Indian Journal of Marine Sciences
Vol. 28, December 1999, pp. 443-448

Wave attenuation characteristics of single row of perforated hollow piles in laboratory

Subba Rao, N B S Rao & J S Prasad

Department of Applied Mechanics & Hydraulics, Karnataka Regional Engineering College, Srinivasnagar 574 157, Karnataka, India

Received 15 June 1998; revised 19 July 1999

Laboratory investigation on perforated hollow piles in a single row was conducted in a two dimensional regular wave flume to study the performance of such an arrangement in dissipating wave energy. The influence of spacing between the piles, size of perforations, different percentage of perforations and water depth on wave attenuation has been investigated. It is found that water depth has insignificant effect on transmission coefficient (K_t) at higher wave steepness. K_t decreases as the relative clear spacing of piles (b/D) decreases and also it decreases as the incident wave steepness increases. At lower value of b/D, K_t decreases with increase in percentage of perforations. For the same percentage of perforations, the pile groups with larger size of perforations transmit more wave energy than pile groups with smaller size of perforations. The perforated hollow pile breakwater is an alternative solution to protect the coast from erosion where the erosion is due to wave energy concentration or onshore offshore movement of sand.

There is an ever increasing demand for land near shoreline for locating recreation centers, industries connected with marine resources and transportation of marine products. Developments have been taking place near the shoreline due to practical advantage of setting up industries related to marine products. But severe erosion in certain stretches of coastline threatens such developmental activities. To combat coastal erosion, both permeable and impermeable types of breakwaters are used. Pile breakwater consisting of single row/multiple rows of circular piles is one among such permeable structures which attenuates the waves partially. Partial protection from waves is sufficient for small fisheries, recreational harbours and marinas. For such small harbours at locations where large littoral drift or onshore-offshore movement of sediments exists permeable breakwaters such as piled structure is ideal. The pile breakwater, while attenuating the waves partially, will not disturb much the littoral movement as there will be enough space between the piles for the littoral movement. Depending upon tranquillity requirements of water area intended for protection and prevailing littoral movement condition, suitable pile breakwater can be designed. The pile breakwaters are likely to be economical compared to other types of conventional breakwaters as reported by Hutchinson & Raudkivi[1]. In addition to the reduced cost of structures, pile breakwaters would facilitate the exchange of water on either side of the structure, so that seawater in the protected area can be kept relatively clean.

It is reported in literature[2-4] that wave attenuation by pile breakwaters is due to the turbulence caused around the piles due to wave-structure interaction. If the turbulence is increased, then more energy dissipation is possible. It is felt that the turbulence can be increased by introducing perforations on the surface of hollow cylinders, which are used as piles. This has lead to the idea of perforated hollow pile breakwaters. Substantial amount of investigations have been carried out by various researchers[1-7] on non-perforated pile breakwaters and conducted mainly the laboratory investigations on performance of non-perforated pile breakwaters. Some theoretical analyses of non-perforated pile breakwaters are also available[4,7]. But studies related to the performance of perforated pile breakwaters have not been reported except the work carried out by Prasad[8], Sathyanarayana *et al.*[9] and Subba Rao *et al.*[10]. Further it is possible to design a system of pile breakwaters such that perforated hollow piles will have to satisfy the hydraulic performance alone and the structural stability is satisfied by a combination of inclined and vertical pile system constructed at regular intervals as reported by Hutchinson & Raudkivi[1]. Hence, detailed experimental studies were undertaken to understand the performance characteristics of perforated hollow pile breakwaters. Observed wave transmission characteristics of a perforated hollow pile breakwater (consisting of single row) is presented in this paper.

Materials and Methods

The experiments were conducted in a regular two dimensional wave flume available in the Marine Structures Laboratory. The details of the flume and other facilities are presented below.

