R of with-core, however, is considerably smaller than that of the core only, and approaches to that of no-core and is a little smaller than it as a whole. This suggests that installing a suitable core layer possibly decreases K_R besides K_T.

2) Effect of Core Thickness on K_T and K_R

Effect of the thickness of core on decreasing K_T is greater for the rubble core than for the lattice core as expected. K_T and K_R for cases of rubble core are shown in Fig. 5 for three kinds of thickness. In the figure, relative width of breakwater B/L which has been known as one of the most important parameters to determine K_R for single layer breakwaters[1] and to wave pressures on the impervious wall behind the permeable absorbers[3]. The thickness, however, doesn't give appreciable change of K_R, especially for the rubble core.

3) Effects of Core Location on K_T and K_R

With a kind of core, the location of core in a armour greatly affects K_R but scarcely does K_T, an oposite trend to the effect of thickness. Fig. 6 presents the case that a rubble core is installed at three different locations in lattice breakwater of trapezoidal cross section. It shows that the breakwater with the rear core gives considerably smaller K_R than the others do for waves of the relative width B/L less than 0.7. Most of protype breakwaters and waves are satisfied with the above B/L condition. To the contrary, K_T hardly depends upon the core location.

Fig. 7 is an example to explain effect of the relative wave height H_I/h on the transmission and reflection coefficients, with location as parameter. K_T decreases as H_I/h increases, irrespectively of core location. Meanwhile K_R decreases slightly with H_I/h in the range of experiment, H_I/h less than 0.14.

4) Wave Height Distribution in and around Breakwaters

Fig. 8 exhibits wave height distributions measured at seaward and shoreward water areas of breakwaters, and in the armour layers of lattice, too. The case of rear core has another maximal wave height in addition to the one appearing near the seaward face of breakwater. The latter maximal of the rear-core breakwater is remarkably smaller than those found for the front-core and no-core ones. Behind the location of the rear-core, the two wave heights of cases with core are almost the same and scarcely depends upon the core location.

Inspecting the distribution characteristics, it may be assumed that the reflected waves appearing in front of breakwater with core are composed of the two reflective waves, namely, the one from seaward face of armour and the another from seaward face of core. Accordingly, a larger distance between the two faces contributes to obtain less reflected wave energy and consequently lower K_R because of a greater phase difference between the two reflected waves at the seaward water area. On the other hand, the transmitted waves may be approximated with the one kind wave which penetrates through the breakwater and

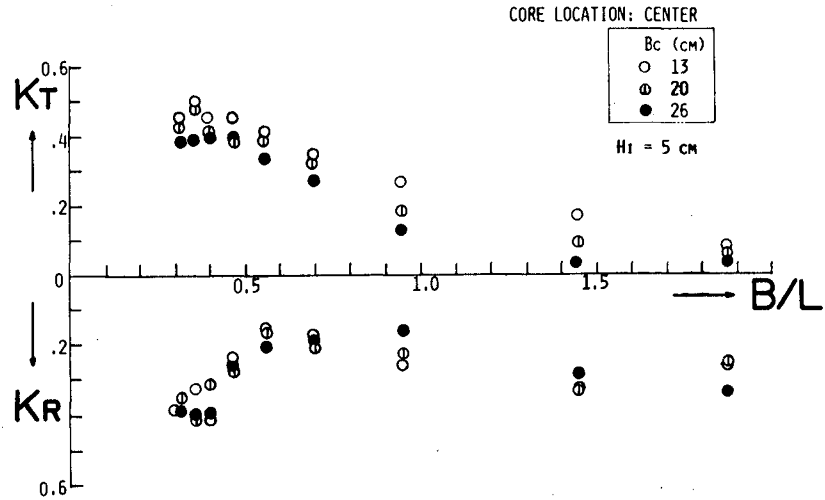

Fig. 5 Effect of Core Thickness on K_T and K_R (Rubble Core)

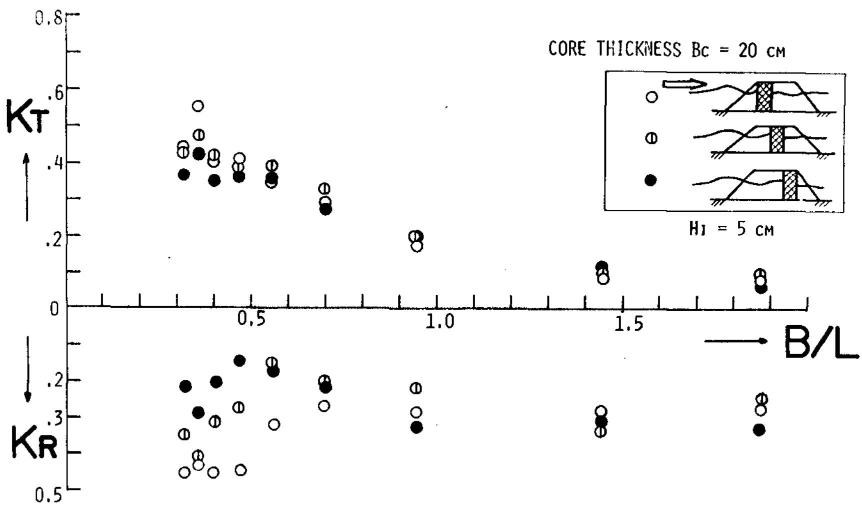

Fig. 6 Effect of Core Location on K_T and K_R (Rubble Core)

