PERFORMANCE CHARACTERISTICS OF SUBMERGED BREAKWATERS

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INTRODUCTION

Submerged breakwater is a barrier with its crest at or slightly below the still water level. In situations where complete protection from waves is not required, submerged breakwaters offer a potentially economic solution. Submerged breakwaters have been effectively used to protect harbour entrances, to reduce siltation in entrance channels, against beach erosion, and for creation of artifical fishing grounds. However quantitative information available about the hydraulic behaviour of these submerged breakwaters is rather limited. Theoretical analysis of the problem has not proved satisfactory primarily because of the difficulties in quantifying the energy losses that always accompany these wave - structure interactions. Recourse has to be taken to laboratory studies to provide the necessary information regarding the performance characteristics of submerged breakwaters.

A comprehensive laboratory investigation to evaluate the performance characteristics of the submerged breakwaters of various types and shapes, permeable and impermeable was undertaken. The results of these investigations are presented in this paper.

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EXPERIMENTAL FACILITIES AND PROCEDURES

The experiments were conducted in a wave flume (25m x 0.9m x 0.9m) provided with a plunger type regular wave generator. The water surface time histories were recorded using a parallel - wire resistance probe in conjunction with a Kempf and Remmers three channel strip chart recorder.

The submerged breakwaters investigated were:

1) Horizontal fixed plate type,
2) Thin vertical wall type, Impermeable,
3) Triangular type, Impermeable,
4) Rectangular type, Permeable and Impermeable,
5) Trapezoidal type: Sea face sloping and beach face sloping, Permeable and Impermeable,
6) Trapezoidal type: Sea face sloping and beach face vertical, Impermeable.

The impermeable breakwater models were fabricated using mild steel and aluminium plates of 6mm thickness. For the sloping faces, a slope of 2 horizontal to 1 vertical was used. The details of all the breakwater models investigated is given in Fig.1. To study the influence of permeability, the breakwaters of the rectangular type (50 cm crest width) and the trapezoidal type (both faces sloping) were used. These breakwaters were formed using crushed stone aggregates, and the required cross-sections were maintained by confining the aggregates in wire mesh cages. Two types of aggregates, Type A and Type B were used. Type A aggregate had a median size of 16.5mm and a porosity of 0.41, while the Type B aggregate had a median size of 43.4 mm and a porosity of 0.42.

The water depth, d, was maintained constant at 50cm. The depth of crest submergence, d_s, of the breakwater was altered to any desired value by keeping the water depth constant but varying the crest level of the breakwater.

