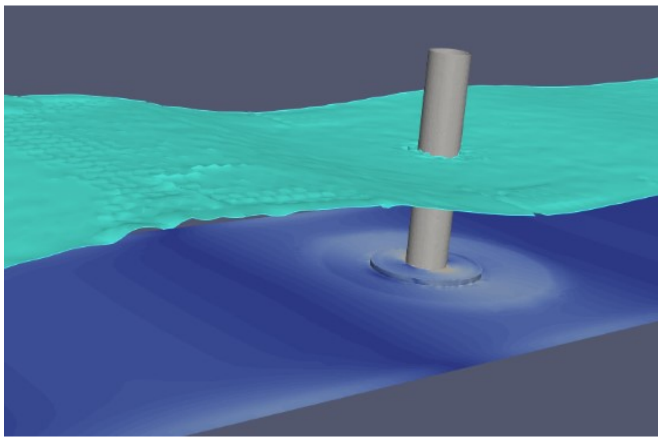
Scour Analysis Around the Foundation of a Bottom-mounted Offshore Wind Turbine Using Optimization Calculations

Plans for large-scale offshore wind farms are progressing in many countries, with the continued adoption of bottom-mounted wind turbines expected for the time being. The manufacturing and installation costs of foundation structures are estimated to account for approximately 20% of the capital cost of bottom-mounted offshore wind turbines, highlighting the need for further cost reductions are expected.

This scour analysis is one of the technologies that contribute to cost reduction in the foundation structures of bottom-mounted offshore wind turbines. By integrating computational fluid dynamics with optimization calculations, the analysis enables the evaluation of scour patterns around foundation structures in a relatively short time. Scour, caused by the transport of seabed materials due to waves and currents, has traditionally been challenging to estimate through simple calculations. This document provides an overview of this analysis technology.



Keywords

computational fluid dynamics, scour, bottom-mounted offshore wind turbines, suction foundation, monopile foundation

■ Purpose

The Japanese government has set a target to achieve 10 GW of offshore wind power generation by 2030 and 30 to 45 GW by 2040. In the near term, the development of wind farms using bottom-mounted foundation structures is expected to take precedence. Various organizations are currently engaged in the design and business feasibility studies of facilities employing bottom-mounted foundation structures, such as monopiles. Furthermore, in recent years, Europe has seen the development of suction foundations aimed at reducing the cost of bottom-mounted foundation structures. There are also successful cases where offshore wind turbines with capacities exceeding 10 MW have been installed on suction foundations. **Fig. 1** illustrates typical bottom-mounted wind turbine foundation structures.

For foundation types constructed on sedimentary layers, accurately evaluating and mitigating scour around foundation structures caused by waves and currents is a critical design requirement. Scour prevention measures, such as the use of blocks and bagged stabilization materials, are typically implemented. However, due to the limited availability of long term observational data on scour phenomena specific to offshore wind turbine foundations, it remains challenging to optimally design the quantity and coverage of scour prevention materials.

This scour analysis introduces a novel scour evaluation technology using Computational Fluid Dynamics (CFD), aimed at optimizing scour prevention measures. Representing all of the changes in seabed topography through CFD, while considering physical models related to transportation of seabed materials, typically demands an extremely high computational load. Alternatively, simplified methods estimate the location and shape of scour based on physical quantities such as bottom shear stress and vorticity around the foundation, but these approaches do not account for the changes in flow conditions caused by scour. To address these limitations, we developed a scour analysis technology that combines CFD with optimization calculations. This approach aims to establish a simulation technology that not only considers seabed topography but also achieves a significantly reduced computational load.

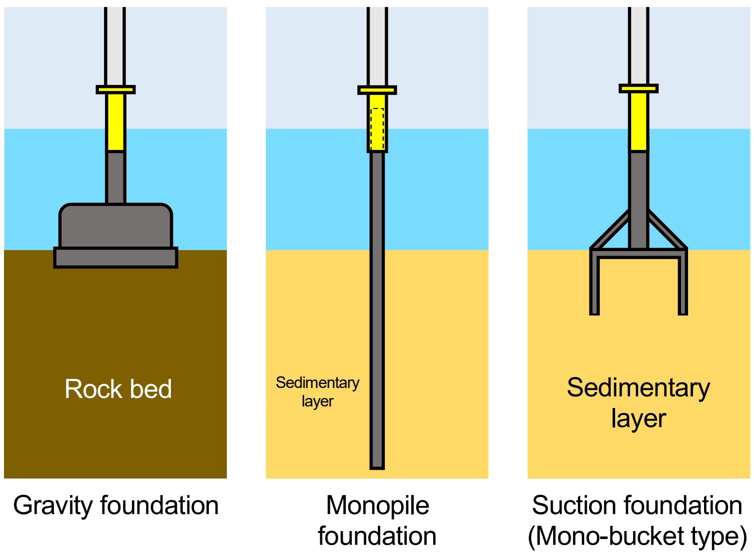


Fig. 1 Typical Bottom-mounted Wind Turbine Foundation Structures

■ Technology Overview

This analysis technology dynamically adjusts the analysis domain based on flow conditions by integrating CFD remeshing (reconfiguration of analysis grids) with optimization calculations. Through iterative calculations, it determines the scour shape as a convergence solution.

