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Submerged Membrane Beakwaters II: A Rahmen Type System Composed of Horizontal and Vertical Membranes

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1. ABSTRACT

In the present paper, the hydrodynamics properties of a Rahmen type flexible porous breakwater with dual fixed-pontoon system interacting with obliquely or normally incident small amplitude waves are numerically investigated. This system is composed of dual vertical porous membranes hinged at the side edges of dual fixed pontoons, and a submerged horizontal membrane that both ends are hinged at the steel frames mounted pontoons. The dual vertical membranes are extended downward and hinged at bottom steal frame fixed into seabed. The wave blocking and dissipation mechanism and its effects of permeability, Rahmen type membrane and pontoon geometry, pre-tensions on membranes, relative dimensionless wave number, and incident wave headings are thoroughly examined.

2. INTRODUCTION

During the past decade, there has been a gradual increase of interest in the use of flexible plate or membrane as desirable characteristics of being transportable, relatively inexpensive, rapidly deployable, easily detachable, and even sacrificial. Thus, it may be an ideal candidate as a portable and temporal breakwater for the protection of various coastal/offshore structures and sea operations requiring relatively calm sea states.

In this regard, the performance of a vertical-screen membrane breakwater was investigated by Thomson et al. (1992), Aoki et al. (1994), Kim & Kee (1996), Kee & Kim (1997), Cho et al. (1997, 1998), and Williams (1996).

The interaction of monochromatic incident wave with dual pre-tensioned, inextensible, vertical nonporous-membrane wave barrier extending the entire water depth has been investigated by Edmond Y.M. (1998) using eigenfunction expansions for the velocity potential and linear membrane theory. Cho et al. (1998) developed an analytic solution for dual solid-membrane system and a boundary integral method solution for more practical dual buoy/membrane wave barriers with either surface piercing or fully submerged system in oblique seas. The more practical and echo-friendlier breakwater system with fully submerged vertical porous membranes has been investigated by Kee (2001 a,b) in the two dimensional linear hydro-elastic theories and Darcy's law, and found that it can be a very effective wave barrier along the wide frequency range, if it is properly designed.

On the other hand, the vertical-elastic-plate breakwater clamped at the seafloor was investigated by Lee & Chen (1990) and Williams et al. (1991, 1992). Wang and Ren (1993 a,b) have studied thin beam-like thin, porous breakwater and the wave-trapping effect due to a flexible porous breakwater located in front of a vertical impermeable wall, and found that the efficiency of these flexible breakwaters can be improved by adding structural porosity. The tuned two vertical screens also have been investigated by (Abul Azm, 1994).

The two-dimensional problem of wave interaction with a horizontal porous flexible

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structure is of growing importance and significant studies in this area have been conducted by several authors. Yu and Chang (1994) investigated the interaction of surface waves with a submerged horizontal porous plate. Cho and Kim (2000) studied the interaction of monochromatic incident waves with a horizontal porous flexible membrane in the context of two-dimensional linear hydro-elastic theory, and found that using a proper porous material can further enhance the overall performance of the horizontal flexible membrane. However, the proposed system has been relatively transparent to the incident wave field, especially the long wave regime. In order to improve its performance at the long wave region, it is necessary for the structure to have a larger width, approximately one wave length, or to occupy the major fraction of water column. In view of this, an ideal Rahman type porous membrane breakwater system for the beginning stage of research has been proposed by Kee (2002), which was composed of a fully submerged porous horizontal membrane hinged at the tips of dual vertical porous membranes hinged at seafloor, and found that such system can effectively reduce both the transmitted and reflected wave heights.

In the present paper, the hydrodynamics properties of Rahman type porous membranes with dual fixed pontoons interacting with obliquely incident small amplitude waves are numerically investigated. This system is composed of one submerged horizontal or slightly inclined porous flexible membrane and two vertical porous membranes hinged at the steel frame mounted on the dual pontoons, and at beneath of pontoons respectively. The two vertical membranes hinged at beneath of pontoons are extended downward, and hinged at a frame that fixed onto seabed allowing gaps for the transportation of sediment or fishery. The fully submerged Rahmen type breakwater is introduced herein in the points of view of marine scenario, water circulation, surface vessel passing, the reduced seabed erosion by standing waves in front of structure, and the reduced hydrodynamic pressures on the body of structures.

To assess the efficiency of this Rahmen type porous membranes system with dual pontoons, two-dimensional hydro-elastic formulation for two fluid domains was carried out in the context of linear wave-body interaction theory and Darcy's law for the wave energy dissipation through fine pores on the membranes. The fluid region is split into two regions, region (1) wave ward, over and in the lee of the structure, and region (2) inside of the structure. It is assumed, for simplicity, that the pre-tensioned membrane is thin, un-stretchable, and free to move only in the transverse direction for vertical membranes, and uniform in the longitudinal direction for the horizontal membrane. The pre-tension is assumed externally provided and much greater than dynamic tension so as to be regarded as constant. The membrane dynamics is modeled as that of the tensioned string of zero bending rigidity, thus one dimensional linear sting equation is applicable. The unknown complex velocity potentials of wave motion, which is containing diffraction and radiation, are fully coupled with deformations of membranes taking account for the fluid viscosity due to its porosity.