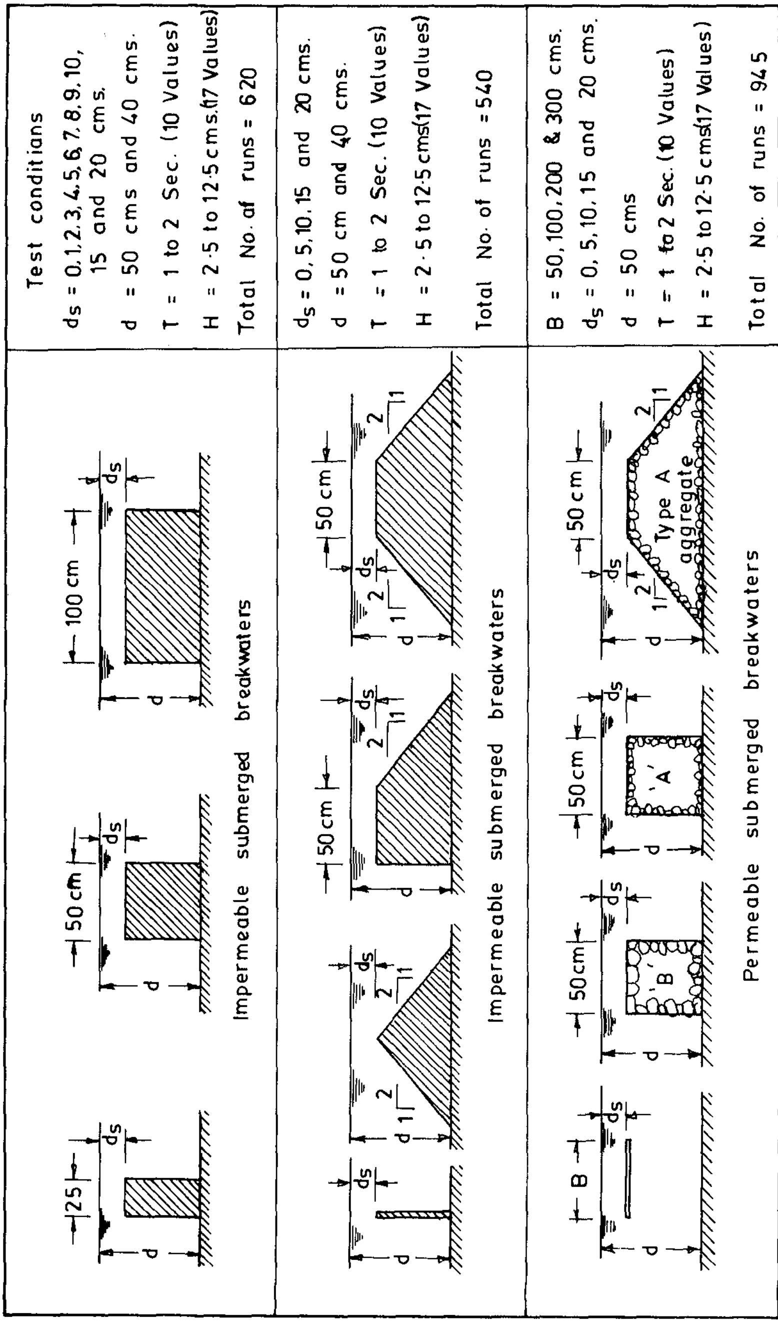

FIG.1 SUBMERGED BREAKWATERS INVESTIGATED : TEST CONDITIONS AND DIMENSIONS

Experiments were conducted covering a wide range of experimental conditions consistent with the available facility. The relative water depth, d/L was varied from 0.123 to 0.331, the incident wave steepness, H_i/L was varied from 0.007 t 0.083, while the relative depth of crest sub - mergence d_s/d was varied from 0.0 to 0.4.

The incident wave characteristics, H_i and L were measured in steady state runs without the breakwater in position. The transmitted wave was generally found to be irregular though periodic. To provide a basis for comparision of test results as free as possible from subjectivity, the equivalent wave height concept of Dick and Brebner (2) was used to evaluate the transmitted wave height, H_t. The reflected wave which results when the incident wave interacts with the structure, gives rise to a partial standing wave in front of the structure. The reflected wave height, H_r was evaluated by resolving the wave envelope of this partial standing wave. An equivalent wave height, H_l corresponding to the energy lost in the wave - structure interaction process was evaluated from energy balance considerations. The experimental data was processed using a IBM 370/155 digital computer facility.

PRESENTATION AND INTERPRETATION OF EXPERIMENTAL DATA

The data obtained from the experiments was analyzed using the method of dimensional analysis. The pertinent parameters influencing the phenomenon were obtain from dimensional considerations. The influence of the various parameters on the Transmission coefficient, $K_T(=H_t/H_i)$, the Reflection coefficient, K_R (= H_r/H_i) and the loss coefficient, K_L(= H_l/H_i) were analyzed. Restriction of space does not permit the presentation of all the results here. The important results regarding the study concerning the transmission coefficient only are presented here.

The complete details can be found in Reference 1.

The following dimensionless parameters can be considered to be important in the study of the transmission coefficient,

$$K_T = H_t/H_i = f\ (H_i/L,\ d/L,\ B/L,\ d_s/d,\ S,\ s, p)$$

in which H_t is the transmitted wave height, H_i is the incident wave height, L is the indident wave length, d is the depth of water, B is the crest width of the submerged breakwater, d_s is the depth of crest submergence below SWL, S is a parameter characterizing the shape of the breakwater, s is the slope of the breakwater faces, and p is the porosity of the breakwater. The dimensionless parameters H_i/L, d/L, B/L, and d_s/d represent the incident wave steepness, the relative depth of water, the relative crest width, and the relative depth of crest submergence respectively.

The shape has been represented by a variable, S only for mathematical definition. S will represent whether the breakwater is triangular, reotangular or trapezoidal. In the analysis that follows, the shape is not represented by assigning any specific value to S, but instead the shape will be specified. Similarly the slope, s was not varied but the distinction will be between a vertical face and a sloping face.

Influence of incident wave steepness, H_i/L on K_T

The incident wave steepness has an important influence on the wave breaking phenomennon. Waves near the critioal steepness may be induced to break by the submerged breakwater, and since wave breaking process is always accompained by energy losses, steeper waves are likely to be attenuated more than the flatter waves. Hence it can be logically concluded that the wave steepness is likely to be a significant parameter. In fig. 2.the transmission

