The 2013 World Congress on
Advances in Structural Engineering and Mechanics (ASEM13)
Jeju, Korea, September 8-12, 2013

Experimental Study of A Floating Structure Connected by Pre-stressing

Young-Wook Lee[1)] *Ji-Yong Chae[2)] and Hyuk-Nyeon Kim [2)]

[1), 2)] *Department of Architecture and Building Engineering, Kunsan National University, Kunsan 573-701, Korea*
[1)] *leeyu@kunsan.ac.kr*

ABSTRACT

To find the behavior of pontoon connected by pre-stressing with superstructure, an experiment is carried out. Also the hydro-dynamic analysis including multi body motion is performed with variation of wave period. As the results, the pitch acceleration of semi-rigid pontoon connected by pre-stressing is similar to that of one-body pontoon, both in case of having superstructure and in case of no superstructure. Also, the pitch acceleration of analysis is nearly equal to the value of the experiment, except for short period of one body.

1. INTRODUCTION

1.1 Background

Floating structure is an effective alternative for environmental problem of rising sea level and reclamation. Also it has been built for developing marine resources and diverse facilities. But floating system has different load compared with structures built on ground because it has environmental loads including wave, mooring loads and etc. Among them, wave load necessarily should be considered, of which it have always effects on floating structures at all time.

In Japan, from 1995 to 2001, Mega-float project was constructed and studied in order to develop VLFS(Very Large Floating Structure) technology. In Korea, from 1999 to 2007, research of design technology of VLFS was performed (C.M. Wang 2011). From these examples, some studies on floating pontoon had been carried out domestically and internationally.

Generally, floating system is consist of superstructure and pontoon. Sometimes floating pontoon is made by connecting each module. Because modular system is also efficient for easy construction and transportation, as in case of buildings in land. There are many jointing methods for modular system. One of them is pre-stressing method to connect each module.

[1)] Professor
[2)] Graduated Student

1.2 Object of research

In this study, the behavior of semi-rigid pontoon connected by pre-stressing is compared with one body pontoon. By comparing with analysis results, the experimental result will be verified.

2. Experiments

2.1 Model design

In this experiment, model is made by aluminum, and connecting method is pre-stressing using modem screw. Dolphin mooring system was used to prevent drift of pontoon. To reduce the friction between pontoon and dolphin fender teflon is used. As shown Fig. 1, two kinds of the experimental modules were designed with length of 1.8 and 0.9m. In case of semi-rigid pontoon, they are connected by pre-stressing and shear key.

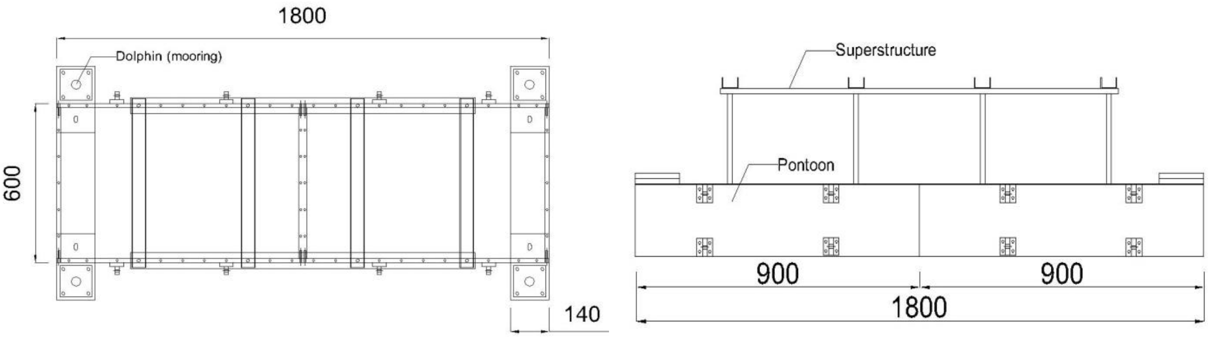
Table. 1 Experiment condition

Water depth(m)	1.0
Wave height (m)	0.1
Incident wave angle (deg)	0
Wave period (sec)	1.2, 1.4, 2.0, 3.0

Period of wave loads is considered from 1.2 to 3 seconds, as shown in Table. 1 and 2. Experiments are carried out in the two dimensional water tanks. The pre-stressing load is calculated from the moment of one –body pontoon to prevent crack.

