DEVELOPMENT ON OFFSHORE STRUCTURE WITH WAVE FORCE REDUCTION

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Authors have developed the offshore structure for control of sea environment named S-VHS construction method, which is composed of the sloping top slit-type caisson and steel pipe piles. The sloping top form enables to realize the remarkable reduction of wave force exerted on the dike body compared with the conventional one.

In this paper, hydraulic feature with wave dissipation ability and wave force reduction effect are verified through some hydraulic experiments. After the preliminary study for the valid structure form, reflection and transmission ability for the selected structure models were tested with the hydraulic experiment relevant to the ratio of caisson width and wave length. Finally, wave force experiment was executed and it revealed the performance of wave force reduction. Based on the results, we proposed specific design wave force formula for S-VHS construction method.

Keywords: hydraulic experiment, sloping top caisson, slit caisson, MMZ, S-VHS construction method, VHS construction method

Introduction

MMZ (Marine Multi Zone) project has executed by Ministry of works of Japan since 1979. over 20 companies such as contractors, steel producers, and shipbuilders are participated in this project. The aim of this project is the development of offshore structures which prevent beach erosion and maintain sea tranquility. After the fundamental studies at that time, required performance of the structure under average wave condition, must have reflection and transmitted ability, reflection ratio was under 0.5, and transmitted ratio was under 0.6. Through some fundamental studies, required reflection and transmission ability are decided for the MMZ structures that reflection and transmission ratio do not exceed 0.5 and 0.6 under average wave condition, respectively.

One of the structures which had satisfied these requirements was VHS construction method, which had devised at this project. The feature of the structure was permeable caisson which consisted of, lower crown, three vertical slit walls, and horizontal slit walls.

Picture-1 shows the VHS jetties, constructed in the Toyama prefecture. As seen in this picture, VHS construction method had been applied to several coasts.

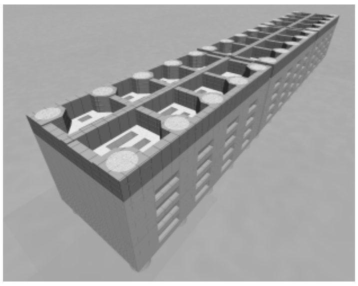
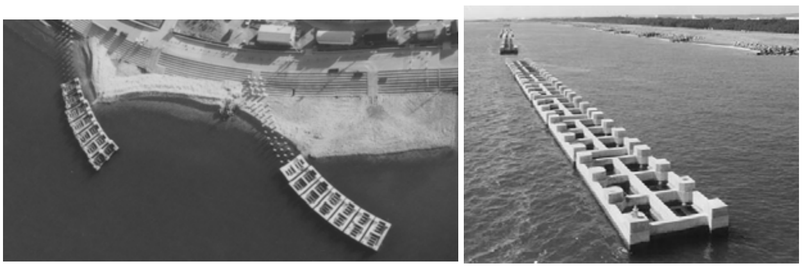


Figure-1 VHS construction method



Picture-1 VHS construction method

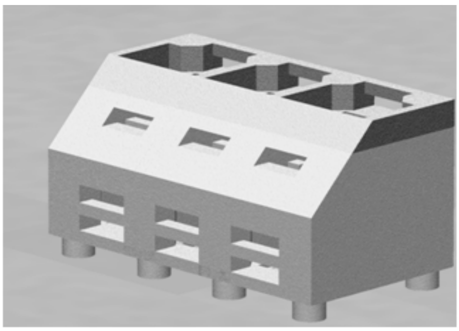


Figure-2 S-VHS construction method

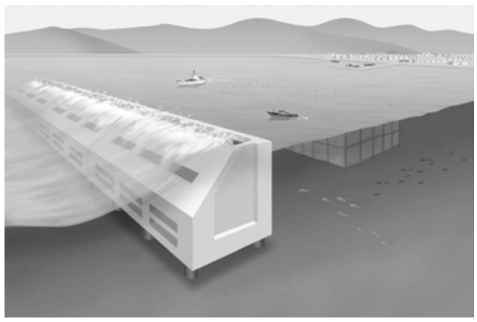


Figure-3 Images of S-VHS

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Good wave dissipation ability was reported for the constructed VHS in some coasts, however, the wave force which acts on an anterior wall was comparatively larger. So the configuration and costs of VHS on construction tends to be large. Then, we had decided to start research towards the advancement of VHS to decrease the external force.

Through the fundamental experiment, making an anterior wall into sloping dike structure enables to reduce wave force and improve economical efficiency. This was named S-VHS construction method (figure-2, and figure-3).