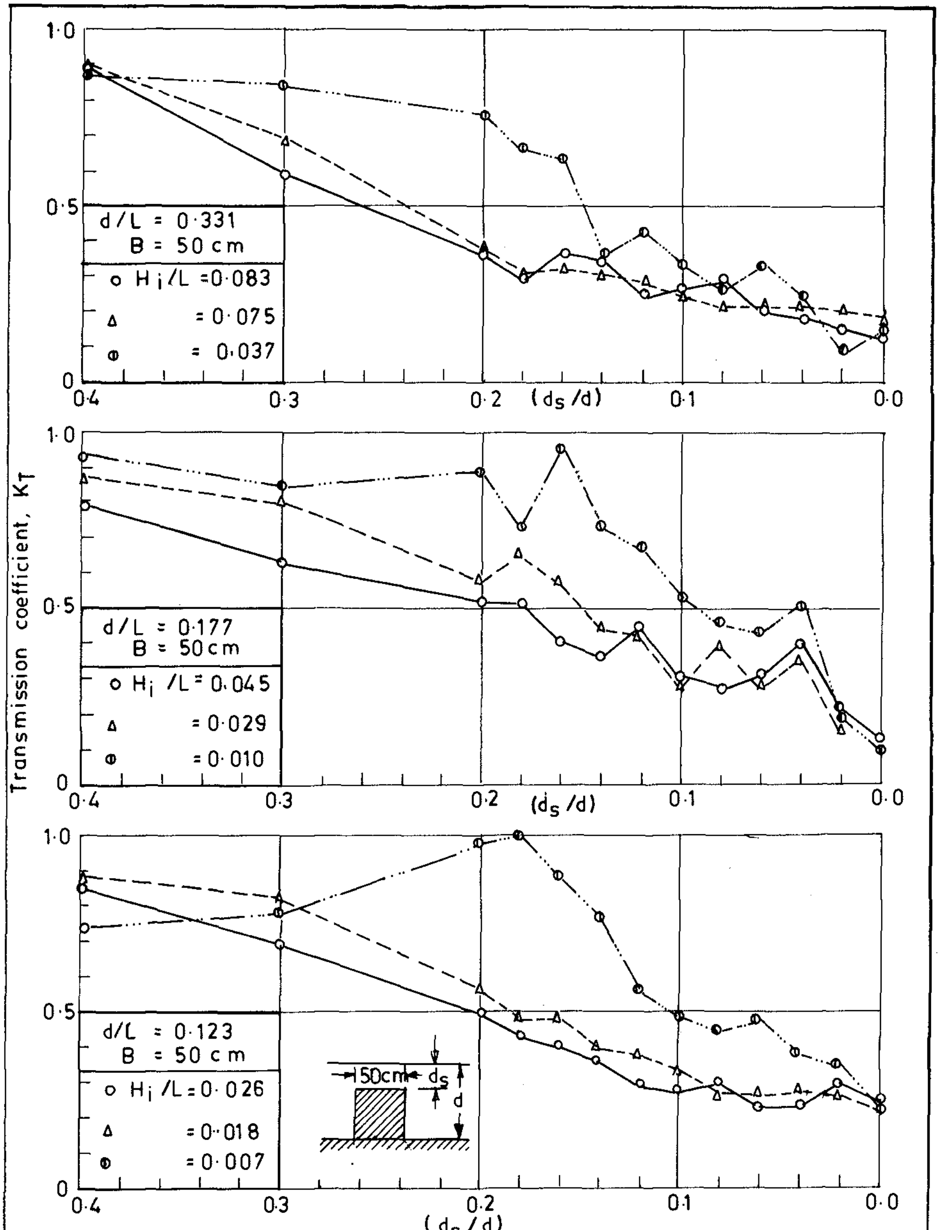

FIG. 2 EFFECT OF WAVE STEEPNESS ON WAVE ACTION OVER A RECTANGULAR IMPERMEABLE SUBMERGED BREAKWATER

coefficient, K_T is plotted against the relative depth of crest submergence, d_s/d, with the incident wave steepness, H_i/L as the third parameter. The curves for the higher steepness values appear to merge into one, indicating that in the range of higher wave steepnesses the influence of H_i/L on K_T is not significant. Similar tendencies were observed for data corresponding to other breakwaters also. Goda et al (3) and Johnson et al (4) have also arrived at similar conclusions.

Another important trend in Fig.2 is the influence of d_s/d on K_T. As d_s/d approaches zero, i.e., the crest of the breakwater approaches the SWL, there is a general decrease in K_T. For large values of d_s/d (= 0.40), the transmission is very high of the order of 75% to 95%. As such d_s/d values greater than 0.40, are not likely to be of any practical significance from the point of view of wave damping. In view of this, the maximum value of d_s/d used in the present investigation was restricted to 0.40.

Influence of relative water depth, d/L on K_T

The data to study the influence of the relative water depth, d/L on K_T is presented in Fig.3. To reduce the influence of other parameters, the incident wave steepness is maintained constant at 0.03. The data show very similar tendencies and in general it can be seen that the relative water depth does not have significant influence on K_T. In the range d_s/d = 0.0 to 0.2, the relative water depth did not have any influence, but in the range d_s/d = 0.2 to 0.4, larger values of d/L show a tendency towards slightly greater transmission. This is to be expected because larger values of d/L correspond to relatively deeper water waves, wherein more energy is concentrated near the surface. When d_s/d is also large, this energy concentrated near the surface is easily transmitted across the structure.

