Proceedings of ISFOG 2025
5TH INTERNATIONAL SYMPOSIUM ON
FRONTIERS IN OFFSHORE GEOTECHNICS
Nantes, France | June 9-13 2025

ISBN 978-2-85782-758-0

Site investigation strategies for offshore wind development in Asia-Pacific

J. W. A. Lakeman*
Equinor ASA, Oslo, Norway

P.R. Larbalestier, Y. S. Shin
Equinor ASA, Oslo/Stavanger, Norway

**jlak@equinor.com*

ABSTRACT: The Asia-Pacific (APAC) region is poised for significant growth in offshore wind energy, with countries like China, Taiwan, South Korea, Australia, and Japan investing heavily and setting ambitious targets. Developing offshore wind projects in this region faces challenges such as complex geological conditions, metocean conditions, logistical complexities, and stringent regulatory frameworks.

A comprehensive survey strategy set by the developer provides a blueprint for preparation, execution and interpretation of geophysical surveys and geotechnical soil investigations. The costs associated with conducting surveys significantly contribute to the overall development expenditure for offshore wind projects. Financial limitations in the uncertain pre-investment phase can pose challenges, especially in regions with unfamiliar regulatory frameworks. Conversely, in APAC countries with well-established auction systems and stringent project schedules, the survey strategy becomes more schedule-driven, balancing survey costs with the need for timely data acquisition.

Geotechnical and geophysical data need to be integrated to ensure accurate site characterization and to support robust infrastructure design. Geotechnical soil investigations and geophysical surveys are generally conducted in tandem and sequentially, commencing with preliminary site-specific reconnaissance surveys, followed by comprehensive detailed campaigns. Geophysical surveys provide spatial data on seabed geology and geohazards, guiding site selection and foundation design, Environmental Impact Assessments (EIA), cable routing, and layout planning. Geotechnical investigations offer specific ground parameters informing infrastructure design.

This paper investigates survey strategies for developers tailored for APAC offshore wind projects, focusing on optimizing the balance between geophysical and geotechnical scopes. Establishing and communicating a survey strategy is essential for efficient resource allocation, risk management, and adherence to timelines, ensuring effective resource use and project success.

Keywords: APAC Region; Geotechnical soil investigation; Geophysical surveys; Survey strategy

1 CONTEXT APAC

1.1 Complex Geological Conditions

The APAC region encompasses a wide range of geological conditions, including varying seabed compositions and seismic activity. Like many regions globally, specific project sites in the APAC region often present unique geological and geotechnical challenges that may be unfamiliar to offshore wind developers with experience primarily in other regions. Local geological or geotechnical institutions are therefore often consulted to develop a comprehensive understanding of the specific geohazards and geotechnical issues in a given area.

1.2 Extreme Weather Conditions

The APAC region is prone to specific local metocean conditions, including typhoons, monsoons, and cyclones, potentially impacting survey schedules and posing risk for equipment damage. In South Korea and Japan, the typhoon season in some regions, generally occurring in July and August, brings strong winds and heavy rainfall, while winter type extreme weather conditions can be expected from December till February. Some regions in Australia are known for consistent rough sea state, almost throughout the year. The regions have local unique vortex currents that may pose challenges for moorings of both survey vessels and anchors. Seasonal weather patterns necessitate robust planning and flexible timelines to accommodate potential delays in survey schedules and ensure the safety of personnel and equipment. Consequently, survey work may be restricted to specific seasons to avoid adverse weather conditions.

1.3 Logistical Complexities

Operating at remote wind farm sites in some areas in APAC can present logistical challenges. Mobilizing vessels, equipment, and personnel to and from these sites requires coordination and can be costly. Additionally, regulations in countries like South Korea and Japan mandate that developers and survey contractors obtain specific permits and licenses to operate. The survey scope needs to be confirmed in a timely manner to secure the appropriate vessels well in advance to ensure all permitting is completed before the intended survey start date. This necessity can limit the flexibility to optimize the scope and schedule of the surveys in response to updated project requirements.