The developed theory and numerical model are validated by comparison with previously published numerical studies by Cho and Kim (2000) based on eigenfunction expansion of the limiting cases of the horizontal porous membrane in monochromatic waves. Relevant numerical results, presented in the paper, relate to the reflection and transmission coefficients. The corresponding wave forces and motions of membranes are also comparatively investigated, but not presented here. The performance evaluation has been conducted for the various parameters such as membrane permeability, Rahmen type membrane and pontoon geometry, pre-tensions on membranes, relative dimensionless wave number, and incident wave headings.

Results presented herein confirm that the overall performance of the Rahmen type flexible membranes with pontoons can be a very echo friendly breakwater system with an outstanding performance as wave barrier by tuning properly the system parameters, since the inclusion of permeability on membrane eliminates the resonance that aggravates the breakwater performance, and mutual cancellation effects between the incident waves and radiated waves by the motions of membranes, in addition, partial wave trapping effects through the gaps of pontoons. The performance of this type of breakwater is found to be highly promising for relatively wide range of frequency and wave headings, if it is properly tuned to the coming waves using the Rahmen's geometry including pontoon and membranes, pre-tensions, and permeability.

3. THEORY AND NUMERICAL METHOD

3.1 Governing Equations

The general features of the proposed system are depicted in fig. 1. The horizontal membranes are hinged at the both frames mounted on the each floating pontoon. The initial tension is assumed to be given by the stiffeners between two pontoons. The pre-tension of vertical membranes should be supplied by the net buoyancy forces, however, is assumed to be given externally, since the motion of pontoon is restrained for simplicity for a second stage of research.

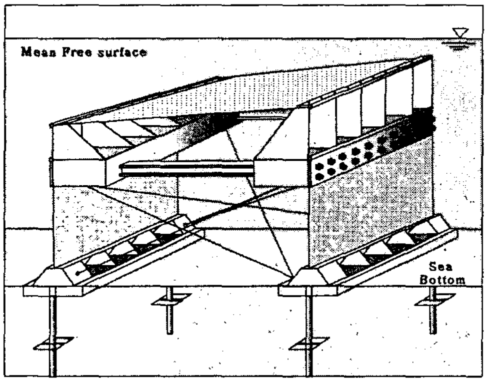

Fig. 1. Conceptual feature of Rahman type porous membrane with dual pontoon breakwater system.

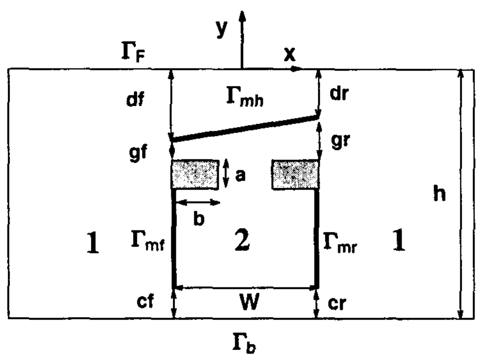

Fig. 2. Definition sketch and integration domains for a proposed system.

The breakwater system with arbitrary porous and flexible boundaries is to compose of a horizontal membrane with width of with *w* submergence depth *df, dr* below the still water level, and two vertical membranes that is extended downward and hinged at some distance from the sea bottom, allowing bottom gaps *cf*, *cr*. The height and width of pontoon are noted as *a, b,* respectively. The size of gaps between the hinged points of horizontal membranes and the top` side of pontoons are noted as *gf, gr.* The sketch diagram is shown in Fig. 2. A Cartesian coordinate system (x, y) is defined with x measured in the direction of wave propagation from a point at mid-way between the vertical membranes, and y measure upward from the still water level. An obliquely incident, regular, small amplitude wave train of half height A and angular frequency w propagates towards the breakwater with an angle θ with respect to χ axis in water of constant depth h as shown in Fig. 2.

If the fluid is assumed to be an ideal fluid such as incompressible, invisid, and irrotational fluid, then the fluid motion can be described by velocity potential Φ that satisfies the Helmholtz equation $\nabla^2\phi_\ell$-$k_z{}^2$=0 within the fluid regions(Ω_ℓ, $\ell=1.2$). In addition, the wave amplitude is assumed sufficiently small enough for linear wave theory to apply. Consequently, Φ is subject to the usual boundary conditions, linearized free surface (Γ_F), rigid structuresΓ_s, bottom (Γ_b), and approximated far field conditions (Γ_c): (see, for example, Sarpkaya and Issacson, 1981). Thus may be expressed in the following form:

$$\Phi(x,y,z,t)=Re[\phi_0(x,y) + \phi_\ell(x,y)e^{ik_z - iwt}] \quad (1)$$

where ϕ_0 is the well-known incident potential, and can be written as;

$$\phi_0 = \frac{igA}{w}\frac{coshk_0(y+h)}{coshk_0h}e^{ik_0cos\theta x} \quad (2)$$

Also, Re[ ] denotes the real part of a complex expression,$i=\sqrt{-1}$, t denotes time, and $k_z = k_0 sin\theta$ is the wave number component in the z direction. The wave number of the incident wave k_0 is the positive real solution of the dispersion equation $w^2 = k_0 g tanh k_0 h$ with g being the gravitational constant. And ϕ_ℓ is time-independent unknown scattered potentials in two fluid domains (see Fig. 2) includes both effects of diffraction and radiation.