Wave flume—The regular wave flume which is used for performing the experiments has a length of 50 m, width of 0.71 m and depth of 1.1 m. The wave flume is provided with glass panels on one side for a length of about 25 m to facilitate the observation and photography. It has a smooth concrete bed for a length of 42 m. The flume at the generator end is widened smoothly to 1.5 m and deepened to 1.4 m. It is provided with a bottom hinged flap type wave generator. The wave absorber used is of rubble mound type. The wave generating chamber is 6.3 m in length. Gradual transition is provided between the normal flume bed level and that of generating chamber by a ramp of 3 m length. The wave filter consists of a series of vertical asbestos cement sheet spaced at about 0.1 m c/c parallel to the length of the flume.

Pile structure—Model piles were of galvanised iron pipes of diameter *(D)* 0.0335 m. The pile structure consists of a group of piles mounted on a frame in such a way that spacing between the piles can be adjusted. In the present study two different sizes of perforations with diameters 0.25*D* and 0.5*D* were used. At any cross-section of the pile along the perforations, three numbers of circular holes were provided at right angles to each other facing the direct wave attack and there is no opening on the rear side of the piles. In addition, the piles with five numbers of perforations with diameter 0.25*D* have been studied. The perforations were provided from the bottom of the pile up to the level of highest crest position. Two different vertical c/c spacing of perforations viz; 0.5*D* and 1.0*D* were considered. Figure 1 and Table 1 give the details of perforated piles.

Instrumentation—Capacitance type wave probes along with amplification units supplied by Delft Laboratories were used for acquiring the wave data. Two such probes were used during the experiments one for acquiring incident wave heights and other for transmitted waves. The signals from the wave probes were captured by a digital oscilloscope and in turn the data was recorded on floppy diskettes by a Mass Storage Unit. The acquired data has been analysed by

Table 1—Details of perforated piles

Pile group type	Description
Group A	$d = 0.25\,D$, $S = 1.0\,D$, $p = 6.25\%$, 3 perforations at a section
Group B	$d = 0.25D$, $S = 0.5\,D$, $p = 12.5\%$ 3 perforations at a section
Group C	$d = 0.25D$, $S = 0.5D$, $p = 25\%$, 5 perforations at a section
Group D	$d = 0.5D$, $S = 1.0\,D$, $p = 25\%$ 3 perforations at a section

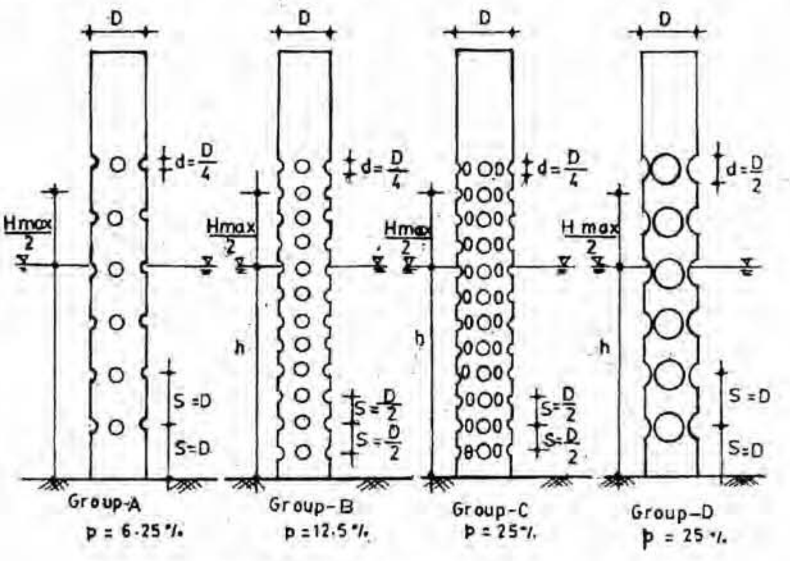


Fig. 1—Details of perforated piles.

a software DASP1234 (version 2.0) using a personal computer.

