Scientific Research and Essays Vol. 5 (4), pp. 378-388, 18 February, 2010
Available online at http://www.academicjournals.org/SRE
ISSN 1992-2248 © 2010 Academic Journals

*Full Length Research Paper*

# The analysis of long wave diffractions due to offshore breakwater and seawall

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Accepted 25 January, 2010

**The purpose of this study was to investigate the long wave-structure interaction that differs with varying incident wave period, length of offshore breakwater, and distance between offshore breakwater and seawall. The theoretical method was based upon the linear diffraction theory obtained by a pair of boundary integral approach. The water depth in the fluid region was assumed to be constant. To investigate the long wave interaction that was affected by offshore structure and seawall, a numerical program was developed, and the simulation was carried out by varying the conditions of the distance between two structures and length of offshore structures, and incident wave period. The results showed that various aspects of wave fields have been observed in accordance with conditions of geometric aspects. This study can effectively be utilized for safety assessment to various breakwater systems and layout of offshore breakwater in the ocean and coastal field. It can give safety information regarding the construction of offshore structure and seawall in coastal regions.**

**Key words:** Long wave-structure interaction, boundary integral approach, offshore breakwater, seawall.

## INTRODUCTION

Recently, with the rise in income and the subsequent increase in leisure time, there has been an increasing interest in ocean leisure activities. Due to this rise, old harbor facilities have to be remodeled to become eco-friendly. In the case of fishery ports, in order for these ports to accommodate the demand for tourism and leisure activities, they need to be redeveloped to embrace a multi-functional concept. Therefore instead of using traditional breakwaters such as the upright breakwater, the rubble mound breakwater, and the block-type breakwater, various new types of breakwaters are appearing.

By constructing this sort of offshore structure in the fluid region that is in front of the sea wall, this fluid region is interfered by the breakwater and through interaction between long wave and the structures, oscillation appears in this region. The amplification rate of the oscillation shows up in a complicated manner due to wave period, distance between offshore structure and seawall, and the reflection ratio of the sea wall. Thus the layout of the breakwater in the offshore fluid region for the differing distance between offshore structure and seawall and the differing length of offshore structure change the amplification rate of the fluid region between the offshore breakwater and the seawall. Therefore in order to gain a stable wave height amplification rate in the fluid region between the offshore breakwater and the seawall, it is important to set the breakwater appropriately.

The basic theory of the interaction of wave-structure that is dealt with in this study is from the wave diffraction theory. The calculation of wave diffraction in the nearshore zone has been studied starting from Penny and Price (1944) and has continued through Puttnam and Arthur (1948), Blue and Johnson (1949) and Carr and Stelzriede (1951). The analytical solutions of the researchers above, Wiegel (1962) graphed the diffraction diagram, and then regarding the wave height distribution at the rare side of the gap-type breakwater, Pos and Kilner (1987) did numerical analysis using the Finite element method based on the mild slope equation. Hunt (1990) calculated the wave interval passing through the gap with the first kind of Fredholm Integral Equation. Spring and Monkmyer (1974) investigated the interaction due to fluid power and wave run up, and later researchers

