Ultimate Limit State Analyses of Multi-pile Steel Foundation for Offshore Wind Farm Using FEM

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1. Introduction

In recent years, there has been increased interest in renewable energy worldwide owing to concerns about the global energy shortage and environmental pollution due to fossil fuels. As one of the highly anticipated renewable energies, there has been much research on obtaining wind energy from the ocean because of its environmentally friendly nature and economic feasibility. In particular, with respect to the substructures of offshore wind-turbine generators (WTGs), many studies have been performed and many designs developed to investigate their feasibility.

The Saemangeum lagoon, which is located in the western coastal area of South Korea, has good potential as a wind resource area, and is composed of deep mud seabed layers. Therefore, in this study, the application of the structural behavior in ULS to the optimal design of an MSF installed in Saemangeum seabed layers is analyzed using FEM.

2. Abstract

In this study, ultimate limit state (ULS) analysis are performed using the finite-element method (FEM) for a multi-pile steel foundation (MSF) to be installed at the Saemangeum Offshore Wind Farm in Korea. The suitability of ULS is verified for a substructure investigated in ANSYS. In addition, this ULS study is performed for project verification purposes. This study uses the DNV-GL design standard, which is available for other projects. Both the yielding and bucking phenomena, which occur in MSF, are verified by this structural analysis. The results of this analysis show that the highest yield location on the structure is found at the top, and the value is 271.2 MPa as Von Mises, which does not exceed the design yield strength of 322 MPa. The buckling load factors obtained from linear and non-linear analysis also show that the structure does not reach the critical buckling limit with the applied loads. Based on the simulation results, it is found that the primary steel of MSF does not exceed the yielding limit, and the critical buckling capacity is within the limitations.

3. Geometry

Fig. 1 shows the geometry of the foundation structure, which is composed of a trunk, transition cone, bottom cap, top cap, vertical plate, pile sleeve, and pile, having the range of thickness of min. 0.025~0.65 m. The foundation structure was generated using the software ANSYS Workbench 18.0, which can perform the CAD model construction and FEM analysis. The geometry of the foundation was designed under the condition of Saemangeun lagoon seabed layers, which are composed mainly of deep mud and sand rock with a water depth at wind farms ranging between 0.8 m and 15 m. The plans involve performing dredging at the site in order to obtain three WTG clusters with water depths of 5 m, 10 m, and 15 m.

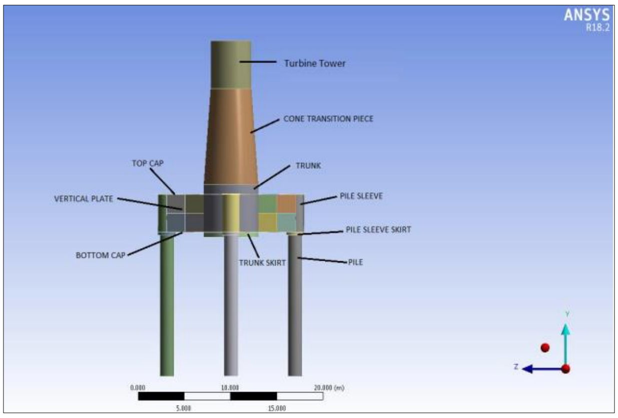

Fig.1 Geometry Overview

Table 1 Geometry thickness – Cluster 3

Item	Description	Thickness [m]
Trunk	Cylinder	0.1
Transition Cone	Cylinder Cone	0.1
Bottom Cap	Plate	0.65
Top Cap	Plate	0.55
Vertical Plate	Plate	0.040
Pile Sleeve	Cylinder	0.025
Pile	Cylinder	0.03

4. Results and Discussion

The aim is to determine whether the structure can withstand the extreme loads for yielding as well as buckling. Therefore, the ULS analysis was performed for the worst-case scenario, which is Cluster 3.

