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Case Study on Habitability of Superstructure built on Floating Structure

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Abstract : *Researches on a superstructure built on a floating structure in the shape of pontoon type have begun in recent years. A superstructure responds by wave load and it is important to evaluate its habitability. The purpose of this study is evaluation and investigation of habitability of a superstructure due to wave for 10 year return period. In this study, response analyses of the superstructure built on middle-sized floating structure due to the waves of three cases were carried out by 3-D integration analysis, which means analyzing the calculation model integrated a superstructure with a floating structure, and its habitability was evaluated by the evaluation diagrams. As the result, the habitability differed by each wave condition. The use of a superstructure is restricted according to the disposition of a floating structure for incident wave angle.*

Key words : *Floating structure, Superstructure, Habitability, Wave for 10 year return period, 3-D integration analysis*

1. Introduction

A floating structure is one of the methods for utilization of ocean space and has a possibility that a building will be constructed on it for a space of person's activities. The building is called a superstructure in this paper.

Researches on a superstructure have begun in recent years (Kwak et al., 2002). In some references, the superstructure was analyzed without the floating structure by separation analysis, which means that the displacements of the floating structure at the joints of the both structures were input to the columns of the superstructure. And they show on structural safety of the superstructure principally.

Habitability of a superstructure due to wave load is very important problem for person's activities as the same as its structural safety. It is necessary that structural design of a superstructure considers habitability in the step of the primary design.

We confirmed the structural safety of our calculation model by wave for 100 year return period but show about the habitability in this paper mainly. Therefore wave for 10 year return period was used for evaluation of the habitability. Response of the superstructure was calculated by three-dimensional integration analysis (Saijo et al., 2004). The habitability of the superstructure was evaluated using the evaluation diagrams presented by Saito (Saito et al., 2003).

This study aimed for evaluation and investigation of habitability of the superstructure analyzed by integration analysis due to the significant waves for 10 year return period at three locations that the wave height and the wave period were different respectively.

2. Analysis Method

2.1 Dynamic Response Analysis

The responses of both the floating structure and the superstructure were found by finite element method.

Each wave load was calculated as diffraction problem and the added mass was calculated as radiation problem by boundary element method. The damping ratio, which composed of the structural damping and the radiation damping, was used the same as land buildings. (Maruyoshi et al., 2005). The floating structure was considered as plate structural system (three degrees of freedom) and the superstructure was considered as frame structural system (six degrees of freedom) because this paper aimed for grasp the characteristics of response of the superstructure due to wave load and the calculation time was reduced.

The response was analyzed by integration analysis. The integration analysis means analyzing the model integrated a superstructure with a floating structure. The superstructure

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and the floating structure interact in the integration analysis. The equation of motion is shown in Eq (1).

$$([M_f]+[M_s]+[M_{ad}])\{\ddot{\delta}\}+([C_f]+[C_s]+[C_w]\{\dot{\delta}\}) + [K_f]+[K_s]+[K_w])\{\delta\}=\{F_w\}e^{i(w_w t+\varepsilon)} \quad (1)$$

where; $[M_f]$: mass matrix of floating structure, $[M_s]$: mass matrix of superstructure, $[M_{ad}]$: added mass matrix, $[C_f]$: damping matrix of floating structure, $[C_s]$: damping matrix of superstructure, $[C_w]$: radiation damping matrix, $[K_f]$: stiffness matrix of floating structure, $[K_s]$: stiffness matrix of superstructure, $[K_w]$: stiffness matrix due to buoyancy, $\{\delta\}$: displacement vector, $\{\dot{\delta}\}$: velocity vector, $\{\ddot{\delta}\}$: acceleration vector, $\{F_w\}$: wave load vector,

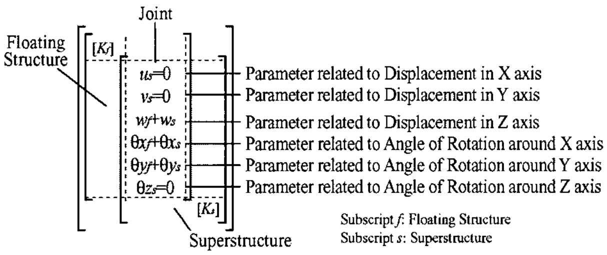


Fig. 1 Superposition of Matrixes in Integration Analysis

Fig. 1 shows the superposition of the both matrixes of the floating structure and superstructure in integration analysis. In the joints of the both structure, parameters related to the displacements in X axis, Y axis and angle of the rotation around Z axis become zero because the joints are considered as fixed ends and the floating structure is assumed as plate.

