Title of the Invention

Flow-Permeable Breakwater Structure

Background of the Invention

[Technical Field]

The present invention relates to a flow-permeable breakwater structure which is employed to form a water area of calmness in a port or harbor, or to decrease entry of waves into water-inlet and water-outlet of a thermal electric power plant in a coastal area.

[Background Technology]

In cases where piers or marinas are constructed in ports or harbors, where places for increase in planting or for curing are established, where the operating efficiency for offshore construction operations, or where moored structures are protected, it is necessary to install a wave damper structure in a required area of water and thereby ensure a desired level of calmness in such area of water. An ordinary gravity-type breakwater increases in cost as the water depth increases, whereby a limitation is imposed on the use thereof. In addition, since such breakwater obstructs inflow and outflow into and from the relevant water area, in some cases a limitation is also imposed on the use thereof from the viewpoint of placing stress upon the environments. In cases where the water depth is relatively large or stress is placed on the inflow and outflow of water into and from the

water area as mentioned above, the use of a flow-permeable breakwater structure which would not completely interrupt the water flow in the depth direction has been being considered and studied.

Examples of a conventionally employed flow-permeable breakwater structure are illustrated in Figs. 12 and 13.

First, Fig. 12 is a side view of a flow-permeable breakwater structure of a type called "curtain wall type", comprising an orthogonal plate structure (a) which is disposed in such a manner as to pierce through the water surface and reach a halfway position of the water depth. This type of wave damper structure is designed to obstruct, among the revolving motions of the water particles due to the waves, the revolving motions thereof occurring near the water surface and to thereby decrease the propagation of the waves to behind the structure. In this type of wave damper structure, in cases where the waves have a long wavelength, measures are taken to increase the amount of piercing as viewed in the water-depth direction. And when it is desired to suppress the transmission coefficient Ct (the ratio of the transmitted wave height Ht to the incident wave height Hi, namely Ht/Hi), which is an indicator of the wave-damping performance, to 0.5 or less, it is conventionally known that in such cases the amount of piercing of the curtain wall needs to be approximately 1/7 of the wavelength.

Accordingly, while the amount of piercing may be slightly smaller than 4 m in case of and with respect to the wave having a wave period of 8 seconds and a wavelength of 25 m, the amount of piercing needs to be as large as 14 m in case of and with respect to the wave having a wave period of 8 seconds and a wavelength of 100 m. As a result, the scale of the wave damper structure disadvantageously increases. Furthermore, in a water area where the tide level difference is great, the scale of the wave damper structure disadvantageously further increases. Further, if the amount of piercing is increased, the inflow and outflow of water into and from the water area become unsmoothed with the result that the function as that of the transmission type structure does not sufficiently work. Further, although the transmission coefficient is small in case of and with respect to the frequently generated waves having a short wave-period, the reflected waves thereof are non-ignorable, which results in the disadvantage of obstacle occurring for ships or operating boats to sail in a water area in front of the curtain wall where incident waves and reflected waves are overlapped with each other.

Fig. 13 is a side view of a flow-permeable breakwater structure of a type called "submerged horizontal plate type", comprising a horizontal plate structure (b) which is disposed in such a manner as to be completely submerged near and under

the water surface. This type of wave damper structure is designed to cause the wave energy to be consumed utilizing the action or function of obstruct the revolving motions of the water particles by means of a flat plate b, or of causing the wave to be broken on the flat plate b, or of causing vortexes to be generated by the ends of the flat plate b. In cases where a long-wavelength wave is an object wave to be damped, the width of the flat plate needs to be increased correspondingly. In addition, in cases where it is desired that the transmission coefficient be suppressed to 0.5 or less, the width of the flat plate needs to be from 1/3 to 1/4 of the wavelength. Accordingly, in cases where the wavelength is 100 m, the width of the flat plate needs to be approximately 30 m or so, which results in a disadvantage that the structure scale becomes vary large. Further, in cases where the tide level difference is large, the submerged depth of the flat plate becomes large during high tide-level period, raising also the problem that the wave-damping performance deteriorates.

Object of the Invention

The present invention is intended to solve the above-mentioned problems that are inherent in the conventionally employed flow-permeable breakwater structure and the object of the present invention is to provide a flow-permeable breakwater structure which while keeping its good water

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transmission characteristics enables a sufficient wave-damping effect upon the long-wavelength waves to be obtained with a smaller scale of structure than in the prior art and which can decrease the reflected waves and can also cope with the variation in the tide level as well.

Summary of the Invention

In order to attain the above object, the present invention adopts a flow-permeable breakwater structure having the following constructions.

A submerged horizontal plate which is laid in the horizontal direction intersecting the advancing direction of the waves substantially at right angles thereto is disposed substantially in parallel with the water surface and in such a manner as to be completely submerged in the water and an orthogonal flat plate which is erected at and fixed to around an end of the submerged horizontal plate on the upwave or downwave side in such a manner as to pass through or pierce the water surface and be upwardly directed are disposed.

Namely, the flow-permeable breakwater structure according to the present invention comprises a supporting frame erected on a sea bottom and permitting the passage of sea water therethrough, a submerged horizontal plate supported by the supporting frame and located under the water surface, and an orthogonal flat plate disposed on around an end of the submerged horizontal plate on the downwave or

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upwave side in such a manner as to intersect the advancing direction of the incoming wave substantially at right angles thereto and to pass through the water surface.