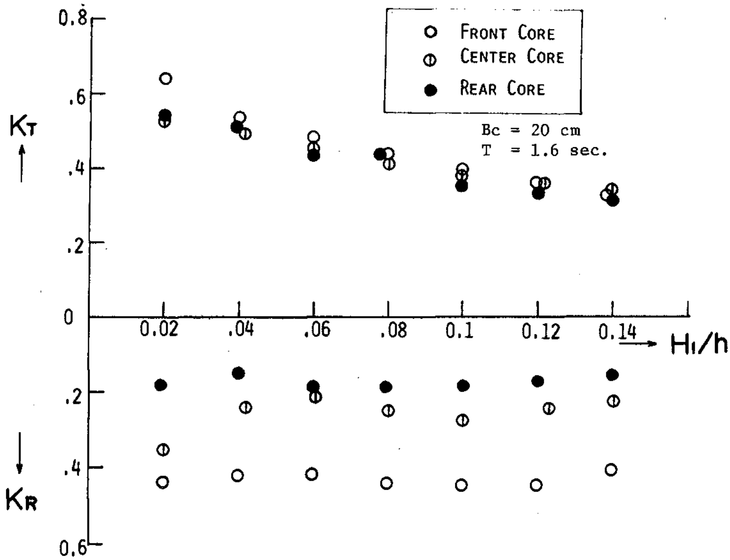

Fig. 7 K_T and K_R versus H_I/h for Rubble Core

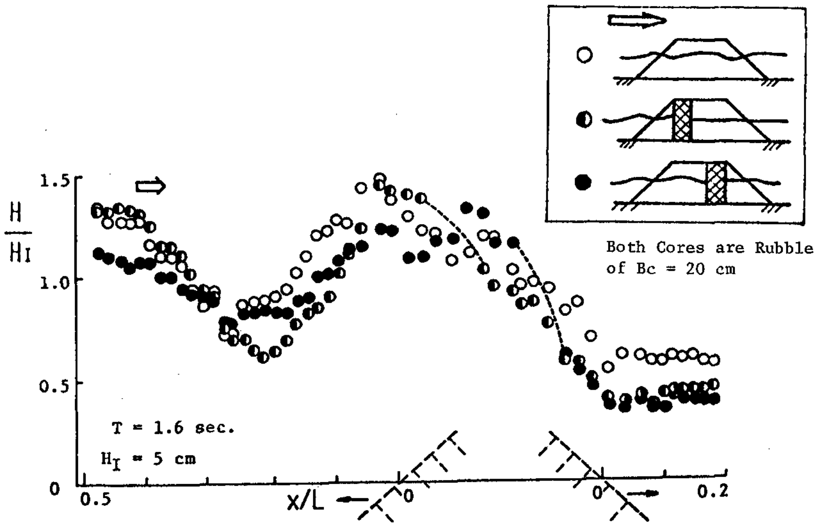

Fig. 8 Wave Height Distribution in and near Breakwaters

appear in the shoreward water area.

The following several figures show the results of harmonic analysis of water surface fluctuations in and around various kinds of breakwater. They bring wave height distribution of higher harmonics other than that of fundamental one whose period is that of the incident wave, as seen in Figs. 9-14. Wave height distribution of fundamental harmonic almost coincides with the directly determined height of crest to trough from the recorded profile, depicted with triangles in the figures. Types of standing wave prevail in front of structures and progressive wave pattern do behind them for the two waves.

Dimensionless wave heights, H_N/H_1 in the figures, for slit walls made of single row or double rows of cylinders are less than 0.2 everywhere for 2nd and 3rd harmonics. The case of two rows is shown in Fig. 9 in which distribution of the higher harmonics looks like a standing wave too and the size is nearly the same to that found for incident waves.

Inside of the single layer breakwater made of lattice, 2nd harmonic has nodes at the front and the rear faces of breakwater (See Fig. 10). The higher harmonics are considered to be generated due to the quadratic loss of internal flow within breakwaters [4]. As for the rubble core layer itself, 2nd harmonic gives a clear pattern of standing wave in the seaward water area, especially for longer waves, which suggests the higher harmonics are generated in the case due to abrupt change of water particle velocity.

The wave height distribution of 2nd harmonics for the rubble core breakwaters of Bc=20cm was investigated in the armours of both sides of core. In the seaward armour, it has usually a node near the front face , but at the rear face of armour it doesn't necessarily has a loop. The latter trend possibly relates to that the fundamental or the directly determined waves do not necessarily take a loop at the rear face of armour. In the shoreward armour behind core, however, it has always nodes at the both faces, while the fundamental ones have loops at the front face and nodes at the rear face.

Heights of 2nd harmonic in armours are relatively greater for rectangular ones. The cause of this trend can be sought in the fact that a kind of resonance which brings large differece of horizontal velocity within breakwater, likely occurs for rectangular one than for trapezoidal one.

