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Moment increase of 3 storied Building on Floating Concrete Pontoon According to Incident Wave Angle

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ABSTRACT

To find the change of moment of steel MRF on rectangular concrete floating pontoon according to various wave incident angles, the hydro-dynamic analysis was performed. And static analysis is performed with the mapped wave pressure and the dynamic analysis is performed with input base acceleration calculated from the hydro-dynamic analysis. Considering both wave pressure and base acceleration from the motions of pontoon, the moment increase according to base acceleration is much greater than that of wave pressure for all wave incident angle. Base acceleration has more effect on the increase of moment for both longitudinal and transverse direction. Only for long period wave, the wave pressure has effects on the moment increase.

1. INTRODUCTION

1.1 Background and Purpose

In the early 20th century, floating structures are built for developing offshore resources. In the second half of the 20th century, floating structures actively had been built as residential and leisure facilities for marine space in Europe and other developed countries. In recent years, the number of projects to develop marine space is increased like Saemangeum development and Han River Renaissance Project, in Korea. [1].
Generally floating structures are exposed to environmental impacts including wind, tide and etc. And special loads such as mooring, berthing, collision force should be considered. Among these loads floating structures are greatly affected by wave load. The analysis for wave loads necessarily should be carried out because wave load is dependent on the site and may be occurred even by towing .
In previous research, the behavior of floating structure was studied with the stiffness change of pontoon in case of wave incident angle 0° [2]. In this case, wave incident angle is in the longitudinal direction of the pontoon. Therefore, it’s necessary to consider the effect of various wave incident angles. In this study, the structural behavior between floating pontoon and superstructure will be studied through the numerical analysis when it is exposed to the wave load with various incident angles.

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2. RANGE AND METHOD

2.1 Case model for analysis

Floating pontoon is assumed as a rectangular type made of reinforced concrete. Analysis model has length of 96m, width of 48m and height of 2.5m. In pontoon, the ratio of long side to short side is assumed to be 2. And, the superstructure is steel moment resisting frame, 3 storied building and each floor height is 3.5m. The columns are designed as H-310 × 305 × 15 × 20, beams are as H-480 × 300 × 11 × 15. The span of the superstructure is 8m, same as in pontoon.
The load type of superstructure is assumed as uniformly distributed load. Dead load is assumed as 25kN/m^2 and live load 15kN/m^2.
Wave periods are increased from 5 to 15 seconds by every 2 seconds and wave incident angle was varied as 0°, 30°, 60° and 90° to longitudinal direction. Water depth is assumed as 10m. Calculated draft is 2.0m

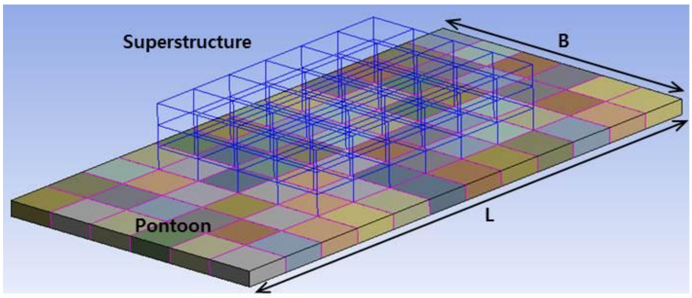


Fig. 1 Case study model

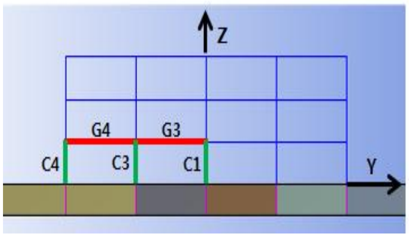


Fig. 2 Position of element of superstructure in elevation

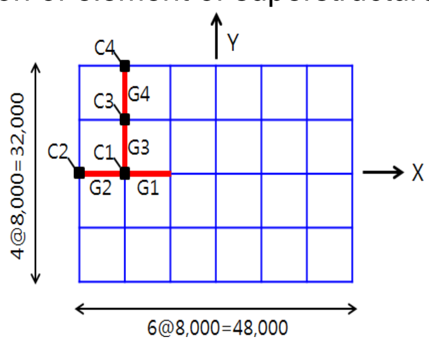


Fig. 3 Positions of column and girder of superstructure in plan

In superstructure, the internal girder is notified as G1, external girder as G2 and internal column as C1 and external column as C2 in x direction as shown in Fig. 2, 3

