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EFFICIENCY OF DOUBLE ROWS OF PILES USED AS A BREAKWATER

"كفاءة صفين من الخوازيق تستخدم كحاجز أمواج"

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ملخص البحث :

يهتم البحث بالنمذجة المعملية لانتقال الأمواج خلف الحواجز الخازوقية المكونة من صفين من الخوازيق المربعة أو الدائرية و التي بينها مسافات صغيرة نسبيا. وقد تمت دراسة العوامل المختلفة المؤثرة على كفاءة هذه الحولجز مثل المسافة بين الخوازيق في اتجاه الأمواج و في الاتجاه العمودي عليها و ترتيب الخوازيق و طول الأمواج. و قد تم رسم العديد من العلاقات الترابطية لتوضيح تأثير هذه العوامل و المتغيرات على كفاءة هذه النوعية من الحواجز. و قد أوضحت النتائج أن الحواجز الخازوقية ذات القطاع المربع أكثر كفاءة من الحواجز ذات القطاع الدائري. كما أوضحت النتائج أيضا أن كفاءة الحواجز الخازوقية تزداد كلما قلت المسافة بين الخوازيق في الاتجاه العمودي على اتجاه الأمواج و كلما زادت أيضا المسافة بين صفوف الخوازيق في الاتجاه الآخر. كما تمت دراسة تأثير ترتيب الخوازيق ذات الصفين و اتضح أنه ليس لها تأثير كبير على كفاءة هذه الحواجز الخازوقية.

ABSTRACT:

The wave transmission, reflection, and energy loss due to closely spaced pile breakwaters consisted of two rows of vertical piles were investigated experimentally. Different parameters were tested such as, the gap-diameter or width ratio, the relative distance between the rows of piles, the wave length, the shape of the piles (square or circular), and the arrangement of the piles (straight or staggered). The square pile breakwater was found to be more efficient than the circular piles in decreasing the transmitted waves. Also, it was concluded that the efficiency of the breakwater was increased as the gap-diameter or width ratio decreased and as the relative span between pile rows increased. Finally, it was noticed that the effect of the pile arrangement (straight or staggered) was slightly affected the breakwater efficiency.

1. INTRODUCTION:

Piles are widely used in practice to support marine structures such as berths, breakwaters and dolphins. Also, it can be ranged in one or more rows and used as a breakwater. The two rows of the relatively closely spaced piles extending from the seabed to some distance above the water surface is considered as economic 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 with poor foundation conditions. The breakwater system can be successfully employed at low and moderate wave energy locations. This type permits the water exchange along the beaches, which minimizes the pollution aspects.

The functional performance of the pile breakwater was 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 such as Wiegel (1961), Hayashi et al (1966), Herbich (1989), Kakuno and Lui (1993), Abdel-Mawla and Balah (2001), Heikal and Koraim (2004) and Koraim (2005). Efforts towards developing theoretical models for predicting the wave reflection and transmission were also made. Martin and Dalymple (1988), Kakuno and Liu (1993), Kakuno et al. (1996), Park et al (2000) and Koraim (2005) provided theoretical solutions for pile breakwaters consisted of one row of piles.

In this paper the efficiency of the closely spaced pile breakwaters consisted of two rows of vertical square or circular piles ranged in straight or staggered positions was investigated experimentally.

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The breakwater efficiency was measured as function of transmission, reflection, and wave energy loss coefficients. The effect of different wave and structural parameters on the breakwater efficiency were presented, such as; wave length, wave period, spacing between piles, distance between rows of piles, piles shape, and arrangement of piles.

2. EXPERIMENTAL WORK:

Several experiments were conducted in a tilting wave flume in the Hydraulics and Water Engineering Laboratory of the Faculty of Engineering, Zagazig University, Zagazig. The wave flume dimensions were 15 m long, 0.45 m deep and 0.30 m wide. The variable speed flap type wave generator was used with generated wave periods ranged between 0.66 and 2.86 seconds with stroke distance of 22 cm. A 3:1 steel screen wave absorber was existed at the end of the flume to absorb the transmitted waves at the end of the flume. The experimental setup details and the dimensions of the breakwater models are shown in Table (1) and Figure (1). The position of the tested model in the wave flume is shown in figure (2).

Table (1) The experimental setup and the breakwater models details.

Parameter	The ranges	Notes
Water Depth (h) (cm)	15, 20 and 25	At the breakwater site
Wave Periods (T) (sec)	0.68, 0.71, 0.75, 0.84, 1.0, 1.2, 1.5, 2.0 and 3.0	
Wave Length (L) (cm)	65 to 490	At the breakwater site
Pile Cross Section Shape	Square and Circular	
Piles Arrangement	Straight and Staggered	
Pile Diameter or Width (d) (cm)	3.3	
Gap between Piles (G) (cm)	0.45, 1.0, 1.7 and 2.7	Perpendicular to wave direction
Pile Rows Spacing (S) (cm)	10 and 20	Parallel to wave direction
Bed Slope (s_b)	0%	

The wave height was measured using Non-Contact Ultrasonic Distance Transmitter, NCUDT, (Omega's LV400) that displays and transmits the distance between the sensor and the water surface with accuracy of 1.0%. The measured wave height was equal the difference between the maximum reading and the minimum reading obtained from NCUDT.

The maximum and the minimum wave heights ($H_{max.}$ and $H_{min.}$) at the wave generator side and the transmitted wave heights (H_t) at the wave absorber side were measured to estimate the reflection and the transmission coefficients (k_r and k_t) as follows:

$$H_i = (H_{max.} + H_{min.}) / 2 \qquad (1)$$

$$H_r = (H_{max.} - H_{min.}) / 2 \qquad (2)$$

Then;

$$k_r = H_r / H_i \qquad (3)$$

$$k_t = H_t / H_i \qquad (4)$$

In which, H_i and H_r are the incident and the reflected wave heights respectively.

