Mooring system design for underwater floating tidal current power(TCP) device

Chul-Hee Jo, Su-Jin Hwang, Seong-Ho Jo and Yo-Seop Kang

Abstract—Tidal current is considered one of the most promising energy sources as tides are more predictable than wind energy and solar power. The tidal turbine consists of blades, rotor, generator and a foundation. There are various types of foundations – rigid monopile, gravity foundations or floating structures etc.

The most common type of foundations for floating structure is moorings which are designed to position the structure in mid-water column or at the surface using buoyancy and forces of the mooring lines. The well-designed mooring system can be inexpensive option as this type of foundation does not require large footprint. However, the major obstacle in this design is to ensure vertical equilibrium between buoyancy of the device and weight of both the turbine and mooring lines because any fluctuations of structure may lower the amount of energy extracted.

The hydrodynamic analysis program, WADAM, is used herein to analyse motions of underwater floating device. Firstly, response amplitude operators (RAOs) are obtained to conduct hydrodynamic analyses in time domain. Secondly, inclusion of the mooring system in calculation of motion is done in OrcaFlex 10.1a. With various hang-off and specific gravity of floater, the proper mooring system to minimize pitch motion has been simulated considering extreme ocean condition of south-west coastal line of South Korea. Lastly, model tests are carried out to validate the computational results.

As a result, the most desirable hang-off angles in operational condition are 64° with the maximum pitch angle the better stability of floater itself.

Keywords— **Mooring system, Response amplitude, Tidal current, Underwater floating, Hydrodynamic coefficient**

I. Introduction

Oceans, covering more than 70% of the earth, are considered as a sustainable and predictable energy source among renewable energies.

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Specially, south-west coastline of South Korea is highly indented, and the wave and current speed along the coast is fast enough for tidal electric generators thanks to more than 3,000 islands existing adjacent to the Korea peninsula

Conventional studies of the footing system for tidal energy devices are mainly focusing on pile type or gravity foundations. However, these types of footing system are limited by the depth of region, high cost and difficulties in construction. To overcome these obstacles, mooring system is widely studied for floating tidal current devices.

Rho et al (2014) investigate complex mooring system; a combination of tension leg moorings and catenary moorings.

Flory, J.F. et al (2016) test nylon type mooring line to demonstrate its suitability for use on marine energy converters.

Cho et al (2017) simulate motions of a duct and single point mooring (SPM) system considering RAOs and clamp weight.

In UK, Plat-O#2, hosting four turbines, is moored in mid-depth. Hydrodynamic responses are simulated and tested with CFD software, ProteusDS and model testing. (The Bivol et al., 2017).

In this study, pitch motion is perceived as a major parameter that indicates the stability of structure. Different specific gravities of structure, hang-off angles of mooring system have been analysed to find optimal conditions that restrain the pitch motion.

Software programs, WADAM and OrcaFlex 10.1a are used to simulate response motions of structure.

II. Modelling

The model of tidal power generator in mid-water is depicted in Fig. 1. The structure must have both sufficient buoyancy and moments of inertia to resist rotational motion.

By considering various widths from 4.2 to 6.2m and heights from 3.2 to 5.2m of structure respectively, Moments of inertia have been calculated by using CATIA V5R19. The optimal dimensions of structure are described in Table 1.

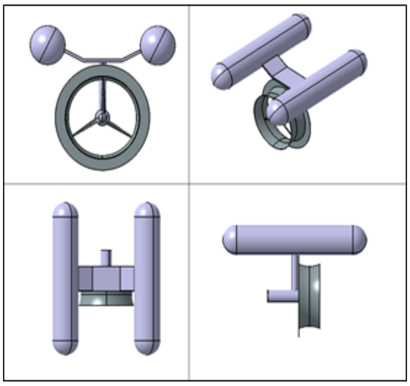

Fig. 1. Modelling of floating TCP.

TABLE 1
PRINCIPAL DIMENSIONS OF FLOATING TCP

Description	Value
Length [m]	6.2
Width [m]	4.2
Height [m]	3.2
Buoy Dia. [m]	1.4
Turbine Dia. [m]	2.7
Duct Dia. [m]	3.7
Roll moment of inertia [kg ·m²]	62,067
Pitch moment of inertia [kg ·m²]	44,149
Yaw moment of inertia [kg·m²]	89,845

III. SIMULATION

A. Environment condition

As tidal current device is on operation during the mild weather condition, the operational environmental condition is mainly considered.

The operational environmental effects to be applied in mooring line response calculation include the significant wave height and the peak wave period of 1.1m and 3.6s respectively based on the data measured at near coastal line. The current velocity at turbine point is assumed to be 1.5m/s.