Table. 1 Case study model data

Length, L(m)	96	Pontoon Height (m)	2.5
Breadth, B(m)	48	Wave Period (sec)	5~15 (by 2 second)
Draft, d(m)	2.0	Wave Incident Angle (°)	0°, 30°, 60°, 90°

2.2 Analysis method

The interaction between pontoon and the superstructure is evaluated with the hydro-dynamic analysis for various wave incident angles. For this study, the ANSYS and AQWA program was used.
Numerical analysis is performed in 4 steps, as shown in Fig. 4. In first step, geometric modeling is done using ANSYS. Then hydro- dynamic analysis is performed using AQWA program. The pressure loads from AQWA analysis is mapped to ANSYS for static structural analysis. In hydro-dynamic analysis, a vibration characteristic of the superstructure is not considered. Therefore, to consider the dynamic effect of superstructure, the dynamic analysis of superstructure is performed with the input ground acceleration which was calculated from the hydro-dynamic analysis.

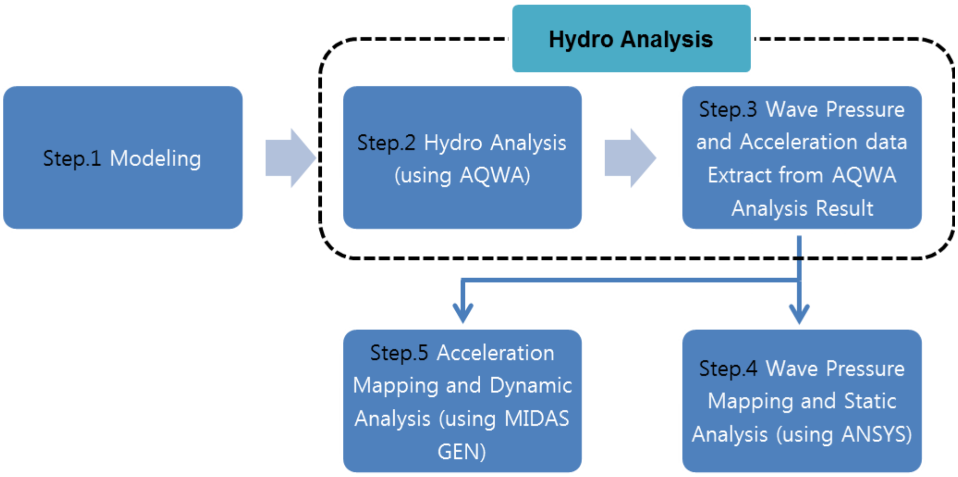


Fig. 4 Analysis Sequence

The input ground acceleration is calculated with Eq. (1) and (2). To calculate the acceleration in x-direction, both the horizontal component (surge) and the rotational component θ (pitch) of the y-direction are considered. The x-directional acceleration can be calculated using Eq. (1), where r is a distance from the water surface to the base of superstructure. To calculate the y-directional acceleration, both sway and pitch should be considered.

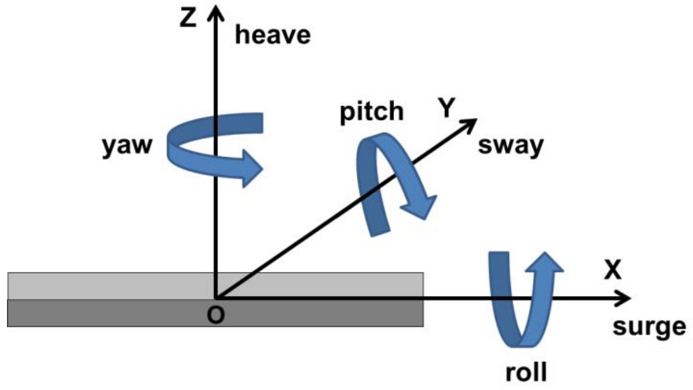


Fig. 5 axis of coordinates and behavior of 6-DOF

$$\text{Equivalent Lateral Acceleration} = \ddot{x} + r\ddot{\theta} \quad (1)$$
$$\text{Equivalent Vertical Acceleration} = \ddot{z} \quad (2)$$

