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Conceptual design of 5MW floating wind turbines for Korean offshore

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ABSTRACT

Two full-scale floating wind turbines of spar type Hywind and semi type WindFloat with 2MW capacity were installed in 2009 and 2011, respectively. Both wind turbines had been reported to operate and generate electricity successfully. However, for a cost effectiveness of a wind farm, a large wind turbine is recommended and one of the choices will be a 5MW wind turbine.

This paper presents conceptual design of 5MW floating wind turbines for Korean offshore. Spar and TLP types of offshore wind turbines (OWTs) were considered and designed in this study. Basis of design of a 5MW OWT was summarized first; Hull, mooring and foundation of an OWT was sized and numerical verification analysis was followed. Platform transportation and installation plan for each type of OWT was proposed and highlighted and high level cost estimate was presented.

1. INTRODUCTION

A floating offshore wind turbine is installed on a floating platform which generates electricity in the relative deeper water depth, say more than 50m. For shallower water than 50m, bottom-mounted wind turbines have been installed for more than one decade. For a deeper water depth, a floating wind turbine is believed to be more economical. In addition, the wind field is typically more uniform and stronger in deep water open sea.

Floating wind farm consists of many floating wind turbines installed in close proximity to share common power transmission facilities for reducing operating cost, easy management and maintenance. A floating wind turbine is designed to provide adequate buoyancy and stability and meet design criteria, such as heave and roll/pitch motions and accelerations as well as strength and fatigue requirements of mooring and foundation.

For the present conceptual study, a typical approach used for other similar offshore projects was implemented, covering metocean criteria, platform design criteria, platform hull and mooring sizing, design verification, execution of transportation and installation and costing.

A 5MW NREL turbine was selected for the OWTs. Three different types of OWT platforms with 5MW turbine were proposed: Spar, three-column TLP and mono-column

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TLP. Water depths for Spar OWT were assumed to be 150, 200 and 250m while a water depth of 70 m was considered for TLP type OWT. Metocean conditions were determined with combining available site data and international Standards for offshore wind turbine design.

By considering Basis of Design, the OWT platform sizing, weight estimation and mooring system design were performed. Hydrodynamic coefficients of the hull were estimated using WAMIT. Aero-hydrodynamic coupling was not included in the numerical analysis at this conceptual stage and will be considered in the FEED. However, rotor static thrust and tower wind loads were considered in numerical simulation. Global performances of OWTs were carried out with a HOE (Houston Offshore Engineering) in-house program to estimate the responses of motion, acceleration and tensions, through both frequency and time domain analysis. The mooring analysis was performed for intact case for Spar type and both intact and line damage cases for the TLP types. In addition, a study of execution of OWT platform transportation, installation and tower integration was conducted for a costing exercise.
Cost estimate requires information on Korean local rates including steel, labor, crane and anchor handling vessels, tug boat and others associated with integration, towing and installation. Since those required local cost data were market sensitive and not available in public domain, rates based on the past similar international projects were used for the cost estimate. A wind farm consists of 20 units of OWTs were assumed.

2. Basis of Design

2.1 Design Life

Design life of the hull and turbine structure for the wind turbine rated 5MW power was assumed to be 20 years. Hull plate thickness and mooring line size were determined accordingly by considering the corrosion allowance. Also, all the structural members were also designed to meet the requirement.

2.2 Wind Turbine

5MW wind turbine base line data (Jonkman *et al.* 2009) is summarized in Table 1. Total weight including blades, hub, rotor, nacelle and tower is about 697 Mt. Hub height above the tower base is 90 m. Total hub height is obtained by adding air gap to the baseline hub height.

Table 1 5MW NREL Turbine Data

Properties	Unit	Specification
Power Rate	MW	5
Wind Speed: Cut-in/Rated/Cut-out	m/s	3.0/11.4/25.0
Hub Height above MSL	m	90
Rotor Diameter	m	126
Thrust: Cut-in (3 m/s)	KN	200
Rated (11.4 m/s)	KN	800
Cut-out (25 m/s)	KN	350
Total Mass (Tower+Nacelle+Rotor)	kg	697,460
CoG: (x, y, z above Base)	m	(0.2, 0, 64)

2.3 Metocean Criteria

Metocean criteria for the return periods of 50 and 100 years in the Korean western offshore are presented in Table 2. The currents and tidal variation are from the database by KOHA (Korean Oceanographic and Hydrographic Association). Per GL (2005) and DNV (2010), wind speed for a site of shallow and sheltered water was used. Hmax, Tmax, Hs and Tp are maximum wave height, wave period associated the maximum wave height, significant wave height and spectral peak period.