TABLE 2
ENVIRONMENTAL CONDITION

Description	Value	
	Operation condition	Survival condition
Current speed (at turbine) [m/s]	1.5	3.1
Significant wave height (H_s) [m]	1.1	1.6
Peak period (T_p) [s]	3.6	4.4
Wave type	TMA spectrum	
Environmental force direction	0°-180°, 15° Intervals	
Water depth [m]	-20	
Location [m]	-10	

The TMA spectrum is a modified JONSWAP spectrum in shallow water. It is based on the fact that waves have limited heights in shallow water because of water depth. Therefore, the spectrum is multiplied by a function of water depth.

$$\emptyset(\omega,h)=\begin{cases} 0.5\left(\omega\sqrt{\frac{h}{g}}\right)^2 & if \quad \omega\sqrt{\frac{h}{g}}<1 \\ 1-0.5\left(2-\omega\sqrt{\frac{h}{g}}\right)^2 & if \quad 2>\omega\sqrt{\frac{h}{g}}\geq 1 \\ 1 & if \quad \omega\sqrt{\frac{h}{g}}\geq 2 \end{cases}$$

The TMA spectrum can be expressed

$$S_{TMA}(\omega)=\alpha g^2\omega^{-5}\emptyset(\omega,h)\,exp\left[-\frac{5}{4}\left(\frac{\omega_p}{\omega}\right)^4+(\ln(r)\,exp\left(-\frac{1}{2}\left(\frac{\omega-\omega_p}{\sigma(\omega)\omega_p}\right)^2\right)\right]$$

B. Mooring lines

Drag, lift and thrust forces are applied to the structure due to the wave and current flow. The mooring lines are usually tensioned in order to reduce the structure motions, which helps structure resist against environment forces and lowers loading in the lines.

Line tensions were calculated when no flow velocity is applied. The proper line specification is in Table 2.

Four lines are attached to each end considering structure weight and azimuth angles. (Fig 2)

TABLE 3
MECHANICAL PROPERTIES OF MOORING LINE (6X19 IWRC WIRE ROPE)

Description	Value
Diameter [mm]	20
Mass in air [kg/m]	1.6
Breaking load [kN]	252.1
Axial stiffness [kN]	16,160

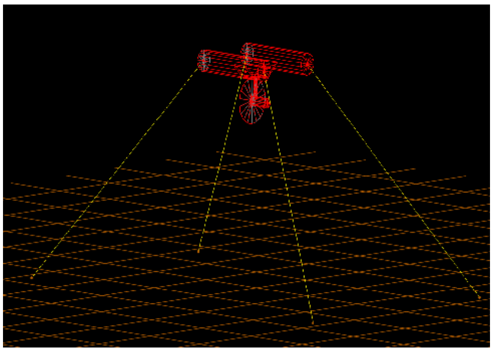

Fig. 2. OrcaFlex 10.1a modelling.

C. Fairlead point optimization

The fairlead point is of vital importance because a high-tension load is applied at the fairlead point and the motions of a structure are affected by the fairlead points.

With a 0.5m interval of the fairlead point, four cases were set and analysed shown in Fig. 3. Table 4 shows pitch motions according to location of fairleads.

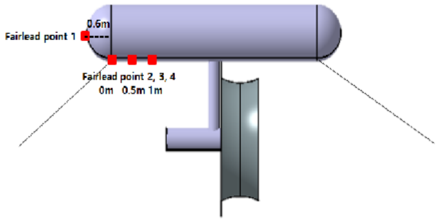

Fig. 3. Fairlead points.

D. Other factors

Values of hang-off angle and specific gravity of structure are taken into account to find suitable conditions that minimize the pitch motion.

Specific gravity is also one of imperative factors on which mass and buoyancy of structure depend. If value of specific gravity is low then the upward force from buoyancy is also low, which determines level of tensions applied on mooring lines.

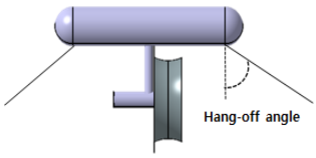

Fig. 4. Hang-off angle definition.

TABLE 4
HANG-OFF ANGLE AND SPECIFIC GRAVITY

Description	Value
Hang-off angle [deg.]	50° ~ 64°, 2° intervals
1/S.G	1.45, 1.7, 1.9

IV. ANALYSIS RESULT

Table 5 is the results of pitch motion, the fairlead point located point 2 showing minimum pitch motion with value of 9° is adopted.

TABLE 5
MAX. PITCH MOTION BY FAIRLEAD POINTS

Fairlead point	Pitch motion (°)			
	Max.	Min.	Mean	Std. dev
1	10.84	7.68	9.17	0.42
2	9.00	5.46	7.18	0.47
3	9.65	5.91	7.73	0.49
4	10.40	6.46	8.39	0.51

Fig. 5 and 6 are illustrating the result of pitch motion response with respect to hang-off angles and specific gravities and mooring tensions in time domain. As hang-off angle increases, pitch motion of structure is restrained. It is because the tension of mooring system is also increasing. (Fig. 6)

Based on the results, the optimal hang-off angle is 64° and in that case, maximum pitch response is 5.33°.