3. HYDRO DYNAMIC ANALYSIS

3.1 Motion equation

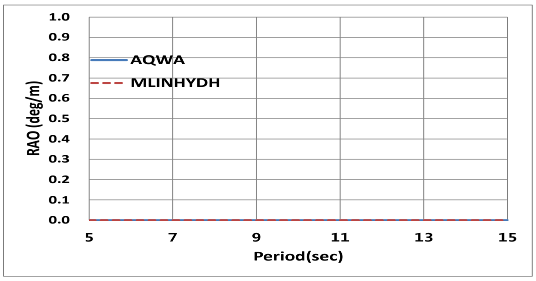
In the elastic response analysis, water is incompressible, inviscid and irrotational. Free surface is assumed to extent infinitely in all directions in order to simulate the dynamic response of structures. Analysis is performed in frequency domain by linear theory and the response is performed in 3 dimensions [3]. Hydro -dynamic equations of floating pontoons with superstructures can be expressed as shown Eq. (3).

$$M(s)\ddot{X} + M(a)\ddot{X} + C\dot{X} + K(s)X = F^{I} + F^{D} \quad (3)$$

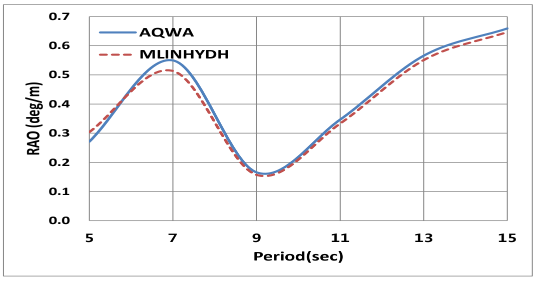
Where, M(s) = mass matrix, M(a) = added Mass matrix, C = structural damping matrix, K(s) = restoring force matrix by hydrostatic, F^I = Froude-Krylov force, F^D = diffraction force

3.2 RAO Analysis

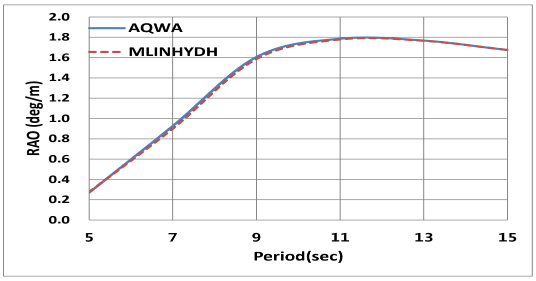
Hydro-dynamic analysis is performed to find RAO(Response Amplitude Operator) for wave periods. Roll and pitch RAO of the pontoon are shown as in Fig.6 and 7. In Fig 6 and 7, X-axis is wave period and Y-axis is RAO of roll or pitch.
In Fig 6 and 7, the results of MLINHYDH [4] and AQWA are drawn together and compared, which shows good correspondence in all periods.
In Fig.6, It is shown that RAO-Roll is continually increased as wave incident angle is increasing. But it is shown in Fig.7 that RAO-Pitch is decreased as wave incident angle is increasing.