Specifically, the analysis begins by extracting the Shields number (a dimensionless value representing the ease of sediment movement, refer to **Fig. 2**), from the shear stress near the seabed based on the CFD results around the foundation. This value is then compared with the critical Shields number, which represents the threshold for scour initiation. If the Shields number exceeds the critical value, the seabed shape is modified, and the CFD analysis is repeated. By minimizing the objective function, which is defined as the difference between the Shields number and the critical Shields number near the seabed, across the entire analysis area through optimization calculations, a convergent scour depth is determined. **Fig. 3** shows the flow of this analysis. To simplify the parameters influencing scour and to ensure a smooth representation of the scour shape, the shape of the scour hole is defined as circular in this analysis.

This analysis technology can regenerate fluid regions for any foundation shape, making it applicable to complex foundation shapes, such as suction foundations and jacket foundations (structures composed of steel pipes arranged in a truss configuration). Additionally, this analysis technology also supports unsteady analysis, enabling the evaluation of scour under wave conditions.

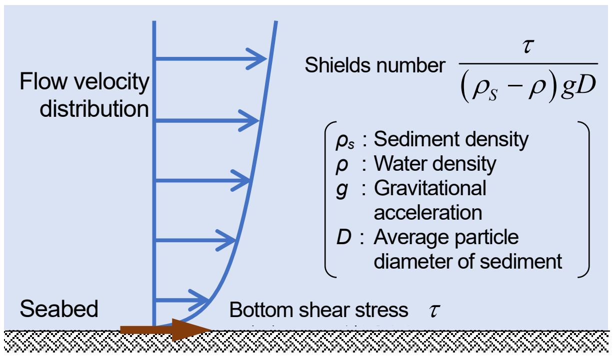


Fig. 2 Shields Number Derived from Shear Stress on the Seabed

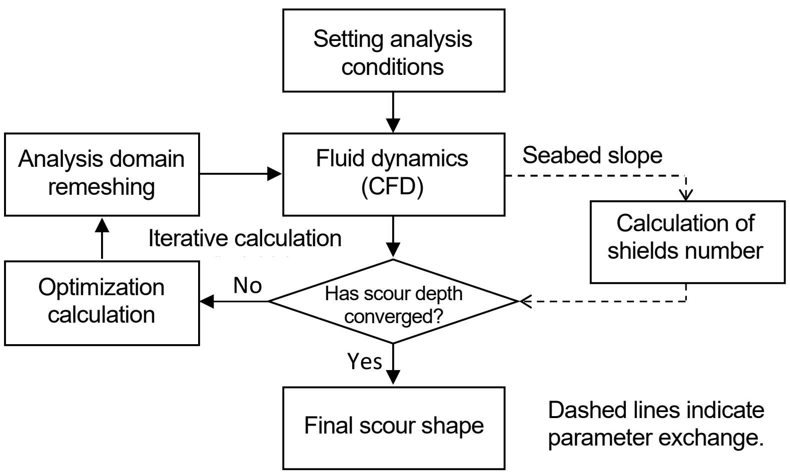


Fig. 3 Coupled Flow of CFD and Optimization Calculation[1)]

■ Calculation Examples and Accuracy Verification

Fig. 4 illustrates an example of the fluid analysis domain used in this analysis technology. Waves and currents are generated at the inlet boundary and applied to the foundation structure. A shape-changeable area is designated on the seabed around the foundation structure, while the rest of the seabed is set to remain unchanged. A convergent scour shape is obtained through iterative calculations based on the flow shown in **Fig. 3**. An example of the scoured underwater topography is shown in **Fig. 5**. The figure demonstrates that the scour hole around the foundation is slightly shifted toward the downstream side, in line with the direction of waves and currents.

Hydraulic model experiments were conducted to verify the accuracy of this analysis technology. **Fig. 6** compares the scour depth s around the foundation obtained from the hydraulic model experiment and numerical analysis. The horizontal axis represents the experimental values, while the vertical axis represents the analytical values, both normalized by the shaft diameter D. The results include uniform flow (Flow) under various flow velocity conditions and irregular waves (Wave) under various wave height conditions. All plots are distributed near the straight line, indicating agreement between the experimental and analytical values.

