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An Attempt to Make High Performance Wave Energy System

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ABSTRACT

This paper deals with the method to amplify the vertical motion of the water around the floats whose vertical motion is utilized in movable body type wave generation system combined with OWC. Differently from the ordinary OWC, it does not need to endure the high pressure nor need air/water tight property of the wall. Model experiment performed in a water pool using a model caisson showed that amplification ratio increases with decrease of the ratio of caisson space (a) to the wave length (L). Amplification ratio distributes in the range about 0.75-2, 1.3-2.5, and 2-3.5, when the value of a/(L/4) is 1.0, 0.67 and 0.33, respectively. Also the theory of Malmo & Reiten is examined.

KEY WORDS: Movable body; Floats-type; Vertical motion; OWC; Amplification; Free from pressure; Space/wave length ratio.

INTRODUCTION

The authors are developing a movable body type wave energy generation system which utilizes vertical motion of the floats to extract wave energy (Hadano et al.,1998). In the present study we try to get high performance by setting the walls to amplify the motion of floats which enclose the floats and whose top and bottom are open to constitute OWC. This system is a movable type combined with OWC system, which seems to have advantage of low cost. Differently from the ordinary OWC, this system employs the vertical motion of floats as movable body and does not use turbine. Therefore it neither needs to endure high pressure nor needs water/air tight property of walls. As usual OWC, the above constitution makes motion of the water inside the walls vertical and suppresses the horizontal motion there. This also solves the problem that horizontal force acts on the floats and therefore on the supporting part of the system, which has been one of the most serious problems of authors' system.

Model experiments were carried out in the water pool with water depth fixed and changing the wave period (T). The experimental model used consists of a frontal lip whose lower part is submerged a little, a back wall and side walls, and is placed on the bottom of the pool, i.e. like the model caisson used for model experiment of MOWC(cf. Thiruvenkatasamy et al.(1998), ISOPE). The experiments were made imaging the MOWC each of which is separated with spacing (S), with the width of the model (b) fixed. In the experiments, distance between back wall and frontal lip (a), submergence of the frontal lip (d), spacing between the next models (S) are changed. Thus the dependence of the amplification on the dimensionless parameters of a/L, d/H, b/S, a/b is closely examined. The result of amplification was compared with the theory of Malm & Reiten(1985,JFM). It proved that the present experimental data is well described by the theory of Malm & Reiten.

ROUGH ESTIMATION OF THE ENERGY GAIN

Energy Conversion System

We try to estimate the energy by the system that the authors are developing (e.g., Hadano et al., 1998). The energy converting mechanism of the authors' system is briefly explained. A wire both ends of which are connected with a pair of a float and a counterweight connected is hanged from the pulley placed above the water surface. If the float is on the water surface and the water wave occurs, the pulley rotates alternately. The alternate rotational motion is converted into a uni-directional rotational motion of the shaft. This is the basic element of the energy conversion. If the multiple energy conversion elements are connected, each pair of the float and counterweight moves independently by water wave motion and cooperates to rotate generator. By inserting a part that transmits power by only the tension of the wire, this system has solved the main part of the structural strength problem popular to the most movable body type.

Energy gain estimated by the static consideration

In this system, a pair of float and counter weight do up/down motion according to the water wave motion. Exact energy gain should be estimated by taking account of the dynamic effect due to the accelerating motion of the heavy floats(Saito at al., 1999). However since the speculation of the generator used in the prototype system such as the electric resistance which influences the float motion are not confirmed by the authors, we decided to make estimation neglecting the dynamic effects at present. If we ignore dynamic effect of the up/down motion of the float, the greatest value of the possible rate of energy gain would be obtained when the amplitude of the vertical motion is half that of the water level change. In this case, the rate of energy gain would be estimated as

$$Pf=wAH^2/(16T) \quad (1)$$

Where, w is the unit weight of water, A the horizontal cross-sectional area of a float, H the wave height, T the wave period. The energy gain, however, can not exceed the product of wave power (Fe) and the length of the float in the direction of wave crest line (D). Therefore, the possible rate of energy gain in this system would be roughly expressed as below.