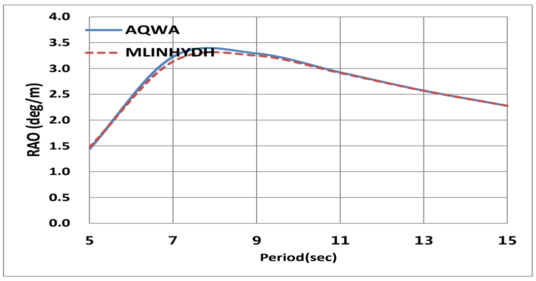
(a) Incident angle = 0°



(b) Incident angle = 30°

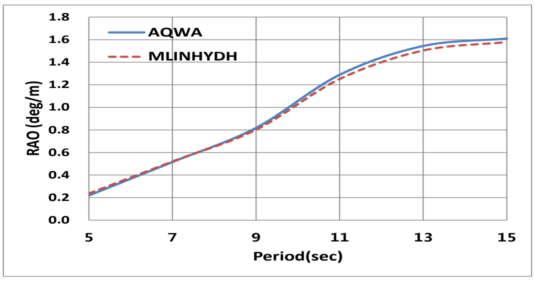


(c) Incident angle = 60°

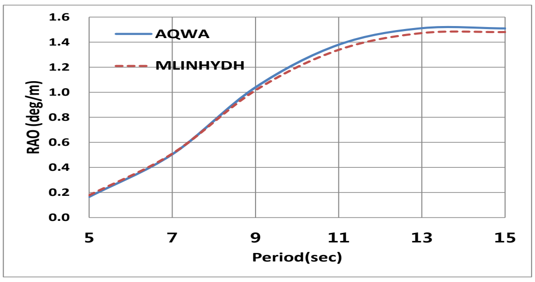


(d) Incident angle = 90°

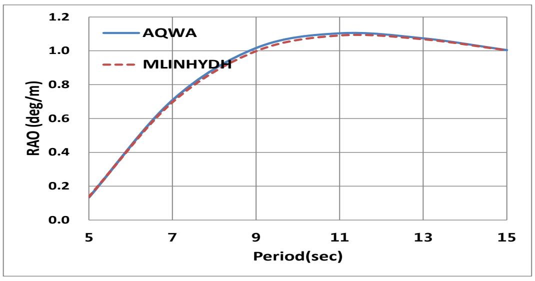
Fig.6 RAO-Roll graph



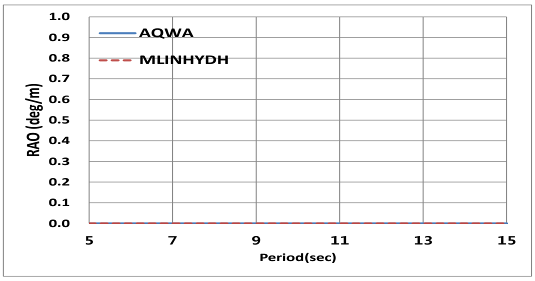
(a) Incident angle = 0°



(b) Incident angle = 30°



(c) Incident angle = 60°



(d) Incident angle = 90°

Fig.7 RAO-Pitch graph

4. STRUCTURE ANALYSIS

4.1 Moment increase of girders of superstructure

The static analysis was performed, which has a modeling not only of a pontoon but also of a superstructure. Dead load(DL) and live load (LL) are applied to superstructure and the pressure load which was taken from hydro-dynamic analysis are applied to the water contact area of the pontoon.

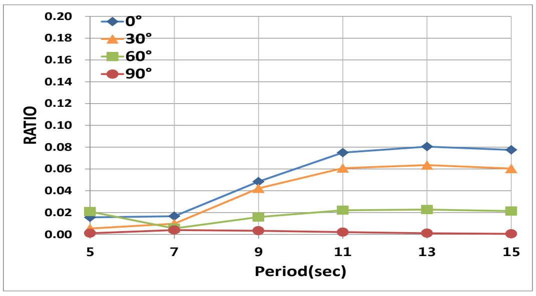
Moment increase about girders (G1, G2, G3 and G4) of the superstructure according to the wave pressure with wave incident angle is shown in Fig.8 and Table. 2.

Fig. 8 shows the moment ratio of beams. The ratio means the value of the moment of the members divided by to the maximum moment 230 kN·m caused by vertical load (DL + LL). For G1 and G2 which is in longitudinal direction of the pontoon, it can be seen that the wave pressure has no effect on the moment increase when wave incident angle is 90°. When wave incident angle is 0°, the moment increase of G1 and G2 is greatest. It means that longitudinal beams such as G1 and G2 have relation with pitch motion. As the incident angle increases, the moment increase of longitudinal beam decreases.

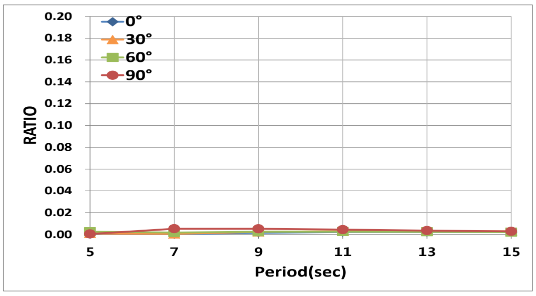
But the moment increase of G3 and G4 which are in the transverse direction of the pontoon is the greatest when wave incident angle is 90°. This is closely related to the Roll motion. From Fig. 8, it can be seen that as the incident angle increases, the moment increase of transverse beam increases. But the maximum ratio of transverse beams is far less than that of longitudinal beams.

4.2 Moment increase of columns of superstructure

Increase of moment of columns in transvers direction, My is shown in Fig.9 and Table 2 according to the wave incident angle. For C1 and C2 in longitudinal direction, it is shown that moment increase is decreased as wave incident angle is increasing. Also, C3 and C4 show the same pattern but the maximum value is about half of C1 and C2.

