부유식 해양구조물을 위한 돌핀 계류시스템의 설계 연구

A Study on the Design of Dolphin System for VLFS

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요 지

돌핀계류시스템은 부유식 해양구조물의 계류장치로서 강도 및 유용도 관점에서 바람직한 대안이 될 수 있다. 돌핀계류시스템 설계과정에서 정확한 파력산정과 필요한 지지파일의 개수선정은 주요 설계요인이 된다. 본 논문에서는 파의 충격하중을 포함한 외력에 대한 구조해석을 통하여 적정한 돌핀시스템의 설계과정과 형식을 제시하였다. 부유식 해양구조물을 위한 돌핀계류시스템의 경우 다수의 지지파일시스템보다 단주의 지지파일시스템이 설계관점에서, 제한적이기는 하나, 유용성이 높다는 점을 알 수 있었다.

핵심용어 : 돌핀계류시스템, 모리슨식, 파력, 충격하중, 부유식해양구조물

Abstract

Dolphin mooring system can be a good candidate for the VLFS fastening system in view point of strength and effectiveness. In the design process of the dolphin system, precise calculation of the wave forces and the subsequent selecting the proper number of the piles adopted are one of the main factors. In this paper, one of the design process of the dolphin system is investigated and a proper configuration of the system is derived based on the structural characteristics of the system that was obtained through the structural analysis of the basic pile element confronted to the external loadings including wave impact load. It was found that for the better design of the mooring system for VLFS, mono pile mooring system is more recommendable in a specific condition than other multi piles mooring system.

keywords : *Dolphin System, Morison Equation, Wave Force, Impact Load, Very Large Floating Structure*

1. Introduction

To fasten VLFS, Very Large Floating Structure, to a secure location on sea bottom, a dolphin mooring system may be used. Generally dolphin mooring piles contain vertical, inclined, jacket type and so on. The mooring force that acts on a VLFS is extensive thus the design of a dolphin pile configuration was to first decide the proper size of the relevant piles. The importance of the impact force on the vertical pile in the surf zone due to the breaking wave has been recognized as well as the inertia force and drag force.

In this paper, one of a design process of the dolphin system is investigated and a proper configuration of the system is derived based on the structural characteristics of the system that was obtained through the structural analysis of the basic pile element confronted to the external loadings including wave impact load.

Several types of the dolphin mooring systems, i. e., mono pile, multi piles are investigated to identify the effects of the impact load due to the breaking wave as well as the

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effects of the number of piles used for the dolphin system in view point of resultant deformation and stress. Relating to this work, several research works dealing with Morison Equation were found recently. Statistical treatments of a guyed tower analysis were carried out by using Morison equation for the calculation of the wave and current forces.(Ryu *et al.*, 1991) Bottom boundary treatments between fixed and soft condition were studied for the analysis of a soil-pile interaction case.(Kim, *et al.*, 2000) For the analysis of a pile in the load combination of wind, wave, current were dealt (Jo *et al.*, 2001) Park did numerical analysis for dynamic behaviors of a vertical pile by using finite element method.(Park, 2004) In most cases of the research works the wave force calculation was done by using Morison Equation without including of possible impact loads due to the surf zone effects. It is quite natural to deal the wave load using the Morison Equation excluding the impact load for the non breaking wave zone. However for the case of drastic slope changing sea bottom conditions, the effects of the wave breaking are to be considered.

2. THEORETICAL ANALYSIS

2.1 Morison Equation

This equation was developed for the calculation of the surrounding inertia force and the drag force that act on the vertical pile in the water. The wave particle speed and the drag force are affected by the shape of the structure, roughness of the surface state, Reynolds number, and so on. The equation is especially applicable when the characteristic dimension of a structure is smaller than the incident wave length. The equation can be expressed, when the objective structure is a pile of diameter , by Equation (Faltinsen,1990; Goda,1984).

$$F=\int_{-h}^{\eta}\frac{\rho}{2}C_D\cdot D\cdot u\cdot |u|\cdot dz + \int_{-h}^{\eta}\rho\cdot C_M\cdot\frac{\pi}{4}\cdot D^2\cdot\frac{du}{dt}\cdot dz \qquad (1)$$

Where ρ = water density
C_D = drag coefficient
D = diameter of the pile
u = water particle velocity
C_M = inertia coefficient

However the equation (1) can not account the impact force due to the breaking wave that is important in the design of offshore structure in the surf zone.