Theoretically, energy equilibrium of an incident wave attack the structure can be expressed as follows:

$$E_i = E_r + E_t \qquad (5)$$

In which, E_i is the energy of incident wave, E_r is the energy of reflected wave, and E_t is the energy of transmitted wave. Also, equation (5) can be rewritten as follows:

$$k_r^2 + k_t^2 = 1 \qquad (6)$$

In practice, when the wave reaches the structure, some of the wave energy dissipated by the structure itself. The wave energy loss coefficient (k_L) can be estimated as a function of the reflection and transmission coefficient as follows:

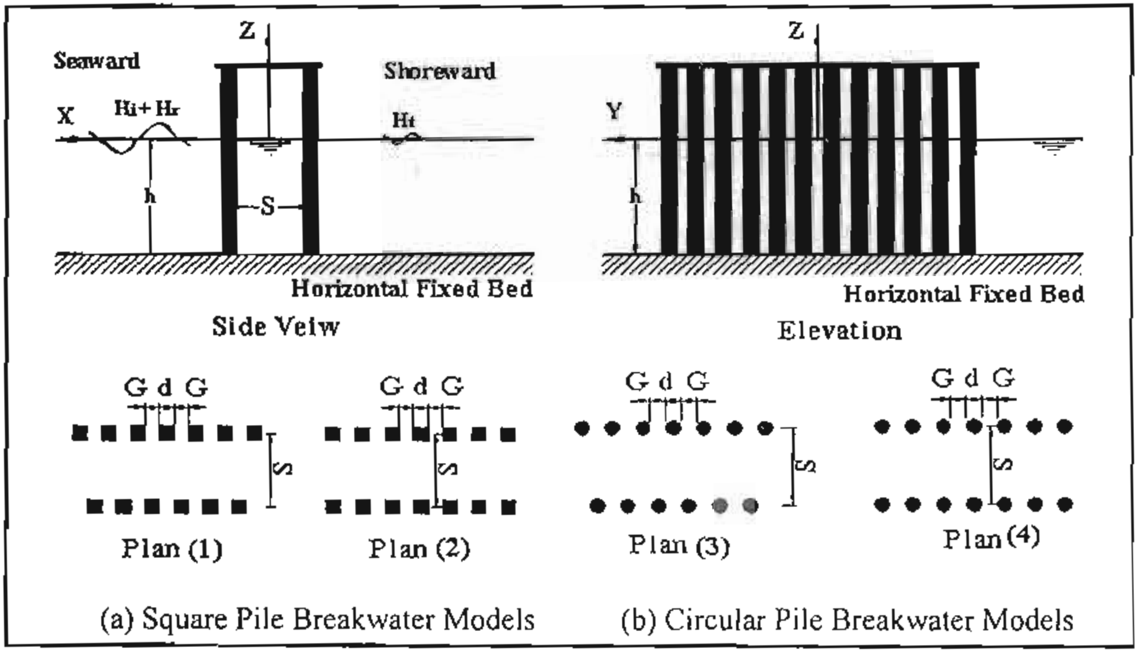
$$k_L = 1 - k_r^2 - k_t^2 \qquad (7)$$

3. EXPERIMENTAL RESULTS AND ANALYSIS:

Experiments were carried out to investigate the wave field shoreward and seaward of the suggested pile breakwater system. The dimensional analysis showed that the efficiency of the double pile breakwater depends upon the pile cross section shape, the piles arrangement, the dimensionless wave number [kh], the relative distance between the rows of piles [S/d], and the gap-diameter or width ratio [G/d]. This means that,

$$k_t,\ k_r,\ \text{and}\ k_L = \phi(kh,\ S/d,\ G/d,\ \text{Pile Shape, Piles Arrangement}) \qquad (8)$$

In which k is the wave number (k=2π/L, L is the wave length), h is the water depth, d is the pile diameter or width, G is the gap between piles and S is distance between the rows of piles.



(a) Square Pile Breakwater Models (b) Circular Pile Breakwater Models

Fig. (1) Definition Sketch for Breakwater Models.

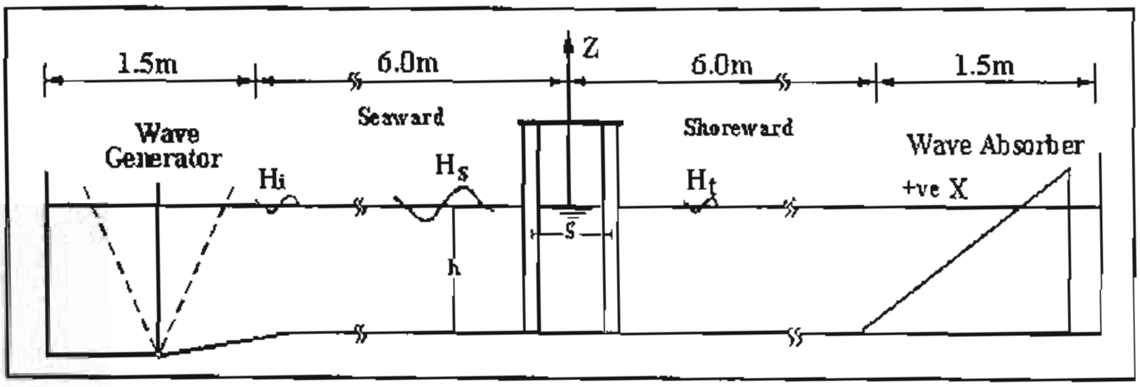


Fig. (2) Position of Breakwater Model in the Wave Flume.

Figures (3) and (4) present the relationship between the dimensionless wave number (kh) and the different hydrodynamic coefficients (k_t, k_r, and k_L) for SEVERAL gap-width ratios (G/d). This is for the pile breakwater consisted of two rows of square piles ranged at straight positions when S/d=3 and 6 respectively. Figures (3a) and (4a) show that k_t decreases with the increase of kh. Also, k_t

decreases as G/d decreases. This may be attributed to the increase in the screen resistance as G/d decreases, and then the percentage of waves, which allowed to be transmitted, decrease.

