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Welding Analysis of Lifting Points on a Commercial Container Structure

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ABSTRACT

This paper presents a comprehensive welding analysis of a commercial container structure equipped with four lifting points, which are widely utilised in transportation and offshore operations. The primary objective is to design, model, and evaluate the welded joints at these lifting points to ensure compliance with safety and structural standards under heavy lifting conditions. A detailed 3D model of a standard 20-foot container was developed using SolidWorks, incorporating structural I-beams and reinforced lifting points. Static structural analysis and edge weld connector simulations were conducted to examine stress distribution, displacement, strain, factor of safety, and optimal weld sizes under a 30-tonne lifting load scenario. The analysis revealed that critical weld regions, particularly at the curved sections of the lifting points, experienced higher stress concentrations compared to other areas. However, the overall structural stress remained below the yield strength of the selected materials, S275 structural steel for the container frame and alloy steel for the lifting points. The design achieved a minimum factor of safety of 5.0, meeting the requirements of ASME B30.20, ISO 3874, and AWS D1.1 standards. Furthermore, variations in weld size across different weldments demonstrated an efficient layout, strategically reinforcing areas subjected to maximum stress. This study validates the structural integrity of the container design and emphasises the critical role of weldment analysis in enhancing safety and reliability during lifting operations. The findings provide valuable insights for engineers and manufacturers in optimising welded joint configurations for heavy-duty applications.

Keywords: Weldment; commercial container; lifting point; safety factor; welding simulation

INTRODUCTION

Shipping containers are standardized structures designed for transporting goods across land, sea, and air (Olsen & Karkori 2024; Chen et al. 2024). A typical container, such as the ISO 20-foot or 40-foot type, consists of a steel frame with corrugated panels, reinforced corner posts, and cross-members to ensure rigidity and durability under stacking and handling loads (Zhu et al. 2024; Li et al. 2024). For lifting operations, containers are equipped with lifting lugs or points, usually integrated into the corner castings or added as pad eyes for offshore and heavy-duty applications (Liu et al. 2025, Samir, 2025). These lifting lugs are critical for safe hoisting using cranes or spreader bars.

The structural design of lifting lugs must account for extreme loads, dynamic effects, and sling angles, as they transfer the entire container weight (often exceeding 30 tonnes) to the lifting equipment (Chao et al. 2025). Materials commonly used include high-strength alloy steel for lugs and structural steel (e.g., S275 or ASTM A36) for the container frame. Welded connections between lugs and the container frame are essential for load transfer (Kumar et al. 2024) and must comply with standards such as ISO 3874 (container handling), ASME B30.20 (lifting devices), and AWS D1.1 (welding). These standards dictate minimum safety factors, weld quality, and inspection requirements.

Simulation and analysis of these structures typically involve finite element modeling to evaluate stress distribution, displacement, and weld integrity under lifting conditions (Admi et al. 2024). Critical areas include curved regions of lifting lugs and weld toes, which experience high stress concentrations. Proper weld sizing, geometry optimization, and compliance with safety factors (≥3 or higher) are vital to prevent failure during lifting operations.

Lift lugs are critical components used for hoisting heavy equipment and containers, and their design must ensure structural integrity under extreme loads (Arifuddin et al. 2025). FEA is widely applied to evaluate stress distribution, deformation, and safety margins in lift lug assemblies. Typical lift lugs FEA analysis using 3D CAD model of the I-beam with lift lugs considered as one body. The analysis focuses on the design and the safety factor of the lift lug itself. Studies often recommend geometry refinement (e.g., increasing fillet radius, adjusting plate thickness) and weld size variation to reduce stress concentration.