$$P = Min(Pf, FeD) \quad (2)$$

Where, Min indicates a function indicating the minimum of the values in the bracket, and Pf is given by eq. (1). Anyway obtainable energy is proportional to the square of wave height. Figure 1 shows an example of the estimation obtained in the above process for the case of a cylinder of diameter D=5m. The open symbols express the obtainable energy for the case of simple sinusoidal wave, and the closed symbols express those for the case in which the amplitude near the float is increased to the twice that of the incident wave. It is clear that when the wave period T is 2 and 3 second, the possible rate of energy gain P is governed by the value of limited wave power in these short periods. So the effect of amplification of the vertical motion of the water inside the caisson can not be expected. Whereas in the case of longer period, the possible rate of energy gain will be governed by of the vertical motion of the floats and therefore water around the float, so the effect of the amplification can be expected.

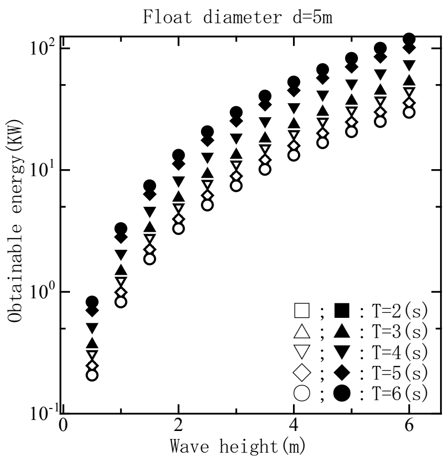


Fig.1 Rough estimation of obtainable energy

EXPERIMENT

Experimental model and the procedure

Experiments were performed in a water pool of Nippon Bunri University. The pool is 40m long, 15m wide and the water depth was set at 0.35m. The wave height (H) was set at 0.6m and wave period (T) was changed as 1sec, 2sec, and 3sec, wave length (L) 1.42m, 3.49m, and 5.45m, respectively. Figure 2 shows a schematic view of the experimental model. As shown in the figure, experimental model used consists of a frontal lip whose lower part is submerged a little, a back wall and side walls, and is placed on the bottom of the pool, i.e. like the model caisson used for model experiment of MOWC(cf. Thiruvenkatasamy et al.,1998). The dimension of the model was b=0.5m wide, and the longitudinal length (a) was changed as a/(L/4)=0.33, 0.67 and 1.0. Submergence of the frontal lip (d) was changed as 0.05m, 0.07m, and 0.1m, spacing between the next models (S) set imaging MOWC was changed as 1m, 1.5m, 2.0m so that S/b is around 3 at which high efficiency is expected for usual MOWC (cf. Thiruvenkatasamy et al.,1998). Table 1 indicates the experimental condition. According to the condition of resonance, the value of (a+l) in Fig.2 was set at a quarter the wave length. In the experiments, the maximum value of the vertical change in the water level was measured at the positions out side the model caisson (H1), inside 0.1m apart from the frontal lip (H2), at the midpoint of these lip and wall (H3), and at 0.1m from the back wall (H4) on the center line of the model caisson. These quantities will be called here the wave height at these positions for convenience. Also the quantities H2/H1, H3/H1, and H4/H1 will be called the amplification ratio.

Table 1 Experimental conditions

T(sec)	H(cm)	a/(L/4)	S/b	d(cm)
1,2,3	6	0.33, 0.66, 1.0	2, 3, 4	5, 7, 10
1,2,3	6	0.33, 0.66, 1.0	2, 3, 4	5, 7, 10
1,2,3	6	0.33, 0.66, 1.0	2, 3, 4	5, 7, 10

