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Comparative Study of Marine Skid Structure for Different Lifting Conditions

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ABSRACT: Marine skid structures play a vital role in offshore handling, transportation, and installation of heavy equipment. The present study focuses on a containerized marine skid structure, commonly used in offshore and marine applications, and investigates its structural performance under multiple lifting configurations. Lifting operations are often associated with high risk due to dynamic forces, sling-induced load distribution, equipment eccentricity, and varying support conditions. To ensure safe operations, it becomes essential to analyse how different lifting configurations affect the overall behaviour of the skid. A detailed lifting lug design is carried out for each lifting condition as per relevant offshore standards. The study identifies performance variations between symmetric and asymmetric lifting arrangements and highlights the influence of dynamic factors for marine applications. This thesis presents a comparative structural study of the skid under four primary lifting conditions: Single-point top lifting, Four-point top lifting, Single-point bottom lifting, and Four-point bottom lifting. These configurations significantly influence stress distribution patterns, load transfer paths, global deformation, and the behaviour of critical components such as lifting lugs.

Keywords: Marine skid structures, lifting, lifting lugs.

INTRODUCTION

Marine industries, particularly offshore oil & gas, subsea engineering, and maritime logistics, continuously rely on robust structural systems capable of sustaining harsh environmental conditions while ensuring operational safety. Among these systems, containerized marine skid structures have become fundamental due to their versatility, modularity, and ability to safely house and transport heavy industrial equipment. This chapter provides an in-depth, comprehensive introduction extended to a full-length academic standard—to set the context for the comparative study of different lifting configurations of containerized marine skid structures.

Overview of Marine Skid Structures

Marine skids are engineered platforms designed to support critical mechanical equipment such as pumps, compressors, generators, hydraulic power units, or process modules. Their primary functions include:

- Providing a stable base for equipment operation.
- Facilitating safe transportation between vessels, platforms, and docks.
- Enabling lifting and installation in offshore environments.

A containerized marine skid is a specialized type of skid enclosed within a structural frame like ISO containers. The design typically features:

- Corner blocks for lifting and stacking.
- Structural side frames for rigidity.
- Roof frames offer additional bracing.
- Base skid beams engineered for equipment loads.

Over the past decade, these structures have been increasingly preferred due to greater emphasis on safety compliance, standardized handling, and resistance to marine exposure. Their ability to integrate multiple systems into a single modular unit significantly reduces logistical complexity in offshore operations.

Objectives of the Study

- To analyze the structural behaviour of a containerized marine skid under four different lifting configurations—single-point top lifting, four-point top lifting, single-point bottom lifting, and four-point bottom lifting—using finite element analysis (FEA).
- To design and evaluate lifting lugs for each lifting configuration as per offshore lifting standards (DNV-ST-

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N001, ISO 10855, ASME B30, etc.) and compare their stress distribution, load paths, and safety margins.

- To determine the influence of lifting type and lifting position (top vs. bottom) on global deformation, stress concentration, sling forces, and dynamic response of the skid structure.

To identify the most structurally efficient, safe, and cost-effective lifting configuration for marine operations and provide engineering recommendations for skid lifting design.

METHODOLOGY

The methodology adopted in this research provides a systematic procedure for analyzing the structural behaviour of a containerized marine skid during lifting operations. Since marine lifting involves highly dynamic, safety-critical, and load-sensitive conditions, it is essential to follow a structured and codified approach to evaluate the skid under different lifting arrangements. The selected structure, measuring 12.5 m (L) × 3.5 m (H) × 3.3 m (W), represents a typical offshore containerized module and therefore requires careful modelling, lifting lug design, and numerical analysis.

The methodology integrates analytical lifting lug design, finite element modelling, and comparative analysis of four distinct lifting configurations—

1. Single-point top lifting
2. Four-point top lifting
3. Single-point bottom lifting
4. Four-point bottom lifting

The workflow includes developing an accurate 3D model of the skid, defining material and loading parameters, designing lifting lugs as per offshore lifting codes, creating a validated FEA model, and comparing key response parameters such as stress distribution, deformation, load transfer, and stability. This structured approach ensures that the behaviour of the skid is captured comprehensively, allowing the identification of the safest and most efficient lifting configuration for marine operations.