2.2 Evaluation of Habitability

The habitability of the superstructure was evaluated from the both obtained acceleration and response period by the evaluation diagrams presented by Saito. Fig. 2 and Fig. 3 show the evaluation areas of habitability for vertical direction and horizontal direction. Each evaluation level shown in Fig. 2 and Fig. 3 is explained in Table 1.

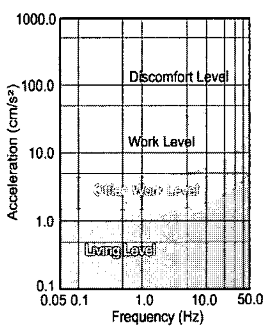


Fig. 2 Habitability for Vertical Direction

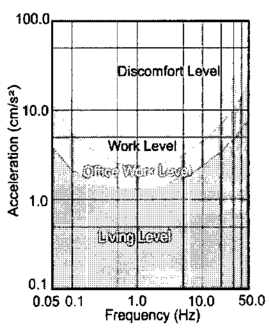


Fig. 3 Habitability for Horizontal Direction

Table 1 Evaluation Level

Living	Neither motion nor vibration is felt at recumbent position.
Office Work	It is possible to work at seated position.
Work	It is possible to work at standing position.
Discomfort	Motion and vibration discomfort most people and make person's activity difficult.

3. Calculation Model

3.1 Floating Structure & Superstructure

The coordination of the calculation model was defined as shown in Fig. 4. Table 2 shows the parameters of the calculation model. The density of floating structure is $0.41 t/m^3$ and the material density of superstructure is $7.85 t/m^3$.

The scale of the floating structure was 196m×112m×3m. It was about four times as large as the Floating Multipurpose Park existing at Minami Awaji city, Hyogo.

Table 2 Parameters of Calculation Model

		Floating Structure	Superstructure
Length		196m(7m×28)	42m(7m×6)
Width		112m(7m×16)	28m(7m×4)
Height		3m	17.5m(3.5×5-story)
Draft		1.34m	
Column (SS400)		C1	H-400×400×13×21
		C2	H-440×300×11×18
Beam (SS400)		B1	H-500×200×10×16
		B2	H-450×200×9×14

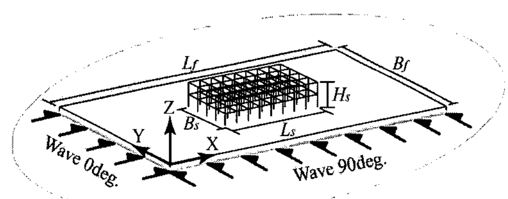


Fig. 4 Coordination of Calculation Model

In Fig. 4, L_f, B_f, L_s, B_s, H_s are length of floating structure, width of floating structure, length of superstructure, width of superstructure and height of superstructure respectively.

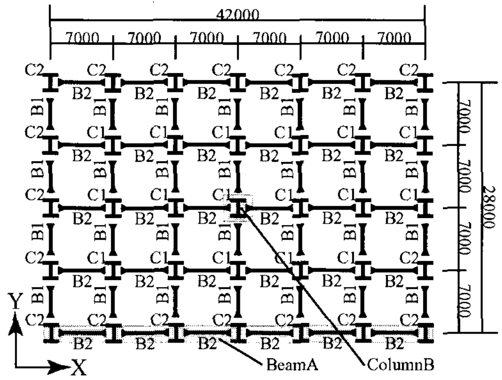


Fig. 5 Floor Plan

The scale of superstructure was 42m×28m×17.5m and it was five-story building. The span of each column was 7m. The superstructure was designed by H section steels and the joints of each member were fixed end. Stress analysis due to static load composed of dead load and live load was carried out and the members were designed so that stress ratio, which was ratio of each member stress for allowable stress, became 70% without considering stress due to wave load. Fig. 5 shows the floor plan. All floor plan were same.