Welding and weldment emphasize optimizing joint quality, mechanical properties, and process efficiency across various techniques and materials. For friction stir welding (FSW) of aluminum alloys, welding parameters such as tool rotation speed and feed rate significantly influence mechanical properties, including strength and toughness (Mamgain et al., 2023). Post-weld treatments like rolling further enhance joint performance by improving strength (Selamat et al., 2018). Advanced approaches, including machine learning, have been applied to predict and optimize FSW outcomes, reducing experimental costs and improving reliability (Nasir et al., 2020). In resistance spot welding of aluminum-steel joints, surface treatments play a critical role in determining hardness and strength, highlighting the importance of interface preparation (Ahmad et al., 2025). For Gas Tungsten Arc Welding (GTAW), pulsed current parameters affect intergranular corrosion resistance in stainless steel welds (Shah et al., 2022), while modeling efforts on Charpy V-Notch toughness provide insights into weld deposit behavior (Chauhan et al., 2022). Additionally, distortion control in welded joints using the Taguchi method has proven effective for dimensional accuracy (Arifin et al., 2019), and studies on tailor welded blanks formed via Single Point Incremental Forming (SPIF) demonstrate the influence of process parameters on surface roughness (Razak et al., 2025).

Although finite element analysis (FEA) and other simulation tools are widely used for structural design (Mnati et al. 2025), their application to pad eye weldment analysis remains limited and often simplified. Current simulation practices typically assume idealized weld geometry (uniform throat size, perfect penetration) and linear-elastic material behavior (Sarivan et al. 2024; Ma et al. 2024), which fails to capture the true complexity of welded joints under heavy lifting conditions. Most simulations ignore thermal effects from welding, residual stresses, and microstructural changes in the heat-affected zone (HAZ). These factors significantly influence fatigue life and fracture resistance but are rarely modeled in pad eye studies. Simulations often apply static, unidirectional loads, neglecting multi-axial stresses, dynamic amplification, and sling angle variations common in offshore lifting operations. This leads to underestimation of stress concentrations at weldments and curved regions. Welds are frequently modeled as ideal fillets or edge connectors, without accounting for realistic weld profiles, defects, or discontinuities (Kumar et al. 2025). This simplification limits the accuracy of stress and strain predictions at critical points.

The throat size of the weld is a critical design parameter because it directly affects the structural integrity and safety of the lifting point under extreme conditions. The weld between the lift lug and I-beam must safely transmit the lifting forces without failure. A correctly sized throat ensures the weld can handle shear and bending stresses generated by sling angles and dynamic loads. Undersized throats risk weld fracture, jeopardizing container safety. In FEA models (SolidWorks), throat size determines the effective weld area and stiffness. Larger throats reduce stress concentration at the weld toe and root, especially at curved regions of the lug where stress peaks occur. Accurate throat sizing in simulation ensures realistic predictions of stress, strain, and displacement. Standards like AWS D1.1 and ISO 3874 require weld sizing based on plate thickness and load type (Orlando et al. 2024). For heavy lifting, throat size must meet or exceed minimum requirements to achieve safety factors (≥4 or 5) as per ASME B30.20 guidelines. Oversized welds increase fabrication time and cost, while undersized welds compromise safety (Ajenifuja et al. 2025, Renken et al. 2025). Simulation helps identify the optimal throat size that balances strength, compliance, and economy.

In this paper, a weldment analysis of lift lugs on I-beam structure (Figure 1) of a standard industrial container is performed using commercial FEA software SolidWorks. The weldment throat size, factor of safety and stress distribution are analyzed. Recommendation of weldment is provided for specific industrial application.

METHODOLOGY

LIFTING POINTS

Lifting points, lift lugs or pad eyes are essential components that provide safe lifting points on a wide variety of equipment and structures, including shipping containers. These mechanical devices are designed to facilitate the safe lifting and movement of heavy loads in construction and industrial settings. Typically welded to the main structure, lifting lugs ensure that lifting equipment, such as cranes or hoists, can be securely attached without damaging the load or the container itself.

A typical lifting lug consists of steel parts such as plates, channels, rods, or hollow sections, welded to the main members of the lifted structure. This design creates a strong and secure connection between the lifting lug and the main structure (Figure 2). The dimension of the I-beam is tabulated in Table 1. The material for the I-beam is S275JR (Table 2).

The design of lifting lugs (Figure 3) considers several factors, including load calculations and material properties. High-strength steel is commonly used for these components to withstand the significant forces encountered during lifting operations. Properly designed lifting lugs help distribute loads evenly and prevent stress concentrations that can lead to structural failure.