Flowchart of the study

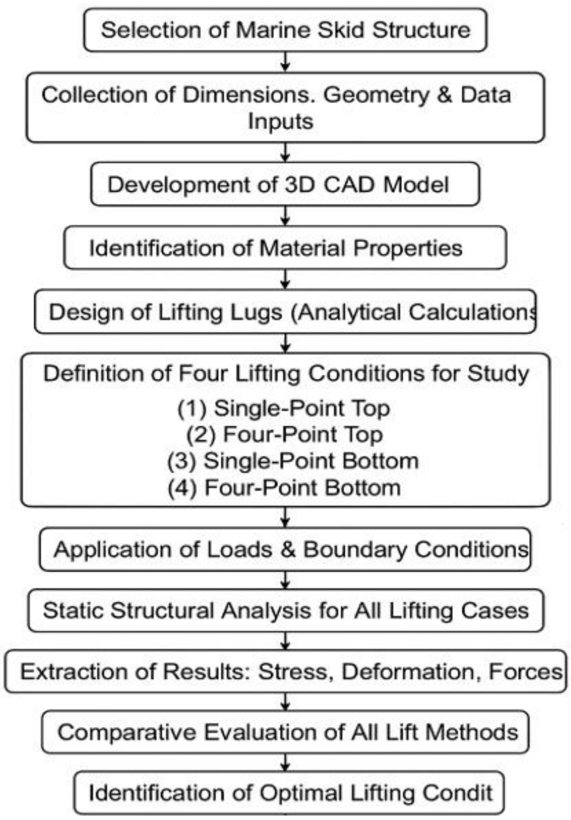

Figure 1: Flowchart of the study

Analysis of the study

The structural behaviour of the containerized marine skid structure under different lifting configurations was evaluated in STAAD.Pro. The study investigates four primary lifting conditions:

1. Single-point top lifting
2. Four-point top lifting
3. Single-point bottom lifting
4. Four-point bottom lifting

Each lifting configuration was analysed separately to understand its influence on stress distribution, load transfer mechanism, global deformation, and lifting lug performance.

Modelling Philosophy

The skid structure was modelled as a three-dimensional space frame using beam elements. The following modelling assumptions were adopted:

- All primary structural members were modelled using beam elements.
- Proper nodal connectivity was ensured at all intersections.
- Member offsets were defined where eccentric connections exist.
- Local member axes were verified to ensure correct force extraction.

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- Secondary members that do not significantly influence global behaviour were idealized appropriately.

Lifting lugs were either:

- Modelled using plate elements for local stress study, or
- Represented as equivalent beam elements for global load transfer analysis.

Material Properties

Structural steel properties used in analysis:

- Modulus of Elasticity (E) = 200 GPa
- Poisson's Ratio = 0.30
- Density = 7850 kg/m³
- Yield Strength (Fy) = As per selected structural steel grade

Material properties were defined prior to load application.

Loading Considerations

The following loads were considered in the structural analysis:

Dead Load (DL)

- Self-weight of structural members (generated automatically in STAAD)
- Weight of permanently mounted equipment
- Weight of accessories and attachments

The self-weight command was applied in the global vertical direction.

Equipment Load

Equipment load was applied as:

- Joint loads at support points, or
- Uniformly distributed loads where applicable

The Centre of gravity (CG) of equipment was considered. Any eccentricity between CG and geometric Centre was included in the model to simulate realistic load effects.

Lifting Load Calculation

The lifting analysis incorporates dynamic effects, sling geometry, and potential unequal load distribution.

Total Lifted Weight

$$\boldsymbol{W} = \boldsymbol{W}_{structure} + \boldsymbol{W}_{equipment}$$

Where:

- $W_{structure}$= Self-weight of skid
- $W_{equipment}$= Weight of mounted equipment

Dynamic Amplification Factor (DAF)

During lifting operations, additional dynamic effects arise due to crane motion, vessel movement, wave action, and sudden load pick-up. To account for these effects, a Dynamic Amplification Factor (DAF) was applied.

$$\boldsymbol{W_d = W \times DAF}$$

Typical values considered:

- Yard lifting: 1.1 to 1.2
- Offshore lifting: 1.3 to 1.5

The adopted DAF value was selected based on offshore lifting practice as per DNV-ST-N001.

