LOCAL SEABED SCOUR AROUND TWO ROWS OF CLOSELY SPACED PILES

نحر قاع البحر الموضعي حول صفين من الخوازيق المتقاربة

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ملخص البحث :

يهتم البحث معمليا بدراسة النحر الموضعي للقاع بالقرب من حواجز الأمواج المكونة من صفين من الخوازيق الرأسية المتقاربة ذات القطاع الدائري. و ذلك لتحديد طول الخوازيق الإضافية نتيجة النحر حول الخوازيق و الناتج من فعل الأمواج. وقد تم قياس تغيرات القاع حول الحاجز وتحديد عمق النحر الأقصى و كذلك ارتفاع الإطماء الأقصى لظروف أمواج مختلفة. ولقد أوضحت النتائج أن النحر الموضعي يزيد عند صف الخوازيق المواجه للبحر عن صف الخوازيق المواجه للشاطئ و أن عمق النحر الأقصى للصفين 0.29 و 0.20 من عمق الماء على الترتيب. ولقد أوضحت النتائج أيضا أن كفاءة الحاجز تزداد في منع انتقال الرسوبيات العمودية على خط الشاطئ عندما يكون الرقم الموجي النسبي اكبر من أو يساوي 1.0.

ABSTRACT:

The seabed changes around the pile breakwater were examined experimentally. The breakwater consists of vertical double rows of closely spaced circular piles. This is for determining the additional imbedded length of the pile in the soil due to scour caused by the wave action. The seabed hydrography was recorded and the maximum scour and maximum deposition were determined for different wave conditions. Intermediate and shallow water waves were applied. It is concluded that the seabed scour reaches the maximum value when the dimensionless wave number ranged between 0.5 and 1.0 under the experiment conditions. The relative maximum scour depths around the seaward and shoreward rows are 0.29 and 0.20 respectively. Also, the breakwater is more effective for reducing the sediment transports normal to the shore-line when the dimensionless wave number is greater than or equal 1.0.

1. INTRODUCTION:

Piles are widely used in practice to support marine structures such as breakwaters and dolphins. Also, it can be ranged in one or two rows and used as a breakwater. This breakwater system may be used for coastal areas, fishing harbors, and marina protection where the tranquility requirements are low. Such structures are more convenient in areas of poor foundation conditions. The breakwater system has been successfully employed at low and moderate wave energy locations. This type permits the water exchange along the beaches, which minimizes the pollution aspects.

As for the seabed stability is a major concern in the design of many marine structures. Considerable research has been devoted to the foundation analysis of piles. Bed scour at the piling is of

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importance in connection with the stability of the structure. Large bed scour may reduce the structure stability, leading to its failure. Chow and Herbich (1978), Wang and Herbich (1983), Sumer et al. (1992), Sumer and Fredsqe (1993), Kobayashi and Oda (1994), Sumer and Fredsqe (1998), Bayram and Larson (2000), Sumer and Fredsqe (2001) and Heikal (2004) studied the scour around single and group of vertical piles subject to wave and wave-current systems.

In this paper, the seabed equilibrium around the pile breakwater consisting of vertical double rows of closely spaced circular piles was examined experimentally. This is for determining the additional imbedded length of the pile in the soil due to scour caused by the wave action. The seabed configurations were measured along the bed for intermediate and long water waves around the breakwater system. Also, the maximum scour depth and the maximum deposition height were determined for different wave conditions.

2. EXPERIMENTAL SET UP:

Several experiments were conducted in a tilting wave flume 12 m long, 0.45 m deep, and 0.30 m wide. The variable speed flap type wave generator was used and the generated wave periods ranged between 0.66 to 3.0 seconds with stroke distance of 22 cm. A wave absorber at the end of the flume exists. The sidewalls of the flume were made of Perspex. The tested breakwater system consisted of two vertical circular piles. The characteristics of breakwater system and experimental setup are determined in Table (1). The bed topography around the proposed breakwater model was recorded for the equilibrium scour and deposition using linear scale (point gage). The details and the dimensions of the breakwater model are shown in the Figure (1) and Photo (1).