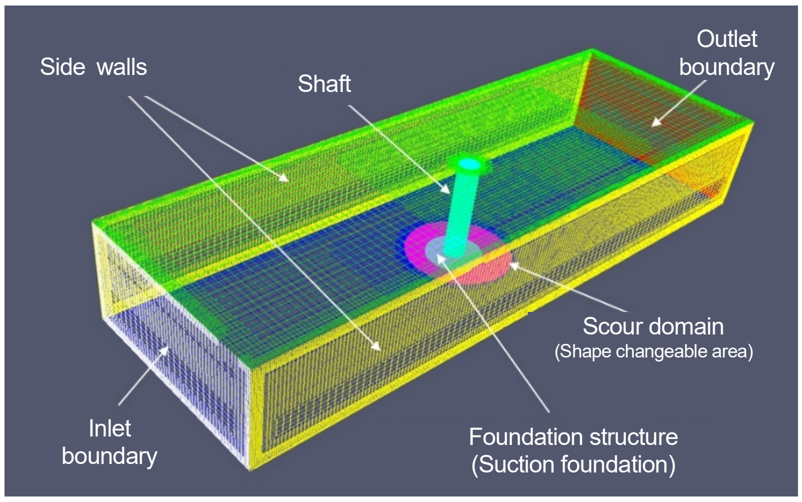


Fig. 4 Example of a Fluid Analysis Domain[1)]

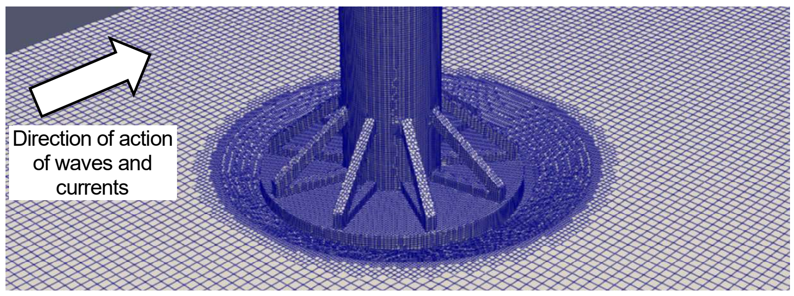


Fig. 5 Example of a Scour Shape Around the Foundation (Suction Foundation)

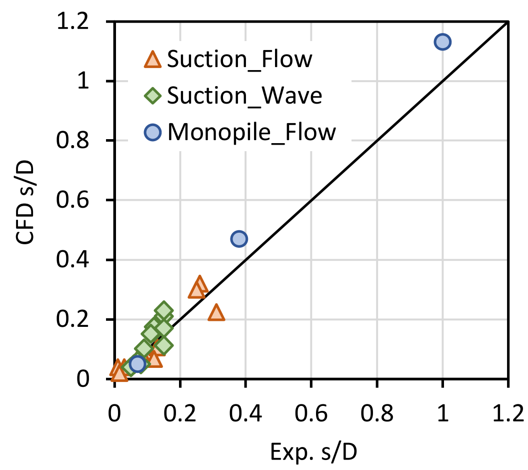


Fig. 6 Verification of Analysis Accuracy Using Hydraulic Model Experiments

Furthermore, the computation time for a single case is about two days on a computer with an 8-core, 3.2 GHz CPU. This allows results to be obtained in a shorter time compared to conventional scour analysis. **Fig. 7** illustrates an example of the convergence process for this scour analysis.

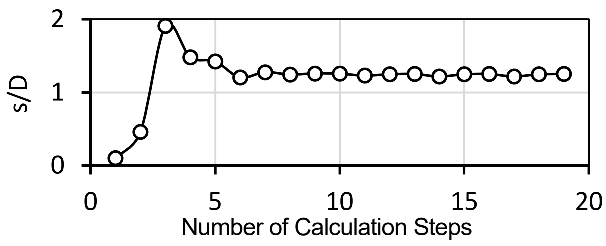


Fig. 7 Changes in Scour Depth During Calculation Progresses

■ Conclusion

By integrating CFD remeshing and optimization calculations, we have developed an analytical technology capable of rapidly evaluating the scour shapes that form around the foundations of bottom-mounted offshore wind turbines. A comparison with hydraulic model experiments confirmed that this technology delivers high analytical accuracy. Moving forward, we will assess its applicability in real-world environments by comparing the analytical results with actual measurements of scour shapes observed on operational machines.

In addition, anti-scouring structures, such as blocks, are installed around the foundations of actual offshore wind turbines to mitigate scouring. To optimize the design of anti-scouring materials, we plan to further enhance this analysis technology by incorporating considerations for the differences in fluid properties of various materials.

References

1) Thaw Tar, Yuichiro Kimura, Proposal of a Numerical Method for Estimating the Shape of Scour Around Foundation Structures, Proceedings of the Japan Society of Civil Engineers, Special Issue (Ocean Development), Volume 80, 2024 (in publication)

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