Wave-Induced Motion of Offshore Support Structures simulating Marine Down-Positioning by Crane

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Abstract: In this study, in order to investigate wave-induced motion of offshore support structures simulatingmarine installation by crane lifting and seabed down positioning, wave-induced motion tests were carried out for the three types of offshore support structures under the regular wave conditions. As the results of this study, it was found that, GBS and Hybrid type indicated lower wave-induced motions than the Monopile under the normal wave condition. It caused by lower center of gravity of GBS and Hybrid. Therefore, in respects of the low swing motion during the marine installation work, it is advantaged to low center of gravity of the support structures. Hybrid model indicated the lowest wave-induced motion among the three models. It was caused by low wave force thanks to the multipile members of the upper part as well as low center of gravity. It is contribute to expand marine working time during the days and to save installation cost dramatically.

Keywords: Support structure, Wave-induced motion, Test, Marine installation, Normal wave, Center ofgravity

I. INTRODUCTION

Offshore support structures have been installed by the crane lifting and seabed down positioning at marine conditions of the wave and current, as presented in Fig. 1. In order to exactly down positioning offshore support structure on arranged seabed point and to prevent breakdown of the boom of the offshore crane due to the large motion of the offshore support structures, it is important to minimize motion of offshore support structure by the wave and current during the seabed down positioning. Therefore, marine installation works of offshore support structures have been carried out only during the steady-state marine condition of no-wave and no-current.

Fig. 1. Offshore support structure installation by crane lifting and down positioning

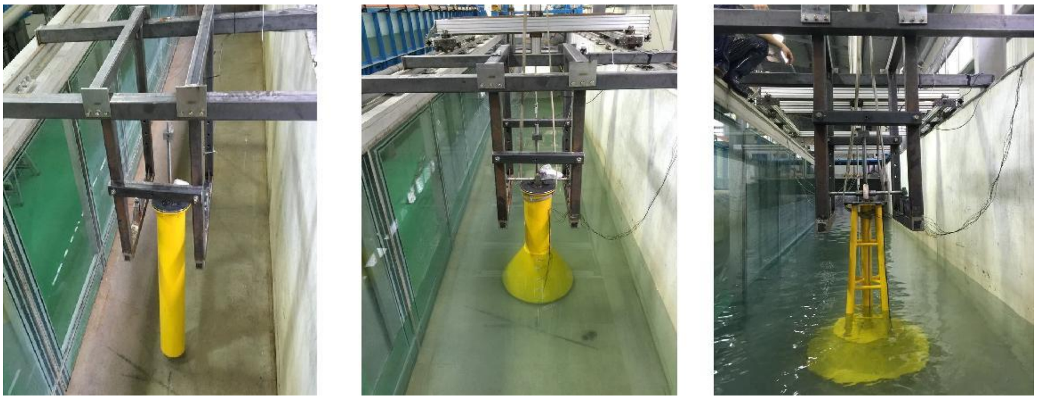
However, this steady-state marine condition occurs in short time during the days. Namely, marine installation works has been carried out in short time during the days and it caused increasing of marine working periods and installation cost due to the expansive cost of offshore crane and vessel. If wave-induced motion of offshore support structure during the crane lifting and seabed downpositioning can be minimized, marine installation works can be expanded to the certain levels of marine conditions of some-wave and some-current. Accordingly, marine working time can be increased during the days and installation cost can be reduced dramatically.

In this study, in order to investigate wave-induced motion of offshore support structures simulating marine installation by crane lifting and seabed down positioning, wave-induced motion tests were carried out for the three types of offshore support structures, Monopile [1], GBS (Gravity Base System) [1], [2], and Hybrid types [3], [4], [5] under the regular wave conditions. Based on the wave-induced motion resulting from the tests, wave-induced motions to the offshore support structure types were analyzed and compared with each other.