Experimental procedure—The experiments were conducted on single row of both perforated and non-perforated pile groups. Two water depths namely 0.4 m and 0.5 m were used for the investigation. The wave probes were calibrated both at the beginning and end of each days work. For a given wave period, waves of different heights were generated by changing the eccentricity of the bar-chain on the flywheel, which controls the movement of the wave flap. The tests were conducted for different combinations of wave periods and heights. The signals from the probes were recorded for the incident and transmitted wave height. Incident and transmitted wave heights were also measured manually as a cross check with an accuracy of 1mm. Experiments were conducted for different spacing combinations for perforated and non-perforated piles. The list of governing variables with their ranges used in the present investigation are given in Table 2. In the present model study, rigid bed conditions were considered. In the analysis the effect of sediment movement across the pile structure on wave transmission was neglected.

Results and Discussion

The experimental results are analysed by considering the influence of various non-dimensional parameters on the transmission coefficient K_t. The different parameters considered and their influence on K_t are discussed below.

Water depth (h)—In Figure 2 H_i / gT^2 vs K_t is plotted for constant *b/D* with water depth *h* as third parameter. By comparing the best fit lines drawn in this figure, it is clearly seen that at lower steepness, the effect of water depth on K_t is negligible. As the wave steepness increases, the K_t value for higher water depth of 0.5 m is greater than the corresponding value for lower water depth of 0.4 m. However the difference in K_t values for these two water depths even at higher wave steepness is marginal (At incident wave steepness of 0.01, the difference in transmission coefficient is about 3%). Hence it can be concluded that the effect of water depth on wave transmission is negligible for all the wave steepness values considered in the present investigation.

Incident wave steepness (H_i / gT^2)—The variation of K_t with incident wave steepness H_i / gT^2 is depicted in Figs 2 and 3. In Fig. 3 the best fit lines drawn through obtained data points are shown. From these figures, it is found that irrespective of values of *h*, *b/D* and percentage of perforations, K_t decreases as H_i/gT^2 increases. This agrees with the findings of other researchers like Mani[4], Van Weele & Herbich[6], and Satyanarayana *et al.*[9]. Figure 4 shows the comparison of the results. This trend can be explained by considering the water particle motion. As the wave steepness increases the water particle velocity and acceleration increase. When the wave comes across the pile breakwater the water particle velocity and acceleration suddenly change, causing attenuation of wave energy due to the turbulence produced by this sudden change in the water particle motion. Hence steeper the wave, more is the turbulence and greater will be the loss resulting in lower K_t.

Relative clear spacing of piles (b/D)—In Fig. 3 variation of K_t with H_i / gT^2 is plotted with *b/D* as the third variable. From this figure it is clear that closer the piles in a row, more is the wave attenuation for all the wave steepness considered. This is similar to the results reported for non-perforated piles by Hayashi & Kano[2], Grune & Kolhase[3], Mani[4] & Wiegel[7]. Figure 5 gives the comparison of the results. However

Table 2—Details of experimental variables

Variable	Expression	Ranges for depth of water (*h*) = 0.40 m	Ranges for depth of water (*h*) = 0.5 m
Diameter of pile	*D*	33.5 mm	33.5 mm
Relative spacing between piles in a row	*b/D*	0.15, 0.25	0.15, 0.25
Diameter of perforation	*d*	0.25*D*, 0.5*D*	0.25*D*, 0.5*D*
Vertical c/c spacing of perforations	*S*	0.5*D*, 1.0 *D*	0.5*D*, 1.0 *D*
Percentage of perforations	*p*	0, 6.25, 12.5, 25	0, 6.25, 12.5, 25
Wave period	*T*	1.5, 1.75, 2.0, 2.25 (in seconds)	1.5, 1.75, 2.0, 2.25 (in seconds)
Incident wave height	H_i	3.5 cm to 17.5 cm	4.3 cm to 23.0 cm
Relative water depth	h/gT^2	0.0081 to 0.0181	0.0101 to 0.0227
Incident wave steepness	H_i/gT^2	0.0007 to 0.0077	0.0009 to 0.0104

it is clearly seen in Fig. 3 that perforations cause further reduction in K_t by about 10 % to 15% for $b/D = 0.5$ and similar trends were also observed for other b/D ratios. For $H_i / gT^2 = 0.01$, as the b/D value changes from 0.5 to 0.15, K_t value decreases by about 15%.