On the contrary, if the permitting structure is well understood and followed up diligently, an effective workflow of the preparations of the surveys can be obtained. Industrialized countries in APAC offer good opportunities in terms of efficient port handling and possibilities to apply local adjustments to scope, vessels and equipment.

1.4 Specific Technical Requirements

The technical requirements for conducting geotechnical soil investigations and geophysical surveys, as well as the parameters for foundation design, are dictated by the specific geological formations and ground conditions at a given site. For example, carbonate soils in Australia or shallow bedrock in Japan necessitate specialized survey techniques. Additionally, the risk of liquefaction in sedimentary soils in some coastal regions of Japan requires specific type of investigations, such as Standard Penetration Tests (SPTs) traditionally linked to foundation design in Japan. However, it is important to note that while Standard Penetration Tests (SPTs) may be required to meet the Japanese standards set by Class NK, they may not always be the most appropriate method for design purposes. SPTs are typically performed in parallel with Cone Penetration Tests (CPTs) and possibly with conventional soil sampling, depending on the specific ground conditions and requirements of the project.

The value of performing SPTs has its background in Japanese foundation design, where the results of the SPTs provide input to specific foundation analyses, including pile capacity analysis and liquefaction analysis. Furthermore, it's traditionally used to identify the depth of rock or sufficiently dense sand within the ground profile (base layer).

The meaningfulness of performing SPTs should be weighed against the purpose it serves for foundation design and the applicability to the local ground conditions. Where required, this should be discussed with local authorities to ensure the most appropriate methods are used.

Another example is the limited suitability of Cone Penetration Tests (CPTs) in high carbonate materials in certain areas in Australia. While Watson et al. (2019) suggest that CPTs can be effectively used in offshore carbonate sediments, Giretti et al. (2016) highlight significant differences in the interpretation of CPT data between crushable carbonate sands and silica-rich sands. They emphasize that empirical methods developed for silica sands should not be directly applied to carbonate sands. Instead, soil-specific relationships based on engineering mechanics should be developed to ensure accurate characterization and reliable estimation of engineering parameters

1.5 Regulations and Environment

Regulatory and environmental considerations vary significantly across the APAC region. Navigating these regulations requires a thorough understanding and compliance with local laws and environmental protection standards. This may involve lengthy permitting processes and adherence to strict environmental impact assessments, which a developer needs to be prepared for in order not to delay project timelines.

An illustrative example is South Korea, where a Cultural Heritage Assessment (CHA) survey is required for any development within 12 nautical miles from the coastline. The scope of this survey typically exceeds the minimum requirement a developer may have in terms of geophysical survey. In addition, to perform surveys a Marine Scientific Research (MSR) permit is required for using a non-Korean vessel, and a Water Permit (WP) is required for intrusive geotechnical testing and sampling.

2 OBJECTIVE OF STRATEGY

2.1 Survey strategy

In the context of this paper, a survey strategy refers to a comprehensive plan prepared by the offshore wind developer, that outlines the approach for conducting surveys to acquire the data needed for design and installation of foundations, cables and other infrastructure. It includes defining the objectives, selecting appropriate methodologies (such as geotechnical and geophysical techniques), determining the scope and scale of the various surveys, planning the logistics, and ensuring the integration of various data collection methods. The strategy also involves setting timelines, budgeting, and addressing any regulatory or environmental considerations specific to the region or project. Essentially, it is a roadmap that guides the entire survey process from pre-auction to final delivery, to ensure that the data collected is accurate, reliable, and useful for design and decision-making. The strategy is by nature iterative and needs to be reviewed and updated after each survey phase. As new data is gathered, it must be interpreted and integrated, leading to a re-evaluation and refinement of subsequent survey focuses.