Table 2 Metocean Data

Item	Unit	50 yr (Parked)	100 yr (Parked)
Water Depth	m	70 (TLP)	
	m	150/200/250 (Spar)	
Hmax	m	7.64	8.52
Tmax	s	13.08	13.81
Spectrum	-	JONSWAP	JONSWAP
Hs	m	4.11	4.58
Tp	s	12.03	12.43
Current	m/s	1.20	1.22
Wind (10min Ave.)	m/s	42.5	44.6
Tidal Variation	m	±2.2	±2.2

2.4 Geotechnical Data

Seabed survey data of the southwestern offshore of Korea provided by RIST (Research Institute of Industrial Science and Technology, Korea) was used for the present work. As presented in Fig. 1, silt and sand layer is very shallow, which is about 7m only from the seabed. Beyond that, rock bottom is identified.

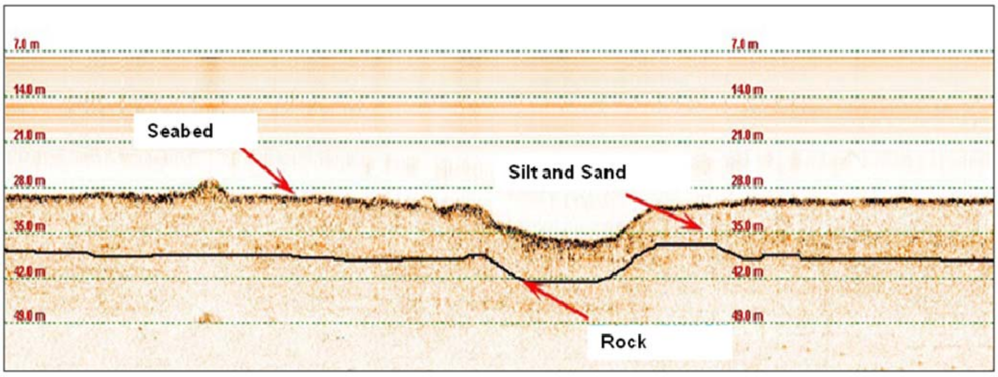

Fig. 1 Soil Survey Result

2.5 Platform Design Criteria

Table 3 presents OWT platform (hull) design criteria. Platform pitch rotations and accelerations are based on the wind turbine operation criteria.

Turbine tower shall be connected to hull above a mean water level (MWL) such that an appropriate air gap between the highest water surface (maximum enhanced wave crest + high tide) and bottom of the tower (or lowest tip of blade) is kept to avoid potential impact to the structures by the waves. A minimum air gap required is 1.5m (ABS 2013).

Table 3 Platform Design Criteria

Item	Unit	50 year	100 year
Platform Pitch (Max)	deg	≤ 10	-
Nacelle (Horizontal) Max Acceleration	m/s^2	≤ 0.4g	-
Air Gap	m	>1.5	>1.5
Mooring/Tether Tension (TLP case)	Mt	>0	>0

2.6 Mooring System Design Criteria

For TLP tethers, a typical R4 Studless chain was considered. Safety factor of the mooring lines with chain shall meet the design criteria specified in API RP 2SK (2005), as shown in Table 4. For the present study, a quasi-static mooring analysis was performed.

Table 4 Mooring System Design Criteria

Analysis Method	Tether Status	DEC	Safety Factor (Chain)
Quasi-static	Intact	100-yr	2.0
Quasi-static	One Line Broken	100-yr	1.43

2.7 Load Cases Based on DNV

Wind conditions in the offshore regime are defined in guidelines by DNV (2010) and IEC (2009). Load cases selected for the wind turbine global performance and mooring analysis are summarized in Table 5, which is based on DNV (2010).

Table 5 Operating and Extreme Load Cases for Wind Turbine Analysis

Design Case	Load Case	Wind Speed (Uhub)	Wave Height	Wind and Wave Directionality	Current	Water Level
Power Production	**1.1**	Vin < U10,hub < Vout	Hs = E[Hs|U10,hub]	Co-directional	Wind-generated	MWL
Parked (standing still or idling)	**6.1a**	U10,hub = U10,50-yr	HS = Hs,50-yr	Misaligned, Multiple directions	50-yr	50-yr

Vin	cut-in wind speed
Vout	cut-out wind speed
U10,hub	10-minute mean wind speed at hub height
U10,50-yr	10-minute mean wind speed at hub height with a return period of 50-yr
Hs	Significant wave height
Hs,50-yr	50-year extreme significant wave height based on a 3-hr reference period
E[Hs| U10, Hub]	Expected significant wave height at U10,Hub

Based on Table 5, 50-yr event is a design extreme and 100-yr event is not required which can be treated as a robust check case. The detailed design extreme load cases are shown in Table 6.