3. 2 Permeable Membrane Boundary Condition

The required linearized kinematic boundary condition on the surface of the permeable flexible structure may be developed based on the formulation of Wang and Ren (1993a). This may be expressed for vertical membranes as:

$$\frac{\partial\phi_1}{\partial x} = -\frac{\partial\phi_2}{\partial x} = -iw\xi + u(y) \quad (3)$$

where $u(y)$ is spatial component of the normalvelocity $U(y, t)$ of the fluid flow passing through a thin porous media, which is assumed to obey Darcy's law. The harmonic membrane motion is $Re[\xi e^{-iwt}]$. The porous flow velocity inside of membrane with fine pores $U(y, t) = Re[u(y)e^{-iwt}]$ is linearly proportional to the pressure difference between both sides of the thin membrane. Therefore, it follows that

$$U(y, t) = \frac{B}{\mu}(p_1 - p_2) = \frac{B}{\mu}\rho iw(\phi_1 - \phi_2)e^{-iwt} \quad (4)$$

where B is the constant called permeability having dimension of a length, μ is constant coefficient of dynamic viscosity, and ρ is constant fluid density. From Eqs. (3) and (4), has an expression as follows:

$$u(y) = \frac{B}{\mu}\rho iw(\phi_1 - \phi_2) \quad (5)$$

The non-dimensional porosity parameter G, commonly called Chang's parameter (Chang, 1983) is employed as follows,

$$G = 2\pi\rho wB/k_x\mu \quad (6)$$

This parameter can be regarded as a sort of Reynolds number representing the effects of both viscosity and porosity, considering the phase velocity of incident wave (w/k_x) and a measure of porosity with length dimension (B).

In order to match the two solutions on the surface of permeable membranes, ϕ and ξ, the scattered potentials must also satisfy the following linearized dynamic boundary conditions on the membrane surface:

$$\frac{d^2\xi}{dy^2} + \lambda^2\xi = \frac{\rho iw}{T}(\phi_1 - \phi_2)\ (on\ \Gamma_m) \quad (7)$$

where $\lambda = w/c$, and c is membrane wave speed given by $\sqrt{T/m}$ with T and m being the membrane tension and mass per unit length respectively.

3.3 Boundary Integral Equation

The fundamental solution (Green function) of the Helmholtz equation and its the normal derivative of G are given using the modified zeroth $K_0(\lambda r)$ and first order $K_1(\lambda r)$ Bessel function of the second kind (see, for example, Rahman & Chen, 1993), and where r is the distance from source point to the field point. After imposing the boundary conditions, the integral equations in fluid domain can be written as

$$\begin{aligned} C\phi_1 &+ \int_{\Gamma F}[k_zK_1(k_zr)\frac{\partial r}{\partial n} - vK_0(k_zr)]\phi_1 d\Gamma \\ &+ \int_{\Gamma C}[k_zK_1(k_zr)\frac{\partial r}{\partial n} - ik_xK_0(k_zr)]\phi_1 d\Gamma \\ &+ \int_{\Gamma m}[\phi_1 k_zK_1(k_zr)\frac{\partial r}{\partial n} \\ &+ \frac{B}{\mu}i\rho wK_0(k_zr)(\phi_2 - \phi_1) \\ &+ s1_{fhr}iw\xi K_0(k_zr)]d\Gamma \\ &+ \int_{\Gamma b,s}\phi_1 k_zK_1(k_zr)\frac{\partial r}{\partial n}d\Gamma \\ = &- \int_{\Gamma m}K_0(k_zr)(\frac{\partial\phi_0}{\partial n} + i\rho w\frac{B}{\mu}\phi_0)d\Gamma \\ &- \int_{\Gamma s}K_0(k_zr)\frac{\partial\phi_0}{\partial n}d\Gamma \qquad (\text{in } \Omega_1)(8) \end{aligned}$$

$$\begin{aligned} C\phi_2 &+ \int_{\Gamma m}[\phi_2 k_zK_1(k_zr)\frac{\partial r}{\partial n} \\ &+ \frac{B}{\mu}i\rho wK_0(k_zr)(\phi_1 - \phi_2) \\ &- s2_{fhr}iw\xi K_0(k_zr)]d\Gamma \\ &+ \int_{\Gamma b.s}[\phi_2 k_zK_1(k_zr)\frac{\partial r}{\partial n}d\Gamma \\ = &- \int_{\Gamma m}K_0(k_zr)i\rho w\frac{B}{\mu}\phi_0 d\Gamma \\ &- \int_{\Gamma s}K_0(k_zr)\frac{\partial\phi}{\partial n}d\Gamma \qquad (\text{in } \Omega_2)(9) \end{aligned}$$

where C is solid-angle constant, and $V = w^2/g$ is the infinite-depth dimensionless wave number $s1_{fhr} = -,+,+$, $s2_{fhr} = +,-,-$ for front vertical, horizontal, rear vertical membrane respectively.

The integral equations (8~9) can then be transformed to the corresponding algebraic $N\times N$ matrix. The entire boundary is discretized into a large finite number of segments, and can be replaced by matrix equations. Then, N includes numbers of segments along all boundaries, and there exist N unknowns for, ϕ_1 ,ϕ_2, N_{mf}, N_{mh}, N_{mr} for membrane motions, which can be given in discrete form for each segment.

