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Research paper

Analysis of Offshore Platform Structural Integrity Under Extreme Weather Conditions

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Abstract

Extreme weather patterns have caused damage and destruction all around the world in recent years, making climate change a more urgent concern. To comprehend the consequences of climate extremes for risk and resilience, new methods for evaluating their incidence, distribution, and dependency are needed. Risk and resilience assessment is a difficult work because of the complexity of climate systems, complex ecosystem-climatic interactions, interdependence of climate extremes, and predominant nonstationary. Furthermore, the risk posed by extreme weather events depends on a variety of factors, including exposure and vulnerability, in addition to the severity of the extremes themselves. Accurately estimating the likelihood of a hazardous physical event and how it interacts with exposure and susceptibility factors including population, infrastructure, environmental services, and economic assets are critical to risk reduction and climate change adaptation. Therefore, in order to further assess the implications for risk and resilience in the context of climate change, a deeper comprehension of the climate extremes in terms of their occurrence, dependency on various causes, dynamics, and predictability is required. The study conducted to provide a thorough evaluation of India's extreme weather conditions and their consequences for risk and resilience is presented in this thesis. The thesis's first section explains how nonlinearity and determinism have changed over the past century in India's temperature and precipitation profiles. A time series' nonlinear component can be quantified by comparing variance measures, which is what the Delay Vector Variance (DVV) approach is used for this inquiry. The findings demonstrate that temperature and precipitation both show significant nonlinearity and declining predictability, especially in the nation's most extreme climate zones.

Keywords: *Climate Change; Weather Conditions; Challenges; Integrity.*

1. Introduction

Finding discrepancies and holes in previous research was difficult in this thorough benchmark study, which was especially focused on enhancing ship structural component requirements [1]. With a focus on ship structural components, it uses finite element modelling and experimental investigations to synthesize the effects of several defect factors, such as crack length, angle, position, corrosion severity, pit corrosion, pit dimension, and pit models [2]. A significant resource for upcoming research and studies centered on ship structural strength and design, this review offers a comparative analysis of approaches and criteria [11]. To prevent structural breakdown, offshore platforms' structural integrity must be guaranteed [4]. An offshore platform's structural integrity may be impacted by two things [6]. They are too heavy and not strong enough [3]. Environmental, operational, and unintentional loads are the sources of the excessive loads. On the other hand, a design, manufacture, installation, operating, or degrading error could result in inadequate strength [8].

Fig. 1: Offshore Platform Construction.

Wave Load and Fatigue Analysis:

This section reviews wave load modeling techniques, fatigue damage mechanisms, and their relevance to offshore platform structural performance. The interaction between wave energy and wave-induced ship reactions, which embrace ship motion and load distribution, can be appreciated by determining the energy spectrum of a wave system [12]. The most widely applied method in determining structural load in the frequency-domain approach is a technique that is widely used for fatigue analysis. Spectral fatigue analysis is a statistical process that utilizes strip theory approximations and dynamic loading techniques [10]. To determine fatigue damage, the Palmgren-Miner cumulative damage rule is generally used in combination with S-N curves for material, structural details, and welded joints after the stress distribution has been established [5].

The model is compared with full-scale measurements or experimental data and calibrated for reliable predictions of fatigue life under operating conditions of interest [15].

2. Review of literature

A 5500 TEU container ship's wave loads and structural stresses were investigated by Sun et al. They acquired Response Amplitude Operators (RAOs) for the middle section at different angles, maximum loads and motions, motion amplitudes in regular waves of unit amplitude, and load conversion functions. Applying spectrum theory, they used long-term wave loads and compared them with values derived in classification rules. According to reports, the largest vertical bending moment occurred between 103 and 162 meters from the after perpendicular, according to the finite element study performed with ANSYS software [13].

Fig. 2: Examples of Extreme Storm Impacts on Coastal and Offshore Petroleum Infrastructure.

In order to comply with classification rule criteria, their research describes a technique for predicting wave loads and stresses.

A comparison of modeling approaches highlights their respective advantages and limitations. In contrast, Folso and Dogliani's [7] probabilistic modeling incorporates stochastic sea-state conditions, enabling more comprehensive fatigue life estimation under realistic operational scenarios. Sun et al. [13] employed finite element modeling to capture detailed structural responses to wave-induced loads. While this method provides precise insights into localized stresses, it may not account for environmental variability Furthermore, wave load characterization benefits from both first- and second-order wave theories. First-order linear wave theory provides suitable approximations for moderate sea states, whereas second-order nonlinear theory, as discussed by Alizadeh et al. [9], offers enhanced accuracy under extreme conditions by capturing nonlinear wave effects. Classic formulations such as the Pierson-Moskowitz spectrum remain foundational for simulating fully developed seas.