Sling Angle Effect

When slings are inclined, tension in each sling increases as the angle increases.
For n lifting points:

$$\boldsymbol{T = \frac{W_d}{n\cos\theta}}$$

Where:

- $\boldsymbol{T}$= Tension in each sling
- $\boldsymbol{\theta}$= Angle between sling and vertical
- $\boldsymbol{n}$= Number of lifting points

This calculation ensures realistic force input at lifting nodes.

Skew Load Factor

To account for uneven load sharing due to fabrication tolerances, sling length variation, or CG shift, a skew load factor was applied.
One lifting point was assumed to carry additional load:

$$\boldsymbol{T_{max}} = \boldsymbol{T} \times (\boldsymbol{1} + \text{Skew Factor})$$

Typically, 5% to 10% additional load was considered for critical lifting point.

Modelling of Lifting Configurations in STAAD

Each lifting configuration was modelled as a separate analysis case.

- **Single-Point Top Lifting**

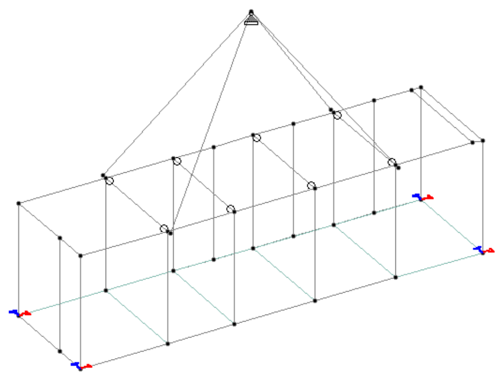

Figure 2: Single point Top Lifting

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The above figure shows the three-dimensional STAAD.Pro model of the marine skid structure under the Single-Point Top Lifting condition. In this configuration, the entire weight of the skid, including structural self-weight and equipment load, is suspended from a single top lifting hook located at the central upper position. The sling members connect the master hook to the designated top lifting lugs, through which the load is transferred into the top frame and subsequently distributed to the longitudinal, transverse, and vertical members of the skid. No supports are provided at the base nodes, simulating a fully suspended condition. The gravity load is applied in the global vertical direction along with the appropriate Dynamic Amplification Factor to account for lifting effects. This lifting arrangement induces significant global bending and torsional effects due to load eccentricity, resulting in high stresses in the top longitudinal members and lifting lug region. Hence, this configuration is considered critical for evaluating maximum bending stresses, sling forces, reaction at the lifting point, and overall structural deflection.

- **Four-Point Top Lifting**

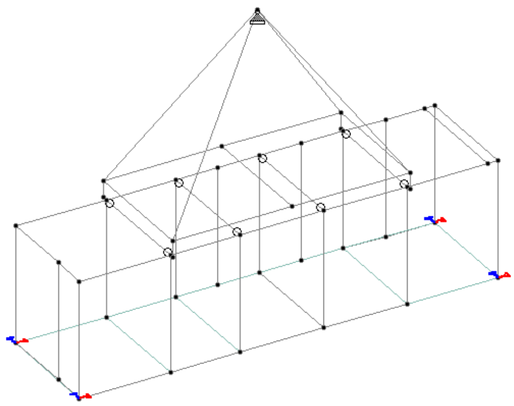

Figure 3: Four-Point Top Lifting

The STAAD.Pro model for the Four-Point Top Lifting configuration represents the skid structure suspended from four designated lifting lugs located at the top corners of the frame. In this condition, the total lifted weight, including self-weight and equipment load, is distributed among four lifting points through inclined sling members connected to a master hook or spreader arrangement. Vertical restraints are provided at the lifting lug nodes to simulate suspension. The applied loads include gravity load factored with the appropriate Dynamic Amplification Factor, and sling forces are calculated considering sling angle and possible load skewness. Compared to single-point lifting, this configuration results in improved load distribution, reduced global bending, and lower torsional effects. However, unequal load sharing due to fabrication tolerances or centre of gravity eccentricity is also considered to identify the most critical lifting point. This arrangement is generally more stable and structurally efficient than single-point top lifting.