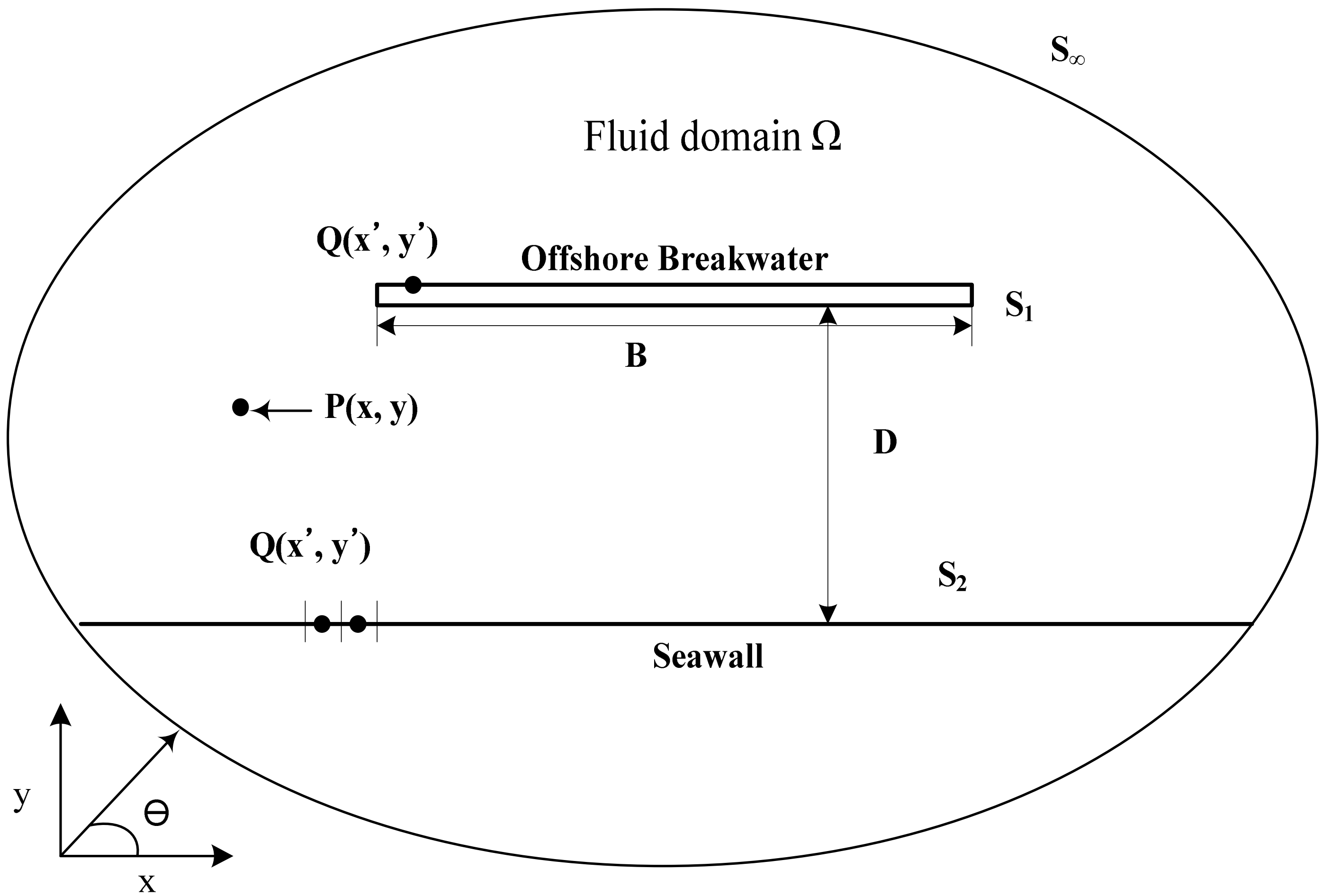



**Figure 1.** Definition sketch of an offshore breakwater and seawall.

such as Linton and Evans (1990), Kagemoto and Yue (1986) studied the 3-dimenstional wave diffraction problem regarding the interaction of offshore structures. Dalrymple and Martin (1990) studied the diffraction problem due to in-line segment using eigenvalue-expansion, Abul-Azm and Williams (1997) also investigated the diffraction theory due to offshore breakwater using the Green function. Recently, Kim and Lee (2009) studied wave diffraction due to gap type breakwater using analytical solutions.

This study has investigated the oscillation of long waves in broad band period (frequency) caused by the interaction with wave-structures, in order to set up a breakwater that effectively interferes with waves for construction of new eco-friendly harbors, fishery ports, and marina. First the seawall needs to be displayed as an upright wall that is in a straight line, and the offshore structure must be placed at a set distance. The length of the offshore breakwater is designated as 2*L* (*L* = wavelength), and the distance between the seawall and the offshore structure is 1, 1.5 and 4.0 *L*. The long wave period is ranged at 5.0 *k* (*k* = wave number) to 25.0 *k* s and the incident wave angle is 90°. The amplification factor of the oscillation caused by the differing distance between the two structures is investigated and then the wave height distribution at the fluid region between the two structures is studied.

## THEORETICAL DEVELOPMENT

The geometry of the problem is presented in Figure 1. The boundary regions are express as $S_1$ (offshore breakwater boundary) and $S_2$ (seawall region), *D* is the distance between the offshore breakwater and the seawall, *B* is the length of the breakwater. In Figure 1 the Cartesian coordinates are designated as having the origin at a corner of the seawall. The *x*- and *y*- are directed in the horizontal plane and the *z*-axis is directed vertically upward from the equilibrium water surface. The offshore structure is subject to a train of regular component waves of angular frequency $\omega$ and height $H_I$ propagating at angle $\theta$ to the positive *x*-axis.

Assuming that the fluid is inviscid, incompressible, and the flow irrotational, the fluid motion in each of the fluid regions may be described in terms of velocity potential $\Phi(x,y,z,t)=\mathrm{Re}[\phi(x,y,z)e^{-i\omega t}]$ . The velocity potential satisfies the Laplace equation, and then the Helmholtz equation may be written as

$$\frac{\partial^2\phi(x,y)}{\partial x^2}+\frac{\partial^2\phi(x,y)}{\partial y^2}+k\phi(x,y)=0 \qquad (1)$$

Where the wave number $k$ is related to the wave frequency through the dispersion relation, $\omega^2 = gk\tanh kh$ .

The boundary conditions on the free-surface and sea-bed can be expressed in the following form:

$$\frac{\partial\phi}{\partial z}-\frac{\omega^2\phi}{g}=0 \quad \text{on} z=0 \qquad (2)$$

$$\frac{\partial\phi}{\partial z}=0 \quad \text{on } z=-h \qquad (3)$$

Where $g$ is the acceleration due to gravity. Satisfying boundary conditions, general solution of velocity potential is

$$\phi(x,y,z)=-\frac{igA_I}{\omega}\frac{\cosh k(z+h)]}{\cosh(kh)}\varphi(x,y)e^{-i\varpi t} \qquad (4)$$

Where $A_I$ is the amplitude of the incident wave and $\varphi(x,y)$ is the wave function. Applying Green's second identity to $\varphi(x,y)$ and $G(Q,P)$ over the fluid domain( $\Omega$ ), the following integral equation can be expressed:

$$\varphi(x,y)=-\frac{1}{2}\int_{S_1+S_2}\left\{\varphi(Q)\frac{\partial G}{\partial n}(Q,P)-G(Q,P)\frac{\partial\varphi}{\partial n}(Q)\right\}d\Omega \qquad (5)$$

Where $\Omega$ is the entire fluid region except for the offshore breakwater region and seawall region, and $G$ is Green's function. $G$ may now be defined as follows (Lee, 1971):

$$G(Q,P)=\frac{i\pi}{2}H_0^{(1)}(kR) \qquad (6)$$

Where $H_0^{(1)}$ is the Hankel function of the first kind of order zero: $Q=(x',y')$ , $P=(x,y)$ and $R=\sqrt{(x-x')^2+(y-y')^2}$ .

The boundary conditions on $S_1$ and $S_2$ can be expressed as:

$$\frac{\partial\varphi}{\partial n}=-\left(\frac{\partial\varphi_i}{\partial n}+\frac{\partial\varphi_r}{\partial n}\right) \quad \text{on } S_1 \qquad (7)$$

$$\frac{\partial\varphi}{\partial n}=\frac{\partial\varphi}{\partial y}=0 \quad \text{on } S_2 \qquad (8)$$

Where $\varphi_i$ and $\varphi_r$ are incident and reflect wave function, respectively.