5) Comparison Between Rectangular and Trapezoidal Breakwaters

K_T and K_R of trapezoidal breakwaters are compared with those of rectangular ones which have the width B that coincides with the mean width below the still water of the trapezoidal ones. K_T is larger for the trapezoidal ones, as expected. K_R of rectangulars oscillates more sharply with B/L than that of trapezoids. Distribution of K_R plotted agaist B/L gives different trends for the two cases, which suggests a difference of location of reflective planes between the two structures. Discrepancy of the two K_R becomes smaller as the core location moves shoreward, as seen in Figs. 15 and 16.

6) Analytical Prediction of K_T and K_R

Several analytical approaches to estimate K_T and K_R for porous breakwaters have been proposed recently [5)-8)]. But they deal with essentially breakwaters made of one kind of materials and take no accout of the effect of core location as found hitherto.

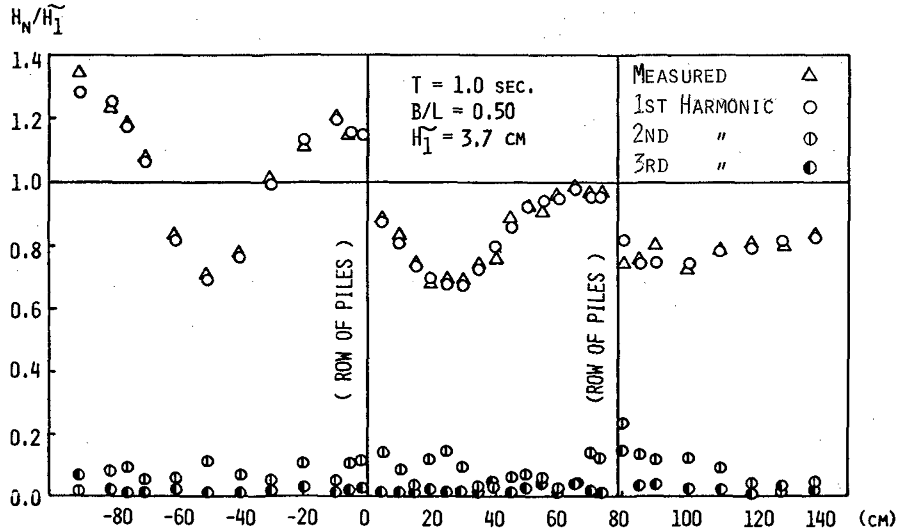

Fig. 9 Wave Heights of 1st - 3rd Harmonics (Two Rows of cylinders)

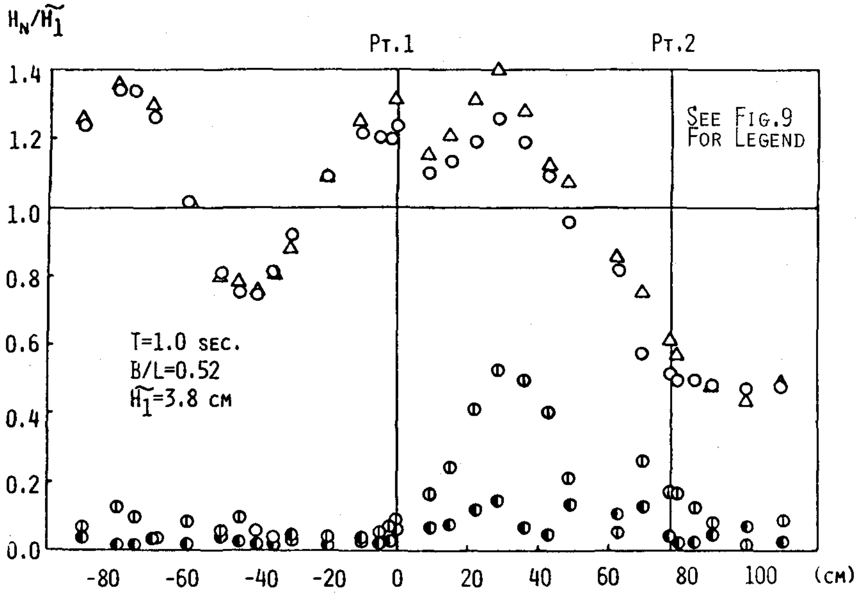

Fig. 10 Wave Heights of 1st - 3rd Harmonics (Rectangular Lattice of No Core)

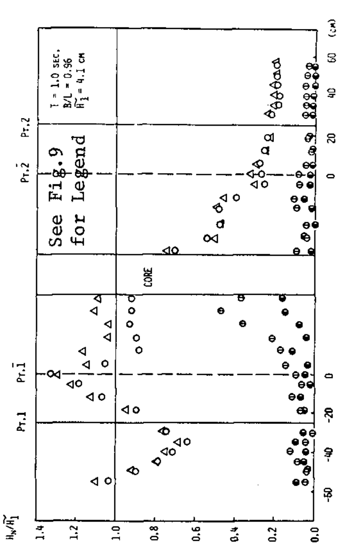

Fig. 12 Wave Heights of 1st - 3rd Harmonics (Trapezoidal Center-Core)

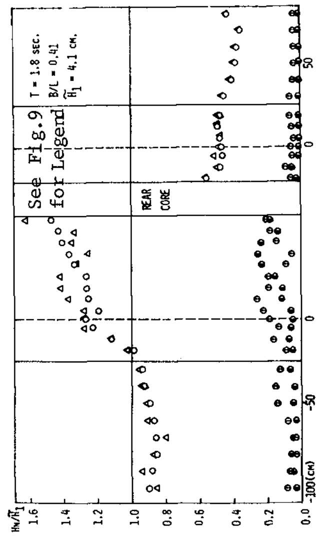

Fig. 14 Wave Heights of 1st - 3rd Harmonics (Trapezoidal Rear-Core)