- **Single-Point Bottom Lifting**

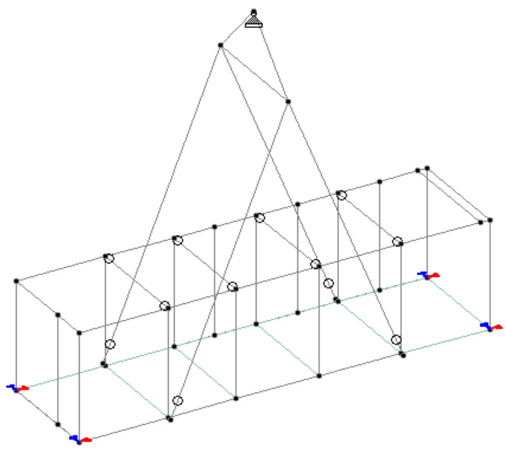

Figure 4: Single-Point Bottom Lifting

In the Single-Point Bottom Lifting configuration, the skid structure is suspended from a single lifting point located at the bottom central region of the frame. The entire factored lifted weight is transferred through this bottom lifting node, and no supports are provided at other base nodes, simulating a hanging condition. The load path in this case differs significantly from top lifting, as the bottom frame members primarily resist tensile forces while upper members experience compression and bending. The application of gravity load combined with Dynamic Amplification Factor generates considerable bending and torsional effects due to eccentricity between the lifting point and the centre of gravity. This configuration is critical for assessing bottom frame strength, connection adequacy, and lifting lug design at the base level.

- **Four-Point Bottom Lifting**

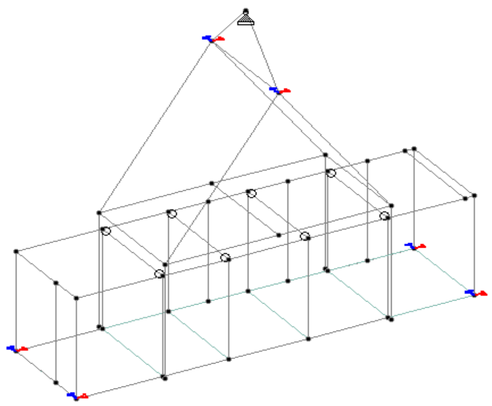

Figure 5: Four-Point Bottom Lifting

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The Four-Point Bottom Lifting configuration consists of four lifting points located at the bottom corners of the skid structure. The total lifted load, including dynamic effects, is distributed among the four bottom lifting lugs through sling members. Supports are assigned at these lifting nodes to simulate suspended behaviour. This arrangement provides better load sharing and reduces excessive global bending compared to single-point bottom lifting. However, local stresses in the base frame members become significant, particularly near lifting lug connections. Unequal load distribution due to skew factors is also considered to determine the most critical lifting point. This configuration is evaluated to ensure adequate strength of base members, lifting lugs, and weld connections under combined axial, shear, and bending actions.

Load Combinations

Load combinations were generated for Ultimate Limit State (ULS).
General load combination used:

$$\mathbf{LC = (DL + Equipment) \times D \times Sling\ Factor}$$

For skew conditions:

$$\mathbf{LC = (DL + Equipment) \times DAF \times Skew\ Factor}$$

Where:

- DAF = Dynamic Amplification Factor
- Skew Factor = Load redistribution factor

Analysis Procedure

For each lifting condition:

1. Assign supports at lifting nodes
2. Apply factored gravity load
3. Include DAF and sling factors
4. Perform linear static analysis
5. Extract results:

- Axial forces
- Shear forces
- Bending moments
- Support reactions
- Nodal deflections

Critical members were identified based on maximum utilization ratio.

Acceptance Criteria

The structure was considered safe when:

- Utilization ratio ≤ 1.0
- Maximum deflection within permissible limits
- No local buckling observed
- Lifting lug stresses within allowable limits
- Reaction equilibrium satisfied

RESULTS AND DISCUSSION

This chapter presents the structural analysis results of the marine skid structure subjected to four different lifting configurations. The comparison is primarily based on total steel requirement obtained after design optimization and the maximum sling forces developed during lifting analysis.
Variation in steel tonnage reflects the structural demand imposed by each lifting configuration, while sling force comparison governs lifting lug design, shackle selection, and crane capacity verification. The objective of this chapter is to evaluate structural efficiency, material optimization, and lifting safety performance of each configuration.