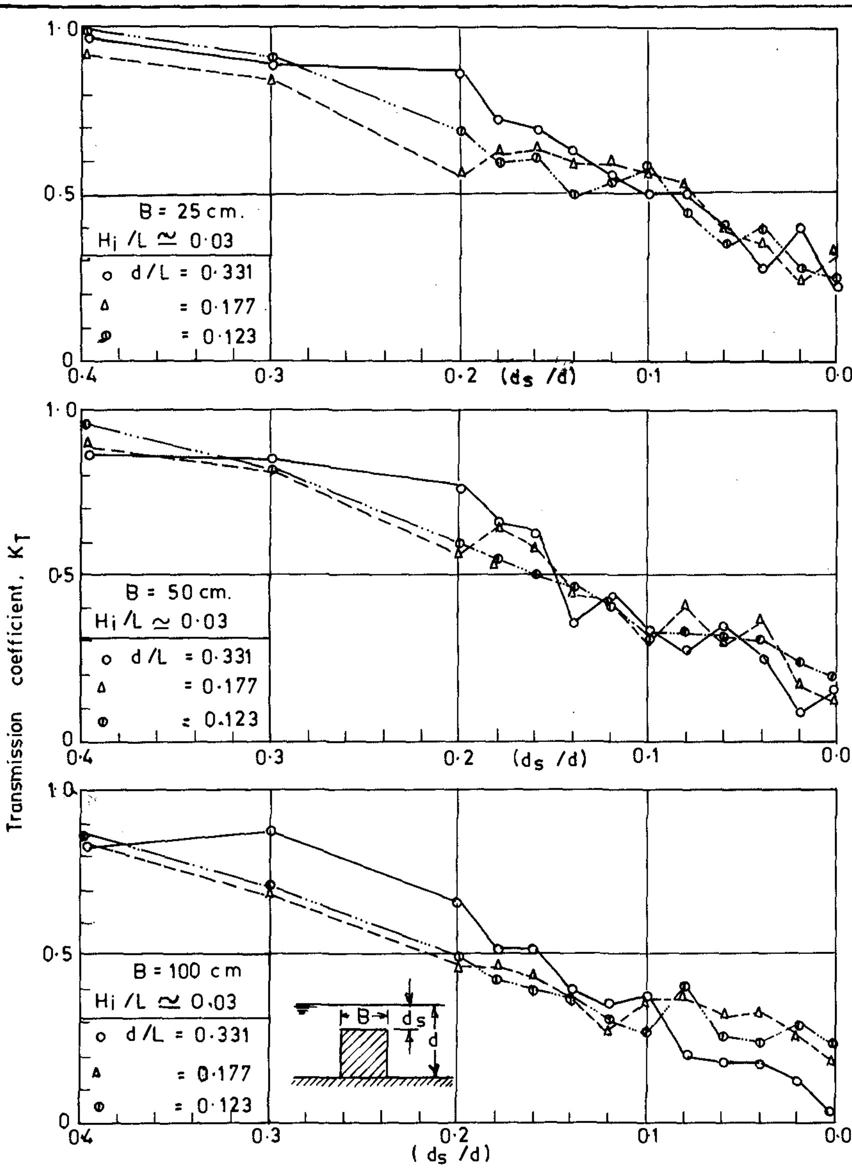

FIG. 3 EFFECT OF RELATIVE WATER DEPTH ON WAVE ACTION OVER A RECTANGULAR IMPERMEABLE SUBMERGED BREAKWATER.

Influence of relative crest width, B/L, and relative depth of crest submergence, d_s/d, on K_T.

In the case of impermeable submerged breakwaters, the energy transmission to the shoreward side must take place only above the crest of the breakwaters. The amount of energy transmitted across will naturally be more, if the depth of crest submergence is more. So it is logical to conclude that the relative depth of crest submergence, d_s/d is likely to be the most important parameter influencing the performance characteristics of the submerged break waters. This conclusion is in general also applicable to the permeable breakwaters also, since the energy trans - mitted through the structure is likely to be a small percentage of the energy transmitted over the crest.

The relative crest width, B/L influences the wave transformation over the breakwater. In the case of breakwaters with very small crest widths, it was observed that the incident wave steepens and reaches a condition when it is about to break. But before the wave can break, it enters the relatively deeper waters in the lee of the breakwater, which prevents the wave from breaking. In the case of breakwaters with sufficient crest width, the wave breaks resulting in a greater dissipation of energy and consequently lesser transmission. An increase in the crest width over the minimum necessary to trigger breaking, is unlikely to have any significant influence on the transmission characteristics.

The experimental data is in general agreement with these logical conclusions as can be clearly seen in Fig.4. The data for the rectangular impermeable breakwaters is plotted in Fig.4. in terms of K_T and B/L with d_s/d as the third parameter. The scatter of data is slightly large for small values of B/L. The data corresponding to the

