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THEORETICAL STUDY FOR ONE ROW OF PILES USED AS A BREAKWATER

دراسة نظرية لصف واحد من الخوازيق يستخدم كحاجز أمواج

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الملخص العربي

يهـتم هـذا البحث بدراسة كفاءة حواجز الأمواج الخازوقية المكونة من صف واحد من الخوازيق المربعة أو الدائرية نظريا باستخدام مفكوك دالة أيجـن. حيث تم حساب كلا من معامل الانتقال و معامل الارتداد للعديد من خصائص الأمواج و المنشأ. و قد تم اختبار قابلية النموذج الرياضي المقترح لحساب كفاءة هذه الحواجز عن طريق مقارنة نتائجه بنتائج نظرية و معملية لدراسات أخرى. و لقد أوضحت النتائج أن النموذج الرياضي المقترح يمكن أن يستخدم بكفاءة عالية للتنبؤ بكفاءة حواجز الأمواج الخازوقية المكونة من صف واحد من الخوازيق.

Abstract:

The performance of the pile breakwater consisted of one row of vertical circular or square piles was investigated theoretically using Eigenfunction expansion method. The transmission and the reflection coefficients were calculated for different wave and structure parameters. The validity of the theoretical model was examined by comparing the results with the theoretical and the experimental results from different studies. It was concluded that; the proposed theoretical model could be used efficiently to predict the performance of the pile breakwaters consisting of one row.

1. Introduction:

The row or more of the closely spaced piles extending above the seabed to some distance over the water surface was considered as wave control barrier. This barrier may be used as a breakwater used for protecting coastal areas, fishing harbors, and marina. The pile breakwater was successfully employed in a variety of low and moderate wave energy applications. This type of breakwaters minimized the pollution aspects near shores in where it permits exchanging the water mass. The control of wave height near shores using the pile breakwaters was required for decreasing the beach erosion and enables to use the protected coasts efficiently.

The functional performance of the pile breakwater is evaluated by examining the wave reflection and transmission around the breakwater. In order to examine the wave scattering by vertical pile breakwaters, physical hydraulic tests were developed by Wiegel (1961), Hayashi and Kano (1966), Herbich (1989), Kakuno and Lui (1993), Mani and Jayakumar (1995), Abdel-Mawla and Balah (2001), and Heikal and Koraim (2004). Efforts towards developing analytical models for predicting the wave reflection and transmission have also been made. Hayashi et al (1968), Martin and Dalymple (1988), Kriebl (1992) Kakuno and Liu (1993) Mani (1998), and Park et al (2000) provided analytical solutions for pile breakwaters.

In this research paper, the wave transmission and reflection around breakwater which consisted of one row of square or circular piles was modeled for linear, monochromatic, normal waves. This was by using the Eigenfunction expansion method. The transmission and reflection coefficients were calculated for different wave and structure parameters. Also, the comparison between the theoretical results

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and the theoretical and experimental results from different studies was carried out.

2. Theoretical Analysis:

The wave diffraction around breakwater which consisted of one row of square or circular cylinders (piles) was modeled for linear, monochromatic, normal waves. The analysis proceeded under the assumptions that the fluid is incompressible, inviscid and that the motion is irrotational. Further assumption was that the boundary condition on the free surface could be linearized. The breakwater is continuous and located at x=0 as shown in Figure (1). The distance between the centers of to adjacent cylinders is denoted as "a", the width of an opening is "G" and the pile diameter or width is "d".

The velocity potential consists of free propagating modes and non-propagating evanescent wave modes. Appling the assumption of wide spacing approximation (Park et al , 2000) so that the evanescent wave modes near the cylinders may be neglected. The velocity potential can be expressed as follows:

$$\phi(x,z,t) = \frac{-gH_i}{2\omega}\phi(x)\frac{\cosh k(z+h)}{\cosh kh}e^{-i\omega t} \quad (1)$$

In which $\phi(x)$ is the horizontal velocity potential, H_i is the incident wave height, g is the gravitational acceleration, h is the water depth, k is the wave number ($k=2\pi/L$, where L is the wave length) and ω is the angular wave frequency ($\omega=2\pi/T$, where T is the wave period).

2.1 Governing Equation:

The governing equation for the potential function, $\phi(x)$, is the modified Helmholtz equation which can be defined as follows:

$$\frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial z^2} + k^2\phi = 0 \quad (2)$$

2.2 The Flow Potential Solution:

The reduced potentials seaward, ϕ_1, and shoreward, ϕ_2, are presented in Park et al [9] as follows:

$$\phi_1(x) = e^{ikx} + k_r e^{-ikx} \quad , x < 0 \quad (3)$$

$$\phi_2(x) = k_t e^{ikx} \quad , x > 0 \quad (4)$$

In which k_r and k_t are the complex value of reflection and transmission coefficients and k must satisfy the dispersion relationships for the propagating mode only:

$$\omega^2 = -gk \tanh(kh) \quad (5)$$

The reduced potentials seaward, ϕ_1, and shoreward, ϕ_2, must satisfy the matching conditions at the location of the piles (at x = 0). These potentials provide continuity of potential and horizontal velocity normal to the vertical plane separating the fluid regions as follows:

$$\phi_1(x) = \phi_2(x) + 2C\frac{\partial\phi_1(x)}{\partial x} + \frac{i\alpha}{\omega}\frac{\partial\phi_1(x)}{\partial x} \quad \text{at } x = 0 \quad (6)$$

$$\frac{\partial\phi_1(x)}{\partial x} = \frac{\partial\phi_2(x)}{\partial x} \quad \text{at } x = 0 \quad (7)$$

In which C is the blockage coefficient and α is the depth average linearzed dissipation coefficient. The blockage coefficient (C) depends only on the shape and geometry of the row of the piles. The depth average linearzed dissipation coefficient (α) is related to the wave characteristics near the piles. The second and third terms on the right hand side of equation (6) represents the inertia resistance and the energy dissipation due to flow separation near the row of piles. The blockage coefficient (C) and the depth average linearzed dissipation coefficient (α) are estimated in Kakuno and Liu [5].