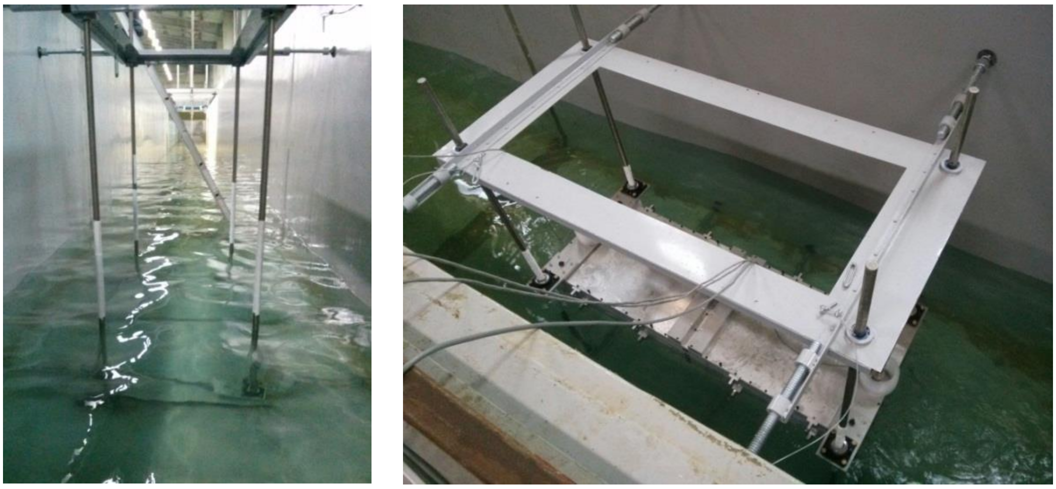
Table. 2 Model applications

	Length (m)	Drift (m)	Mass (kg)	Stiffness k (kg/m , kg.m)	pre-stressing (kgf)	Superstructure
case 1	1.8	0.095	102	-	-	o
case 2	1.8	0.086	82	-	-	x
case 3	0.9+0.9	0.095	51*2	$Ka=8.52\times10^4$ $Kf=1.59\times10^2$	20	o
case 4	0.9+0.9	0.086	41*2	$Ka=8.52\times10^4$ $Kf=1.59\times10^2$	20	x



(a) plan (b) elevation

Fig. 1 Experimental model

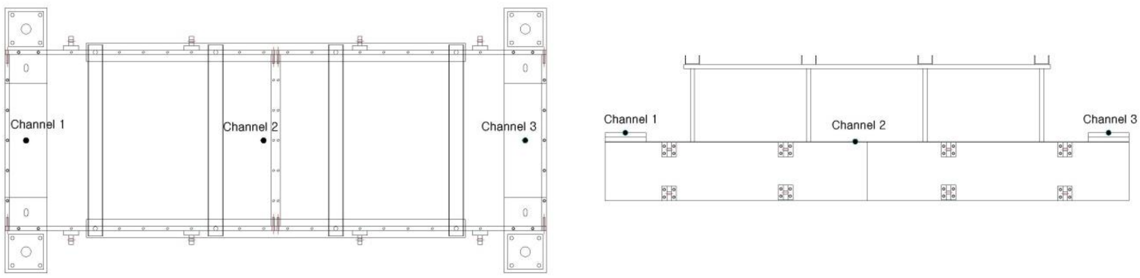


(a) Mooring system (b) installed experiments

Fig. 2 Experiment site

2.2 Measurement

In Fig. 3, the position of accelerometer is drawn. When incident wave angle is 0°, main response of pontoon is heaving and pitching. Hence, accelerometers were located at front end (channel 1), back end (channel 3) and center (channel 2).