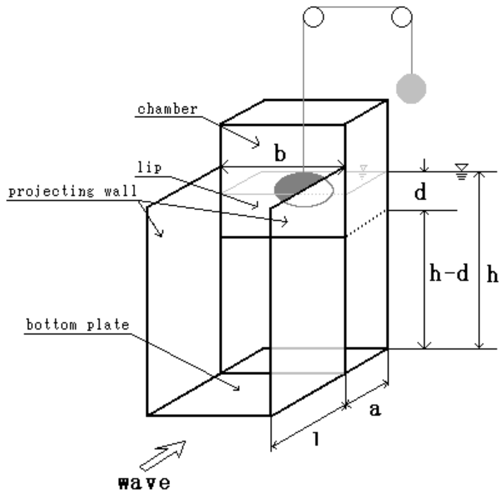


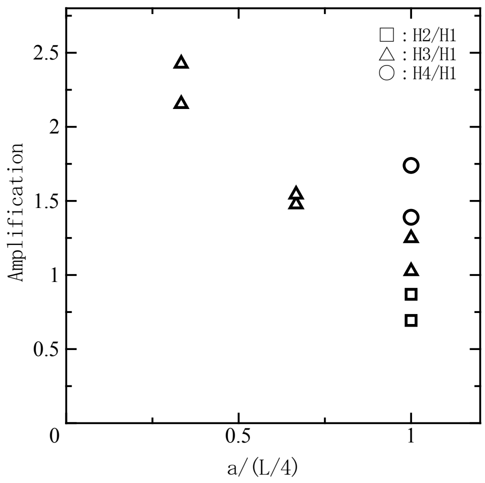
Fig.2 Schematic view of model caisson

Experimental Results

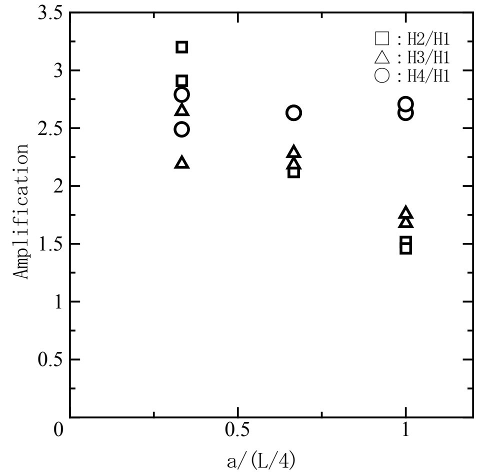
The dependence of amplification on the dimensionless parameters a/(L/4), d/H, b/S was examined. Fig. 3 shows examples of the relation between amplification ratio and the space to a quarter wave length ratio a/(L/4). It is clear that the amplification ratio decreases with increase of the space to a quarter wave length ratio a/(L/4). The value of amplification ratio distributes in the range about 0.75-2, 1.3-2.5, and 2-3.5, when the value of a/(L/4) is 1.0, 0.67 and 0.33, respectively. The variation of H4/H1 is smaller than that of H2/H1 and H3/H1. Value of the amplification ratio in the case of T=3sec is greater than that in the case of T=1sec. These tendencies are common to all other combinations of the dimensionless parameters mentioned before. Change in the value of amplification ratio due to the wave period will be considered from the theory of Malm & Reiten(1985).

The change of the amplification ratio by the changes of parameters d/H and S/b was also examined. Figure 4 shows the examples of the relation between the amplification ratio and the submergence of the frontal lip to wave height ratio (d/H1). Tendency of the change in amplification ratio due to d/H can not be recognized. This property seems to be common to the cases of other values of the dimensionless parameters. Fig.5 shows the examples of the change in amplification ratio due to the value of spacing to width ratio (S/b). It is recognized that the amplification ratio becomes the maximum at S/b value of about 3 as was shown by Thiruvenkatasamy et al.(1998). It seems that about 3 would be recommended for the value of S/b if we expect high amplification ratio.

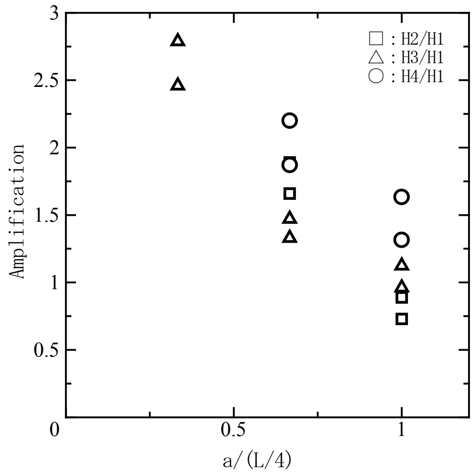
Next the experimental result of amplification will be compared with the theory of Malm & Reiten(1985). Fig.6 shows the result for preliminary experiments performed by the conditions: T=1sec, L=1.424m, a=0.2m, l=0.356m, S=1m, d=0.05, 0.07 and 0.10m. In the figure vertical scale is the amplification ratio and the horizontal scale is frequency of the wave. Experimental values, which are based on the measurement made at the midpoint of model caisson, are indicated by open square(d=0.05m), closed circle(d=0.07m) and closed triangle(d=0.10m). Theoretical results are indicated by curves; dotted line, broken line and real line indicate the results for d=0.05m, 0.07m and 0.10m, respectively. From the figure the values of amplification ratio predicted by the theory of Malm & Reiten are a little greater than those of experiments. Though the experimental data of H3 were used, if experimental data for H4 had been used, the difference between the theory and experiment will be reduced. In the case of this model dimension and the wave periods amplification ratio is the greatest when d=0.10m and is the least when d=0.05m. This relation is consistent between the experiment and theory. So it would be concluded that the theory is applicable to the present experiment for the prediction of the amplification.