While the reflection coefficient (k_r) follows the opposite trend of the transmission coefficient as expected as shown in figures (3b) and (4b). Figures (3c) and (4c) show that the wave energy loss coefficient (k_L) increases with decreasing kh. This is attributed to the increase of k_r by large values for the square piles while k_t decreases by small values with increasing of kh. Also, k_L increases with increasing G/d. This can be explained by considering the friction effect. As G/d increases, the friction between the waves and the square piles surface increases causes the dissipation of wave energy.

Figures (5) and (6) present the relationship between kh and the different hydrodynamic coefficients (k_t, k_r, and k_L) for many G/d. This is for the pile breakwater consisted of two rows of circular piles ranged at straight positions when S/d=3 and 6 respectively. Figures (5a) and (6a) show that k_t decreases with increasing of kh and decreasing of G/d. While k_r follows the opposite trend as shown in figures (5b) and (6b). Figures (5c) and (6c) show that k_L slightly increases with decreasing kh when S/d=3. But when S/d=6, k_L becomes near constant especially for small G/d (G/d=0.15 and 0.30) while it slightly decreases when G/d= 0.50 and 0.80. Also, k_L increases with decreasing G/d. This can be explained by considering the friction and gradually contraction effect. As G/d decreases, the friction between the waves and the circular piles surface increases causes the dissipation of wave energy.

Figure (7) presents the relationship between kh and the different hydrodynamic coefficients (k_t, k_r, and k_L) for several G/d values. This is for the pile breakwater consisted of two rows of circular piles ranged at staggered positions when S/d=6. Figure (7a) shows that k_t decreases with increasing of kh and decreasing of G/d. While k_r follows the opposite trend as shown in figure (7b). Figure (7c) show that k_L becomes near constant when G/d=0.15 and 0.30 while it slightly decreases when G/d= 0.50 and 0.80. Also, k_L increases with decreasing G/d.

Figure (8) shows the effect of the pile cross section shape on the different hydrodynamic coefficients (k_t, k_r, and k_L) when S/d=6. This figure shows that the performance of the square section in reducing the transmitted waves is higher than the circular section by about 5 to 15 %. This is may be due to the wave energy dissipation by the effect of the sudden contraction. While the performance of the circular section in reducing the waves at the sea side is higher than the square section. Also, the circular piles are efficient for dissipating the wave energy when G/d becomes small while the square piles are efficient when G/d becomes large.

Figure (9) shows the effect of the distance between the rows of piles (S) on the different hydrodynamic coefficients (k_t, k_r, and k_L) for circular piles ranged in straight positions. The figure shows that the performance of the breakwater system in reducing the transmitted and reflected waves increases with increasing S/d from 3 to 6 (k_t and k_r become low). Also, as S/d increases the breakwater system more dissipating the wave energy. Figure (10) shows the effect of the piles arrangement on the different hydrodynamic coefficients (k_t, k_r, and k_L) for circular piles when S/d=6. the figure shows that the effect of the piles arrangement (straight or staggered) is small and not more than 5 %.

4. CONCLUSIONS

Series of experiments were carried out to study the performance of the double circular and square pile breakwaters. The conclusions were as follows:

1. About 15 to 55 % of the wave energy were lost due to the effect of the tested breakwater system.
2. The circular piles are efficient for dissipating the wave energy when "G"

becomes small while the square piles are efficient when "G" becomes relatively large.

3. The efficiency of the pile breakwater is high as a wave barrier for short waves and when the relative gap between piles is relatively small.
4. The efficiency of the double rows pile breakwaters increases as the distance between the two rows of piles increases.
5. The square pile breakwater is more efficient than the circular pile breakwater by 5 to 15 %.
6. The effect of the piles arrangement on the breakwater system efficiency is relatively small and not more than 5%.

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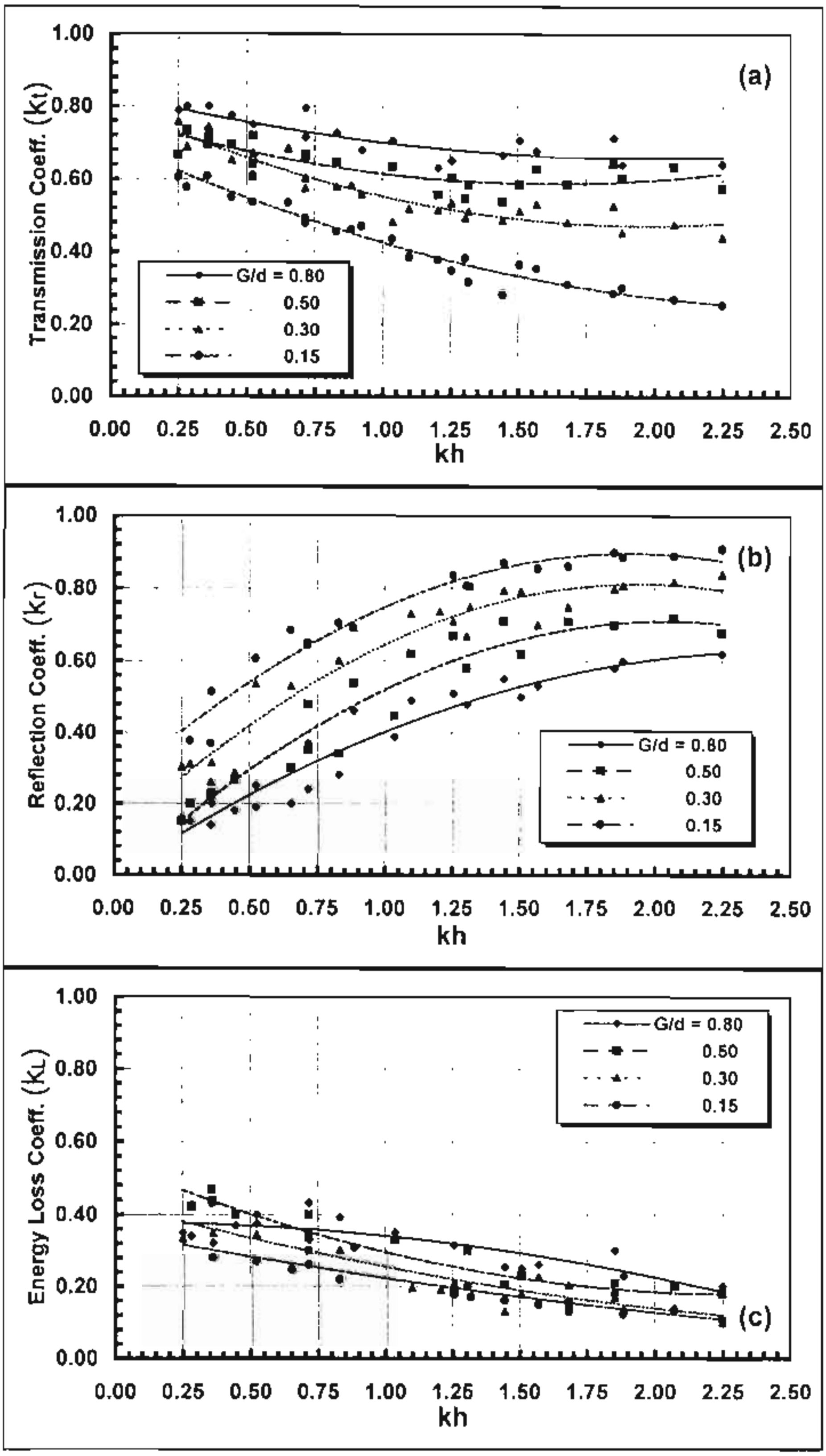

