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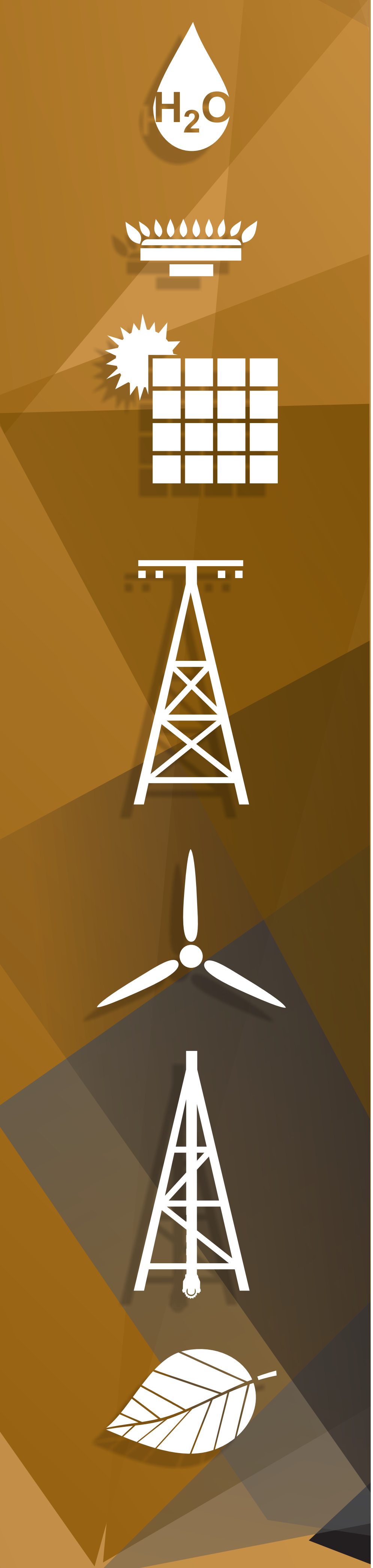

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Wydawnictwa AGH (AGH University Press)
al. A. Mickiewicza 30, 30-059 Kraków
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e-mail: redakcja@wydawnictwoagh.pl
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CONTENTS

Sagarika Sharma
A Geotechnical Characterization for Wind Turbine Construction 5

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ARTICLE

Sagarika Sharma

Sikkim Manipal University, Sikkim
Manipal Institut of Techology,
Majitar, Sikkim 737136, Sikkim, India
ORCID: 0009-0008-6723-3526
e-mail: sagarikasharma432@gmail.com

A GEOTECHNICAL CHARACTERIZATION FOR WIND TURBINE CONSTRUCTION

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Abstract: This paper explores the critical role of geotechnical aspects in optimizing the performance and resilience of wind turbine foundations. It emphasizes the importance of comprehensive geotechnical investigations, including soil borings, in-situ testing, geophysical surveys, and laboratory analysis, to inform foundation design parameters. Remote sensing techniques aid in optimizing turbine layout design, while the collaboration between geotechnical and structural engineers ensures effective foundation design. Ultimately, the comprehensive characterization of wind turbine sites is essential for ensuring stability, reliability, and long-term performance, contributing to the sustainable growth of renewable energy infrastructure.

Keywords: geomechanical, soil borings, geophysical surveys, remote sensing techniques

1. Introduction

Wind turbines play a crucial role in the development of renewable energy infrastructure by efficiently converting wind power into electricity. In late 2020, the worldwide capacity for wind energy generation reached an impressive 733 GW. The addition of new constructions contributed 111 GW to this total, nearly doubling the amount installed in 2019 [1]. As wind turbine capacity and tower height continue to rise, the need for stronger foundations becomes increasingly crucial in supporting these complex systems. Considering economic factors and optimizing the design process while ensuring reliability is the highest priority [2]. There is a significant relationship between the geomechanical and geotechnical properties of the locations where wind turbines are erected and the performance and lifetime of these renewable energy sources. Geomechanics and geotechnics are of the utmost importance in the field of wind turbine foundation design, stability analysis, and overall structural integrity. These fields enter into a complex study of how soils and rocks react when exposed to various applied loads. Energy geotechnics contains a broad range of applications, all of which require a thorough understanding of the interactions between deformation, reaction processes, and flow that occur during the extraction, processing, protection, exploration, and storage of energy resources in the subsurface [3]. Geotechnically the characterization of wind turbine foundations has focused much attention on the cyclic behavior, soil-structure interaction, and stiffness degradation characteristics [4]. The efficiency of energy recovery is a major concern when it comes to geo-storage applications and, in addition to the design and construction considerations, this is worth mentioning. This thesis primarily focuses on the geomechanical and geotechnical aspects of both onshore and offshore wind turbine. The purpose of this study is to increase the knowledge on how to maximize the performance of wind turbine foundations. It focuses on analyzing soil-structure interaction dynamics, foundation design techniques, geotechnical site inspection approaches, and risk assessments for geohazards.