Figure 6 shows the variation of K_t with b/D for different percentages of perforations. From this graph it is clearly seen that K_t increases as b/D increases. The trend is same for all the percentages of perforations considered. At higher values of b/D (for $b/D > 0.75$) the reduction in K_t is not much even for higher percentage of perforations especially for steeper waves. Thus it can be concluded that K_t decreases as b/D decreases for all the incident wave steepness considered in the present investigation.

Percentage of perforations (p)—The plot of K_t vs H_i / gT^2 for different values of percentage of perforations is shown in Fig. 7. It is observed that at higher values of wave steepness, perforated piles transmit less wave energy than non-perforated piles. For $b/D = 0.15$, K_t value for pile groups with percentage of perforations p=12.5% is lower by about 10% to 12% when compared to non-perforated piles. It is also seen that with the increase in percentage of perforations, K_t value decreases. As the percentage of perforations increases from 6.25% to 12.5%, K_t value decreases by about 8% to 10%. For lower values of incident wave steepness mixing up of best fit lines is observed. Further as indicated in Fig. 6 at higher values of b/D, for steeper waves, K_t is not much influenced by percentage of perforations. But for steeper waves at lower b/D values, percentage of perforations has significant influence on K_t . Figure 8 shows the variation of K_t with percentage of perforations for different H_i / gT^2 values and for b/D=0.15. It is clear from the figure that K_t is decreasing with the increase in percentage of perforations. However, the increase in percentage of perforations from 12.5% to 25% does not reduce the K_t value considerably for the range of steepness values considered.

Size of perforations (d)—The effect of size of perforations can be observed from Fig. 9. Variation of K_t vs H_i / gT^2 with size of perforations as third variable, keeping percentage of perforations constant (25 %) is shown in this figure. It is evident from this figure that piles with larger size of perforations are transmitting more wave energy than the piles with smaller size of perforations. This trend is clear for the spacings and water depths considered in the present investigation. In Fig. 8 the single highlighted points correspond to 25% of perforations with larger size of openings. This also shows that larger the size of perforations, the transmission coefficient is higher by about 5% to 8%. It can be concluded that for the range of variables considered in the present

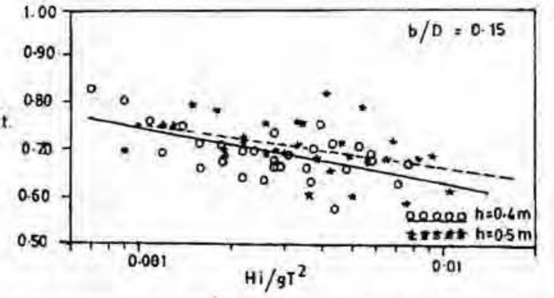


Fig. 2—Variation of K_t with H_i / gT^2 for single row of perforated piles with $d = 0.25\ D$ and $S = 1.0\ D$

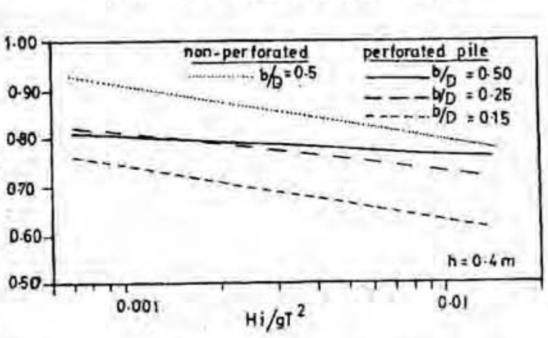


Fig. 3—Variation of K_t with H_i / gT^2 for different b/D ratios with $d = 0.25\ D$ and $S = 1.0\ D$