II. WAVE-INDUCED MOTION TEST

2.1 Test Models

In order to investigate wave-induced motion of offshore support structures simulating marine installation by crane lifting and seabed down positioning, three types of offshore support structures of Monopile, GBS, and Hybrid were fabricated and tested under the regular wave conditions, as shown in Fig. 2. Three types of support structures were designed and fabricated to have the same total weight and height applying Froude scale law of 1:25. The details of three offshore support structure models were summarized in Table 1.



(a) Monopile (b) GBS (c) Hybrid

Fig. 2. Test models

Table 1: The details of test models

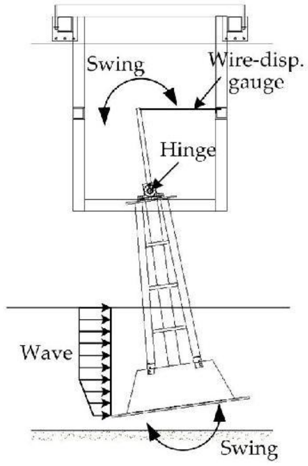
No.	Type	Dimension (mm)	Weight (kg)	Wave Area (cm^2)	Wave Volume (cm^3)	Scale
1	Mono	240(D_1)×240 D_2)×1,500(H)	203.00	1,920.0 (1.0)	11,520.0 (1.0)	1:25
2	GBS	260(D_1)×740(D_2)×1,500(H)	203.00	4,000.0 (2.1)	50,000.0 (4.3)	1:25
3	Hybrid	272(D_1)×740(D_2)×1,500(H) *** D_1=(4·Ø48+Ø80)***	203.00	3,462.4 (1.8)	38,863.1 (3.4)	1:25

*** D_1: top diameter, D_2: bottom diameter, H: height

2.2 Test Setup

In order to investigate wave-induced motion of the offshore support structures simulation marine installation by crane lifting and seabed down positioning, experimental studies were conducted at the flume of the CheonNam National University (local campus at Yeusu) of the South Korea in July, 2015. The dimensions of the flume were 100 m (L) × 2.0 m (W) × 3.0 m (H).

The mechanical frame was specially designed and fabricated to allow wave-induced swing motion of test models with the minimum friction. In order to remove tension effect of the crane rope during the crane lifting and seabed down positioning, hinge part of the swing motion for the offshore support structures made atthe top of the test models, not crane top, and wave-induced motions were measured using the wire-displacement gauge installed at the rebar connected to the test model, as shown in Fig. 3.



(a) Wave-induced motion test method

(b) Installation of test models

Fig. 3. Test setup

2.3 Wave Conditions

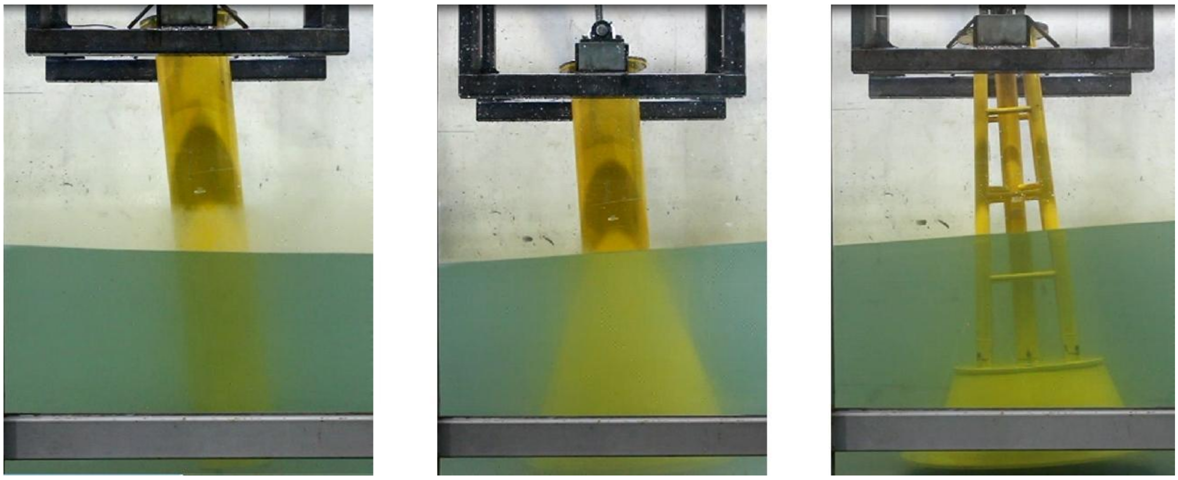
Offshore support structure models were tested under the five different regular wave conditions, as presented in Table 2 and Fig. 4. Marine installation works of offshore support structures have been carried out only during the steady-state marine condition of no-wave and no-current and the purpose of this study was to expand marine installation works to the certain levels of marine conditions of some-wave and some-current. Therefore, wave condition of this study should be low level of wave height and wave period.

