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Wave Force Characteristics for Structural Members of Hybrid Marine Structure

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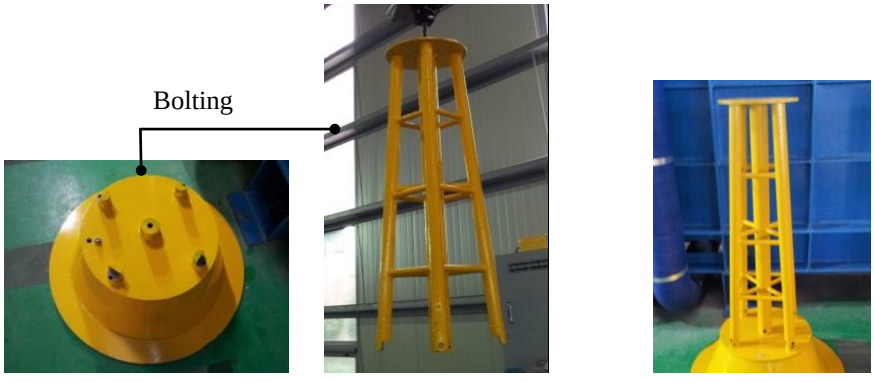
ABSTRACT: In this study, in order to evaluate wave force characteristic for the structural members of multipile-gravity based (hybrid) marine support structures, wave force tests were carried out. As the results of this study, it was found that wave force portions for the structural members, namely multipile part and gravity base part consisting of hybrid support structure system, indicated consistency according to the various wave conditions. However, at the high wave height cases, wave force portions for the multipile part increased due to the impact wave force effects near the water surface. Accordingly, wave force portions for the gravity base at the bottom part decreased since the underwater members was less sensitive to impact wave force effects. These results should be contributed to enhance structural design of hybrid support structure since impact wave force effect at the extreme wave condition could not obtain by analytically.

KEYWORDS: Wave Force Characteristics, HybridMarine Support Structure, Structural Members, Test.

I. INTRODUCTION

In order to optimally arrange structural members of marine support structure so as to satisfy both low-wave force and high-overturning safety, hybrid types of support structure have been developed in Japan [1], France [2], and South Korea [3,4]. Hybrid types were designed by adopting the advantages of both the gravity and jacket (or multipile) system, as presented in Fig. 1. Upper part of this system adopted jacket or multipile to reduce wave force to the support structure and bottom part adopted the gravity base to improve overturning resistance. In respects of the structural design, it is important to exactly evaluate wave force subjected to the structural members of the multipiles and gravity base from wave force test, since wave forces subjected to the marine support structures indicated nonlinearity to the shape of support structure and to the wave conditions [3,4].



(a) Gravity base (b) Multipile (c) Hybrid model

Fig. 1 Structural members assembling for test model

In this study, wave force tests were carried out to evaluate wave force characteristic for the structural members of the multipiles and gravity base consisting of hybrid support structure. Based on the wave force tests, wave force characteristic for the multipile at the upper part and gravity base at the bottom part were analyzed, respectively.

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II.WAVE FORCE TEST PROGRAM

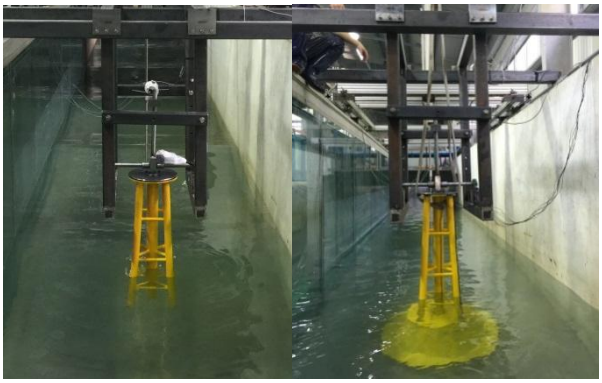
A. Test Models

In order to measure wave force to both the multipile part and gravity base part, respectively, test model was fabricated so as to separate multipile part from the gravity base by the bolting, as presented in Fig. 1 and Fig. 2. The detail of test model was summarized in Table 1.

Table 1 Details of test models

Structural members	Dimension (mm)	Weight (kg)
Multipile (upper)	(4·Ø48+Ø80)×1,180(H)	27.17
Gravity base (bottom)	568(D_1)×740(D_2)×320(H)	175.83
Hybrid system (total)	272(D_1)×740(D_2)×1,500(H)	203.00

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



(a) Multipile (b) Hybrid

Fig. 2 Test model setup

B. Wave Force Test

Multipile model(excluded gravity base part) and hybrid model were tested under the six regular wave conditions respectively [3,4], as presented in Table 2. Where, wave #3 was corresponded to the normal marine condition and wave #6 was corresponded to the extreme marine condition at the structural design.

