Studies on fixed rectangular surface barrier against short waves

CHING-HER HWANG* FREDERICK, L.W. TANG**

1. INTRODUCTION

In short waves, the particle motion in deeper region are to be negligible. For rigid vertical breakwaters built in considerable deep water, the lower part of vertical wall does not play the vital role of wave defending. It can be replaced by a frame to support the surface barrier which bears the wave force, and remain vacancy of the lower part of breakwater. Hence the theoretical and experimental characteristics of wave transmission and spectra alternation are investigated respectively here for this kind of the fixed, rigid, rectangular surface barrier in order to obtain an economic section and verify its capable relative depth as the design basis of deep port breakwater.

2. THEORITICAL CONSIDERATIONS

The theoritical considerations in this study are on the basis of the concept of the surface horizontal plate velocity potential theory derived by Dr. IJIMA and extended to this kind of rigid, rectangular surface barrier. Its coordinate scheme is shown as figure 1.

The flow in the fluid region about the breakwater is assumed to be irrotational, the fluid is incompressible and wave of small amplitude. These assumptions imply the existence of a velocity potential $\Phi\ (x,z;t)$

$$\Phi\ (x,z;t) = \phi\ (x,z)\ \exp\ (i\sigma t)\ \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

* Associate Researcher, Institute of Harbor and Marine Technology, Wuchi, Taichung District, Taiwan, R.O.C.

**Ph.D., Professor of Hydraulic and Ocean Engineering Graduate School, National Cheng Kung University, Tainan, Taiwan, R.O.C.

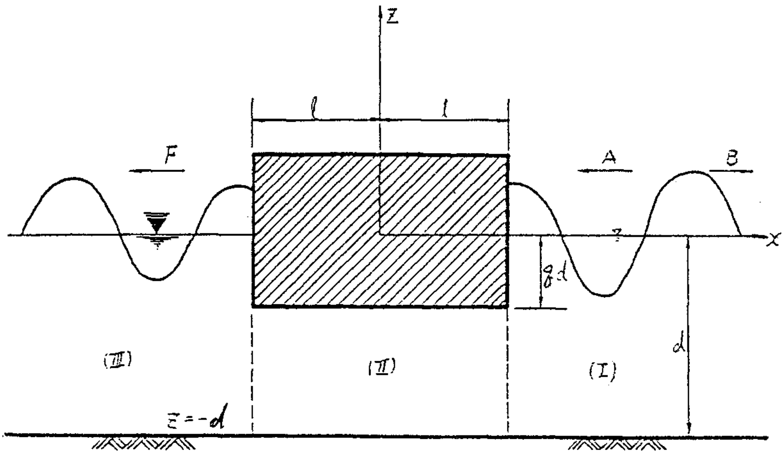

Fig.1 Coordinate system and notation

Table-1 Experimental conditions

	SINUSOIDAL		RANDOM	
RUN	T	H	$T_{1/3}$	$H_{1/3}$
R 1.	0.87	6.00	0.89	5.50
R 2.	1.03	6.24	1.02	5.58
R 3.	1.02	12.40	1.06	9.12
R 4.	1.24	6.19	1.23	6.09
R 5.	1.24	12.36	1.23	12.29
R 6.	1.47	6.38	1.48	6.26
R 7.	1.48	12.81	1.44	12.84
R 8.	1.93	6.63	1.85	5.95
R 9.	1.93	11.75	1.97	11.68

which satisfies the Laplace equation for a scale function $\phi(x,z)$

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

In this equation, x is the horizontal coordinate axies, measured positive to the right, z is the vertical coordinate axies,measured positive up from the still water level, and t is the time variable.