The strategy should be communicated through detailed project plans and regular team meetings, ensuring all members understand the objectives, methodologies, and timelines. Externally, the strategy must be conveyed to survey contractors and advisory firms through comprehensive briefs and contractual agreements. These documents should outline the scope of work, technical specifications, and expected deliverables, ensuring alignment with the project's goals and standards. Regular progress reviews and open communication channels with external partners are essential to monitor compliance, to address issues promptly, and to maintain the integrity of the survey data.

2.2 Leveraging contractor expertise

Survey contractors should be engaged in the survey strategy and scope of work, as they often possess extensive local knowledge, having previously operated in the country and understanding the limitations and challenges of their equipment and vessels in specific ground conditions and water depths. By doing so, the local knowhow can be used to refine survey methodologies, anticipate potential obstacles, and adapt strategies to local conditions. Establishing a partnership type of working environment fosters a shared commitment to the project's success, ensuring that parties work towards common objectives with a mutual understanding of the project's complexities and requirements.

2.3 Project requirements and site conditions

The development of a comprehensive survey strategy should encompass both geotechnical and geophysical methodologies. The project requirements must be clearly documented, including the type and size of wind turbines, water depth (fixed or floating), and the wind farm layout. Often, the final concept hasn't been decided yet, and turbine size and lay-out might change. For floating wind farms, the need for flexibility in foundation layout is typically larger than for bottom-fixed projects, which demands higher resolution geophysical data. The seabed information acquired may be used to select the appropriate anchoring concept, as outlined in (Crowle, 2023).

The site conditions of the area and the regulatory constraints should be screened. The geological and geotechnical characteristics of the site, including seabed homogeneity and the presence of geohazards, influence the choice of surveys. In the APAC region, specific challenges such as silty soils in Taiwan, calcareous soils in Australia, and soft soils in South Korea must be considered. Additionally, the impact of geohazards, such as seismic activity and the presence of liquefiable soils, should be thoroughly assessed. As mentioned, in Japan, the risk of liquefaction in sedimentary soils necessitates specific investigations like Standard Penetration Tests (SPTs), which are technically challenging and costly to perform offshore.

2.4 Survey Costs

Estimating and allocating budgetary resources for both geophysical surveys and geotechnical soil investigations should be based on the project's scope and site-specific conditions. Detailed financial modelling is necessary to balance cost-efficiency with the need for high-quality data.

The financial investment in these surveys must be justified by the benefits they provide. These benefits include advantages for the design and installation of wind farm infrastructure, such as foundations, inter-array cables, export cables, offshore substations, and environmental impact assessments.

The extent of data acquisition should be evaluated based on its impact on the accuracy, safety, and reliability of the engineering. Collaborating with the foundation engineering team to explore alternative survey strategies ensures that the chosen approach optimally balances technical benefits with project costs.

3 SITE INVESTIGATION STRATEGY

3.1 Geotechnics and geophysics

Geophysical surveys, including seismic data acquisition, SBP, SSS, MBES and MAG provide extensive spatial data on the seabed's physical formations and subsurface structures. The seismic nomenclature is following Hill et al., 2024. These preliminary data are key for identifying potential geohazards, such as slopes, gas pockets, and fault lines, and for mapping geological features that influence site selection and infrastructure engineering.

Geotechnical soil investigations, encompassing borehole drilling, cone penetration testing (CPT), standard penetration tests (SPTs), and amongst others laboratory soil testing, offer detailed information on ground properties such as strength, stiffness, and ground stratigraphy at the geotechnical investigation points selected. Performing SPT tests offshore, as required in Japan, can be costly and technically challenging due to factors like variable hammer efficiency and water depth corrections.

Geophysical surveys may guide the strategic placement of geotechnical soil investigation points, optimizing the scope and focus of soil sampling. Conversely, geotechnical data provides ground truthing for geophysical models, improving their accuracy. The integration of the geophysics and geotechnics is used for hazard identification and to provide parameters needed for the geotechnical design of infrastructure. In the APAC region, geohazards such as seismic activity and liquefiable soils must be thoroughly assessed to inform survey scope and methodologies

Effective risk mitigation involves using geophysical and geotechnical soil investigations to identify potential geohazards early in the project timeline. By integrating data from both survey types, developers can make informed decisions, reducing the risk of unforeseen issues during construction.

