11th LIS International Conference
Liga Ilmu Serantau 2025

ISSN: 2985-4393

A Comparative Analysis of Conventional and Meshless Methods for the Design Verification of a Water Injection Bullhead Pump Offshore Skid

M.R. Lias[1,2 a)], N. Arshad[2, b)] and Zaini A[1, c)]

[1]*Centre of Chemical Technology (ChemTech), Petrochemical Engineering Department*
Tun Syed Nasir Syed Ismail Polytechnic Hab Pendidikan Tinggi Pagoh, KM 1,
Jln Panchor, Panchor, 84600 Pagoh, Johor, Malaysia

[2]*Skidtech Engineering Sdn Bhd (1475030-M)*
21, Lorong Seri Gambut 2, Techno Industrial Park, 41000 Klang, Selangor.Malaysia

[a)] *Corresponding author: rizal@ptsn.edu.my*
[b)] *norizal@skidtechengineering.com*
[c)] *zaini@ptsn.edu.my*

Abstract. The structural integrity of portable offshore units is critical for ensuring safety and operational reliability in harsh marine environments. Stringent design verification according to standards like DNVGL-ST-E273 is therefore mandatory. While traditional verification methods are well-established, their inherent conservatism may lead to over-engineering. This paper presents a comparative structural verification of a water injection bullhead pump skid using two distinct approaches: a conventional spreadsheet-based calculation based on the OffCon DNV 2006 tool and a modern meshless analysis conducted with Altair Simsolid. The analysis was performed in accordance with the DNVGL-ST-E273 standard. Both methodologies successfully confirmed that the skid's structural design, including padeye strength and overall frame deflection, meets all required safety criteria. However, the results revealed a significant variance in conservatism; the traditional spreadsheet method yielded stress and deflection predictions that were approximately 25% more conservative than those from the high-fidelity meshless analysis. The findings validate the skid's fitness for service while also demonstrating that advanced meshless methods can provide a more precise and less conservative assessment than traditional techniques. This suggests a significant potential for optimizing future designs by reducing material usage and weight without compromising safety, highlighting the evolving role of high-fidelity simulation in modern engineering.

Keywords: Offshore Skid, Meshless Method, DNVGL-ST-E273, Design Verification, Structural Analysis, Pump.

1. Introduction

The oil and gas industry operate in some of the most demanding environments on Earth. Offshore platforms and marine vessels are subjected to relentless forces, including severe weather, corrosive saltwater, and extreme operational loads. Consequently, the safety and reliability of all equipment deployed in these settings are of paramount importance. A single structural failure can lead to catastrophic consequences, including environmental disaster, significant financial loss, and, most critically, loss of life. To mitigate these risks, the industry relies on a robust framework of standards and verification processes governed by classification societies like DNV (Det Norske Veritas).

All portable offshore units (POUs), such as equipment skids, containers, and temporary modules, must undergo rigorous structural verification before they are deemed "fit for service." This verification ensures that the unit can withstand all anticipated loads during its lifecycle, from fabrication and lifting to transport and operation. This paper focuses on the structural verification of a critical piece of equipment: a water injection bullhead pump skid. These pumps play a vital role in secondary oil recovery by injecting water into reservoirs to maintain pressure and enhance extraction.

The verification of this pump skid is conducted according to the DNVGL-ST-E273 – Portable Offshore Units standard. To provide a comprehensive analysis, this study employs and compares two distinct methodologies [1]:

1. A Traditional Spreadsheet Method: Based on the OffCon DNV 2006 calculation tool, which uses established engineering formulas and beam theory. This approach is widely accepted and known for its inherent conservatism.
2. A Modern Meshless Analysis Method: Utilizing Altair SimSolid, a next-generation structural analysis software that operates directly on CAD geometry without the need for traditional mesh generation. This method promises faster results and higher fidelity for complex geometries.

The primary objective of this paper is to perform a complete structural verification of the water injection bullhead pump offshore skid such as shown in Figure 1, compare the outcomes of the traditional and meshless methods, and ultimately confirm the design's compliance with DNV standards. This comparative analysis will also shed light on the evolving landscape of engineering simulation tools and their role in modern design verification.