4. NUMERICAL RESULTS AND DISCUSSIONS

A boundary integral equation method based on the distribution of simple sources along the entire boundary is developed for the numerical solution. The two vertical truncation boundaries are located sufficiently far from the side edge of structures, usually 3~4 times of water depth away, such that far filed boundary condition is valid, i.e. to ensure that the exponentially decaying local standing wave effect is negligible.

The numerical results were checked against the energy conservation formula i.e.$R_f^2+T_r^2=1$, since the energy relation is satisfied in the case of zero porosity (or an impermeable membrane). For a submerged horizontal membrane for $(df/dr)/h=0.2$, $W/h=1.0$,$\theta=0°$, $G=2.0$, analytic solution has been developed by Cho and Kim (2000), and is compared to numerical results with good agreement as shown in Fig. 3~4 for dimensionless pre-tensions of horizontal membrane $\tilde{T}_h=0.1$. The externally provided tension of membrane is normalized by $\rho g h^2$, i.e. $\tilde{T}=T/\rho g h^2$.

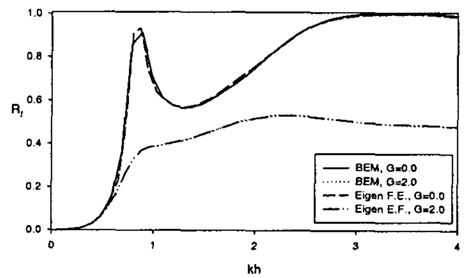

Fig. 3. Comparison of numerical method with analytic solutions. The reflection coefficients are for $(df,dr)/h=0.2$, $W/h=1.0$, $\theta=0°$,$\tilde{T}_h=0.1$, $G=2.0$

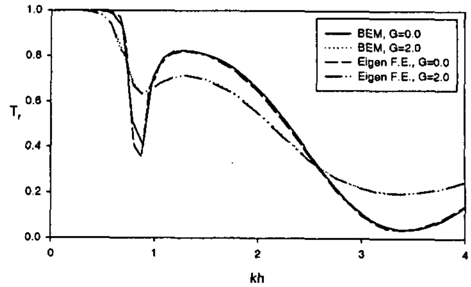

Fig. 4. Comparison of numerical method with analytic solutions.

The transmission coefficients are for $(df,dr)/h=0.2$, $W/h=1.0$, $\theta=0°$, $\tilde{T}_h=0.1$, $G=2.0$

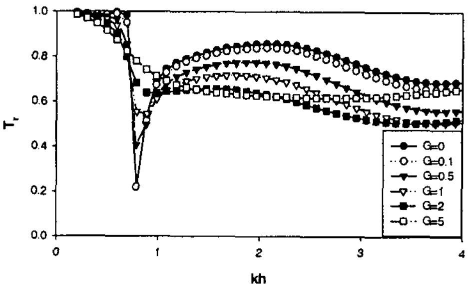

Fig. 5. Transmission Coefficient for $(df,dr)/h=0.2, W/h=1.0, \tilde{T}_f=\tilde{T}_h=\tilde{T}_r=0.1$, $a/W=0.2$, $b/W=0.35$, $gf/h=gr/h=0.1$, $cf=/h=cr/h=0.1$, and $\theta=0°$

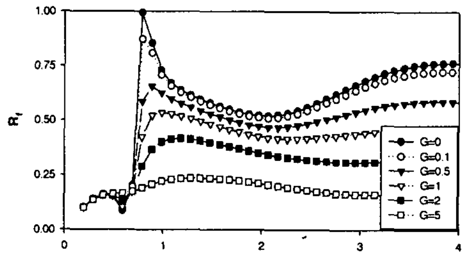

Fig. 6. Reflection Coefficient for $(df,dr)/h=0.2$ $W/h=1.0$, $\tilde{T}_f=\tilde{T}_h=\tilde{T}_r=0.1$, $a/W=0.2$, $b/W=0.35$, $gf/h=gr/h=0.1$, $cf=/h=cr/h=0.1$, and $\theta=0°$

Transmission and reflection coefficient as function of for the various porosity parameters

G=0, 0.1, 0.5, 1, 2, 5 for a beam sea ($\theta = 0°$) and dimensionless pre-tensions of membrane ($\tilde{T}$) are shown in Figs. 5~6. The symbols $\tilde{T}_f$, $\tilde{T}_h$, $\tilde{T}_r$ represent the non-dimensional pre-tensions for a front vertical, a horizontal, and a rear vertical membrane respectively. The reflection and transmission coefficients are gradually decreased as porous parameter G increases, up to G=2 where the transmitted wave starts to increase for the wide range of frequency. This kind of phenomena can be found easily in the deviation rate of energy relation as shown in Fig. 7. Thus, largest wave energy dissipation in harmonics with hydrodynamics of membranes may be directly related to the performance of a system as a wave barrier. For a higher porosity over the G=2, improperly larger transmitted waves surpass the wave blocking efficiency by the hydrodynamic effects of flexible system. The non-dimensional porous parameter G is linearly proportional to the permeability as $2\pi\rho w B/k_x\mu$ with a strong dependence of incident wave length. The porosity P on the flexible membrane equivalents to G based on the linear relation G=57.63P-0.9717 between porosity and porosity parameter, which was obtained from experiments for various porous plates (Kee, Kim, and Cho et al., 2002). This could be also a validation for the assumption that the permeability is not too high (say less than $B = 1E-07m^2$) by Kim et al. (2000) to solve the wave interaction with arbitrary porous and rigid boundaries based on potential theory and Darcy' law. Thus, the permeability G=2 can be defined as an effective porosity that causes, generally along the wide frequency range, largest energy dissipation for a system with given various parameters as shown in Fig. 7.