Table 2 Wave conditions

No.	H_W (m)	P_W (s)	L_W (m)	H_W/L_W
#1	0.137 (3.435)	1.50 (7.5)	3.217 (80.429)	1/23.41
#2	0.137 (3.435)	1.90 (9.5)	4.530 (113.269)	1/32.97
#3	0.137 (3.435)	2.30 (11.5)	5.787 (144.674)	1/42.11
#4	0.137 (3.435)	2.74 (13.5)	7.124 (178.122)	1/51.85
#5	0.137 (3.435)	3.10 (15.5)	8.197 (204.940)	1/59.66
#6	0.511 (12.78)	2.74 (13.5)	7.124 (178.122)	1/13.94

*** ( ) outside: small-scale model, ( ) inside: full-scale model

At the wave force test, incident wave 45° as well as 0° was added to verify maximum wave forces according to the incident wave effect [3,4]. The dimensions of the flume were 100 m (L) × 2.0 m (W) × 3.0 m (H).Based on the measured data, wave force amplitudes were calculated for the small-scale models and converted for the real-scale

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models according to the Froude scale law.

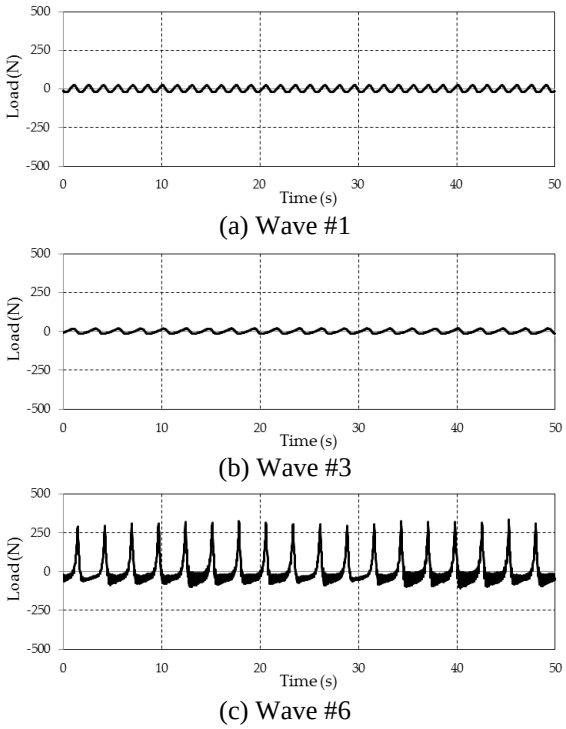
III. WAVE FORCE TEST RESULTS

A. Measured Wave Forces

As the results of wave force tests on the regular wave, measured wave forces for the small-scale models were presented in Fig. 3 and Fig. 4 to the structural members of multipiles part (upper) and hybrid model, respectively. Wave force amplitude for the real-scale models were summarized in Table 3. Wave forces for gravity base part obtained by Eq.(1), where, F_G, F_H, and F_M, were the wave forces to the gravity base part, hybrid, and multipile part, respectively.

$$F_G = F_H - F_M \quad (1)$$

At the normal wave condition of wave #1 to wave #5, measured wave force had a similar tendency that, as the wave period increased from wave #1 to wave #5 maintaining the same wave height, wave forces subjected to the test models decreased for the multipile, gravity base, and hybrid model, as presented in Fig. 5. At the extreme wave condition of wave #6, wave forces for the multipile part drastically increased, about 1,355 % and 1,543 % level of normal wave height cases [3], which was over wave height ratio of 373%, as indicated in Table 3 and Fig. 6.