Table 6 Detailed Design Load Cases – Operating and Extreme Conditions

Items	Unit	Power Production Case	Parked Case (Standing still or idling)
Load Case No.	-	1.1	6.1a
Hs	m	4.11	4.11
Current Speed	m/s	1.2	1.2
Wind Speed at hub	m/s	11.4 (rated)	42.5 (50yr wind)
Tide Level (TLP only)	m	+ 2.2 (high tide)	+ 2.2 (high tide)
	m	- 2.2 (low tide)	- 2.2 (low tide)
Mooring Line Condition	-	Intact	Intact
	-	One Line Damage	One Line Damage
Directionality	-	Co-directional	Co-directional
Note: 1. Since significant wave height and current for the “Power Production Case” is not known, data of “Parked Case” was used. 2. Line damage on the Spar platform was not considered.			

3. Rotor Thrust, Wind and Current Loads

3.1 Rotor Thrust and Tower Wind Loads

Rotor thrust on the hub center was read from the speed vs. thrust plot (Jonkman et al. 2009). The thrusts for cut-in, rated and cut-cut out speeds are presented in Table 7. Pressure on the windage of the structure can be calculated, using a method in ABS (2007) as;

$$P=0.61*Cs*Ch*V_w^2 \quad (N/m^2)$$

where Cs=shape coefficient, Ch=height coefficient, Vw=wind velocity. Pressure center above the tower base can be estimated by considering the projected area of the structure. Wind loads on towers and nacelles are summarized in Table 7.

Table 7 Wind Load and Rotor Thrust

		Cut-in	Rated	Cut-out	50-yr
Wind Speed	m/s	3	11.4	25	42.5
Rotor Thrust	KN	200	800	350	0
Wind Load on Tower	KN	1.5	21.0	101.0	291.9
Wind Load on Nacelle	KN	0.2	2.6	12.6	36.5
Total Load	KN	201.6	823.6	463.6	328.4

3.2 Current Load on Platform

Current load on wind turbine platform, mooring tether and other submerged structures can be calculated using a current profile;

$$F_{current} = ½\ \rho * C_d * A * V_c^2$$

where ρ=seawater density, Cd=drag coefficient, A=projected area, Vc=current velocity. Here uniform current was assumed for a conservative result. For current load on TLP hull, in-house program was employed to account for shielding factors on rear columns and pontoons.

4. Mooring Foundation

There are several options to moor the proposed wind turbine platforms, such as, driven pile, suction anchor, drag embedment anchor and gravity foundation. By considering the soil depth described before, the gravity foundation was, thus, selected for the wind turbine mooring foundation. It was assumed the foundation is made from a concrete with steel reinforcement, with a square shape template. The foundation needs to be transported to the site and installed before the OWT platform is arrived at the site.

The submerged dead-weight of the gravity anchor was sized properly to resist the maximum design load. Gravity foundation design is based on design criteria of the soil material coefficients (DNV 2011) and shown in Table 8.

Table 8 Soil Material Coefficient

Condition	Material Coefficient
Extreme, Intact (Ultimate Limit State)	1.3
Damage (Accidental Limit State)	1.0

5. OWT Platform Design

Three water depths of 150/200/250m were considered for the Spar type OWTs while 70m for the TLP type OWTs were chosen. Three-column and single column hull forms were considered for TLP type OWTs. Design summary of the OWTs are presented in Table 9. Drawings of the Spar and TLP type OWTs are shown in Fig. 2 and Fig. 3, respectively.

Table 9 5MW Floating Wind Turbine Design Summary

item	Unit	Spar	Three-Column TLP	Mono-Column TLP
Turbine Power Rate	MW	5	5	5
Water Depth	m	150/200/250	70	70
Draft	m	100	20	28
Displacement	Mt	**7,710**	**6,159**	**7,106**
Diameter (largest)	m	10	9.4	16
Hub Height above MWL	m	93	95	93
Turbine Weight	Mt	697	697	697
Hull Steel+ Marine System+ Appurtenance Weight	Mt	2,134	1,551	2,077
Total Ballast	Mt	4,742	1,229	1,067
Number of Mooring Lines	-	3 (1*3)	9 (3*3)	12 (3*4)
Mooring Chain Type	-	R4 Studless	R4 Studless	R4 Studless
Mooring Chain Size (OD)	in	3.38	5.25	4.50
Mooring Chain Length (each)	m	500/600/700	48	40
Vertical CoG above Keel	m	36.26	24.75	25.85
Natural Period (Heave/Roll/Pitch)	s	33.7/37.2/36.5	1.1/2.0/1.9	1.2/1.9/1.9