3. EXPERIMENTAL ANALYSIS:

The equilibrium scour depth "D_s" and the deposition height (D_d) are obtained when the sediment transport in the scour area is equal to the sediment transport far from the structure (live bed case) and may be dependent upon the following non-dimensional parameters:

$$\frac{D_s}{h} = \phi_1 \left(\frac{H_t}{H_i}, \frac{H_r}{H_i}, kh, \frac{D}{h}, \theta\right) \qquad (1)$$

$$\frac{D_d}{h} = \phi_2 \left(\frac{H_t}{H_i}, \frac{H_r}{H_i}, kh, \frac{D}{h}, \theta\right) \qquad (2)$$

Where H_t is the transmitted wave height, H_r is the reflected wave height, H_i is the incident wave height, k is the wave number ($k=2\pi/L$, L is the wave length), and θ is the Shield's parameter defined as [7]:

$$\theta = \frac{U_{fm}^2}{(s_r - 1) g d_{50}} \qquad (3)$$

$$U_{fm} = \sqrt{\frac{f}{2}}\; U_m \qquad (4)$$

$$f = \frac{2}{R_n^{1/2}} \qquad (5)$$

$$R_n = \frac{U_m d}{\nu} \qquad (6)$$

Where, [d] is the piles diameter, [s_r] is the sediment relative density, [U_{fm}] is the maximum value of the undisturbed bed shear velocity, [f] is the friction coefficient, [U_m] the maximum orbital velocity [$U_m=\omega a$], [ω] is the angular wave frequency ($\omega=2\pi/T$), [T] is the wave period, [a] is the wave amplitude (a=H/2 H is the wave height), [R_n] is Reynolds's number, and [ν] is the kinamatic viscosity of water at 20^{o}c (10^{-2} m^2/sec.).

When a structure is placed in a marine environment, the presence of the structure will change the flow pattern in its immediate neighborhoods, resulting in one or more of the following phenomena: the contraction of flow; the formation of a

Table (1) The Experimental Setup Parameters for Pile Breakwaters.

Parameter	The ranges	Notes
Water Depth (h)	20 cm	at the breakwater sit
Wave Periods (T)	0.68 to 3.0 sec.	
Wave Length (L)	65 to 490 cm	at the breakwater sit
Pile Diameter (d)	3.3 cm	
Pile Gap (G)	0.45 cm	Normal to wave direction
Pile Spacing (S)	20 cm	Parallel to wave direction
Bed Slope (s)	0%	
Grain Size (d_{50})	0.3 mm	
Run Time	2.0 Hours	