(a) plan (b) elevation

Fig. 3 Installed location of accelerometers

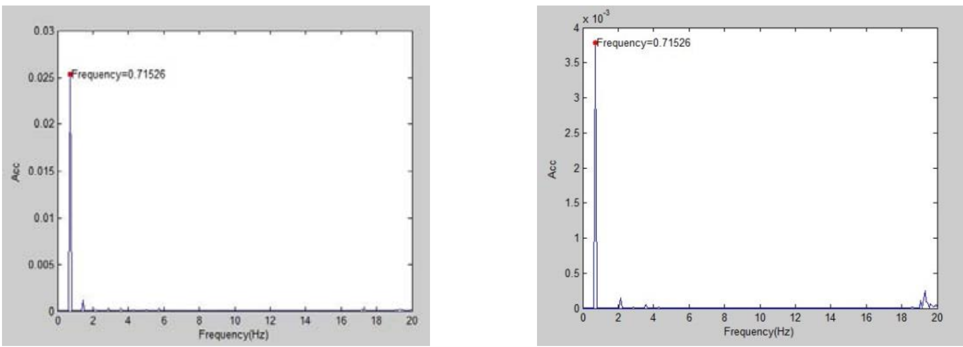
3. Experiment result

Maximum acceleration of pontoon are measured and summarized at each position as in Table. 3.

Table. 3 Acceleration of pontoon at each channel (unit : g)

	channel	before filtering				after filtering			
		1.2 s	1.4 s	2 s	3 s	1.2 s	1.4 s	2 s	3 s
case 1	channel 1	0.121	0.118	0.049	0.025	0.0855	0.0942	0.0334	0.0219
	channel 2	0.039	0.038	0.026	0.009	0.0257	0.0262	0.0183	0.008
	channel 3	0.08	0.094	0.046	0.017	0.0579	0.0739	0.0415	0.0151
case 2	channel 1	0.155	0.141	0.078	0.033	0.0781	0.0831	0.0479	0.0244
	channel 2	0.058	0.049	0.029	0.009	0.0226	0.0218	0.018	0.0629
	channel 3	0.104	0.088	0.049	0.023	0.072	0.0603	0.0351	0.0157
case 3	channel 1	0.129	0.122	0.062	0.023	0.0824	0.0779	0.0311	0.0183
	channel 2	0.061	0.045	0.027	0.009	0.0286	0.0254	0.0161	0.0062
	channel 3	0.09	0.087	0.064	0.009	0.0667	0.0548	0.0406	0.0038
case 4	channel 1	0.166	0.162	0.076	0.028	0.0815	0.0813	0.0301	0.0226
	channel 2	0.06	0.055	0.045	0.008	0.0248	0.023	0.0154	0.0449
	channel 3	0.131	0.101	0.053	0.012	0.0593	0.0476	0.0295	0.0214

Experiment data is including unnecessary components like mooring impact. In order to remove unnecessary components spectrum analysis was carried out. Fig. 4 is a graph showing spectrum analysis according to FFT. The data was filtered by low pass filter and cut off frequency is 10Hz.



(a) at front end (b) at center

Fig. 4 Spectrum of acceleration in Case 1(T= 1.2sec)

In case of with superstructure, to find the behavior of superstructure, analysis and experiment of natural period is carried out in Fig. 5. It is shown that natural period of superstructure is calculated as 50.6 Hz and has little effect on the response of pontoon.