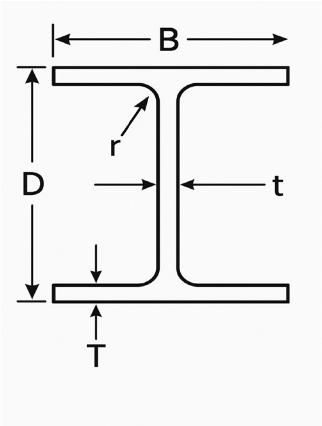


FIGURE 1. Standard I-beam dimensions

TABLE 1. I-beam dimensions

	Dimension
Section size	200 mm ´ 200 mm
Section depth, D	200 mm
Flange width, B	200 mm
Web, t	8 mm
Flange, T	12 mm
Corner radius, r	13 mm

TABLE 2. Structural steel S275JR properties

Material property	Value
Elastic Modulus	210000.0031 N/mm^2
Poisson's Ratio	0.28
Shear Modulus	79000 N/m m^2
Mass Density	7800 kg/ m^3
Tensile Strength	410 N/m m^2

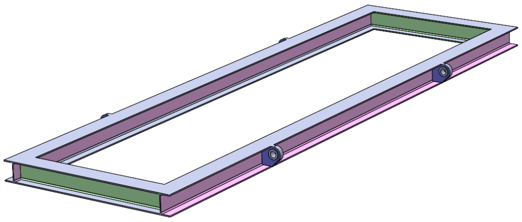


FIGURE 2. Lifting points on the container support beam

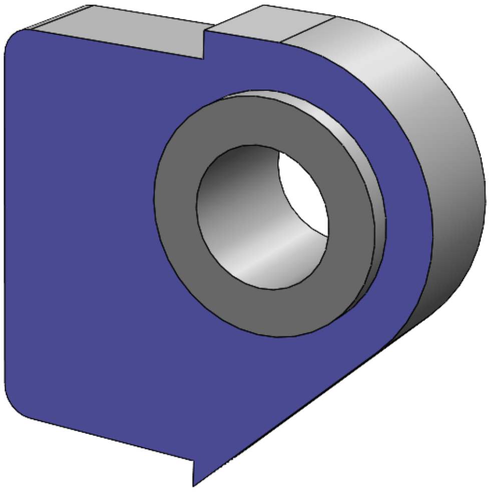


FIGURE 3. Lifting point

LIFTING OPERATION

International standards for container lifting operations are critical for ensuring the safety and efficiency of handling shipping containers across various modes of transport. These standards provide guidelines on the proper methods, equipment, and safety practices necessary to minimize risks during lifting operations. Key standards in this area include ISO 3874, which focuses on safe handling and securing of containers, as well as other relevant regulations that govern lifting practices.

ISO 3874: Handling and Securing Containers is a fundamental international standard that outlines the basic principles and procedures for the safe operation of containers during lifting. This standard specifies allowed lifting methods for both loaded and empty containers, ensuring that operations are conducted safely and effectively. It covers various aspects, including the use of appropriate lifting equipment such as spreaders and slings, and emphasizes the importance of securing loads properly to prevent accidents. The standard also addresses considerations for specific loading scenarios and potential hazards, promoting secure and efficient container handling practices.

According to ISO 3874, lifting a packed ISO container should generally be performed using a spreader or vertical slings attached to the top corner fittings. Methods that lead to asymmetrical loads, such as angled slings, are discouraged due to the risk of tilting or instability. The standard also highlights the need for careful planning of lifting operations by competent personnel to ensure that all safety measures are in place.

By aligning with international standards like ISO 3874, organizations can reduce maintenance-related risks and ensure that lifting operations are performed using equipment in optimal condition.

The implementation of these international standards not only enhances safety but also improves operational efficiency in logistics and transportation sectors. By adhering to established guidelines, stakeholders can effectively manage risks associated with container handling, ensuring safe working environments for personnel involved in lifting operations. Figure 4 shows the fix, load and weldment of the model. The load applied for each lifting point is 75000 N. There are six weldment connectors between the I-beam and the lifting point.