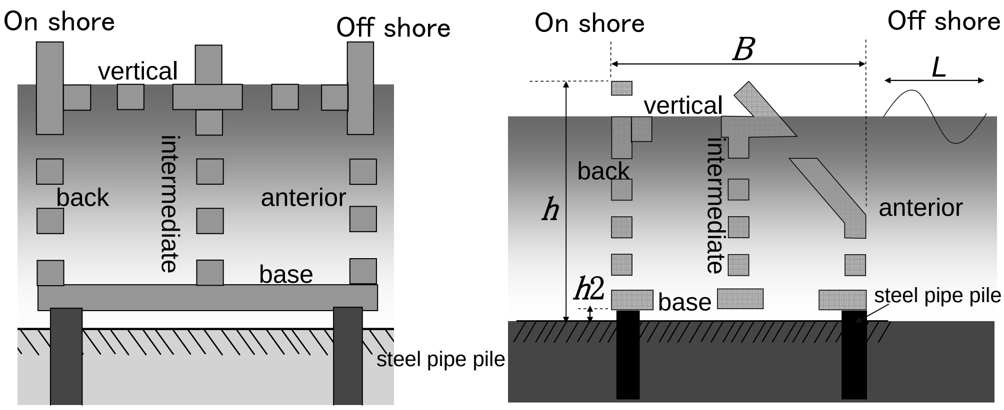
The purpose of the study is to confirm the wave dissipation ability of S-VHS method in detail and to establish the design method of wave force.

Basic parameter of the structures

Table-1 shows comparison of the open aperture ratio of each member of framework. After preliminary analysis and experiment, we have decided that S-VHS has a sloping dike with aperture ratio of 25%, back wall of 35%, and base slab of 30% in addition we proposed 2 types ratio of base slab clearance to whole structure height(h2/h). The reasons for raising aperture ratio had been to reduce the weight of box and up-lift force from waves within maintaining the wave dissipation performance. On the other hand, introduced sloping dike was expected to decrease the horizontal wave force acted on anterior wall and the up-lift pressure exerted on both upper and bottom slabs.

Table-1 Comparison aperture ratio of VHS and S-VHS construction method

Parts	Aperture rate	
Type	VHS	S-VHS
Anterior	25%	Slope 15% Vertical 25%
Horizontal	15%	30%
Intermediate	25%	25%
back	25%	35%
base	0%	30%
h2/h	0	0.05,0.2



VHS construction method S-VHS construction method

Figure-4 Cross sectional view of VHS and S-VHS construction method

Methodology

Two types of hydraulic experiments are carried out in a 2-dimensional water flume. One is the experiment for the inspection of wave dissipation ability (shown in figure-5), and the other is for that of wave force reduction(shown in figure-7). Wave gages and the hydraulic model are set in the flume for the former experiment to measure the incident, reflected and transparent wave height based on the Goda et. al.'s method. For the latter one, a component wave force gage, pressure sensors and slopes with the 1/10 or 1/50 angle are additionally set to determine both horizontal wave force and up lift pressure. The scales of the experiments are 1/25 according to the law of Froude similitude.

In the former experiment, water depth is constant and wave conditions are non-breaking. The experimental cases of wave dissipation ability are shown in Table-2.Wave heights which conducted in the experiments are 0.04 to 0.12m in the form of regular and irregular wave conditions. Wave periods are given from 1.0 to 2.8s. In the latter experiment, the experimental cases of wave force reduction ability are shown in Table-3.Wave heights are 0.18 to 0.45m, where whole of wave condition are regular waves and irregular conditions are added in part. Wave periods are given from 1.8 to 3.2s.

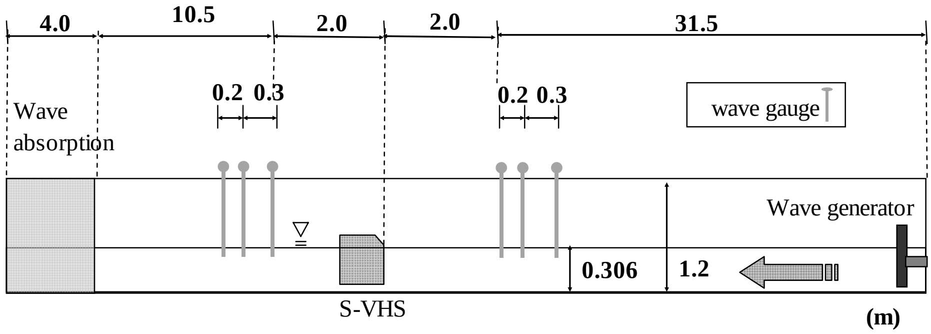


Figure-5 Cross sectional view of the experiment (conduct wave dissipation ability)