As a result, in the flow-permeable breakwater structure according to the present invention, in cases where the orthogonal flat plate is erected at around the end of the submerged horizontal plate on the downwave side, the incoming wave W that has come up propagated on the water surface performs the following motions. Namely, it once attempts to pass through the structure along the upper surface of the submerged horizontal plate and then is reflected by the orthogonal flat plate and then turned back on the submerged horizontal plate, and thereafter passes under the submerged horizontal plate. And in case of such a return wave, the motions reversed from the motions mentioned above are performed.

In this way, part of the wave has its phase delayed and simultaneously moves the water on the submerged horizontal plate, which results in that the wave energy is partly consumed. Therefore, the wave that is being transmitted through the structure is effectively damped.

Further, in the case where the orthogonal flat plate is erected on around the end of the submerged horizontal plate on the upwave side, owing to the synergetic effect of the orthogonal flat plate and the submerged horizontal plate upon

the incoming wave the transmission wave is also sufficiently damped.

In another flow-permeable breakwater structure according to the present invention, a plurality of partitioning plates 3 each connecting the submerged horizontal plate and the orthogonal flat plate are juxtaposed at space intervals along the advancing direction of the incoming wave.

And if, as mentioned above, a plurality of the partitioning plates for connecting the submerged horizontal plate and the orthogonal flat plate are juxtaposed in parallel relation to the advancing direction of the wave and at space intervals, the above-mentioned motion of the wave moving along the submerged horizontal plate is not only smoothly performed and the damping of the transmission wave is effectively performed but is also the strength of bond between the two plates increased by intervention of the partitioning plates.

Further, in still another flow-permeable breakwater structure according to the present invention, each of the partitioning plates is formed like a right-angled triangle having an inclined side obliquely extending from around an upper edge of the orthogonal flat plate to around the end edge of the submerged horizontal plate.

As a result of this, by the inclined side of the right-angled triangle obliquely extending from around the upper end

edge of the orthogonal flat plate to around the end edge of the submerged horizontal plate, the strength with which the partitioning plates per se are mounted is maintained to be at an appropriate level.

Further, in a further flow-permeable breakwater structure according to the present invention, the width of the submerged horizontal plate is set to be greater than the height of the orthogonal flat plate.

As a result of this, the ratio d/B of the submerged depth d to the width B is decreased with the result that it is possible to make large the maximum value of the wavelength λ at which the transmission coefficient is 0.5 or less.

Namely, even when the incoming wave has a long wavelength λ, the wave-damping effect thereupon is obtained by decreasing the transmission coefficient by use of the submerged horizontal plate with a relatively small value of width. Thus, the flow-permeable breakwater structure can be made small in scale.

Further, in a yet further flow-permeable breakwater structure according to the present invention, to end of the submerged horizontal plate at which the orthogonal flat plate is not erected there is attached a protrusion member so as to obstruct the flow of the water going along an upper or lower surface of the submerged horizontal plate.

As a result of this, by means of the protrusion member,

vortexes for example are formed utilizing the flow of the water around the submerged horizontal plate, thereby the action of positively reducing the energy of the wave is performed.

Accordingly, the above-mentioned action is remarkably performed to effectively reduce the reflected wave because the protrusion member is provided at a position where the above-mentioned resonance phenomena on the submerged horizontal plate are not obstructed and the speed of the water flow is high.

Further, in a yet further flow-permeable breakwater structure according to the present invention, a plate structure is provided at around the end of the submerged horizontal plate at which the orthogonal flat plate is not erected in such a manner as to be located above the submerged horizontal plate and under the water surface.

As a result of this, the plate structure acts in the same manner as in the case of the above-mentioned protrusion member to thereby remarkably reduce the energy of the wave.

Further, in a yet further flow-permeable breakwater structure according to the present invention, a plate structure is disposed in such a manner as to be spaced away from the submerged horizontal plate on the upwave side and located under the water surface.

As a result of this, as in the case of the above-

mentioned protrusion member and plate structures, vortexes for example are generated utilizing the flow of the water around the submerged horizontal plate, thereby reducing the energy of the wave and effectively decreasing the reflected wave. Nor are the resonance phenomena on the submerged horizontal plate obstructed.

Further, in a yet further flow-permeable breakwater structure according to the present invention, there are provided a supporting frame erected on a sea bottom and permitting the passage of sea water therethrough, a submerged horizontal plate supported by the supporting frame and located under the water surface, and an inclined plate erected at around an end of the submerged horizontal plate on the downwave or upwave side and upwardly inclined toward the downwave side in such a manner as to substantially intersect the advancing direction of the incoming waves and pass through the water surface.

As a result of this, the apparent width B of the submerged horizontal plate changes in correspondence with and simultaneously with a change in the submerged depth d, so that the value of B/d does not change so much against a change in the tide level.

Accordingly, the value of B/d at which while, as it increases, the structure more effectively dumps the incoming wave with a large value of wavelength, the structure becomes

more likely to permit the passage therethrough of the incoming wave with a small value of wavelength can be maintained to be optimum.