2.3 Solution Procedure:

Let us express the complex reflection (k_r) and transmission (k_t) coefficients as follows [9]:

$$k_r = a_0 + ib_0 \quad (8)$$

$$k_t = c_0 + id_0 \quad (9)$$

substituting equations (8) and (9) into (3) and (4), then;

$$\phi_1(x) = e^{ikx} + (a_0 + ib_0)e^{-ikx} \quad , x < 0 \quad (10)$$

$$\phi_2(x) = (c_0 + id_0)e^{ikx} \quad , x > 0 \quad (11)$$

Appling the matching condition defined in equation (7), then yield:

$$(b_0 + d_0) + i(1 - a_0 - c_0) = 0 \quad (12)$$

Then,

$$b_0 + d_0 = 0 \quad (13)$$

$$1 - a_0 - c_0 = 0 \quad (14)$$

Appling the matching condition defined in equation (6), then yield:

$$[(1 - R_n) + (1 + R_n)a_0 + P_n b_0] +$$
$$i[P_n - P_n a_0 + (1 + R_n)b_0] = c_0 + id_0 = 0 \quad (15)$$

Then;

$$(1 - R_n) + (1 + R_n)a_0 + P_n b_0 - c_0 = 0 \quad (16)$$

$$P_n - P_n a_0 + (1 + R_n)b_0 - d_0 = 0 \quad (17)$$

Where $P_n = 2Ck$, and $R_n = \alpha k / \omega$

Solving the system of linear equations in the unknowns a_0, b_0, c_0 and d_0 in equations (13), (14), (16) and (17), then yield:

$$a_0 = \frac{R_n(2 + R_n) + P_n^2}{(2 + R_n)^2 + P_n^2} \quad (18)$$

$$b_0 = -\frac{2P_n}{(2 + R_n)^2 + P_n^2} \quad (19)$$

$$c_0 = \frac{2(2 + R_n)}{(2 + R_n)^2 + P_n^2} \quad (20)$$

$$d_0 = \frac{2P_n}{(2 + R_n)^2 + P_n^2} \quad (21)$$

2.4 Reflection and Transmission Coefficients:

substituting equations (18) to (21) in to equations (8) and (9), then the transmission and the reflection coefficients are as follows:

$$k_t = \frac{R_n(2 + R_n) + P_n^2}{(2 + R_n)^2 + P_n^2} - \frac{2P_n}{(2 + R_n)^2 + P_n^2} i \quad (22)$$

$$k_r = \frac{2(2 + R_n)}{(2 + R_n)^2 + P_n^2} + \frac{2P_n}{(2 + R_n)^2 + P_n^2} i \quad (23)$$

3. Theoretical Results Verification:

Figures (2) and (3) present the comparison between the present theoretical and the experimental transmission coefficients obtained by Heikal and Koraim (2004) [3]. This is for circular and rectangular pile breakwaters respectively. The figures show that a reasonable agreement between the theoretical results and the experimental results is achieved. This means that the theoretical model can be used for predicting the transmitted wave energy through the structure.

Figure (4) presents the comparison among the present theoretical results and the experimental and theoretical results obtained by Kakuno et al (1993) [5]. This is for transmission, reflection and energy loss coefficients for slotted breakwater when kh=0.48, G/d=0.17, d/h=0.6 and B/h=0.2. The figure shows that the Kakuno theoretical results equal the present theoretical results. Also, the figure shows that a reasonable agreement between the present theoretical results and Kakuno experimental results.

Figure (5) shows the comparison between the present theoretical transmission coefficient and the results obtained by different studies. This is for slotted breakwater when kh=0.48, G/d=0.5, d/h=0.7 and B/h=0.2. The figure shows a good agreement between the present results and the different theoretical results. Also, the figure shows a reasonable agreement between the present results and the experimental results.

Figure (6) shows the comparison among the present theoretical transmission coefficient and the results obtained by different studies. This is for square pile breakwater when kh=0.48, G/d=1.0 and d/h=0.2. The figure shows that a good agreement between the present results and the different theoretical and experimental results.

4. Theoretical Results:

Figures (7) and (8) present the theoretical results of circular pile breakwater. This is for different wave and structural parameters. Figure (7) presents the relationship between the theoretical transmission coefficient (k_t) and the dimensionless wave steepness (H_i/L). This is for different values of gap-diameter ratios (G/d) and dimensionless wave number (kh). The figure shows that the transmission coefficient (k_t) decreases with the increase of H_i/L. Also, the transmission coefficient (k_t) decreases with the decrease of (G/d).

Figure (8) presents the relationship between the theoretical reflection coefficient (k_r) and the dimensionless wave steepness (H_i/L). This is for different values of gap-diameter ratios (G/d) and dimensionless wave number (kh). The figure shows that the reflection coefficient (k_r) take the inverse trade. This means that the reflection coefficient (k_r) increases with the increase of H_i/L. Also, the reflection coefficient (k_r) increases with the decrease of (G/d).

Figures (9) and (10) present the theoretical results of rectangular pile breakwater. This is for different wave and structural parameters. Figure (9) presents the relationship between the theoretical transmission coefficient (k_t) and the dimensionless wave steepness (H_i/L). This is for different values of gap-diameter ratios (G/d) and dimensionless wave number (kh). The figure shows that the transmission coefficient (k_t) decreases with the increase of H_i/L and the decrease of (G/d).

Figure (10) presents the relationship between the theoretical reflection coefficient (k_r) and the dimensionless wave steepness (H_i/L). This is for different values of gap-diameter ratios (G/d) and dimensionless wave number (kh). The figure shows that the reflection coefficient (k_r) increases with the increase of H_i/L and the decrease of (G/d).