A solution is sought for $\phi(x,z)$ which satisfies the fluid equations of motions and the boundary conditions for the fluid and the fixed solid surface breakwater as following
the surface boundary condition

$$\frac{\partial\phi}{\partial z}=\frac{\sigma^2\phi}{g} \quad ; \quad z=0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

the rigid body boundary condition at bottom z=-d , -qd

$$\frac{\partial\phi}{\partial z}=0 \quad ; \quad z=-d\ ,\ -qd \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

In addition to the above boundary conditions, the velocity potential at arbitrary assigned fictitious vertical boundaries on either side of the breakwater must satisfy the radiation conditions, which states that the velocity potential at the boundaries must match the velocity potential for the incident and outgoing waves. Then region I, II and III, the velocity potential are expressed as, respectively

$$\phi_{I}(x,z)=\left[Ae^{ik(x-\ell)}+Be^{-ik(x-\ell)}\right]\frac{\cosh k(z+d)}{\cosh kd}+\sum_{n=1}^{\infty}C_n e^{-k_n(x-\ell)}\frac{\cos k_n(z+d)}{\cos k_n d} \quad \ldots\ldots\ldots\ldots(5)$$

$$\phi_{II}(x,z)=\sum_{r=0}^{\infty}\left(D_r\frac{\cosh\frac{r\pi x}{d-qd}}{\cosh\frac{r\pi\ell}{d-qd}}+E_r\frac{\sinh\frac{r\pi x}{d-qd}}{\cosh\frac{r\pi\ell}{d-qd}}\right)\cos\frac{r\pi(z+qd)}{d-qd} \quad \ldots(6)$$

$$\phi_{III}(x,z)=Fe^{ik(x+\ell)}\frac{\cosh k(z+d)}{\cosh kd}+\sum_{n=1}^{\infty}G_n e^{k_n(x+\ell)}\frac{\cos k_n(z+d)}{\cos k_n d} \quad \ldots\ldots\ldots\ldots(7)$$

The coefficients A,B and F are incident, reflective and transmitted wave height respectively. Cn Gn Dr and Er are the undetermined coefficients. The symbols k and k_n represent the wave number in which.

$$\frac{\sigma d^2}{g} = kd \tanh kd = -k_n d \tan k_n d \qquad (n= 1,2,3....)..(8)$$

Then the continuity of mass and energy flux, or similarly the continuation of the velocity and pressure at the fluid-breakwater media interface was considered.

at $x = \ell$

$$\phi_I = \phi_{II}$$

$$\frac{\partial \phi_I}{\partial x} = \frac{\partial \phi_{II}}{\partial x} \quad ; \quad -qd > z > -d \quad ....(9)$$

$$= 0 \quad ; \quad 0 > z > -qd$$

at $x = -\ell$

$$\phi_{II} = \phi_{III}$$

$$\frac{\partial \phi_{II}}{\partial x} = \frac{\partial \phi_{III}}{\partial x} \quad ; \quad -qd > z > -d \quad ....(10)$$

$$= 0 \quad ; \quad 0 > z > -qd$$

we obtain

$$B = \frac{i}{2} \sum_{r=0}^{\infty} \left[I_{or}\, Er + Dr\, I_{or} \tanh \frac{r\pi k\ell}{\bar{\lambda}_o} \right] + A \quad ....(11)$$

$$F = -\frac{i}{2} \sum_{r=0}^{\infty} \left[I_{or}\, Er - Dr\, I_{or} \tanh \frac{r\pi k\ell}{\bar{\lambda}_o} \right] \quad ....(12)$$

$$Cn = -\frac{i}{2} \sum_{r=0}^{\infty} \left[Dr\, I_{nr} \tanh \frac{r\pi k\ell}{\bar{\lambda}_o} + Er\, I_{nr} \right] \quad ....(13)$$

$$Gn = -\frac{i}{2} \sum_{r=0}^{\infty} \left[Dr\, I_{nr} \tanh \frac{r\pi k\ell}{\bar{\lambda}_o} - Er\, I_{nr} \right] \quad ....(14)$$

$$\left.\begin{aligned} Do &= \frac{1}{2} \left[\sum_{n=1}^{\infty} (Cn + Gn) R_{nr} + (A+B+F) R_{or} \right] \\ Dr &= \sum_{n=1}^{\infty} (Cn + Gn) R_{nr} + (A+B+F) R_{or} \end{aligned}\right\} \quad ....(15)$$

$$Er \tanh \frac{r\pi k\ell}{\bar{\lambda}_o} = (A+B-F) R_{or} + \sum_{n=1}^{\infty} (Cn-Gn) R_{nr} \quad ....(16)$$