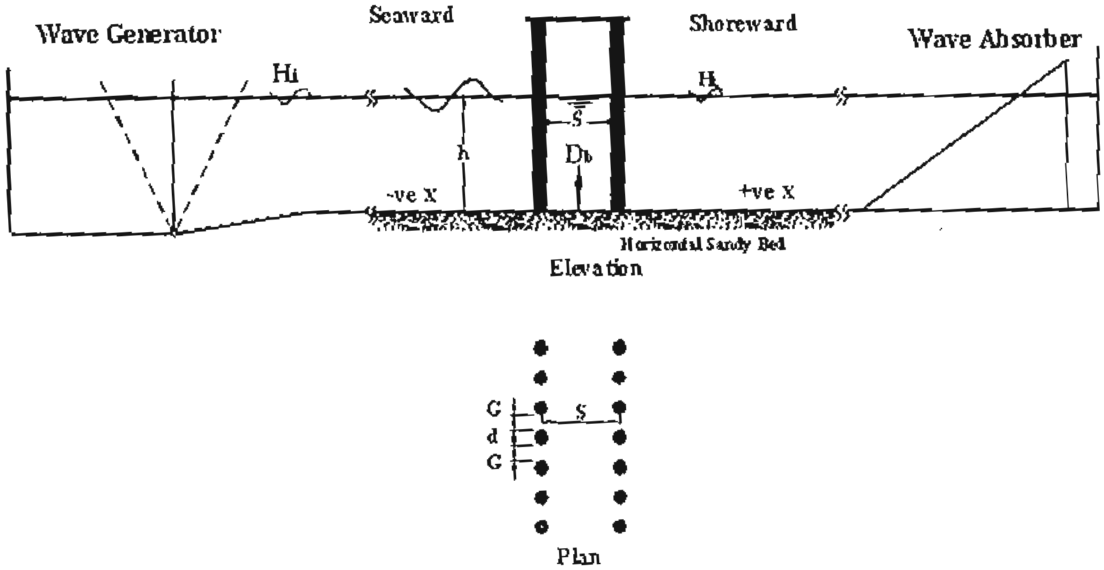

Fig. (1) Definition Sketch for Breakwater System

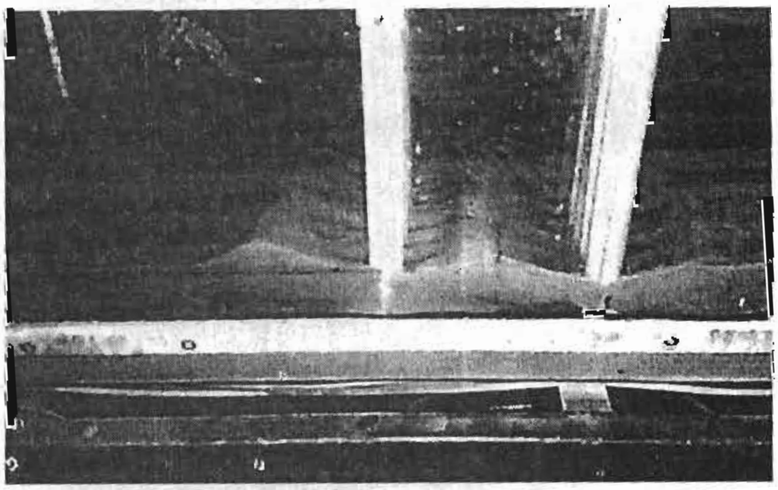

Photo (1) The Breakwater Model

horseshoe vortex in front of the structure; the formation of lee-wake vortices (with or without vortex shedding) behind the structure; the generation of turbulence; the occurrence of reflection and diffraction of waves; the occurrence of wave breaking; and the pressure differentials in the soil that may produce "quick" condition/liquefaction allowing material to be carried off by currents. These changes usually cause an increase in the local sediment transport capacity and thus lead to scour [9].

The scour occurs around the rows of piles. The large scour hole occurs around the seaward row which can be attributed to the effect of the reflected waves. Then the maximum bottom pressure occurs around the seaward row and large velocities are two times greater than the amplitude of the incident wave bottom velocity. While the small scour hole occurs around the shoreward row due to the effect of the gap flow (the jet effect) and the vortices.

Figure (2) presents the contour maps of the seabed around the two rows of piles for the different dimensionless wave numbers. Figure (2a) presents the seabed contour map when kh = 1.88. The figure shows that the maximum relative seaward scour hole depth and length (D_{smax}/h and l_{smax}/L) are 0.1 and 0.16 respectively. While the maximum relative shoreward scour hole depth and length (D_{smax}/h and l_{smax}/L) are 0.05 and 0.08. Also, there are large deposition zone occurs seaward the model with maximum relative height (D_{dmax}/h) of 0.12. The breakwater model affect the sediment transport normal to the shore line in which D_{dmax}/h shoreward is 0.03.

Figure (2b) presents the seabed contour map when kh = 0.62. The figure shows that, there are over lapping between the seaward and shoreward scour holes. D_{smax}/h and l_{smax}/L at the seaward row are 0.29 and 0.15. While D_{smax}/h and l_{smax}/L at the shoreward row are 0.20 and 0.13. Also, there are large deposition zone occurs shoreward the model with maximum relative height (D_{dmax}/h) of 0.15. This means that the effect of the breakwater model on the sediment transport is small. This may be due to the increase of the transmitted wave energy through the piles. Figure (2c) presents the seabed contour map when kh = 0.26. The figure shows that, D_{smax}/h and l_{smax}/L at the seaward row are 0.17 and 0.032. While D_{smax}/h and l_{smax}/L at the shoreward row are 0.13 and 0.04. Also, there are two large deposition zones occur between piles and shoreward the model with maximum relative heights (D_{dmax}/h) of 0.15 and 0.17 respectively.

Figure (3) presents the longitudinal sections of the seabed at the middle of the wave flume around the two rows of piles. This is for different dimensionless wave numbers (kh = 1.88, 0.62 and 0.26). The figure shows that, there are two major scour holes occurred around the two rows of piles. The large one occurs around the seaward row while the small one occurs around the shoreward row. Also, the figure shows that, there are over lapping between the seaward and shoreward scour holes when kh = 0.62.

Figure (4) shows the maximum dimensionless bed scour depth (D_{smax}/h) at the seaward and shoreward rows versus the dimensionless wave number (kh). The results indicate that the maximum equilibrium scour depth occurs when kh = 0.62. This is due to the maximum bottom pressure and increasing of the wave orbital velocity. The scour depth around the seaward row is larger than the scour depth around the shoreward row.