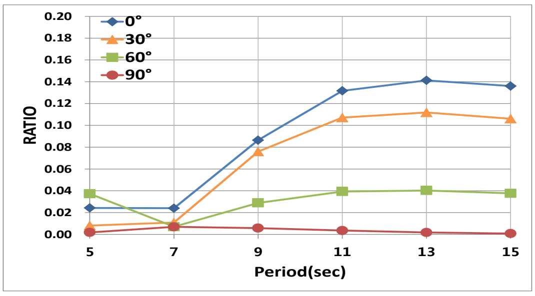


(a) G1

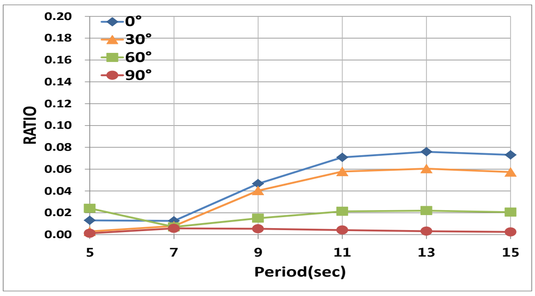


(b) G3

Fig.8 Moment ratio of girders by the wave pressure



(a) C1



(b) C3

Fig.9 Moment ratio of columns by the wave pressure

Table. 2 Moment of girders according to the wave pressure and Base acceleration

		Wave pressure				Base acceleration			
member	Wave incident angle / Period(sec)	0°	30°	60°	90°	0°	30°	60°	90°
G1	5	3.6	1.2	4.8	0.2	46.3	27.4	14.5	0
	7	3.8	2.2	1.3	0.9	41.7	40.8	41.1	0
	9	11.1	9.7	3.7	0.8	37	34.9	27.3	0.1
	11	17.2	14	5.1	0.5	25.5	18.8	5.9	0
	13	18.5	14.6	5.2	0.2	9.9	4	4.1	0
	15	17.8	13.9	4.9	0.1	2.5	7.2	8.9	0
G2	5	5.1	1.8	9.7	0.5	60.5	35.7	22.3	0.1
	7	4.4	1.1	1.1	1.8	54.5	53.2	50.8	0.1
	9	22.9	20.2	7.8	1.5	48.4	45.6	36.4	0
	11	34.1	27.9	10.3	0.9	33.3	24.6	7.9	0
	13	36.6	29	10.5	0.5	12.9	5.3	5.4	0
	15	35.2	27.5	9.8	0.2	3.2	9	8.9	0.1
G3	5	0.1	0.2	0.6	0.1	0	1.5	26.9	145.8
	7	0	0.1	0.4	1.2	0	8.4	134.9	223.5
	9	0.4	0.6	0.6	1.2	0	8.1	132.1	174.1
	11	0.5	0.7	0.6	1	0	13.2	99.2	129
	13	0.5	0.7	0.6	0.8	0	16.9	79.4	100
	15	0.5	0.7	0.5	0.7	0	27.2	62	81
G4	5	0.3	0.1	1	0.3	0	2.4	40.9	223.6
	7	0.2	0.3	0.9	3.2	0	12.9	197	343.9
	9	1.2	1.2	0.9	3.1	0	13.5	217	268.1
	11	1.8	1.4	0.8	2.6	0	22	161	198.6
	13	1.8	1.4	0.7	2.1	0	24.8	118.3	154
	15	1.7	1.3	0.5	1.7	0	42.1	96.4	125

5. DYNAMIC ANALYSIS OF SUPER STRUCTURE

5.1 Moment increase of girders due to acceleration effect

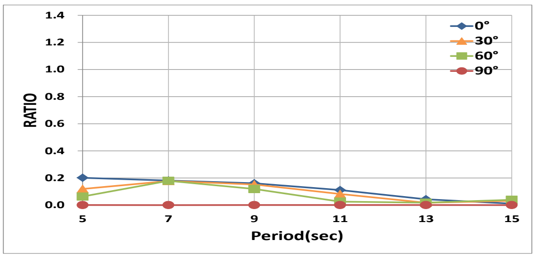
In order to consider the effect of the acceleration acting on the MRF, the dynamic analysis was performed using input with the ground based acceleration according to the Eq. (1) and (2). In dynamic analysis, only superstructure is modeled with base acceleration. The result is summarized in Table. 3.

Fig. 10 draws the increase of moment of beam. When wave incident angle is increased, the moment increase ratio of G1 and G2 is decreased significantly. In particular, influence of acceleration is the greatest at 5 seconds and decreased as the wave period is increasing.

