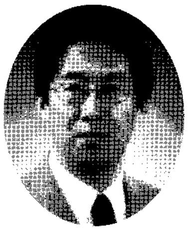
플로팅구조물의 상부구조체에 대한 거주성 평가

Habitability Evaluation of Superstructure built on Floating Structure



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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 (Fig. 1). The building is called a superstructure in this paper.

Researches on a superstructure have begun in recent years (Takenaka Co., Ltd. & Mitsui Engineering Shipbuilding Co., Ltd., 1999 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 Busan Port.

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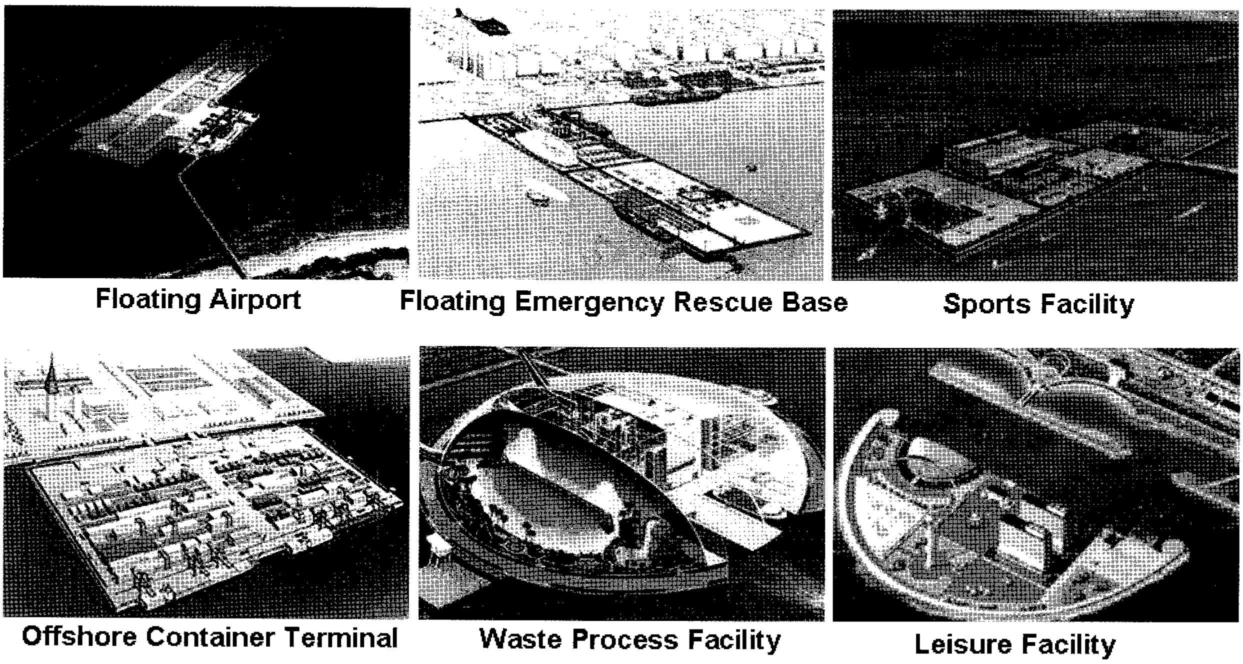


〈Fig. 1〉 Utilization of ocean space using floating structures

2. Analysis Method

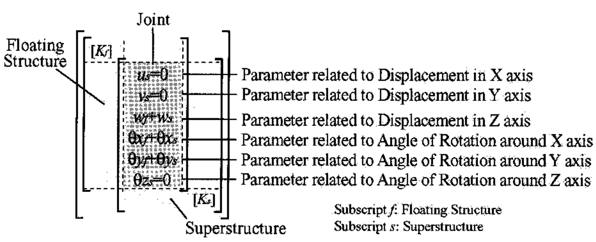
2.1 Dynamic Response Analysis

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

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

where; [Mf]: mass matrix of floating structure, [Ms]: mass matrix of superstructure, [Mad]: added mass matrix, [Cf]: damping matrix of floating structure, [Cs]: damping matrix of superstructure, [Cw]: radiation damping matrix, [Kf]: stiffness matrix of floating structure, [Ks]: stiffness matrix of superstructure, [Kw]: stiffness matrix due to buoyancy, {δ}: displacement vector, {Fw}: wave load vector.