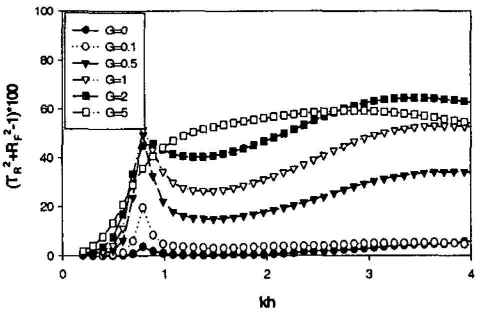

Fig. 7. The deviation rate of energy relation for $a/W = 0.2$, $b/W = 0.35$, $(df, dr)/h = 0.2$, $\tilde{T}_f = \tilde{T}_h = \tilde{T}_r = 0.1$, $cf = /h = cr/h = 0.1$ $W/h = 1.0$, $gf/h = gr/h = 0.1$, and $\theta = 0°$

The performance of such system is not impressive, compared to the performances of a tuned system (Kee, 2002) in the previous stage of research. It is mainly due to the transmitted waves in the lee sides through the clearances between horizontal membranes and pontoons, in addition, the gaps between the ends of membranes and seafloor, which is intentionally designed for the eco-friendly system. Thus, a slightly inclined horizontal flexible porous membrane is employed for further wave energy dissipation in order to improve its efficiency.

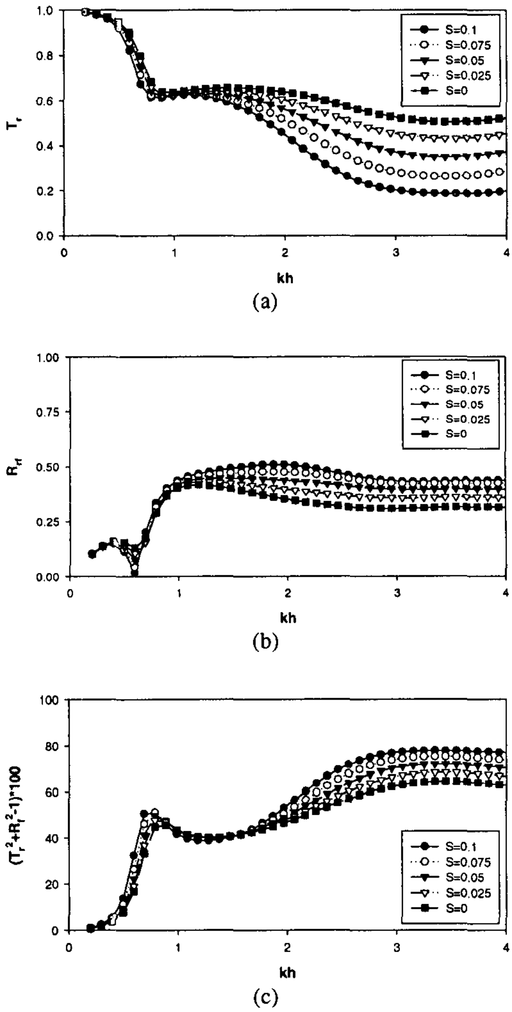

Fig. 8. Transmission (a), reflection (b) coefficients and the deviation rate (c) of the wave relation for $a/W = 0.2$, $b/W = 0.35$, $\tilde{T}_f = \tilde{T}_h = \tilde{T}_r = 0.1$, $gf/h = 0.1$, $gr/h = 0.2$, $df/h = 0.2$, $dr/h = 0.1$, $cf/h = cr/h = 0.1$, and $\theta = 0°$

Fig. 8. shows the transmitted and reflection waves and the deviated ratio away, in percentage, from the energy relation for a inclined horizontal membrane system for various slopes changing from S=0 to S=0.1. The effects of inclined system are manifest for the all frequency rages. The transmitted waves are dramatically reduced especially for the high frequency regime, mainly due to the further energy dissipation, by the circular motions of waves partially in the vertical direction, and mutual cancellation between the incidents waves, for relatively short wave length, and the generated waves by the motions of membranes.

Thus, this eco-friendly system with a slightly inclines shows generally better performance compared to the horizontal membrane only system as shown in Fig. 4. However, the performance of such eco-friendly system is not generally closer to the tuned breakwater efficiency by the previous stage of the research, since it was not tuned yet against the incident waves using parametric study.

Tentatively, we can conclude that a weakly slopped horizontal flexible porous membrane system could be a better choice for the enhancement of wave energy blocking and dissipating efficiency. It is a very interesting to note that for further wave energy dissipation it is necessary for the structures to occupy the water column slightly in the vertical direction, which obtain much more energy dissipation through fine pores by the orbital motions of waves, passing through the inclined horizontal system.