5. Conclusions:

The main conclusions are summarized as follows:

1. The transmission coefficient decreases with the increase of the wave steepness and the decrease of the gap between piles.
2. The reflection coefficient increases with the increase of the wave steepness and the decrease of the gap between piles.
3. The proposed theoretical model can be used for predicting the performance of the pile breakwaters.

6. References:

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7. LIST OF SYMBOLS:

Symbol Definition

a_o, b_o, c_o, d_o = Unknown Coefficients
a = Distance Between Piles Centers
C = Blockage Coefficient
d = Pile Diameter or Width
e = Exponential Number (2.72)
g = Acceleration of Gravity
G = Gap Between Piles
h = Water Depth at the Breakwater Site
H_i = Incident Wave Height
H_r = Reflected Wave Height
H_t = Transmitted Wave Height
i = Imaginary Number ($\sqrt{-1}$)
k = Incident Wave Number
k_r = Reflection Coefficient
k_t = Transmission Coefficient
L = Wave Length at Breakwater Site
t = Time
T = Wave Period
x, z = Three Dimensional Axis
α = Linearized Dissipation Coefficient
ϕ, ϕ_1, ϕ_2 = Flow Velocity Potential
π = 3.14
ω = Angular Wave Frequency

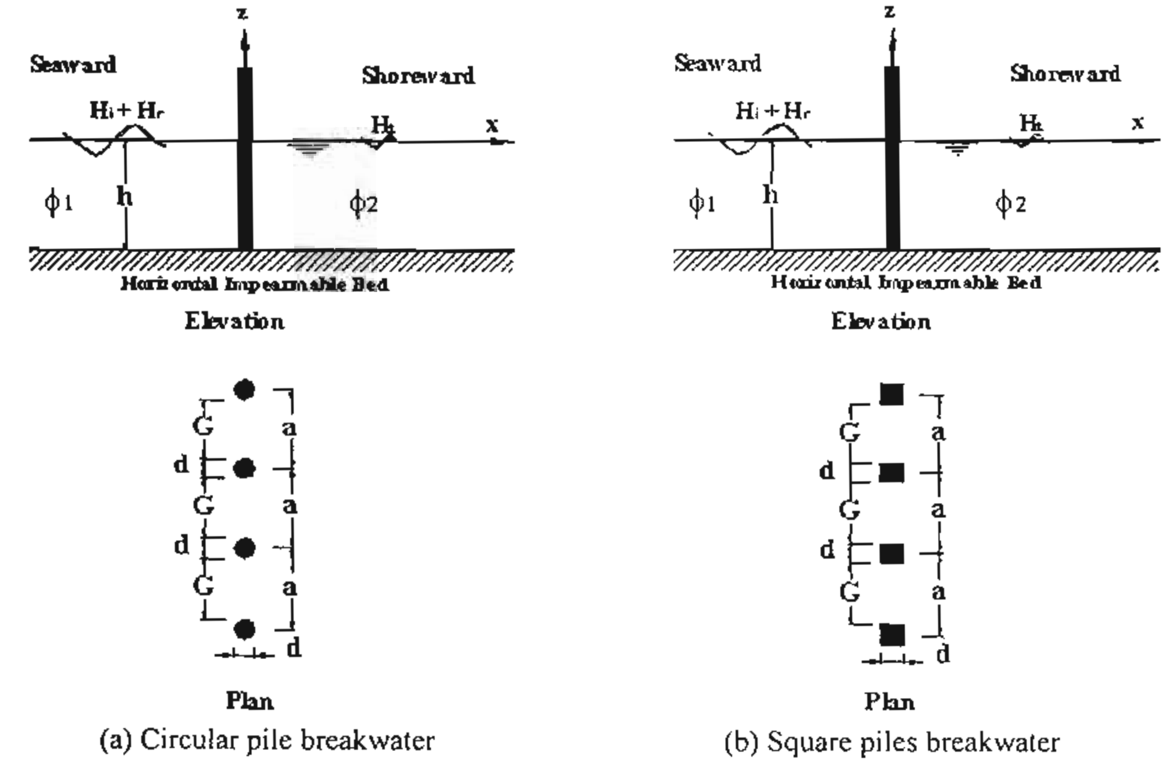
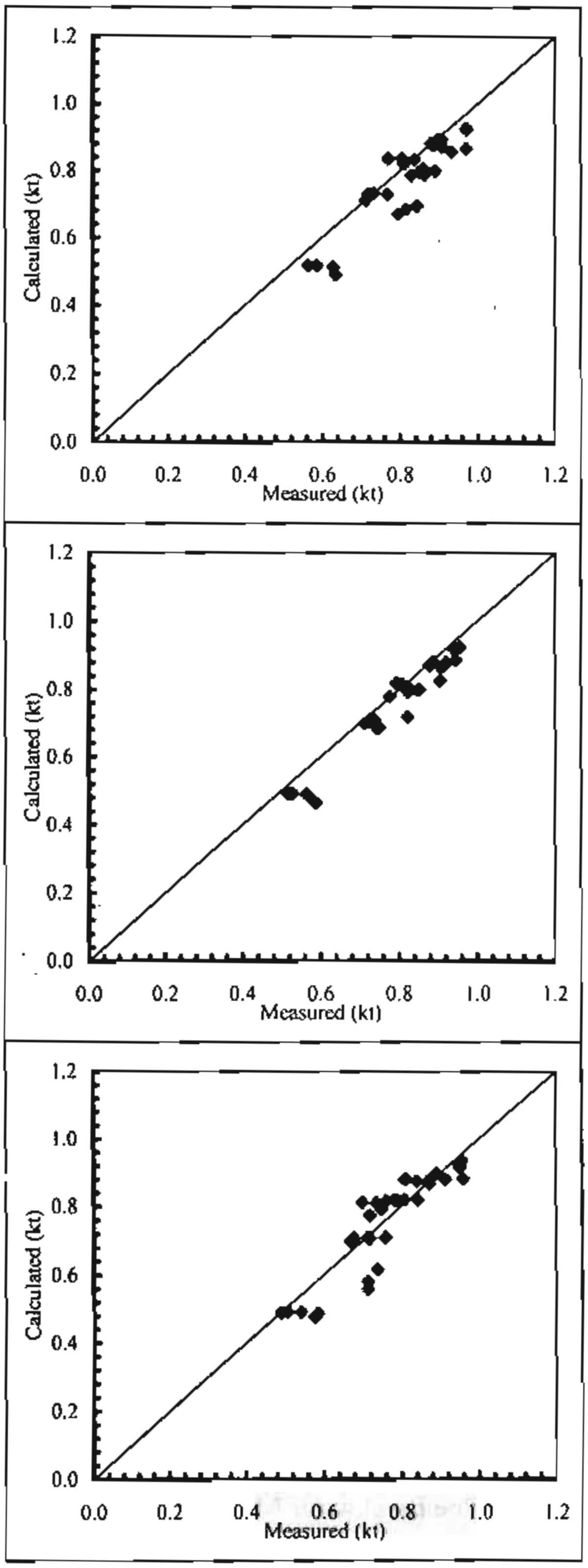