3.2 Wave Condition

The incident waves were regular. Table 3 shows wave conditions. Significant waves of three cases were used to our calculations. Wave for 10 year return period was applied to evaluate habitability of a superstructure in the port . The significant waves at Busan and Yokohama were estimated from each observational data, and the Pukari was the significant wave used to the design of the Pukari Pier. The waves of each angle 0deg, 30deg, 45deg and 90deg were incident.

Table 3 Wave Conditions

Case	100 Year Return Period		10 Year Return Period	
	Height	Period	Height	Period
Busan	2.6m	5.8sec	2.2m	5.4sec
Yokohama	2.0m	5.2sec	1.6m	5.0sec
The Pukari	1.7m	3.5sec	1.3m	3.2sec

4. Results

The results of the natural periods and the habitability of each case are shown as follows. The vertical accelerations at beam end and the horizontal accelerations at top of columns are shown on behalf of the results.

4.1 Natural Period

Table 4 shows the natural periods of the floating structure, the superstructure and the integration structure. The 1st natural period of the superstructure was obtained as 1.42sec. Large difference was found between the 1st natural period and the wave periods of three cases. And the both natural periods of the floating structure and the integration structure were very near in each mode. It is thought that the superstructure did not influence on the motion of the floating structure very much, and the superstructure moved according to the floating structure through these results.

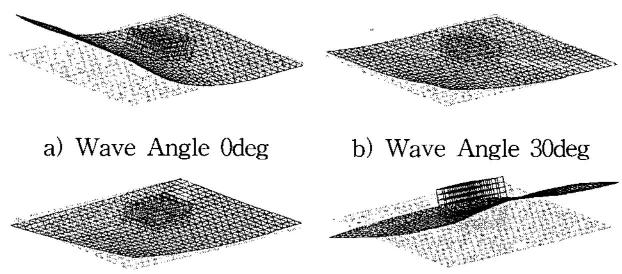
Table 4 Natural Periods

Mode	FS	SS	Integration(FS&SS)
1st	4.00sec (Heave)	1.42sec (X 1st)	4.07sec (Heave)
2nd	3.86sec (Pitch)	0.95sec (Y 1st)	3.85sec (Pitch)
3rd	3.76sec (Roll)	0.92sec (RZ 1st)	3.76sec (Roll)
4th	3.07sec (Elastic 1st)	0.48sec (X 2nd)	3.09sec (Elastic 1st)
5th	2.93sec (Elastic 2nd)	0.30sec (Y 2nd)	2.91sec (Elastic 2nd)

FS : Floating Structure, SS : Superstructure

4.2 Case of Busan

The response in case of Busan became the largest in three cases because the wave height was the highest. The integration structure showed rigid motion as shown in Fig. 6 and Fig. 7. Especially the motion was found clearly in case of 90deg wave. The vertical response became the largest at the side of the incident wave.



a) Wave Angle 0deg　b) Wave Angle 30deg

c) Wave Angle 45deg　d) Wave Angel 90deg

Fig. 6 Visualization of Displacement in case of Busan

The horizontal and vertical maximum accelerations of the superstructure (26.97cm/sec^2, 12.09cm/sec^2) were found in case of 90deg from Fig. 7 and Fig. 8. And the habitability of the superstructure was evaluated as Work Level in vertical axis and Discomfort Level in horizontal axis respectively. It was found that the case of 90deg wave was the hardest condition. If a floating structure below this size will be constructed at Busan, some breakwaters will be needed to make response of the structure decrease and it is thought use of the superstructure will be restricted.