Table-2 Experimental case(conduct wave dissipation ability)

Type	S-VHS
B/h	1.04, 1.18
h2/h	0.05, 0.2
Water depth(m)	MWL(0.306)
Wave height (m)	Regular and Irregular 0.04, 0.08, 0.12
Wave period (s)	1.0, 1.2, 1.6, 2.0, 2.4, 2.8

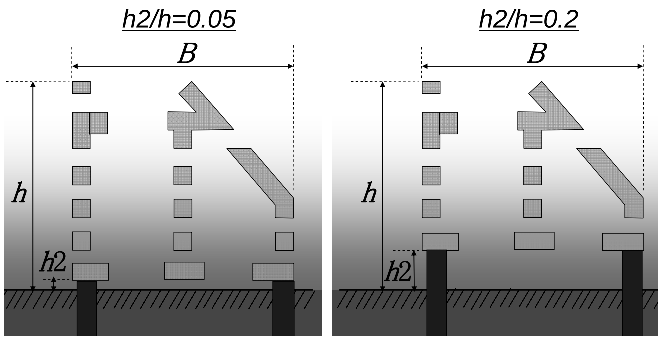


Figure-6 Caisson type of h2/h=0.05 and 0.2

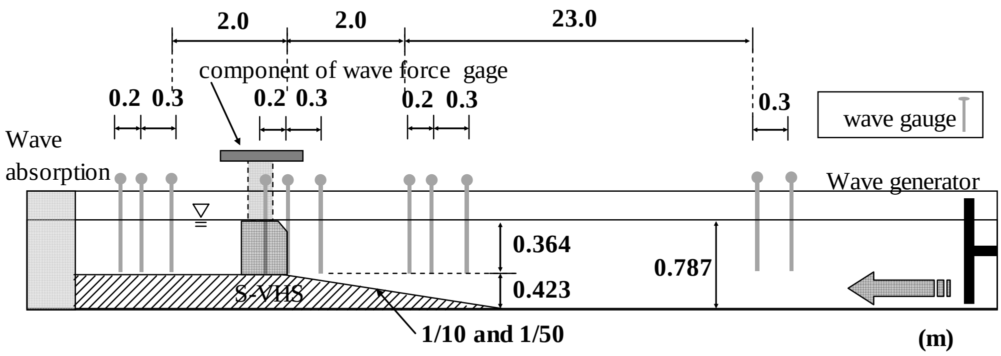


Figure-7 Cross sectional view of the experiment (conduct wave force reduction ability)