Further, in a yet further flow-permeable breakwater structure according to the present invention, there are provided a structural body which is constructed of a submerged horizontal plate located under a water surface and an orthogonal flat plate erected at around an end of the submerged horizontal plate on the downwave or upwave side in such a manner as to substantially intersect the advancing direction of the incoming waves and pass through the water surface, the structural body being supported by a supporting frame erected on a sea bottom and permitting the passage of sea water therethrough, so that the submerged depth thereof may be controllable according to the tide level.

As a result of this, the submerged depth of the submerged horizontal plate can be maintained to be constant and freed from the variation in the tide level and the B/d can be maintained to have an optimum value corresponding to the wavelength. In addition, a submerged depth which can give a better wave-damping performance can be advantageously selected by changing the submerged depth of the submerged horizontal plate according to the wave period of the incoming wave. Thus, a low transmission coefficient can be obtained with respect to short-period waves and, in addition, a

desired transmission coefficient can be also obtained with respect to relatively-long-period waves. Besides, the wave damper structure can be sailed as a floating body, the structure installation water-area or direction can be easily changed.

As mentioned above, according to the flow-permeable breakwater structure of the present invention, the following advantages and effects can be obtained.

(1) With respect to the long-wavelength waves, it is possible to decrease the transmission waves with a smaller scale of structure than in the prior art. As a result of this, the manufacturing cost is not only decreased but is also the water-flow transmission characteristic at around the structure, i.e.,the inflow and outflow of water into and from the relevant water area to be calmed improved. This provides very useful effects in the industrial field.

(2) By installing the additional structure components used for decreasing the reflected waves, no obstacle can be made to rise for ships or operating boats to sail in front of the wave damper structure. And,

(3) Since a substantially constant level of wave-damping action is always performed independently of the variation in the tide level, the wave damper structure is effective as that for use in a water area where the tide level largely varies.

Detailed Description of the Preferred Embodiments

Embodiments of the present invention will be described hereunder with reference to the drawings affixed hereto, in which:

Fig. 1 is a perspective view showing a flow-permeable breakwater structure as a whole according to a first embodiment of the present invention,

Fig. 2 presents graphic diagrams showing the wave-erasing performance of the flow-permeable breakwater structure shown in Fig. 1 with respect to regular waves; Fig. 2(a) illustrating the wave-erasing performance in the case where the ratio of the depth d to the width B of a submerged horizontal plate is 1/3 while, on the other hand, Fig. 2(b) illustrates the wave-damping performance in the case where the ratio of the depth d to the width B thereof is 1/2,

Fig. 3 is a graphic diagram showing the wave-damping performance of the transmission type wave eraser structure shown in Fig. 1 with respect to irregular waves,

Fig. 4 presents views showing first modified embodiments of the flow-permeable breakwater structure shown in Fig. 1; Fig. 4(a) being a typical side sectional view showing a first modified 1st embodiment, Fig. 4(b) being a typical side sectional view showing a first modified 2nd embodiment, and Fig. 4(c) being a typical side sectional view showing a first modified 3rd embodiment,

Fig. 5 presents views showing second modified embodiments of the flow-permeable breakwater structure shown in Fig. 1; Fig. 5(a) being a typical side sectional view showing a second modified 1st embodiment, Fig. 5(b) being a typical side sectional view showing a second modified 2nd embodiment, and Fig. 5(c) being a typical side sectional view showing a second modified 3rd embodiment,

Fig. 6 presents views showing third modified embodiments of the flow-permeable breakwater structure shown in Fig. 1; Fig. 6(a) being a typical side sectional view showing a third modified 1st embodiment, Fig. 6(b) being a typical side sectional view showing a third modified 2nd embodiment, Fig. 6(c) being a typical side sectional view showing a third modified 3rd embodiment, Fig. 6(d) being a typical side sectional view showing a third modified 4th embodiment, and Fig. 6(e) being a typical side sectional view showing a third modified 5th embodiment,

Fig. 7 is a perspective view showing a flow-permeable breakwater structure as a whole according to a second embodiment of the present invention,

Fig. 8 presents views showing the correlations each between the flow-permeable breakwater structure shown in Fig. 7 and the water surface at the time of high and low tide levels; Fig. 8(a) being a side view showing the correlation therebetween at the time of a low tide level, and Fig. 8(b)

being a side view showing the correlation therebetween at the time of a high tide level,

Fig. 9 is a graphic diagram showing the wave-damping performance of the flow-permeable breakwater structure shown in Fig. 7 when the tide level varies,

Fig. 10 is a graphic diagram showing the wave-damping performance of the flow-permeable breakwater structure having orthogonal flat plates when the tide level varies,

Fig. 11 is a perspective view showing a flow-permeable breakwater structure as a whole according to a third embodiment of the present invention,

Fig. 12 is a side view showing a curtain-wall type flow-permeable breakwater structure as an example of a conventional flow-permeable breakwater structure, and

Fig. 13 is a side view showing a submerged-horizontal-plate type flow-permeable breakwater structure as another example of the conventional flow-permeable breakwater structure.