Steel Take-Off Results

Four-Point Bottom Lifting

Table 1: Steel Take-Off for Four-Point Bottom Lifting

Profile	**Length (m)**	**Weight (kg)**
ST TUB1001006.3	14.00	254.429
ST TUB1001003.6	31.60	339.124
ST HE180A	69.76	1589.744
ST TUB1001004.0	58.50	696.547
Total		**2879.844 kg**

The total steel required for the Four-Point Bottom Lifting configuration is 2879.844 kg (2.88 tons), which is the lowest among all analyzed cases. In this arrangement, the load is distributed through four lifting points located at the bottom frame, ensuring uniform load sharing. The improved load path minimizes global bending and torsional effects in the structure. As a result, lighter tubular sections and HE180A beams were adequate to satisfy strength and stability requirements. This configuration demonstrates maximum material efficiency and optimizes structural behavior.

Four-Point Top Lifting

Table 2: Steel Take-Off for Four-Point Top Lifting

Profile	**Length (m)**	**Weight (kg)**
ST TUB80805.0	14.00	161.212
ST TUB80806.3	31.60	448.040
ST HE180A	69.76	1589.744
ST TUB90906.0	58.50	907.344
Total		**3106.340 kg**

The total steel required for Four-Point Top Lifting is 3106.340 kg (3.11 tons). Although the load is shared between four lifting points, top lifting introduces additional bending effects in the upper frame members due to load transfer above the center of gravity. Consequently, slightly heavier tubular sections are required compared to the bottom lifting case. However, the

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configuration remains structurally efficient and significantly more economical than single-point lifting cases.

Single-Point Bottom Lifting

Table 3: Steel Take-Off for Single-Point Bottom Lifting

Profile	Length (m)	Weight (kg)
ST TUB2001008.0	14.00	491.311
ST TUB1501006.0	31.60	698.051
ST HE200A	44.80	1888.040
ST TUB1001006.0	58.50	1017.325
Total		**4094.727 kg**

The total amount of steel required for Single-Point Bottom Lifting is 4094.727 kg (4.09 tons), which is the highest among all configurations. In this case, the entire lifted load is concentrated at a single bottom location, leading to severe bending and stress concentration in base frame members. To satisfy strength criteria and serviceability requirements, heavier structural sections such as HE200A and larger tubular profiles were necessary. This configuration represents the most structurally demanding and material-intensive case.

Single-Point Top Lifting

Table 4: Steel Take-Off for Single-Point Top Lifting

Profile	Length (m)	Weight (kg)
ST TUB1001006.0	14.00	243.462
ST TUB1201206.0	31.60	668.347
ST HE180A	44.80	1589.744
ST TUB1001006.3	58.50	1063.150
Total		**3564.703 kg**

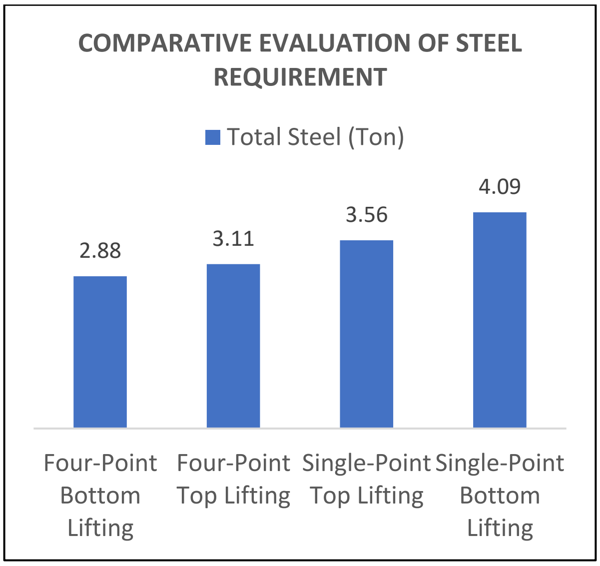
The total steel required for Single-Point Top Lifting is 3564.703 kg (3.56 tons). Load concentration at a single top lifting point induces significant global bending and torsion in upper frame members. Although the structural demand is lower than single-point bottom lifting, the configuration still requires substantially higher steel compared to four-point lifting cases. This arrangement is structurally less efficient than distributed lifting systems.