Figure (5) shows the maximum dimensionless scour hole length (l_{smax}/L) at the seaward and the shoreward rows versus

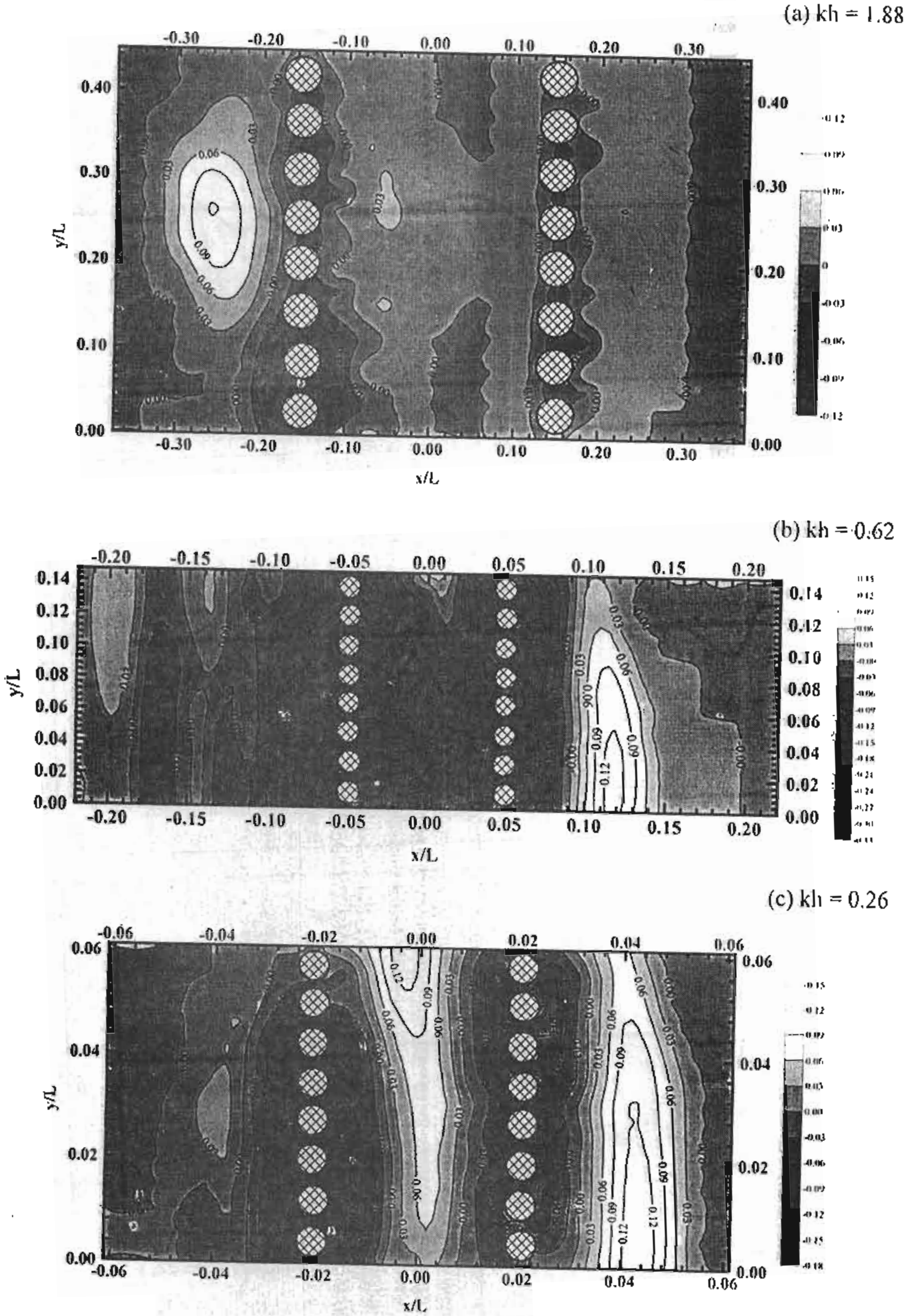

Fig. (2) Contour Maps of the Seabed Changes Around the Double Rows of Circular Pile Breakwater Model for Different Wave Conditions.