However, it was difficult to generate low levels of wave height and wave period at the wave maker of the flume because of the limited capacity of the wave maker. Therefore, the wave height (H_W) 3.435 m, which was corresponded to normal wave height condition for 1 year, was selected for the full-scale models and it was scale downed to 0.137 m for the small-scale model. The wave variables of this wave-induced motion tests were the wave periods. For the wave height 3.435 m, five cases of wave period (P_W) 7.5 s, 9.5 s. 11.5 s, 13.5 s, and 15.5 s were selected and these were scale downed to 1.5 s, 1.9 s, 2.3 s, 2.74 s, and 3.1 s for the small-scale model. Water depth was 20.0 m and scale downed to 0.8 m.

Table 2: Wave conditions

No.	Wave Height H_D (m)	Wave Period T_D (s)	Wave Length L_D (m)	H_D/L_D
#1	0.137 (3.435)	1.500 (7.5)	3.217 (80.429)	1/23.41
#2	0.137 (3.435)	1.900 (9.5)	4.530 (113.269)	1/32.97
#3	0.137 (3.435)	2.300 (11.5)	5.787 (144.674)	1/42.11
#4	0.137 (3.435)	2.740 (13.5)	7.124 (178.122)	1/51.85
#5	0.137 (3.435)	3.100 (15.5)	8.197 (204.940)	1/59.66

In case of Hybrid model, incident wave 45° as well as 0° was added to verify maximum wave-induced motion according to the incident wave effect. Since the upper part of Hybrid model consist of the multiplies and indicate different wave force to the wave direction, in order to act incident wave 45° effects, Hybrid model was repositioned to the 45° direction for the wave direction.Wave-induced motion tests were carried out during the 300 s. Among the measured time series wire-displacement data set, 50 s data sets from 200 s to 250 s was selected as the typical wave-induced motion, whichwas well present wave-induced motions of test models.