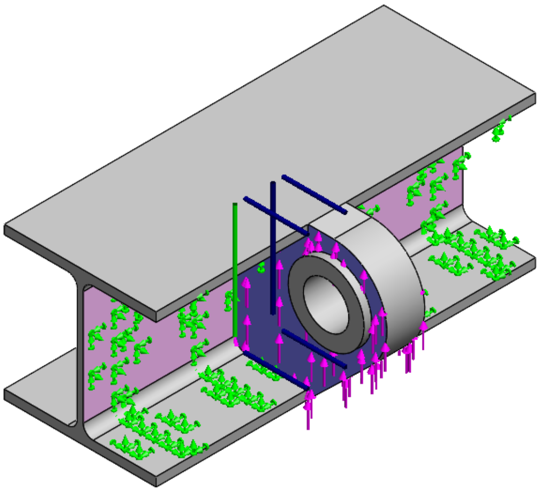


FIGURE 4. Fix, load and weldment

WELDING SIMULATION

Commercial FEA software, SolidWorks is used for welding analysis and simulation. It can be used to draw and model welded structures, providing engineers with an intuitive interface and a complete set of features tailored specifically for creating and analyzing welded assemblies. By leveraging SolidWorks, users can efficiently design complex welding frameworks, ensuring their structures meet both aesthetic and functional requirements. The software's simulation capabilities allow for advanced analysis, including stress and static loading simulations, which are essential for verifying the structural integrity of designs before physical fabrication. SolidWorks Simulation provides a robust platform for analyzing weldment structures, enabling engineers to subject their designs to real-world conditions. This computational analysis enhances product quality while significantly reducing the costs associated with physical testing. By utilizing SolidWorks Simulation, users can evaluate the performance of welded assemblies under various load scenarios, ensuring that their designs are both safe and efficient. One of the key features of SolidWorks Simulation is its ability to analyze mixed geometry types, including weldments, sheet metal, and solid components. This flexibility allows engineers to create comprehensive models that accurately represent the complexities of real-world applications. For instance, during a typical analysis of a skid assembly model, users can perform linear static analysis to determine the safe operating loads that the structure can withstand. The Load Case Manager feature further enhances this capability by allowing users to manage and validate multiple use case scenarios efficiently. Figure 4 shows the meshing of the welding assembly.

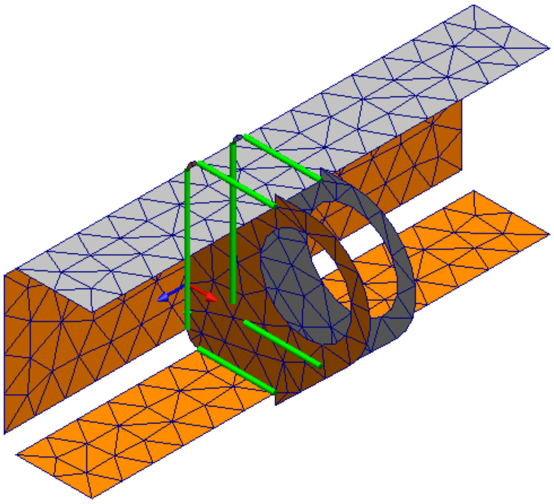


FIGURE 5. Part meshing

RESULTS AND DISCUSSION

STRESS

SolidWorks Simulation, a Finite Element Analysis (FEA) tool integrated within the SOLIDWORKS CAD environment, enables virtual testing, prediction, and validation of designs prior to the fabrication of physical prototypes. Several structural analyses were conducted, including stress distribution, displacement, strain, factor of safety, and edge weld size evaluation. These simulations are crucial for verifying the design's reliability and identifying potential failure points or areas of concern.

By analyzing the weldment under realistic loading conditions, the study assesses whether the current design meets the required safety and structural standards. The insights gained from these simulations can support early identification of potential issues, thereby reducing development time and cost. To ensure the weld designs comply with industry requirements, the results were also benchmarked against recognized standards such as ASME B30.20, ISO 5817, and AWS D1.1.

The von Mises stress plot shows the regions of maximum stress experienced by the structure under the applied lifting load. This plot is used to evaluate whether the material will yield or fail under the combined loading conditions. As shown in Figure 6, the maximum von Mises stress is 57.94 MPa, which is located near the weld zone between the pad eye and the I-beam.