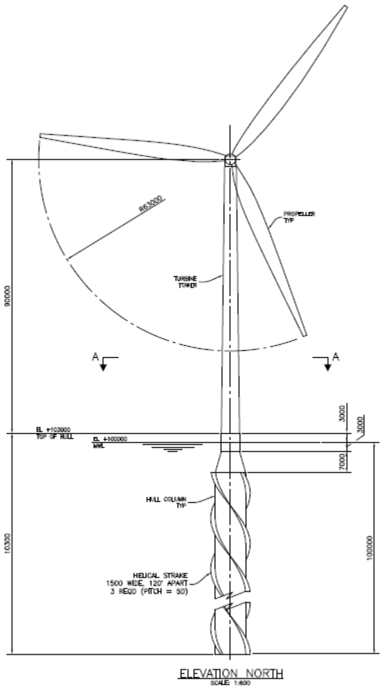

Fig. 2 Spar Type OWT Drawings

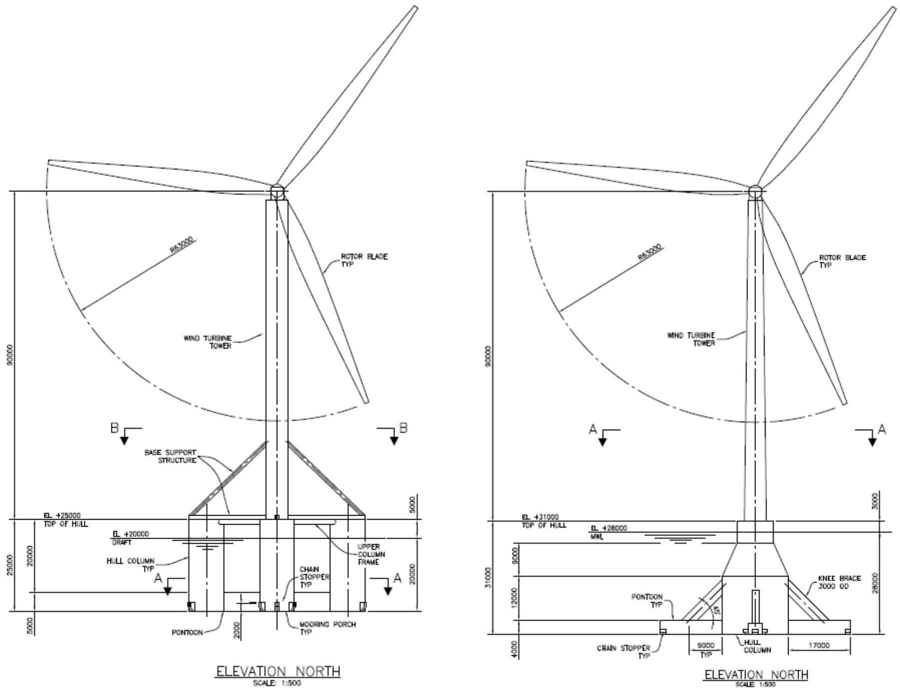

Fig. 3 Three and Mono Column TLP Type OWT Drawings

6. Hydrodynamic Response Analysis Results

6.1 Motion Analysis

Response RAOs were computed with WAMIT and HOE in-house program, using 3-D panel model as illustrated in Fig. 4 and Fig. 5, respectively. Production and extreme motion responses of the Spar and TLP types OWTs are summarized in Table 10 to Table 12, respectively. It is demonstrated that the pitch motions at the nacelle are within the maximum allowable limit of 10 degrees. It is seen that the Spar type OWT pitch motions are much greater than the TLP type OWT motions.