Figure. (1) Schematic Diagram for the Pile Breakwater Models



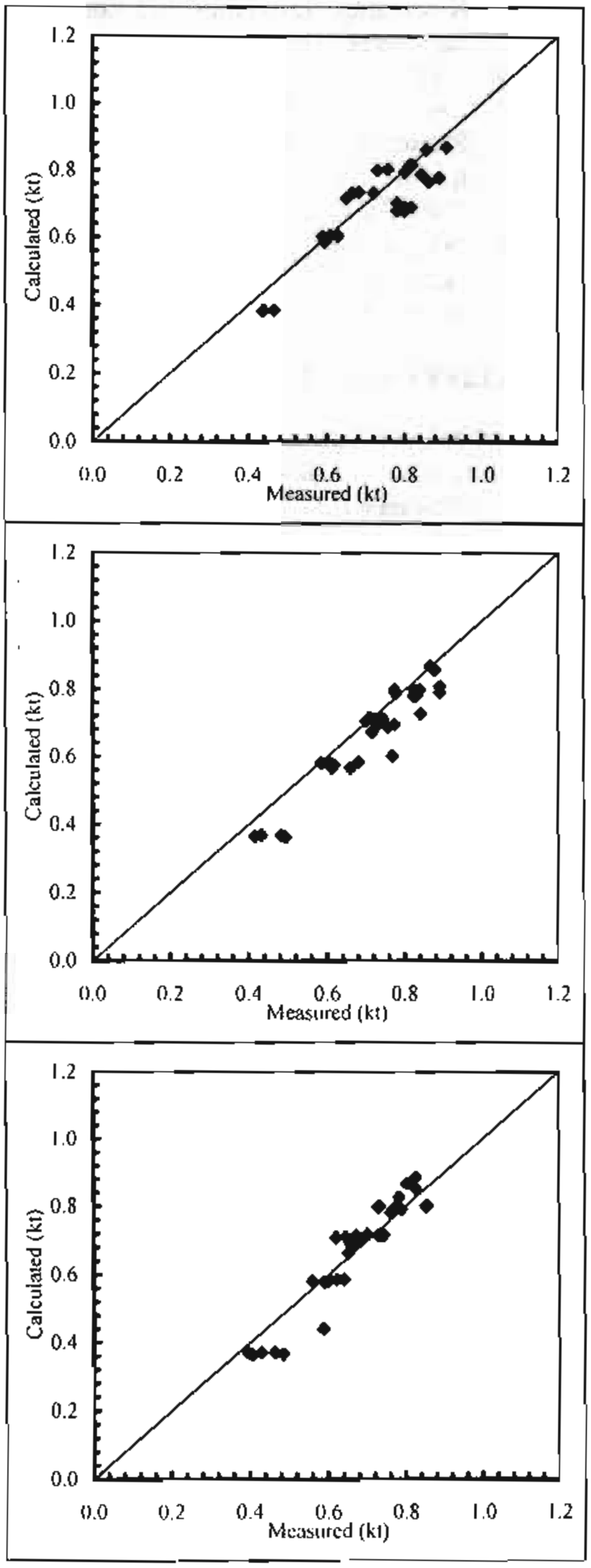


Fig. (2) Comparison Between Measured and Calculated Transmission Coefficients by One Row of Circular Piles for: (a) d/h = 0.22 (b) d/h = 0.17 (c) d/h = 0.13

Fig. (3) Comparison Between Measured and Calculated Transmission Coefficients by one Row of Square Piles for: (a) d/h = 0.22 (b) d/h = 0.17 (c) d/h = 0.13