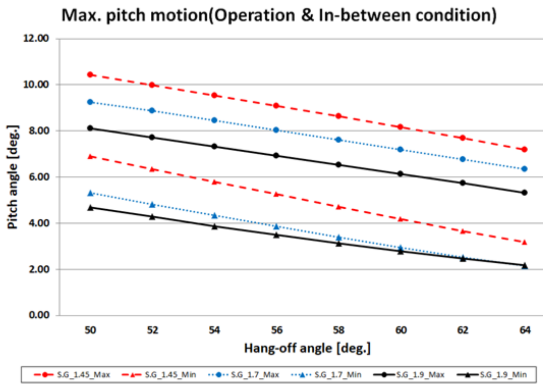

Fig. 5. Time domain pitch response along with parameters.

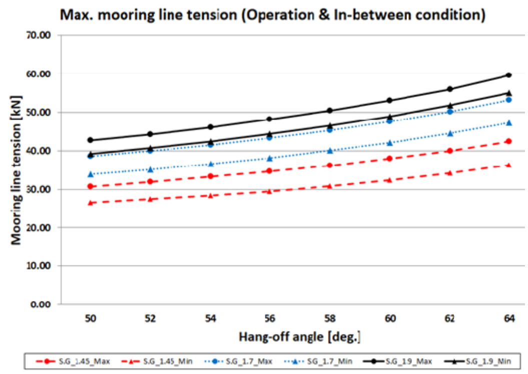

Fig. 6. Time domain mooring tension along with parameters.

V. HYDRODYNAMIC MODEL TEST

E. Experiment condition

A 1:12TH scaled physical model was tested in flume tank facility to validate results from OrcaFlex. Motion sensor is installed inside of structure and tension of line is measured by using loadcell.

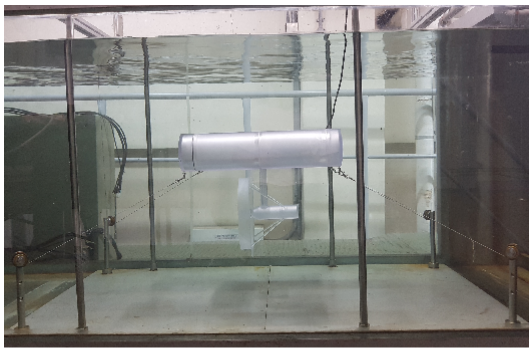

Fig. 7. Physical model.

Froude scaling deals with the relationship between gravity and inertia forces, whilst the Reynolds number deals with the relationship between frictional and inertial forces.

In the presented study, modelling the prototype as tested, at tank scale is done to eliminate scaling errors and to improve the accuracy of modelled motion and line tensions.

The test took two velocities into consideration. One was 0.43 m/s meaning operational condition (=1.5m/s in environment condition), the other was 0.89 m/s (=3.1m/s in environmental condition) as survival condition.

F. *Experimental results*

Similar to the results from OrcaFlex, it is found that higher hang-off angle and lower specific gravity ensure lower pitch motion regardless of flow velocities. This is because mooring line tensions are higher when hang-off angle is high and specific gravity is low.

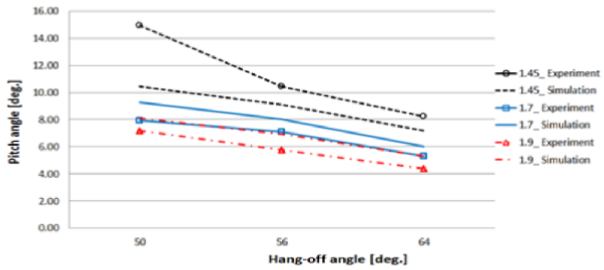

Fig. 8. Maximum pitch motion (Operational condition, 0.43m/s).

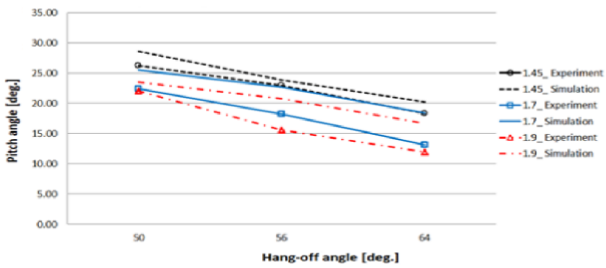

Fig. 9. Maximum pitch motion (Survival condition, 0.89m/s).

VI. CONCLUSION

In this paper, the optimal design approach for floating tidal current devices was conducted. Pitch motion responses and line tensions were analysed in time domain and measured along with specific gravities and hang-off angles throughout the model tests.

As a result, the most desirable hang-off is 64° with the maximum pitch angle of 5.33° and the reciprocal of specific gravity is 1.9 in operational condition.

It can be concluded that high level of pretension of mooring line procures better stability of floater itself.

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