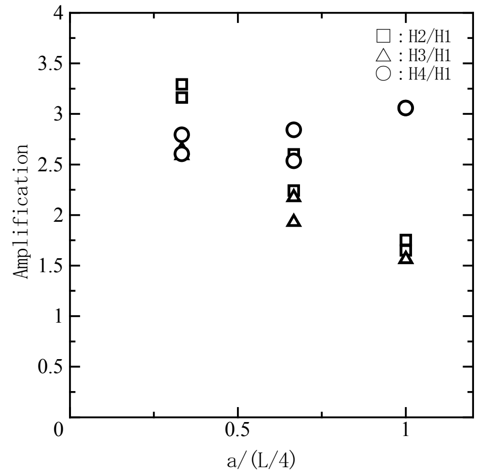
(a) T=1sec, S/b=4, d=5cm



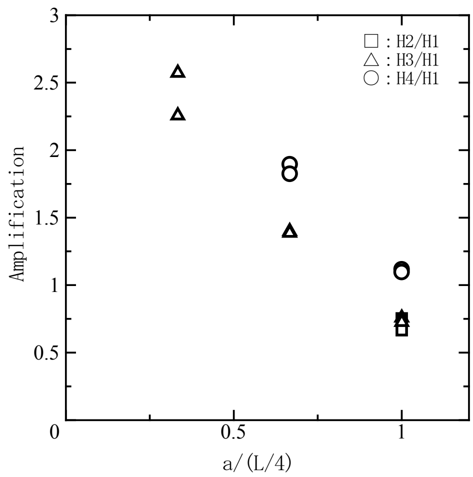
(d) T=2sec, S/b=4, d=5cm



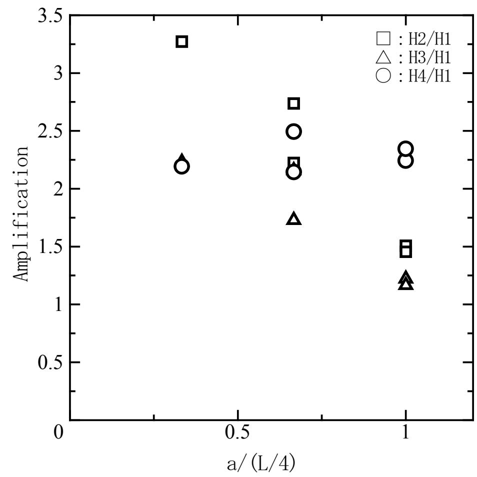
(b) T=1sec, S/b=4, d=7cm



(e) T=2sec, S/b=4, d=7cm

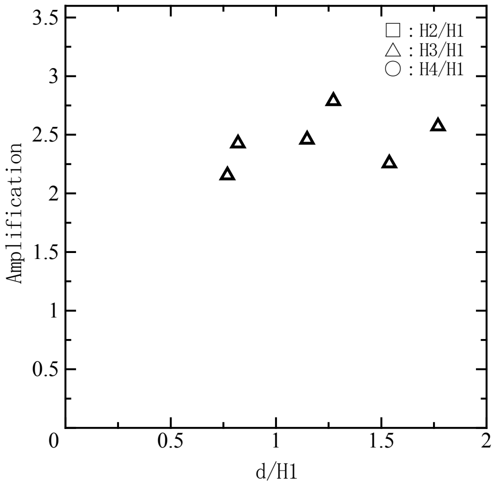


(c) T=1sec, S/b=4, d=7cm

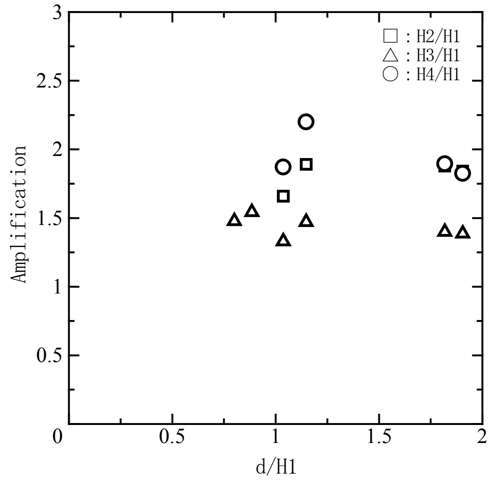


(f) T=2sec, S/b=4, d=7cm