The high stress concentration near the weld zone is expected due to the direct transfer of load from the lifting pad eye to the supporting I-beam. Welds are often critical areas in structural components because they introduce geometric discontinuities and localized stiffness variations, both of which can intensify stress. It is important to check that the maximum stress remains below the material's yield strength. If the stress is too high, design improvements such as increasing the weld size, using better welding techniques, or adding reinforcement may be needed to maintain the strength and safety of the structure during lifting.

The stress distribution shown in Figure 6 aligns with the expected behavior during lifting, where stress accumulates at welded lifting points due to the concentrated load transfer. These zones are critical when assessing the structural performance and safety of the welds. The maximum stress of 57.94 MPa remains well below the yield strengths of both materials used in the structure. S275 structural steel, used for the I- beam, has a yield strength of 275 MPa, while the alloy steel used for the pad eye has a yield strength between 400 and 600 MPa. This confirms that the structure is operating safely within the elastic range, and no plastic deformation is expected.

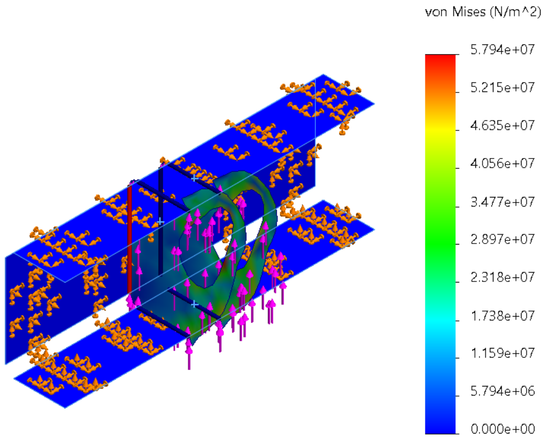


FIGURE 6. Stress distribution

DISPLACEMENT

The displacement result indicates how much the structure deforms under the lifting load. As shown in Figure 7, the maximum resultant displacement is 0.05226 mm, located near the mid-span of the top beam. This very small deflection indicates that the container frame has excellent global stiffness and retains its shape under operational conditions. The deformation pattern aligns with beam theory, where the central portion of the span shows the highest deflection due to bending, while the ends and welded lifting points remain fixed. The low displacement magnitude confirms that the structure will not suffer from distortion, and all welded joints maintain their integrity during lifting. Thus, the structure is both strong and rigid enough to prevent misalignment or vibration damage during real-world operations.

Furthermore, the low displacement also shows that the boundary conditions and load setup in the simulation are working well. The fixed support at the container base and the equal force applied to the four lifting points successfully represent a real lifting situation. This small amount of movement means that the I-beam structure and welds are strong enough to resist bending during lifting. Having such a stiff structure is very important, especially in situations where the load may shift or the container is lifted many times. It helps the container keep its shape, stay safe during stacking or transport, and avoid damage over time. These results show that the design is not only strong but also stable under lifting conditions.