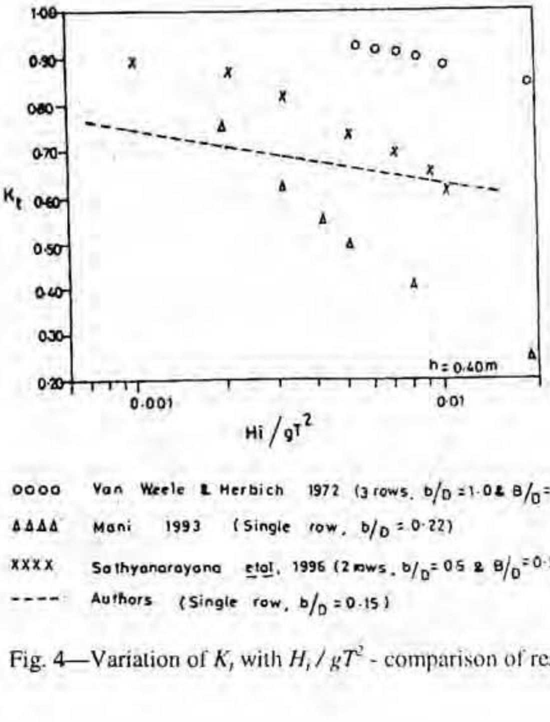
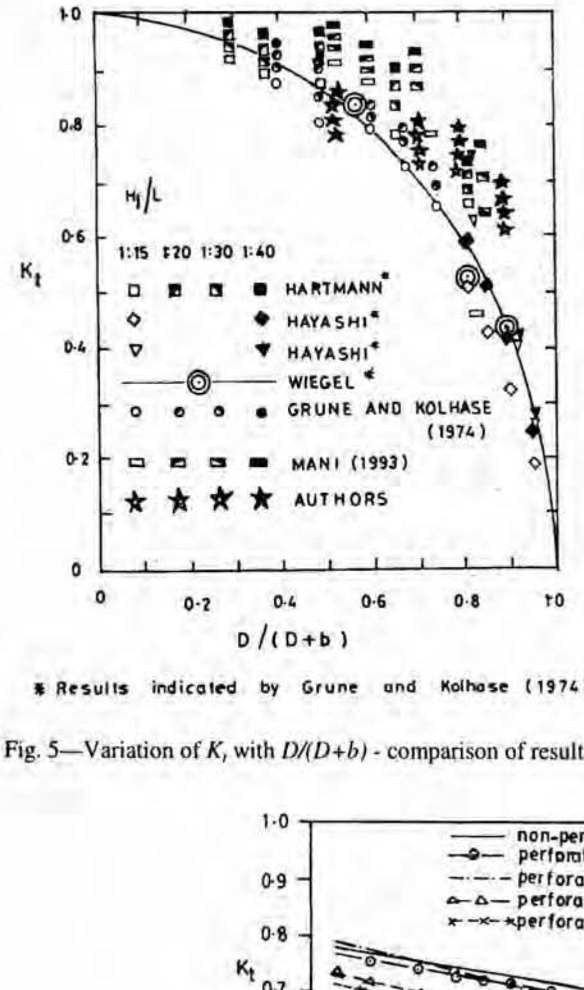


Fig. 4—Variation of K_t with H_i / gT^2 - comparison of results

investigation, structure with piles having larger size of openings transmits more wave energy than smaller openings with the same percentage of perforations. Better wave attenuation can be achieved by providing smaller openings with increased percentage of perforations.