Fig.(3) Effect of the Gap Ratio Between Piles (G/d) and the Dimensionless Wave Number (kh) on the Different Hydrodynamic Coefficients. (Square Piles Ranged in Straight Positions and S/d=3).

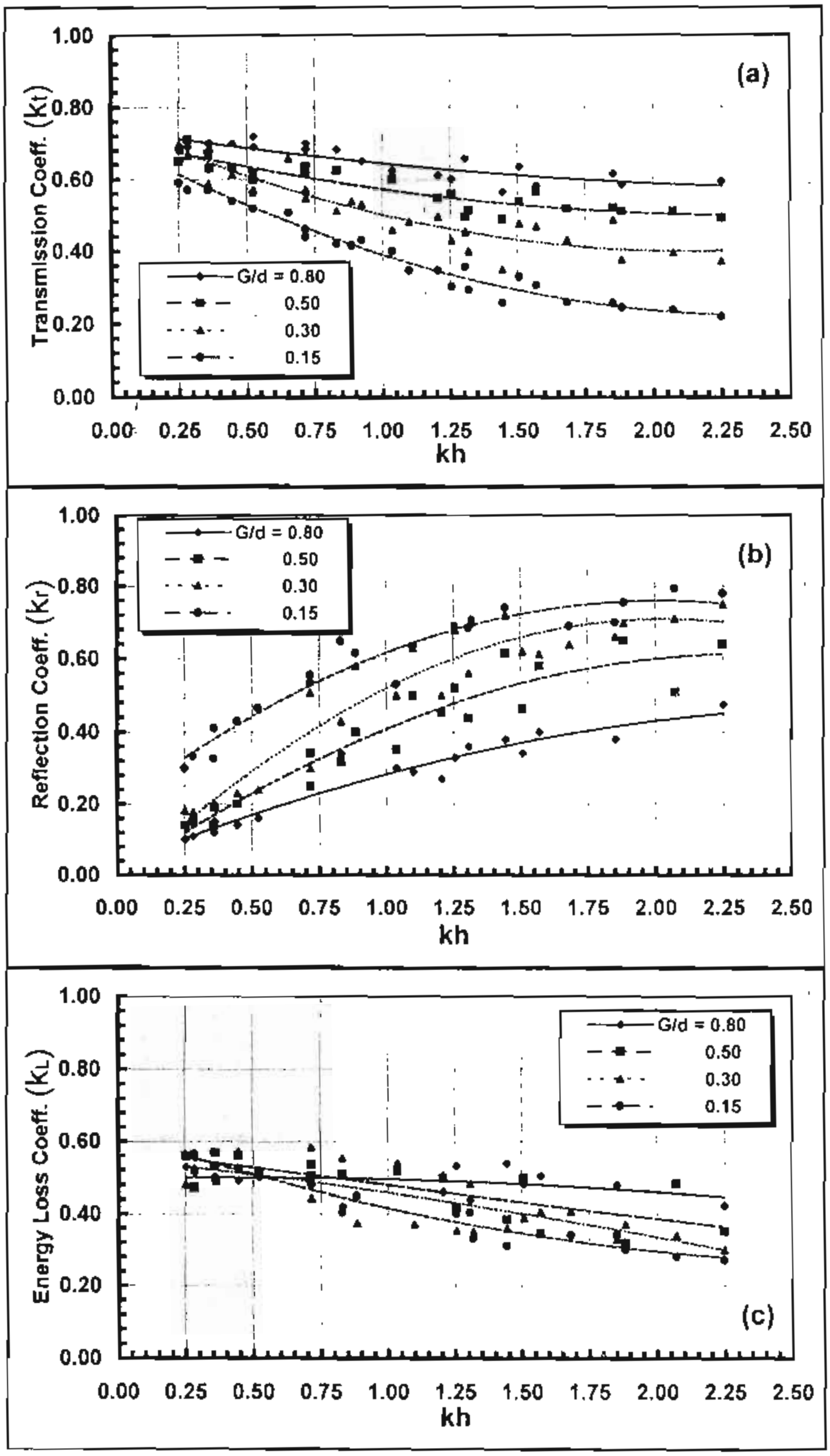

Fig.(4) Effect of the Gap Ratio Between Piles (G/d) and the Dimensionless Wave Number (kh) on the Different Hydrodynamic Coefficients. (Square Piles Ranged in Straight Positions and S/d=6).