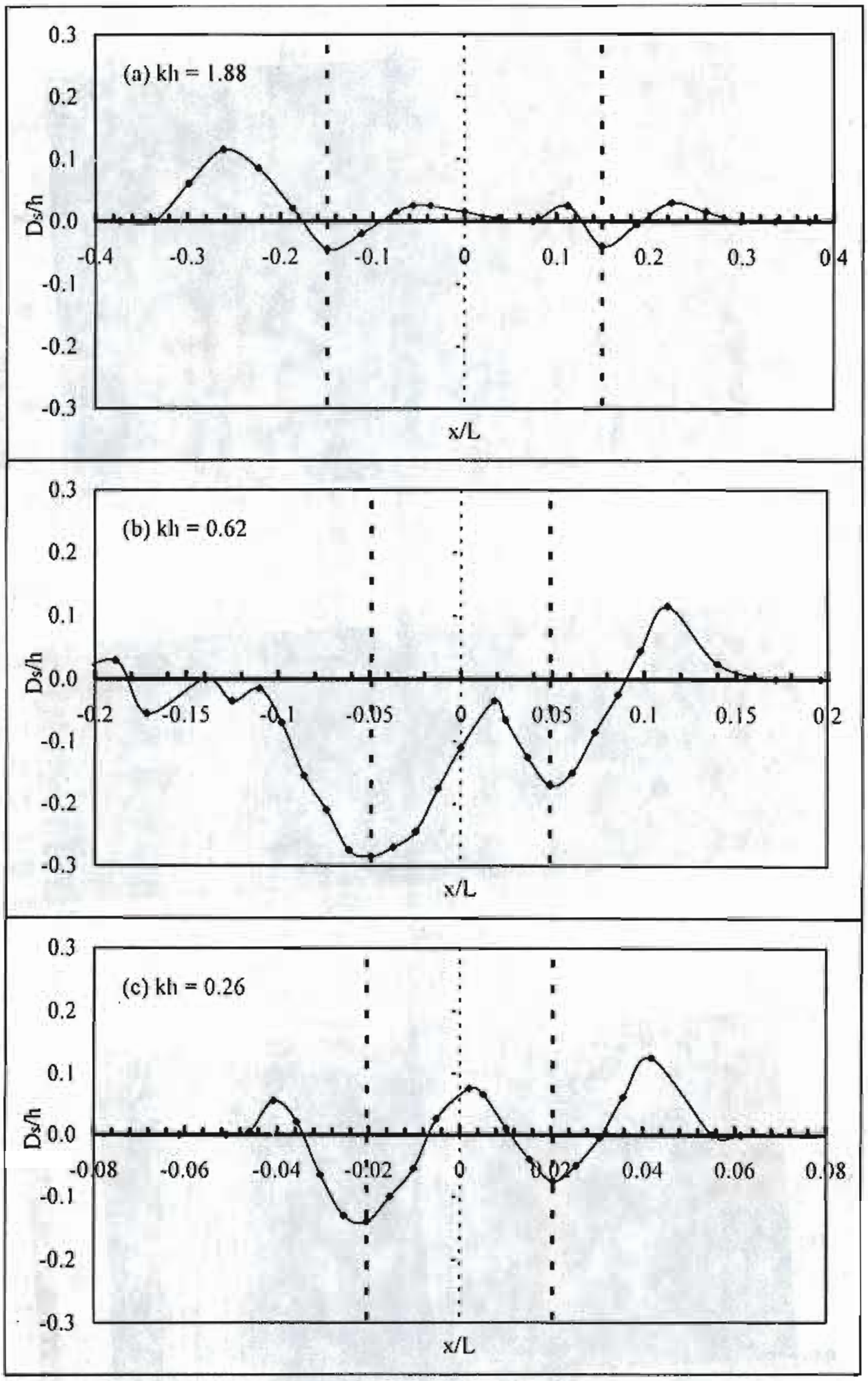

Fig. (3) Longitudinal Sections of the Seabed at the Middle of the Wave Flume Around the Double Rows Pile Breakwater for Different Wave Conditions