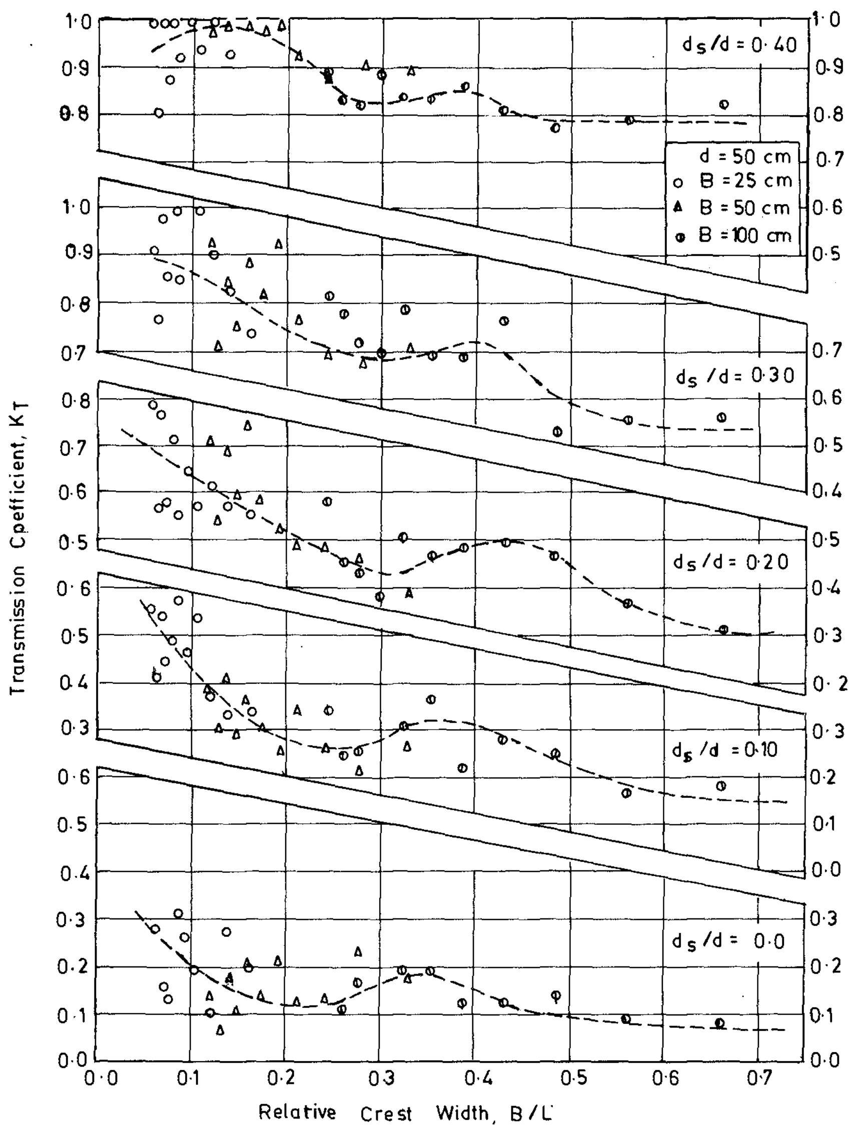

FIG.4 TRANSMISSION COEFFICIENT Vs RELATIVE CREST WIDTH: RECTANGULAR IMPERMEABLE SUBMERGED BREAKWATER.

three crest widths (25, 50, and 100cm) overlap in this range and the scatter may be partly due to this. K_T decreases as B/L increases, until K_T reaches a minimum value. This occurs for B/L values between 0.2 and 0.3. The position of the minimum shifts gradually from 0.2 to 0.3, as d_s/d increases from 0.0 to 0.4. After the minimum is reached, K_T tends to increase slightly with further increase in B/L, before it becomes asymptotic. Increase of crest widths beyond B/L = 0.3, does not significantly add to the damping characteristics of these breakwaters. Fig.4 clearly points to the existence of an optimum crest width of the breakwater (B/L = 0.2 to 0.3). The K_T Vs B/L curves show some sort of a sinusoidal variation which cannot be satisfactority explained.

The data in Fig.4 group themselves remarkably well for the different values of d_s/d, and the trend lines for constant values of d_s/d, show consistent tendencies. As is to be expected, larger values of crest submergence show greater transmission.

Influence of shape and slope

The transmission characteristics of the impermeable breakwaters of different shapes, but with finite crest width (50 cm) are shown in Fig.5. The transmission curves for the three shapes have very similar characteristics. In the case of the rectangular breakwaters, the reflections will be high, while for the trapezoidal breakwater, the reflection would be low but the losses are likely to be higher due to wave breaking. Thus in both cases, the transmission would be the same. Providing a slope on the beach face of the breakwater has not influenced the transmission characteristics in comparison with the trapezoidal breakwater with beach face vertical. Kabelac (5) has concluded that the magnitude of the wave attenuation depends not only

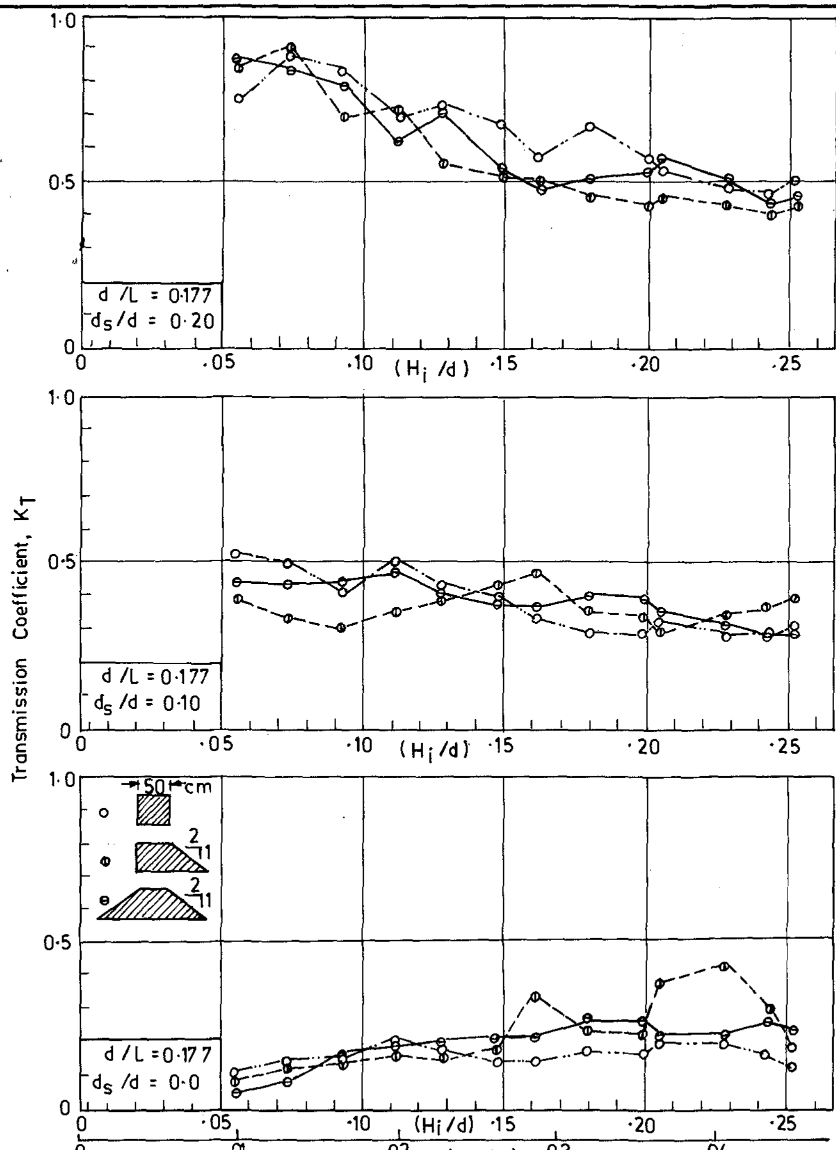

FIG. 5 EFFECT OF SHAPE ON THE TRANSMISSION COEFFICIENT: IMPERMEABLE BREAKWATERS - FINITE CREST WIDTH.