Where

$$R_{nr} = \frac{\sin \bar{\lambda}_n}{\cos \lambda_n} \cdot \frac{1}{\bar{\lambda}_n \left[1-\left(\frac{r\pi}{\bar{\lambda}_n}\right)^2\right]}, \quad \lambda_n = k_n d, \quad \bar{\lambda}_n = k_n(d-qd)$$

$$R_{or} = \frac{\sinh \bar{\lambda}_o}{\cosh \lambda_o} \cdot \frac{1}{\bar{\lambda}_o \left[1+\left(\frac{r\pi}{\bar{\lambda}_o}\right)^2\right]}, \quad \lambda_o = kd, \quad \bar{\lambda}_o = k(d-qd)$$

$$I_{or} = \frac{2\sin\bar{\lambda}_n\cos\lambda_n}{N_n\lambda_n}\cdot\frac{r\pi/\bar{\lambda}_n}{[1-(r\pi/\bar{\lambda}_n)^2]},\quad N_n = \frac{1}{2}\left(1+\frac{\sin 2K_n d}{2K_n d}\right)$$

$$I_{or} = \frac{2\sinh\bar{\lambda}_o\cosh\lambda_o}{N_o\lambda_o}\cdot\frac{r\pi/\bar{\lambda}_o}{[1+(\frac{r\pi}{\bar{\lambda}_o})^2]},\quad N_o = \frac{1}{2}\left(1+\frac{\sinh 2kd}{2kd}\right)\ \ldots(17)$$

After substituting eq (11) ~ eq (14) into eq (15)~(16), we get

$$D_r + \sum_{n=1}^{\infty}\left[\sum_{r=0}^{\infty}\left(D_r I_{nr}\tanh\frac{r\pi k\ell}{\bar{\lambda}_o}\right)\right]R_{nr} - i\left[\sum_{r=0}^{\infty}\left(D_r I_{or}\tanh\frac{r\pi k\ell}{\bar{\lambda}_o}\right)\right]R_{or} = 2R_{or}\ \ldots\ldots(18)$$

$$\left(\tanh\frac{r\pi k\ell}{\bar{\lambda}_o}\right)E_r + \sum_{n=1}^{\infty}\left[\sum_{r=0}^{\infty}\left(E_r I_{nr}\right)\right]R_{nr} - i\left[\sum_{r=0}^{\infty}\left(I_{or}E_r\right)\right]R_{or} = 2R_{or}\ \ldots\ldots(19)$$

Then, the water level variations at Region I, the up-lift dynamic pressure distribution of barrier bottom at Region II and the transmitted coefficient at Region III are found respectively

- Water level variations at Region I

$$\eta/A = -\frac{i\sigma}{g}\left\{e^{i[k(x-\ell)+\sigma t]} + (B/A)\,e^{-i[k(x-\ell)-\sigma t]} + \sum_{n=1}^{\infty}(C_n/A)e^{-[K_n(x-\ell)-i\sigma t]}\right\}\ \ldots\ldots(20)$$

- Up - lift dynamic pressure of barrier bottom at Region II

$$\frac{p}{gA} = -\frac{i\sigma}{g}\left\{\sum_{r=0}^{\infty}\left\{\left[(D_r/A)\frac{\cosh\frac{r\pi x}{d-gd}}{\cosh\frac{r\pi\ell}{d-gd}} + (E_r/A)\frac{\sinh\frac{r\pi x}{d-gd}}{\cosh\frac{r\pi\ell}{d-gd}}\right]\cos\frac{r\pi(z+gd)}{d-gd}\right\}\right\}e^{i\sigma t}\ \ldots\ldots(21)$$

- Transmitted coefficient of barrier at Region III

$$K_t = |F/A|\ \ldots\ldots(22)$$

3. EXPERIMENTAL TESTS

Experiments of wave spectra alternation characteristics of this fixed, rigid, rectangular barrier were investigated also in a

$100^m \times 2^m \times 1.5^m$ wind wave flume in Institute of Harbor and Marine Technology. Its arrangement was shown in Figure 2 .

Then, the different immerged depth q ratioes and relative width B/L of barrier were used to investigate its characteristics of the spectra altemation under different relative water depth d/L. Various kind of wave conditions were also carried out in this study as shown in Table 1.