3. Materials and methods

They are obtained as irregular waves are decomposed with the application of Fourier analysis. One of several idealized formulations that are intended to closely resemble actual sea conditions can then be used to model the wave spectrum. While some of these formulations are grounded in real research data, others are solely mathematical.

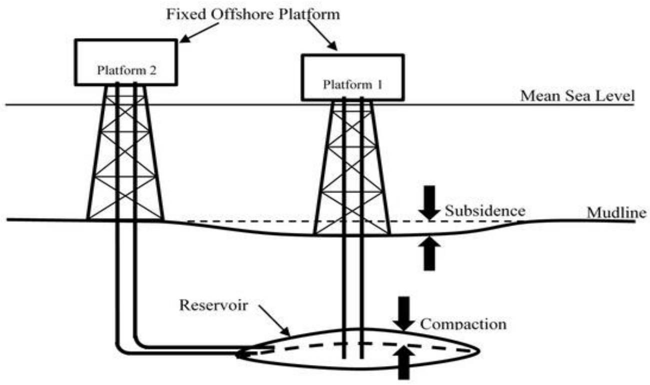

Fig. 3: Offshore Platform with and without Subsidence.

The reservoir may become compacted as a result of subsidence brought on by its depletion. As reservoir depletion increases, compaction will also rise. Over time, this will cause a surface subsidence. Figure Platform 1 represents the offshore structures with sinking, while Platform 2 represents the structures without subsidence [14].

This further makes wave prediction complex, as it allows more realistic wave profiles, like ocean waves with more gradual troughs and steeper crests, to be simulated. The accuracy given by second-order wave theory renders it most helpful in crucial circumstances, as it is able to model nonlinear effects [18].

4. Results and discussion

Extreme weather events, particularly tropical cyclones, represent a significant hazard to offshore platform stability due to intense wave action, high wind loads, and storm surges. Studies such as Alizadeh et al. [9] have highlighted that cyclone-induced wave loads can accelerate structural fatigue and compromise platform integrity. Understanding how these loads interact with offshore structures is critical for risk assessment and design optimization.

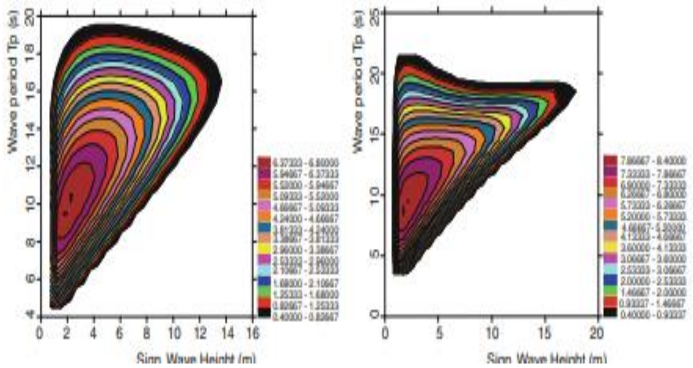

Fig. 4: Spectral Wave Period and SWH Joint Probability Densities That Were Fitted.

Climate Extremes and Structural Impacts:

This section examines how extreme weather events, particularly cyclones, generate environmental loads that affect the structural integrity of offshore platforms. Compared to other climate extremes or natural disasters, tropical cyclones pose a far greater risk. Historical data indicate that the Bay of Bengal and Arabian Sea experience approximately 5–6 significant cyclonic events annually, with wave heights exceeding 10 meters during severe storms [19]. Figure 4 presents spectral wave period distributions and significant wave heights under cyclone conditions, revealing elevated energy concentrations at critical frequencies. Such increases in environmental loading significantly reduce fatigue life and can compromise platform stability, highlighting the need for robust structural design and effective risk mitigation strategies.

Cyclonic disturbances continue to cause massive losses in terms of life and property, as well as far-reaching social and economic repercussions due to extremely violent winds, heavy and concentrated rainfall, and storm surge that result in widespread flooding and high floods.

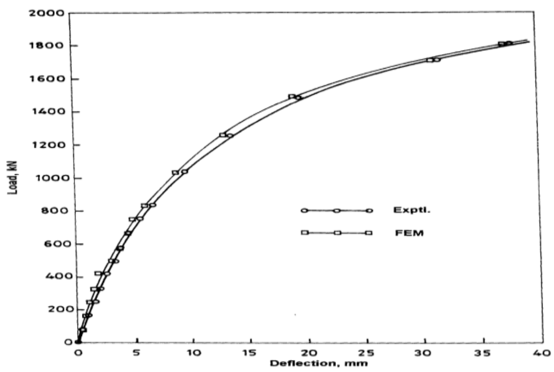

Fig. 5: Deflection Curve.