First, an explanation will be given as to a flow-permeable breakwater structure according to a first embodiment illustrated in Fig. 1. The reference numeral 1 denotes a submerged horizontal plate disposed at a position corresponding to a depth (d) as measured downwardly from the water surface. The wave damper structure is composed of the submerged horizontal plate 1 and an orthogonal flat plate 2

erected at an end of the submerged horizontal plate 1 on the downwave side. This wave damper structure is supported by a supporting frame 4 erected on the sea bottom so as to permit the transmission of sea water therethrough.

As mentioned above, the orthogonal flat plate 2 is provided so as to cross the advancing direction 5 of an incoming wave W substantially at right angles thereto and to pass through the water surface. And the ratio (d/B) of the submerged depth (d) to the width B of the submerged horizontal plate 1 is set to be approximately 1/2 to 1/3.

Further, a plurality of partitioning plates 3 connecting the submerged horizontal plate 1 and the orthogonal flat plate 2 are juxtaposed with each other with a predetermined spacing therebetween so as to direct along the advancing direction 5 of the incoming wave W.

Each partitioning plate 3 is formed like a right-angled triangle having an oblique side 3a obliquely extending from around an upper end of the orthogonal flat plate 2 to around an end edge of the submerged horizontal plate 1.

Note that the supporting frame 4 is formed of elongate members such as, for example, iron bars or rods, iron pipes, or the like, thereby the water transmission characteristic is enhanced.

Note also that the wave damper structure is disposed such that the longitudinal direction 6 thereof intersects the

advancing direction 5 of the incoming wave W at right angles thereto. In the figure, the reference symbol B denotes the width of the submerged horizontal plate 1, the symbol D denotes the height of the orthogonal flat plate 2, the symbol s denotes a free board portion of the orthogonal flat plate 2, and the numeral 10 denotes the water surface level.

Since the flow-permeable breakwater structure according to this embodiment is constructed as mentioned above, the incoming wave W that has come up propagated on the water surface performs the following motions. Namely, it once attempts to pass through the structure along the upper surface of the submerged horizontal plate 1 and is reflected by the orthogonal flat plate 2 and then turned back on the submerged horizontal plate 1, and thereafter passes under the submerged horizontal plate 1. And in case of such a return wave, the motions reversed from the motions mentioned above are performed. In this way, part of the wave has its phase delayed and simultaneously moves the water on the submerged horizontal plate 1, which results in that the wave energy is partly consumed. Therefore, the wave transmitted through the structure is damped.

Further, in the case where the orthogonal flat plate 2 is erected on around the end of the submerged horizontal plate on the upwave side, owing to the synergetic effect of the orthogonal flat plate 2 and the submerged horizontal

plate 1 upon the incoming wave the transmission wave is also sufficiently damped.

And if a plurality of the partitioning plates 3 for connecting the submerged horizontal plate 1 and the orthogonal flat plate 2 are juxtaposed in parallel relation to the advancing direction of the wave, the above-mentioned motion of the wave moving along the submerged horizontal plate 1 is not only smoothly performed but is also the strength of bond between the two plates 1 and 2 increased.

Further, since the partitioning plate 3 is formed like a right-angled triangle having an oblique side 3a obliquely extending from around the upper end edge of the orthogonal flat plate 2 to around the end edge of the submerged horizontal plate 1, the strength with which the partitioning plates 3 per se are mounted is maintained to be at an appropriate level.

Fig. 2 illustrates the wave-damping performance curve with respect to a regular wave that is obtained from simulation computations and water-tank experiments. The abscissa represents the values obtained by making dimensionless the wavelength λ of the incoming wave (regular wave) by the width B of the submerged horizontal plate 1 while, on the other hand, the ordinate represents the transmission coefficient of the wave.

While Fig. 2(a) illustrates a case where the ratio of

the submerged depth d to the width B of the submerged horizontal plate 1 is 1/3, the maximum value of the wavelength λ at which the transmission coefficient is not greater than 0.5 is eighteen times as great as the width B of the submerged horizontal plate 1.

Further, while Fig. 2(b) illustrates a case where the ratio of the submerged depth d to the width B of the submerged horizontal plate 1 is 1/2, the maximum value of the wavelength λ at which the transmission coefficient is not greater than 0.5 is about twelve times as great as the width B of the submerged horizontal plate 1.

Fig. 3 illustrates the result obtained by computation determining the wave-damping performance curve with respect to irregular waves by using Bread Schneider/light-easing type spectra, from the wave-damping performance curve with respect to regular waves. As a result, the wavelength at which the transmittance is not greater than 0.5 can be understood to be at up to fifteen times as great as the width of the submerged horizontal plate 1. Specifically, for example, if the wavelength is 100m, a relatively small scale of wave-damping structure wherein the width of the submerged horizontal plate 1 is approximately 7 m and the submerged depth thereof is a depth which slightly exceeds 2 m would sufficiently serve the purpose.

For the above-mentioned reasons, even when the submerged

depth of the submerged horizontal plate 1 varies due to the variation in the tide level and the ratio of (d) to B is resultantly varied within the range of from 1/2 to 1/3, it would suffice that a relatively small scale of wave-damping structure wherein the width of the submerged horizontal plate 1 is approximately 8 m and the submerged depth thereof is approximately from 2.7 to 4 m be employed with respect even to, for example, an incoming wave having a period of 8 seconds and a wavelength of 100 m. Further, as regards an incoming wave having a period of 6 seconds and a wavelength of 56 m, it suffices that the width of the submerged horizontal plate 1 be approximately 5 m while, on the other hand, as regards an incoming wave having a period of 12 seconds and a wavelength of 225 m, it is necessary that the width thereof be approximately 20 m.