1. **Geotechnical investigation:** An ongoing geotechnical investigation aims to enhance our understanding of the site's subsoil along with its characteristics. Phases of the geotechnical investigation typically include design investigations, preliminary investigations, and monitoring, and controlling based on the questions that arise during design, planning, and construction phases as well as geophysical surveys, soil borings and geologic reconnaissance [5]. To achieve the required geotechnical characteristics for the specific foundation at each turbine location, a comprehensive geotechnical site analysis is essential during the engineering design phase.
2. **Soil borings:** Soil borings are necessary for geotechnical and geomechanical characterization in wind turbine projects. They provide crucial data to ensure solid foundations, assess risks, and ensure long-term performance. Soil sampling involves the use of split spoon samplers such as SPT and thin wall tube samples. Drilling boreholes at critical sites across the wind turbine site is an essential process known as conducting soil borings. The depth of these borings can vary depending on the project's requirements. Typically, the depth ranges from a few meters to dozens of meters. The differential pressure in the bottom-hole is regulated by both the solid content and mud density then the soil samples that are obtained from borings are collected with great care and labeled to ensure that their integrity is preserved while they are being transported to the laboratory. Depending on the conditions of the soil and the requirements of the project, several different sample methods. Some of these procedures include Shelby tube sampling and split spoon sampling.

2.1. In-situ testing: In addition to selecting samples from the soil, in-situ testing methods are frequently utilized during soil borings to evaluate the characteristics of the soil directly at the location. Standard penetration testing (SPT), cone penetration tests (CPT), and pressuremeter tests are some examples of the types of tests that may be performed. These tests deliver data in real time regarding the resistance of the soil, its density, and other factors that are pertinent. The SPT is widely recognized as a reliable in-situ soil test. The process involves inserting a split-spoon sampler into the bottom of the borehole using a standard weight and falling height. The SPT "N-value". indicates the quantity of blows necessary to penetrate the sampler 12 inches or 300 mm. The SPT N-values provide crucial information about soil stiffness and resistance, which are essential for foundation design and settlement analysis.

2.2. Cone penetration testing: Continuous profile testing (CPT) is an innovative method of in-situ testing that captures the soil's profile in real time. Using a cone-shaped penetrometer, the earth is carefully probed to determine sleeve friction (f_s) and cone resistance (q_c) while excavating the borehole. Understanding the geotechnical characteristics of a soil involves analyzing factors like shear strength, soil type, and sleeve friction, which can be determined by examining the cone resistance and sleeve friction measurements.

2.3. **Geophysical surveys:** Using several geophysical methods such as electrical resistivity, seismic refraction, and ground-penetrating radar (GPR) can enhance the information gathered from soil borings, giving an improved understanding of subsurface conditions. These techniques are useful for detecting anomalies, identifying layer boundaries, and characterizing soil properties in areas where direct sampling may be difficult.

2.4. **Laboratory testing:** Extensive laboratory testing is conducted on soil samples retrieved from borings to determine various technical fields. These properties include shear strength parameters, grain size distribution, and consolidation characteristics, Atterberg limits. These tests are crucial for understanding how the soil will behave under various loading conditions and providing valuable insights for foundation design.

3. **Foundation design parameters:** To develop key parameters for foundation design, it is necessary to undertake laboratory tests and analyse the data obtained from soil borings. Bearing capacity, settlement analysis, lateral earth pressures, and piling capacities are some of the factors that are included in this category. It is vital to have a thorough understanding of these criteria to select the appropriate foundation type and size to ensure the structural integrity and stability of the wind turbine [2].
4. **Remote sensing:** Remote sensing techniques, such as LiDAR and SODAR, are used to analyze the wake effects generated by operational wind turbines. These methods study the variations in wind speed, turbulence, and atmospheric conditions that occur downstream of turbines to understand the impact of wakes on nearby turbines. By utilizing wake analysis, one can optimize turbine spacing and layout design to minimize power loss caused by wake-induced losses and maximize the overall performance of wind farms.
5. **Geotechnical reports:** The data that are collected from soil borings and other research that are pertinent are included in the geotechnical reports that are created. Along with documentation of the presentation of results and of analysis results, and site-specific conditions, these reports include recommendations for foundation construction and design concerns. Additionally, these reports include the presentation of results.
6. **Limit state design:** The ULS and Load and Resistance Factor Design (LRFD) methods have been widely accepted and commonly used in the structural design of different structures. The structures consider uncertainties associated with design loads, load combinations, material strength variability, and limitations in design methods and analysis. Accounting for these uncertainties, the load and resistance factors play a crucial role.

6.1. **Ultimate limit states:** When it comes to wind turbine foundations, ULS focuses on ensuring their ability to endure extreme loading conditions without any risk of failure or collapse. ULS considers various geotechnical problems, such as bearing capacity failure, excessive settlement, and global stability failure of the foundation system. When designing the foundation, certain parameters are taken into consideration, such as soil strength, foundation size, and load distribution. This ensures that the turbine is securely supported even under maximum loads. These loads consist of wind loads, dynamic forces, and gravity loads.