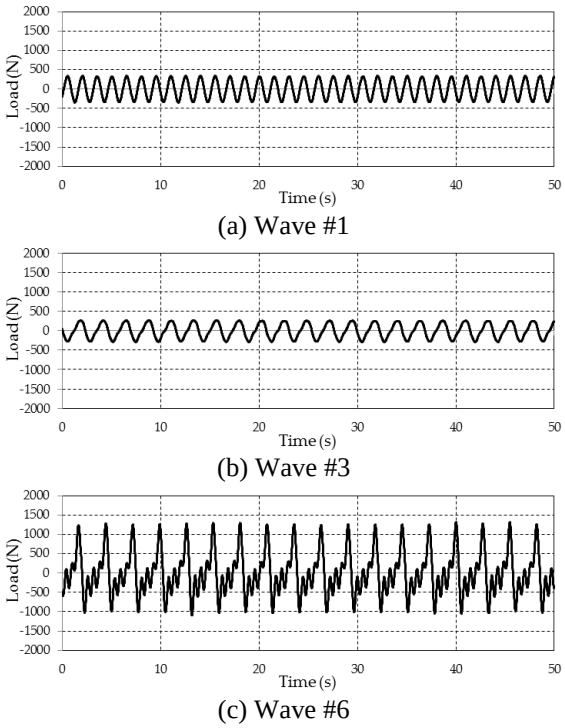


(a) Wave #1

(b) Wave #3

(c) Wave #6

Fig. 3 Measured wave forces for multipile



(a) Wave #1

(b) Wave #3

(c) Wave #6

Fig. 4 Measured wave forces for hybrid

Wave forces for the gravity base part and hybrid model increased similar range with the wave height ratio of 373%, about 322~323% for the gravity base part and about 423~435% for the hybrid model, respectively, as indicated in Table 3 and Fig. 6. As considering wave height ratio (373%) and impact wave force factors (4.3~5.15) for the cylinder Monopile [5], impact wave force affect largely on the wave force of the upper multipile part, which located near the water surface and sensitive to the wave height, as presented in Fig. 7. Also, wave-induced little vibration of test modes influenced on wave forces at the extreme wave condition of wave #6, as presented in Fig. 8. The maximum gradient of multipile model due to the wave-induced vibration was about 0.7°, and hybrid model was about ±1.4°, respectively.

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B. Wave Force Portions for Structural Members

As the results of the wave force test, wave forces portions of the structural members of the multipile part (upper) and gravity base part (bottom) were indicated in Table 4 and Fig. 9. At the normal wave conditions of wave #1 to wave #5, wave force portions for the structural members, namely multipile part and gravity base part consisting of hybrid support structure system, indicated consistency according to the various wave periods. Wave force portions of the multipile part, among the total wave force to the hybrid model, ranged about 8.41~10.43% for the incident wave 0° and 8.64~11.11% for the incident wave 45°, respectively. Wave force portions of the gravity base part ranged about 89.57~91.59% for the incident wave 0° and 88.89~91.36% for the incident wave 45°, respectively. Although, wave force amplitudes were different with each other to the wave condition, wave force portion of each structural member presented the similar percentage.

Table 3 Summary of maximum wave forces for real-scale models (kN)

Wave No.	Multipile(upper, F_M)		G.base(bottom, F_G)		Hybrid (F_H)	
	0°	45°	0°	45°	0°	45°
#1	164	171	1,409	1,368	1,573	1,539
#2	125	125	1,362	1,321	1,487	1,446
#3	123	126	1,141	1,140	1,264	1,266
#4	102	106	998	987	1,100	1,093
#5	85	89	869	848	954	937
#6	1,574	1,436	3,212	3,187	4,786	4,623

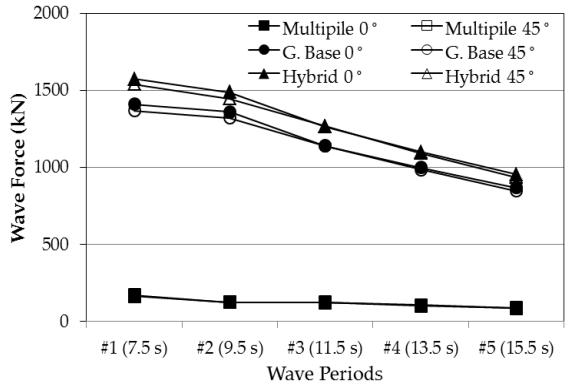


Fig. 5 Wave forces to wave periods

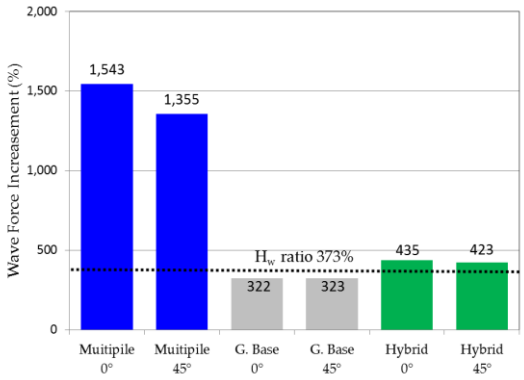
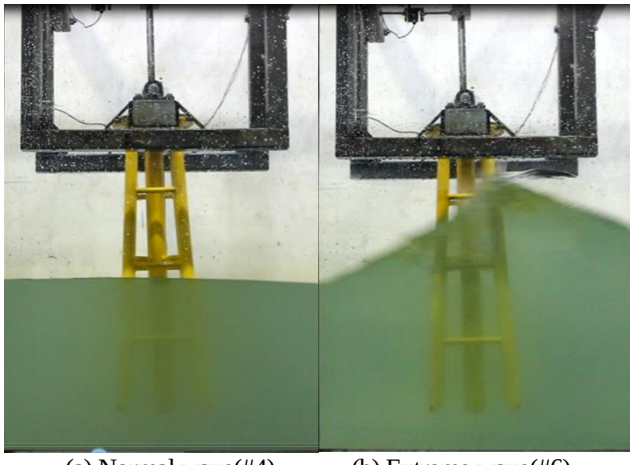