Figure 1. Water Injection Bullhead Pump Offshore Skid

2. THE DNVGL-ST-E273 STANDARD

The DNVGL-ST-E273 standard sets the benchmark for the design, manufacturing, and testing of portable offshore units. Its purpose is to ensure that such units are designed to be safe for all personnel and to avoid damage to the unit, other installations, and the environment. The standard provides a detailed framework for calculating design loads and defines the acceptance criteria for structural integrity. Key requirements stipulated by DNVGL-ST-E273 includes [1]:

a) Load Cases: The structure must be analyzed for a minimum set of load scenarios, primarily lifting and transport.
    - Lifting: The analysis must account for the unit's gross mass, the geometry of the lifting sling set, and a Dynamic Amplification Factor (DAF) to simulate the dynamic effects of being lifted by a crane. The standard typically specifies a DAF of 2.0.
    - Transport: The analysis must consider inertial loads due to vessel motion (heaving, pitching, rolling) and impacts. These are represented by applying accelerations in three orthogonal axes (vertical, transverse, and longitudinal).

b) Material Requirements: The standard specifies minimum requirements for materials, including yield strength, toughness at low temperatures, and weldability. For this analysis, S355 grade structural steel is used, which is common for offshore applications.

c) Acceptance Criteria: The structural integrity is assessed by comparing the calculated stresses against the material's allowable stress. This is often expressed as a Unity Check (UC) or Safety Factor (SF) for the verification status of the skid,

$$\sigma_{vm} \leq 0.85\, \sigma_{Re}$$

Where,
σ_{vm} = Von misses Henchy stress
σ_{Re} = Allowable material yield stress

For a design to be considered safe, the SF must be $SF \geq 3$. The allowable stress is typically a fraction of the material's minimum yield strength, adjusted by a material factor given by the specification from standard [1]. This is the main key factor to the definition of DNV unit's compliance and suitability for offshore operations.

2.1 Traditional vs. Modern Analysis Techniques

For decades, structural verification has been performed using hand calculations, spreadsheets, and traditional Finite Element Analysis (FEA) [2]. Spreadsheet methods, like the OffCon tool used in this study, are based on simplified models (e.g., beam theory) and are excellent for standard geometries [3]. They are transparent and computationally inexpensive but often introduce significant conservatism to account for modeling uncertainties. Traditional FEA improved upon this by allowing for more detailed 3D analysis, but it comes with its own major bottleneck: mesh generation. Creating a high-quality computational mesh for a complex assembly can be extremely time-consuming and requires significant user expertise.

Meshless methods, as implemented in software like Altair SimSolid, represent the next evolution. They eliminate the meshing step, analysing the original, un-simplified CAD geometry directly. This dramatically reduces pre-processing time and makes analysis more accessible. The underlying technology uses approximations on a system of particles or nodes without connecting them into a mesh, which is particularly effective at handling complex contacts and geometric imperfections that are difficult to mesh [4]. This study investigates whether this modern approach provides reliable results consistent with established industry practices.

3. RESEARCH METHODOLOGY

The structural analysis and verification of the water injection bullhead pump skid were conducted using two distinct methodologies to provide a comprehensive assessment and comparative insight into their respective capabilities and verification.

The first method is calculation based on Conventional Spreadsheet (OffCon DNV 2006). This verification method employed a conventional spreadsheet-based calculation, drawing extensively from the principles and formulas outlined in DNV 2.7-3 (the predecessor to DNVGL-ST-E273), often facilitated by tools like OffCon DNV 2006. This approach represents a "design by code" or simplified analytical method, where structural components are analyzed using established engineering formulas and empirical data, often incorporating inherent safety factors, details calculation and equation given from the spreadsheet can be referred to the report[5]. The Acceptance Criteria of calculated stresses, deflections, and buckling resistances were compared against the allowable limits specified in DNVGL-ST-E273, which typically include material yield strength, ultimate tensile strength, and buckling capacities, all factored by appropriate safety coefficients. The OffCon DNV 2006 spreadsheet, or similar internal tools based on the standard, automates many of these calculations, providing a systematic way to apply the DNVGL-ST-E273 formulas and check for compliance. This method is generally efficient for preliminary design and simpler geometries but can be conservative due to its reliance on simplified models and worst-case assumptions.

The second methodologies employed verification method involved a modern meshless analysis, performed using advanced numerical simulation software from Altair Engineering known as SimSolid. General equation to the method is governed such as details showed in references given [6]. This software solvers use finite element methods (FEM) which are meshless or often refers to advanced numerical techniques that reduce or eliminate the need for traditional, structured mesh generation, allowing for more flexible and accurate modeling of complex geometries and contact conditions. For the purpose of this paper, it implies a highly detailed and sophisticated numerical simulation.