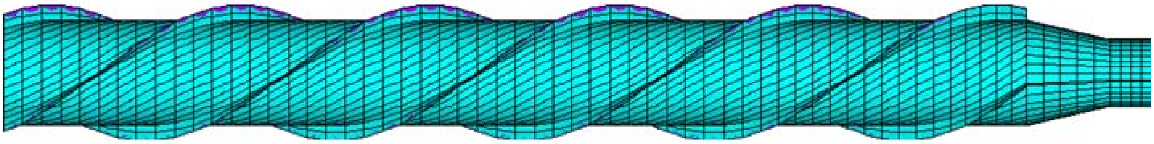

Fig. 4 Mesh Plot of Spar Type OWT

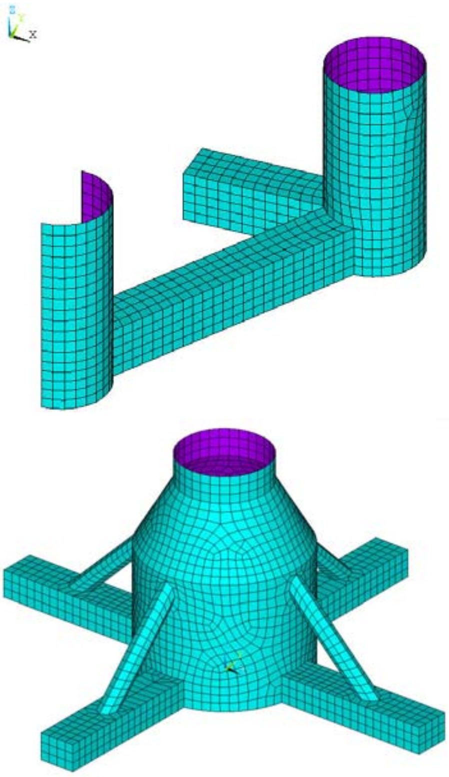

Fig. 5 Mesh Plots of TLP Type OWTs

Table 10 Spar Type OWT Motions at Nacelle

Production Case

Motion	Spar-150m	Spar-200m	Spar-250m	Max Angle Allowable	Pass (Yes/No)
	Pitch	Pitch	Pitch	Pitch	
	deg	deg	deg	deg	
Mean	7.27	7.24	7.37	-	-
RMS	0.28	0.28	0.28	-	-
Max	8.27	8.23	8.36	≤ 10	Yes

Parked Case

Motion	Spar-150m	Spar-200m	Spar-250m	Max Angle Allowable	Pass (Yes/No)
	Pitch	Pitch	Pitch	Pitch	
	deg	deg	deg	deg	
Mean	1.89	1.82	1.81	-	-
RMS	0.30	0.30	0.31	-	-
Max	2.89	2.85	2.84	≤ 10	Yes

Table 11 Three-Column TLP Type OWT Motions at Nacelle

Production Case

Motion	High Tide, Intact	Low Tide, Intact	High Tide, One Line Sudden Damage	Low Tide, One Line Sudden Damage	Max Angle Allowable	Pass (Yes/No)
	Pitch	Pitch	Pitch	Pitch	Pitch	
	deg	deg	deg	deg	deg	
Mean	0.06	0.07	0.17	0.15	-	-
RMS	0.02	0.02	0.04	0.03	-	-
Max	0.14	0.13	0.42	0.33	≤ 10	Yes

Parked Case

Motion	High Tide, Intact	Low Tide, Intact	High Tide, One Line Sudden Damage	Low Tide, One Line Sudden Damage	Max Angle Allowable	Pass (Yes/No)
	Pitch	Pitch	Pitch	Pitch	Pitch	
	deg	deg	deg	deg	deg	
Mean	0.02	0.02	0.13	0.10	-	-
RMS	0.02	0.02	0.03	0.03	-	-
Max	0.11	0.09	0.36	0.28	≤ 10	Yes

Table 12 Mono-Column TLP Type OWT Motions at Nacelle

Production Case

Motion	High Tide, Intact	Low Tide, Intact	High Tide, One Line Sudden Damage	Low Tide, One Line Sudden Damage	Max Angle Allowable	Pass (Yes/No)
	Pitch	Pitch	Pitch	Pitch	Pitch	
	deg	deg	deg	deg	deg	
Mean	0.07	0.07	0.09	0.09	-	-
RMS	0.02	0.02	0.04	0.04	-	-
Max	0.15	0.14	0.30	0.29	≤ 10	Yes

Parked Case

Motion	High Tide, Intact	Low Tide, Intact	High Tide, One Line Sudden Damage	Low Tide, One Line Sudden Damage	Max Angle Allowable	Pass (Yes/No)
	Pitch	Pitch	Pitch	Pitch	Pitch	
	deg	deg	deg	deg	deg	
Mean	0.02	0.02	0.04	0.04	-	-
RMS	0.02	0.02	0.03	0.03	-	-
Max	0.10	0.09	0.23	0.22	≤ 10	Yes

6.2 Acceleration Response

Table 13 to Table 15 presents accelerations of the Spar and TLP type OWTs. It is also demonstrated that horizontal accelerations including gravity effect at the nacelle meet the design criteria.

Table 13 Spar Type OWT Accelerations at Nacelle

Production Case

Acceleration	Spar-150m	Spar-200m	Spar-250m	Max Angle Allowable	Pass (Yes/No)
	Surge	Surge	Surge	Surge	
	g	g	g	g	
RMS	0.138	0.138	0.140	-	-
Max	0.281	0.281	0.285	≤ 0.4	Yes

Parked Case

Acceleration	Spar-150m	Spar-200m	Spar-250m	Max Angle Allowable	Pass (Yes/No)
	Surge	Surge	Surge	Surge	
	g	g	g	g	
RMS	0.138	0.138	0.140	-	-
Max	0.188	0.188	0.190	≤ 0.4	Yes

Table 14 Three-Column TLP Type OWT Accelerations at Nacelle

Production Case

Acceleration	High Tide, Intact	Low Tide, Intact	High Tide, One Line Sudden Damage	Low Tide, One Line Sudden Damage	Max Angle Allowable	Pass (Yes/No)
	Surge	Surge	Surge	Surge	Surge	
	g	g	g	g	g	
RMS	0.133	0.123	0.131	0.122	-	-
Max	0.135	0.125	0.138	0.127	≤ 0.4	Yes