Applying boundary integral equation and separating into offshore breakwater boundary and seawall boundary, the seawall boundary ( $S_2$ ) is line segment so equation (5) can be written as:

$$\varphi(x,y)=-\frac{1}{2}\int_{S_1}\left\{\varphi(Q)\frac{\partial G}{\partial n}(Q,P)-G(Q,P)\left(\frac{\partial\varphi_i}{\partial n}+\frac{\partial\varphi_r}{\partial n}\right)\right\}dS-\frac{1}{2}\int_{x_1}^{x_2}\left\{\varphi(Q)\frac{\partial G}{\partial n}(Q,P)\right\}dx \qquad (9)$$

By approaching the point of the fluid region $(x,y)$ to the boundary point $(x',y')$ , equation (9) can be expressed following form

$$\varphi(x',y')=-\int_{S_1}\left\{\varphi(Q)\frac{\partial G}{\partial n}(Q,P)-G(Q,P)\left(\frac{\partial\varphi_i}{\partial n}+\frac{\partial\varphi_r}{\partial n}\right)\right\}dS-\int_{x_1}^{x_2}\left\{\varphi(Q)\frac{\partial G}{\partial y}(Q,P)\right\}dx \qquad (10)$$

## NUMERICAL PORCEDURES

A computer program has been developed to implement the above theory for long wave diffraction due to offshore breakwater. The boundaries $S_1$ and $S_2$ were divided by infinitesimal elements of M and N.

Discretizing equation (8) and (9), it can be written as

$$\varphi(x,y)=-\frac{1}{2}\sum_{j=1}^{M}\left[\varphi(Q)\cdot\overline{A}_{ij}+A_{ij}(\overline{\varphi}_i+\overline{\varphi}_r)\right]-\frac{1}{2}\sum_{j=M+1}^{M+N}\left[\varphi(Q)\cdot\overline{B}_{ij}\right]$$

$i$=1,2,…$M$…$M$+$N$ (11)

$$\varphi(x',y')=-\sum_{j=1}^{M}\left[\varphi(Q)\cdot\overline{A}_{ij}+A_{ij}(\overline{\varphi}_i+\overline{\varphi}_r)\right]-\sum_{j=M+1}^{M+N}\left[\varphi(Q)\cdot\overline{B}_{ij}\right]$$

$i$=1,2,…$M$…$M$+$N$ (12)

Where, $\overline{\varphi}_i=\frac{\partial\varphi_i}{k\partial n}$ , $\overline{\varphi}_r=\frac{\partial\varphi_r}{k\partial n}$ (13)

$$\bar{A}_{ij} = \int_{\Delta S_j} \frac{\partial}{\partial n}\left(-\frac{1}{\pi}G(Q,P)\right)ds = \frac{1}{\pi}G(Q,P)\cdot\left(\frac{x'_j - x'_i}{R}k\Delta y'_j - \frac{y'_j - y'_i}{R}k\Delta x'_j\right)$$

$(i \neq j)$ (14)

$$= \frac{1}{2\pi}\left(x'\Delta S - y'\Delta S\right)\Delta S_i \qquad i = 1,2,\ldots M \ (i = j)$$

$$A_{ij} = \int_{\Delta S_j}\left(-\frac{1}{\pi}G(Q,P)\right)kds = -\frac{1}{\pi}G(Q,P)k\Delta S_j \quad (i \neq j) \qquad (15)$$

$$= \frac{1}{\pi}\left(0.5772 - 1 + \log\frac{k\Delta S_i}{4} - i\frac{\pi}{2}\right)k\Delta S_i \quad (i = j)$$

$$\bar{B}_{ij} = \int_{\Delta S_j} \frac{\partial}{\partial y}\left(-\frac{1}{\pi}G(Q,P)\right)dx = \frac{1}{\pi}G(Q,P)\cdot\left(\frac{x'_j - x'_i}{R}k\Delta y'_j - \frac{y'_j - y'_i}{R}k\Delta x'_j\right)$$

$(i \neq j)$ (16)

$$= \frac{1}{2\pi}\left(x'\Delta S - y'\Delta S\right)\Delta S_i \qquad i = M+1 \ldots M+N \quad (i = j)$$

$$\bar{\varphi}_i = \frac{\Delta x_j'\sin\theta - \Delta y_j'}{\Delta S_j}\cdot e^{-ik(x'_j\cos\theta + y'_j\sin\theta)} \qquad (17)$$

$$\bar{\varphi}_r = \frac{-\Delta x_j'\sin\theta - \Delta y_j'}{\Delta S_j}\cdot e^{-ik(x'_j\cos\theta - y'_j\sin\theta)} \qquad (18)$$

On the boundary $Q = (x', y')$ and the fluid region $P = (x, y)$, equation (11) and equation (12) can be written as

$$\varphi(x',y') + \sum_{j=1}^{M}\left[\varphi(Q)\cdot\bar{A}_{ij}\right] + \sum_{j=M+1}^{M+N}\left[\varphi(Q)\cdot\bar{B}_{ij}\right] = -\sum_{j=1}^{M}A_{ij}\left[\begin{array}{c}\dfrac{\Delta x_j'\sin\theta - \Delta y_j'}{\Delta S_j}\cdot e^{-ik(x'_j\cos\theta + y'_j\sin\theta)} \\ -\dfrac{\Delta x_j'\sin\theta + \Delta y_j'}{\Delta S_j}\cdot e^{-ik(x'_j\cos\theta - y'_j\sin\theta)}\end{array}\right]$$

(19)

$$\varphi(x,y) = -\frac{1}{2}\sum_{j=1}^{M}\left[\varphi(Q)\cdot\bar{A}_{ij}\right] + A_{ij}\left[\begin{array}{c}\dfrac{\Delta x_j'\sin\theta - \Delta y_j'}{\Delta S_j}\cdot e^{-ik(x'_j\cos\theta + y'_j\sin\theta)} \\ -\dfrac{\Delta x_j'\sin\theta + \Delta y_j'}{\Delta S_j}\cdot e^{-ik(x'_j\cos\theta - y'_j\sin\theta)}\end{array}\right] - \frac{1}{2}\sum_{j=M+1}^{M+N}\left[\varphi(Q)\cdot\bar{B}_{ij}\right]$$

(20)

The diffraction coefficient at the point of the fluid region $(x, y)$ can yield,

$$K_d = \left|\varphi_i(x,y) + \varphi(x,y)\right| \qquad (21)$$

## NUMERICAL RESULTS AND ANALYSIS

The diffraction by offshore breakwater and seawall has been made by numerical work using equation (11) to (21), and we have illustrated the diffraction diagrams with different incident wave periods for the two cases of distances between offshore breakwater and seawall. In this study, the condition of calculations are water depth at the vicinity of breakwater $h = 10m$, distance between offshore breakwater and seawall ($D/L$ =1.0 and 1.5), incident wave angle $\theta = 90^\circ$, and incident wave period $t$ = 5.0, 10.0, 15.0, 20.0 and 25.0 $k$ for the regular wave, respectively. Figures 2 and 3 present the results for the diffraction coefficient obtained by the present numerical model with various incident wave periods and different distances between two structures.