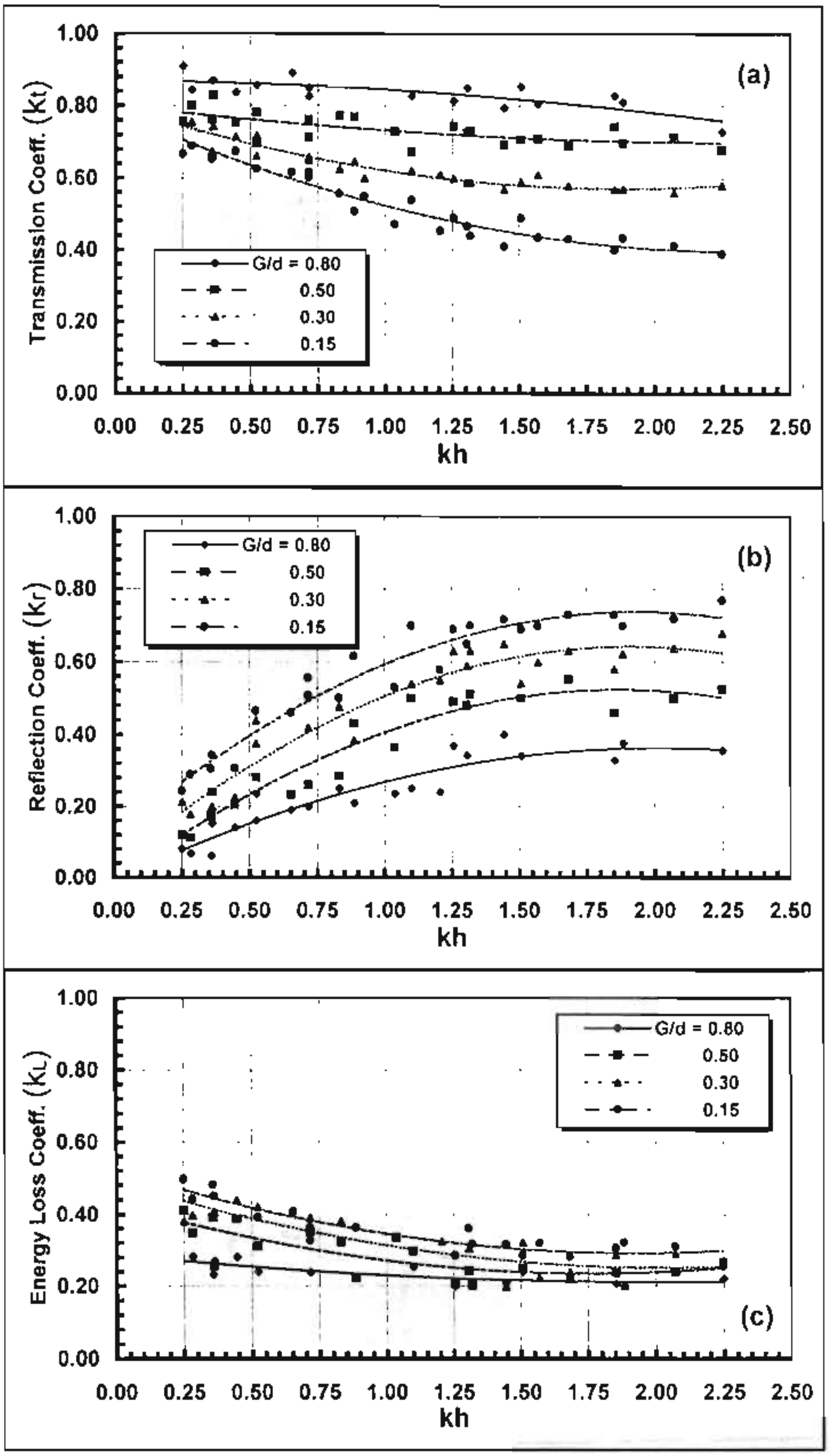

Fig.(5) Effect of the Gap Ratio Between Piles (G/d) and the Dimensionless Wave Number (kh) on the Different Hydrodynamic Coefficients. (Circular Piles Ranged in Straight Positions and S/d=3).