Fig. 6 Wave force at extreme wave



(a) Normal wave(#4) (b) Extreme wave(#6)

Fig. 7 Wave run-up at extreme wave(#6)

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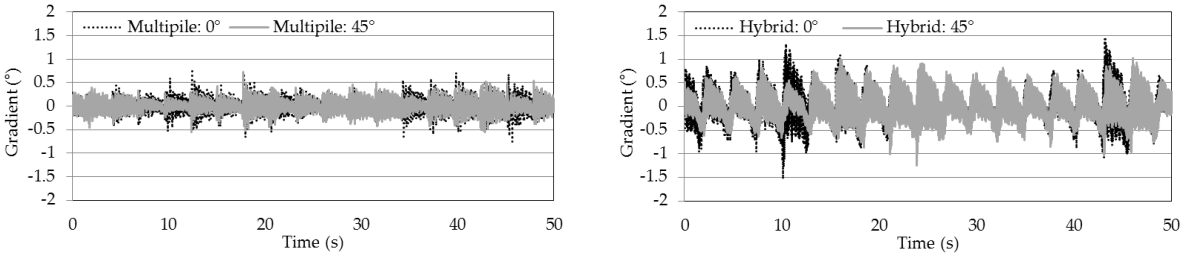

(a) Multipile model (b) Hybrid model

Fig. 8 Wave-induced vibration at extreme wave #6

Table 4 Wave force portions for the structural members

Wave No.	Incident wave 0°		Incident wave 45°	
	Multipile	G. Base	Multipile	G. Base
#1	10.43 %	89.57 %	11.11 %	88.89 %
#2	8.41 %	91.59 %	8.64 %	91.36 %
#3	9.73 %	90.27 %	9.95 %	90.05 %
#4	9.27 %	90.73 %	9.70 %	90.30 %
#5	8.91 %	91.09 %	9.50 %	90.50 %
#6	32.89 %	67.11 %	31.06 %	68.94 %

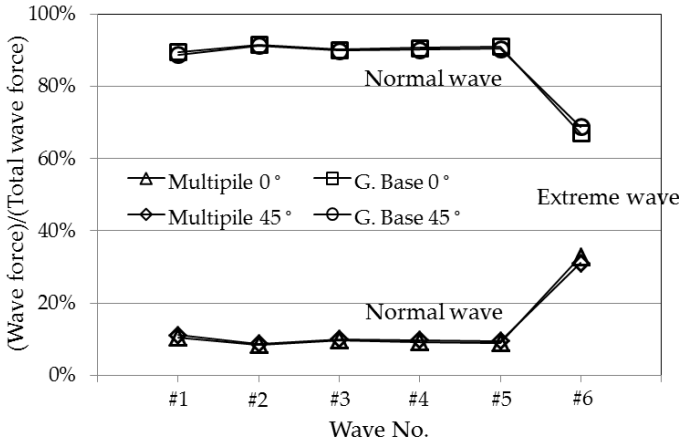

Fig. 9 Wave force percentages for the structural members

However, at the extreme wave condition of wave #6, wave force portions of the multipile part increased to 31.06~32.89 % and wave force portions of the gravity base part decreased to 67.11~68.94% for the incident wave 0° and 45°, respectively, as presented in Fig. 9. It was caused by impact wave force called slamming force at the extreme wave condition of wave #6 [6-11], as illustrated at the section 3.1. At the high wave height cases, wave force of the multipile part near the water surface was sensitive to the impact wave force effects. On the other hand, the underwater member was less sensitive to impact wave force effects. Accordingly, wave force portions for the multipile part increased and wave force portions for the gravity base decreased at the high wave height cases.

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IV. CONCLUSION

In this study, in order to evaluate wave force characteristic for the structural members of multipile-gravity based (hybrid) marine support structures, wave force tests were carried out.

As the results of this study, it was found that wave force portions for the structural members, namely multipile part and gravity base part consisting of hybrid support structure system, indicated consistency according to the various wave conditions. At the normal wave conditions, although wave force amplitudes were different with each other to the wave periods, wave force portion of each structural member presented the similar percentage. However, at the high wave height cases, wave force portions for the multipile part increased due to the impact wave force effects near the water surface. Accordingly, wave force portions for the gravity base at the bottom part decreased since the underwater members was less sensitive to impact wave force effects.

These results should be contributed to enhance structural design of hybrid marine support structure since impact wave force effect at the extreme wave condition could not obtain by analytically. Furthermore, more research is needed to access the impact wave force for the support structure shapes and wave conditions since it has known that the impact wave force were dependent on the support structure shape, wave height, and wave period.

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