2.2 Impact force due to the breaking wave

The importance of the impact force on the vertical offshore circular structure member in the surf zone due to the breaking wave has been recognized recently. The form for the impact force is proposed as the concise one composed of the water particle velocity and the slamming coefficient as shown in equation (Goda,1985; Cho,1993)

$$F_I=\frac{1}{2}\cdot\rho\cdot C_s\cdot D\cdot u^2 \qquad (2)$$

Where C_s = slamming coefficient

For the brief review of the approach the way for dealing the impact load is explained as follows. The concept of equivalent deepwater wave was introduced in order to relate the phenomena of wave breaking, run-up, overtopping and other processes to the characteristics of deep water waves. Various processes of wave deformation and wave action are investigated through hydraulic tests in laboratory wave flumes, and data sets from many experiments are available. It is possible to incorporate the effects of wave reflection and diffraction into hydraulic model tests of wave breaking, overtopping by adapting the so called equivalent deepwater wave concepts, but it is not recommended in general because of the excessive cost and time required. A train of regular waves in a laboratory flume can be observed easily that undergoes shoaling over a sloping bottom and breaks at a certain depth. This breaking wave induces the impact load to the offshore structure if the structure is in the surf zone.

Dealing the impact load with a concise form was the objective of the ocean engineers for the practical design basis. Thus the form of the impact load was derived through the experiments as well as theoretical backgrounds. Equation (2) was proposed and used for the early design stage of the vertical pile in the surf zone and also for the analysis of the slamming force calculation of a jacket member during transportation when the structural member hit the water surface with the submersing velocity in the rolling condition. The approach to use the equation (2) is natural for the practical calculation of the slamming force which is quite similar to the impact load case when the pile is located in the surf zone.

The slamming coefficient C_s has a maximum theoretical value of π to 0.4 decreasingly and going up to 1.35. For the conservative calculation of the impact force, the value of π may be used. For the reasonable usage of the C_s can be 1.48 that is from the average value during the slamming period.(Yi *et al.*, 1988)

2.3 Total wave force on the vertical pile

Total wave force F_T can be expressed as the sum of the inertia term, drag term, and the impact term, Equation (3) is the total wave force composed of the above mentioned 3 terms.

$$F=\int_{-h}^{\eta}\frac{\rho}{2}C_D\cdot D\cdot u\cdot|u|\cdot dz+\int_{-h}^{\eta}\rho\cdot C_M\cdot\frac{\pi}{4}\cdot D^2\cdot\frac{du}{dt}\cdot dz+\int_{(1-\lambda)_{\eta_0}}^{\eta_0}dF_I \qquad (3)$$

And a model for the calculation of the total wave force based on the equation (3) is shown in Figure 1.

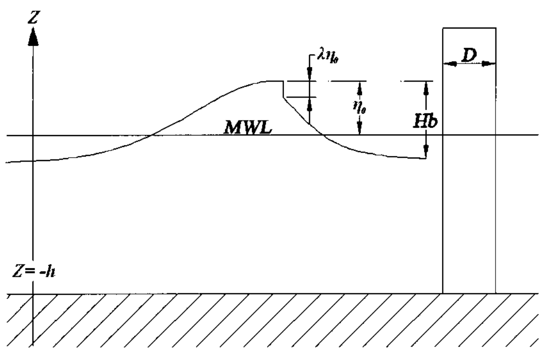


Fig. 1 Wave model for the vertical pile

2.4 Maximum Inertia force and Maximum Drag force

The first and the second term of equation (3) can be modified as shown below.