6.2. **Serviceability limit states (SLS):** It is of the utmost importance to make certain that the wind turbine runs within acceptable performance parameters, without incurring significant deformation or serviceability difficulties. In the case of SLS, geotechnical factors may include taking into consideration settlement restrictions in order to ensure that the turbine continues to perform properly, foundation stability in order to prevent excessive vibrations. To manage deformation and maintain the stability of the foundation and soil, design parameters are carefully determined. This is done even when the foundation and soil are subjected to normal operating circumstances, wind-induced vibrations, and transient loads.

7. **Collaboration between geotechnical and structural engineers:** It is imperative that the disciplines collaborate and communicate with one another since foundations include crucial structural and geotechnical elements. A geotechnical report by itself does not provide the structural designer with the necessary contact information to be able to grasp the geotechnical and structural design specifications required to enable the most effective and economical foundation design forsite conditions. Mostly, the structural designer and the geotechnical consultant should have a discussion before the geotechnical exploration is carried out. This will ensure that every design requirement is considered during the study. Furthermore, a thorough understanding of the designspecifications by the structural and geotechnical experts facilitates the prompt solution of challenges that may occur during installation due to construction faults or variations in the quality of the materials.

2. Discussion

This study shows how important it is to optimize wind turbine foundation designs for sustainable renewable energy infrastructure by utilizing geotechnical studies, remote sensing methods, and interdisciplinary collaboration. Extensive geotechnical investigations yield crucial information on the stability of foundations, and remote sensing assists in optimizing layout. Coordination between structural and geotechnical engineers guarantees good design integration. Through the application of these techniques, engineers can improve wind turbine foundation performance and dependability, thereby promoting the expansion of renewable energy sources while reducing their negative environmental effects.

3. Conclusion

In conclusion, the effective conception, design, and execution of wind turbine projects depend heavily on geomechanical and geotechnical characterization. The stability, dependability, and long-term performance of wind turbines can be efficiently ensured by engineers through the appropriate design of foundations through a thorough understanding of subsurface conditions, soil qualities, and geotechnical hazards. Engineers collect vital information to guide foundation design, evaluate risks, and optimize solutions catered to the unique site circumstances by using methods like soil borings, in-situ testing, laboratory analysis, and remote sensing. When structural and geotechnical engineers work together, foundation designs are guaranteed to adhere to safety regulations, structural integrity specifications, and environmental considerations. To reduce risks to the wind turbine structure and the surrounding environment, potential geohazards such as soilliquefaction, landslides, and foundation settlement can be identified and mitigated using geotechnical and geomechanical characterization. Additionally, engineers may test design assumptions, optimize operational efficiency, and continually monitor foundation performance throughout the lifecycle of wind energy projects by incorporating sophisticated technologies and processes. In the end, developing renewable energy infrastructure, assisting in the production of sustainable energy, lowering carbon emissions, and promoting a greener future for generations to come all depend on the comprehensive geomechanical and geotechnical characterization ofwind turbine sites.

Author contributions: conceptualization, S.S; methodology, S.S; investigation; resources, S.S; writing – original draft preparation S.S.; writing – review and editing, S.S.; visualization.

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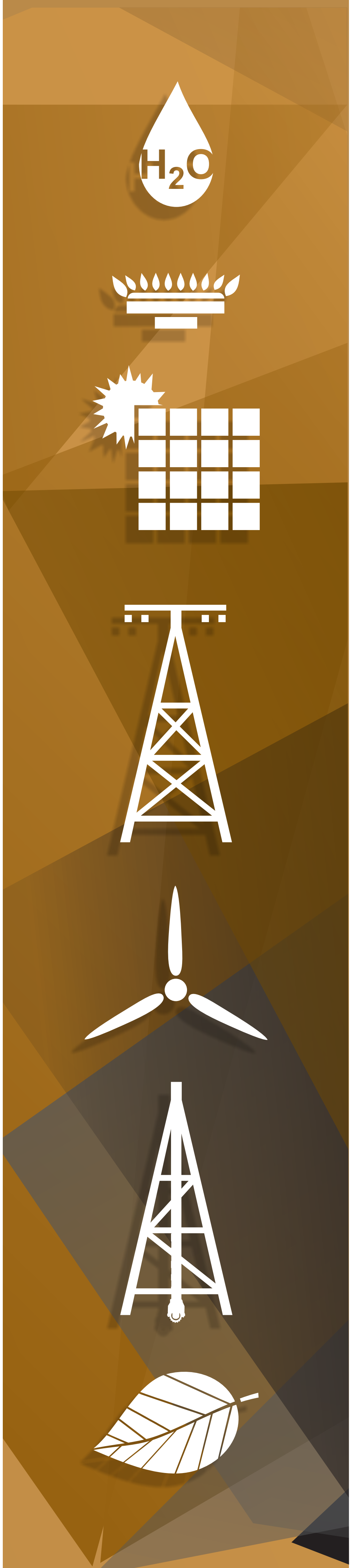
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