3.2 Technical parameters

For geophysical surveys, parameters such as resolution, type of required instrumentation, penetration depth, survey line spacing, and grid need to be defined, ensuring that the chosen techniques are suitable for the site conditions and project requirements. For geotechnical soil investigations, the type and number of tests, required penetration depths, sampling intervals, and laboratory testing programs need to be selected, ensuring that these specifications align with the project's requirements for amongst others engineering, certification and regulations.

3.3 Data Integration Strategy

To effectively utilize geotechnical and geophysical data for site characterization, a clear and structured plan must be outlined before the survey begins. The data integration process involves several key stages.

In the pre-survey planning objectives are defined, data requirements are identified, and pre-existing data is utilized to optimize the scope of future surveys, identify data gaps, and streamline the planning of geotechnical soil investigations, as outlined in Terente, 2016.

During data acquisition, geophysical surveys should be conducted with appropriate resolution, instrumentation, penetration depth, and survey line spacing to suit site conditions and project requirements. Geotechnical soil investigations should select the type and number of tests, required penetration depths, sampling intervals, and laboratory testing programs to align with project needs.

Data processing and analysis involve the integration of geophysical and geotechnical data using advanced software tools for effective visualization. Spatial variability needs to be addressed, hereby considering the sub-surface complexity due to geological processes, ensuring comprehensive data analysis and interpretation, as noted by Vanneste et al., 2021. Early-stage models should be developed using limited initial data to obtain a preliminary site characterization, with continuous refinement as the project progresses, updating the model with data from ongoing surveys.

Validation and calibration of the interpretation should be done through cross-referencing data and iterative refinement to ensure it accurately reflects site conditions. Insights gained from data interpretation should be used to further adjust and optimize the survey strategy, ensuring the collection of necessary data for accurate site characterization. Post-survey interpretation involves utilizing the integrated data to inform foundation design, assess geohazards, and optimize the layout, with continuous refinement based on new data and insights.

4 DATA INTEGRATION

A balance must be struck between geotechnical soil investigations and geophysical surveys to ensure optimal site assessment and project success. This balance is influenced by several factors, including the type of wind farm (floating vs. bottom-fixed), geological complexity, flexibility in layout, remoteness of the country/site and mobilization cost, project type, and project uncertainty.

Geotechnical soil investigations involve the investigation of soil and rock properties to determine the suitability of the seabed for supporting wind turbine foundations. The first geotechnical soil investigation provides an initial assessment of the seabed conditions, typically involving spatially widely spaced sampling and testing to identify general trends and potential problem areas. A detailed geotechnical survey, on the other hand, involves spatially closely spaced sampling and in-depth testing to provide comprehensive data for the design and installation of foundations, as outlined in (SUT, 2022).

A reconnaissance geophysical survey provides a broad overview of seabed conditions, identifying major features and potential hazards. This type of survey is typically used in the early stages of a project to gather preliminary data and assess the general layout of the seabed. In contrast, a detailed geophysical survey involves high-resolution mapping and extensive data collection. This survey type supports detailed engineering and design work, offering precise information on the seabed's structure, composition, and potential challenges. Techniques such as high-resolution seismic reflection, multi-beam sonar, and sub-bottom profiling are often employed to achieve this level of detail.

In the APAC region, geophysical surveys are particularly significant due to the area's diverse marine environments and extensive coastline. For instance, advanced geophysical techniques are used to evaluate the seabed's suitability for wind turbine foundations and to identify potential seismic risks in earthquake-prone areas.

Table 1 summarizes the focus areas of initial survey strategies for different contexts, highlighting their relative importance based on these factors. This table offers a general guide for initial survey strategies, recognizing that various factors may influence the final approach. An overall strategy must consider all relevant factors to guide decision-making effectively.