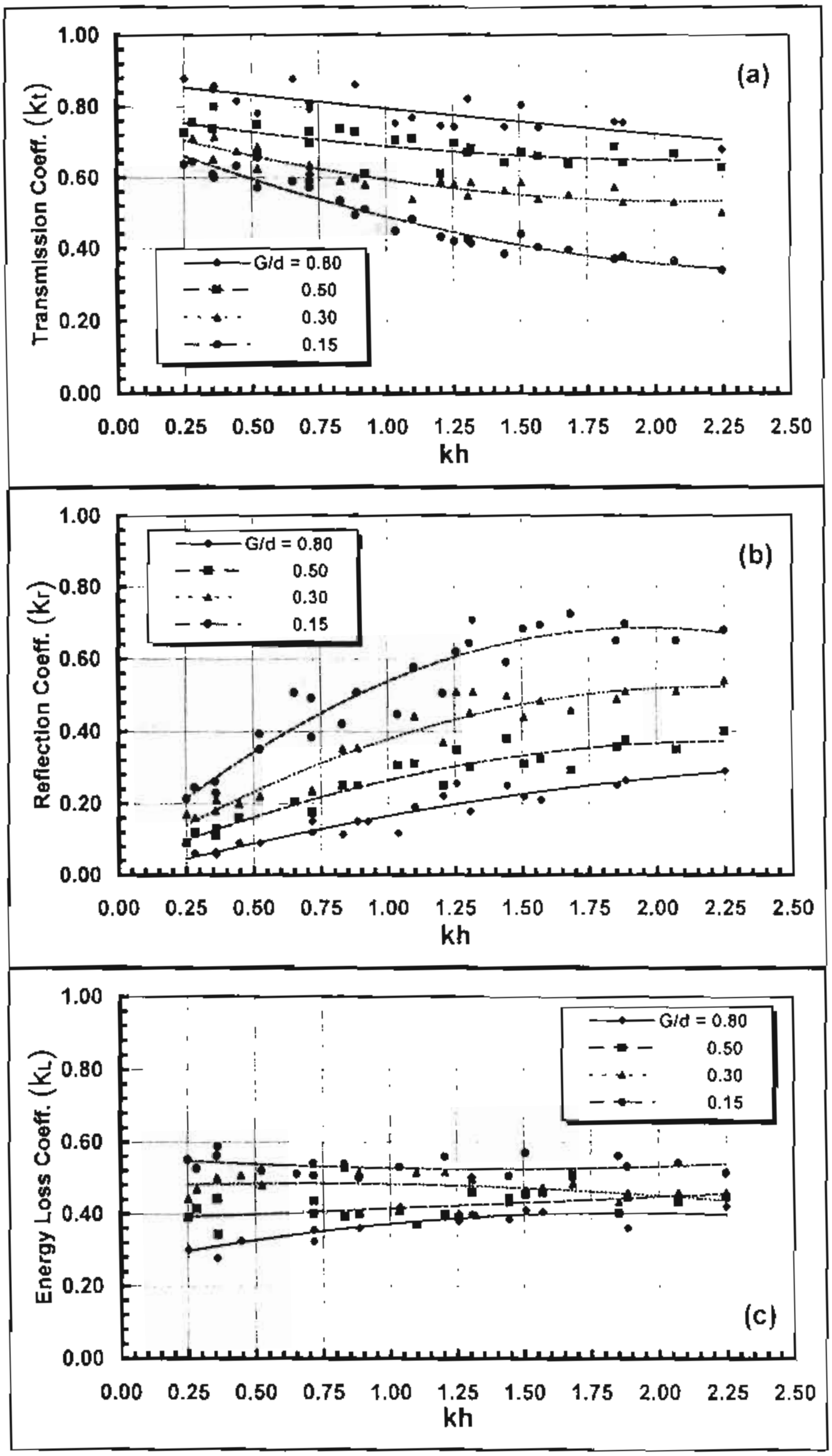

Fig.(6) Effect of the Gap Ratio Between Piles (G/d) and the Dimensionless Wave Number (kh) on the Different Hydrodynamic Coefficients. (Circular Piles Ranged in Straight Positions and S/d=6).

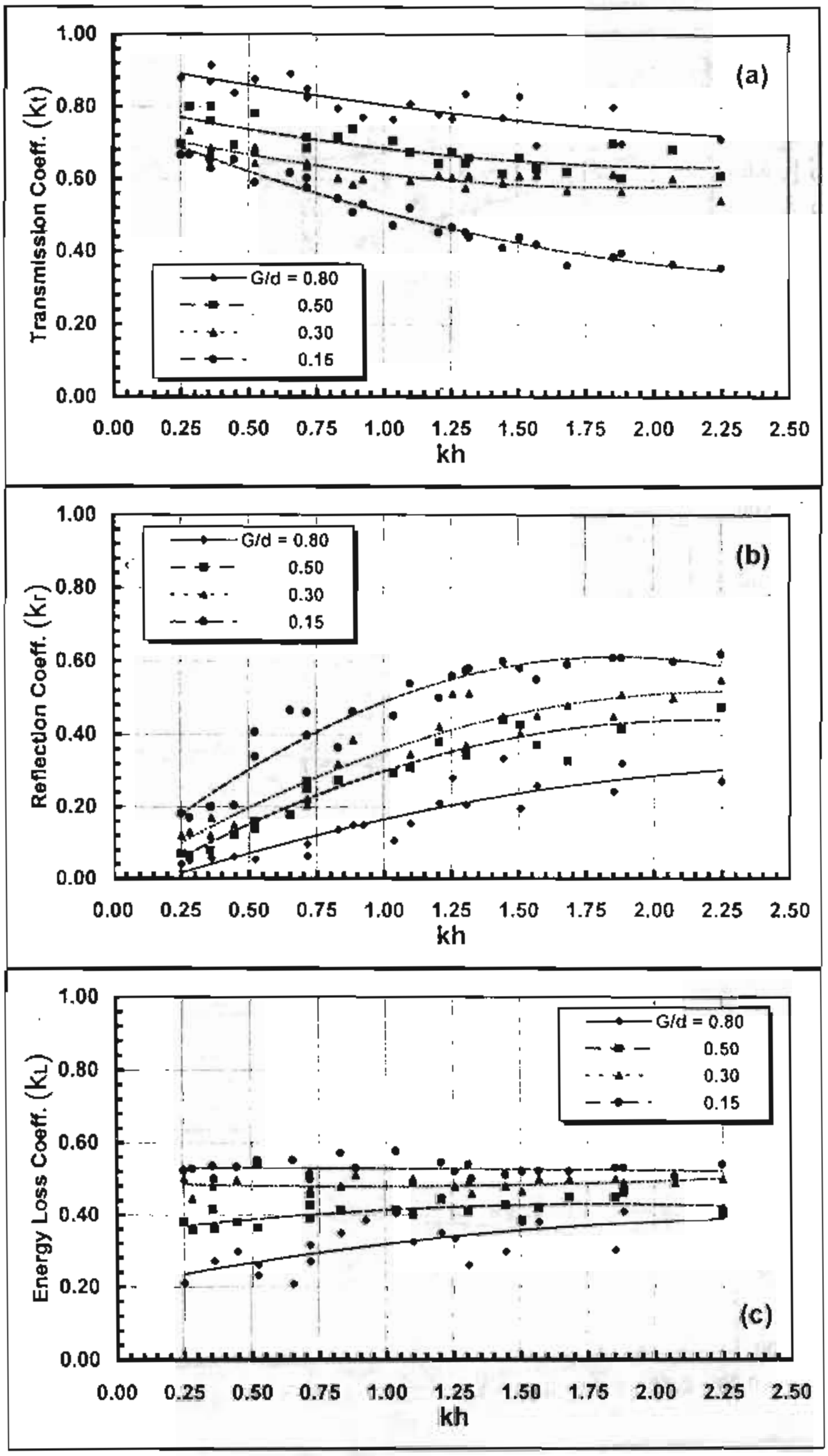

Fig.(7) Effect of the Gap Ratio Between Piles (G/d) and the Dimensionless Wave Number (kh) on the Different Hydrodynamic Coefficients. (Circular Piles Ranged in Staggered Positions and S/d=6).