on the slope of the sea face of the breakwater, but also on its cross-sectional area. The cross-sectional areas of the three breakwaters whose results are presented in Fig.5, are 2500, 5000 and 7500 cm^2. But the transmission characteristics of all these three types are very nearly the same although the cross-sectional areas have a three fold variation.

It can be concluded that for the various shapes of the breakwaters tested in the present investigations, the transmission characteristics do not depend on the shape. Breakwaters with vertical faces on the sea side induce large reflections, creating partial standing waves. These create problems of scour and consequent undermining at the base of the breakwaters. Further, large reflections result in greater wave forces on the structure due to the formation of the standing wave. These considerations necessarily preclude the rectangular type of submerged breakwaters for practical use.

Submerged breakwaters with their sea faces sloping have the possible advantage that they allow for the free passage of sediment on its face compared to a vertical face. If the beach face of the breakwater is also sloping, the sediment trapping efficiency will be less. So the ideal one appears to be a breakwater with sea face sloping and beach face vertical. The prototype experience as reported by Kabelac (5) confirms the sediment trapping efficiency of these types of breakwaters, in addition to their efficient wave damping characteristics.

Influence of porosity

The experimental data to study the effect of porosity is presented in Fig.6. The data corresponding to the horizontal plate type is also included. This type can be considered as a rectangular breakwater with a porosity,