3.1. Design Data of Water Injection Bullhead Pump Offshore Skid

The water injection bullhead pump skid is a purpose-built portable offshore unit designed to house a high-pressure water injection pump with valves, control systems, and ancillary equipment. The skid structure itself is a robust steel frame, approximately 4531mm x 2150mm x 1483mm length, width, and height, with an estimated gross weight of 5.749 tonnes when fully equipped. Its primary function is to deliver high-pressure water for reservoir pressure maintenance or waterflooding operations on offshore platforms or vessels. The design incorporates dedicated lifting points (pad eyes) for offshore handling and sea-fastening points for secure transportation such as shown in Table 1.

Table 1: Technical Data of the Skid Structure

Parameters	**Exact Value**
Design Temperature	65º C
Design Pressure	2495 psi @ 172 bar
Overall Dimension, L x W x H	4531mm x 2150mm x 1483mm
Center of Gravity, COG	X2423mm, Y1171mm, Z661mm
MGW (Actual)	5749 kg
Design reference	DNVGL ST E273
POU type	B
Classification	DNV 2.7-3

The 3D CAD Model Generation with high-fidelity model of the entire water injection bullhead pump skid, including all structural members, stiffeners, equipment mounting points, and lifting pad eyes, was created. This model accurately represented the geometry and connections. Detailed material properties (e.g., Young's Modulus, Poisson's Ratio, yield strength, ultimate tensile strength) for the steel grades used in the skid construction were input into the software parametric description. The model is then welded and prepared for the post-processing calculation such as showed in figure 2 (a) front panel welded preparation, (b) side panel welded preparation.

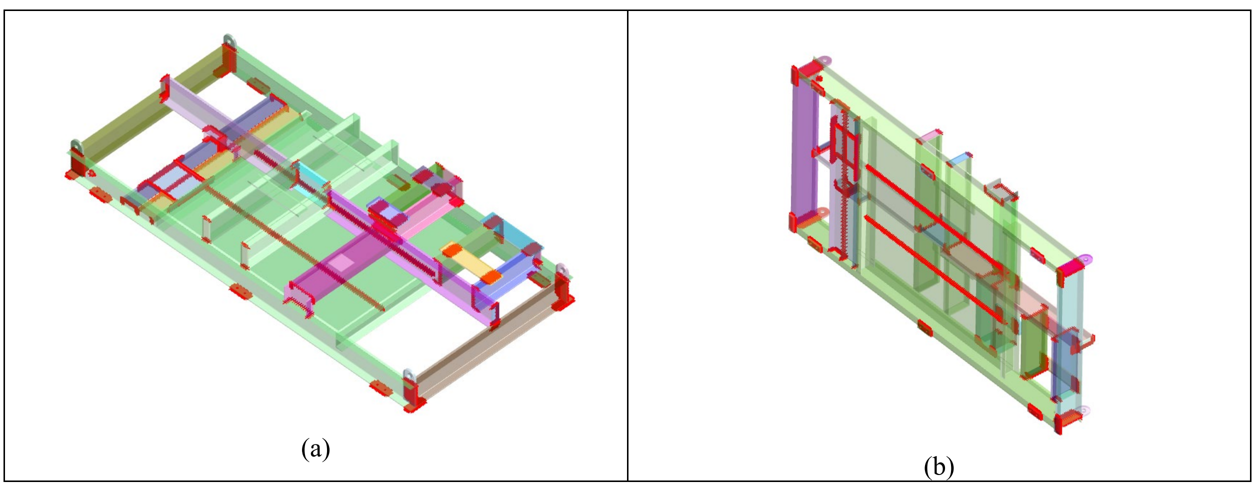

Figure 2. CAD pre-post-processing calculation for Skid Structure (a) front panel welded preparation, (b) side panel welded preparation.

Appropriate boundary conditions were applied to simulate the real operational scenarios in offshore conditions. For lifting analyses, constraints were applied at the lifting points, allowing for realistic load transfer. For sea transport, the skid was constrained at its pad eye points, and accelerations were applied to simulate the possible swaying of the pump's motions during lifting. Details of the load application are shown in Figure 3. Main equipment is represented in load form with their gross weight as specified according to the standard. This means that, during the transport case, the base of the skid was constrained, and the inertial accelerations were applied to the entire model's mass.