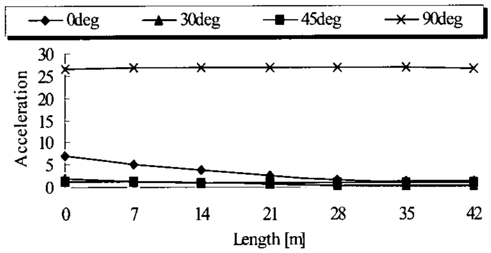


Fig. 7 Vertical Acceleration in case of Busan [cm/sec^2]

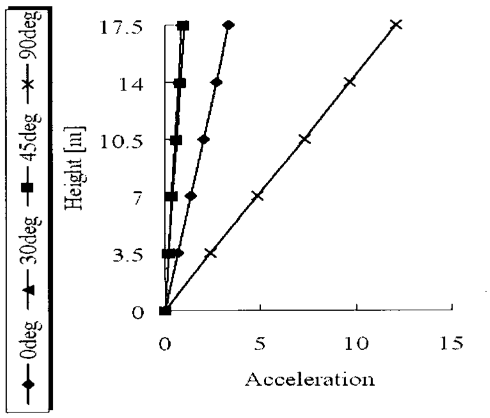


Fig. 8 Horizontal Acceleration in case of Busan [cm/sec^2]

Table 5 Maximum Accelerations & Results of Evaluation of Habitability in case of Busan

θ_w	Vertical		Horizontal	
0deg	7.16cm/sec^2	Work	3.35cm/sec^2	Office
30deg	1.78cm/sec^2	Living	1.18cm/sec^2	Living
45deg	1.33cm/sec^2	Living	1.24cm/sec^2	Living
90deg	26.97cm/sec^2	Work	12.09cm/sec^2	Dis-comfort

4.3 Case of Yokohama

In case of Yokohama, the structure showed motion like the case of Busan because the both wave periods at Yokohama and Busan were near. From Fig. 10 and Fig. 11, the vertical and horizontal maximum accelerations (15.07cm/sec^2, 7.59cm/sec^2) were found in case of 90deg wave and the each habitability was evaluated as Work Level.

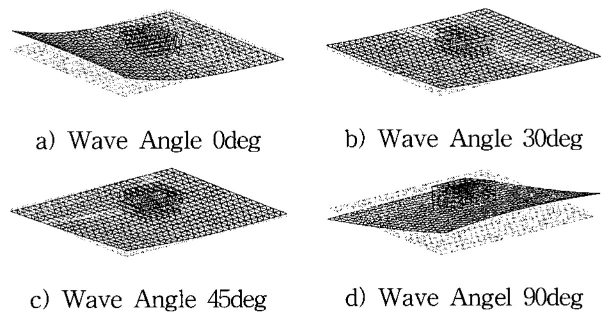


Fig. 9 Visualization of Displacement in case of Yokohama

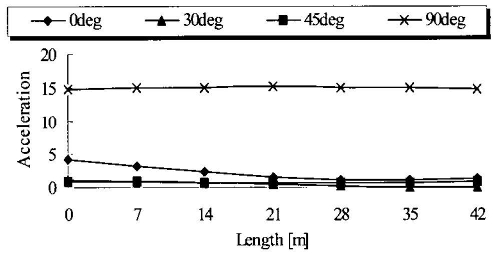


Fig. 10 Vertical Acceleration in case of Yokohama [cm/sec^2]

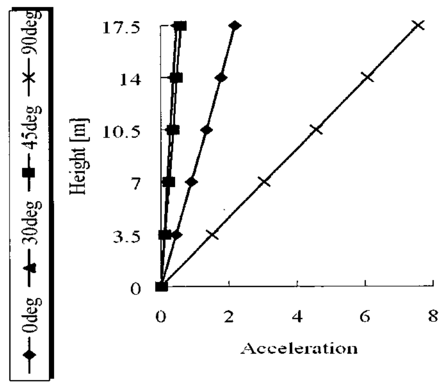


Fig. 11 Horizontal Acceleration in case of Yokohama [cm/sec^2]

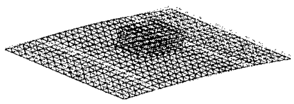
It is thought that the use of the superstructure will be restricted in case of 90deg wave. But the habitability in other wave angles was evaluated as Office Work Level or low. It is thought that the habitability can be kept by considering the disposition of a floating structure in case of Yokohama.

