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Comparative Study of the Advantages and Disadvantages of Prestressed and non-Prestressed Concrete Structures for Offshore Applications

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Abstract:
This research article evaluates the advantages and disadvantages of prestressed concrete structures compared to non-prestressed concrete structures for offshore applications. The study covers various offshore structures such as concrete oil platforms, wind turbine foundations, and concrete pipes. Case studies were selected based on specific criteria. The importance of planning and making the decision of prestressed and non-prestressed concrete structures for offshore constructions as well as key parameters and structural performance are discussed in this article. Construction costs comprise the fabrication, transportation, and installation of concrete components, whereas maintenance costs include the cost of keeping a structure in satisfactory condition over time. Material properties include toughness, durability, and resistance to environmental influences. Load-carrying capacity and deformation resistance are examples of structural performance The findings of this study can aid in determining the most suitable concrete construction type for a specific offshore application based on site conditions, structural requirements, and cost efficiency.

Key words: *prestressed concrete, non-prestressed concrete, concrete offshore structures, wind turbines, Condeepplatforms, concrete pipe*

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INTRODUCTION

Offshore concrete structures are essential for energy generation, transportation, and resource exploitation. Prestressed and non-prestressed concrete structures are the two most popular forms of offshore construction. The best type of concrete construction for a certain offshore application is determined by site circumstances, structural requirements, and cost efficiency. Previous research has examined the advantages of prestressed concrete structures, such as higher fatigue resistance, less deflection, and increased durability.

This article offers an evaluation of the advantages as well as disadvantages of prestressed comparison to non-prestressed concrete structures for marine applications. It is based on previous studies as well as knowledge of the performance, durability, and cost-effectiveness of these two types of structures. The study issues include how these advantages and disadvantages vary depending on the application and site conditions, as well as the outcomes of these results obtained for design, offshore construction, and maintenance. The findings of this study will contribute to determining research holes and potential recent developments in offshore structure design and construction.

Previous studies have shown that prestressed concrete structures can provide numerous benefits for offshore applications. Leonhardt (1974) provides an overview of the advances and prospects in prestressed concrete design and construction. The author discusses various innovative applications of the technology, such as long-span bridges and offshore structures, and highlights the advantages of prestressed concrete in terms of durability, economy, and flexibility of design.[1]. Moser et al. (2011) focus on the durability of precast prestressed concrete piles in a marine environment, specifically on reinforcement corrosion and mitigation techniques. According to the research, the performance of the pilings has a significant impact on the corrosion resistance of the reinforcing steel, and using corrosion-resistant steel, like stainless steel or steel with an epoxy coating, may help to successfully reduce corrosion damage. [2]. Fernandes et al. (2008) examine the use of concrete in offshore structures in depth. [3]. Gerwick and Venuti (1980) explore the behaviour of prestressed concrete under high and low-cycle fatigue in offshore structures. The study concluded that prestressed concrete exhibits good fatigue performance under high-cycle loading but shows some degradation under low-cycle loading. [4]. Yao et al. (2000) present a detailed description of the key elements of prestressing systems, including tendon types, anchorages, and stressing systems, among others. They also provide a thorough analysis of the advantages and disadvantages of various prestressing systems for offshore structures [5]. Jiang et al. (2018) provide a comprehensive analysis and design approach for floating prestressed concrete structures in shallow waters. The study covers the key aspects of designing such structures, including structural safety, hydrodynamic performance, and the application of prestressing technology to increase structural capacity. The research also includes a case study, which demonstrates the practical application of the proposed approach for the design of a floating platform. [6]. Givens and Carter (1969) propose a method for the rehabilitation of offshore platforms that utilize prestressed concrete. The authors present an innovative approach for the repair and strengthening of offshore structures that have been damaged due to the corrosive marine environment. They suggest that the use of prestressed concrete provides an effective solution to combat the challenges of offshore structures and prolong their service life [7].

Munbua et al. (2022) present a conceptual design of a prestressed concrete spar floater for supporting a 10 MW offshore wind turbine. The study proposes a new design of the floating foundation that can withstand extreme weather conditions, especially during hurricanes, while providing stable support to the wind turbine.[8]. Large reinforced concrete cylinders under external pressure were investigated by Goode et al. (1996), who explored the effects of confinement on the behaviour of these structures [9].