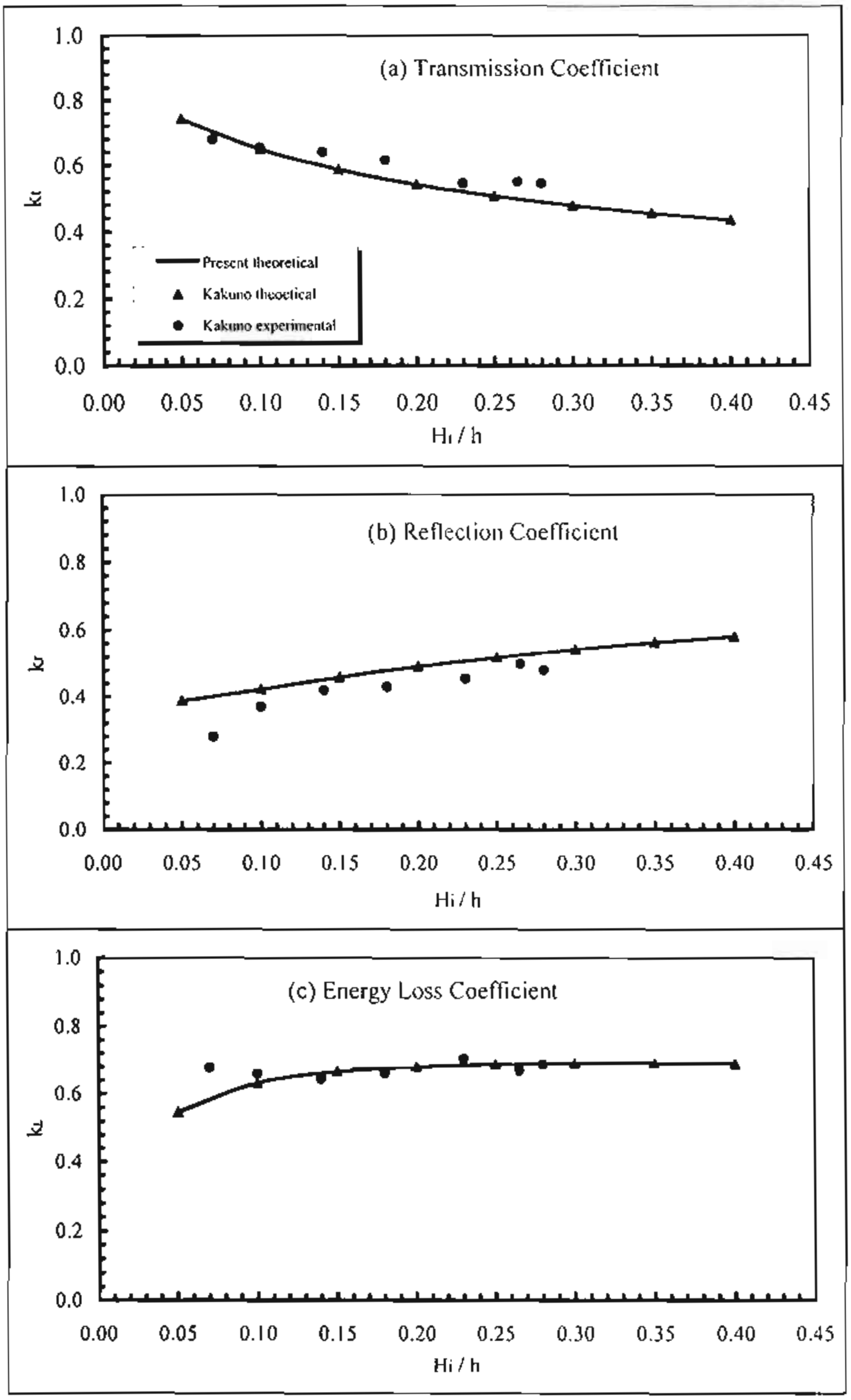


Fig. (4) The Comparison Between the Present Theoritical Results and Kakuno et al (1993) Results for Rectangular slotted Breakwater when kh=0.48, G/d=0.17, d/h=0.7 and B/h=0.2

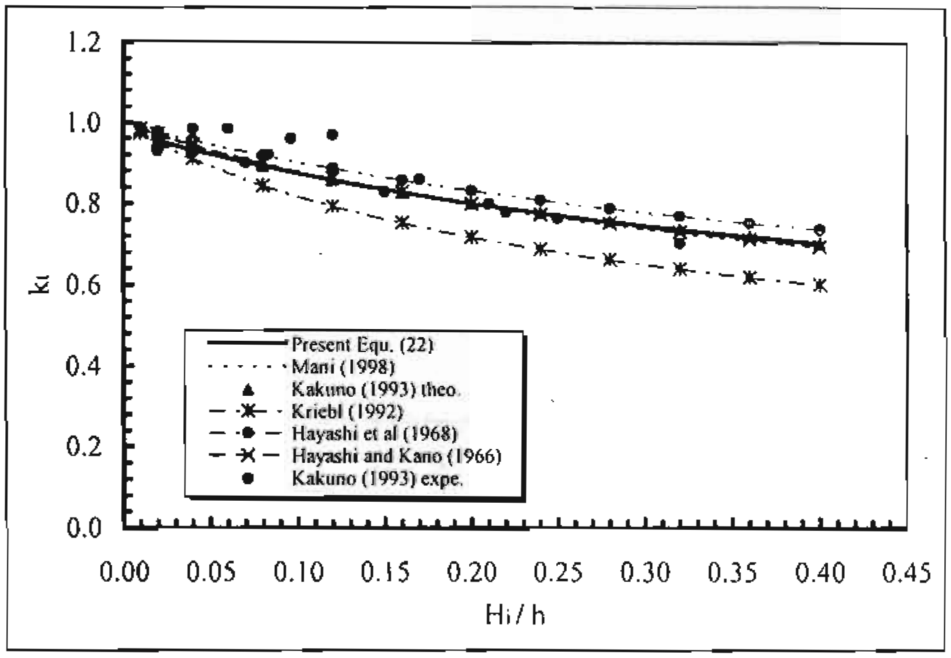


Fig. (5) The Comparison Between the Present Theoritical Results Equ. (22) and Different Studies for Rectangular slotted Breakwater when kh=0.48, G/d=0.5, d/h=0.7 and B/h=0.2