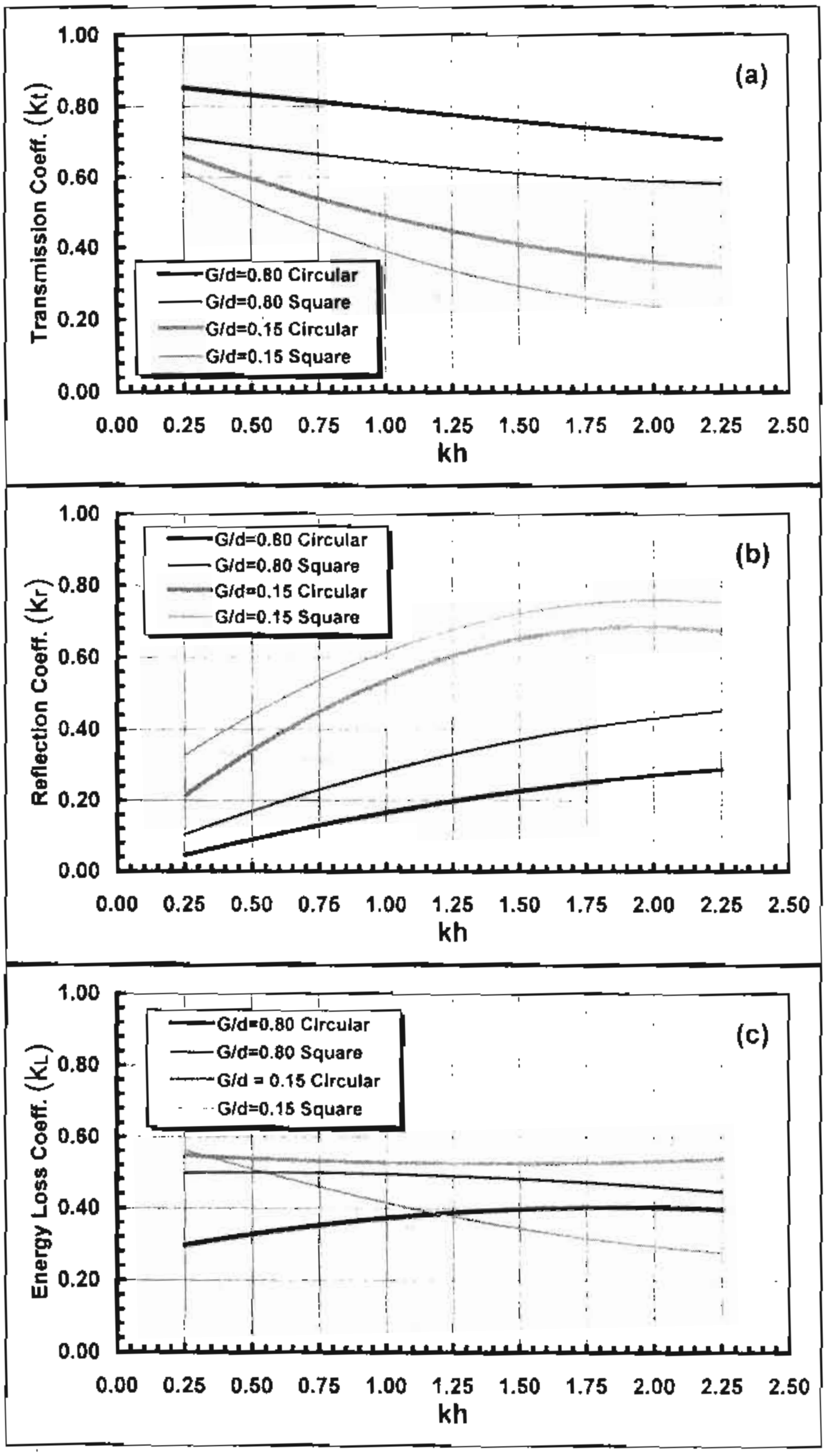

Fig.(8) Effect of the Pile Shape on the Different Hydrodynamic Coefficients when S/d = 6 (The Piles Ranged in Straight Position)