Parked Case

Acceleration	High Tide, Intact	Low Tide, Intact	High Tide, One Line Sudden Damage	Low Tide, One Line Sudden Damage	Max Angle Allowable	Pass (Yes/No)
	Surge	Surge	Surge	Surge	Surge	
	g	g	g	g	g	
RMS	0.133	0.123	0.131	0.122	-	-
Max	0.135	0.124	0.137	0.127	≤ 0.4	Yes

Table 15 Mono-Column TLP Type OWT Accelerations at Nacelle

Production Case

Acceleration	High Tide, Intact	Low Tide, Intact	High Tide, One Line Sudden Damage	Low Tide, One Line Sudden Damage	Max Angle Allowable	Pass (Yes/No)
	Surge	Surge	Surge	Surge	Surge	
	g	g	g	g	g	
RMS	0.131	0.127	0.131	0.127	-	-
Max	0.134	0.129	0.137	0.132	≤ 0.4	Yes

Parked Case

Acceleration	High Tide, Intact	Low Tide, Intact	High Tide, One Line Sudden Damage	Low Tide, One Line Sudden Damage	Max Angle Allowable	Pass (Yes/No)
	Surge	Surge	Surge	Surge	Surge	
	g	g	g	g	g	
RMS	0.131	0.127	0.131	0.127	-	-
Max	0.133	0.128	0.135	0.131	≤ 0.4	Yes

7. Mooring Analysis Results

Table 16 to Table 18 summarize the mooring analysis results for the Spar, three-column TLP and mono-column TLP type OWTs. In case of TLP type platform, one line sudden damage condition was also considered to evaluate the mooring line performance. Transient effect due to the failure was considered in the analysis. For example, Fig. 6 shows typical top tension time histories for the one line sudden damage condition for Production and Parked Cases of the three-column TLP type OWT. It is seen that there is a huge tension increase due to a transient effect right after the sudden failure of a mooring line. Also, both high and low tide conditions were considered as TLP tensions are sensitive to the tidal elevations. It is proven that all the mooring line design meet the required design criteria.

Table 16 Spar Type OWT Mooring Analysis Result Summary

Production Case

Water Depth	Pre-Tension	Max Tension	MBL	FoS Estimated	Min FoS Required	PASS (Yes/No)
m	KN	KN	KN	-	-	
150	900	2,949	6,032	2.05	≥ 2	Yes
200	1,000	2,919	6,032	2.07	≥ 2	Yes
250	1,100	2,959	6,032	2.04	≥ 2	Yes

Parked Case

Water Depth	Pre-Tension	Max Tension	MBL	Safety Factor Estimated	Safety Factor Required	PASS (Yes/No)

m	KN	KN	KN	-	-	
150	900	2,324	6,032	2.60	≥ 2	Yes
200	1,000	2,285	6,032	2.64	≥ 2	Yes
250	1,100	2,322	6,032	2.60	≥ 2	Yes

Table 17 Three-column TLP Type OWT Mooring Analysis Result Summary

Production Case

Condition	Pre-Tension	Max Tension at Top	MBL	FoS Estimated	Min FoS Required	Pass (Yes/No)
	KN	KN	KN	-	-	
Intact, High Tide	3,437	5,502	14,323	2.6	2	Yes
Intact, Low Tide	2,413	4,461	14,323	3.21	2	Yes
One Line Sudden Damage, High Tide	3,437	8,985	14,323	1.59	1.43	Yes
One Line Sudden Damage, Low Tide,	2,413	6,859	14,323	2.09	1.43	Yes

Parked Case

Condition	Pre-Tension	Max Tension at Top	MBL	FoS Estimated	Min FoS Required	Pass (Yes/No)
	KN	KN	KN	-	-	
Intact, High Tide	3,437	5,142	14,323	2.79	2	Yes
Intact, Low Tide	2,413	3,888	14,323	3.68	2	Yes
One Line Sudden Damage, High Tide	3,437	8,242	14,323	1.74	1.43	Yes
One Line Sudden Damage, Low Tide,	2,413	6,196	14,323	2.31	1.43	Yes

Table 18 Mono-column TLP Type OWT Mooring Analysis Result Summary

Production Case

Condition	Pre-Tension	Max Tension at Top	MBL	FoS Estimated	Min FoS Required	Pass (Yes/No)
	KN	KN	KN	-	-	
Intact, High Tide	2,517	4,150	10,711	2.6	2	Yes
Intact, Low Tide	2,227	3,812	10,711	2.81	2	Yes
One Line Sudden Damage, High Tide	2,517	6,338	10,711	1.69	1.43	Yes
One Line Sudden Damage, Low Tide	2,227	5,765	10,711	1.86	1.43	Yes