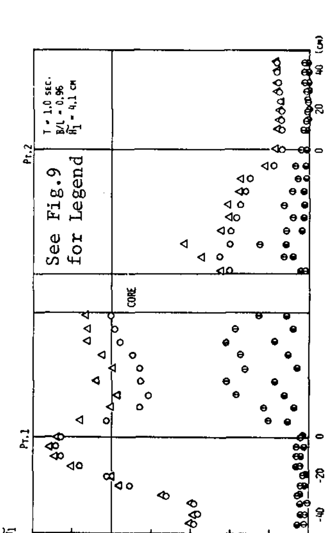

Fig. 11 Wave Heights of 1st - 3rd Harmonics (Rectangular Center-Core)

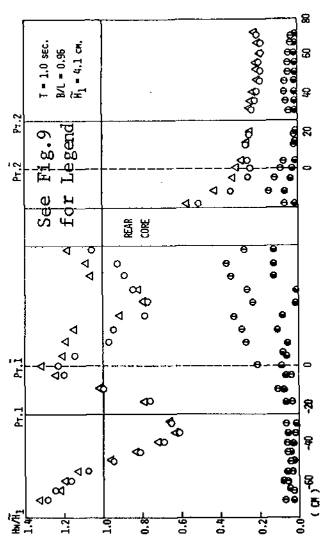

Fig. 13 Wave Heights of 1st - 3rd Harmonics (Trapezoidal Rear-Core)

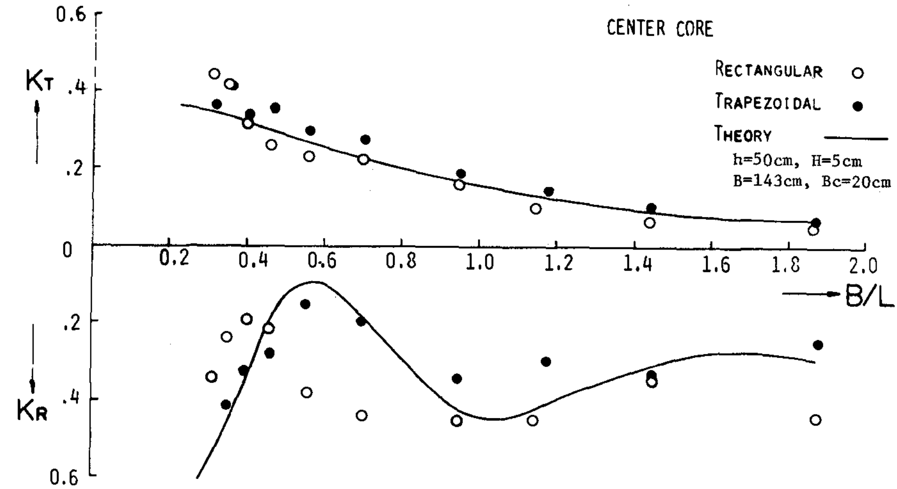

Fig. 15 Comparison Between Rectangular and Trapezoidal Breakwaters (Center Core)

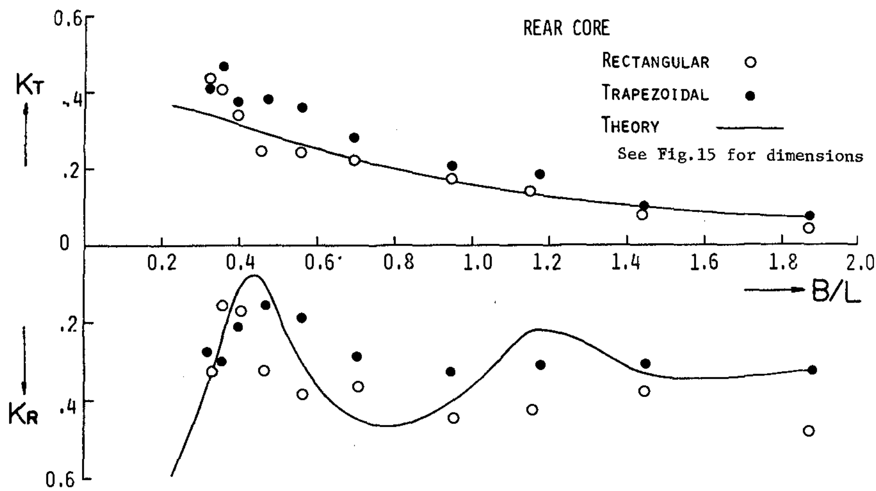

Fig. 16 Comparison Between Rectangular and Trapezoidal Breakwaters (Rear Core)

Problems of wave transmission and reflection coefficients for multi-layered porous breakwaters may be solved as one of boundary value problems as performed by a few researchers for single layer pervious breakwaters[6),7)]. But such a solution will becomes extremlely cumbersome as number of layers increases for multi-layered breakwaters.