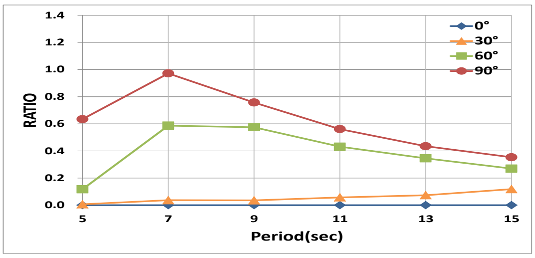
But the moment increase of G3 and G4 is maximum at 7 seconds, the maximum is also can be seen in RAO-Roll in Fig. 6

5.2 Moment increase of columns due to acceleration effect

In Fig. 11 and Table 3 show that the moment increase of column due to acceleration. When wave incident angle are 0°, 30° and 60°, it is shown that the ratio of My of C1 and C2 is increased significantly. When wave incident angle is 90°, the ratio of C1 and C2 is 0. Comparing the wave incident angle 90° and 0°, It can be showing that when the wave incident angle is 0°, the moment increase in the column members is greater than 90°. In other wave incident angles, except 90°, the significant change is not appeared.
When wave incident angle are 60° and 90°, it is shown that moment-x ratio of C3 and C4 is increased significantly. In particular, influence of acceleration is the greatest at 7 seconds and decrease at 15 seconds. When wave incident angle are 0° and 30°, it is shown that moment-x ratio of C3 and C4 is increased slightly. Comparing the wave incident angle 90° and 0°, It can be showing that when the wave incident angle is 90°, the moment increase in the column members is greater than 0°. In other wave incident angles, except 30° and 60°, the significant change is not appeared.

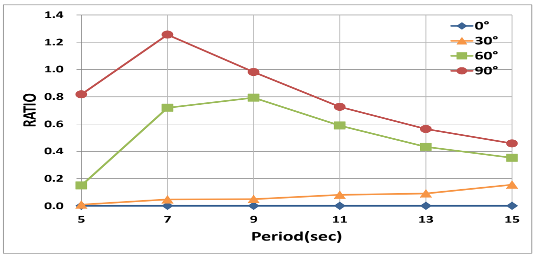


(a) G1

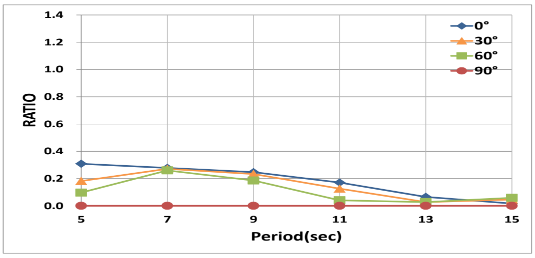


(b) G3

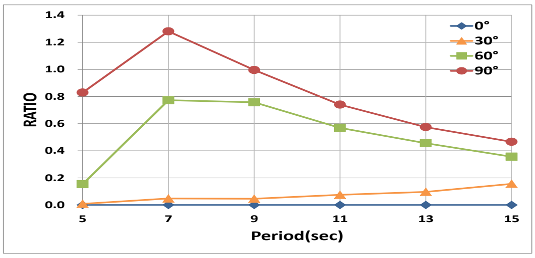
Fig.10 Increased Moment ratio of Beams by Base acceleration



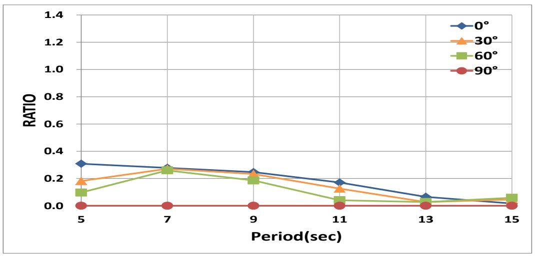
(c) C1-M_X



(d) C1-M_Y



(c) C3- M_X



(c) C3- M_Y

Fig.11 Increase Moment ratio of girders and columns by acceleration

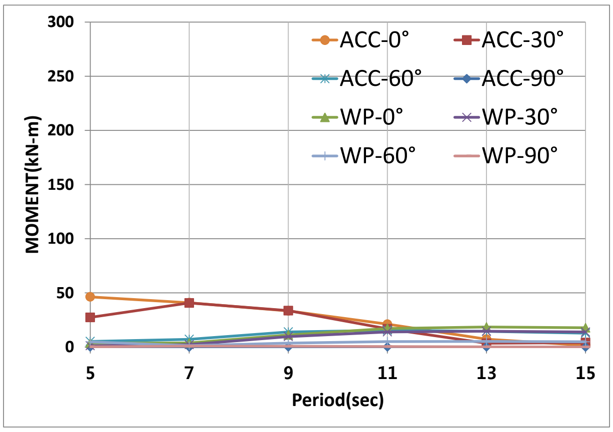
Table 3 Moment of columns according to the wave pressure and Base acceleration