The Maximum drag force F_{dm} is calculated using equation (3).

$$\begin{aligned}F&=\frac{1}{2}\cdot\rho\cdot C_D\cdot D\cdot\int_{-h}^{\eta}u\cdot|u|\cdot dz\\&=\frac{1}{2}\cdot\rho\cdot C_D\cdot H^2\cdot\left(\frac{1}{H^2}\int_{-h}^{\eta}u\cdot|u|\cdot dz\right)\\&=\frac{1}{2}\cdot\rho\cdot C_D\cdot H^2\cdot K_{dm}\end{aligned} \qquad (4)$$

Where C_D = drag coefficient

u = water particle velocity

$K_{dm}=\frac{1}{H^2}\int_{-h}^{\eta}u\cdot|u|\cdot dz$, the drag force factor

The maximum inertia force F_{im} can be calculated using equation (3)

$$\begin{aligned}F_{im}&=\frac{\rho}{2}\cdot C_m\cdot\frac{\pi D^2}{4}\cdot\int_{-h}^{\eta}\frac{du}{dt}\cdot dz\\&=\frac{\rho}{2}\cdot C_m\cdot D^2\cdot H^2\cdot\left(\frac{\pi}{2H}\cdot\int_{-h}^{\eta}\frac{du}{dt}\cdot dz\right)\\&=\frac{1}{2}\rho C_m\cdot D^2\cdot H\cdot K_{im}\end{aligned} \qquad (5)$$

Where C_m = mass or inertia coefficient

D = diameter of the pile
H = wave height
ρ = water density
$K_{im} = \frac{\pi}{2H} \cdot \int_{-h}^{\eta} \frac{du}{dt} \cdot dz$, inertia force factor

The total wave force is calculated as the sum of equation (4), (5) and (2).(SNAK,1993; Cho, 1993)

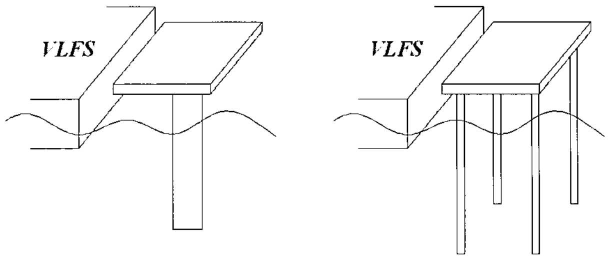
3. VERIFICATION EXAMPLES

In order to find the merits and the demerits of the single pile dolphin and the multi piles dolphin mooring system, a typical model of a pile is investigated and combined multi piles dolphin mooring system of 4, 6, 8 piles are investigated here. Environmental design condition is shown in Table 1. Single member of diameter 3m is chosen as a typical mono pile. Height of a member is chosen as 18m and the thickness of 20mm is chosen. Equivalent weight of 4, 6, 8 piles structure have diameters of 0.76m, 0.51m, 0.38m respectively.

Table 1 Design Condition Case

Pile type	Mono pile	Multi piles		
		4 piles	6 piles	8 piles
Significant wave height	2.4m	-		
Significant wave period	15sec	-		
Refraction Coefficient	0.9	-		
Diffraction Coefficient	0.9	-		
Design water depth	8m	-		
Sea bottom slope	1/20	-		
Member Diameter	3m	0.76	0.51	0.38
Shoaling Coefficient	1.0	-		

Wave force acting on the 1st cases of mono pile is calculated. Wave force acting on the 2nd case of multi piles that is composed of 4, 6, 8 piles of equivalently weighted members also are calculated. The maximum stress and the deflections of 4 structures are calculated by using FEM. Figure 2 shows the models of 2 different dolphin mooring structures.



Mono pile dolphin system　　Multi piles of 4 dolphin system

Fig. 2 Two dolphin Mooring System

Figure 3, 4 show wave force acting on the dolphin system 1, 2 respectively.

4. APPLICATION BY FEM

Several different examples are studied and analyzed by using Finite Element Method. (Timoshenko,2001; Choi,2004; Gere, 2005)

The models are the same one used in chapter 3. Distributed loads by the relevant wave force are applied to the structure. Deformations and the stresses are calculated and compared each other. Figure 5 shows the FEM models and Figure 6 shows the deformed shapes of the models. For the calculation of the wave load including the impact load, the equation (2) was used with the calculation of the water particle velocity in the surf zone. Distributed external load was converted to the nodal point load and the load was applied into the elements nodes. Boundary condition of the pile is fixed condition at the bottom of the structure in the bottom surface.