It is important to note that the contexts in Table 1 are meant to identify the influence of different factors on the survey strategy. A comprehensive survey strategy should consider all relevant factors, as different factors may have conflicting survey focuses. For example, floating offshore wind farms with high layout variability could be paired with either homogeneous ground conditions or highly complex ground conditions. The combination of these factors ultimately defines the overall survey strategy.

For instance, floating offshore wind farms with high layout uncertainty require a higher reliance on geophysical surveys to understand seabed topography and identify hazards for anchor placement. In contrast, bottom-fixed offshore wind farms emphasize geotechnical soil investigations for detailed ground data to design and install fixed foundations.

Homogeneous areas may benefit from extensive geophysical surveys to map seabed conditions over large areas, with geotechnical soil investigations at representative locations to validate geophysical data. Deep-water projects necessitate a combination of high-resolution geophysical surveys and targeted geotechnical investigations to understand complex seabed conditions.

The decision-making process with regards to striking the right balance between the different survey mobilizations and durations is complex, as it involves multiple project disciplines, among which foundation design, risk management, permitting and compliance, cost management and schedule. This complexity necessitates commitment of the members in the project team of the developer to understand the technical aspects involved. A strategic approach is essential to navigate these complexities effectively. It may help for the technical survey team to adopt a multi survey campaign as the base-case scenario for reference. In that way the benefits and drawbacks of immediate detailed surveys as an alternative, facilitates informed decision-making within the developer’s project team, ensuring that the technical quality and associated risks are thoroughly considered.

In the context of the APAC region, regional conditions such as environmental factors, regulatory frameworks, and socio-economic dynamics must be integrated into the strategy. For instance, environmental factors like the high frequency of natural disasters in Southeast Asia necessitate robust risk management plans to mitigate potential disruptions to survey activities. Regulatory frameworks vary significantly across countries; for example, Japan's stringent environmental regulations require comprehensive compliance measures, whereas emerging markets like Vietnam are rapidly evolving their regulatory landscapes to attract foreign investment. By incorporating these regional specifics, the strategy ensures that the approach is not only compliant but also optimized for the unique challenges and opportunities in the APAC region

Table 1. Initial Survey Strategies for Different Offshore Wind Farm Contexts

Context	Initial Survey Method	Survey Focus and Details
Floating offshore wind farms with high lay-out uncertainty	Geophysical surveys	Higher reliance on geophysical surveys to understand seabed topography and identify hazards for anchor placement. Limited geotechnical data in the beginning to identify anchor concept feasibility.
Homogeneous areas	Geophysical surveys with limited geotechnical soil investigations	Extensive geophysical surveys to map seabed conditions over large areas. Geotechnical soil investigations at representative locations to validate geophysical data and provide indicative geotechnical ground properties.
Fixed layout of wind turbine generators	Geotechnical soil investigations	Focus on geotechnical soil investigations for detailed ground data at fixed turbine locations. Geophysical surveys may be minimized to provide basic understanding of the geological formations and where required data to support micrositing, particularly in challenging ground conditions
Deep-water projects	Combination of geophysical and geotechnical soil investigations	High-resolution geophysical surveys combined with targeted geotechnical investigations to understand (complex) seabed conditions.
Cable route surveys	Geophysical surveys with targeted geotechnical soil investigations	Geophysical surveys to map seabed along cable routes. Geotechnical soil investigations at specific points to ensure suitable conditions for cable burial and design parameters, such as thermal properties.
Bottom-fixed offshore wind farms	Geotechnical soil investigations	Emphasis on geotechnical soil investigations for detailed ground data to design and install fixed foundations. Geophysical surveys used initially to map seabed stratigraphy and identify suitable locations.
Complex geology	Combination of detailed geophysical and geotechnical soil investigations	Detailed geophysical surveys to map intricate seabed structures. Geotechnical soil investigations provide data to design foundations that can withstand challenging conditions.
Shallow bedrock	Geophysical surveys with focused geotechnical soil investigations	Geophysical surveys to map depth and extent of bedrock. Geotechnical soil investigations to obtain detailed data about bedrock properties for designing appropriate foundation solutions at specific locations

5 CONCLUSIONS

Developing offshore wind projects in the APAC region presents unique challenges due to complex geological conditions, extreme weather patterns, logistical complexities, and stringent regulatory frameworks. A comprehensive survey strategy tailored to these specific challenges is necessary for successful project development.