A simplified approach to estimate K_T and K_R for multi-layered porous breakwaters has been proposed [9)], whose summary is presented in APPENDIX. It is applied for the experimental data, which seems to be useful for K_T of both rectangular and trapezoidal breakwaters and K_R of trapezoidal ones, as we can see in Figs. 15 and 16.

K_T and K_R of three kinds of prototype breakwater, namely, center-core, rear-core and no core ones, are calculated for cases H_I = 1.0, and 5.0 meter with varying T. The result is shown in Figs. 17 and 18. K_T can be sucessfully reduced by installing a core, while K_R can be lowered by locating the core shoreward in breakwater.

7) Perforated Plate Breakwaters

Employment of pervious core for porous breakwaters can be expected to reduce the transmitted wave height. One of the simplified pervious cores may be thin plates or slab with pores and/or slits. Several studies have been disclosed about perforated wall breakwaters with chambers, but not with those filled with granular materials. Perforated steel plates with circular holes were used as thin cores. Breakwaters of rectangular cross section were only tested (Photo. 2). One to three plates were installed at the front and the rear faces of, and at the center of breakwaters

K_T and K_R of the plate breakwaters are shown in Figs. 19 and 20. The plate installed at the rear face of breakwater works successfully for reducing K_T especially for longer waves. Breakwaters having the two plates at the both faces bring higher K_R than the cases of rear plate only and no plate, though they can lower K_T considerably.

Photo. 2 Rubble Breakwater with Perforated plates

CONCLUSIONS

1) Pervious core layers installed in porous breakwaters effectively decrease the transmitted wave height, and possibly reduce the reflected wave height too provided they being placed shoreward in breakwaters.
2) The simplified analytical approach is confirmed to be useful to predict the transmission and reflection coefficients for pervious core breakwaters.
3) Thin perforated plates set at the rear face of pervious breakwa-

ters are effective to decrease K_T without increasing K_R. They may replace the cores made of granular materials in prototype breakwaters if practically feasible.

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REFERENCES

1) Kondo, H. and S. Tōma: Reflection and Transmission for a porous structure, Proc. of XIIIth Coastal Eng. Conf., Vol. III, pp. 1847-1866, 1972.
2) U.S. Army Coastal Engineering Research Center: Shore Protection Manual, 2nd Edition, 1975.
3) Kondo, Hideo: Wave pressures on vertical wall with porous absorbers, Proc. of Japan Society of Civil Engineers, No. 223, pp. 85-97, 1974.
4) Mei, C. C., P. L-F Liu, and A. T. Ippen: Quadratic loss and scattering of long waves, Jr. of the Waterways, Harbors an Coastal Eng. Div., Proc. of ASCE, WW3, pp. 217 - 239, 1974.
5) Kondo Hideo: An anlytical approach to wave transmission through permeable structures, Coastal Engineering in Japan, Vol. 13, pp. 31 - 42, 1970.
6) Ijima, T., Y. Eguchi and A. Kobayashi: Study on pervious breakwaters and quay walls, Proc. of 18th Conf. on Coastal Eng. of JSCE, pp. 121 - 130, 1971 (in Japanese).
7) Sollitt, C. K. and R. H. Cross: Wave Reflection and Transmission at permeable breakwaters, Rt. No. 147, R. M. Parsons Lab., MIT, 1972.
8) Madsen, Ole Secher: Wave transmission through porous structures, Jr. of the Waterways, Harbors and Coastal Eng. Div., Proc. of ASCE, WW3, pp. 169 - 188, 1974.
9) Kondo, H., S. Tōma and K. Kasai: An analytical approach to predict the transmission and reflection coefficients for multi-layered porous breakwaters, Memoirs of the Muroran Institute of Technology, Science and Engineering, Vol. 9, No. 1 (to be published in 1976, in Japanese).
10) Kondo, H. and S. Tōma: Breaking wave transformation by porous breakwaters, Coastal Engineering in Japan, Vol. 17, pp. 81 - 91, 1974.