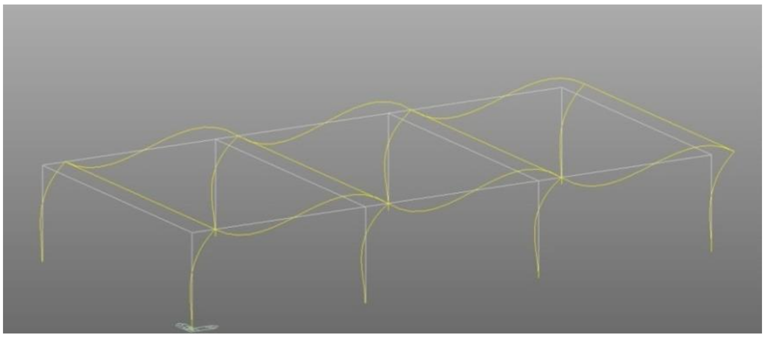


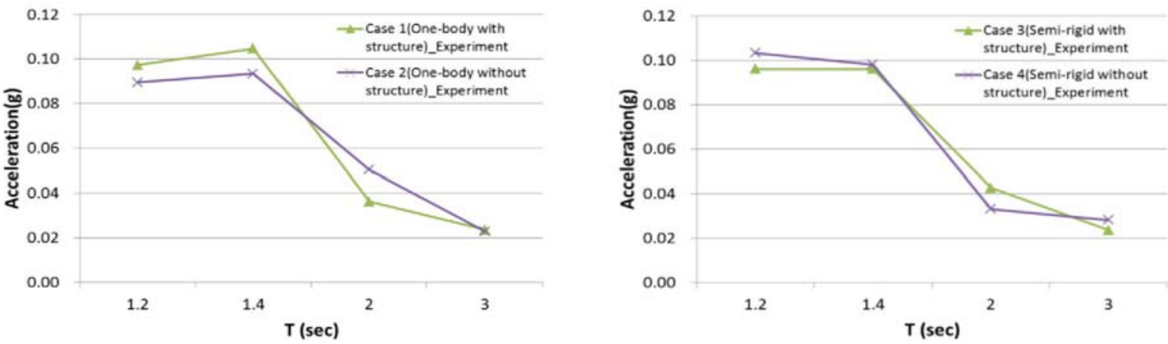
Fig. 5 First mode of superstructure by analysis

In Fig. 6, pitch acceleration is drawn, which is measured at channel 1. Pitch acceleration is calculated by eq. (1).

$$(acceleration\ difference\ of\ channel\ 1\ and\ channel\ 3)/distance \qquad (1)$$

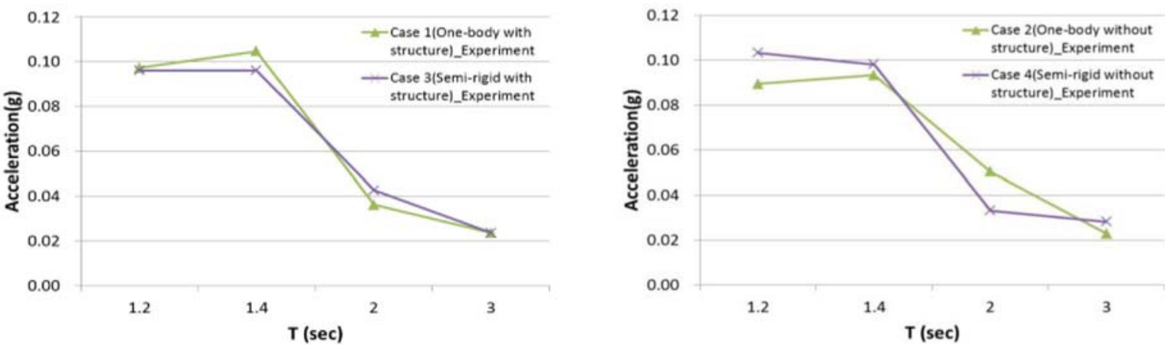
Where, distance is the distance of channel 1 and channel 3.

It was shown that the pitch acceleration of semi-rigid pontoon is nearly equal to that of one-body pontoon, both in case with superstructure and without superstructure, as shown in Fig. 6. Also, it is shown that pitch acceleration of one-body and semi-rigid pontoon are similar in Fig. 7.



(a) One-body pontoon (b) Semi-rigid pontoon

Fig. 6 Comparison of pitch acceleration of pontoon with superstructure or not



(a) With superstructure (b) Without superstructure

Fig. 7 Comparison of pitch acceleration of one body and semi-rigid pontoon

4. Hydro-dynamic analysis

4.1 Motion equation

In the hydro-dynamic analysis, the floating pontoon is modeled as rigid-body. The fluid is incompressible, inviscid and irrotational. Analysis was carried out in frequency domain by linear theory and response is performed in three dimensions.