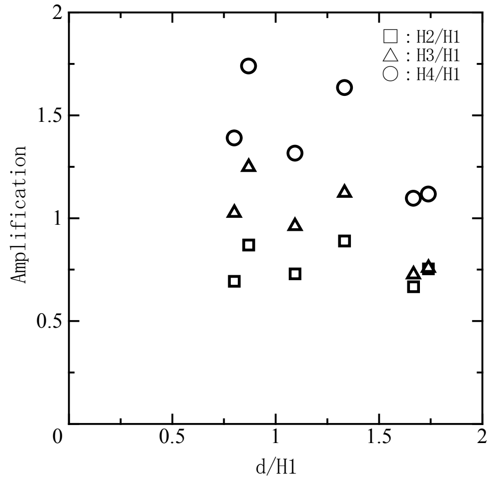
Fig.3 Relation between Amplification ratio and a/(L/4)



(a) T=1sec, S/b=4, a/(L/4)=0.33

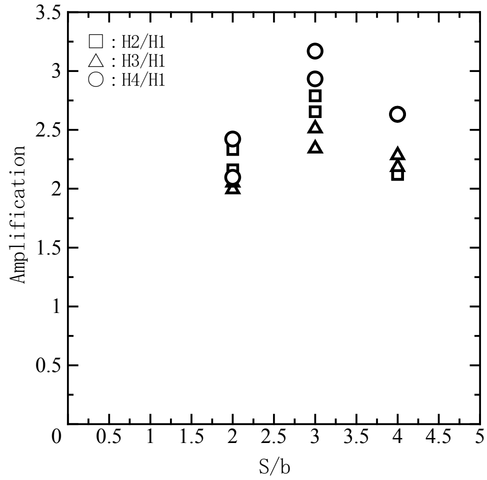


(b) T=1sec, S/b=4, a/(L/4)=0.67

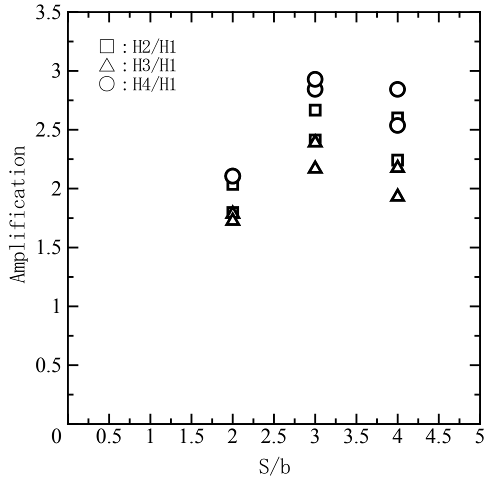


(c) T=1sec, S/b=4, a/(L/4)=1.00

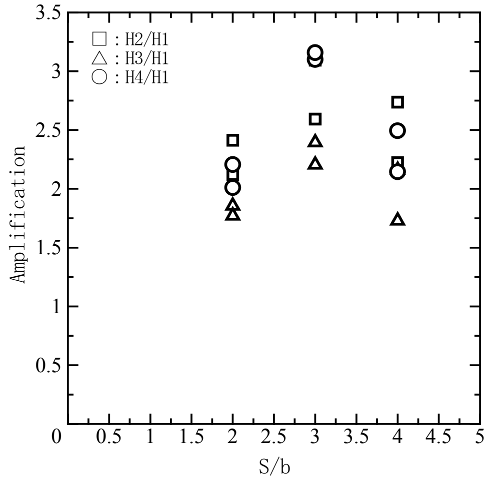
Fig.4 Relation between Amplification ratio and d/H