member	Wave incident angle / Period (sec)	By wave pressure								By base acceleration							
		M_X(kN-m)				M_Y(kN-m)				M_X(kN-m)				M_Y(kN-m)			
		0°	30°	60°	90°	0°	30°	60°	90°	0°	30°	60°	90°	0°	30°	60°	90°
C1	5	0	0.2	0.4	0.1	5.6	1.9	8.6	0.4	0.0	2.0	34.30	187.9	70.9	41.8	22.3	0
	7	0	0	0.2	0	5.5	2.5	1.6	1.6	0.0	10.8	165.4	288.7	64	62.4	59.7	0
	9	0	0.3	0.5	0	19.9	17.5	6.6	1.3	0.0	11.3	182.4	225.7	56.8	53.6	42.7	0
	11	0	0.4	0.6	0	30.3	24.6	9	0.8	0.0	18.5	135.4	167.0	39.2	28.9	9.3	0
	13	0	0.4	0.5	0	32.5	25.7	9.3	0.4	0.0	20.8	99.5	129.6	15.1	6.2	6.3	0
	15	0	0.4	0.5	0	31.3	24.4	8.7	0.2	0.0	35.7	81.1	105.2	3.8	10.6	13.5	0
C2	5	0	0.4	0.6	0	5.3	1.8	10.7	0.5	0	2	34.3	187.9	63.6	37.5	20	0
	7	0	0	0.7	0	4.4	0.7	1.2	2.1	0	10.8	165.4	288.7	57.4	56	53.5	0
	9	0	0.7	1.5	0	25.3	22.5	8.8	1.8	0	11.3	182.4	225.7	50.9	48.1	38.3	0
	11	0	1	1.5	0	37.5	30.8	11.4	1.1	0	18.5	135.4	167	35.1	26	8.3	0
	13	0	1.1	1.4	0	40.2	32	11.6	0.6	0	20.8	99.5	129.6	13.6	5.6	5.7	0
	15	0	1	1.2	0	38.8	30.3	10.8	0.3	0	35.7	81.1	105.2	3.4	9.5	12.1	0
C3	5	0.2	0.2	0.7	0.1	3	0.7	5.5	0.3	0.2	2.0	35.3	190.7	70.9	41.8	35.3	0
	7	0.1	0.2	0.5	1.7	2.9	1.8	1.6	1.3	0.1	11.1	177.7	294.5	64	62.4	177.7	0
	9	0.6	0.7	0.2	1.7	10.7	9.3	3.5	1.2	0.6	10.6	174.2	229.0	56.8	53.6	174.2	0
	11	0.9	0.9	0.1	1.5	16.3	13.3	4.9	1	0.9	17.3	130.9	170.2	39.2	28.9	130.9	0
	13	0.9	0.9	0.1	1.2	17.5	13.9	5	0.7	0.9	22.3	104.8	132.1	15.1	6.2	104.8	0
	15	0.9	0.8	0	1	16.8	13.2	4.7	0.6	0.9	35.9	81.9	107.2	3.8	10.6	81.9	0
C4	5	0.3	0	0.7	0.1	3	0.5	6.3	0.3	0	1.8	35.3	173.4	70.8	41.8	22.3	0
	7	0.1	0.2	0.6	2.1	2.7	2.3	2.8	1.5	0	10.1	177.7	266.8	64	62.4	59.7	0
	9	1.1	1	0.5	2.1	11	8.9	2.7	1.5	0	8.6	174.2	208.4	56.8	53.6	42.7	0
	11	1.6	1.2	0.4	1.8	16.5	13	4.3	1.2	0	15.1	130.9	154.2	39.2	28.9	9.3	0
	13	1.6	1.2	0.3	1.4	17.6	13.6	4.6	0.9	0	20.2	104.8	119.7	15.1	6.2	6.3	0
	15	1.5	1.1	0.2	1.1	17	12.9	4.3	0.7	0	32.5	81.9	97.1	3.8	10.6	13.5	0