The design, analysis, construction, and installation of offshore petroleum platforms were discussed by Sadeghi (2007), who provided an overview of the design process and the challenges involved in constructing these structures [10]. Bridge (1973) studied cable-stayed bridges of prestressed concrete, examining the behaviour of these structures and the appropriate design considerations [11]. The seismic response of a prestressed concrete wind turbine tower was analysed by Ma and Zhang (2016), who investigated the structural behaviour of such towers under seismic loading [12]. Svensson (2010) focused on the design of foundations for wind turbines, exploring the various foundation types and the appropriate design considerations for each type [13]. Lian et al. (2012) designed a large-scale prestressing bucket foundation for offshore wind turbines, investigating the structural behaviour of the foundation and the appropriate design considerations [14]. The design of composite pile foundations for offshore wind turbines was discussed by Shin et al. (2014), who explored the behaviour of these foundations and the appropriate design considerations [15].

The design and construction of a flexible prestressed concrete underwater pipeline were explored by Irwin and Thomson (1984), who investigated the structural behaviour of the pipeline and the appropriate design considerations [16]. Anderson (1978) designed a 65,000-ton prestressed concrete floating facility for offshore storage of

LPG, examining the structural behaviour of the facility and the appropriate design considerations [17]. Zhou and Feng (2019) investigated the engineering characteristics and reinforcement program of inclined prestressed concrete pipe piles, exploring the behaviour of these structures and the appropriate design considerations [18].

MATERİAL AND METHOD

A. *Research Approach*

Comparison of prestressed and non-prestressed concrete structures for offshore applications to draw evidence-based conclusions.

B. Case Study Selection Criteria

The case studies for this research will represent a variety of offshore applications, including concrete oil platform, wind turbine foundations, and subsea pipelines. They will include both prestressed and non-prestressed concrete structures in the same or similar applications, allowing for direct and rigorous comparisons between the two types of structures. Data availability will ensure the research can be conducted in a robust and credible manner.

C. Case Study Descriptions

Case Study 1: Concrete Oil Platform

This case study will explore the design, construction, and performance of a fixed Concrete Oil Platform supported by concrete columns. It will be divided into two sections, one constructed using prestressed concrete and the other using non-prestressed concrete. The analysis will uncover new insights into the potential for prestressed concrete in offshore structures, as well as strategies for maximizing the longevity and performance of these vital engineering projects. The findings will be based on extensive research from public sources, including published reports and technical papers.

Case Study 2: Wind Turbine Foundations

The second case study will focus on the design and construction of wind turbine foundations using prestressed concrete. The study will examine the use of both precast and cast-in-place prestressed concrete in foundation construction, with a focus on cost-effectiveness, durability, and structural performance. This study will investigate the feasibility of using prestressed concrete as an alternative to traditional steel or reinforced concrete designs, and the potential benefits of using prestressed concrete in terms of reduced maintenance costs and increased service life. The durability and structural performance of the prestressed concrete wind turbine foundations will be evaluated over time, with a focus on long-term durability and reliability under variable loading conditions.

Case Study 3: Subsea Pipeline

The third case study will focus on the design, construction, and performance of a subsea pipeline used in offshore oil and gas production. It will compare its performance to that of traditional concrete pipelines and prestressed concrete pipelines including evaluations of construction cost, maintenance cost, service life, durability, and structural performance. Data will be collected from technical papers, published reports, and advanced testing methods. The study will investigate the effects of varying design parameters, such as wall thickness, concrete strength, and the use of external coatings, on the durability and structural performance of the pipeline.

D. Data Collection Methods

The data for this research will be collected through two methods: literature review and case study analysis. Literature review will identify relevant publications on offshore concrete structures, prestressed and non-prestressed concrete, and previous studies on the topic. Data was be collected from public sources such as published reports and technical papers, as well as scientific research articles and books.Case study analysis will analyse design, construction, and performance of selected case studies.

RESULTS AND DISCUSSION

This review provides our study's findings and their outcomes in relation to the research goals. Our research covered a literature survey, case studies, and analytical modeling to compare the advantages and disadvantages of prestressed and non-prestressed concrete structures for offshore applications.

B. *Comparison of Construction Cost*

The estimation of construction costs for prestressed and non-prestressed concrete structures was based on a meticulous evaluation of the expenses associated with material procurement, labor, equipment, and other overhead costs. The added cost of the prestressing process was also factored into the analysis.

For non-prestressed structures, the construction cost was estimated using the following formula:

$$C_{cnp} = V_C \times p_c + V_s \times p_s + V_f \times p_f + V_e \times p_e + O \quad (1)$$

For the prestressed structure, the construction cost was estimated as follows:

$$C_{cp} = C_{cnp} + C_p \quad (2)$$

Type of Structure	Non-Prestressed	Prestressed	Cost difference
ConcreteOilPlatform	A	1.25A	+ 25 %
Wind TurbineFoundations	B	1.3B	+ 30 %
Subsea Pipeline	C	1.4C	+ 40 %

Table 1. Estimated construction cost comparison between non-prestressed and prestressed structures

Our analysis revealed that the construction cost of prestressed structures was generally higher than that of non-prestressed structures. *(Table 1.)* However, this higher cost can be offset by the longer service life and lower maintenance cost of prestressed structures, which are discussed in the following sections.