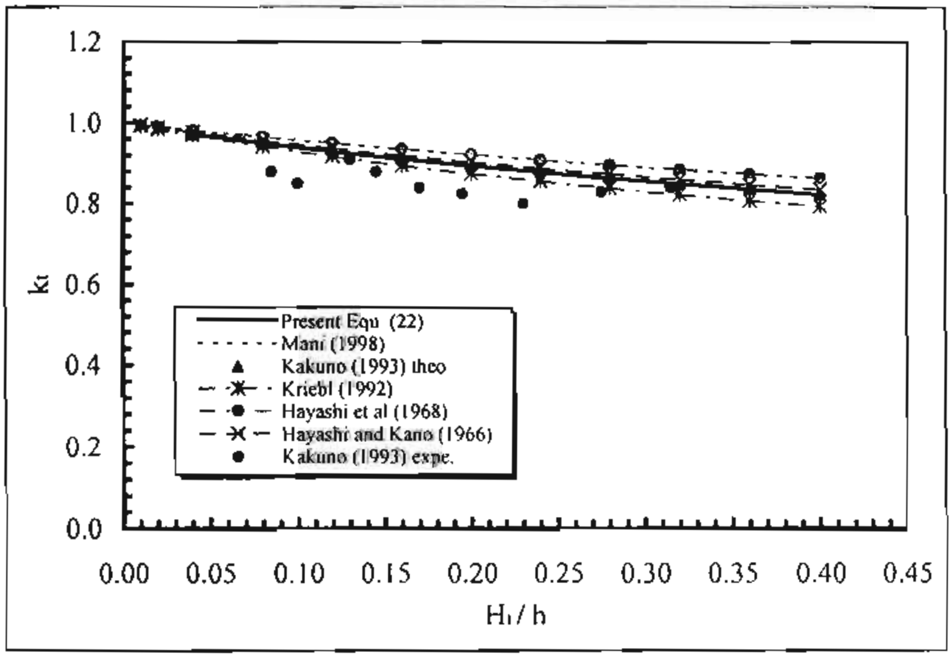


Fig. (6) The Comparison Between the Present Theoritical Results Equ. (22) and Different Studies for Square Pile Breakwater when kh=0.48, G/d=1.0 and d/h=0.2

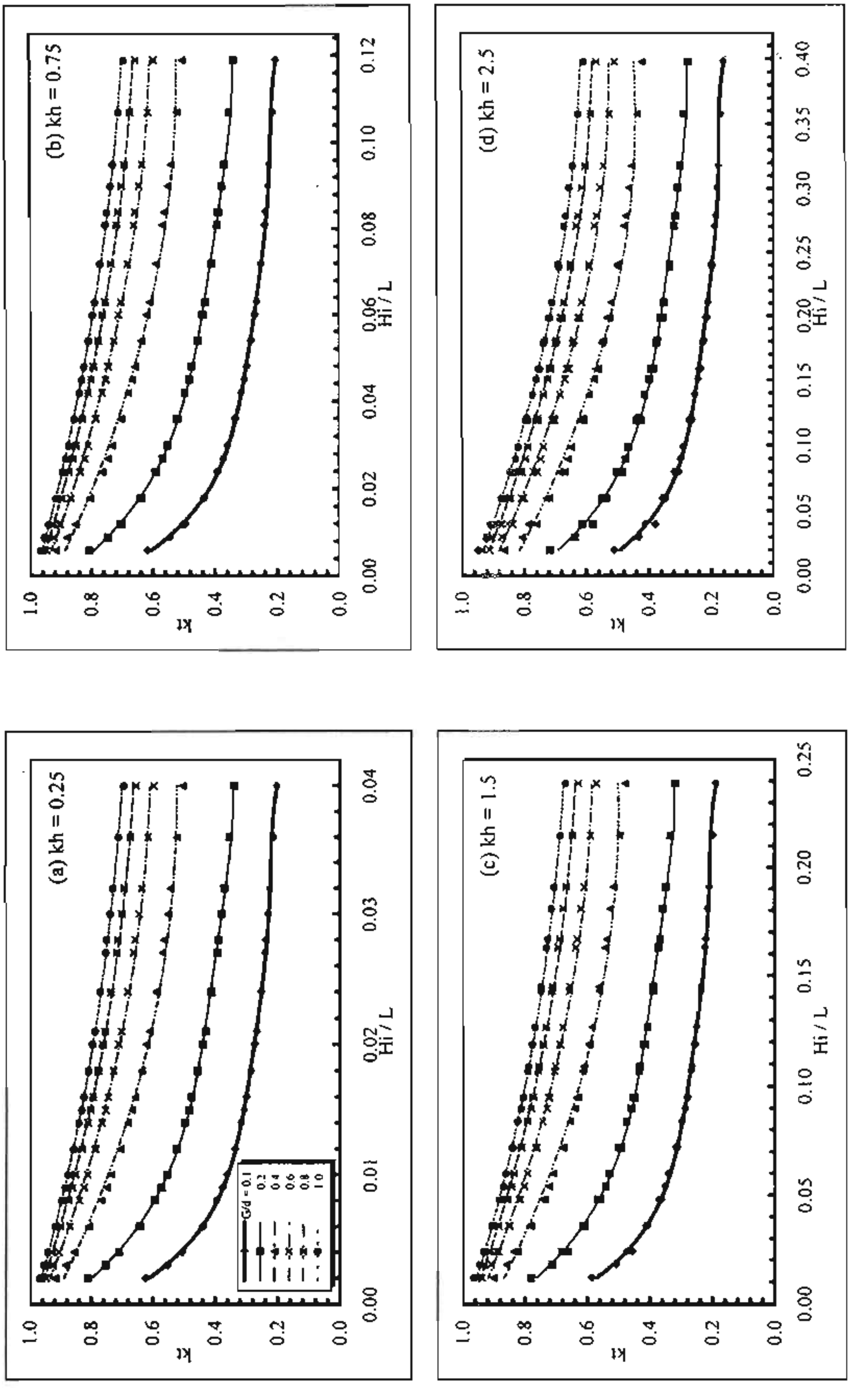


Fig. (7) The Theoretical Transmission Coefficient (kt) Versus Wave Steepness (Hi/L) for Different Wave and Structural Parameters for Square Pile Breakwater