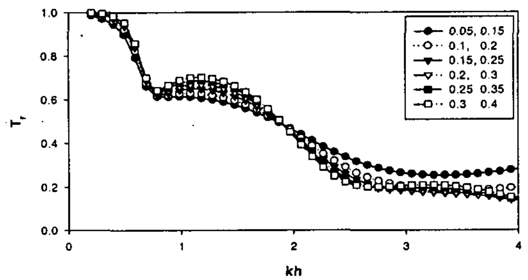

Fig. 9. Transmission coefficients with various $(gf, gr)/h$ for $W/h=1.0$, $\tilde{T}_f=\tilde{T}_h=\tilde{T}_r=0.1$, $cf/h=cr/h=0.1$, $dr/h=0.1$, $a/W=0.2$, $b/W=0.35$, and $\theta=0^\circ$

At this point, we may expect intuitively that the performance of the inclined porous membrane only system may be affected to negative aspects by the presence of the submerged pontoons, which has some gaps apart away from the inclined horizontal membrane. Thus, the performance has been checked for such various gap distances from $gf/h=0.05-0.3$, $gr/h=0.15-0.4$, and is shown in the Fig.9 .

The shortest gap distance $gf/h=0.05$, $gr/h=0.15$ has a better efficiency for the frequency range of $0.9 \le kh \le 1.6$, however, a poor efficiency for higher frequency ranges. For the frequency range of $0.9 \le kh \le 1.6$, the effects of gap distances are gradually worse as the gap increase. Therefore, the system with $gf/h=0.1$, $gr/h=0.2$ has good performances, in general, along the wide frequency range, and the gap distance effects are not significant except for a limited frequency range. The wave energy dissipation and mutual cancellation mechanism by the fully submerged slightly inclined horizontal porous flexible membrane has a generally good efficiency as wave barrier regardless of the sub structure geometry. However, at the frequency of $0.9 \le kh \le 1.6$, the effects of sub structure geometry occurs by the enlarged gaps, which allows relatively large wave transmission, and reduced wave trapping effects especially for long waves.

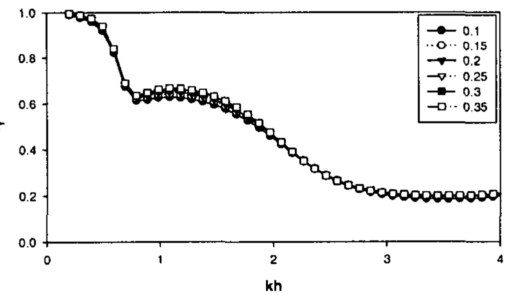

Fig. 10. Transmission coefficients with various cf/h for , $W/h=1.0$, $\tilde{T}_f=\tilde{T}_h=\tilde{T}_r=0.1$, $a/W=0.2$, $b/W=0.35$, $df/h=0.2$, $dr/h=0.1$, $gf/h=0.1$, $gr/h=0.2$, $cr/h=0.1$ and $\theta=0^\circ$

If the geometry variation, in the vertical direction, of the structure does not influence its performances, we checked the effects of the front vertical membrane with varying membrane length allowing equivalent bottom gaps, and are shown in Fig. 10. We also checked the effect when the both vertical membranes are shortened, and shown in Fig. 11. The varying performance for the shortened length of membranes is very similar to the trends that are found in Fig. 9.

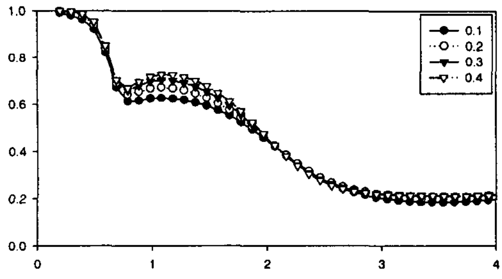

Fig. 11. Transmission coefficients with various $(cf, cr)/h$ for $W/h=1.0$, $\tilde{T}_f=\tilde{T}_h=\tilde{T}_r=0.1$, $a/W=0.2$, $b/W=0.35$, $df/h=0.2$, $dr/h=0.1$, $gf/h=0.1$, $gr/h=0.2$, and $\theta=0°$

In addition, the performance has been investigated for the various the width of pontoon structures that allows larger distance between two pontoons in horizontal direction, and allows more water circulation in the vertical directicn. The effects are depicted in Fig. 12. The blockage effects by the both pontoons are very manifest for the range of $kh \geq 1$, especially for the wider pontoons, which has small gaps, blocking its space in the vertical direction.