4. RESULTS AND DISCUSSIONS

4-1 Analytical solutions of velocity potential theory

Analytical solution of velocity potential theory were shown in figure 3 to figure 7. Figures 3(a) (b) (c) represent respectively the curves of water level variations before the barrier at region I under relative immerged water depth q=0.3 and different relative width B/L = 0.004 , 0.08 and 0.2 etc. Results indicate the more larger relative water depth d/L and relative width B/L are, the more closed sine curves the water level profiles are. For short waves (ie d/L $\fallingdotseq$ 0.5), the minimum η/A ratio value is equal to 1.25 when both q and B/L are equal to 0.3 and 0.2 respectively, and this value is increasing with the relative water depth d/L.

Figure 4~6 show the analytical solutions of the up-lift dynamic pressure distribution at the bottom of barrier at Region II under different relative water depth and relative width. Results indicate that the dynamic pressure distribution has the relationship with B/L , d/L and q etc. respectively. In general, the larger the relative width is, the larger up-lift dynamic pressure difference between both side bottom of the surface barrier is. And its distribution at the bottom of the barrier more uniform if the q value is larger. Moreover, up-lift pressure decreased as the d/L decreased and tend to a horizontal distribution when the relative water depth is equal to 0.2-0.3. For example, as shown in figure 6, the dynamic pressure variations at both sides of the surface barrier bottom are obviously increased with the relative width, comparing with the Figure 4 and 5, under different relative immerged water depth q values. This means that its slope is more