Table-3 Experimental case of wave force reduction

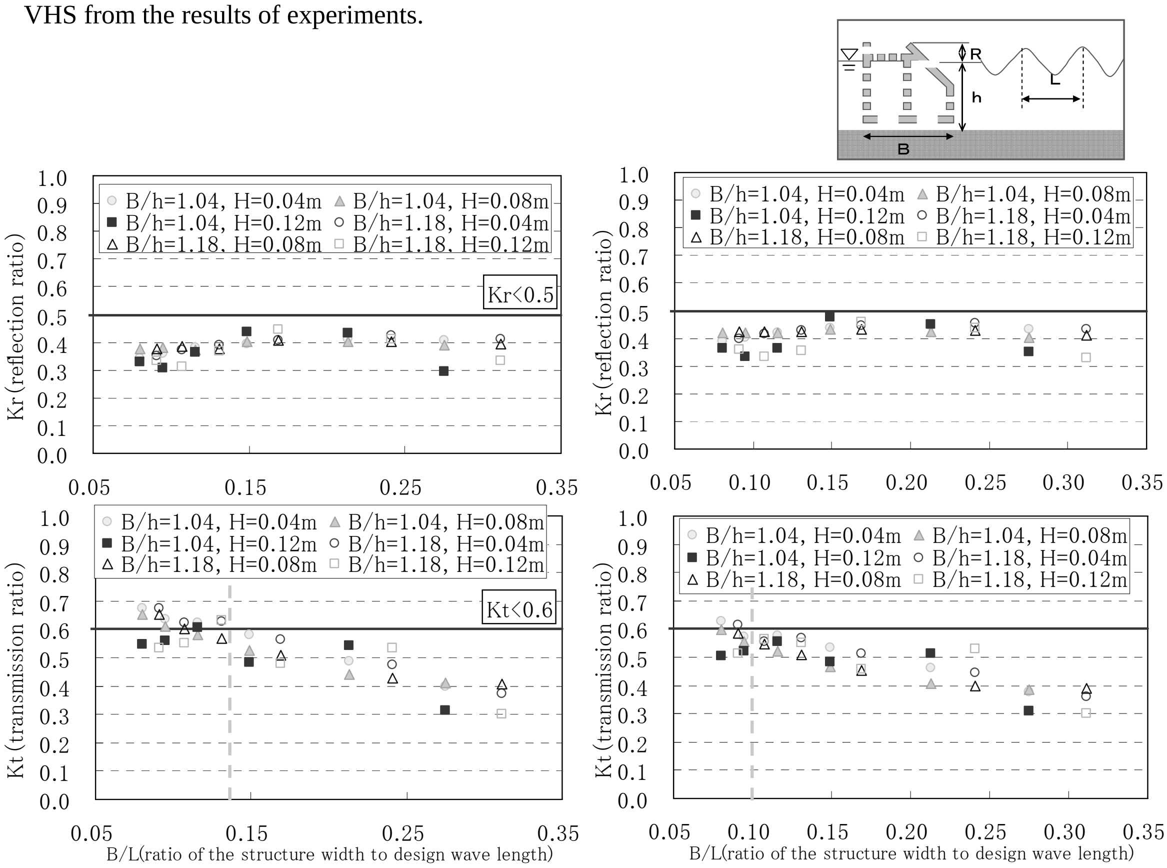
Type	S-VHS
h2/h	0.05, 0.2
Water depth(m)	HHWL(0.787),LWL(0.695)
Wave height (m)	Regular wave 0.18, 0.23, 0.25, 0.275, 0.30, 0.35, 0.40,0.45 Irregular wave 0.30, .35, 0.40
Wave period (s)	1.8, 2.0, 2.4, 2.8, 3.2

Wave dissipation ability (reflection and transmission ratio)

First, we have conducted preliminary study to search for valid structure form which has suitable void ratio of walls, slit number for each wall through some numerical analyses and fundamental hydraulic experiments. After deciding the basic configuration of the structure as shown in Table-1, lots of experiments for wave dissipation ability are executed with changing the incident wave condition, B/h(ratio of the structure width to depth) and h2/h(ratio of the bottom clearance length to the structure height).

If permeable ratio shows more than 0.6 in the case, where B/L(ratio of the structure width to wave length) is smaller than 0.1 or 0.15, in other words, the longer the wave periods are, the larger the transmission ratios become.

By using figure-8, we are able to decide to set up the structure width corresponding to the period of the design wave. For example, structure type 0.05, B/L is set to over 0.1, in the form of 0.2, set to over 0.14 , to satisfy the required wave dissipating ability. That is, in order to hold equivalent wave dissipation performance, the type of h2/h=0.2 structure needs larger width than that of 0.05 type. If chosen the transmission ratio of 0.6, the width of S-VHS structure turns out almost to agree with that of VHS from the results of experiments.



h2/h=0.2 type　　　　　h2/h=0.05 type

Figure-8 Experimental results of wave dissipation ability

Secondary, we prepare another miniature structure type of h2/h=0.05, the width of which set to B/L=0.10(design wave period is assumed to 2.8s). We conducted another experiment shown in Figure-9 concerning with wave steepness and reflection or transmission ratio. Whole of experimental results indicates required wave dissipation ability (reflection ratio is under 0.5, transmitted ratio is under 0.6).

The experimental results clarify that optimal proportion of the B/L(ratio of the structure width to design wave length) exists for the design reflection and transmission rate in each h2/h and is not depend on the wave steepness .