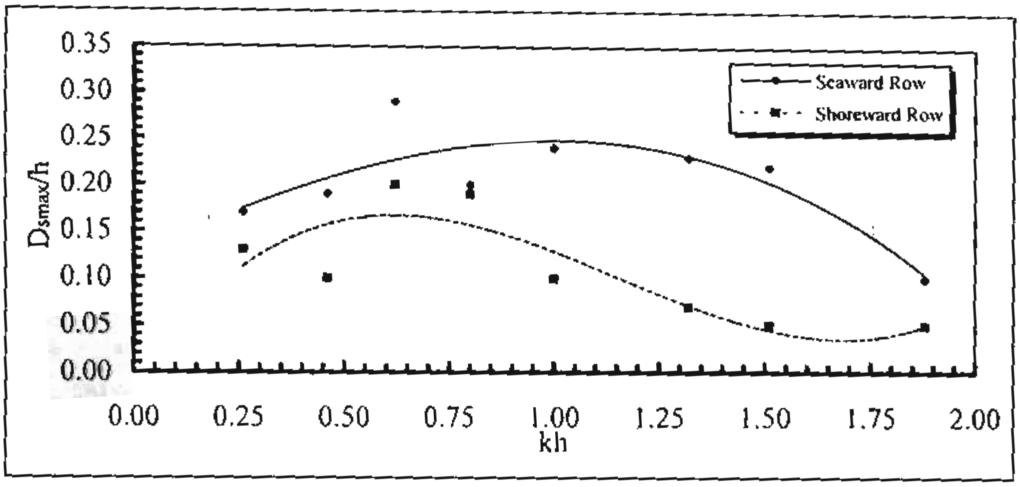

Fig.(4) The Effect of the Dimensionless Wave Number (kh) on the Maximum Dimensionless Seabed Erosion Depth (D_{smax}/h) Around Rows of Piles.

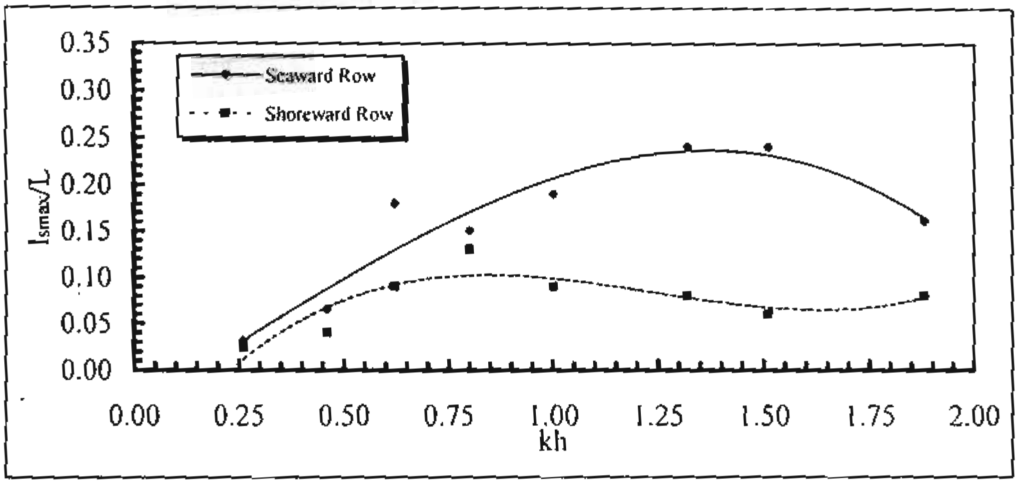

Fig.(5) The Effect of the Dimensionless Wave Number (kh) on the Maximum Dimensionless Seabed Erosion Hole Length (l_{smax}/h) Around Rows of Piles.

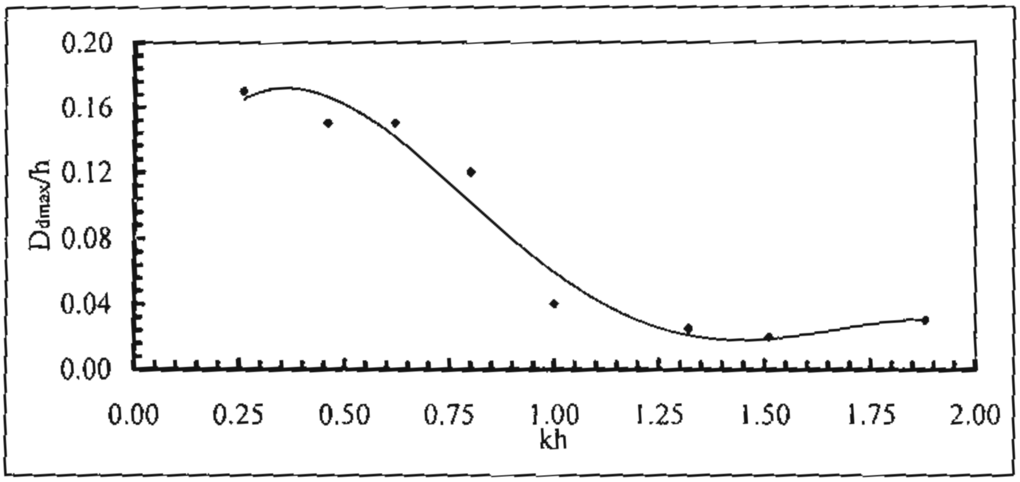

Fig.(6) The Effect of the Dimensionless Wave Number (kh) on the Maximum Dimensionless Seabed Accretion Hieght (D_{dmax}/h) Shoreward Structure.