An integrated approach combining geotechnical and geophysical methodologies is required. This strategy must address the specific geological, logistical, and regulatory challenges of the region. For instance, Japan's requirement for offshore Standard Penetration Tests (SPTs), South Korea's soft soil conditions, and Australia's calcareous soils necessitate tailored survey techniques.

A well-defined survey strategy should outline precise project requirements and clear objectives. By integrating geophysical surveys and geotechnical soil investigations, developers can achieve thorough site characterization, ensuring accurate data for foundation design.

A phased investigation strategy allows for iterative data collection and risk mitigation, balancing the need for comprehensive data with the risks of encountering unexpected subsurface conditions. This approach ensures that survey strategies are adaptable and responsive to new information.

Clear communication within the developer's teams and with external partners, including geological institutions and survey contractors, is necessary to ensure alignment and collaboration. A comprehensive survey strategy not only documents technical specifications and challenges but also fosters collaboration and alignment with project goals.

To advance the field, it is recommended that offshore wind developers, survey contractors, and geotechnical advisory companies document and publish case studies detailing specific survey strategies. These case studies should include vessel and equipment allocation at various project stages and assess the usefulness of acquired data for foundation design and geohazard mitigation, leveraging local expertise and continuously refining survey strategies to navigate the complexities of the APAC region.

AUTHOR CONTRIBUTION STATEMENT

J. Lakeman: Conceptualization, Formal Analysis, Methodology, Writing—Original Draft, Writing—Review & Editing. **P.R. Larbalestier**: Review & Editing, Investigation, Geophysical Analysis, Validation. **Y.S. Shin**: Review & Editing, Geotechnical Analysis, Investigation, South Korea-Specific Contextualization.

REFERENCES

Crowle, A. (2023). Geo-engineering for Floating Wind Turbines. Presented at the 5th International Conference on Geotechnics for Sustainable Infrastructure Development.

Giretti, D., Been, K., Fioravante, V., & Dickenson, S. (2018). CPT Calibration and Analysis for a Carbonate Sand. Géotechnique.

Hill, A., & Cook, M. (2024). A Proposed Standard Seismic Frequency Nomenclature for Geophysical Site Investigation Surveys in the Offshore Energy Sector. First Break, 42(11), 23-32.

Society for Underwater Technology (SUT). (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. 1st ed. London: Society for Underwater Technology.

Terente, V. A., Owen, M. J., Higgs, D. M., & Ellery, G. (2016). Derivation of Ground Models and Characteristic Geotechnical Profiles in Offshore Wind Farms at pre-FID stage. Paper presented at the 26th International Ocean and Polar Engineering Conference, Rhodes, Greece, June 2016. Paper Number: ISOPE-I-6-411.

Vanneste, M., L'Heureux, J.S., Nadim, F., & Kvalstad, T.J. (2021). "Data-Driven Ground Models: The Road to Fully-Integrated Site Characterization and Design." Lecture Notes in Civil Engineering, 208, 3-21. Singapore: Springer Singapore Pte. Limited..

Watson, P., Bransby, F., Delimi, Z. L., Erbrich, C., Finnie, I., Krisdani, H., Meecham, C., O'Neill, M., Randolph, M., Rattley, M., Silva, M., Stevens, B., Thomas, S., & Westgate, Z. (2019). Foundation Design in Offshore Carbonate Sediments–Building on Knowledge to Address Future Challenges. Presented at the XVI Pan-American Conference on Soil Mechanics and Geotechnical Engineering, Cancun, Mexico, November 2019.