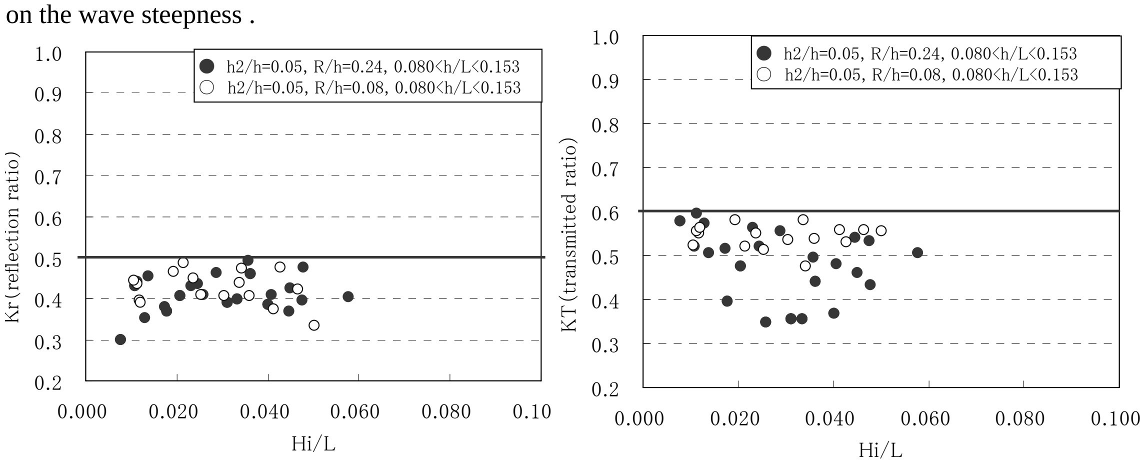


Figure-9 Experimental results of wave dissipation ability (h2/h=0.05)

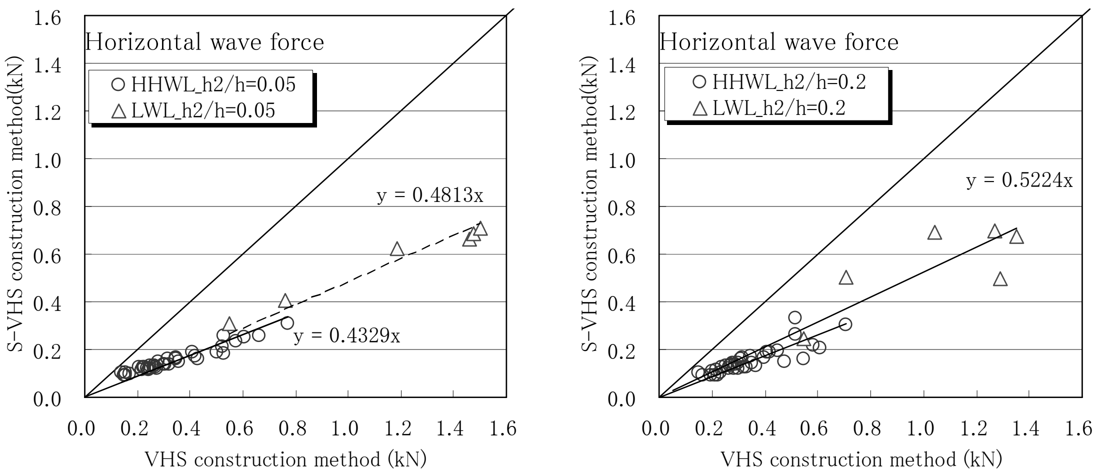
Wave force reduction ability

Next, we did the experiments about wave force acting on S-VHS. Maximum wave force of the horizontal direction and the vertical direction which acts on the whole model are measured by a component force gage attached to the upper part of a model.Figure-10 and Figure-11 show the comparison graphs between observed wave force acting on S-VHS construction method and wave force for VHS construction method when the identical wave supposed to attack.. In the figures, vertical axis indicates the experimental maximum wave force, while horizontal axis means the calculation result of wave force according to the formula used in the design of VHS construction method.

As a result of comparing with both maximum wave force, horizontal wave force of S-VHS construction method inclines to 30 to 50 percent smaller than that of VHS one .

For uplift pressure, although the data fluctuation has arisen, the similar tendency could be seen that the pressure measured on S-VHS model is smaller than that of calculation formula with VHS construction method.

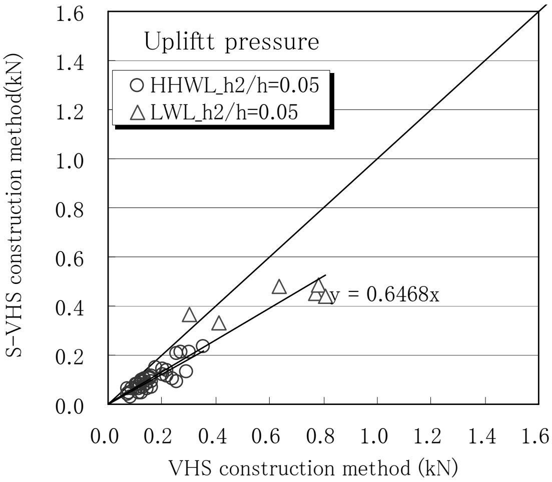
The reduction effect for both horizontal wave force and uplift pressure is achieved by the modification of the parts of the structure form into slant upper dike and large aperture slit slabs.