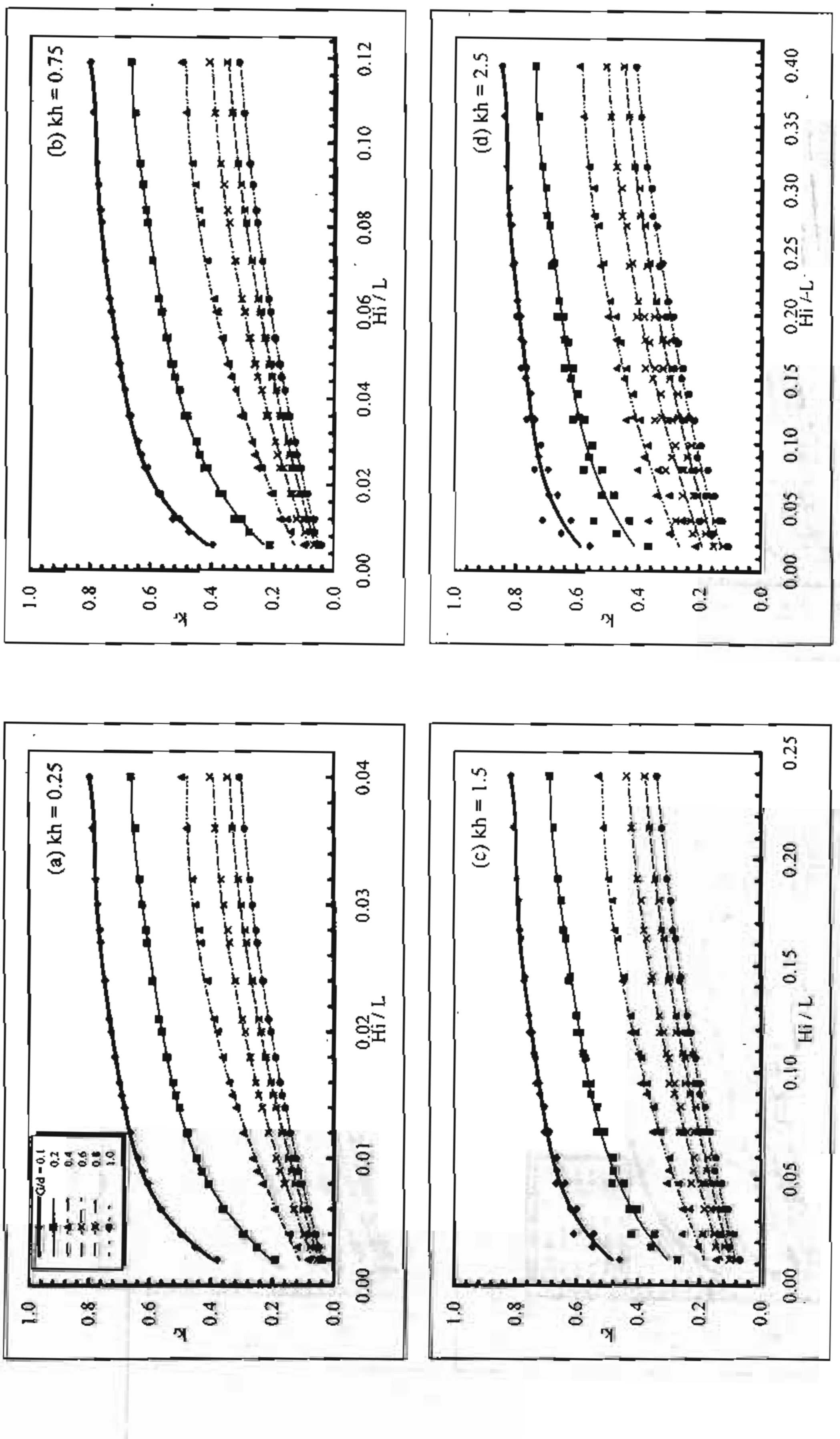


Fig. (8) The Theoretical Reflection Coefficient (kr) Versus Wave Steepness (Hi/L) for Different Wave and Structural Parameters for Square Pile Breakwater