Note that although in this embodiment the submerged horizontal plate 1 and the orthogonal flat plate 2 have each been formed of a simple flat plate, they may each be formed using a somewhat largely thickened steel plate structure or a concrete-clad block structure, for example.

Further, although in this embodiment the sectional configuration of a combined structure of the plates 1 and 2 has been shaped like a character L, no inconvenience occurs even when one of the two plates 1 and 2 may be slightly partially projected from the other.

Furthermore, although in the illustrated embodiment an example has been shown in which the orthogonal flat plate 2 is provided at the end of the submerged horizontal plate 1 on the downwave side, it is confirmed from the computations and experiments that even if the former plate 2 is provided at the end of the plate 1 on the upwave side, the same effect can be obtained. Note that in the case where the orthogonal flat plate 2 is provided at the end of the submerged horizontal plate 1 on the upwave side, the incoming wave in Fig. 1 changes to the one which is indicated by the symbol W'.

The principle of the wave-damping action performed by the flow-permeable breakwater structure of the first embodiment having been formed of the above-mentioned submerged horizontal plate 1 and orthogonal flat plate 2 will now be explained.

The wavelength λ of the wave when the water depth is deep can be expressed using the wave period T as in the equation (1).

$$\lambda = \frac{g\ T^2}{2\ \pi} \text{ -------- } (1)$$

where g represents the gravitational acceleration and π represents the ratio between the circumference of a circle and the diameter thereof.

On the other hand, when the water depth is very shallow,

the wavelength λ_h of the wave with the effect of the water depth h thereon being taken into consideration can be expressed as in the equation (2).

$$\lambda_h = T\sqrt{(gh)} \text{ -------- } (2)$$

Accordingly, the smaller the depth is, the shorter the wavelength is.

In the present invention, utilizing the so-called "resonance phenomena" occurring on the submerged horizontal plate 1 that the antinode of the wave is made by the front face of the orthogonal flat plate 2 and the node of the wave is made by the other end of the submerged horizontal plate 1, the energy of the incident wave is dissipated, thereby making the transmission coefficient small. Namely, considering a case where the resonance phenomenon is caused in which the wavelength on the submerged horizontal plate 1 is four times as large as the width thereof, the relation between the wavelength λ_d on the submerged horizontal plate 1 and the width B of the same can be expressed as in the equation (3).

$$4\ B = \lambda_d \text{ -------- } (3)$$

In the above-mentioned structured mode of the flow-permeable breakwater structure, since the water depth h on the submerged horizontal plate is regarded seemingly as being the submerged depth d of this horizontal plate, when replacing the water depth h in the equation (2) by the depth d and substituting this depth d into the equation (3) and

thereby determining the relation between the width B and the wave period T at the time of resonance, the following equation (4) holds true.

$$T = \frac{4\ B}{\sqrt{(g\ d)}} \quad \text{--------} \quad (4)$$

Since the equation (4) is an approximate equation in which the motion of water outside the other end of the submerged horizontal plate 1 is left out of consideration, in actuality the following corrected equation (5) can be considered to be instead available.

$$T = \alpha \frac{4\ B}{\sqrt{(g\ d)}} \quad \text{--------} \quad (5)$$

Since the water that exists outside the other end of the submerged horizontal plate 1 has effectiveness as additional mass, the resonance period needs to be corrected to be somewhat longer. Therefore, the value of α becomes larger than 1.

In case of off-land waves (incoming waves), since the equation (1) is established between the wave period T and the wavelength λ, when eliminating the T using this expression (1) and the equation (5), the equation (6) can be obtained after all.

$$\frac{\lambda}{B} = \frac{8\ \alpha^2}{\pi} \cdot \frac{B}{d} \quad \text{------} \quad (6)$$

For example, if the value of B/d is 2 with the value of

α being assumed to be 1.5, the resonance phenomenon would be caused when the value of λ/B is approximately 11.5.

This means that a structure having a width of approximately 1/12 or less based on the wavelength of the incoming wave would exhibit the wave-damping performance.

The value of α is indefinite in the strict sense. Therefore, when estimating by determining the fluidic phenomena around the structure by using the numerical calculation technique, it has been proved that when the value of B/d is approximately from 2 to 3, the value of α is from 1.4 to 1.5.

As mentioned above, according to the first embodiment, in order to cause the occurrence of resonance phenomena, an open space, which is open at one side of the flow-permeable breakwater structure, is created by a combined unit of the orthogonal flat plate 2 and the submerged horizontal plate 1. In addition, the submerged depth of the submerged horizontal plate 1 is shallowed, thereby the width thereof is narrowed. As a result, a longer-wavelength wave which could not have been conventionally erased can be damped by a relatively small scale of the wave damper structure.

Note that when the value of B/d is increased so that the wave damper structure may be effective for damping of a wave having a wavelength which is as long as possible, a wave having a short wavelength becomes easy to pass through the

wave damper structure.