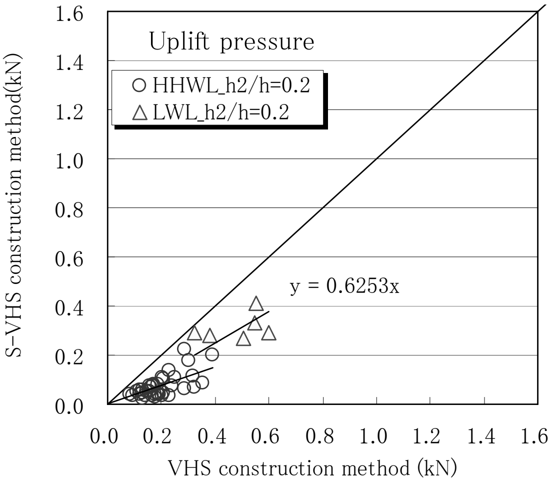
h2/h=0.05 type

h2/h=0.2 type

Figure-10 Experimental results of wave force (horizontal force)



h2/h=0.05 type



h2/h=0.2 type

Figure-11 Experimental results of wave force (uplift pressure)

Suggestion of the design wave force formula (apply to Hosoyamada et,al(1994) formula)

Based on the experimental results, we are going to argue the design method of wave force in this section. To begin with, we compare the wave force formula of the Hosoyamada et,al(1994) to experimental result which are often applied to sloping top type caisson.

In comparison with a wave force, Another set of pressure gages attached to each wall is used. Hosoyamada et.al(1994) has proposed the wave force distribution (shown in equation (1), and equation (2)) which accounts for the wave force reducing factor with a slope and partially uses Goda(1975) wave force formula at an erection wall.

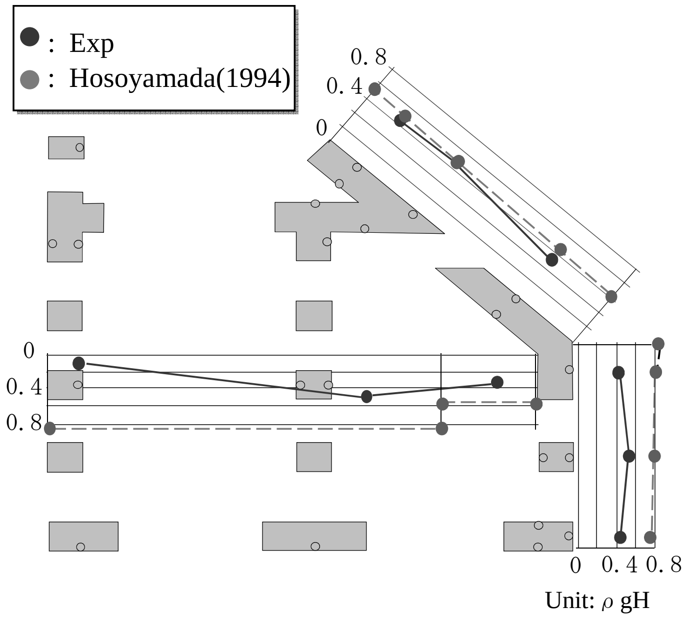


Figure-12 An example of wave pressure distribution

(h2/h=0.05 type, H=0.4m, T=3.2s)

$$\lambda_{SL}^{'} = \min\left[\max\left\{1.0, -23(H/L)/\tan^2\alpha + 0.46/\tan^2\alpha + 1/\sin^2\alpha\right\}, 1/\sin^2\alpha\right] \quad (1)$$

$$\lambda_V = \min\left[1.0, \max\left\{1.1, 1.1 + 11 d_c / L\right\} - 5.0(H/L)\right] \quad (2)$$

where, parameter $\lambda_{SL}^{'}$ is the reducing factor applied to horizontal wave force on sloping top, λ_V is the reducing factor applied to horizontal wave force on upright wall, H is wave height, L is wave length, α is slope angle, and d_c is the distance from still water level to lower end of the slope .

Figure-12 shows the example which compared an experimental wave pressure distribution with the Hosoyamada et.al's(1994) formula. In the figure, wave pressure distribution of a slope part is well agrees with each other. On the other hand, discordance between observation and formulae is shown in other member of frame-work.

As mentioned above, the wave force evaluation method using the formulae of the Hosoyamada et.al(1994) may be applied only for a sloping top part. So it is necessary to consider another option about other parts of the structure. In addition, wave force reduction mechanisms expressed by the formula of Hosoyamada et.al(1994) differs from an erection part with slits and a slit bottom slab with some clearance from the sea bed. To design the formula of S-VHS construction method, we decided to take only (1) formula into consideration, and (2) formula decided not to adopt.