(a) T=2sec, a/(L/4)=0.67, d=5cm



(b) T=2sec, a/(L/4)=0.67, d=7cm



(c) T=2sec, a/(L/4)=0.67, d=10cm

Fig.5 Relation between Amplification ratio and S/b

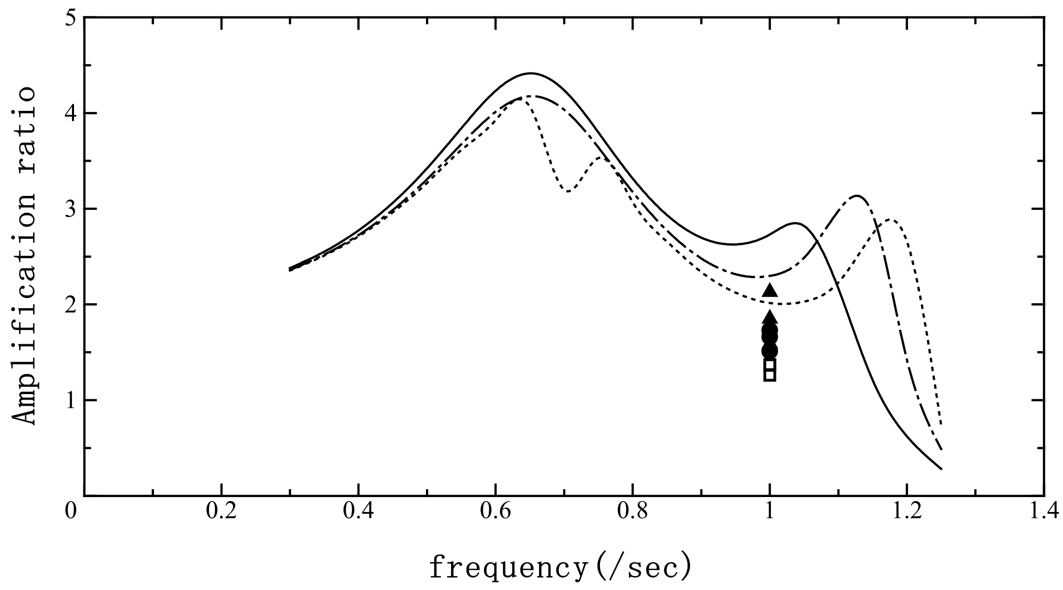


Fig.6 Examination of Malmo & Reiten's theory

CONCLUSION

So far we examined the amplification of the vertical motion of water inside of the caisson to be used for OWC combined with the movable body type wave generation system. It has been made clear that the amplification ratio decreases with increase of the ratio of the distance between frontal lip and back wall (a) to wave length (L). In the present experiments, value of amplification ratio distributed in the range about 0.75-2, 1.3-2.5, and 2-3.5, when the value of a/(L/4) is 1.0, 0.67 and 0.33, respectively. Effect of the submergence of frontal lip to wave height ratio was not recognized. About 3 times the width of the caisson would be recommended for the spacing between the next models in the MOWC arrangement. Result of the examination of Malmo & Reiten's theory implies that the theory is applicable to the problem of amplification of vertical motion of the water inside the caisson in array.

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REFERENCES

K. Hadano, T. Saito, S.Kawano, M.Hashida and T.Ozaki (1998) "A proposal of multi-floats type wave energy conversion system", Proc 8th ISOPE Conference, pp.100-105.

O. Malmo and A. Reiten (1985) "Wave power absorption by an oscillating column in a channel", J Fluid Mech, 158, pp.153-175, 1985.

T.Saito, K. Hadano, N.Murakami and T.Ozaki "Research on fundamental performance of multi-floats type wave energy conversion system", Proc 9th ISOPE Conference, vol1. pp.150-155, 1999.

K. Thiruvenkatasamy, S. Neelamani and M. Sato (1998) "On the dynamic parametric comparison of MOWC wave energy caisson in array", Proc 8th ISOPE Conference,vol1. pp.119-126.