In Figure 2a D/L = 2.0, and it shows the comparison of wave height at the center line. In the case of the short wave the amplification rate of diffraction wave height between offshore structures and seawall is much smaller than the incident wave. This means that in the case of the short wave, the incident wave has been greatly interfered by the offshore breakwater. In the case of long waves the incident wave height and the diffracted wave height show similar distribution. In Figure 2b D/L = 1.5, and it shows the comparison of wave height at the end lines of the breakwater.

In Figure 3a D/L=1.5, and it shows the comparison of wave height at the center line. In the case of the short wave (5.0 $k$) the amplification rate of diffraction wave height between offshore structures and seawall is smaller than the incident wave. But in the case of the long wave, the amplification rate is higher than the incident wave, and at the rare side of the breakwater the wave mode numbers become smaller than the short wave and it has a surge form. It can be inferred that the long wave influences the amplification rate between the offshore structures.

In Figure 3b) D/L = 1.5, and it shows the comparison of wave height at the end lines of the breakwater. When the incident wave comes in at 90° it is symmetric, therefore only one side of either left or right side needs to be studied. As the wave becomes longer, the amplification rate is higher than the incident wave.

In Figure 4 D/L = 1.0, and it shows the comparison of wave height at the center line and the edge line. In the case of the short wave (5.0 $k$) the amplification rate of diffraction wave height between offshore structures and seawall is similar to the incident wave. This is due to the shortening distance between the breakwater and the seawall which results in high reflected waves. But in the case of the long wave, the amplification rate is higher than the incident wave.

The incident wave amplitude at D/L = 1.5 was greater than at D/L = 1.0. The diffracted wave amplitude showed to be similar at D/L = 1.5 and D/L = 1.0 but in comparison to the incident wave amplitude, the diffracted wave

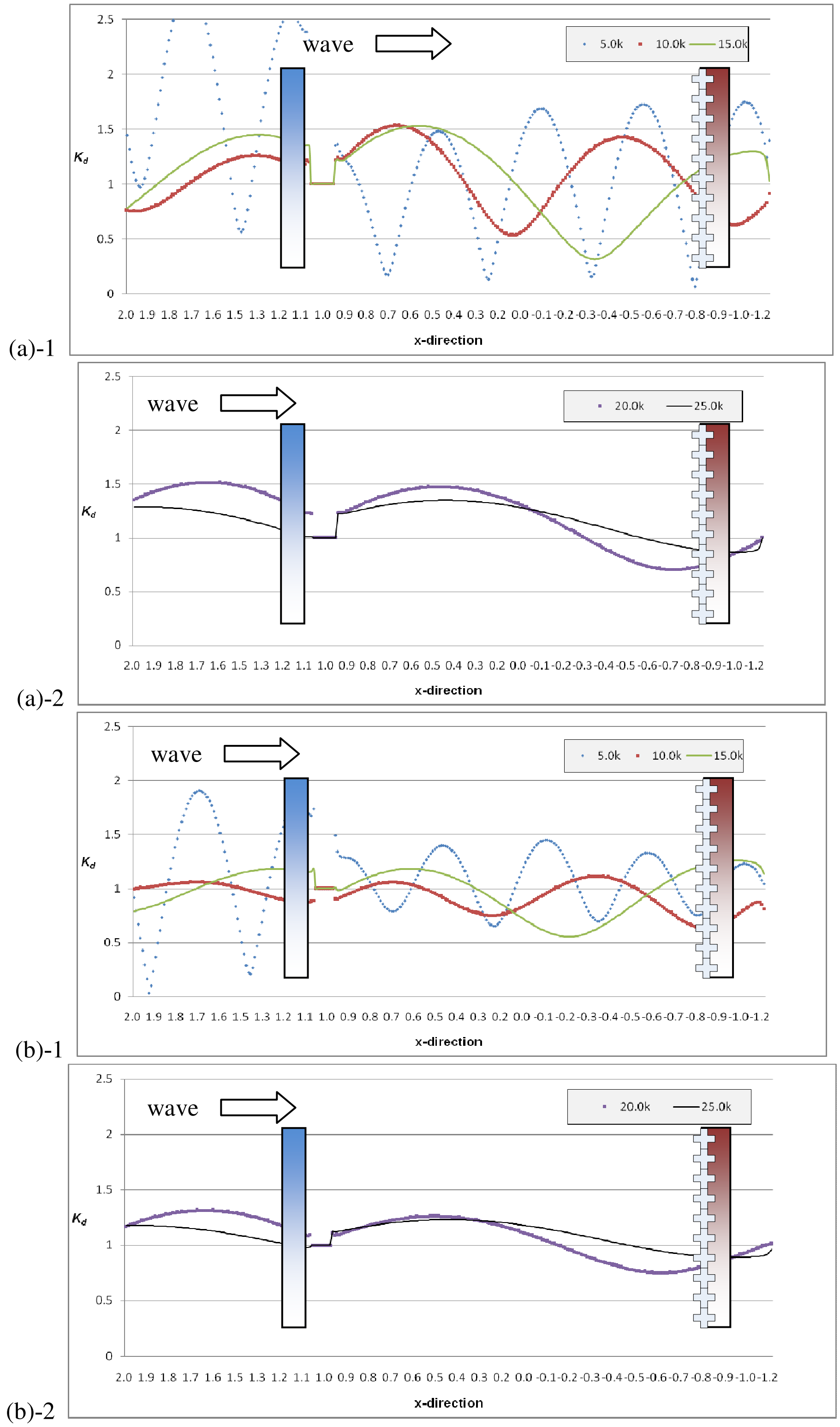
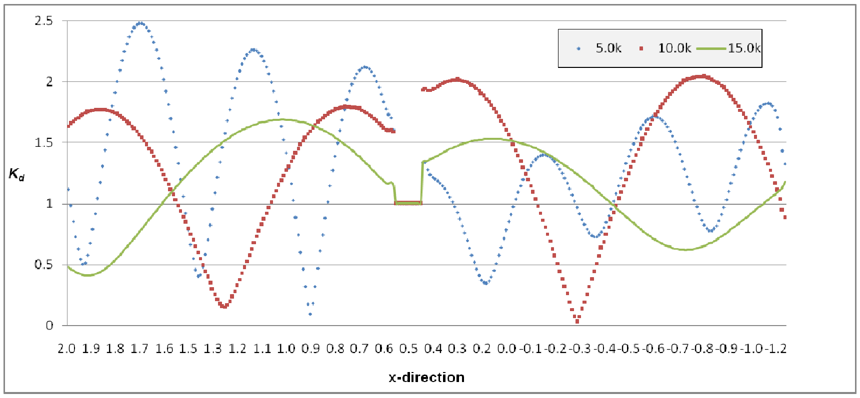
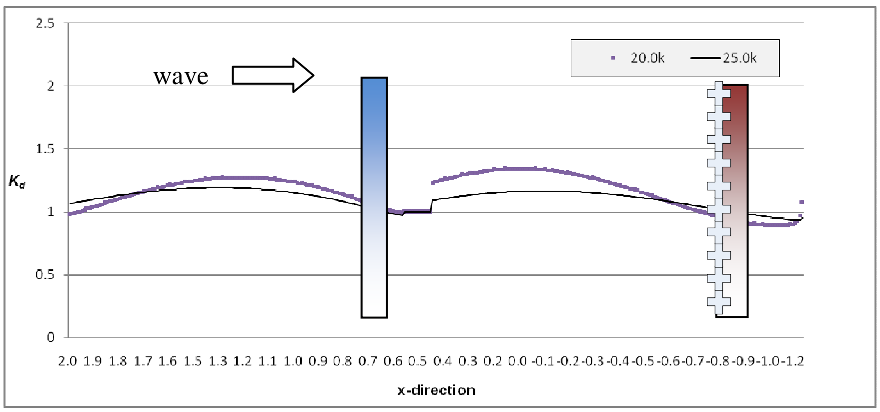
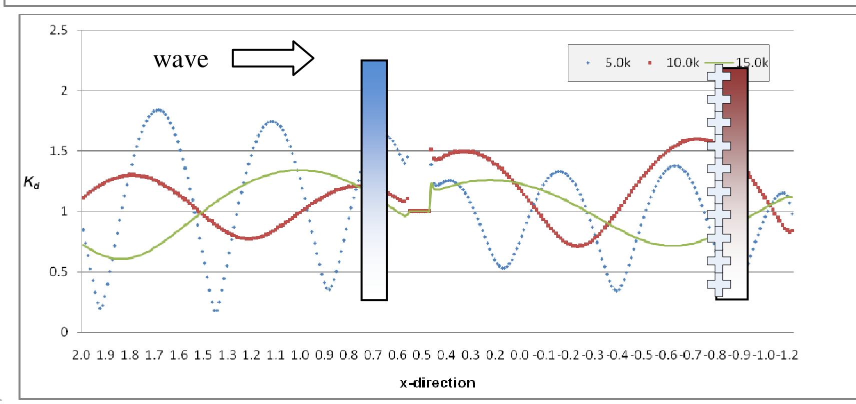