Suggestion of the design wave force formula (apply to Kunisu et,al(1980))

Next, the applicability of the wave force formula of the slit structure which KUNISU and others proposed was confirmed. Kunisu et.al(1980) proposed the wave force reducing factor for Goda(1975) wave force formula as a reduction effect by a slit, and has determined the following parameters of a, b, and c for VHS construction method(shows in (3)).

$$\lambda_V = a + b(H/h) + c \cdot Ir \quad (3)$$

where, parameter λ_V is the wave force reducing factor applied to slit wall, H is wave height, Ir is surf simulality parameter, and a,b,c, are reducing coefficiants referred in Table-4 and Table-5, respectively.

The parameters of both VHS and S-VHS construction method are calculated using the least square method from this experimental result and Kunisu et.al's(1980) calculated one on VHS development.

As a result, both the coefficients of uplift pressure in S-VHS construction method and horizontal wave force will be practically similar with the proposal type of Kunisu et.al(1980).

As mentioned above, it turns out to use the formula of the Hosoyamada et.al(1994) for the sloping part, while to consider the formula introduced by Kunisu et.al(1980) from Goda(1975) formula for other components.

Table-4 Comparison of reducing coefficient (Horizontal wave force)

slope	Type	h2/h	a	b	c
1/10	S-VHS	0.05	0.35	0.25	-0.12
	S-VHS	0.2		0.41	
	VHS	-		0.37	
1/50	S-VHS	0.05	0.25	0.18	0.4
	S-VHS	0.2		0.33	
	VHS	-		0.32	

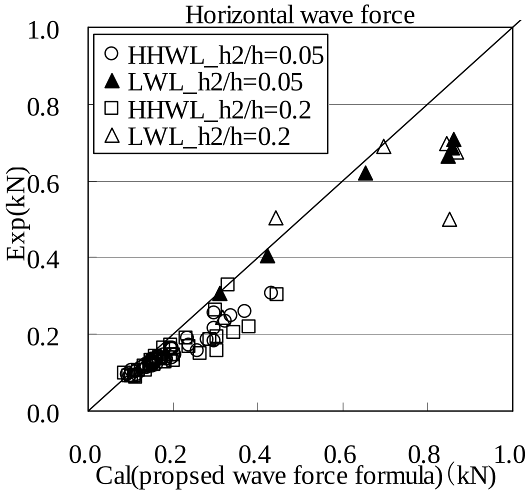
Table-5 Comparison of reducing coefficient (Uplift pressure)

slope	Type	h2/h	a	b	c
1/10	S-VHS	0.05	0.42	0.35	-0.12
	S-VHS	0.2			
	VHS	-	0.35	0.37	-0.12
1/50	S-VHS	0.05	0.19	0.23	0.4
	S-VHS	0.2			
	VHS	-	0.25	0.32	0.4

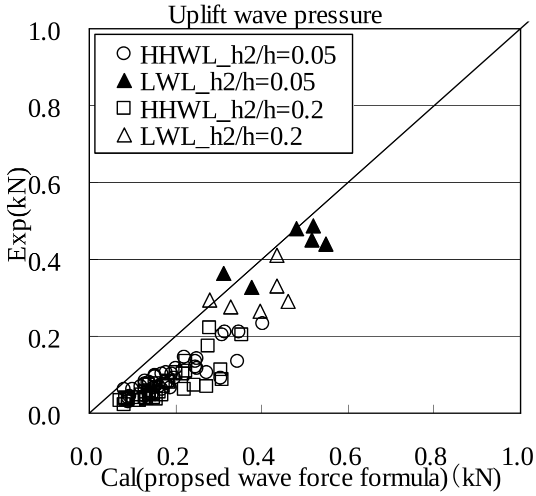
Application of suggested design wave force formula

Finally, comparison of the proposed wave force and experimental result was performed. In the Figure -13, the horizontal axis is the value computed by the combination formulae of Hosoyamada et.al(1994) and Kunisu et.al(1980).

In the Figure, both proposed formula of horizontal wave force and uplift pressure are will be practically similar with the proposal combination formula. So proposed design wave force formula can apply to design of S-VHS construction method.



Horizontal wave force



Uplift pressure

Figure-13 Comparison experimental result of proposed wave force formula

Maximum wave pressure to individual walls

Calculation result of the design wave force which acts on a foundation pile can be directly utilized for an actual design using the maximum of the measurement result by a component wave force gage. However, the maximum wave force or uplift pressure which acts on each slit wall and slabs is necessary to be evaluated separately, since the time phase difference of the wave force arises between each wall.