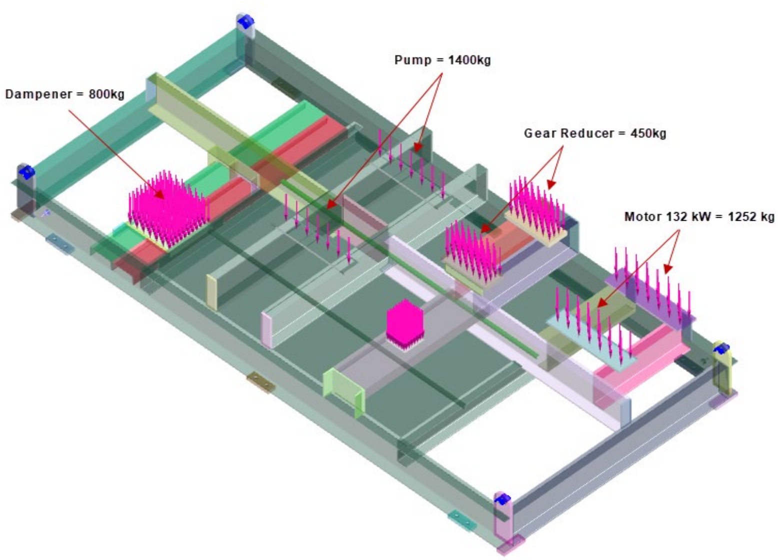

Figure 3. Details of the load condition with applied boundary condition for skid structure

4. Results and discussions

As per objectives of this study to verify a conventional spreadsheet-based calculation (OffCon DNV 2006) and a modern meshless, the main result is presented in Table 2. Results of analytical calculation can be referred to the technical report [5]. FEM meshless analysis was conducted using Simsolid software. Final results of Von misses' equivalence stress were extracted and compared to the design allowable stress according to DNV GL ST 273 [1].

Table 1: Results extracted from Offcon DNV 2006 and meshless FEM analysis

Type of Skid Integrity Analysis	Design Structural Integrity (MPa) ($\sigma_{vm} \leq 0.85\ \sigma_{Re}$)	Allowable Deflection (mm) $\frac{I_n}{250}$	Verification Status ($SF \geq 3$)
Analytical Calculation (Offcon DNV 2006)-			
Padeye strength	$70.01 \leq 234$	-	Highly Safe
Structure Strength Response	$60.96 \leq 234$	-	Highly Safe
Padeye Maximum Deflections	-	$0.04 \leq 20.12$	Highly Safe
Structure Maximum Deflections	-	$2.10 \leq 20.12$	Highly Safe
Meshless FEM analysis			
Padeye strength	$55.56 \leq 234$	-	Highly Safe
Structure Strength Response	$55.08 \leq 234$	-	Highly Safe
Padeye Maximum Deflections	-	$0.026 \leq 20.12$	Highly Safe