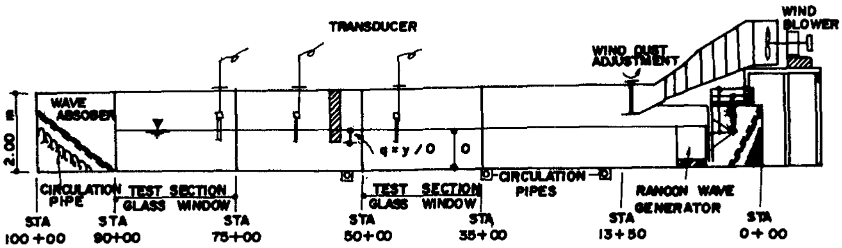

Fig.2 General arrangement

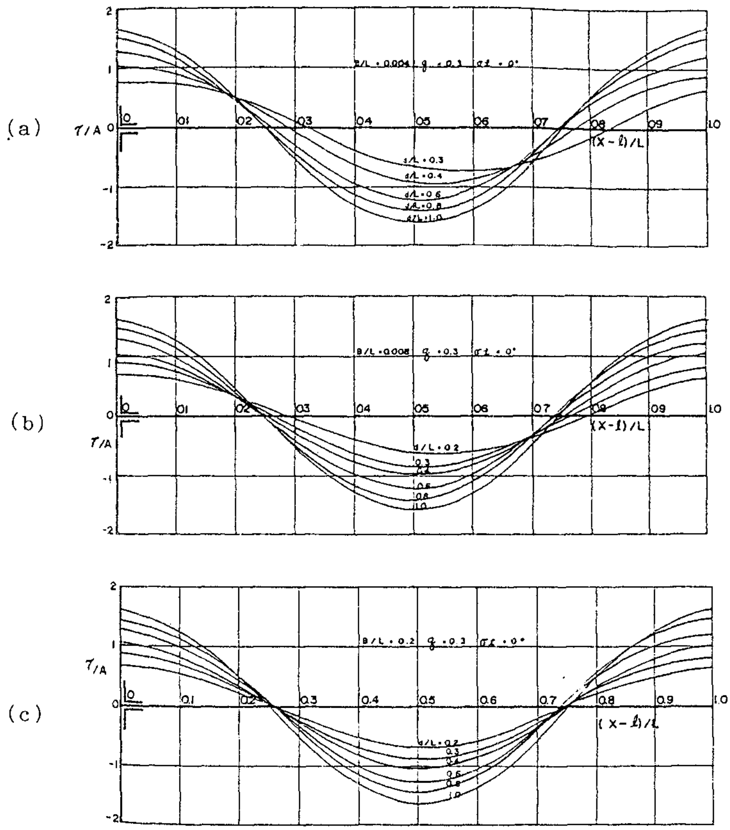

Fig.3 Curves of water level variations before the barrier

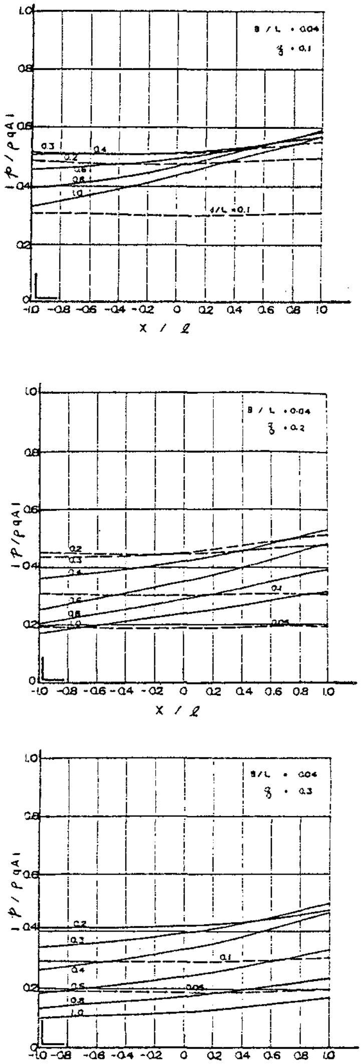

Fig.4 Up-lift dynamic pressure distribution at the bottom of barrier

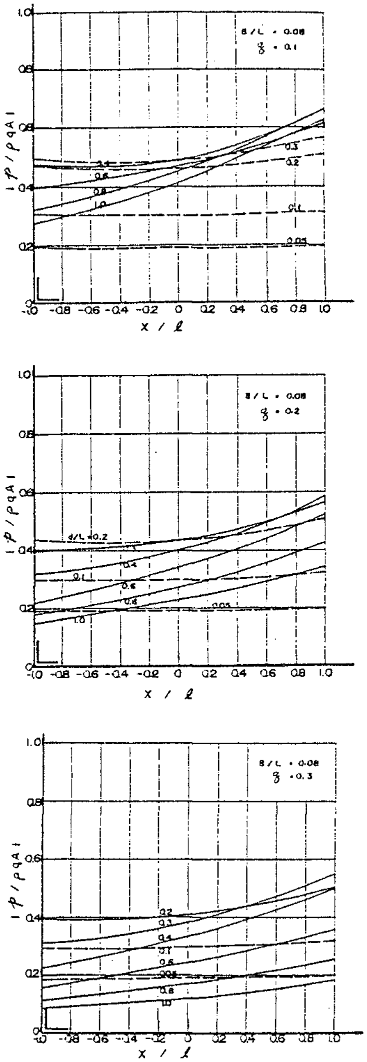

Fig.5 Up-lift dynamic pressure distribution at the bottom of barrier

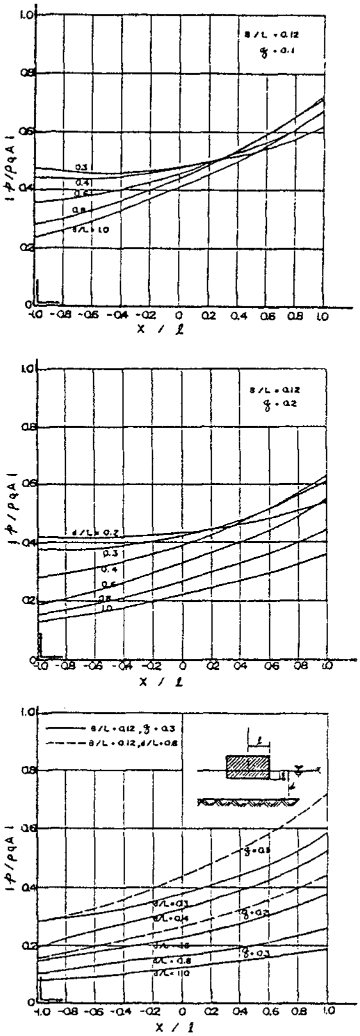

Fig.6 Up-lift dynamic pressure distribution at the bottom of barrier

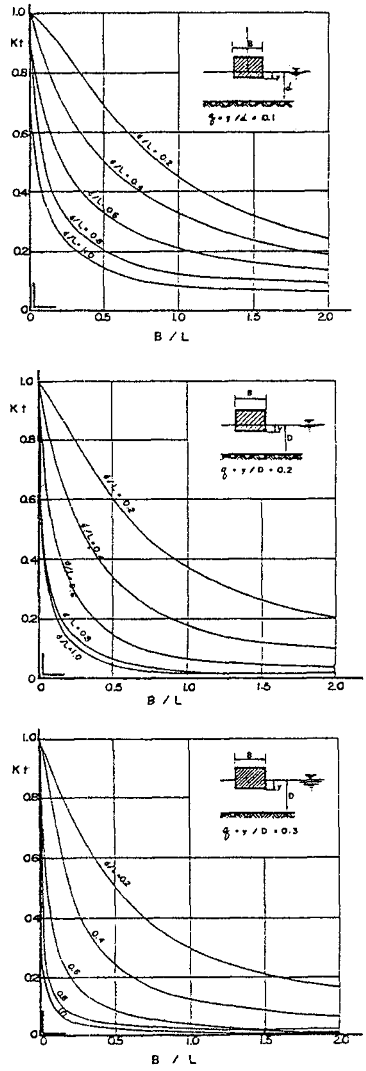

Fig.7 Relationship between K_t and B/L

steepen as the relative width of surface barrier increased.

Figure 7 are results of the analytical relationship between the transmitted coefficient K_t and relative width B/L under various relative water depth d/L at q=0.1,0.2 and 0.3 etc. respectively. Analytical results mean that we can expect to obtain an ideal wave stability behind the barrier when its relative width B/L is equal to 0.2~0.4 and the relative immerged depth q value is equal to 0.3 for the deep water waves i.e. short waves, assume the allowable transmitted coefficient criterion we adopted is equal to 0.2. Therefore, this dimension of barrier is an economic section in theoretical consideration for us to maintain an ideal wave stability at the basin , and can be used as the design section of deep water port breakwater.

4-2 EXPERIMENTAL RESULTS

In order to verify the capability of this type breakwater, laboratory experiments were also carried out under random waves in wind wave flume. Figure 8 and 9 are the results of energy spectrum curves of penestrated wave for various relative width and immerged water depth respectively. Figure 8 (a) ~ (d) are the experimental results for this breakwater under different immerged water depth q value and various relative water depth d/L. Experimental results show that the energy density peak value decreases above one order if q is equal and greater than 0.3, and relative water depth d/L is greater than 0.5 i.e. for short waves. Figure 9 (a) ~ (d) are the experimental results for this fixed rectangular surface barrier under different relative water depth d/L relative width B/L at immerged water depth q value is equal to 0.3. Results also indicate that the energy density peak value decreases above one order if relative width B/L is equal to 0.4 at q=0.3 for deep water waves. This means that we can expect again to obtain the same dimension of breakwater used as the section of the deep port breakwater from the experimental viewpoint.

5. CONCLUSIONS AND RECOMMENDATION

Summarize these results mentioned above, we can obtain some conclusions as following :