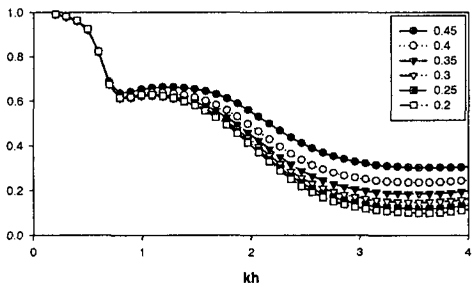

Fig. 12. Transmission coefficients with various b/W for $W/h=1.0$, $\tilde{T}_f=\tilde{T}_h=\tilde{T}_r=0.1$, $a/W=0.2$, $df/h=0.2$, $dr/h=0.1$, $gf/h=0.1$, $gr/h=0.2$, $cf/h=cr/h=0.1$, and $\theta=0°$

It is found that the substructure of the current system does not have some contribution to improve it's over all performances. Thus, based on the result analysis so far, we may assume that horizontal system only with pontoons may be best choice as an efficient wave barrier. The pontoons are needed to support the steel frame to supply the initial membrane tension mechanically and keep the floating and submerged status. In awhile, as shown in Fig. 12, the small size of pontoon with rectangular shape has much better efficiency compared to the wider one, thus one can easily expect that small initial tension of vertical flexible membranes must be supplied by its net buoyancy force. In this second stage of research, the motion of pontoon was restricted for simplicity, and the initial tension of vertical porous membrane are assumed to be given by externally. In here, the initial tension can be dropped as an order of one, such as $\tilde{T}_f=\tilde{T}_f=0.01$ considering the fully submerged geometry of pontoons. Thus, after imposing the proper non-dimensional tension on the vertical membranes, the efficiency has been checked and shown in Fig. 13. The weaker tension has dramatically improved performances in the lower frequency range, however sacrificing its short wave length regions, since the weakly tensioned membranes may allow relatively large motions, further radiation wave generated by its motion can be mutually canceled with incident waves. In the frequency range of $0.7 \leq kh \leq 1.5$, the mutual cancellation effects are very clearly presented, however, the worse effects appears in the high frequency regions mainly due to the propagating waves generated by the motions of membranes to the lee side.

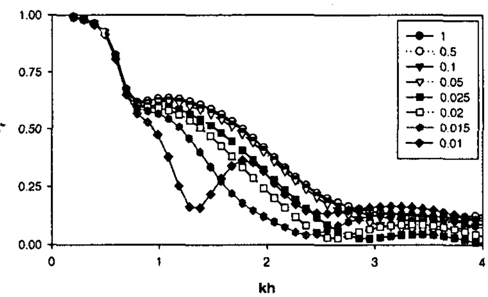

Fig. 13. Transmission coefficients with various $(\tilde{T}_{fr})$ for $b/W=0.2$, $W/h=1.0$, $\tilde{T}_h=0.1$, $a/W=0.2$, $df/h=0.2$, $dr/h=0.1$, $gf/h=0.1$, $gr/h=0.2$, $cf/h=cr/h=0.1$, , and $\theta=0°$

In order to find out the further mutual cancellation effects by the motions of horizontal membranes, we investigated the performances according to the various initial tensions which can be easily controlled mechanically by the supporters installed between two pontoons; the transmission coefficients are calculated for a given test system and plotted against the non-dimensional wave number, shown in Figs. 14~15.

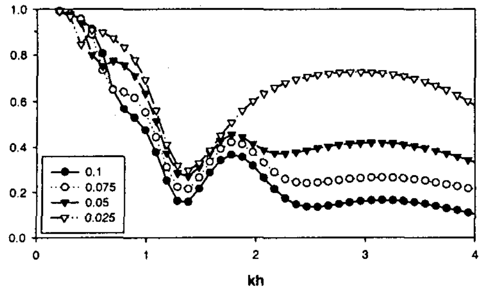

Fig. 14. Transmission coefficients with various $\tilde{T}_h$ for $b/W = 0.2$, $W/h = 1.0$, $\tilde{T}_f = \tilde{T}_r = 0.01$, $a/W = 0.2$, $df/h = 0.2$,$dr/h = 0.1$, $gf/h = 0.1$, $gr/h = 0.2$, $cf/h = cr/h = 0.1$, and $\theta = 0$ °

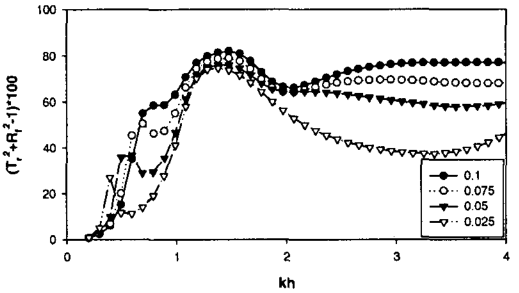

Fig. 15. The deviation rate of energy relation with various $\tilde{T}_h$ for $b/W = 0.2$, $W/h = 1.0$, $\tilde{T}_f = \tilde{T}_r = 0.01$, $a/W = 0.2$,$df/h = 0.2$, $dr/h = 0.1$, $gf/h = 0.1$, $gr/h = 0.2$, $cf/h = cr/h = 0.1$, and $\theta = 0$ °

It is interesting to note that the performance become worse as the initial tension decreased. It may be expected mainly due to relatively large motions of horizontal membranes, which usually aggravates the wave energy dissipation effects through fine pores. Therefore, the deviation of energy relation has been checked in Fig. 15, and found that relatively larger tension of membrane has better ratios for wave energy dissipations.