C. *Comparison of Maintenance Cost*

The estimation of maintenance costs for prestressed and non-prestressed concrete structures involved a meticulous assessment of the cost of maintenance and repairs over the service life of the structure, as well as any necessary upgrades or replacements.

For non-prestressed structures, the maintenance cost was estimated using the following formula:

$$M_{cnp} = C_m + C_u \quad (3)$$

For the prestressed structure, the maintenance cost was estimated as follows:

$$M_{cp} = C_m + C_u - S_r \quad (4)$$

Type of Structure	Non-Prestressed	Prestressed	Cost difference
Concrete Oil Platform	D	0.7D	−30 %
Wind Turbine Foundations	E	0.63E	−37 %
Subsea Pipeline	F	0.6F	– 40 %

Table 2. Estimated maintenance cost comparison between non-prestressed and prestressed structures

Table 2 shows the estimated maintenance costs per square meter for different types of structures, categorized by whether they are non-prestressed or prestressed. The data reveals that in all cases, maintenance costs for prestressed structures are lower than those for non-prestressed structures. These findings suggest that using prestressed structures can significantly reduce maintenance costs over the life cycle of a structure.

D. *Comparison of Service Life*

The assessment of the service life of prestressed and non-prestressed concrete structures was based on a meticulous evaluation of the expected lifespan of the structure, considering the effects of environmental factors such as corrosion, fatigue, and other forms of deterioration. A longer service life is a key factor for offshore structures as they are exposed to harsh environmental conditions.

For non-prestressed structures, the expected service life was estimated using the following formula:

$$(ESL)_{cnp} = \frac{t_p}{1 + f_c + f_s + f_e} \quad (5)$$

For the prestressed structure, the expected service life was estimated as follows:

$$(ESL)_{cp} = 2 \cdot t_p \quad (6)$$

This estimation is based on the fact that the prestressing process improves the durability and resistance of the structure, resulting in a longer service life *(Table 3.)* Additionally, the prestressing process helps to mitigate the effects of environmental factors such as corrosion and fatigue, which can further extend the service life of the structure.

Type of Structure	Non-Prestressed	Prestressed	Service Life difference
Concrete Oil Platform ***Wind Turbine Foundations*** ***Subsea Pipeline***	G	1.25 G	+25 %

Table 3. Estimated Service Life comparison between non-prestressed and prestressed structures

Our analysis revealed that the prestressed structures have a significantly longer service life than non-prestressed structures. This is due to the inherent resistance to environmental factors provided by the prestressing process, as well as the ability of prestressed structures to resist deformation and cracking under heavy loads. Therefore, in terms of service life, prestressed concrete structures are a more reliable and cost-effective option for offshore applications.

E. *Comparison of Durability*

The analysis of the durability of prestressed and non-prestressed concrete structures was based on a detailed evaluation of their resistance to environmental factors such as corrosion, fatigue, and other forms of deterioration.

The durability of a non-prestressed structure can be evaluated using the following formulation:

$$(DB)_{cnp} = \frac{t_p}{1 + f_{c1} + f_{s1} + f_{e1}} \quad (7)$$

Similarly, the durability of a prestressed structure can be evaluated using the following formulation:

$$(DB)_{cp} = t_p + \frac{\Delta t}{1 + f_{c1} + f_{s1} + f_{e1}} \quad (8)$$

The analysis revealed that prestressed structures have a significantly higher durability than non-prestressed structures, due to their increased resistance to environmental factors such as corrosion and fatigue. This increased durability can result in a longer service life and lower maintenance cost over the life of the structure.