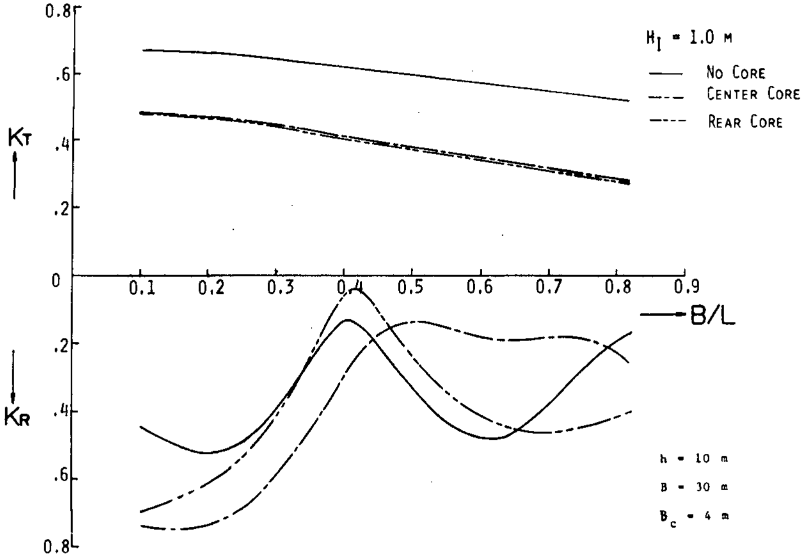

Fig. 17 Prediction of K_T and K_R for Prototype Breakwaters

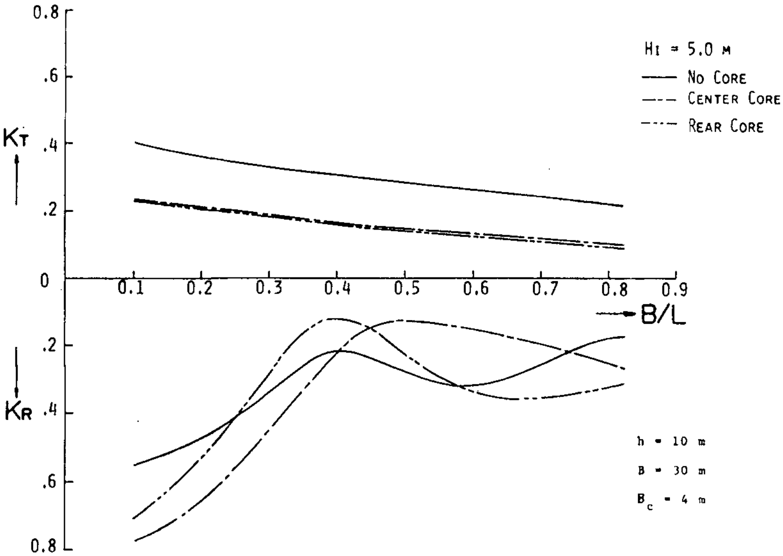

Fig. 18 Prediction of K_T and K_R for Prototype Breakwaters

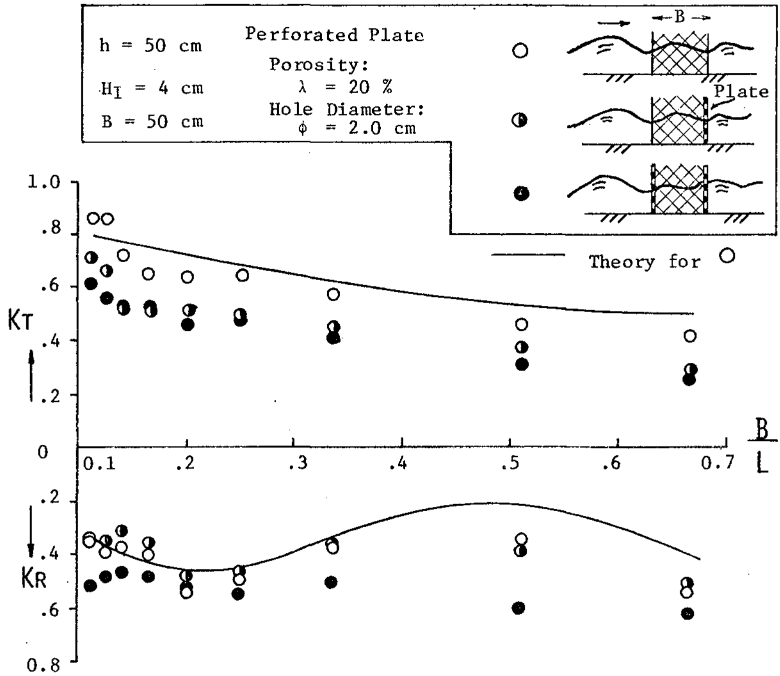

Fig. 19 K_T and K_R of Lattice Breakwaters with Perforated Plate

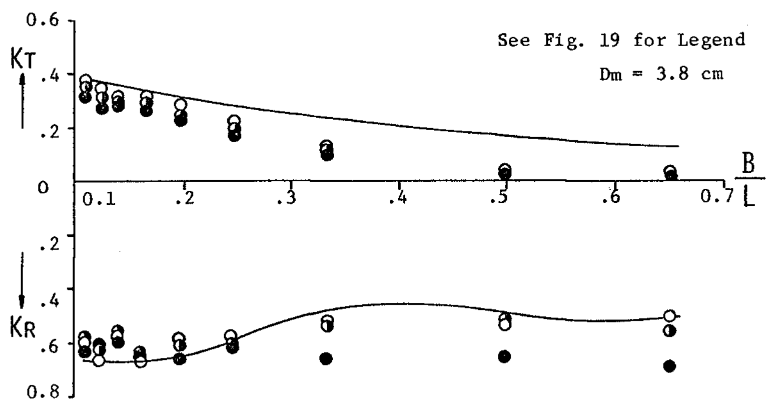

Fig. 20 K_T and K_R of Rubble Breakwaters with Perforated Plate

APPENDIX

AN APPROACH TO PREDICT TRANSMISSION AND REFLECTION COEFFICIENTS FOR MULTI-LAYERED POROUS BREAKWATERS [9)]

The present approach is derived on the basis of linearized Forchheimer's law for the frictional loss in breakwaters provided waves are of shallow water, which is in accordance with the line of the previous approach for single layer one[5),1),10)].

Besides, the following assumptions are made.

(1) Breakwaters are composed of rectangular layers, and the boundaries between layers are vertical.

(2) The tranthmitted waves appearing in the protected water area are the one component waves to which the incident waves develop after passing through all the layers consecutively. The components come to the area after reflected back once or more are neglected.