**Figure 2.** The wave diffraction coefficient due to offshore breakwater and the seawall (a) at the center line of the offshore breakwater and the seawall, (b) at the left or right line of the edge of offshore breakwater for D/L = 2.0.

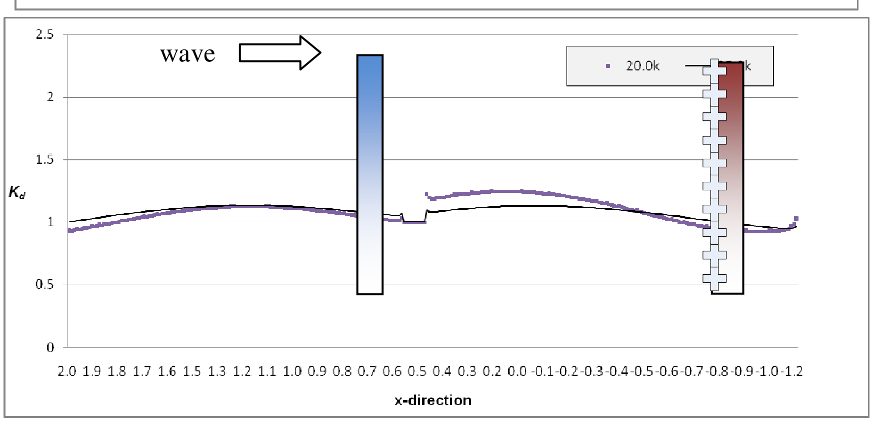



(a)-2

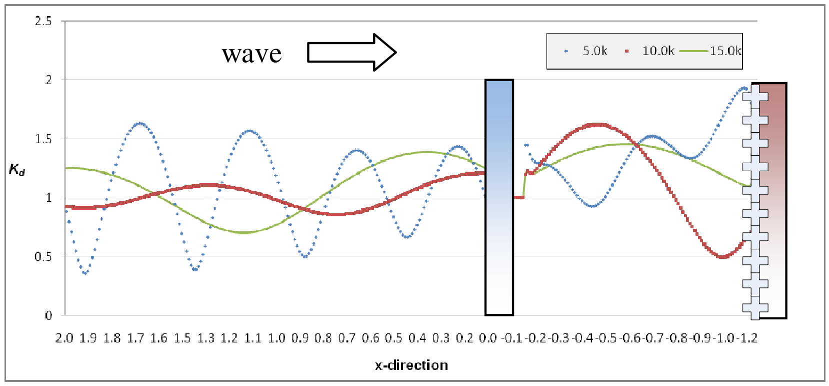



(b)-1

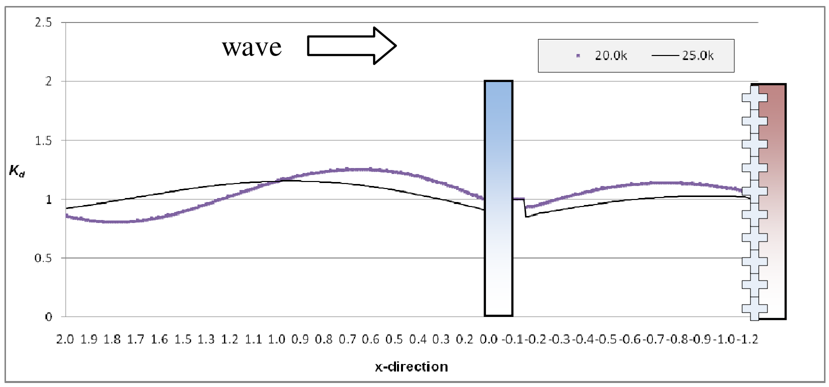



(b)-2

**Figure 3.** The wave diffraction coefficient due to offshore breakwater and seawall (a) at the center line of offshore breakwater and seawall, (b) at the left or right line of the edge of the offshore breakwater for D/L = 1.5.




(a)-1

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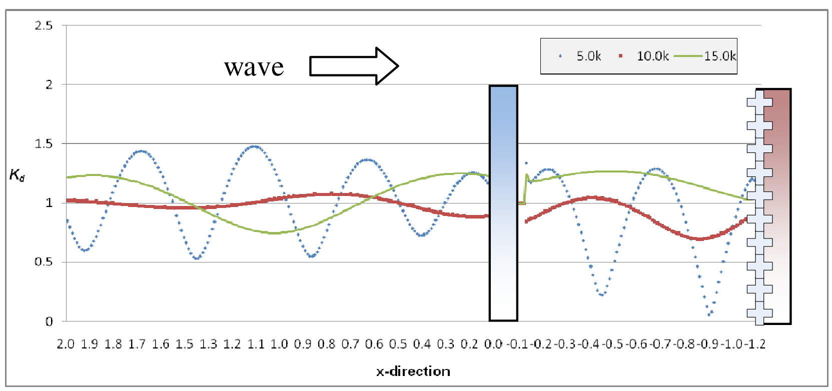
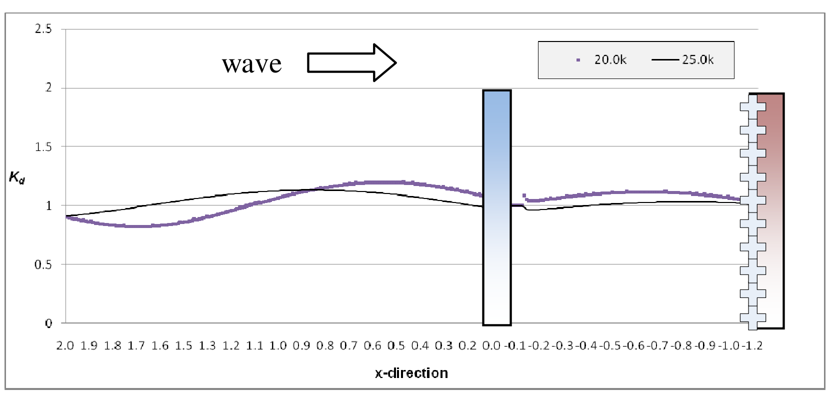



(b)-1




(b)-2

**Figure 4.** The wave diffraction coefficient due to offshore breakwater and the seawall (a) at the center line of the offshore breakwater and the seawall, (b) at the left or right line of the edge of offshore breakwater for D/L = 1.0.