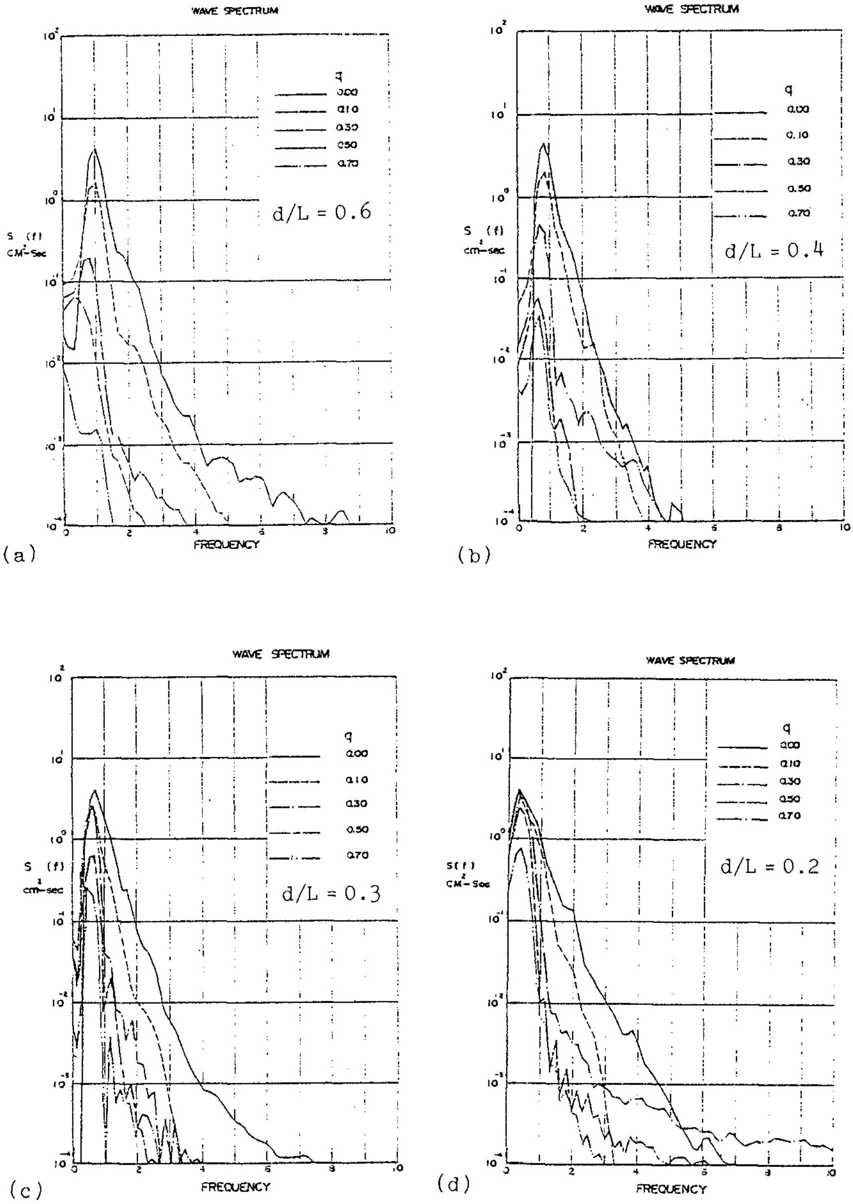

Fig.8 Energy spectrum curves of penetrated wave for various relative width (thin Breakwater)