According to the experimental results or the like, the value of B/d is suitably from 2 to 3. Further, when taking the free board portion (s) and the tide level difference into consideration, the width (i.e., B) of the submerged horizontal plate 1 is suitably from once to twice or slightly more as wide as the height [D= d+s(free board portion)] of the orthogonal flat plate.

Further, according to the wave-damping principle, the orthogonal flat plate 2 is significantly placed at the end of the submerged horizontal plate 1, but may be on the upwave side or on the downwave side.

Next, the modified embodiments of the Fig. 1-illustrated first embodiment which are illustrated in Figs. 4 through 6 will be explained.

In each of those modified embodiments, the above-constructed Fig. 1-illustrated first embodiment flow-permeable breakwater structure is additionally provided therein with a means for damping the wave reflected by the orthogonal flat plate 2.

Namely, in the first modified embodiment of Fig. 4, in order to obstruct the flow of the reflected wave along the upper or lower surface of the submerged horizontal plate 1, a protrusion member 7 is attached to the end thereof at which the orthogonal flat plate 2 is not erected.

The protrusion member 7 in some cases is provided projecting upwardly from the submerged horizontal plate 1 as illustrated in the first modified 1st embodiment of Fig. 4(a), and in other cases is provided projecting downwardly from the submerged horizontal plate 1 as illustrated in the first modified 2nd embodiment of Fig. 4(b). Further, in some cases, the protrusion member 7 is provided projecting both upwardly and downwardly from the submerged horizontal plate 1 as illustrated in the first modified 3rd embodiment of Fig. 4(c). In any case, by means of the protrusion member 7, vortexes for example are formed utilizing the flow of the water around the wave damper structure, to thereby perform the action of reducing the energy of the reflected wave.

Accordingly, in order to cause the above-mentioned action to be effectively performed by the protrusion member 7, this member 7 is provided at a position where the above-mentioned resonance phenomena on the submerged horizontal plate 1 are not obstructed and the speed of the water flow is high, namely at the end of the submerged horizontal plate 1 at which the orthogonal flat plate 2 is not erected.

Further, in a second modified embodiment of Fig. 5, in the vicinity of the end of the submerged horizontal plate 1 at which the orthogonal flat plate 2 is not erected, a plate structure 8 is provided above the submerged horizontal plate 1 and below the water surface 10.

This plate structure 8 provides similar actions and effects to those performed and obtained by the protrusion member 7 according to the above-mentioned first modified embodiment. In some cases, it is attached to the submerged horizontal plate 1 orthogonally with respect thereto as illustrated in the second modified 1st embodiment of Fig. 5(a) and, in other, is attached to the horizontal plate 1 obliquely with respect thereto as illustrated in the second modified 2nd embodiment of Fig. 5(b). Further, in cases where the plate structure having a T-shaped cross section is attached as illustrated in the second modified 3rd embodiment of Fig. 5(c), the reflected-wave-energy attenuating action and effect are also obtained almost similarly.

Further, in a third modified embodiment of Fig. 6, a plate structure 9 is provided at a position that is spaced from the submerged horizontal plate 1 on the upwave side, so that the plate structure 9 may be located under the water surface 10.

This plate structure 9 is disposed in such a manner as to be orthogonal or slantwise with respect to the submerged horizontal plate 1, or in the form having a T-shaped cross section with respect thereto, as illustrated in the third modified 1st-to-3rd embodiments of Figs. 6(a), 6(b), and 6(c). Or the plate structure 9 is plurally disposed orthogonally at substantially the same depth as that in case

of the orthogonal flat plate 2, or in such a manner as to be at different depths and at slantwise spaced positions, as illustrated in the third modified 4th-and-5th embodiments of Figs. 6(d) and 6(e). In any case, by providing the plate structure 9, the wave damper structure according to this third modified embodiments as well can bring about similar actions and effects of enabling the reduction in the energy of the reflected wave to those performed and obtained in the case of the first modified embodiments.

Meanwhile, although according to the above-mentioned equation (6) the wave damper structure can have an effect upon longer-wavelength waves as the value of B/d increases, since it becomes more likely to permit the passage therethrough of shorter-wavelength waves, an optimum value of B/d is selected according to the transmission coefficient when the structure is put to practical use.

However, since the submerged depth d of the submerged horizontal plate 1 exhibits variations in a water area where the variations in the tide level are large, the value of B/d varies according to the tide level. Therefore, it may happen that the wave-damping performance at a B/d value which is not optimum must be utilized, as far as designing stage is concerned.

Thus, the flow-permeable breakwater structures which have been improved so as to cope with the variations in the

tide level are those according to the following second and third embodiments.

Next, a flow-permeable breakwater structure according to a second embodiment of the present invention will be explained with reference to Fig. 7.

As illustrated in Fig. 7, the flow-permeable breakwater structure according to this second embodiment is constructed in such a manner that a submerged horizontal plate 11 disposed submerged under the water surface 10 and an inclined plate 12 erected at around an end of the horizontal plate 11 on the downwave side in a manner upwardly inclined toward the downwave side are supported by a support frame 13 erected on the sea bottom so as to permit the passage therethrough of the sea water. The inclined plate 12 is provided in a direction intersecting the advancing direction W of the incoming wave 5 substantially at right angles thereto and in such a manner as to pass through the water surface.