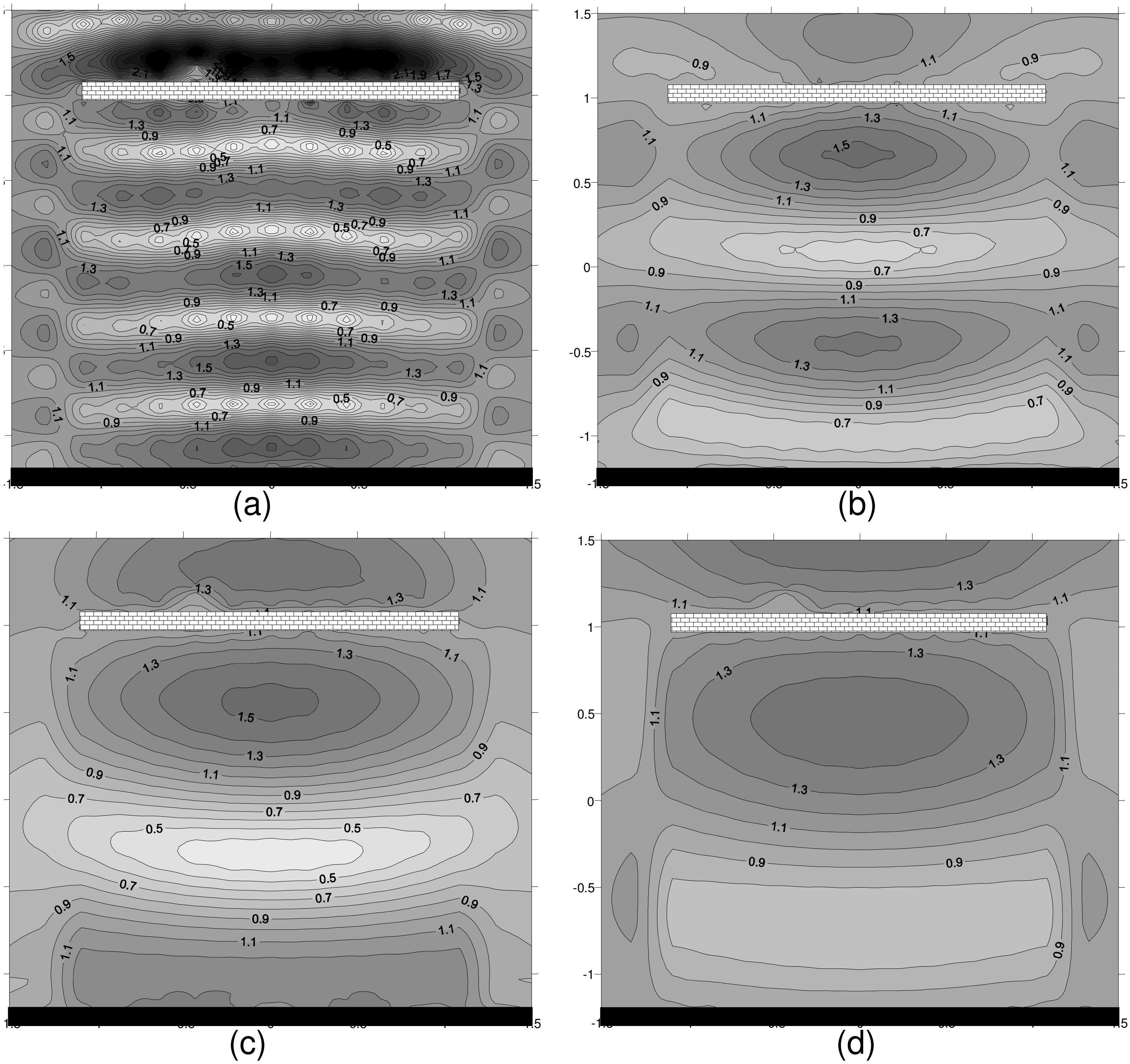



**Figure 5.** The wave diffraction contour plots due to offshore breakwater and the seawall (a) 5.0 *k*, (b) 10.0 *k*, (c) 15.0 *k*, and (d) 20.0 *k* for D/L = 2.0.

amplitude was higher at D/L = 1.0. This is because as the distance between the seawall and the breakwater shortens, the wave mode number decreases.

Figures 5 shows a two-dimentional diffraction diagram regarding D/L = 2.0. In the case of short waves, the number of wave modes increases and the wave amplitude is high.

Figures 6 shows a two-dimentional diffraction diagram regarding D/L = 1.5. As the incident wave period becomes longer, the wave height distribution is in surge form with a longer wave length. This implies that wave energy is high in a long wave. In the case of wave crests short wave periods have a double mode wave crest and long wave periods have a single mode wave crest.

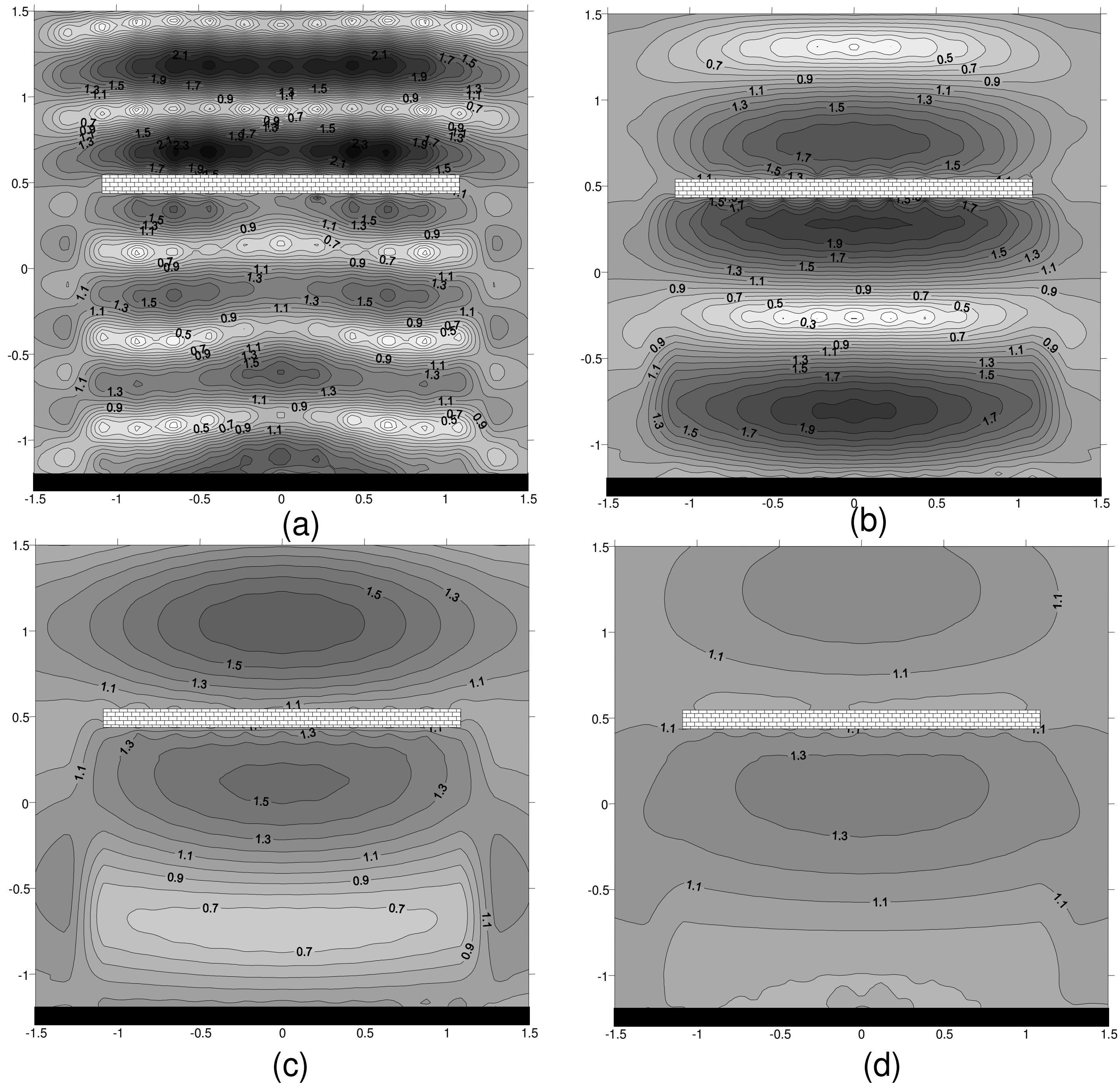



**Figure 6.** The wave diffraction contour plots due to offshore breakwater and the seawall (a) 5.0 *k*, (b) 10.0 *k* (c) 15.0 *k*, and (d) 20.0 *k* for D/L = 1.5.