Parked Case

Condition	Pre-Tension	Max Tension at Top	MBL	FoS Estimated	Min FoS Required	Pass (Yes/No)
	KN	KN	KN	-	-	
Intact, High Tide	2,517	3,634	10,711	2.95	2	Yes
Intact, Low Tide	2,227	3,292	10,711	3.25	2	Yes
One Line Sudden Damage, High Tide	2,517	5,556	10,711	1.93	1.43	Yes
One Line Sudden Damage, Low Tide	2,227	4,951	10,711	2.16	1.43	Yes

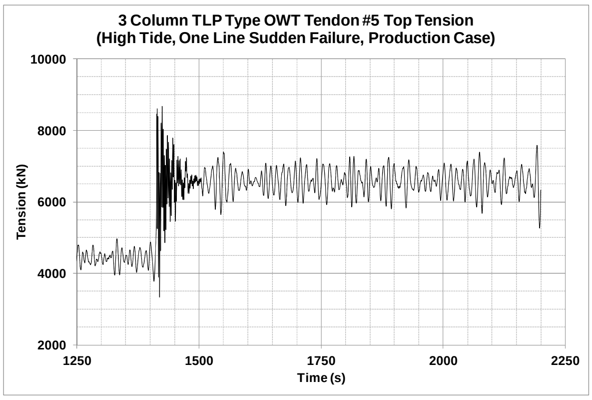

Fig. 6 Top Tension Time Histories for Three-Column TLP Type OWT – One Mooring Sudden Failure

8. Tension Analysis Results

Minimum tension at the bottom of the mooring/tether of the TLP type OWT shall be positive (DNV 2010). Minimum tensions at the bottom of the mooring line of three column and mono-column OWTs are shown in Table 19 and Table 20, respectively.

Table 19 Three-Column TLP Type OWT Minimum Tension

Production Case

Condition	Pre-Tension	Min. Tension at Bottom	Min. Tension Required	Pass (Yes/No)
	KN	KN	KN	
Intact, High Tide	3,437	1,819	> 0	Yes
Intact, Low Tide	2,413	836	> 0	Yes
One Line Sudden Damage, High Tide	3,437	463	> 0	Yes
One Line Sudden Damage, Low Tide	2,413	431	> 0	Yes

Parked Case

Condition	Pre-Tension	Min. Tension at Bottom	Min. Tension Required	Pass (Yes/No)
	KN	KN	KN	
Intact, High Tide	3,437	1,770	> 0	Yes
Intact, Low Tide	2,413	1,156	> 0	Yes
One Line Sudden Damage, High Tide	3,437	850	> 0	Yes
One Line Sudden Damage, Low Tide,	2,413	556	> 0	Yes

Table 20 Mon-Column TLP Type OWT Minimum Tension

Production Case

Condition	Pre-Tension	Min. Tension at Bottom	Min. Tension Required	Pass (Yes/No)
	KN	KN	KN	
Intact, High Tide	2,517	774	> 0	Yes
Intact, Low Tide	2,227	516	> 0	Yes
One Line Sudden Damage, High Tide	2,517	400	> 0	Yes
One Line Sudden Damage, Low Tide	2,227	182	> 0	Yes

Parked Case

Condition	Pre-Tension	Min. Tension at Bottom	Min. Tension Required	Pass (Yes/No)
	KN	KN	KN	
Intact, High Tide	2,517	1,299	> 0	Yes
Intact, Low Tide	2,227	1,041	> 0	Yes
One Line Sudden Damage, High Tide	2517	863	> 0	Yes
One Line Sudden Damage, Low Tide	2,227	774	> 0	Yes

9. Transportation and Installation Concept

9.1 Fabrication Yard and Transportation Route Selection

Wind turbine installation site for the present study was decided based on a recent “Road Map” proposed by Korean Government. The proposed site is assumed to be located at a west coast of Yeonggawng, about 80 km from Gunsan port of Korea as shown in Fig. 7.

Since there are several mid-sized ship yards in Gunsan Port area, the Gunsan Port was selected as a fabrication location of wind turbine platform, tower and foundation. A proposed wet tow route from fabrication yard to the site is presented in Fig. 7. Total towing distance estimated is about 80 km (43 nautical miles).