Fig. 8(a) illustrates the correlation between the water surface 10 and the inclined plate 12 during low sea-surface level (low tide) while, on the other hand, Fig. 8(b) illustrates the same correlation therebetween during high sea-surface level (high tide). The symbols d_L and d_H represent the submerged depths of the submerged horizontal plate 11 during the low tide and during the high tide, respectively, and the symbols B_L and B_H represent the

distances each between the inclined plate 12 and the front edge of the submerged horizontal plate 11 at the water surface level during the low tide and at the water surface level during the high tide, respectively.

In the case of this second embodiment, since the inclined plate 12 is upwardly inclined toward the downwave side, the value of d_L is smaller than the value of d_H and, in correspondence therewith, B_L is also smaller than B_H. As a result, the difference between B_L/d_L and B_H/d_H becomes smaller than in the case where the inclined plate 12 is not inclined.

Assume, for example, that the tide-level difference between during low tide (low sea-surface level) and during high tide (high sea-surface level) be 2 m with the width B_H of the submerged horizontal plate during the high sea-surface level being set to be 16 m and with the submerged depth d_H of the submerged horizontal plate being set to be 8 m. Then, during the high sea-surface level, B_H/d_H= 2.0, whereas, in case that the orthogonal flat plat 2 is used as in the first embodiment, during the low sea-surface level, B_L/d_L= 16m/6 = 2.67. In contrast, in case that the inclination angle of the inclined plate 12 is set to be 53 degrees (in case that the plate 12 is orthogonally disposed, the inclination angle is assumed to be 90 degrees), during the low sea-surface level, B_L= 14.5 m, and d_L= 6 m, and therefore B_L/d_L= 2.42. Thus, it

is possible to approach the value of this ratio more to B_H/d_H= 2.0.

Further, as regards the wave-damping performance obtained with the use of the numerical calculation technique, as is indicated by the performance curves of Fig. 9 which represent the transmission coefficients during the low sea-surface level (broken lines in the figure) and during the high sea-surface level (solid lines in the figure), respectively, the both transmission coefficients can be made substantially equal to each other. Namely, it is seen that, irrespective of the tide-level or sea-surface-level difference, the transmission coefficient of 0.36 or less can be achieved with respect to the wave having a wave period of 12.5 seconds or less and a wavelength of 244 mm or less.

In contrast, Fig. 10 illustrates the calculated results obtained concerning the case of the first embodiment wherein the inclined plate 12 is not adopted but the orthogonal flat plate 2 having an inclination angle of 90 degrees is adopted. The Fig. 10 illustration presents the performance curves obtained under the conditions wherein, with the width B of the submerged horizontal plate being set to be 16 m, during the high sea-surface level the submerged depth d_H of the submerged horizontal plate is 8 m and B/d_H= 2, and during the low sea-surface level d_L= 6 m and B/d_L= 2.67. Although when the Fig. 9 performance curve and the Fig. 10 performance

curve are compared with each other, no significant difference exists regarding the low sea-surface level (broken lines in the figure), in case of Fig. 10 the performance during the high sea-surface level (solid lines in the figure) indicates that although it has a low transmission coefficient with respect to short-period waves, the effective wave-period region is narrower. Since in the stage of designing it is necessary to compare the inferior characteristics of the both performances, it can be said after all that the flow-permeable breakwater structure according to this second embodiment is superior to that according to the first embodiment.

Note that regarding the flow-permeable breakwater structure according to this second embodiment as well it is confirmed by the calculations and experiments that even when the inclined plate 12 is provided at the end of the submerged horizontal plate 11 on the upwave side, similar effects to those obtained when the plate 12 is disposed on the downwave side can be obtained as in the case of the first embodiment.

An explanation will now be given as to a flow-permeable breakwater structure according to a third embodiment of the present invention with reference to Fig. 11.

The flow-permeable breakwater structure according to the third embodiment of the present invention comprises a structural body 17 which, as shown in Fig. 11, is constructed

of a submerged horizontal plate 11 disposed submerged under the water surface 10, an orthogonal flat plate 12a orthogonally disposed at around an end of the submerged horizontal plate 11 on the downwave side in such a manner as to intersect the advancing direction of the incoming wave substantially at right angles thereto and to pass through the water surface, and floating body portions 17a to which both sides of each of the horizontal plate 11 and the orthogonal flat plate 12a are mounted respectively. This structural body 17 is supported so as to have the submerged-depth controlled according to the tide level, by four legs 16 serving as supporting frames which are planted in the sea bottom so as to permit the passage therethrough of the sea water.

That is, in the case of this third embodiment, the wave eraser structure has a submerged-depth controlling mechanism so that the submerged depth of the submerged horizontal plate 11 may be kept to be substantially constant.