Based on the results of present investigation the following conclusions have been drawn. Perforated piles attenuate about 10% to 15% more wave energy than non-perforated piles. Influence of water depth *h* on K_t is insignificant for the range of incident wave steepness considered. For *b/D*=0.15, the transmission coefficient K_t decreases by about 14% as the incident wave steepness increases from 0.001 to 0.01. As the relative clear spacing between the piles decreases, K_t also decreases for the range of variables considered in the present investigation. For *b/D* values greater than 0.75, K_t is not influenced significantly by percentage of perforation, whereas at lower *b/D* values K_t is significantly influenced by percentage of perforations. The transmission coefficient decreases with increase in percentage of perforations up to about 12.5%, and beyond this value the reduction in K_t with increase in percentage of perforations is not significant. The size of perforations does influence K_t. The piles with larger size of perforations are transmitting more wave energy (around 5% to 8%) than piles with smaller openings for the same percentage of perforations.



* Results indicated by Grune and Kolhase (1974)

Fig. 5—Variation of K_t with $D/(D+b)$ - comparison of results.

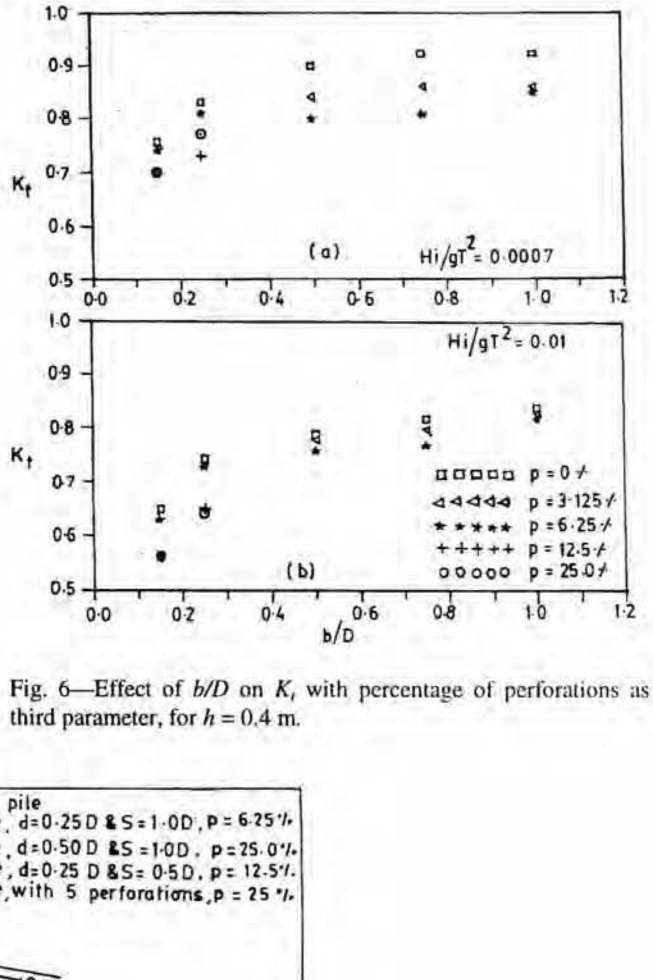


Fig. 6—Effect of *b/D* on K_t with percentage of perforations as third parameter, for *h* = 0.4 m.

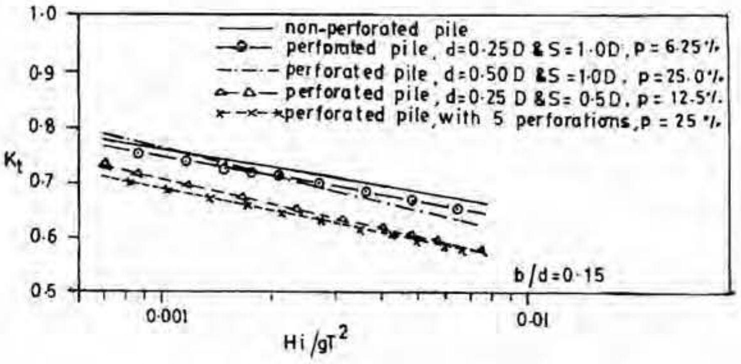


Fig. 7—Influence of perforations on K_t for h = 0.4 m.