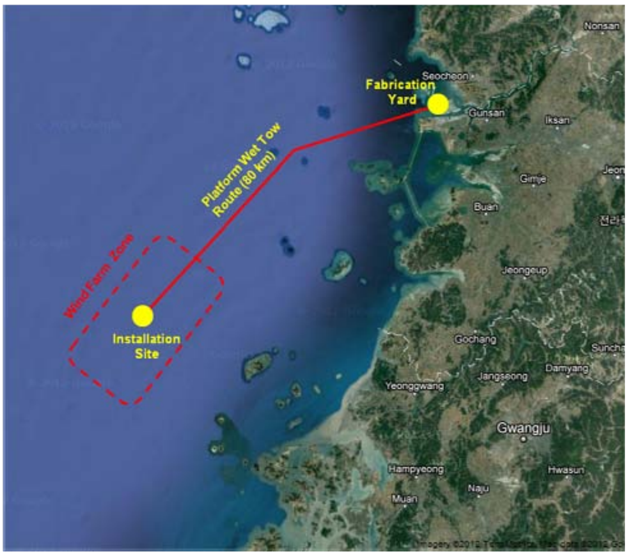

Fig. 7 OWT Installation Site and Wet Tow Route Proposed

9.2 Site Water Depth and Platform Installation Assumption

According to http://kosfic.chonnam.ac.kr/kosfic.html, water depths along the tow route are in the ranges from 8 m to 25 m, which may pose constrains on transportation method.

9.3 Towing and Integration Concept

There are several methods of the wind turbine platform transportation. Either one of wet tow or dry tow can be used depending on weather during tow, towing route water depth and barge/tug availability. Water depth along the tow-route is in the range of 8 to 25 m, which makes the vertical wet-tow of OWT with rotor infeasible. For the present study, it is, thus, assumed that the OWT without tower is wet-towed to the installation site and connected with the pre-installed mooring lines. Then, the tower and nacelle are transported using a barge and integrated with the platform at the site using a lifting offshore crane. Also another reason to choose this execution strategy is that the mono-column TLP wind turbine with tower and nacelle connected is very unstable hydrostatically during the free floating due to a high CoG.

Due to a shallow soil depth of about 7 m below the seabed at the site, a gravity foundation for the present wind turbines was selected. It was assumed the foundation is made from concrete with a square shape template.

Another option in order to reduce a risk during the wet tow of TLP type OWT is a dry tow using a barge which shall be wide enough to accommodate the platform. However, this option was not selected as the availability of the barge is not known yet.

Mooring foundations are also assumed to be transported to the site and installed several months ahead of the platform arrival to allow a soil set-up.

Overall execution duration was estimated accordingly, based on duration of platform tow, installation, mooring hook-up, foundation transportation and installation, rotor transportation and integration, weather contingency and other factors.

To do the cost estimate exercise for a comparison, all the platforms of Spar and TLP OWTs use the same wet tow and offshore integration methods described above.

10 Cost Estimate

Cost estimate of the proposed OWTs was performed considering the hull, mooring, foundation, fabrication, transportation, installation, integration and commissioning costs. Also a 10% contingency was considered.

The unit cost of each wind turbine is estimated assuming twenty (20) series of OWTs are built at a same fabrication yard and installed in a same wind farm area. Local rates for cost driving items were assumed, based on the past project experience. Cost estimate summaries are presented in Table 21, where each OWT cost was normalized using mono-column TLP type OWT cost.

Table 21 5MW Floating OWT Unit Cost Estimate Summary – Procurement Item

Items	Spar 150m	Spar 200m	Spar 250m	3-Col TLP 70m	Mono-Col TLP 70m
Wind Turbine	0.34	0.34	0.34	0.34	0.34
Hull Platform	0.42	0.42	0.42	0.31	0.33
Mooring	0.08	0.09	0.10	0.07	0.06
Foundations	0.14	0.14	0.14	0.25	0.24
Trans., Install. & Commissioning	0.29	0.30	0.32	0.28	0.28
Contingency (10%)	0.09	0.09	0.10	0.09	0.09
TOTAL	1.02	1.04	1.08	1.00	1.00

11 Conclusion

Spar and two different TLP type OWTs were designed to be installed at a Western offshore of Korea. The design of platform, mooing and anchor foundation was verified through hydrodynamic and mooring analysis. Aero-hydrodynamic coupling was, however, not considered for this conceptual study. Instead, the static rotor thrust and wind load on tower were included in the numerical model.

It has been confirmed that the present designs of the OWTs meet the design requirements on nacelle pitch motion, horizontal acceleration at nacelle and mooring line strength.

For the OWT mooring, a R4 studless chain was selected, which could be readily available in the market. Gravity foundation was chosen due to a shallow soil depth at the proposed installation site. Mooring line sudden damage in addition to intact condition was analyzed to ensure the mooring line performances. The present gravity foundation was designed for a high level cost estimate rather than its performance consideration. Hence, the foundation shall be refined further during a future study.

Installed cost of each OWT was estimated assuming a series of 20 units are to be installed. Cost difference between Spar type OWTs is mainly from the mooring line and installation costs due to the different water depths. TLP type OWT costs are comparable to Spar type OWTs. Thus, a proper selection of either one of Spar or TLP type depends upon a site water depth. However, the Spar type is very unlikely suitable to the Korean offshore metocean environments due to a minimum water depth required for the Spar.

Additional detail study of each OWT or selected one is recommended by considering aero-hydro coupling effect.

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