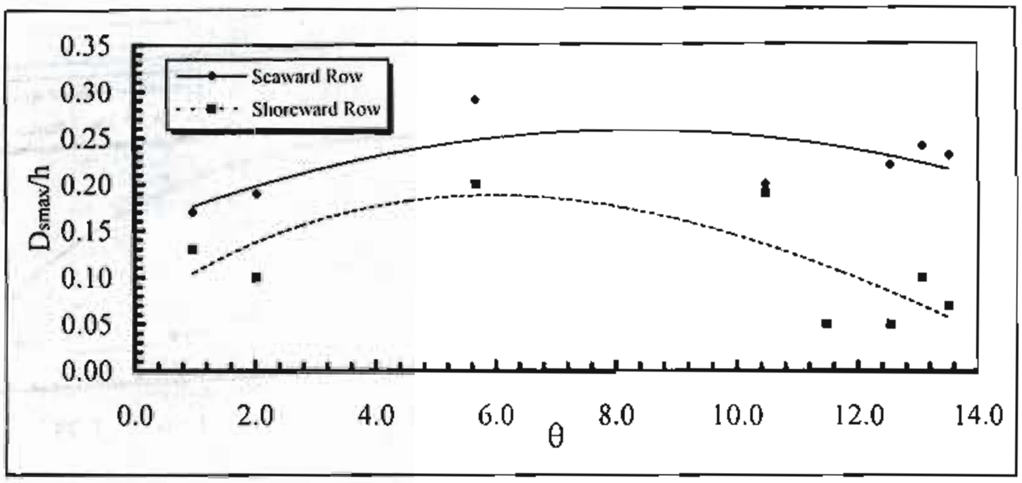

Fig.(7) The Effect of the Shield's Parameter (θ) on the Maximum Dimensionless Seabed Erosion Depth (D_{smax}/h) Around Rows of Piles.

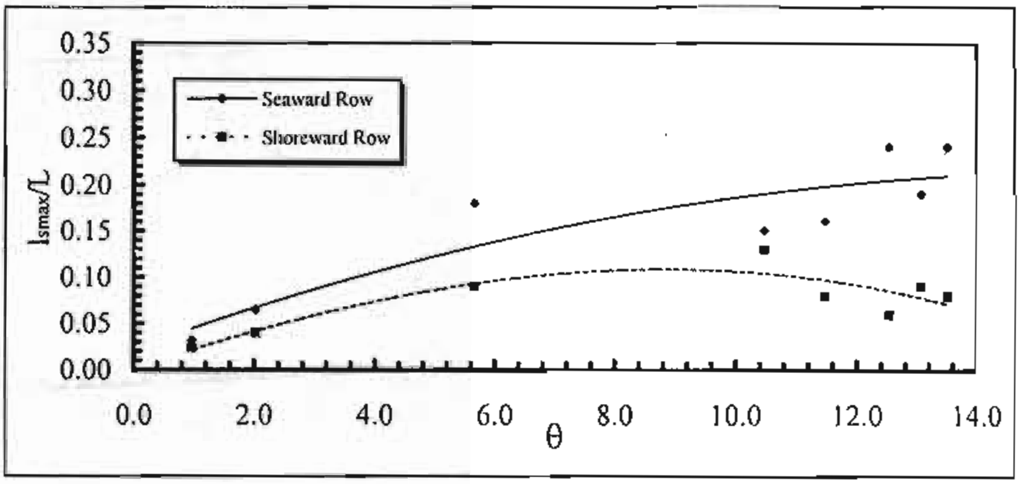

Fig.(8) The Effect of the Shield's Parameter (θ) on the Maximum Dimensionless Seabed Erosion Hole Length (l_{smax}/h) Around Rows of Piles.