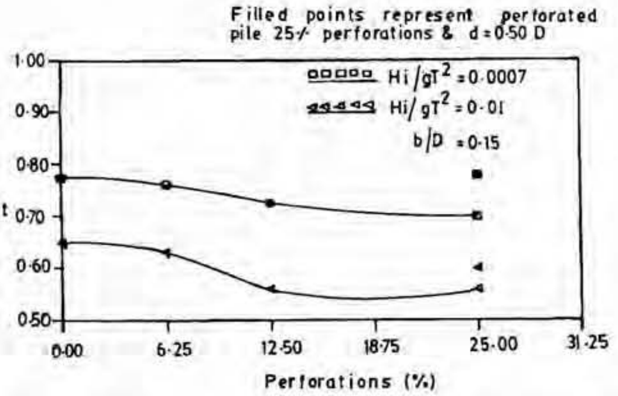


Fig. 8—Effect of percentage of perforations on K_t with H_i / gT^2 as third parameter for $h = 0.4$ m.

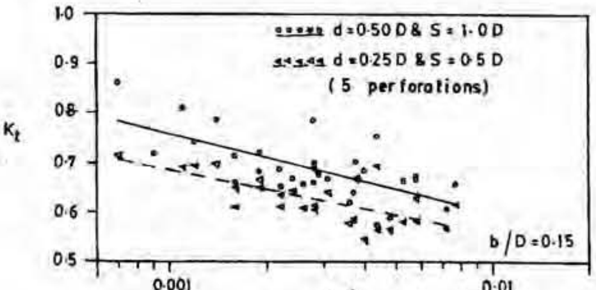


Fig. 9—Variation of K_t with H_i / gT^2 for perforated piles with different sizes of perforations and same percentage of perforations (25%) for $h = 0.4$ m.

The perforated hollow pile breakwater is definitely an alternative solution to protect the coast from erosion. Perforated hollow pile breakwaters will be economical compared to non-perforated pile breakwaters. Further savings could be achieved if suspended perforated hollow pile breakwaters are used. Hence future studies may be taken up with suspended perforated hollow pile breakwaters.

Acknowledgement

The authors are thankful to the authorities of Karnataka Regional Engineering College, Surathkal for the facilities provided during the investigation. The financial support provided by the Ministry of Water Resources through INCH is gratefully acknowledged.

References

1 Hutchinson P S & Raudkivi A J, *Proc 19th Coastal Engineering Conference* (ASCE, New York), 1984, 2530.

2 Hayashi T, Hattori M, Kano T & Shirai M, *Proc 10th Coastal Engineering Conference*, (ASCE, New York), 1966, 873.

3 Grune J & Kolhase S, *Proc 14th Coastal Engineering Conference* (ASCE, New York), 1974, 1906.

4 Mani J S, *J Inst Engin (Civil) India*, 73 (1993) 155.

5 Mani J S & Pranesh M R, *Proc 3rd Indian National Conference on Ocean Engineering* (IIT Bombay, India), 1986, B217.

6 Van Weele J & Herbich J B, *Proc 3rd Coastal Engineering Conference*, (ASCE, New York), 1972, 1935.

7 Weigel R L, *Dock and Harbour Authority*, 42-491, (1961) 150.

8 Prasad J S, *Influence of perforations on the performance of hollow pile breakwaters*, M.Tech thesis, KREC, Surathkal, Mangalore University, India, 1997.

9 Sathyanarayana V S, Rao N B S, Subba Rao & Nagendra Kumar B, *Proc. International Conference in Ocean Engineering*, (IIT Madras, India), 1996, 422.

10 . Subba Rao, Rao N B S, Jayaprakash P & Nagendra Kumar B, *Proc. Conference on Ship and Ocean Technology*, (IIT Kharagpur, India), 1997, 81.