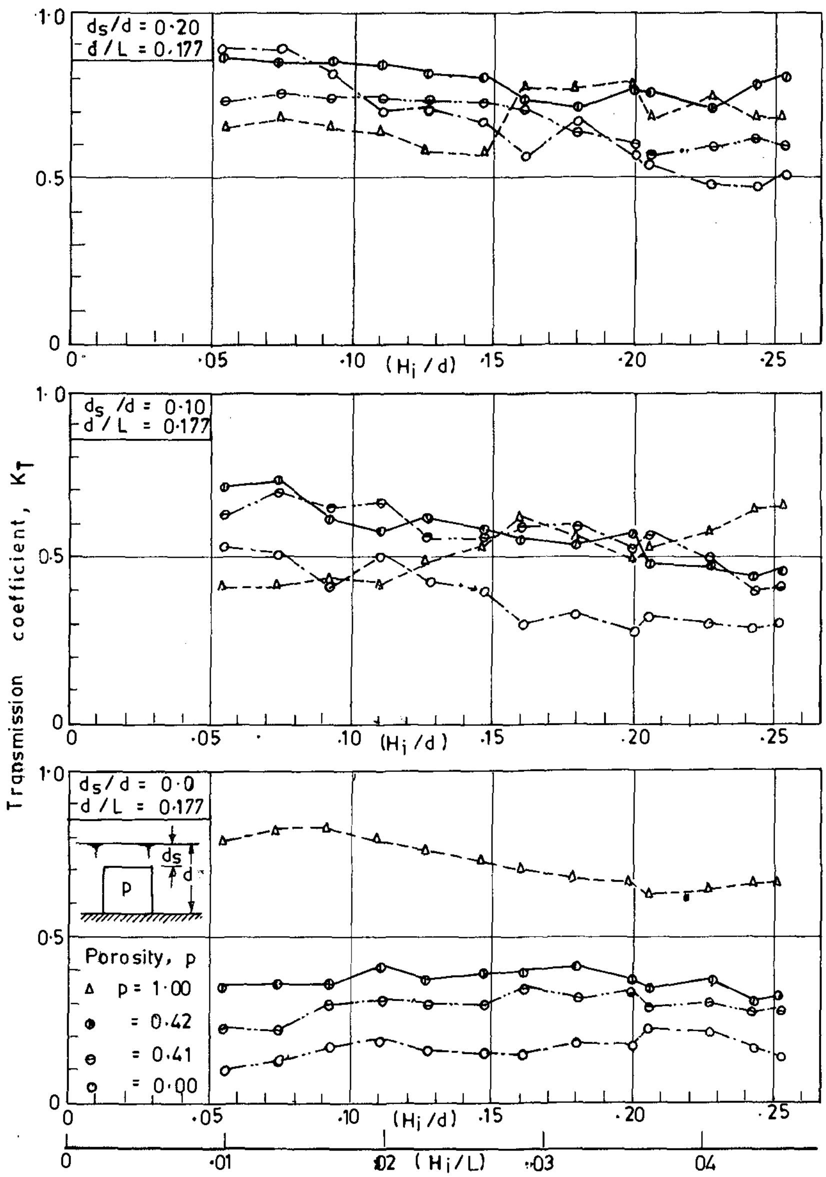

FIG. 6 EFFECT OF POROSITY ON THE TRANSMISSION COEFFICIENT: RECTANGULAR SUBMERGED BREAKWATER

$p = 1.0$, in comparison with the rectangular impermeable type which has a porosity, $p = 0.0$. In Fig.6, K_T is plotted against H_i/d (and H_i/L) with porosity, p as the third variable. The relative water depth, d/L was maintained constant. All the curves are nearly horizontal, which incidentally confirms the earlier conclusion that the wave steepness has no significant influence on K_T. Regarding the influence of porosity, a regular and a systematic trend is seen for the data corresponding to $d_s/d = 0.0$. The impermeable breakwater has the minimum transmission, and as the porosity increases, the transmission also increases. For $d_s/d = 0.10$, the impermeable breakwater has the minimum transmission for most of the range, but the data for other porosities cannot be distinguished from each other. For $d_s/d = 0.20$, the curves for the permeable and impermeable cases appear to merge. This is because for large depths of crest submergence, the energy transmitted through the breakwater will be a very small percentage of the energy transmitted on the top, and hence the porosity is unlikely to have any significant influence on K_T.

In general we find the behaviour of the permeable breakwaters to be very similar to the behaviour of the impermeable breakwaters. This is in contrast to the conclusion of Dick and Brebner (2) that permeable breakwaters behave differently from impermeable types. However it should be noted that the permeable breakwaters used by Dick and Brebner were of the nested tube type, while in the present case they were of crushed stones.

PERFORMANCE CHARACTERISTICS OF SUBMERGED BREAKWATERS

The investigations regarding the influence of the various parameters on the transmission coefficient, K_T as detailed above, indicate that the two parameters, relative depth of crest submergence, d_s/d, and the relative crest width, B/L to be the most significant. The performance characteristics for each of the type of breakwater tested can be represented as K_T Vs B/L plots with d_s/d as the third parameter. Such a plot for the rectangular impermeable submerged breakwaters was presented in Fig.5. In Figs. 7 and 8, the performance characteristics of some of the other submerged breakwaters tested have been presented. An important feature of these plots is the considerable similarities and consistent tendencies.

TRANSMITTED WAVE CHARACTERISTICS

The waves formed shoreward of the submerged breakwaters were quite complex and showed the presence of several smaller waves. However periodicity was maintained and this period corresponds to the incident wave period. This indicates the generation of a system of harmonics with a fundamental frequency equal to that of the incident wave. To examine this aspect, some of the transmitted wave records were subjected to a spectral analysis and the results confirmed this. The generation of higher harmonics was found to be more pronounced when the crest of the breakwater is close to the still water level. However, in a majority of these cases, the energy contents of the higher harmonics were considerably less than that corresponding to the fundamental. Thus it can be concluded that the transmitted wave has the same fundamental frequency as the incident wave but part of the energy is shifted to the higher frequencies.

CONCLUSIONS

The results of the present investigations indicate that submerged breakwaters can effect substantial wave attenuation and can be successfully used in places where only partial protection from waves is required. The important parameters that influence the performance are the