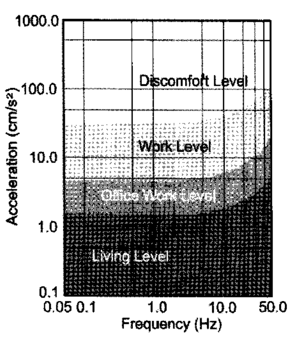


〈Fig. 2〉 Superposition of Matrixes in Integration Analysis

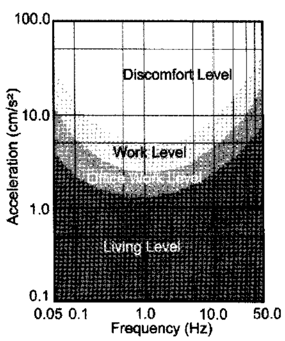
Fig. 2 shows the superposition of the both matrixes of the floating structure and superstructure in integration analysis. In the joints of the both structure, parameters related to the displacements in X axis, Y axis and angle of the rotation around Z axis become zero because the joints are considered 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. 3 and Fig. 4 show the evaluation areas of habitability for vertical direction and horizontal direction. Each evaluation level shown in Fig. 3 and Fig. 4 is explained in Table 1.



〈Fig. 3〉 Habitability for vertical direction



〈Fig. 4〉 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

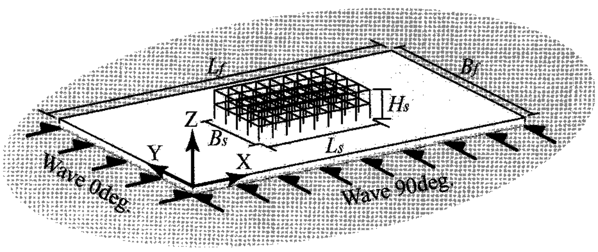
3.1 Floating Structure & Superstructure

The coordination of the calculation model was defined as shown in Fig. 5. Table 2 shows the parameters of the calculation model.

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.

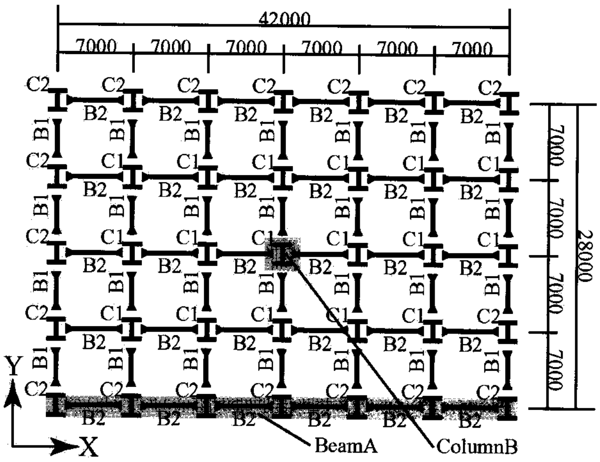
〈Table 2〉 Parameters of calculation model

		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)
Density		0.41t/m³	7.85t/m³
Young's Modulus		8.2×106kN/m²	2.1×108kN/m²
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. 5〉 Coordination of Calculation Model

In Fig. 5, Lf, Bf, Ls, Bs, Hs are length of floating structure, width of floating structure, length of superstructure, width of superstructure and height of superstructure respectively.



〈Fig. 6〉 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. 6 shows the floor plan. All floor plan were same.

3.2 Wave Condition

The incident waves were regular. Table 3 shows wave conditions. Wave for 10 year return period was applied to evaluate habitability of a superstructure. The significant waves at Busan Port were estimated from each observational data, 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

4. Results

The results of the natural periods and the habitability are shown as follows. The vertical accelerations at Beam A and the horizontal accelerations at Column B are shown on behalf of the results (see Fig. 6).