Wave pressure applying to surface of pontoon is combined with forces and moment at each node, so it can be expressed by Eq. (2).

$$M(s)\ddot{X} + M(a)\ddot{X} + C\dot{X} + K(s)X = F^I + F^D \tag{2}$$

Where, M(s): Mass matrix; M(a): Added Mass matrix
C: Structural damping matrix; K(s): Restoring force Matrix by hydrostatic
F^I: Froude-Krylov force; F^D: Diffraction force

4.2 RAO based analysis

RAO(response amplitude operator) is used to determine the response of pontoon when wave load is operated. In this study, because incident angle of wave is assumed to longitudinal direction(x-direction), hydro elastic analysis of floating system is performed to determine heaving and pitching for each wave period.

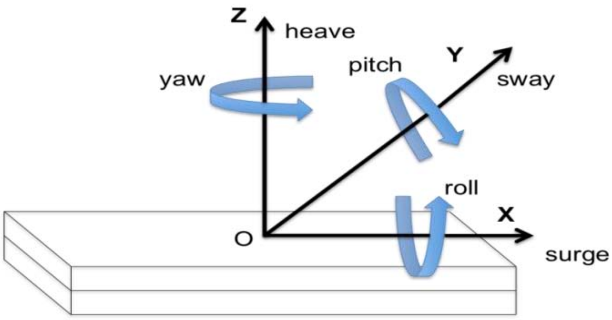


Fig. 8 Axis of coordinates and behavior of 6-DOF

Numerical analysis is carried out using MLINHYDH that was used for analysis of second-order mean forces.

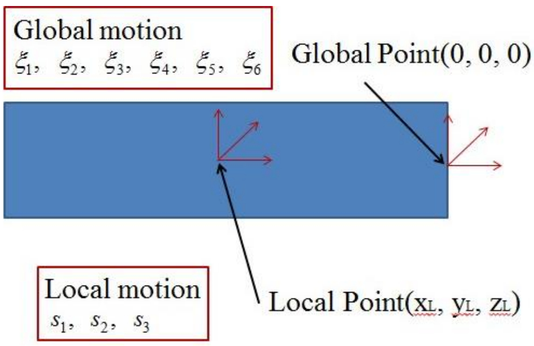


Fig. 9 Local point motion

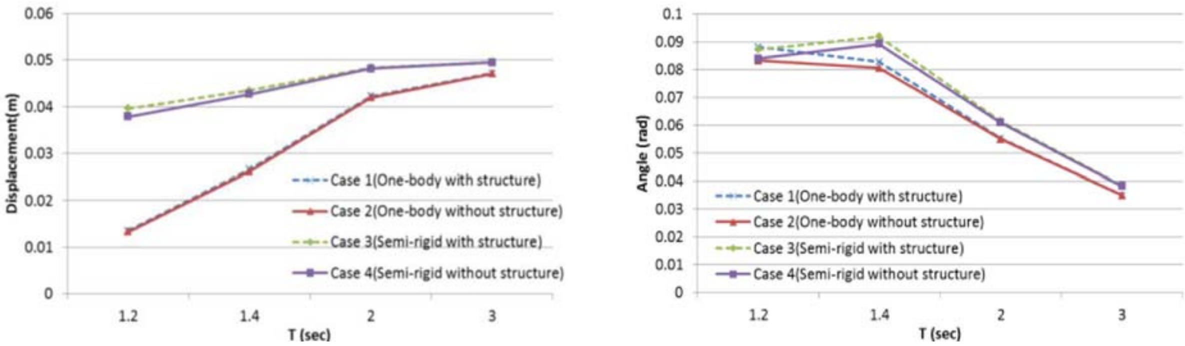
In case of case3 and 4, floating body is consisted of two modules. Because it is considered as multi-body, the connecting springs should be modeled. Response of local motion is calculated as in Eq. (3). To calculate the displacement of the sping, the local motion should be calculated.

$$\begin{aligned} s_1 &= \xi_1 + z_L\xi_5 - y_L\xi_6 & s_4 &= \xi_4 \\ s_2 &= \xi_2 + x_L\xi_6 - z_L\xi_4 & s_5 &= \xi_5 \\ s_3 &= \xi_3 + y_L\xi_4 - x_L\xi_5 & s_6 &= \xi_6 \end{aligned} \tag{3}$$

Multi-body being connected by spring, force and moment is calculated by Eq. (4) and (5) at connected point.