Figure 5 shows the deflection curve of the offshore platform under wave-induced loads, illustrating the platform's vulnerability to bending moments and structural deformation. All activities pertaining to prevention, readiness, and relief are referred to as disaster management. In the context of cyclones, prevention refers to the application of long-term structural measures to lower the seventy percent of damage to property and human life. In order to confine the rides and store the floodwater, the structural methods include coastal afforestation engineering structures such as dykes, embankments, storage reservoirs, etc. Physical planning, enforcement of building codes for cyclone proofing of structures, land use legislation, taxation, insurance, education, and training are some of the tools used to accomplish this goal. Non-structural measures are actions taken to direct human habitation and development projects away from cyclone-prone areas. Forecasting, warning, and timely warning distribution to all parties involved are all part of preparedness. Vulnerable populations are educated and trained to elicit appropriate responses, and disaster situations are organized and managed, including the use of operational plans, training relief organizations, stockpiling supplies, and allocating necessary funds. While preparedness assumes that some disasters are inevitable and plans for the necessary action, disaster prevention aims to lessen the severity of disasters or even completely prevent them wherever possible.

Disaster Management Strategies

This section outlines engineering and non-engineering approaches to mitigate risks posed by climate-induced extreme loads on offshore platforms.

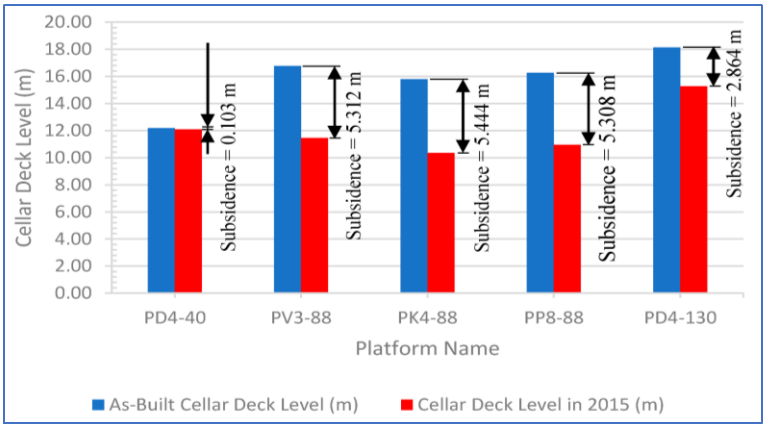

Fig. 6: Platform Subsidence.

Figure 6 depicts platform subsidence resulting from reservoir depletion, emphasizing the critical need for subsidence mitigation measures in structural design. Wind and storms are two of the main causes of structural damage to buildings and infrastructure. The surfaces of a structure are compressed by strong winds, which puts stress on the building's constituent parts. A building may experience uplift, lateral movement, and even structural failure if it is not sufficiently constructed to withstand wind. In addition to warming the upper atmosphere through compression, the sinking of air in the "high" allows more heat from the sun's rays to be absorbed in the layer of air close to the ground. The frequency of a strong upper air temperature inversion is another factor contributing to heat waves. There are instances where the horizontal wind component prevents heat from diffusing. If that is the case, it should be carried to higher levels by vertical currents. If there is a significant upper air temperature inversion, then vertical heat energy transmission will also be stopped. Heat waves, while primarily a terrestrial concern, indirectly contribute to offshore structural risks by intensifying atmospheric instability and generating strong wind events. These high wind speeds subject offshore platforms to additional lateral and uplift loads, increasing the likelihood of fatigue damage or structural failure if not adequately accounted for during the design phase [16].

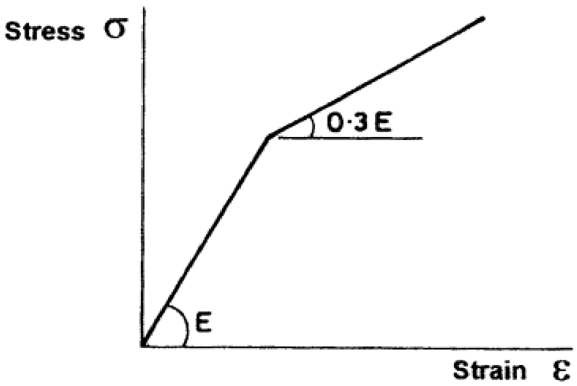

Fig. 7: Proposed Analytical Model.