Structure Maximum Deflections	-	2.06 ≤ 20.12	Highly Safe

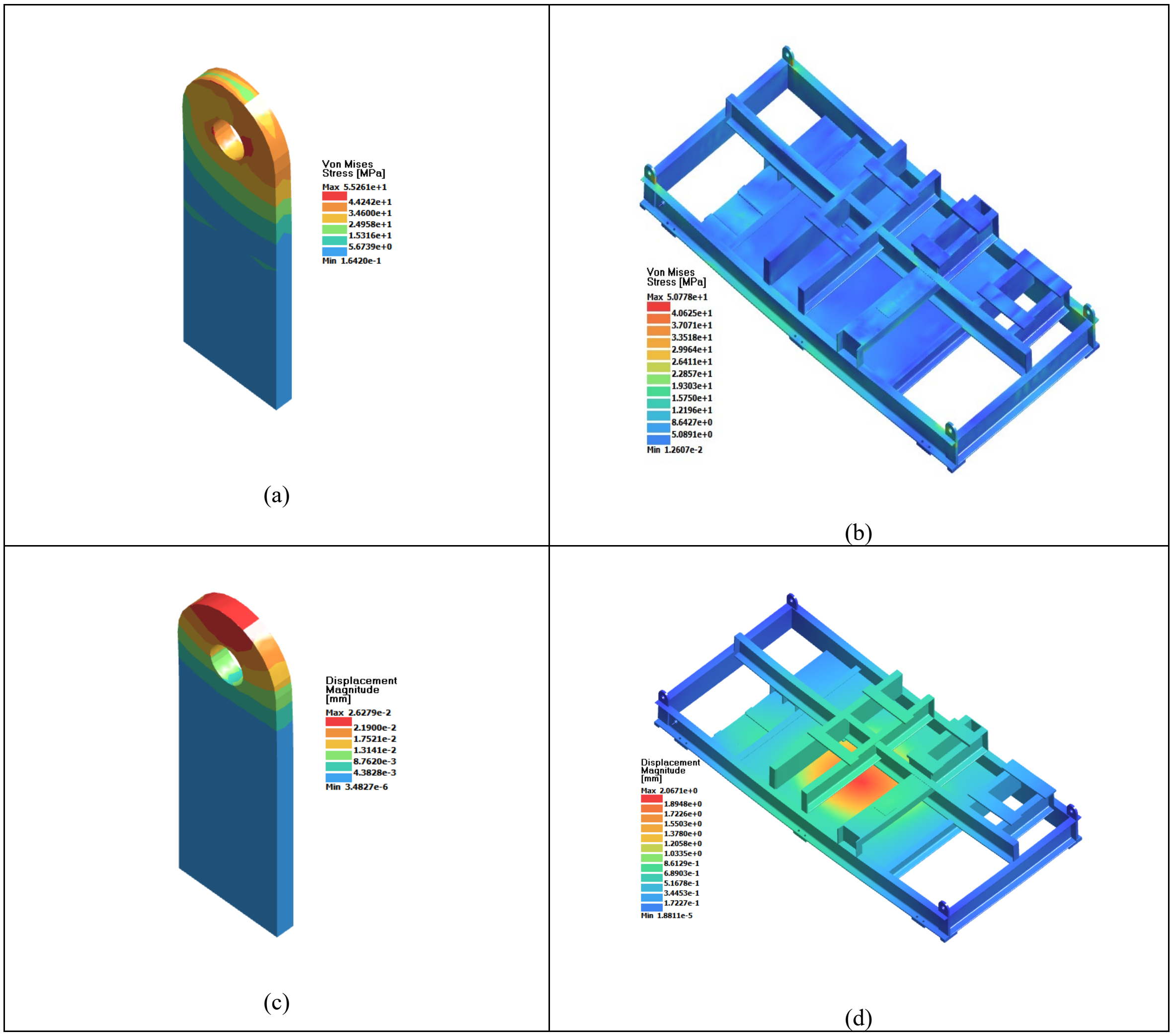

Figure 4. Result from FEM meshless analysis (a) Skid Padeye strength, (b) Skid Structure Strength Response (c) Skid Padeye Maximum Deflections (d) Skid Structure Maximum Deflections

In Figure 4, the results from the FEM meshless analysis are shown, based on four main criteria: (a) Skid Padeye Strength, (b) Skid Structure Strength Response, (c) Skid Padeye Maximum Deflections, and (d) Skid Structure Maximum Deflections. The first two responses, (a) and (b), showed a maximum stress of 55.261 MPa for the padeye and 50.77 MPa for the structure. Both responses are below the allowable design criteria, $\sigma_{vm} \leq 0.85\ \sigma_{Re}$ set by DNVGL-ST-E273. In Figure 4, (c) and (d) show the maximum displacement plotted as 0.026 mm for the padeye and 2.05 mm for the main structure. The results justify that all skid frame members are elastic enough to bend and capable of handling the specified loading conditions as defined in the design standard, $\frac{l_n}{250}$.

It is well known that analytical calculations, based on a spreadsheet method like the OffCon DNV 2006, represents a classical engineering approach. This method relies on simplified formulas based on simply supported beam theory and conservative assumptions to provide a quick, reliable assessment of a structure's capacity [7] , not represent the real case of loading condition . It essentially applies a large factor of safety to account for uncertainties in material properties, load application, and the geometric complexities of the design. This conservative nature is precisely why the spreadsheet method yielded results that were 25% more conservative than the meshless analysis. While highly effective for initial design checks and providing a safe, robust validation, this conservatism can sometimes lead to over-engineering, where components are stronger and heavier than strictly necessary.

.

Conversely, the meshless FEM analysis represents a more advanced, computationally intensive approach, it is much more reflect to the real working condition [8]. Unlike traditional FEM, which requires the structure to be broken down into a complex mesh of elements, this method uses a set of nodes to approximate the solution, making it particularly well-suited for handling intricate geometries and predicting complex stress patterns without the risk of mesh distortion. This capability allows for a more accurate and realistic simulation of the skid's behavior under load. The less conservative results from the meshless analysis are not an indication of a less safe design, but rather a reflection of its superior precision. It can provide a more accurate representation of the actual stresses and deflections, allowing engineers to operate closer to the design's true capacity while still remaining well within safety limits.