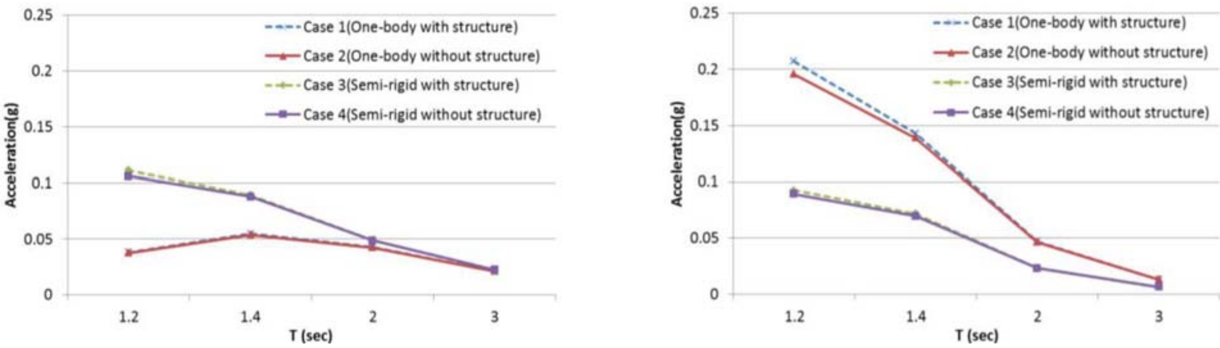
$$\vec{F} = (\, k_x s_1,\ k_y s_2,\ k_z s_3) \qquad \overrightarrow{M_0} = (\, R_x s_4,\ R_y s_5,\ R_z s_6) \tag{4}$$

$$\begin{aligned} \vec{M} &= \vec{r} \times \vec{F} + M_0 \\ &= (k_z s_3 y_L - k_y s_2 z_L + R_x s_4, k_x s_1 z_L - k_z s_3 x_L + R_y s_5, k_y s_2 x_L - k_x s_1 y_L + R_z s_6) \end{aligned} \tag{5}$$



(a) heave (b) pitch

Fig. 10 Revised RAO of 4 cases from Analysis



(a) heave acceleration (b) pitch acceleration

Fig. 11 Revised RAO acceleration of 4 cases from Analysis

Odinarily, RAO is shown when heights of wave is 2m, all of RAO data is revised to 0.1m. It is shown that in Fig. 10 when wave preriod is low, there is little discrepancy between the response with structure and without structure.

In Fig. 11, the acceleration of heave and pitch motion is drawn. It is shown that acceleration of heave and pitch are almost similar. When period of wave are increased, acceleration of heave and pitch is decreased. By comparing acceleration of heave and pitch, it can be known that pitch is major component than heave for short period wave.

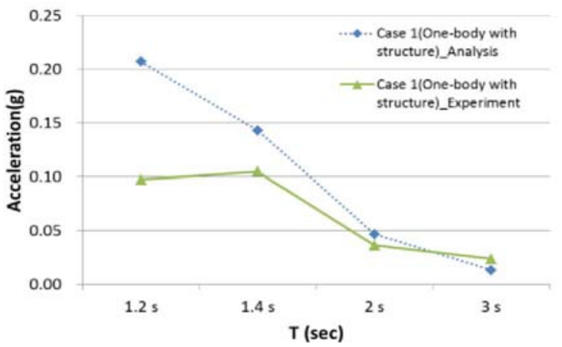
5. Comparison between experiment and analysis

Maximum acceleration of analysis about each case is shown in Table 4. The acceleration of floating pontoon at end is influence by heave and pitch. Because heave and pitch have different phase angle about π/4, the acceleration is calculated by using pitch only.