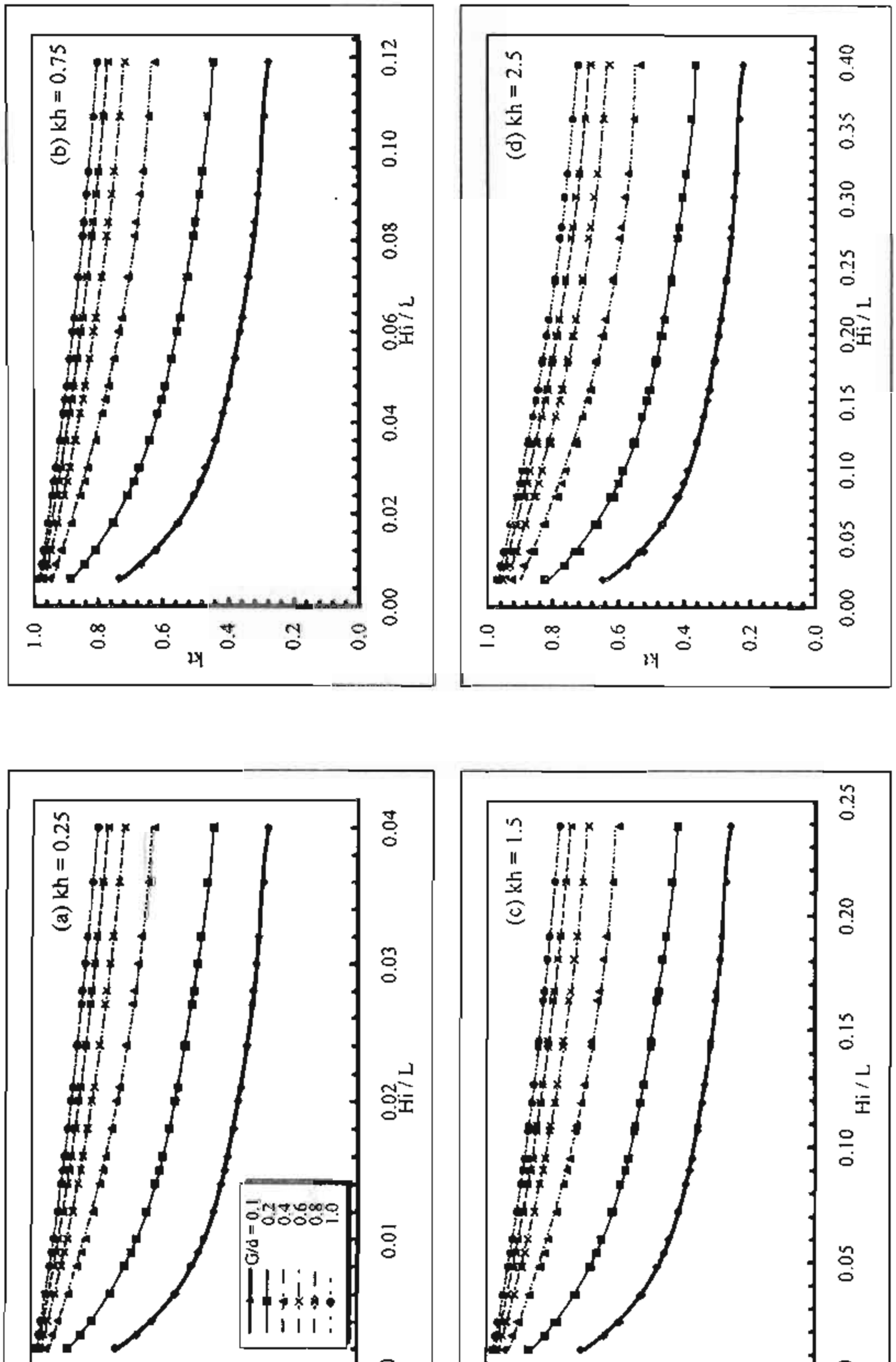


Fig. (9) The Theoretical Transmission Coefficient (kt) Versus Wave Steepness (Hi/L) for Different Wave and Structural Parameters for Circular Pile Breakwater

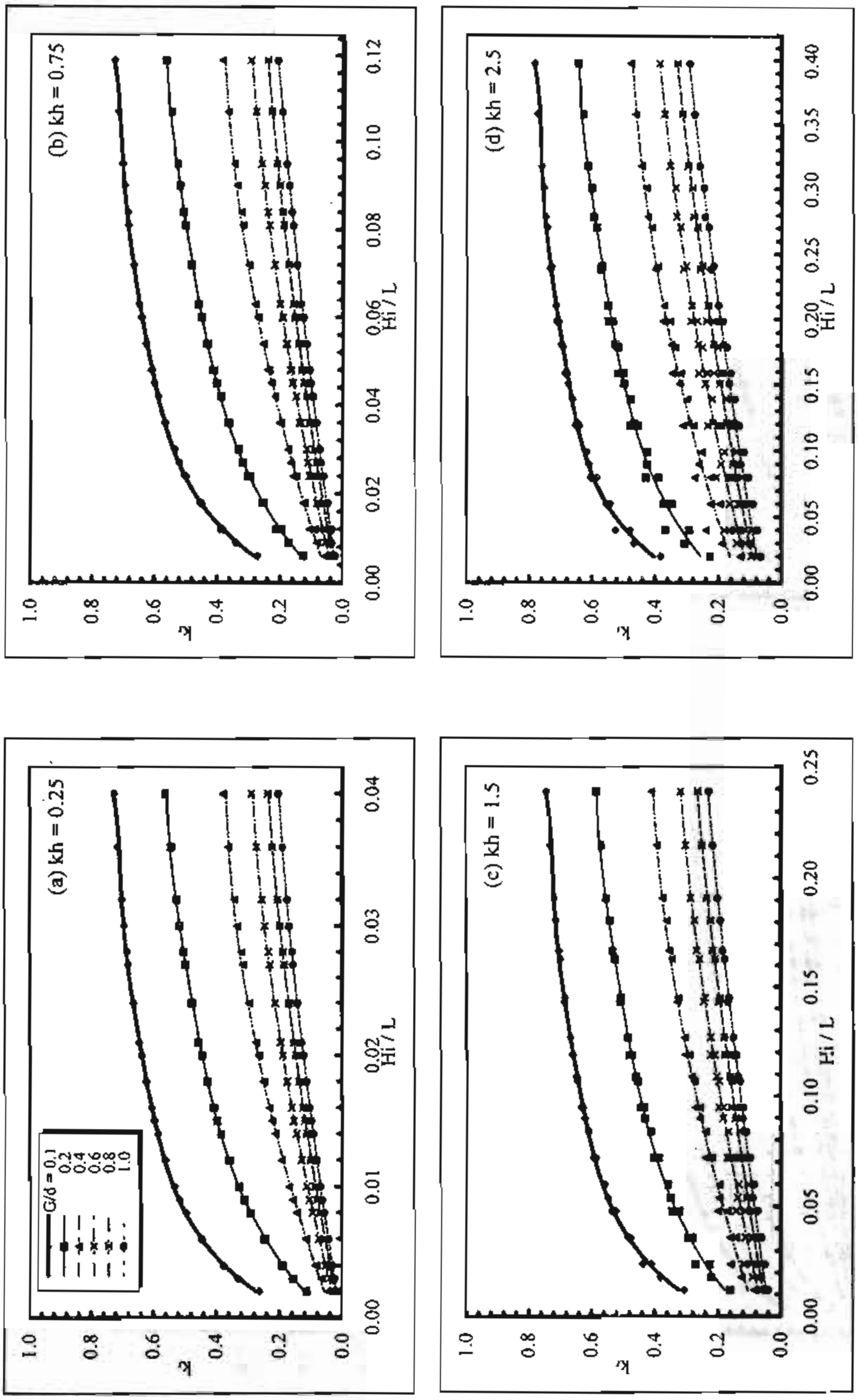


Fig. (10) The Theoretical Reflection Coefficient (kr) Versus Wave Steepness (Hi/L) for Different Wave and Structural Parameters for Circular Pile Breakwater