Comparative Evaluation of Steel Requirement

Table 5: Comparative Evaluation of Steel Requirement

Lifting Configuration	Total Steel (kg)	Total Steel (Ton)
Four-Point Bottom Lifting	2879.844	2.88
Four-Point Top Lifting	3106.340	3.11
Single-Point Top Lifting	3564.703	3.56
Single-Point Bottom Lifting	4094.727	4.09

The below graph shows a comparative evaluation of total steel requirement for different lifting arrangements, namely Four-Point Bottom Lifting (2.88 tons), Four-Point Top Lifting (3.11 tons), Single-Point Top Lifting (3.56 tons), and Single-Point Bottom Lifting (4.09 tons). It is observed that the steel requirement increases as the lifting system changes from four-point to single-point, indicating that distributed lifting reduces structural demand due to better load sharing and lower bending moments. Among all configurations, Four-Point Bottom Lifting requires the least steel, making it the most economical and structurally efficient option, whereas Single-Point Bottom Lifting requires the highest steel quantity due to concentrated loading effects and higher stresses. Overall, multi-point lifting systems are more material-efficient compared to single-point lifting arrangements.



Graph 1: Comparative Evaluation of Steel Requirement

Percentage Comparison (Base: Four-Point Bottom Lifting)

Using Four-Point Bottom Lifting as the reference case:

- Four-Point Top Lifting → 7.9% increase
- Single-Point Top Lifting → 23.8% increase
- Single-Point Bottom Lifting → 42.2% increase

The results clearly indicate that distributing the lifting load through multiple bottom lifting points significantly reduces material demand. Single-point lifting, particularly at the bottom, results in substantial increase in structural reinforcement and steel consumption.

Overall Discussion on Steel Requirement

- The lifting configuration has a significant impact on structural demand and material consumption.
- Four-point lifting configurations reduce bending and torsional effects through improved load sharing.
- Bottom lifting with four lifting points provides the most

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economical solution with minimum steel requirement.

- Single-point lifting configurations cause severe load concentration, resulting in higher stresses and heavier member sections.
- Single-point bottom lifting is the most critical configuration in terms of structural demand.
- From both structural efficiency and economic perspectives, Four-Point Bottom Lifting is the most optimal configuration, while Single-Point Bottom Lifting represents the most conservative and material-intensive case.

Comparison of Maximum Sling Forces

Maximum sling force is a governing parameter for lifting lug design, sling selection, and crane capacity verification. The sling forces were obtained from STAAD.Pro analysis considering Dynamic Amplification Factor (DAF), sling angle effects, and load redistribution due to center of gravity eccentricity.

Single-Point Top Lifting

Parameter	Value
Maximum Sling Force	16,769.20 kg

In this configuration, the entire factored load is transferred through a single sling at the top location. This results in the highest sling force among all cases due to complete load concentration and sling angle amplification. This configuration is therefore the most critical case for lifting lug and shackle design.

Four-Point Top Lifting

Parameter	Value
Maximum Sling Force	14,201.95 kg

Load sharing among four lifting points reduces individual sling forces. However, due to geometric effects and possible skew load redistribution, one sling may attract higher force. The maximum sling force remains lower than single-point top lifting but is still significant.

Single-Point Bottom Lifting

Parameter	Value
Maximum Sling Force	**12,922.12 kg**

Although the entire load is resisted at a single bottom point, the geometric load path reduces sling force amplification compared to top lifting. This configuration produces the lowest maximum sling force among all cases.

Four-Point Bottom Lifting

Parameter	Value
Maximum Sling Force	13,368.41 kg

The sling force in this configuration is slightly higher than single-point bottom lifting due to load redistribution and sling geometry. However, it remains significantly lower than top lifting configurations.