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. 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

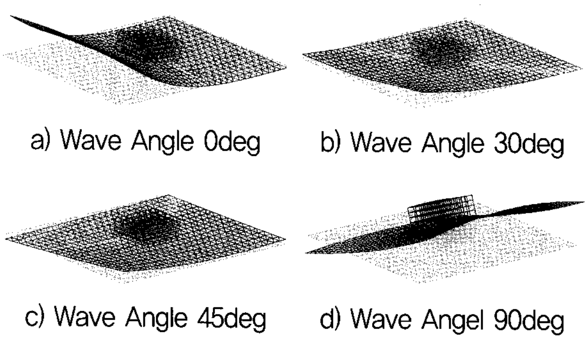
Mode	FS	SS	Integration (FS&SS)
1st	4.00sec (Heave)	1.42sec (X 1st)	4.07sec (Heave)
2nd	3.86sec (Pitch)	0.95sec (Y 1st)	3.85sec (Pitch)
3rd	3.76sec (Roll)	0.92sec (RZ 1st)	3.76sec (Roll)
4th	3.07sec (Elastic 1st)	0.48sec (X 2nd)	3.09sec (Elastic 1st)
5th	2.93sec (Elastic 2nd)	0.30sec (Y 2nd)	2.91sec (Elastic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

FS : Floating Structure, SS : Superstructure

4.2 Case of Busan Port

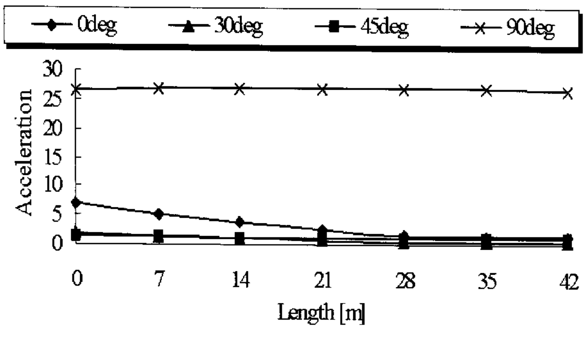
The integration structure showed rigid motion as shown in Fig. 7 and Fig. 8.

Especially the motion was found clearly in case of 90deg wave. The vertical response became the largest at the side of the incident wave.

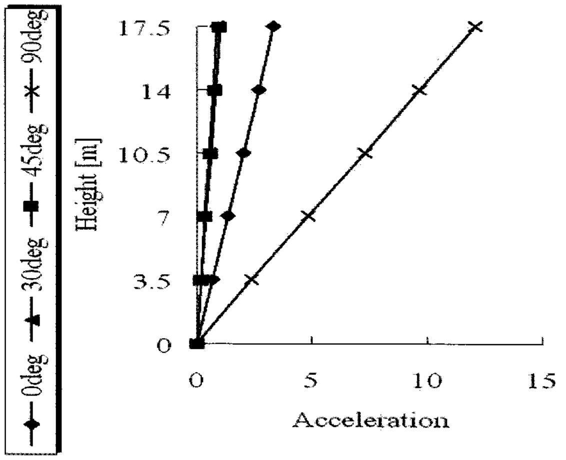


⟨Fig. 7⟩ Visualization of Displacements Busan Port

The vertical and horizontal maximum accelerations of the superstructure (26.97cm/sec^2, 12.09cm/sec^2) were found in case of 90deg from Fig. 8 and Fig. 9. 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. 8⟩ Vertical Acceleration in case of Busan [cm/sec^2]



⟨Fig. 9⟩ Horizontal Acceleration in case of Busan [cm/sec^2]

⟨Table 5⟩ Maximum Accelerations & Results of Evaluation of Habitability

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

5. Conclusion

Habitability of a superstructure due to wave load is very important problem for person's activities as the same as its structural safety.

The response analyses of the superstructure due to the significant waves for 10 year return period at Busan Port 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.

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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