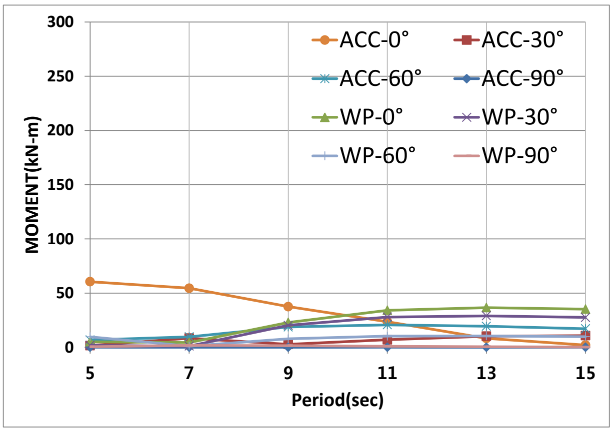
5.3 Comparison of moment by wave pressure and acceleration effect

Moment about girders (G1, G2, G3, and G4) of the superstructure according to the wave pressure and acceleration is shown in Fig. 12. In remarks of graph, WP is wave pressure and ACC is acceleration. When wave incident angle is 0°, moment increase of G1 and G2 due to wave pressure is greater than that due to the acceleration component.
As shown Fig. 12, when wave incident is angle 90°, moment increase of G3 and G4 can be seen by only the acceleration component.

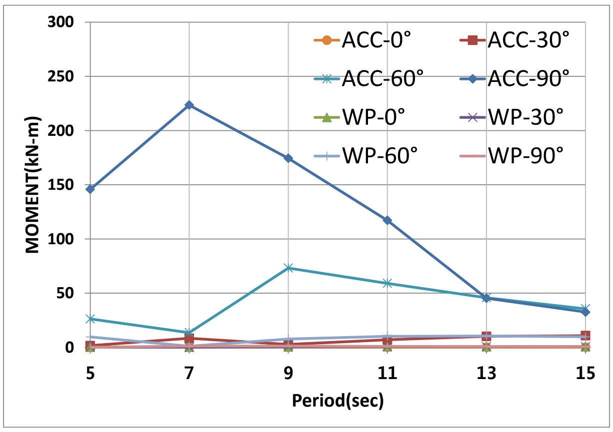
By synthesizing this, the superstructure in the longitudinal direction has a significant effect of the wave pressure compared to the acceleration. But the superstructure in the transverse direction, it has a significant effect of acceleration compared to the wave pressure.



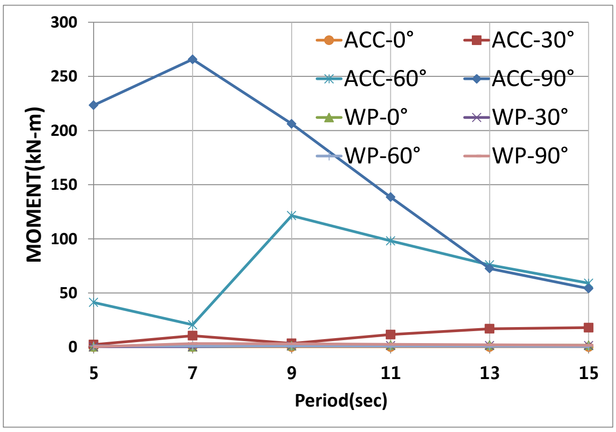
(a) G1



(b) G2



(c) G3



(d) G4

Fig. 12 Comparison of moment by wave pressure and acceleration Incident angle

6. CONCLUSIONS

To find the change of moment of steel MRF on rectangular concrete floating pontoon according to various wave incident angles, the hydro-dynamic analysis was performed, in which wave periods are changed from 5 to 15 seconds. And static and dynamic analysis is performed with the mapped wave pressure and input base acceleration obtained from the hydro-dynamic analysis. Conclusions are as followings.
According to wave pressure, the moment of beams and columns for transverse axis is decreased as the wave incident angle is increased. This increase is influenced by pitch motion. But the moment of beams and columns for longitudinal axis is increased only a little compared to the transverse axis.

According to base acceleration, the moment of beams and columns for transverse axis is decreased to zero as the wave incident angle is increased. But the moment of beams and columns for longitudinal axis is increased greatly compared to the transverse axis. This increase is according to roll motion of pontoon.
Considering both wave pressure and base acceleration from the motions of pontoon, the moment increase according to base acceleration is much greater than that of wave pressure for all wave incident angle. Base acceleration has more effect on the increase of moment for both longitudinal and transverse direction. Only for long period wave, the wave pressure has effects on the moment increase.
Therefore for designing of superstructure on pontoon, the effect of acceleration carefully should be considered, especially for the moment of longitudinal axis and short wave periods.
Because this study is limited on the shape and size, draft of pontoon, there is a need to extent this research in more various cases.

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