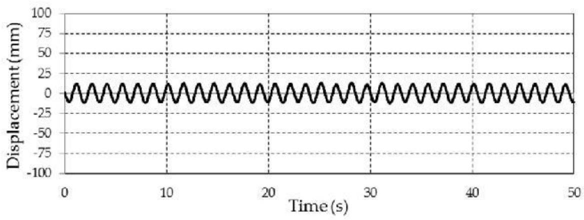


(a) Monopile (b) GBS (c) Hybrid

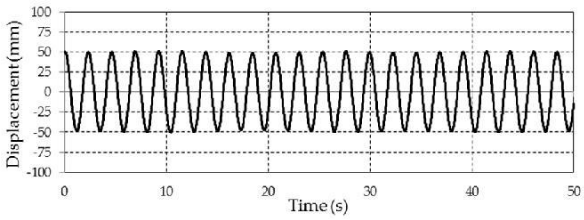
Fig. 4. Wave-induced motion tests

III. WAVE-INDUCED MOTIONS

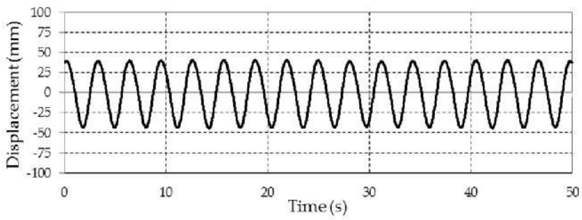
As the results of wave-induced motion tests, measured wave-induced motions for the small-scale models were presented in Fig. 5 to Fig. 8 for the offshore support structure types, respectively. Noise of measured data set was eliminated using moving average data processing method. Based on the measured data, minimum and maximum magnitudes of the wave-induced motions were calculated. Amplitudes, swing distance from maximum to minimum, of wave-induced motions resulting from tests were summarized in Table 3.



(a) Wave #1

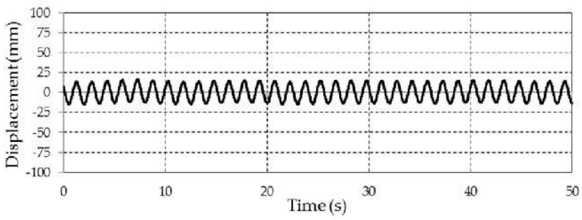


(b) Wave #3

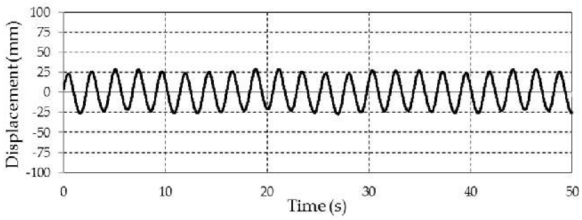


(c) Wave #5

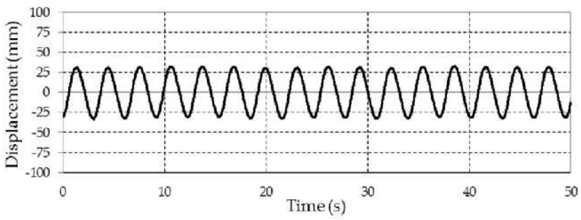
Fig. 5.Measured wave-induced motion of Monopile