With a maximum temperature of 12°C, this heat wave was more severe and lasted for seven days. On May 20, temperatures reached a maximum of 47°C with an intensity of 12°C. At Visakhapatnam, the highest departure is observed. In the summer of 1998, India was hit by yet another extreme heat wave. From 26" May to 6"^June, this hot weather lasted for 12 days. On T' June, the highest recorded temperatures ranged from 44°C to 50°C. In Andhra Pradesh, this ongoing extreme heat wave resulted in 943 heat-related deaths, while many more, particularly the elderly, suffered from heat exhaustion and heat stroke. June 2003 was another recent period of extreme temperatures. The highest temperature recorded in Visakhapatnam was 52.6°C, while numerous other stations recorded temperatures above 45°C. The heat ranges from 6°C to 12°C, with Visakhapatnam recording the highest intensity. Many individuals died during this five-day heat wave. On 4.6.2003, Andhra Pradesh saw a severe heat wave with temperatures as high as 12°C, which claimed numerous lives.

Fig. 8: Wave Crest Height at Collapse and Bottom Steel Height Comparison.

It is believed that the random variables are uncorrelated and independent. There is an exponential distribution in the failure time and the time to weather change. The distributions of repair and inspection times, however, are seen as arbitrary. The repairs and switch devices are flawless. The regenerating point technique is used to construct the expressions for a number of system effectiveness metrics, including mean sojourn times, mean time to system failure (MTSF), availability, the server's busy period, the anticipated number of server visits, and, lastly, the profit function. The numerical results for a specific scenario are assessed in order to graphically depict the models' profit and MTSF behaviour.

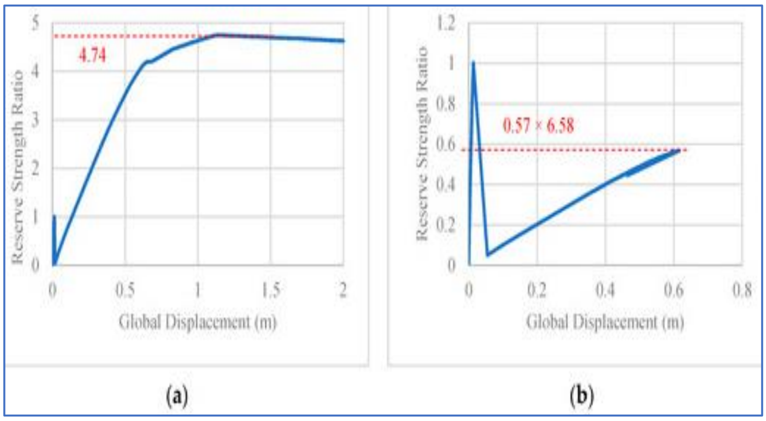

Fig. 9: Global Load Versus Global Displacement for PK4-88: (a) PK4-88: Without Wave-in-Deck Load; (b) PK4-88: with Wave-In-Deck Load.

Figure 9 compares global displacement of the platform with and without wave-in-deck loads, demonstrating the significant impact of extreme wave interactions on structural behavior and overall stability. There are uncomfortable conditions throughout the state during the summer, which is symbolized by the month of May. Heat waves and high temperatures are common throughout this season, particularly in central Andhra Pradesh. During the summer, heat exhaustion and heat stroke are prevalent health issues. In Andhra Pradesh, the 1998 summer crisis heat wave resulted in several heat-related fatalities. The monsoon circulations lower the strain values during the wet season. The strain values range from a state of distress over the rest of the state to poor comfort along Western Andhra Pradesh. excessive temperatures combined with excessive humidity levels are the cause of this discomfort. Following the monsoon's withdrawal, the state as a whole experiences truly agreeable winter weather. Figure 5.6 shows that the strain values have decreased. Conditions are generally rather comfortable throughout the State. Since the weather seems to be perfect for human comfort during this time of year, there is a lot of outdoor activities, and tourists find it to be enjoyable.

5. Conclusion

This section summarizes key findings and proposes future research to enhance offshore platform resilience under extreme weather conditions. Future research should prioritize the development of advanced materials with enhanced fatigue and corrosion resistance to extend offshore platform service life under extreme environmental conditions. Additionally, integrating real-time structural health monitoring systems and predictive wave modeling can significantly improve safety and operational efficiency. Recent advances in machine learning techniques, such as those applied by Muralidharan [17] for anomaly detection, present promising avenues for enhancing wave forecasting and early warning systems. These tools can support proactive maintenance and risk-informed design, strengthening offshore platform resilience in the face of intensifying climate-driven ocean hazards.