Table 2 shows the analysis results done by ANSYS for the various pile systems and Fig. 7 shows the trend of the deformation and stress variations for each model. Based on the results, it is found that the stress and deformation are considerably increased when the impact loads were included as shown in Fig. 7.

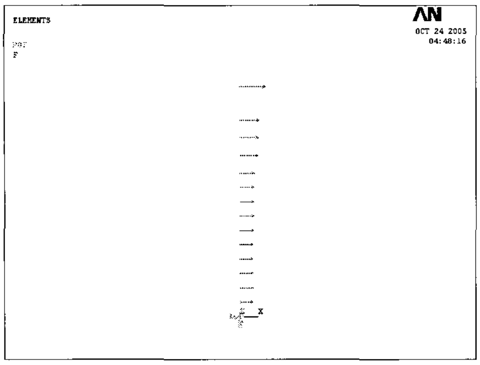


Fig. 3 Mono pile case

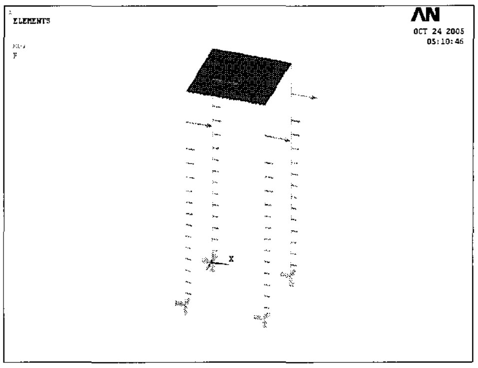
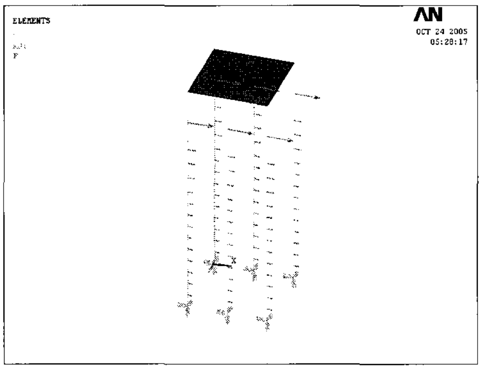
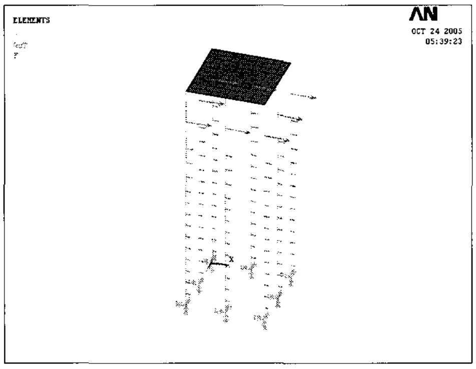


Fig. 4 Multi piles of 4 piles cases

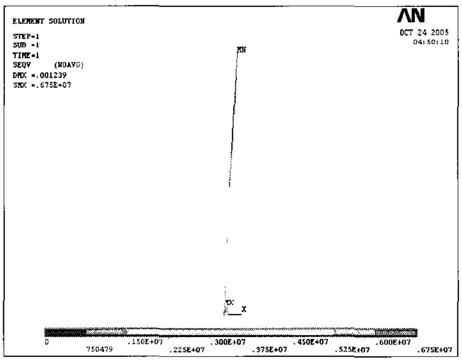


(a)

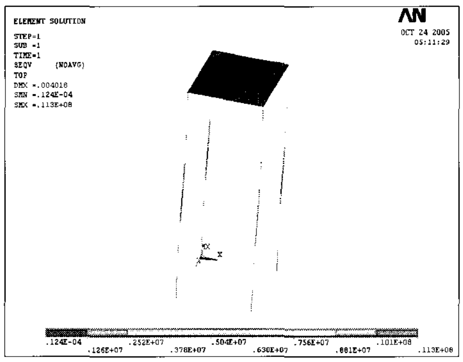


(b)