(a) Wave #1

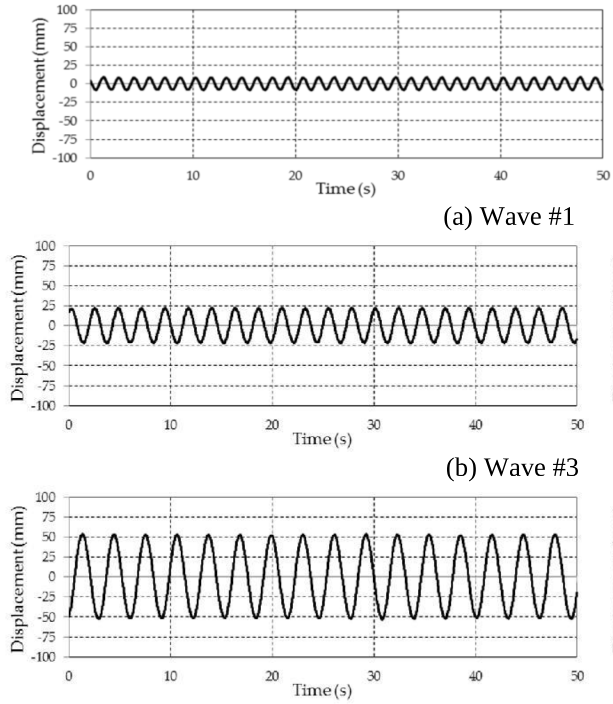


(b) Wave #3



(c) Wave #5

Fig. 6. Measured wave-induced motion of GB

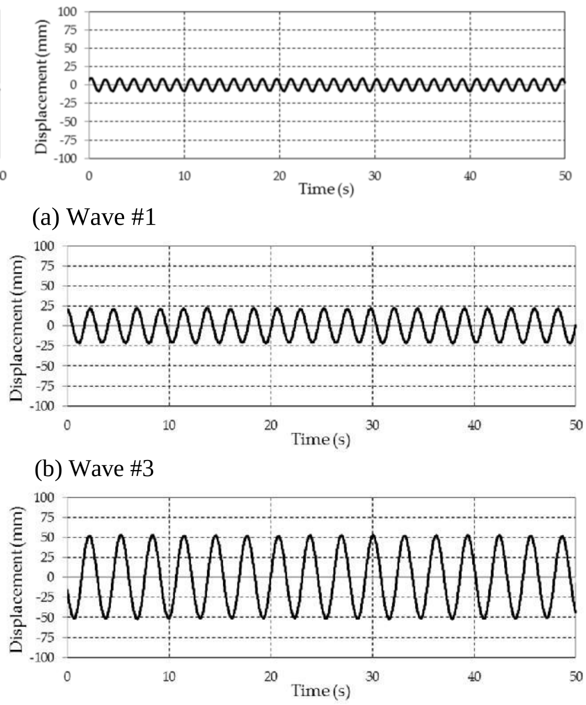


(a) Wave #1

(b) Wave #3

(c) Wave #5

Fig. 7. Measured wave-induced motion of Hybrid: 0°



(a) Wave #1

(b) Wave #3

(c) Wave #5

Fig. 8. Measured wave-induced motion of Hybrid: 45°

Table 3: Summary of wave-induced swing motions

Wave	Motions	Monopile	GBS	Hybrid	
				0°	45°
#1	Magnitude	25.9	31.6	17.9	17.9
	Ratio	1.00	1.22	0.69	0.69
#2	Magnitude	45.8	44.5	29.1	28.4
	Ratio	1.00	0.97	0.64	0.62
#3	Magnitude	101.1	54.8	44.3	44.4
	Ratio	1.00	0.54	0.44	0.44
#4	Magnitude	213.1	64.1	68.0	68.2
	Ratio	1.00	0.30	0.32	0.32
#5	Magnitude	85.1	65.8	106.5	105.2
	Ratio	1.00	0.77	1.25	1.24

Test results of this study indicated a different tendency for the offshore support structure types. In cases of the GBS and Hybrid, as the wave period increased from wave #1 (7.5 s) to wave #5 (15.5 s), wave-induced motions of support structure increased, as presented in Fig. 9. Wave-induced motions for the GBS and Hybrid models at the short wave period of 7.5 s were about 48.0 % and 16.9 % level, respectively, of the long wave period of 15.5 s. However, in cases of Monopile, as the wave period increased from wave #1 (7.5 s) to wave #5 (15.5 s), wave-induced motions of support structure gradually increased and maximize at the wave period 13.5 s (wave #4), as presented in Fig. 9. Wave-induced motion at the short wave period of 7.5 s was about 12.2 % level of the long wave period of 13.5 s.

At the normal wave condition of wave height 3.435 m, almost wave periods raged at the short wave periods below 11.5 s. Therefore, in respects of marine installation works of offshore support structures, it is important to consider normal wave periods condition below wave period 11.5 s. At the short wave periods below

11.5 s, Monopile model indicated the largest wave-induced motion among the three offshore support structures. Whereas, Hybrid model indicated the smallest wave-induced motion, about 69 % at the wave #1 and about 44% at the wave #3 of the Monopile. GBS model indicated higher wave-induced motion, about 122 % of the Monopile, at the wave #1 and lower wave-induced motion, about 54% of the Monopile , at the wave #3.