5. SUMMARY AND CONCLUSIONS

The interaction of oblique incident waves with a Rahman type porous flexible membrane breakwater with dual fixed pontoons for simplicity was investigated in the context of 2D linear hydro elastic theory based on the Darcy□s law due to fluid viscosity. Properly adjusted 2-D B.E.M. code has been developed for parametric study to figure out major parameters influencing its performances. The developed program for porous problem has been checked against the analytic solution for limited cases, and found that it is in good agreement. Using the developed program, we investigated the general performance of an ideally suggested echo-friendly system which is conceptually designed to get the mutual cancellation, wave energy dissipation, partial wave trapping mechanism. Thus the geometry is quite complicated and has following parameters; the various submergence depth measured from the free surface to the top of horizontal membranes, width of horizontal membrane, pre-tensions, permeability, the geometry of pontoon, gap distances from the seafloor to the tip of membranes or from the top of pontoon and the tip of horizontal membranes. Based on the results analysis, it is found that the optimal system with an effective porous parameters G=2 can significantly improved the overall performances as wave barrier along the wide range of incident waves frequencies and headings compared to the case of horizontal porous membrane only. It was also found that the horizontal flexible porous membrane system with slightly inclines could be a better choice for the enhancement of wave energy blocking and dissipating efficiency using the geometric positioning against the various orbital motions of waves according to the incident wave length. In addition, the weakly tensioned vertical membranes and highly tensioned horizontal membrane was found to be a very effective wave barrier for the relatively long wave regions, due to the characteristics of wave energy dissipation and mutual cancellation inside of a system.

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REFERENCES

Abul-Azm, A.G. (1994). Wave diffraction by double flexible breakwaters Journal of Applied Ocean Research , Vol.16, 87-99.

Aoki, S., Liu, H., & Sawaragi, T. (1994). Wave transformation and wave forces on submerged vertical membrane Proc. Intl. Symp. Waves - Physical and Numerical Modeling, Vancouver, 1287-1296

Cho, I.H. & Kee, S.T. & Kim, M.H. (1997). The Performance of Dual Flexible Membrane Wave Barrier in Oblique Incident Waves J. of Applied Ocean Research, Jun./Aug. 1997. Vol.19, No.3-4,

pp.171-182.
Cho, I.H., Kee, S.T. and Kim, M.H. (1998). The performance of Dual Flexible Membrane Wave Barrier in Oblique Sea ASCE J. of Waterways, Port, Coastal & Ocean Engineering, Vol 124, No 1, pp 21-30.
Cho, I.H. & Kim, M.H. (2000). Interactions of Horizontal Porous Flexible Membrane with Waves. ASCE J. of Waterway, Port, Coastal & Ocean Engineering, Vol 126, No 5, pp 245-253.
Chwang, A. T. (1983). A Porous wavemaker theory. J. Fluid Mech., Cambridge, U.K., 132, 395-406.
Edmond, Y.M. (1998). Flexible Dual Membrane Wave Barrier ASCE J. of Waterway, Port, Coastal & Ocean Engineering, Vol 124, No 5, pp 264-271.
Kee, S.T. & Kim, M.H. (1997). Flexible membrane wave barrier. Part 2. Floating/submerged buoy-membrane system ASCE J. of Waterway, Port, Coastal & Ocean Engineering, Vol.123, No.2, 82-90.
Kee, S.T., Kim, D.S., Cho, I.H., Park, G-Y. and Han, J.O. (2003). The development of the sea-state control technology for Aqua-polis, Final Report for the Korea Institute of Construction Technology Research Center Program, Grant Number R&F/00-24-01, Vol. 3, No.2, pp. 55~64
Kee (2001a). Performance of the submerged dual buoy/membrane breakwaters in oblique seas. Journal of Ocean Engineering and Technology Vol. 15, No 2, pp. 11-21.
Kee (2001b). Resonance and response of the submerged dual buoy/porous-membrane breakwaters in oblique seas Journal of Ocean Engineering and Technology Vol. 15, No 2, pp. 22-33
Kee, S. T. (2002). Submerged Membrane Breakwater I: A Rahman Type System Composed of Horizontal and Vertical Membranes, International Journal of Ocean Engineering and Technology, KCORE, Vol 5, No. 1, pp 14-21.
Kim, M.H. & Kee, S.T. (1996). Flexible Membrane Wave Barrier. Part 1. Analytic and Numerical Solutions ASCE J. of Waterways, Port, Coastal & Ocean Engineering, Vol 122, No 1, pp 46-53.
Kim, M.H., W.C. Koo and S.Y. Hong (2000). Wave Interactions with 2D structures on/inside porous seabed by a two-domain boundary element method Journal of Applied Ocean research, Vol 22, pp 255-266.
Rahman, M. & Chen. M. (1993). Boundary Element Method for Diffraction of Oblique Waves by an Infinite Cylinder. Engineering Analysis with Boundary Elements, Vol 11, pp 17-24.
Sarpkaya T, Isaacson M.(1981). Mechanics of Wave Forces on Offshore Structures. New York: Van Nostrand Reinhold.
Thompson, G.O., Sollitt, C.K., McDougal, W.G. & Bender W.R. (1992). Flexible membrane wave barrier ASCE Conf. Ocean V, College Station, 129-148.
Wang, K.H., Ren, X. (1993a). An Effective Wave-Trapping System. Ocean Engineering, Vol 21, pp 155-178.
Wang, K.H., Ren, X. (1993b). Wave Motion Through Porous Structures. J. Engrg. Mech., ASCE, Vol 120, No 5, pp 989-1008.
Yu, X., Chawang, A.T., 1994. Water waves above a submerged porous plate. J. Engrg. Mech., ASCE, Vol 120, No 5, pp 1270-12.