

Design and Fabrication Analysis of Single Pile Foundation for Offshore Jacket Structures

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Abstrak

Meningkatnya kebutuhan akan struktur lepas pantai yang efisien secara biaya telah mendorong pengembangan sistem fondasi alternatif, salah satunya adalah fondasi tiang tunggal (single pile foundation). Penelitian ini menyajikan analisis komprehensif terhadap aspek perancangan dan fabrikasi fondasi tiang tunggal yang diterapkan pada struktur offshore jacket. Kajian ini berfokus pada mekanisme transfer beban, interaksi tanah–tiang, integritas struktur, serta tantangan dalam proses fabrikasi. Metode yang digunakan meliputi pendekatan analitis dan studi literatur untuk mengevaluasi kelayakan serta kinerja sistem tersebut. Hasil penelitian menunjukkan bahwa fondasi tiang tunggal dapat menjadi solusi yang efisien dan andal pada kondisi tanah dan pembebanan tertentu, dengan syarat dilakukan analisis geoteknik yang mendalam serta pengendalian mutu fabrikasi yang ketat (1).

Kata Kunci: *Fondasi Tiang Tunggal, Offshore Jacket, Fabrikasi, Interaksi Tanah–Struktur, Teknik Lepas Pantai.*

Abstract

The increasing demand for cost-efficient offshore structures has led to the development of alternative foundation systems, one of which is the single pile foundation. This study presents a comprehensive analysis of the design and fabrication aspects of single pile foundations applied to offshore jacket structures. The research focuses on load transfer mechanisms, soil–pile interaction, structural integrity, and fabrication challenges. A combination of analytical methods and literature review is employed to evaluate the feasibility and performance of the system. The results indicate that single pile foundations can provide an efficient and reliable solution under specific soil and loading conditions, provided that detailed geotechnical analysis and strict fabrication quality control are implemented (1).

Keywords: *Single Pile Foundation, Offshore Jacket, Fabrication, Soil–Structure Interaction, Offshore Engineering.*

INTRODUCTION

Offshore jacket structures are widely used in the oil and gas industry to support production facilities in shallow to intermediate water depths [1], [2]. Traditionally, these structures rely on multi-pile foundation systems to distribute loads safely into the seabed [1]. However, increasing project cost pressures and the need for simplified installation procedures have encouraged the exploration of alternative foundation concepts [13].

The single pile foundation system has emerged as a promising solution, particularly for small to medium offshore platforms [17]. Unlike conventional systems, this approach utilizes a single large-diameter pile to support the entire jacket structure. While this reduces fabrication complexity and installation time, it also introduces significant engineering challenges related to load concentration and soil behavior [2], [5].

This paper aims to analyze the design considerations, fabrication processes, and performance characteristics of single pile foundations in offshore jacket applications.

LITERATURE REVIEW

Offshore Jacket Structures

Jacket structures are steel-framed tubular systems designed to withstand environmental loads such as waves, currents, and wind [9], [12]. They are typically fixed to the seabed using driven piles [1]. The structural configuration consists of vertical legs and horizontal and diagonal bracings, forming a stable three-dimensional framework [10].

Single Pile Foundation Concept

The single pile foundation, often comparable to monopile systems used in offshore wind turbines, employs a single large-diameter steel pile [17]. This pile transfers loads through a combination of end bearing and shaft resistance [3], [5]. The concept is particularly advantageous in homogeneous soil conditions and moderate loading scenarios [3].



Soil–Pile Interaction

The behavior of a single pile foundation is governed by soil–structure interaction [14]. Key parameters influencing the performance of the foundation include axial bearing capacity, lateral resistance, pile deflection and rotation, as well as soil stiffness and stratification.

METHODOLOGY

This study adopts a qualitative and analytical approach, combining theoretical design principles with fabrication practices. The methodology includes:

1. Data Collection

Relevant data are obtained from geotechnical soil reports, environmental loading conditions, and material specifications required for offshore jacket structure analysis and foundation design.

2. Structural Analysis

The structural analysis includes axial load capacity calculation, lateral load and bending moment analysis, as well as stability and safety factor evaluation to ensure the structural reliability of the single pile foundation system [5], [11].

3. Fabrication Assessment

Fabrication processes are evaluated based on material preparation techniques, welding procedures, assembly accuracy, and inspection and quality control methods to ensure compliance with offshore structural standards [15], [16].

RESULT AND DISCUSSION

Axial Capacity of Single Pile

The axial capacity of the pile is determined by the sum of end bearing resistance and skin friction along the shaft [5], [18]. The results show that increasing pile diameter significantly enhances load-bearing capacity. However, this also increases fabrication complexity and material cost [17].

Lateral Load Behavior

Lateral loads induced by waves and currents play a dominant role in offshore structures [9]. The analysis indicates that pile stiffness and embedment depth are critical factors in controlling deflection [7]. Excessive lateral displacement may compromise structural integrity and operational safety [6], [20].

Optimal Embedment Depth

The embedment depth must be sufficient to mobilize both axial and lateral resistance [3], [5]. In soft soil conditions, deeper penetration is required to reach more competent soil layers [19]. The study suggests that improper depth selection can lead to instability or excessive settlement.

Fabrication Process Analysis

The fabrication process begins with material preparation, where steel plates are cut and rolled into cylindrical sections to form large-diameter piles [16]. Precision at this stage is essential to ensure proper fit-up during welding. Welding is a critical aspect of fabrication because it directly affects structural strength [15]. Both longitudinal and circumferential welds must meet stringent standards [12], as welding defects such as cracks, porosity, and lack of fusion can significantly reduce structural integrity [16]. Furthermore, the integration of the pile with the jacket structure requires accurate assembly and alignment [10]. Misalignment may lead to installation difficulties and uneven load distribution. To ensure fabrication quality, non-destructive testing (NDT) methods such as ultrasonic testing (UT) and radiographic testing (RT) are used to detect internal defects [15]. In addition, quality assurance procedures must comply with international standards [12].

ADVANTAGES AND LIMITATIONS

The single pile foundation system offers several advantages, including a reduced number of structural components, a simplified fabrication process, faster installation time, and potential cost savings [13], [17]. However, the system also has several limitations, such as high load concentration on a single structural element, sensitivity to soil variability, and limited applicability in complex soil conditions. In addition, the system requires high precision in both fabrication and installation processes to ensure structural safety and performance [11], [14].

CONCLUSION

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The single pile foundation system presents a viable alternative for offshore jacket structures under suitable conditions [17]. The study demonstrates that this system can achieve adequate structural performance when supported by proper design and high-quality fabrication practices [1], [12]. The findings indicate that pile diameter and embedment depth are critical design parameters influencing foundation stability and load-bearing capacity [3], [5]. In addition, soil–pile interaction significantly affects structural behavior [14]. Fabrication quality, particularly welding performance, also plays a vital role in ensuring structural integrity and long-term reliability [15], [16]. Overall, the system is considered most suitable for offshore structures subjected to moderate loading and relatively uniform soil conditions [17], [19].

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