Table 2 Yielding Summary

Area	Location	Maximum von Mises stress [MPa]
A	Transition Cone	96.6
B	Top Cap	271.1
C	Bottom Cap	272.4
D	Pile Sleeve and Pile Sleeve Skirt	92.0
E	Vertical Plate	165.1
F	Cylindrical Trunk	147.5

The ULS design provides the minimal dimensions (length and diameter) of the MSF and the required wall thickness. The necessary inputs for the calculations are the site characteristics (e.g., wind and wave data) and turbine data. The load results are listed in Table 2.

Three types of analysis were performed as ULS analysis: (a) Strength analysis (Fig. 2); (b) Linear buckling analysis (Fig. 3); and (c) Modal analysis (Fig 4).

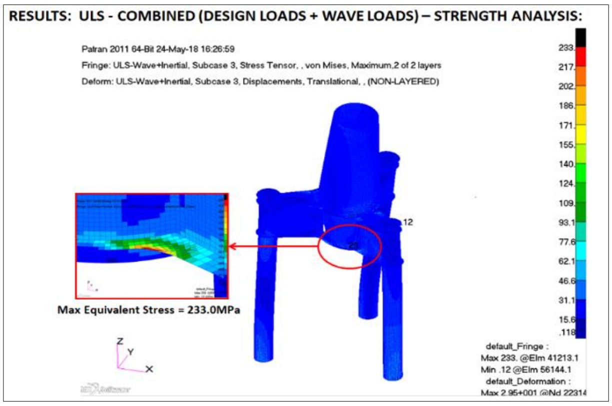

Fig.2 Equivalent stress of the substructure-ULS

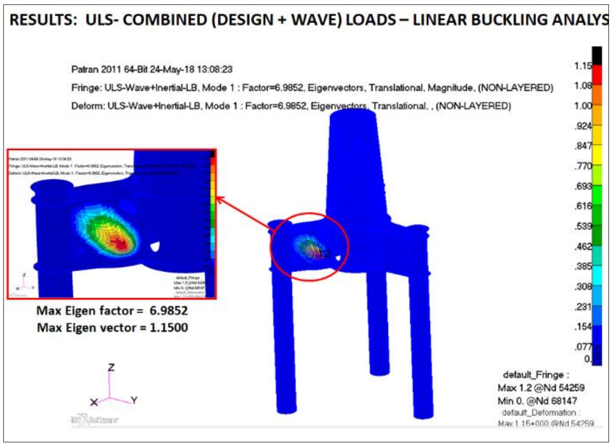

Fig.3 Eigen vectors of the substructure-ULS

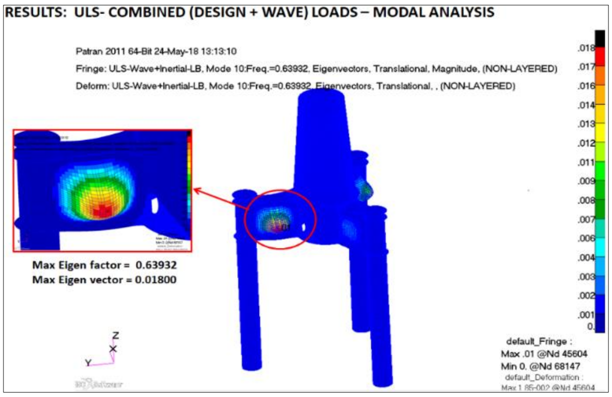

Fig.4 Modal Analysis-ULS combined loads

Conclusion

The allowable stress obtained for the strength analysis using ANSYS Workbench was calculated by using a material factor of 1.1 for a yield strength of 355 MPa, thus resulting in a value of 322 MPa (as allowable stress). From the strength analysis, it can be seen that the maximum equivalent stress is 233 MPa, which is below the allowable stress. Hence, the structure is safe with respect to its yield strength for the given working conditions. It can also be said that even if the load factors are also considered, the obtained stresses will still be below the allowable stresses. The results of the linear buckling analysis show that the buckling factor is 6.98 for an eigen vector of 1.15 and indicate that there is a large margin before the critical buckling point is obtained. Hence, non-linear buckling is not needed. To confirm the buckling strength, modal analysis is performed. The modal analysis shows that even at the 10th mode, the eigen factor is 0.639 for an eigen vector of 0.018. Thus, the structure has sufficient buckling strength.

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