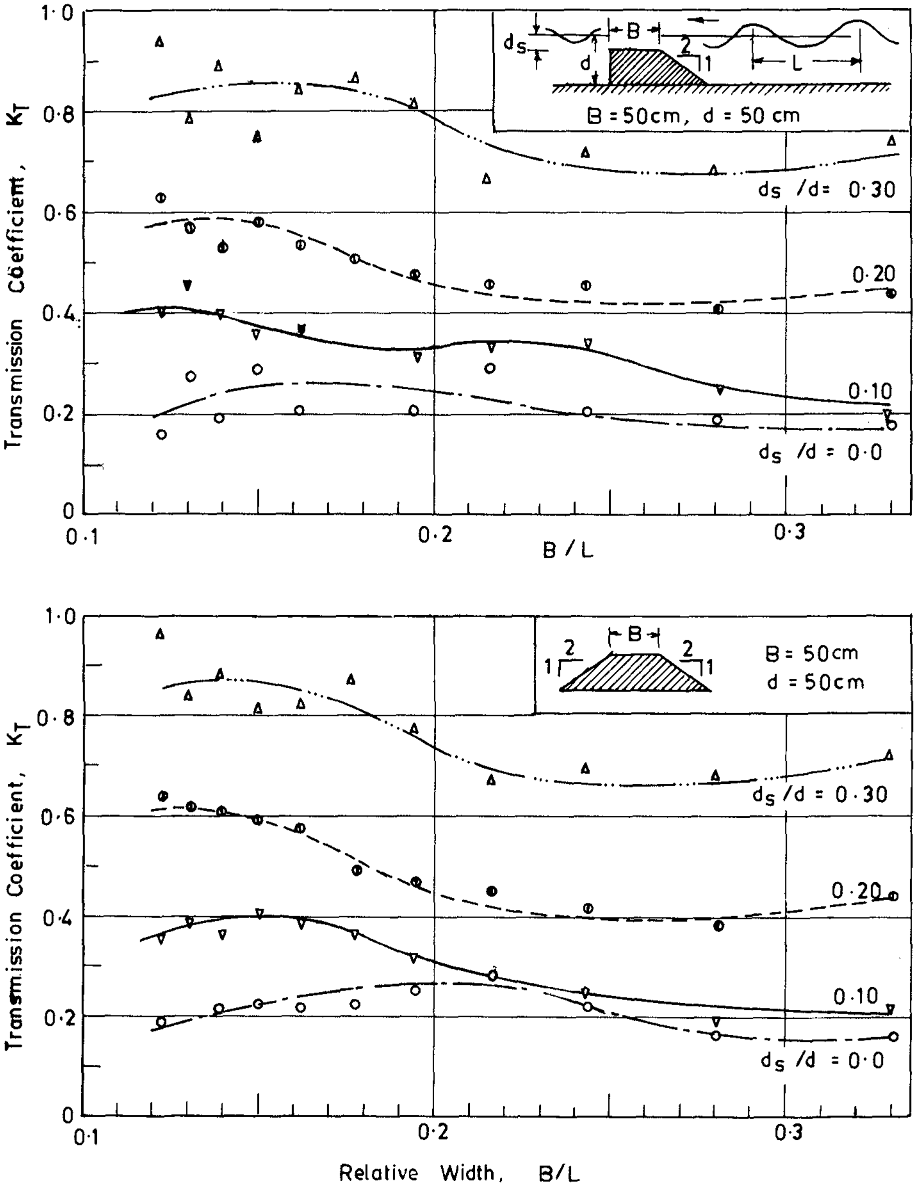

FIG. 7 PERFORMANCE CHARACTERISTICS OF TRAPEZOIDAL IMPERMEABLE SUBMERGED BREAKWATER.

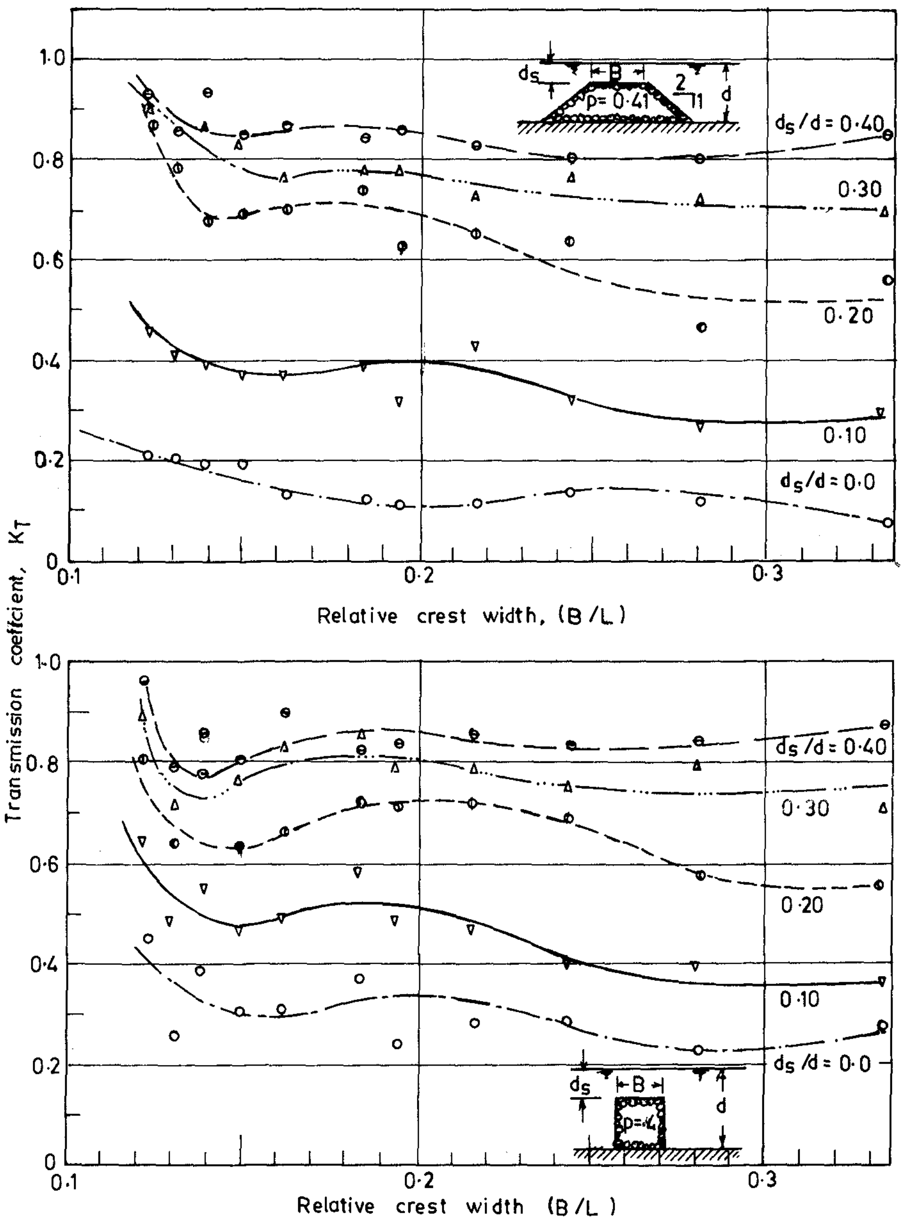

FIG. 8 PERFORMANCE CHARACTERISTICS OF PERMEABLE SUBMERGED BREAKWATERS.

crest width and the depth of crest submergence. Permeability does not have significant influence, particularly for large depths of crest submergence. The shape of the breakwater has significant influence on the reflection characteristics only. The ideal shape appears to be one with the sea face sloping and the beach face vertical. The transmitted wave has the same period as the incident wave, but for cases with the crest of the breakwater near the still water level, higher harmonics are generated.

The performance characteristics of the submerged breakwaters can be represented in the form of design charts with the relative crest width and the relative depth of crest submergence as the significant parameters. These curves show remarkable similarity for the different types studied.

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