Table 6 Maximum Accelerations & Results of Evaluation of Habitability in case of Yokohama

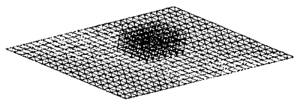
θ_w	Vertical		Horizontal	
0deg	4.35cm/sec^2	Office	2.20cm/sec^2	Office
30deg	1.08cm/sec^2	Living	0.57cm/sec^2	Living
45deg	0.86cm/sec^2	Living	0.72cm/sec^2	Living
90deg	15.07cm/sec^2	Work	7.59cm/sec^2	Work

4.4 Case of the Pukari Pier

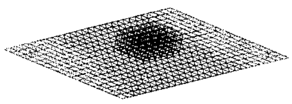
From Fig. 12 and Fig. 13, the structure showed elastic behavior clearly and the response became the smallest in three cases. The elastic mode was predominant because the 4th natural period of the integration structure (3.09sec) was nearly the wave period at the Pukari (3.2sec). From Fig. 13, the vertical maximum acceleration (3.27cm/sec^2) was found in case of 0deg wave and the habitability was evaluated as Office Level. But the habitability at other points was evaluated as Living Level.



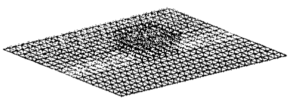
a) Wave Angle 0deg



b) Wave Angle 30deg



c) Wave Angle 45deg



d) Wave Angel 90deg

Fig. 12 Visualization of Displacement in case of the Pukari

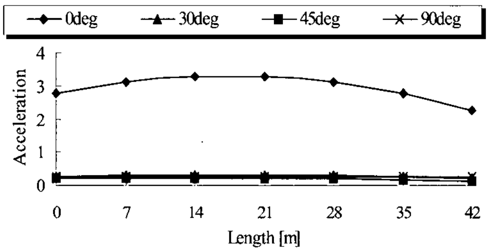


Fig. 13 Vertical Acceleration in case of the Pukari [cm/sec^2]

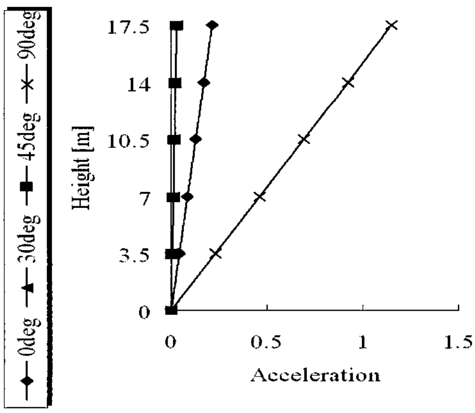


Fig. 14 Horizontal Acceleration in case of Yokohama [cm/sec^2]

The horizontal maximum acceleration (1.15cm/sec^2) was found in case of 90deg wave from Fig. 14. The acceleration was very small and the habitability in all wave angles was evaluated as Living Level. It is thought that the habitability is comfortable and the responses not obstacle to person's activities. The superstructure has a possibility to be applied to various uses.

Table 7 Maximum Accelerations & Results of Evaluation of Habitability in case of the Pukari

θ_w	Vertical		Horizontal	
0deg	3.27cm/sec^2	Office	0.23cm/sec^2	Office
30deg	0.32cm/sec^2	Living	0.05cm/sec^2	Living
45deg	0.21cm/sec^2	Living	0.04cm/sec^2	Living
90deg	1.54cm/sec^2	Work	1.15cm/sec^2	Work

5. Conclusion

The response analyses of the superstructure due to the significant waves for 10 year return period at three locations were carried out and its habitability was evaluated from the obtained acceleration. The conclusions in this study were summarized.

The superstructure did not have influences on the floating structure very much because the both natural periods of the floating structure and the integration structure were very near. And the superstructure responded according to the motion of the floating structure because the natural periods of the superstructure differed from each wave period. Through these results, it was supposed that large differences were not found between integration analysis and separation analysis.

In case of Busan, the acceleration responses became the largest in three cases because the wave height was the highest and the habitability was evaluated as Discomfort Level in horizontal axis. And in case of Yokohama and Pukari Pier, the habitability was evaluated as Work Level in both axis.

It is not easy to satisfy the habitability of a superstructure by the member design if the motion of the superstructure moves according to the motion of the floating structure. Considering some dampers for the response control is necessary. And the habitability depends heavily on wave conditions. It is important that the disposition of the floating structure is arranged considering the incident wave angle by the use of the superstructure. Therefore the characteristic of the incident wave angle at the location must be analyzed so that person's activities are not obstructed.

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