As the above-mentioned submerged-depth controlling mechanism, there can be adopted a so-called rack-and-pinion mechanism wherein while, on one hand, teeth (straight teeth) for example are formed on each leg 16, the gears meshed therewith are, on the other hand, formed within the structural body 17 and, according to the tide level, those gears are each rotated to thereby control the vertical

position of the structural body 17. Also, besides, the legs 16 may be each formed into an expandable/contractible structure wherein the effective length of each leg 16 is controllable by operation of a hydraulic jack. And by operating the hydraulic jack according to the variation in the tide level, the length (depth) of the leg 16 may be controlled so as to keep the submerged depth of the submerged horizontal plate 11 to be substantially constant. Further, an arrangement may be given in which the submerged depth can be maintained by the floating body portions 17a of the structural body 17. With such an arrangement, the structural body 17 may be fixed to the legs 16 according to each specified one of the tide levels.

Note that it is confirmed by the computations and experiments that in this third embodiment as well even when the orthogonal flat plate 12a is attached to around the end of the submerged horizontal plate 11 on the upwave side, similar actions and effects to those performed and obtained when it has been attached to around the plate 11 end on the downwave side can be procured.

According to this third embodiment, in addition to the advantage that the wave damper structure is not influenced by the variation in the tide level, when saying with reference to, for example, Fig. 10, a submerged depth which can give a better wave-damping performance can be advantageously

selected by changing the submerged depth of the submerged horizontal plate according to the wave period of the incoming wave. Therefore, a low transmission coefficient can be obtained with respect to short-period waves and, in addition, a desired transmission coefficient can be also obtained with respect to relatively-long-period waves. Besides, since by providing the structural body 17 the wave damper structure can be sailed as a floating body with its legs being uplifted, the installation water-area or direction can be easily changed.

Note that although the above explanations have been given such that with the width of the submerged horizontal plate being set to be 16 m the relevant wave damper structure can have effectiveness up to the wave having a wave period of approximately 12 seconds, the width of the submerged plate may be narrower if the wave period of the object wave to be damped is short.

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What is claimed is:

1) A flow-permeable breakwater structure adapted to ensure inflow and outflow of water into and from a water area and to decrease the wave height of incoming waves and thereby ensure a desired level of calmness within the water area, characterized by comprising a supporting frame 4 erected on a sea bottom and permitting the passage of sea water therethrough, a submerged horizontal plate 1 supported by the supporting frame 4 and located under the water surface 10, and an orthogonal flat plate 2 disposed on around an end of the submerged horizontal plate 1 on the downwave or upwave side in such a manner as to intersect the advancing direction of the incoming wave W substantially at right angles thereto and to pass through the water surface 10.

2) A flow-permeable breakwater structure according to claim 1, characterized in that a plurality of partitioning plates 3 each connecting the submerged horizontal plate 1 and the orthogonal flat plate 2 are juxtaposed at space intervals along the advancing direction of the incoming wave W.

3) A flow-permeable breakwater structure according to claim 2, characterized in that each of the partitioning plates 3 is formed like a right-angled triangle having an inclined side 3a obliquely extending from around an upper edge of the orthogonal flat plate 2 to around the end edge of the submerged horizontal plate 1.

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4) A flow-permeable breakwater structure according to claim 1, 2, or 3, characterized in that the width B of the submerged horizontal plate 1 is set to be greater than the height D of the orthogonal flat plate 2.

5) A flow-permeable breakwater structure according to claim 1, 2, 3, or 4, characterized in that to an end of the submerged horizontal plate 1 at which the orthogonal flat plate 2 is not erected there is attached a protrusion member 7 so as to obstruct the flow of the water going along an upper or lower surface of the submerged horizontal plate 1.

6) A flow-permeable breakwater structure according to claim 1, 2, 3, or 4, characterized in that a plate structure 8 is provided at around the end of the submerged horizontal plate at which the orthogonal flat plate 2 is not erected in such a manner as to be located above the submerged horizontal plate and under the water surface 10.

7) A flow-permeable breakwater structure according to claim 1, 2, 3, or 4, characterized in that a plate structure 9 is disposed in such a manner as to be spaced away from the submerged horizontal plate 1 on the upwave side and located under the water surface 10.

8) A flow-permeable breakwater structure adapted to ensure inflow and outflow of water into and from a water area and to decrease the wave height of incoming waves and thereby ensure a desired level of calmness within the water area,

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characterized by comprising a supporting frame 13 erected on a sea bottom and permitting the passage of sea water therethrough, a submerged horizontal plate 11 supported by the supporting frame 13 and located under the water surface, and an inclined plate 12 erected at around an end of the submerged horizontal plate 11 on the downwave or upwave side and upwardly inclined toward the downwave side in such a manner as to substantially intersect the advancing direction of the incoming waves and pass through the water surface 10.

9) A flow-permeable breakwater structure adapted to ensure inflow and outflow of water into and from a water area and to decrease the wave height of incoming waves and thereby ensure a desired level of calmness within the water area, characterized by comprising a structural body 17 which is constructed of a submerged horizontal plate 11 located under a water surface 10 and an orthogonal flat plate 12a erected at around an end of the submerged horizontal plate 11 on the downwave or upwave side in such a manner as to substantially intersect the advancing direction of the incoming waves and pass through the water surface 10, the structural body 17 being supported by a supporting frame 16 erected on a sea bottom and permitting the passage of sea water therethrough, so that the submerged depth thereof may be controllable according to the tide level.