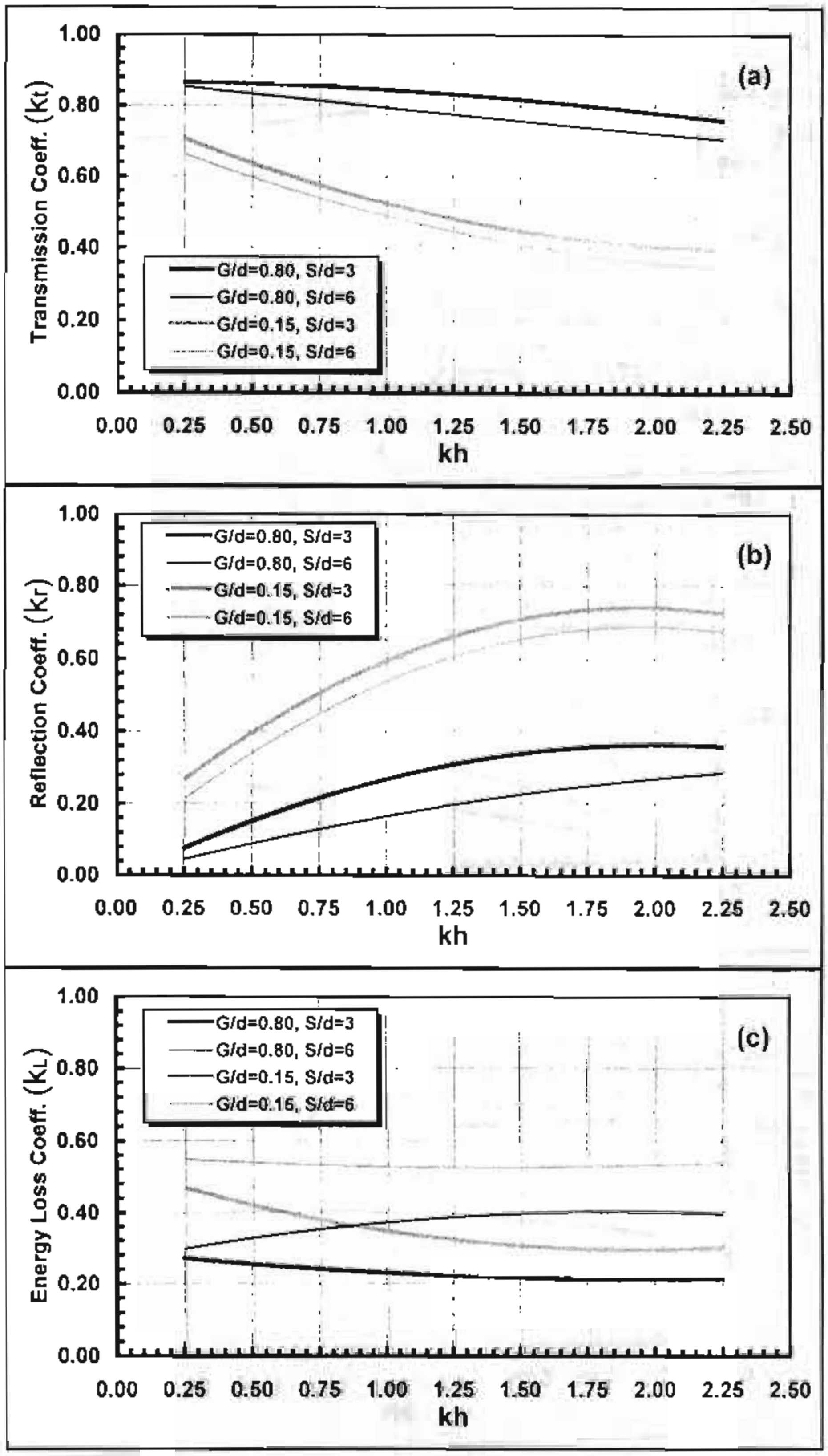

Fig.(9) Effect of the Spacing Between the Rows of Piles on the Different Hydrodynamic Coefficients (Circular Piles Ranged in Straight Position)

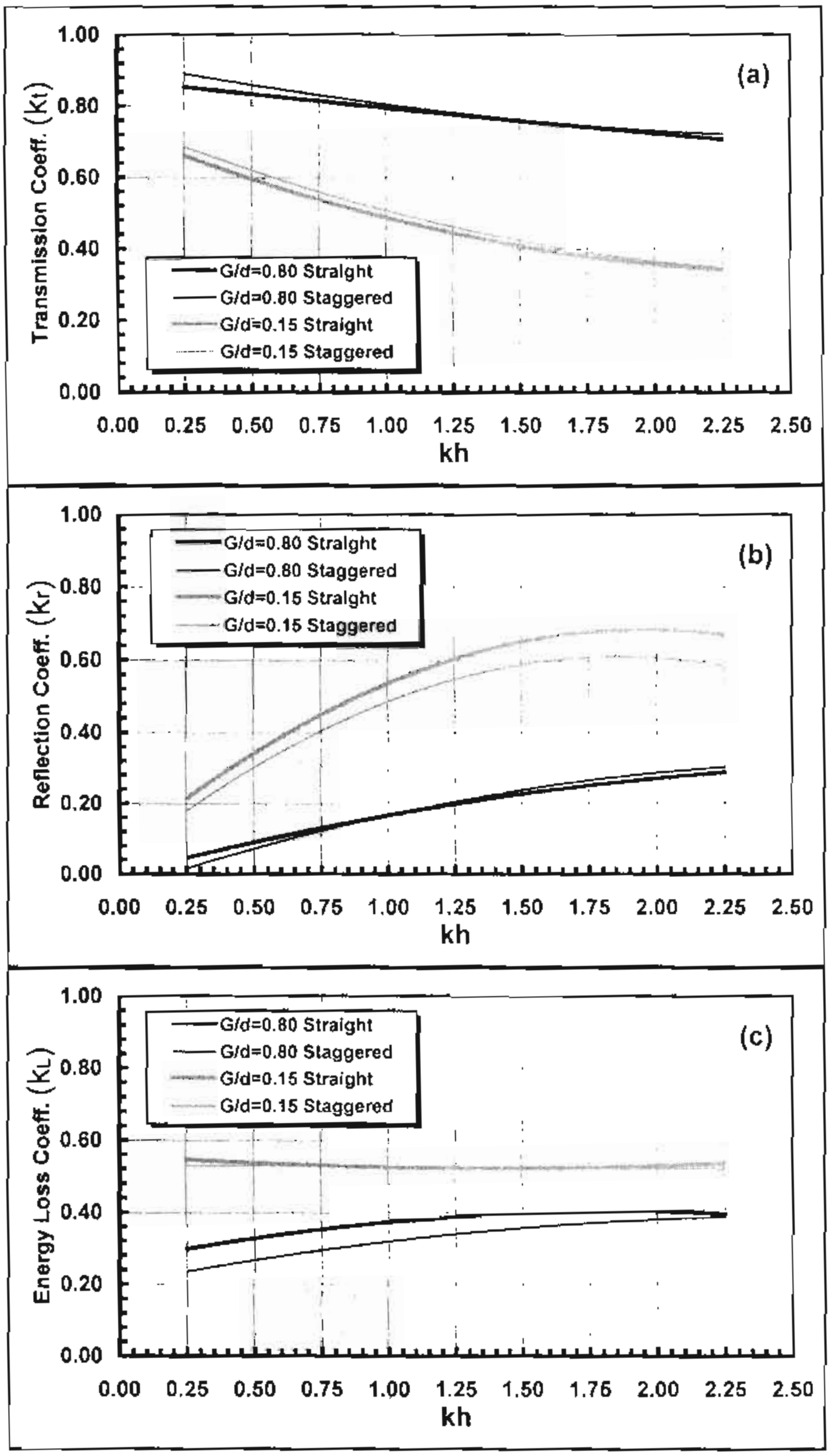

Fig.(10) Effect of the Piles Arrangement on the Different Hydrodynamic Coefficients when S/d = 6 (Circular Piles)