(3) The reflected waves are sum of the waves reflected one time only, each of which is generated when the incident waves of (2) pass a boundary between adjacent two layers.

According to the above assumptions , the transmission coefficient K_T of a breakwater composed of N layers (See Fig. 21), are given by,

$$K_T = K_{t,1} \cdot K_{t,2} \cdot \ldots \cdot K_{t,J} \cdots K_{t,N} \cdot K_{t,N+1} \cdot \exp[-(n_1 B_1 + n_2 B_2 + \ldots \ldots + n_J B_J + \ldots + n_N B_N)], \quad (3)$$

where n_J is the damping factor of wave height while advancing in the J layer of the width B_J, and $K_{t,J}$ is the transmission coefficient when waves penetrates into the layer J+1 from J passing through the boundary J [5),1)].

The equation of the water surface for the resultant reflected waves, η_R, is expressed as the sum of reflected waves', $\eta_{r,J}$ original-

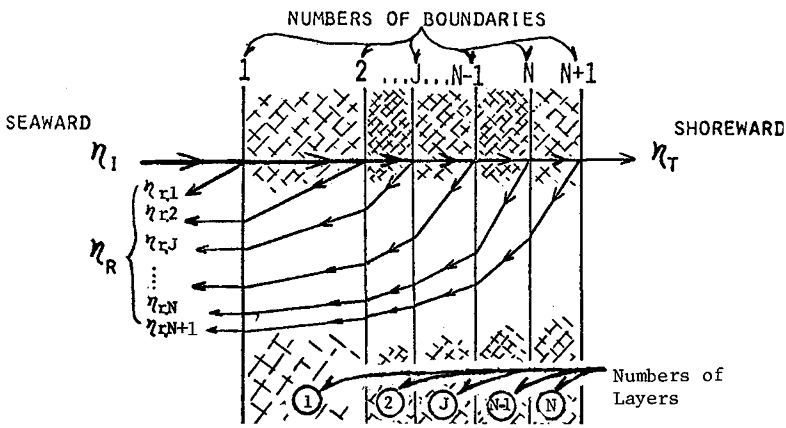

Fig. 21 Scheme of Wave Transformation by Multi-Layered Breakwater

ly generated at the boundary J, (J = 1, 2, ...N, N+1), as

$$\eta_R = \eta_{r,1} + \eta_{r,2} + \dots + \eta_{r,J} \dots + \eta_{r,N} + \eta_{r,N+1} , \qquad (4)$$

where,

$$\eta_{r,1} = \frac{H_I}{2} \cdot K_{r,1} \cdot \sin(\sigma t + m_o x + \alpha_{r,1}), \quad m_o = 2\pi/L,$$

$$\vdots$$

$$\eta_{r,J} = \frac{H_I}{2} \cdot K_{t,1} \cdot K_{t,2} \cdots K_{t,J-1} \cdot K_{r,J} \cdot K_{tb,J-1} \cdots K_{tb,1} \cdot \exp[-\{(n_{i,1} + n_{r,1})B_1 + (n_{i,2} + n_{r,2})B_2 \dots + (n_{i,J} + n_{r,J-1})B_{J-1}\} . \sin\{\sigma t + m_o x - (m_{i.1} + m_{r,1})B_1 - \dots - (m_{i,J-1} + m_{r,J-1})B_{J-1} + \alpha_{t,1} \dots \alpha_{t,i-1} + \alpha_{r,J} + \alpha_{tb,J-1} + \dots + \alpha_{tb,1}\},$$

$$\vdots$$

$$\eta_{r,N+1} = \frac{H_I}{2} \cdot K_{t,1} \cdot K_{t,2} \cdots K_{t,J-1} \cdots K_{t,N} \cdot K_{r,N+1} \cdot K_{tb,N} \cdots K_{tb,1} \cdot \exp[-\sum_1^N (n_{i,J} + n_{r,J})B_J] . \sin[\sigma t + m_o x - \sum_1^N (m_{i,J} + m_{r,J})B_J + \sum_1^N \alpha_{t,J} + \alpha_{r,N} + \sum_1^N \alpha_{tb,J}] ,$$

where m_J is the wave number in the J layer and α is a phase angle. Subscript i, r and t for m, n, K_t, K_r, α and η correspond to the incident, reflected and transmitted waves, respectively. That denoted tb corresponds to the waves transmitting back seaward after reflected at one of the boundaries.

Consequently, the reflection coefficient is obtained as,

$$K_R = [A_1^2 + A_2^2 + \dots + A_{N+1}^2 + 2\{A_1 A_2 \cos(\beta_1 - \beta_2) + A_1 A_3 \cos(\beta_1 - \beta_3) \dots + A_J A_N \cos(\beta_J - \beta_N) \dots + A_N A_{N+1} \cos(\beta_N - \beta_{N+1})\}]^{1/2} , \qquad (5)$$

where,

$$A_1 = K_{r,1}, \quad A_2 = K_{t,1} \cdot K_{r,2} \cdot K_{tb,1} \cdot \exp[-(n_{i,1} + n_{r,1})B_1], \dots\dots\dots$$

$$A_J = K_{t,1} \cdot K_{t,2} \cdots K_{t,J-1} \cdot K_{r,J} \cdot K_{tb,J-1} \cdots K_{tb,1} \cdot \exp[-(n_{i,1} + n_{r,1}) \cdot B_1 + \dots (n_{i,2} + n_{r,2})B_2 + \dots + (n_{i,J} + n_{r,J})B_J], \dots\dots$$

$$A_{N+1} = K_{t,1} \cdot K_{t,2} \cdots K_{t,J} \cdots K_{t,N} \cdot K_{r,N+1} \cdot \exp[-(n_{i,J} + n_{r,J})B_J].$$