Comparative Evaluation of Sling Forces

Lifting Configuration	Maximum Sling Force (kg)
Single-Point Top Lifting	16,769.20
Four-Point Top Lifting	14,201.95
Four-Point Bottom Lifting	13,368.41
Single-Point Bottom Lifting	12,922.12

Percentage Comparison (Base: Single-Point Bottom Lifting)

Using 12,922.12 kg as reference:

- Four-Point Bottom Lifting → 3.45% increase
- Four-Point Top Lifting → 9.90% increase
- Single-Point Top Lifting → 29.76% increase

Overall Discussion on Sling Force Behaviour

- The sling force comparison indicates:
- Single-Point Top Lifting produces the highest sling force, approximately 29.8% greater than the lowest case.
- Bottom lifting configurations result in comparatively lower sling forces due to improved load transfer geometry.
- Single-Point Bottom Lifting produces the lowest maximum sling force.
- Sling force magnitude is strongly influenced by:
  - Sling angle
  - Lifting point elevation
  - Centre of gravity position
  - Skew load redistribution
- From a lifting equipment safety perspective:
- Single-Point Top Lifting is the most critical case for sling design.
- Single-Point Bottom Lifting exhibits the lowest maximum sling force demand.

CONCLUSION

The present study evaluated the structural behavior of a marine skid structure under four different lifting configurations:

- Four-Point Bottom Lifting
- Four-Point Top Lifting
- Single-Point Top Lifting
- Single-Point Bottom Lifting

The comparison was carried out based on total steel requirement after design optimization and maximum sling force developed during lifting analysis using STAAD.Pro. The following conclusions are drawn from the detailed analysis.

Effect of Lifting Configuration on Steel Requirement

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1. Lifting configuration has a significant influence on structural demand and material consumption.
2. Four-Point Bottom Lifting required the minimum steel quantity (2879.844 kg), demonstrating the highest structural efficiency.
3. Four-Point Top Lifting showed a moderate increase (7.9%) in steel requirement compared to the bottom four-point arrangement due to additional bending in upper frame members.
4. Single-Point Top Lifting required 23.8% more steel than the most economical configuration, indicating increased stress concentration and global bending effects.
5. Single-Point Bottom Lifting resulted in the maximum steel requirement (4094.727 kg), representing a 42.2% increase over Four-Point Bottom Lifting.

This configuration is structurally the most demanding due to complete load concentration at a single base location. It can therefore be concluded that distributed lifting significantly reduces structural demand and material consumption.

Effect of Lifting Configuration on Sling Forces

1. Sling force magnitude varies considerably depending on lifting geometry and load distribution.
2. Single-Point Top Lifting produced the highest maximum sling force (16,769.20 kg), approximately 29.76% higher than the lowest case.
3. Four-Point Top Lifting reduced sling force due to load sharing but remained higher than bottom lifting configurations.
4. Single-Point Bottom Lifting generated the lowest sling force (12,922.12 kg), indicating favorable load transfer conditions.
5. Four-Point Bottom Lifting showed slightly higher sling force than single-point bottom lifting due to load redistribution and sling angle effects but remained significantly lower than top lifting cases.

These results confirm that sling angle, lifting point elevation, and center of gravity location strongly influence lifting force demand.

Structural Efficiency Assessment

- Based on combined evaluation of steel consumption and sling force demand:
- Four-Point Bottom Lifting is the most economical and structurally efficient configuration.
- Single-Point Bottom Lifting is the most conservative and material-intensive case.
- Single-Point Top Lifting is the most critical configuration for sling and lifting lug design.
- Four-Point Top Lifting provides a balanced performance but is less efficient than bottom four-point lifting.
- Proper selection of lifting configuration can reduce steel consumption by up to 42% and significantly lower lifting force demand.

Overall Conclusion

- From both structural performance and economic considerations, Four-Point Bottom Lifting is identified as the optimal lifting configuration for the studied marine skid structure.
- It ensures:
- Minimum steel requirement
- Improved distribution load
- Reduced bending and torsional effects
- Lower sling force demand
- Enhanced lifting safety
- Conversely, Single-Point Bottom Lifting represents the most critical structural condition, requiring maximum reinforcement and material usage.

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