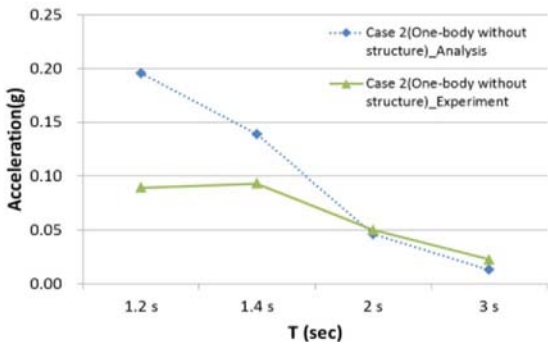
Table. 4 Acceleration at channel 1 from analysis (unit : g)

	Wave period			
	1.2 s	1.4 s	2.0 s	3.0 s
case 1	0.2070	0.1429	0.0467	0.0132
case 2	0.1956	0.1390	0.0465	0.0131
case 3	0.0927	0.0717	0.0235	0.0065
case 4	0.0893	0.0697	0.0233	0.0065

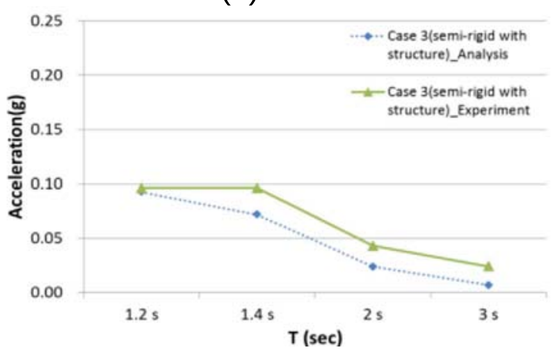
In Fig. 12, the pitch acceleration of analysis an experiment ate compared. In case of short period of one-body pontoon, the analysis results is similar to experimental results.



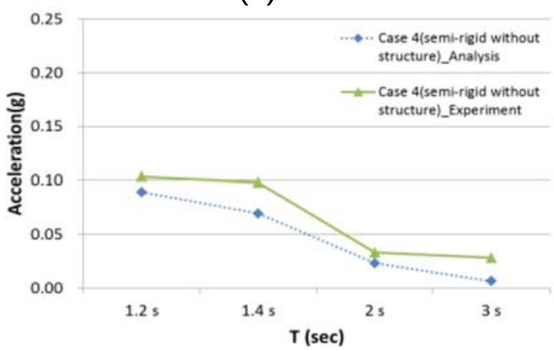
(a) case 1



(b) case 2



(c) case 3



(d) case 4

Fig. 12 Comparison of pitch acceleration of analysis and experiment

6. Conclusion

To find the behavior of semi-rigid pontoon connected by pre-stressing an experimental study is performed, which is compared to the behavior of one body pontoon. In experiment, pontoon shape is rectangular and superstructure is one story. Also the hydro-dynamic analysis with multi body motion is performed and compared with the experiment for verification. Conclusions are like followings.

It was shown that the pitch acceleration of semi-rigid pontoon is nearly equal to that of one-body pontoon, both with superstructure and without superstructure. Also the pitch acceleration of analysis shows similar results compared to experiment, except short period of one body.

In this study, stiffness of connecting spring is also limitedly considered, it needs to study much more.

This research was supported by a grant(10 RTIP B01) from Regional Development Research Program funded by Ministry of Land, Infrastructure and Transport of Korean government

REFERENCES

C.M. Wang, Z,Y, Tay (2011), “Very Large Floating Structure: Applications, Research and Development”, Procedia Engineering 14, 62-72

E. Watanabe, T. Utsunomiya, C.M. Wang (2003), “Hydroelastic analysis of pontoon-type VLFS: a literature survey”, Engineering Structures 26, 245-256

Sa Young Hong, Bo-Woo Nam, Jin-Ha Kim, Young-Shik Kim, Seok Won Hong, Young-Soo Kim (2011), “Second-order Motion Characteristics of a Semi-Submersible Platform in Waves” International Journal of Ocean System Engineering 1(3), 155-164