Both the conventional and meshless methods confirmed that the skid design is safe and meets DNVGL-ST-E273 standards. However, a significant finding is the 25% difference in the conservatism of the results. The analytical calculation, which is based on simplified formulas and conservative assumptions, yielded higher stress values (e.g., 70.1 MPa for pad eye strength) compared to the more precise meshless FEM analysis (55.6 MPa). This difference highlights the trade-off between the speed and simplicity of traditional methods and the accuracy and optimization potential of modern computational tools. While both methods are valid, the meshless approach allows for a more accurate representation of actual stress and deflection, potentially leading to a more optimized design without compromising safety.

The analytical calculation offered a quick and reassuringly conservative baseline, while the meshless FEM analysis provided a high-fidelity, precise confirmation of the design. The difference in their results underscores a crucial trade-off: the speed and simplicity of traditional methods versus the accuracy and optimization potential of modern computational tools. For a final design verification, this dual-methodology approach offers a comprehensive and highly confident assessment of the skid's fitness for service.

5. Conclusion

This study successfully demonstrated the structural integrity and fitness for service of a water injection bullhead pump skid through a comprehensive verification process. The design was rigorously evaluated against the stringent DNVGL-ST-E273 standard, a critical benchmark for offshore units, employing two distinct analytical methodologies. The convergence of results from both the traditional spreadsheet-based calculation and the advanced meshless analysis provides a robust validation of the skid's design. This dual-method approach not only confirms the structure's compliance with all specified safety requirements but also underscores the reliability of both conservative and modern analytical techniques in parallel.

The comparative analysis between the two methods revealed a notable distinction: the conventional spreadsheet model produced results that were approximately 25% more conservative than those from the meshless analysis. This finding is significant, as it highlights the potential for modern, high-fidelity simulation methods to offer more precise assessments of structural behavior. While traditional methods like the OffCon DNV 2006 spreadsheet are proven and reliable, they often incorporate larger safety factors that can lead to over-engineering. The less conservative, yet still compliant, results from the meshless analysis suggest an opportunity for future design optimization, potentially reducing material usage and weight without compromising safety. In summary, the successful verification of the offshore skid confirms its readiness for deployment in demanding marine and offshore environments, while also validating the role of contemporary analytical tools in enhancing the efficiency and accuracy of structural engineering design.

Acknowledgments

The authors would like to acknowledge Politeknik Tun Syed Nasir Syed Ismail, Centre of Chemical Technology for their approval to conduct and complete this project. We are also grateful to Skidtech Engineering Sdn Bhd for their invaluable technical consultancy and financial support, both of which significantly contributed to the robustness of our findings. Finally, we thank the reviewers for their constructive feedback, which greatly improved the clarity and quality of this paper.

References

List all sources cited in the paper using the required citation style (IEEE).

[1] DNVGL, *DNVGL-ST-E273: Portable offshore units*, Dec. 2016, with amendments May 2022. [Online]. Available: https://www.dnv.com/energy/standards-guidelines/dnv-st-e273-2-7-3-portable-offshore-unit.

[2] S. Kamarul, "Comparative Study Of Different Structure Analysis Methods," *Malaysian Journal of Civil Engineering*, vol. 32, no. 1, pp. 24–35, 2020.

[3] J. Uziak, "Spreadsheet application in beam bending calculations," *World Transactions on Engineering and Technology Education*, vol. 12, no. 3, pp. 319-328, 2014.

[4] G. R. Liu and Y. T. Gu, An Introduction to Meshfree Methods and Their Application in Solid Mechanics. *Singapore: World Scientific*, 2005.

[5] M. R. Lias, "Technical Note, Skid Structures Water Injection Bullhead Pump Unit (Tag No.: P-4070)," *Skidtech Engineering & Consultant*, Rep. no. PDC220000023, Jul. 2023

[6] Altair Engineering, "SimSolid Theoretical Background," Help Document, 2021. [Online].
Available:https://2021.help.altair.com/2021/ss/topics/simsolid/get%20started/background_theoretical_r.htm.

[7] C. Kim and S. B. Choi, "A Study on Structural Strength Assessment Methods of Topside Structures on the Offshore Platform," *Journal of the Society of Naval Architects of Korea,* vol. 50, no. 4, pp. 241-248, 2013.

[8] K. M. Liew, X. He, and Y. T. Gu, "A review on recent contribution of meshfree methods to structure analysis," *J. Comput. Sci.,* vol. 4, no. 4, pp. 263–274, 2013.