Figures 7 shows a two-dimensional diffraction diagram and three-dimensional diffraction diagram respectively, regarding D/L = 1.0. As the incident wave period becomes shorter, the wave mode number decreases. This implies that through a change in the distance ratio between the breakwater and the seawall the amplification rate at the fluid region between the offshore structures will show up differently, and therefore that distance ratio is also a factor of influence.

## Conclusion

This research has been conducted to study the wave

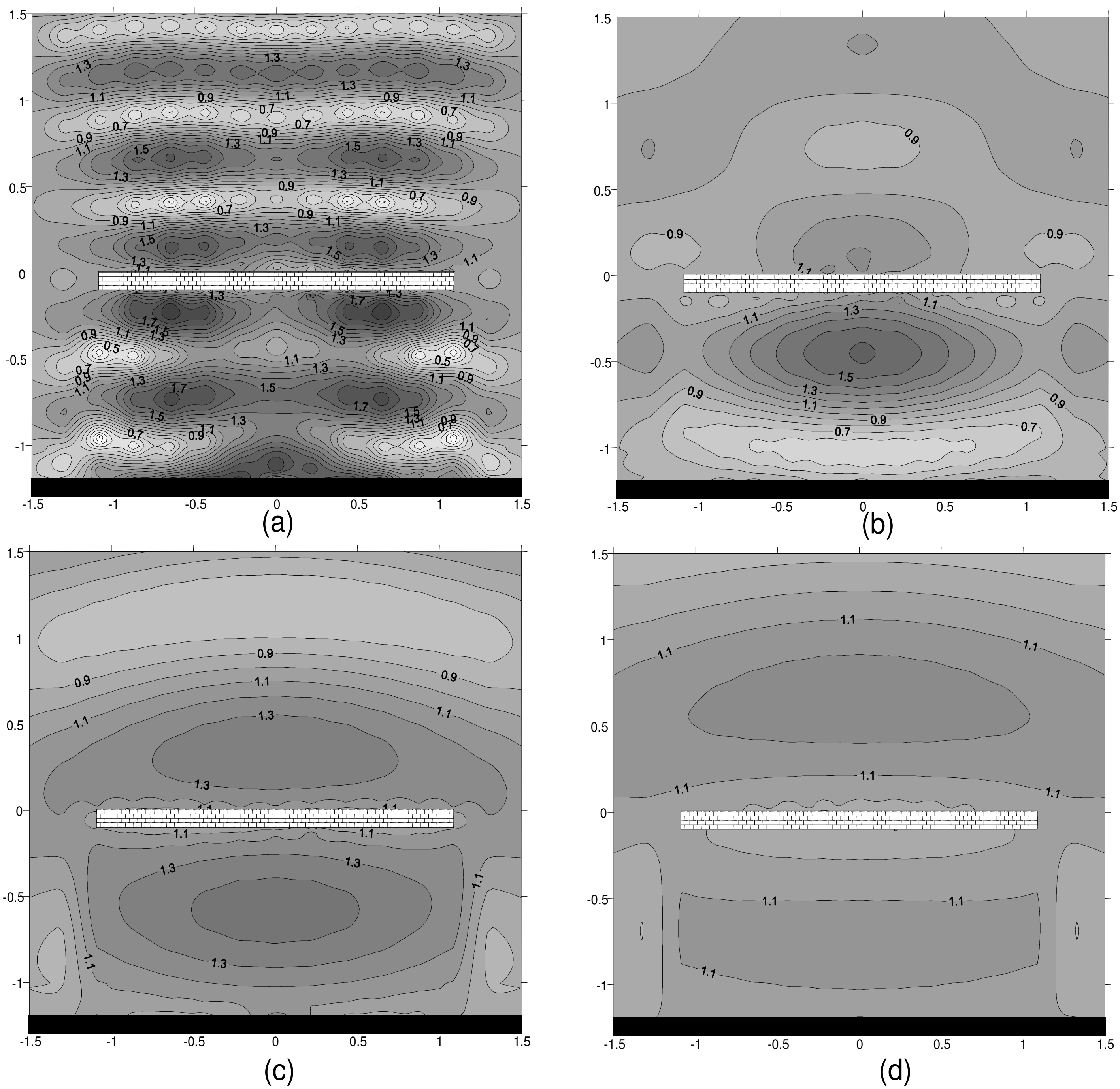


**Figure 7.** The wave diffraction contour plots due to offshore breakwater and the seawall (a) 5.0 *k* (b) 10.0 *k* (c) 15.0 *k* and (d) 20.0 *k* for D/L = 1.0.

height amplification rate by using the oscillation characteristics that have been occurred by reflected waves between the seawall and the offshore structure. Numerical calculations were performed based on various long wave periods and the distance between the offshore structure and the seawall, when the offshore structure and seawall is designated as a straight type.

A numerical model has been developed to analyze the long wave diffraction coefficients by offshore breakwater and the seawall, using the Green function based on the boundary integral equation.

In the case of the short wave the amplification rate of diffraction wave height between offshore structures and seawall is smaller than the incident wave. But in the case of the long wave, the amplification rate is higher than the incident wave, and the wave elevation becomes a surge form. This implies that the different wave period is a factor of influence on the wave field.

As the distance ratio between the offshore structure and the seawall is shorter the wave mode number decreases, and this means that the distance ratio is also a factor of influence on the wave field. In the case of wave crests short wave periods have a double mode wave crest and long wave periods have a single mode wave crest. As the distance ratio between the offshore structure and the seawall is shorter the wave mode number decreases, and this means that the distance ratio is also a factor of influence on the wave field. As a result, this study hopes to provide useful information in the construction of ocean structures and remodeling of coastal area that are recently on the rise such as new harbors, fishery ports and offshore structures.

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