Also,

$$\beta_1 = \alpha_{r,1}, \quad \beta_2 = -(m_{i,1} + m_{r.1})B_1 + \alpha_{t,1} + \alpha_{r,2} + \alpha_{tb,1}, \dots\dots$$

$$\beta_J = [-\{(m_{i,1} + m_{r,1})B_1 + (m_{i,2} + m_{r,2})B_2 + \dots + (m_{i,J} + m_{r,J})B_J\} + \alpha_{t,1} + \alpha_{t,2} + \dots + \alpha_{t,J-1} + \alpha_{r,J} + \alpha_{tb,J-1} + \dots + \alpha_{tb,1}], \dots$$

$$\beta_N = [-\sum_1^N (m_{i,J} + m_{r,J})B_J + \sum_1^N \alpha_{t,J} + \alpha_{r,N+1} + \sum_1^N \alpha_{tb,J}].$$

A Flow Chart of computer program for the pervious core breakwaters, i.e., for the case of N = 3, is presented in Fig. 22.

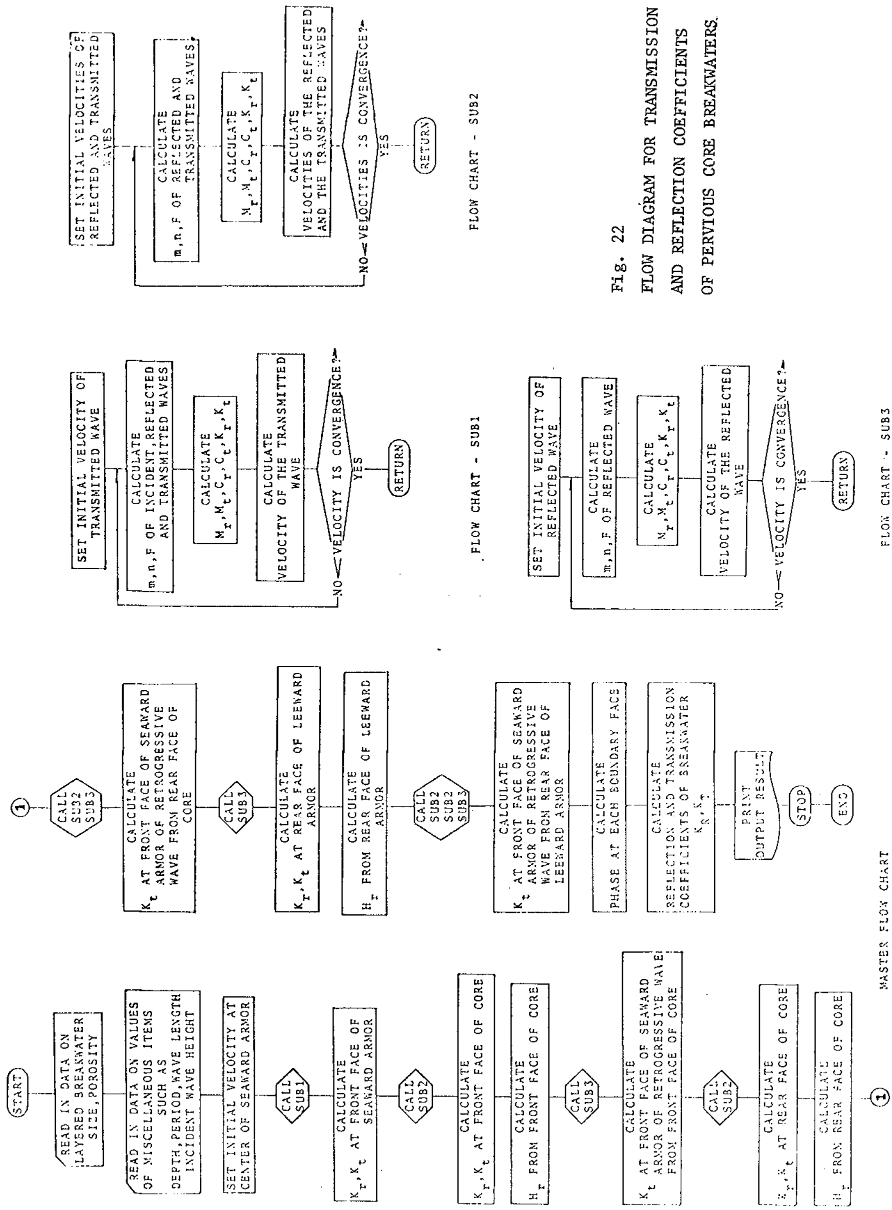

Fig. 22 FLOW DIAGRAM FOR TRANSMISSION AND REFLECTION COEFFICIENTS OF PERVIOUS CORE BREAKWATERS.