Then taking the time phase difference of a wave into account, the maximum pressure observed on every wall was extracted separately and used them as an actual design force. The design wave pressure attached to every wall can be expected as follows.

$$q = \alpha \cdot \rho \cdot g \cdot H \qquad (4)$$

where, parameters α, determined from experimental results, g is gravity, ρ is water density, and q is wave force for the member of framework attached to the wall .

Table-6 member wave pressure coefficient

No	α	No	α	No	α
1	1.50	9	1.10	17	1.25
2	1.65	10	1.25	18	0.60
3	1.35	11	1.00	19	0.60
4	1.30	12	2.00	20	0.60
5	1.30	13	0.60	21	1.35
6	0.60	14	0.60	22	1.35
7	0.60	15	0.60		
8	0.60	16	1.75		

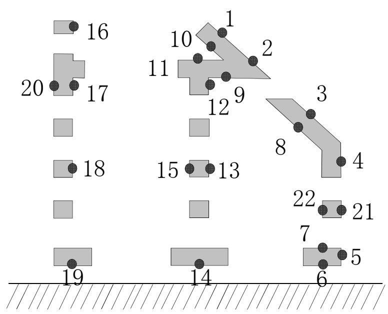


Figure-14 Pressure gage number

Figure-15 shows the arranged component coefficients obtained from the experimental results. The component coefficient of the member of framework below the water surface serves as a comparatively small value. On the other hand, the coefficient in the vicinity of the water surface shows the tendency to become large under the influence of breaking wave force. The following design methods are adopted in the detail design of the structure made from concrete.

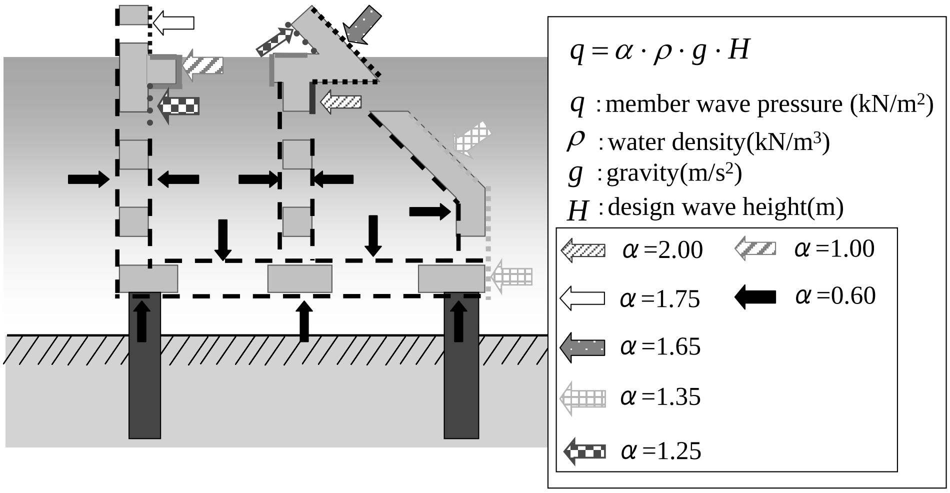


Figure-15 Arranged component coefficient

Cost competition (VHS and S-VHS)

Finally, we have compared the constructional cost of VHS construction method and S-VHS one. Table-7 shows the results of direct construction cost efficiency studies. In the study, we calculated direct construction cost of 100m interval and ordered the ratio of VHS construction cost. From the result, S-VHS construction method enable the remarkable 12 ％ reducing the construction cost.

It was proved that S-VHS construction method not only excels VHS construction method in performance, but also is the economically excellent structure.

Table-7 Ratio of the cost (direct construction cost of 100m interval)

Work item	VHS construction method	S-VHS construction method
Building flame production	1.00	0.95
Pile production		0.85
Foundation work		0.95
Pile head adjustment		1.05
Total cost		0.88

Final Manuscript

We have developed the offshore structure S-VHS construction method which has effective wave dissipation ability. Concluded remarks are summarized as following.

The basic form of S-VHS such as void ratio and slit number of each wall have decided through some numerical analysis and experiments.

Reflection and transmission rate are able to be determined concerning with B/L.

Wave force is remarkably reduced by the sloping top dike and air-gapped bottom slab.

We propose the design wave force estimation formulae considering the characteristic form of both slant top and slit wall of S-VHS construction method.

We recognize that S-VHS has remarkable low cost than that of VHS construction method.

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