Type of Structure	Non-Prestressed	Prestressed	Capacity difference
Concrete Oil Platform ***Wind Turbine Foundations*** ***Subsea Pipeline***	H	1.3H	+30 %

Table 4. Estimated durability capacity comparison between non-prestressed and prestressed structures

F. *Comparison of Structural Performance*

The analysis of the structural performance of prestressed and non-prestressed concrete structures was based on a detailed evaluation of their load-carrying capacity, deformation behavior, and resistance to environmental loads such as wind, waves, and earthquakes.
The structural performance of a non-prestressed structure can be evaluated using the following formulation:

$$(SP)_{cnp} = \frac{\sum N_i}{\sum A_i}; \qquad (9)$$

Similarly, the structural performance of a prestressed structure can be evaluated using the following formulation:

$$(SP)_{cp} = \frac{\sum N_i}{\sum A_i} + \frac{\Delta N}{A_p} \qquad (10)$$

Type of Structure	Non-Prestressed	Prestressed	Performance difference
Concrete Oil Platform	K	1.25 K	+25 %
Wind Turbine Foundations	L	1.32 L	+32 %
Subsea Pipeline	N	1.40 N	+ 40 %

Table 5. Estimated Structural Performance comparison between non-prestressed and prestressed structures

The analysis revealed that prestressed structures have a higher load-carrying capacity and improved resistance to environmental loads, due to the additional compressive forces provided by the prestressing tendons. *(Table 5.)* This improved performance can result in a more resilient and reliable structure, particularly in harsh offshore environments.
The obtained values and rates of differences enable further simulation of the comparative analysis, demonstrating the significance of each of the previously mentioned structures.*(Fig.1).*

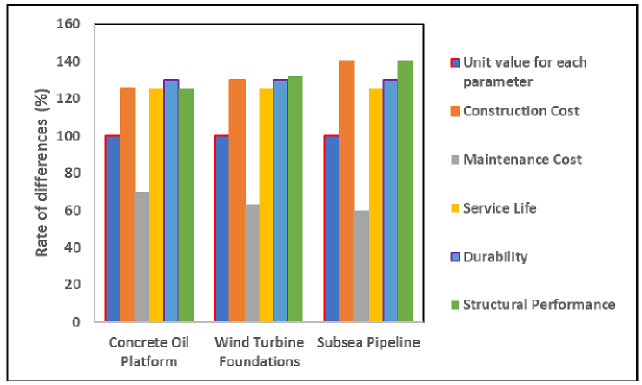

Fig.1. Performans differences due to prestress

CONCLUSIONS

This research compared prestressed and non-prestressed concrete structures for offshore applications, emphasizing on construction costs, maintenance costs, service life, durability, and structural performance. Although prestressed structures have a higher construction cost due to the additional materials and labor required for prestressing, the study's research results demonstrate that prestressed concrete structures have several advantages, including longer service life, lower maintenance cost, and superior durability. Moreover, prestressed structures have increased load bearing capacity and strength to environmental factors, resulting in a more reliable and durable offshore construction. The outcomes provide helpful guidelines for offshore engineers and decision-makers to effectively make decisions. It is suggested that these issues be addressed on a regular basis.

Symbols:

- C_{cnp} – Construction Cost (Non-Prestressed Structures);
- C_{cp} – Construction Cost (Prestressed Structures);
- C_p – cost of the prestressing process.
- M_{cnp} –Maintenance Cost (Non-Prestressed Structures);
- M_{cp} – Maintenance Cost (Prestressed Structures);
- O – Other costs;
- $(ESL)_{cnp}$ –Expected Service Life (Non-Prestressed Structures);
- $(ESL)_{cp}$ –Expected Service Life (Prestressed Structures);

- $(DB)_{cnp}$ −Durability (Non-Prestressed Structures);
- $(DB)_{cp}$ −Durability (Prestressed Structures);
- $(SP)_{cnp}$ − Structural Performance (Non-Prestressed Structures);
- $(SP)_{cp}$ − Structural Performance (Prestressed Structures);
- C_m − cost of maintenance and repair over the service life of the structure;
- C_u − cost of upgrades or replacements.
- S_r − savings from reduced maintenance
- V_C −Volumes of concrete;
- V_s −Volumes of steel reinforcement;
- V_f − Volumes of formwork;
- V_e − Volumes of other materials;
- p_c −prices of concrete;
- p_s −prices of steel reinforcement;
- p_f −prices of formwork;
- p_e −prices of other materials;
- t_p −design life of the structure;
- f_c −deterioration rates due to concrete;
- f_s −deterioration rates due to steel reinforcement;
- f_e − deterioration rates due to environmental factors;
- f_{c1} −factor for concrete cover;
- f_{s1} −factor for steel corrosion;
- f_{e1} − factor for environmental exposure;
- Δt −additional service life provided by prestressing;
- $\sum N_i$ −total load capacity of the structure;
- $\sum A_i$ −total cross-sectional area of the structure;
- ΔN − additional load capacity provided by prestressing;
- A_p − cross-sectional area of the prestressing tendons.
- $A, B, C, D, E, F, G, H, K, L, N$ − unit value indicator for suitable parameters

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