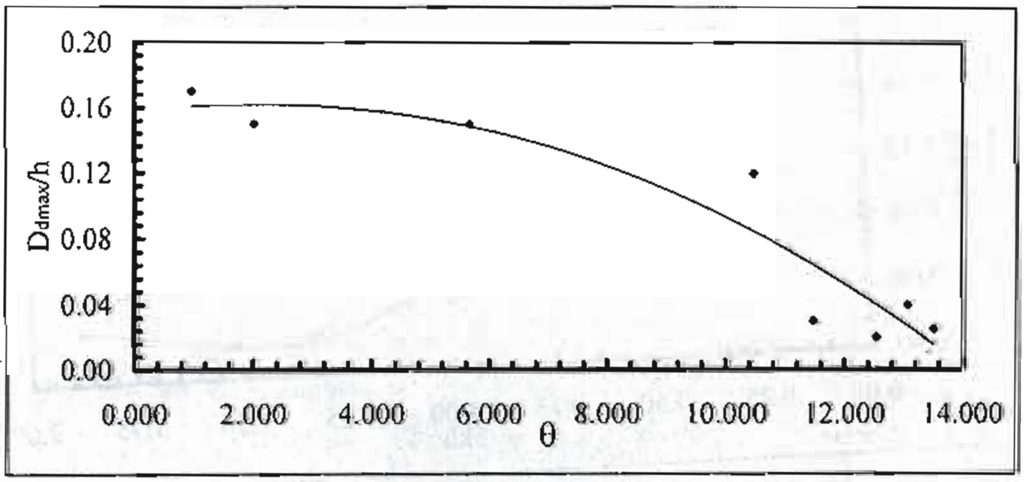

Fig.(9) The Effect of the Shield's Parameter (θ) on the Maximum Dimensionless Seabed Accretion Hieght (D_{dmax}/h) Shoreward Structure.

the dimensionless wave number (kh). The results indicate that the relative seaward scour hole length increases as kh values increase up to kh = 1.5 then begin to decrease. While for the shoreward row, it increases as kh values increase up to kh = 0.8 then begin to decrease. The scour hole around the seaward row is larger than the scour hole around the shoreward row.

Figure (6) shows the maximum dimensionless bed deposition height shoreward the breakwater model (D_{dmax}/h) versus the dimensionless wave number (kh). It is clear that the maximum dimensionless bed deposition height decreases as kh increases. The breakwater is more effective for reducing the deposition height when kh ≥ 1.0.

Figures (7) to (9) present D_{smax}/h, l_{smax}/L (seaward and shoreward pile rows) and D_{dmax}/h (shoreward structure) versus Shield's Parameter (θ). Figure (7) shows that the maximum equilibrium relative scour depth (D_{smax}/h) at the seaward and shoreward rows of piles occur when θ = 6.0. Figure (8) shows that the maximum seaward relative scour hole length (l_{smax}/L) increases as the Shield's Parameter (θ) increases. Also, l_{smax}/L at shoreward row increases as the Shield's Parameter (θ) increases up to θ = 10.4 then begin to decrease. Figure (9) shows that the relative deposition height (D_{dmax}/h) shoreward structure decreases as the Shield's Parameter (θ) increases.

4. CONCLUSIONS

Series of experiments were carried out to study the effect of the closely spaced pile breakwaters on the sea bed stability. The conclusions reached were as follows:

1. The scour hole around the seaward row is larger than the scour hole around the shoreward row.
2. The scour around piles reaches maximum values when: the dimensionless wave number (kh) ranged between 0.5 and 1.0, and the Shield's Parameter (θ) equal 6.0.
3. The maximum scour depths around the seaward row and shoreward row are 0.29 and 0.20 relative to the water depth respectively. So that the safe imbedded pile length may be increased by about 30% from the sea water depth.
4. The breakwater is more effective for controlling the sediment transport normal to the shore-line when kh ≥ 1.0.

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6. LIST OF SYMBOLS:

a : The wave amplitude "$a=H/2$"
D : The breakwater draft
D_b : The seabed deformation
D_d : The accretion height
D_s : The erosion depth
D_{dmax} : The maximum accretion height
D_{smax} : The maximum erosion depth
d : The pile diameter
d_{50} : The effective grain size of sand
f : The friction coefficient
G : The gap between piles
g : The gravitational acceleration
H : The wave height
H_i : The incident wave height
H_r : The reflected wave height
H_t : The transmitted wave height
h : The water depth at the breakwater site
k : The wave number "$k=2\pi/L$"
L : The wave length
L_{smax} : The maximum erosion hole length
R_n : The Reynolds's number
S : The distance between the two rows of piles
s_r : The sediment relative density
T : The wave period
U_{fm} : The maximum value of the undisturbed bed shear velocity
U_m : The maximum orbital velocity
ν : The kinamatic viscosity of water at 20°c "$\nu=1\times10^{-6}$ m^2/sec."
θ : The Shields parameter
ω : The angular wave frequency "$\omega = 2\pi/T$"