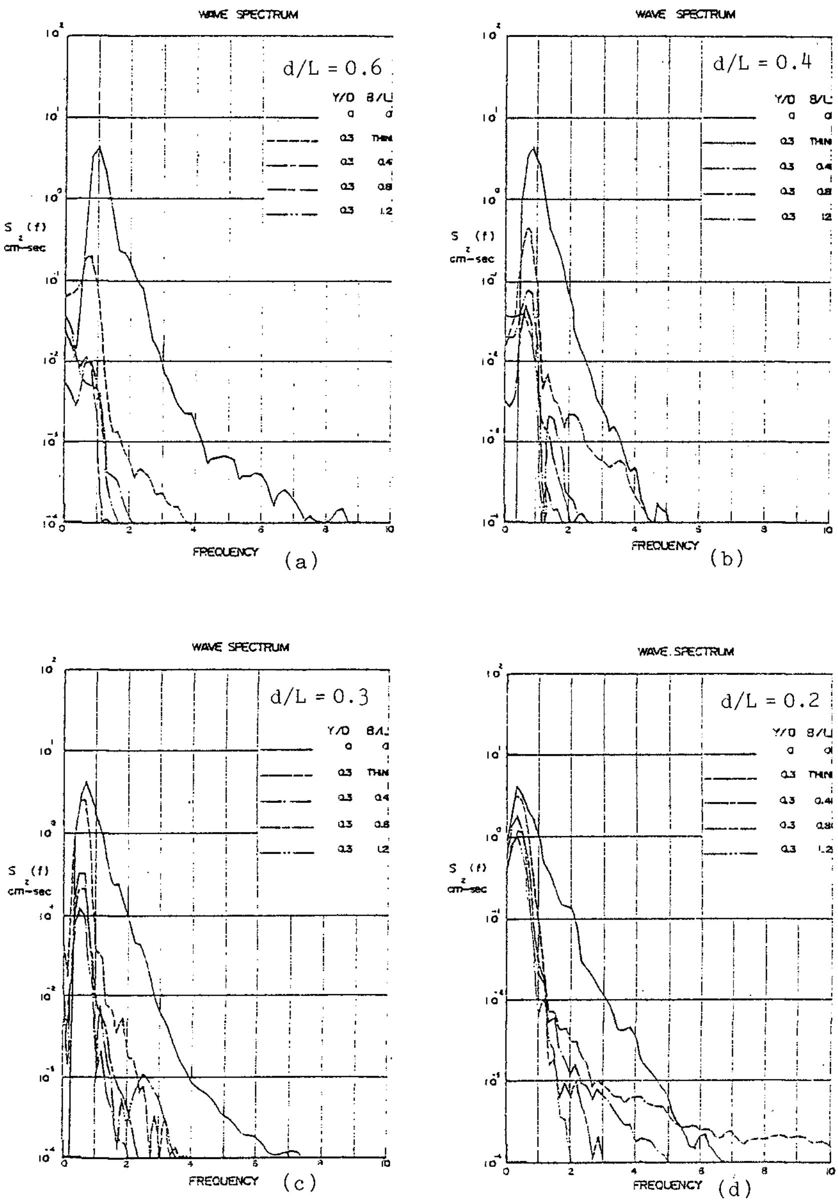

Fig.9 Energy spectrum curves of penetrated wave for various relative width (q = 0.3)

(1) Theoritical results indicate that the up-lift dynamic pressure distribution of barrier has the relationship with B/L, d/L and q etc. respectively. In general, the bigger the relative depth is, the larger the up-lift dynamic pressure difference between both side bottom of the surface barrier is. And its distribution at the bottom of the barrier is more uniform if the q values is larger. Moreover, up-lift pressure decreased as the d/L decreased and tend to a horizontal distribution when the relative depth is equal to 0.2$\sim$0.3.

(2) K_t will decrease as q and d/L decreased for the same B/L value. It verifies that this barrier can defend effectively the short waves when q is equal to 0.3 and B/L is equal to 0.2 $\sim$ 0.4, and its K_t is less than 0.2.

(3) Energy spectrem curves of penestrated wave for various B/L and q of the surface barrier verify that the peak magnitude of energy spectrum would decrease predominantly above one order and filter many short wave components when the q and B/L of the surface barrier is equal to 0.3 and 0.4 respectively.

(4) This type of breakwater and its economic section mentioned above could be used as the design criterion of the outer breakwater of Yeh-Liu deep port, at the North of TAIWAN, in future if we can solve the engineering problem: "How to fix this kind of surface barrier in deep water region ? ".

6. ACKNOWLEDGEMENTS

The laboratory work in this study was carried out through the sincere cooperation of many people, and authers would like to thank all of them. In particular, I would like to express my appreciation to Mr. C.K. Chang, Deputy Director of IHMT, who affords all possible helps. Authers would also like to thank Miss Joanna Chang to type this manuscript.

7. REFERECES

Ippen , T., (1966). Estuary and coastaline Hydrodynamics, New York Mc Graw-Hill, Inc.

URSELL, F.,(1947). The effect of a vertical barrier on surface waves in deep water, proc. Camb phil Soc, Vol 43.

DEAN, W.R.(1945). On the reflection of surface waves by a sub-merged plane barrier, Proc. camb. phil., Soc., Vol. 41.

WIGEL, R.L.,(1960). Transmission of waves past a rigid vertical thin barrier., J. Waterway and Harbor Division, Proc. of ASCE, 86,

KUO, C.T. etl. (1973). The effect of a barrier on surface waves in shallow water., J. of NSC, Taiwan, No. 6, pp. 415 - 430.

IJIMA T.,(1970). Wave effected on horizontal and vertical wall, proc. of the 17 conference on coastal Eng. in Japan.