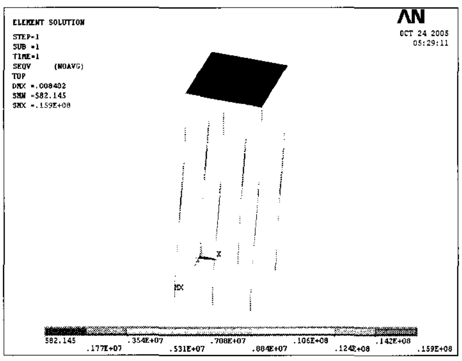
Fig. 5 Multi piles of 6, 8 piles cases



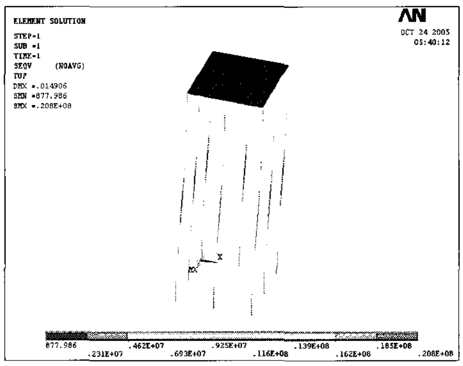
(a)



(b)

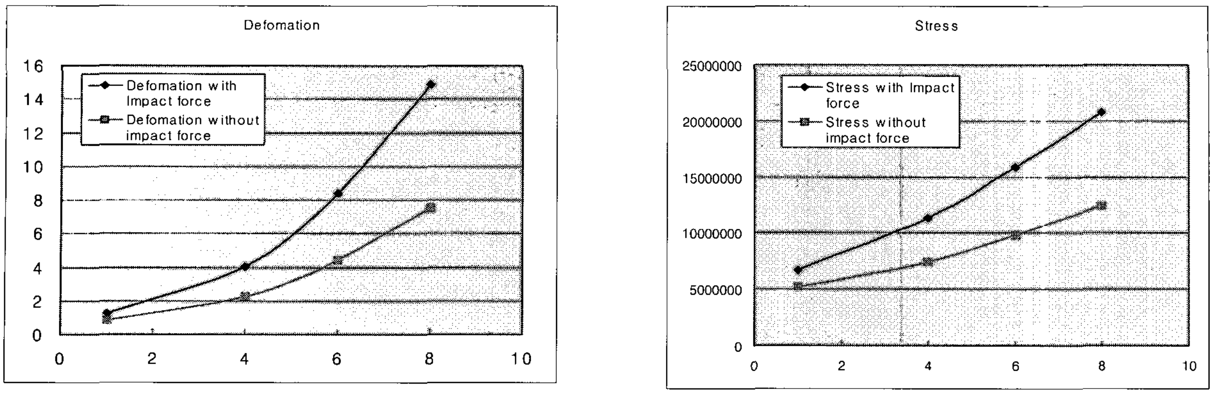


(c)



(d)

Fig. 6 Deformed shapes of various pile models



(a) (b)

Fig. 7 Trend of the deformation and stress variations for each model

Deformations and corresponding stresses of a pile with impact load in the Fig. 7 show that they are quite large approximately 1.6 times of those of a pile without the impact load. It is considered that the impact load is proportional to the value of square of a water particle velocity as shown in equation (2) and the velocity in the surf zone is considerably large. The impact load effects can be easily seen in the shore where wave breaks in the process of approaching to the shore with white bubbles.

Table 2 Results of analysis

Pile type	Mono pile	4 piles	6 piles	8piles
Deformation (mm)	1.239	4.018	8.402	14.906
Stress (N/m^2)	6.75×10^6	11.3×10^6	15.9×10^6	20.8×10^6

5. CONCLUSIONS

In this paper, a new concept of wave force calculation method is proposed. That is the modified Morison equation which includes the impact load due to the wave slamming to the objective pile. Numerical examples show the importance of the impact load. Secondly, mono pile mooring system is found to be more effective in the view point of less deformation and stress. Even though same amount of material weight is adopted, the stress and the deformation of multi piles become worse and worse as the number of piles used is increased. It may be concluded that for the better design of the mooring system for VLFS, in such condition of sudden bottom slope changes as shown in the example mono pile mooring system is more recommendable than other multi piles mooring system.

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