References

[1] Hamedani, S. J., & Khedmati, M. R. (2023). Optimal weather window for transportation of large-scale offshore structures. *Marine Structures, 92*, 103483. https://doi.org/10.1016/j.marstruc.2023.103483.

[2] Tan, W., Sarmiento, J., & Rosales, C. A. (2024). Exploring the performance impact of neural network optimization on energy analysis of biosensor. *Natural and Engineering Sciences, 9*(2), 164–183. https://doi.org/10.28978/nesciences.1569280.

[3] El-Reedy, M. A. (2019). *Offshore structures: Design, construction and maintenance*. Gulf Professional Publishing.

[4] Shin, S. J., Park, Y., & Shin, S. U. (2024). Decentralized fair data trading scheme based on mCL-ME primitive. *Journal of Internet Services and Information Security, 14*(4), 569–589. https://doi.org/10.58346/JISIS.2024.I4.036.
[5] Klavin, C. (2024). Analysing antennas with artificial electromagnetic structures for advanced performance in communication system architectures. National Journal of Antennas and Propagation, 6(1), 23–30. https://doi.org/10.31838/NJAP/06.01.04.
[6] Chakma, K. S. (2025). Flexible and wearable electronics: Innovations, challenges, and future prospects. Progress in Electronics and Communication Engineering, 2(2), 41–46.
[7] Piva, R., Latronico, M., Nero, A., & Sartirana, S. (2013). Managing structural integrity of offshore platforms: Looking back to drive the future. In *International Petroleum Technology Conference* (pp. IPTC-16432). IPTC. https://doi.org/10.2523/IPTC-16432-MS.
[8] Spandan, G., & Theerthagiri, P. (2024). Neural machine translation model using GRU with hybrid attention mechanism for English to Kannada language. *Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications, 15*(4), 259–276. https://doi.org/10.58346/JOWUA.2024.I4.017.
[9] Alizadeh, A., Daghigh, M., Bali, M., Golpour, H., & Kazeminezhad, M. H. (2024). A framework for implementing structural integrity management of an aging fixed offshore platform using wave modeling for risk-based underwater inspection provision. *Ocean Engineering, 309*, 118368. https://doi.org/10.1016/j.oceaneng.2024.118368.
[10] Pius, A. C., & Velmurugan, R. (2024). A study on problems in the insurance repository system in India. *Indian Journal of Information Sources and Services, 14*(4), 73–78. https://doi.org/10.51983/ijiss-2024.14.4.12.
[11] Hajinezhadian, M., & Behnam, B. (2024). A corrosion-and repair-based reliability framework for offshore platforms. *Journal of Marine Science and Engineering, 12*(3), 504. https://doi.org/10.3390/jmse12030504.
[12] Nelson, J., Dyer, A. S., Romeo, L. F., Wenzlick, M. Z., Zaengle, D., Duran, R., Sabbatino, M., et al. (2021). *Evaluating offshore infrastructure integrity* (No. DOE/NETL-2021/2643). National Energy Technology Laboratory (NETL). https://doi.org/10.2172/1780656.
[13] Allahveranov, N. (2021). Structural integrity monitoring: Review of the last 10 years of technological development for offshore oil & gas platforms.
[14] Idichandy, V. G., & Ganapathy, C. (1990). Modal parameters for structural integrity monitoring of fixed offshore platforms. *Experimental Mechanics, 30*, 382–391. https://doi.org/10.1007/BF02321509.
[15] Bucelli, M., Landucci, G., Haugen, S., Paltrinieri, N., & Cozzani, V. (2018). Assessment of safety barriers for the prevention of cascading events in oil and gas offshore installations operating in harsh environment. *Ocean Engineering, 158*, 171–185. https://doi.org/10.1016/j.oceaneng.2018.02.046.
[16] Booch, K., Wehrmeister, L. H., & Parizi, P. (2025). Ultra-low latency communication in wireless sensor networks: Optimized embedded system design. SCCTS Journal of Embedded Systems Design and Applications, 2(1), 36–42.
[17] Muralidharan, J. (2024). Machine learning techniques for anomaly detection in smart IoT sensor networks. Journal of Wireless Sensor Networks and IoT, 1(1), 15-22. https://doi.org/10.31838/WSNIOT/01.01.03.
[18] Rahim, R. (2025). AI-Driven Fault Diagnosis in Three-Phase Induction Motors Using Vibration and Thermal Data. National Journal of Electrical Machines & Power Conversion, 21-28.
[19] Kadhim, R. R., & Shiker, M. A. (2024). Finding the least time and lowest cost to build residential complexes using the simplex method. Results in Nonlinear Analysis, 7(4), 163-169.