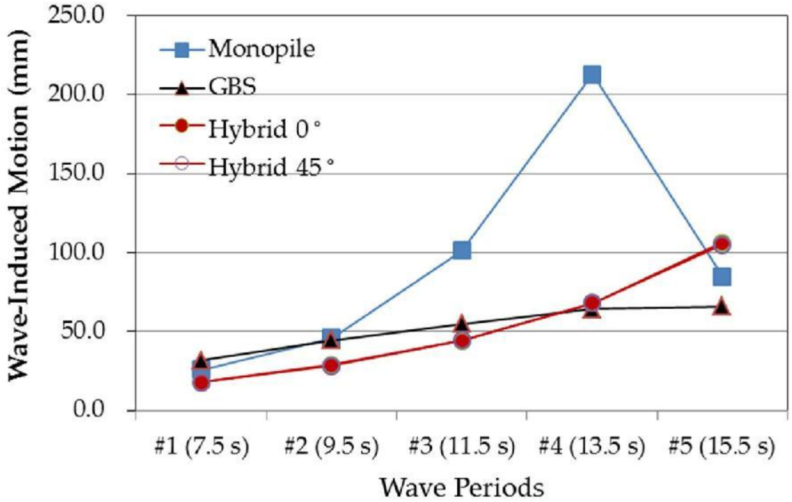
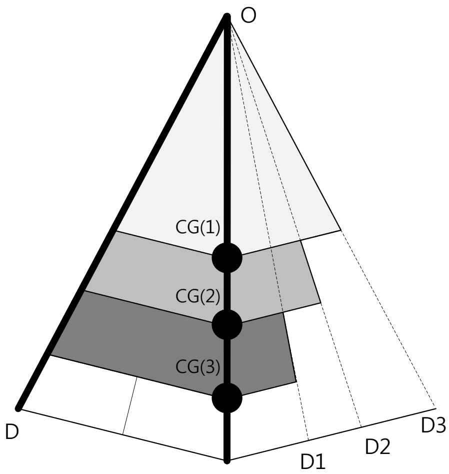


Fig. 9. Measured wave-induced motion to wave periods



(a) Kinetic energy to CG (b) Swing motion to CG

Fig. 10. Swing motion of wave body to the center of gravity

The reason that the wave-induced motions of GBS and Hybrid were lower than the Monopile was that the center of gravity of GBS and Hybrid were lower than the Monopile, although the total weights of the test model were the same with each other. When the center of gravity of the test model was low, it needs more kinetic energy to move the same swing motion D than that the center of gravity was high, as presented in Fig. 10. Namely, as the wave energy subjected to the test models was the same with each other, as the center of gravity was low, swing motion becomes small, as presented in Fig. 10. Hybrid model indicated lower wave-induced motion than the GBS since Hybrid model indicated lower center of gravity than the GBS, and multipile of theupper part contributed to reduce wave force to the Hybrid model [6]. Also, Hybrid models to the incident wave 0° and 45° indicated the similar levels of wave-induced motions because of the same total weight, the same center of gravity, and similar wave force.

IV. CONCLUSION

In this study, in order to investigate wave-induced motion of offshore support structures simulating marine installation by crane lifting and seabed down positioning, wave-induced motion tests were carried out for the three types of offshore support structures, Monopile, GBS (Gravity Base System), and Hybrid types under the regular wave conditions. Based on the wave-induced motion tests, wave-induced motions to the support structure types were analyzed and compared with each other.

As the results of this study, it was found that, GBS and Hybrid type indicated lower wave-induced motions than the Monopile under the normal wave condition of the low wave height and short wave period, which was offshore condition during the marine installation works of offshore support structures. It caused by lower center of gravity of GBS and Hybrid, although the total weight of the three models were the same with each other. Therefore, in respects of the low swing motion during the marine installation work by crane lifting and seabed down positioning, it is advantaged to low center of gravity of the support structures. Hybrid model indicated the lowest wave-induced motion among the three models. It was caused by low wave force thanks to the multipile members of the upper part as well as low center of gravity.

Therefore, it is expected that Hybrid model of this study can be expanded marine installation works to the certain levels of marine conditions of some-wave and some-current. It is contribute to expand marine working time during the days and to save installation cost dramatically.

Acknowledgements

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