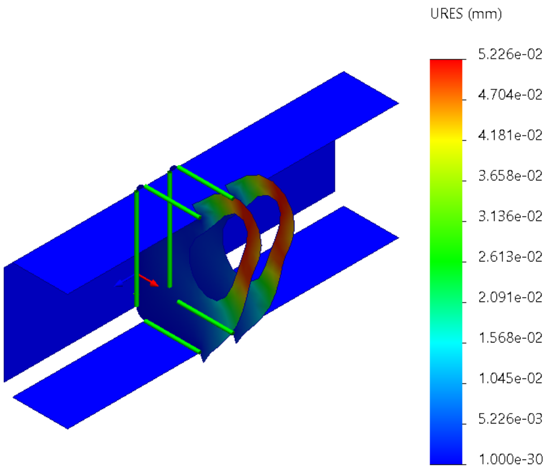


FIGURE 7. Displacement

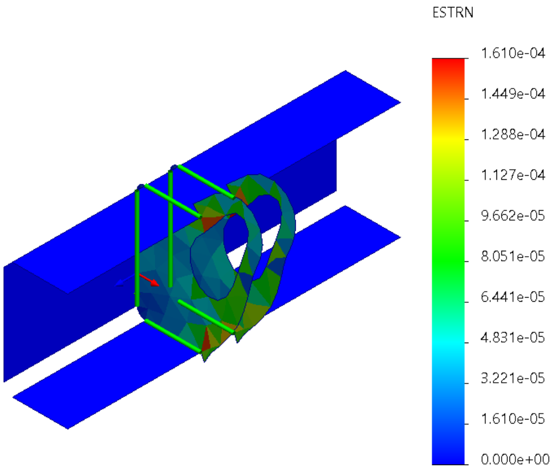


FIGURE 8. Displacement

STRAIN

The equivalent strain result provides insight into how the material deforms under load, particularly in welded and high-stress regions. As shown in Figure 8, the maximum equivalent strain is 1.610 ´ 10^{-4}, located near the junction between the pad eye and the I-beam. This corresponds with the region of highest stress and confirms the expected behavior where stress and strain are concentrated during lifting. The low strain values suggest that the structure remains well within the elastic deformation range, with no permanent deformation or plastic flow occur. This is especially important for welded structures, especially in lifting applications, where repeated loading cycles may lead to fatigue if strain levels are excessive. The strain distribution reveals that high strain values are both localized and small in magnitude. This confirms that the welding and material combination of S275 steel for I-beam and alloy steel for pad eye is suitable for lifting operations. These results support the structure's reliability for repeated use without significant deterioration of weld integrity.

Overall, the strain results help confirm that the design is safe and well- optimized. Since the highest strain occurs only in a small area near the weld and the rest of the structure experiences very low strain, it shows that the stress is properly distributed. This means the container can handle lifting loads without overstressing the materials, reducing the risk of cracks, weld failure, or long-term damage. The strain pattern proves that the structure is not only strong but also durable for repeated lifting operations.

SAFETY FACTOR

The Factor of Safety (FOS) is a critical design parameter used to evaluate structural capacity beyond the expected working load. As shown in Figure 9, the simulation indicates a uniform FOS of 4.1 throughout the container structure. This means that the structure can withstand five times the applied load before failure, ensuring a high level of reliability under lifting conditions.

This safety margin complies with but also exceeds industry standards. According to ASME B30.20, welded lifting devices must maintain a minimum FOS of 3.0, while ISO 3874 sets standards for the safe handling of containers, emphasizing that container lifting points must maintain structural integrity under dynamic forces. The use of an FOS of 4.1 ensures the design is conservative and robust, suitable for demanding offshore or industrial applications.

The uniform FOS value confirms that no region of the structure is overstressed. This indicates that the load is well-distributed, and that the combination of material selection, welding quality, and structural configuration is effective. The visualization in Figure 9 verifies that the lifting point is compliant with international safety standards and safe for real-world application.

In particular, the welded edge connector between the pad eye and the I-beam plays a critical role in transferring lifting loads. The FOS results show no stress concentration or localized weakness in this region. A continuous and evenly distributed safety factor along the welded interface indicates that the weld is neither under-designed nor acting as a weak point. This outcome confirms the weld joint is properly designed for high-load conditions and contributes effectively to the overall structural integrity during lifting operations.

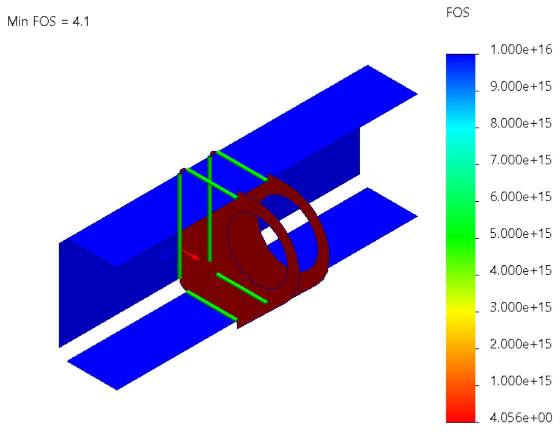


FIGURE 9. FOS

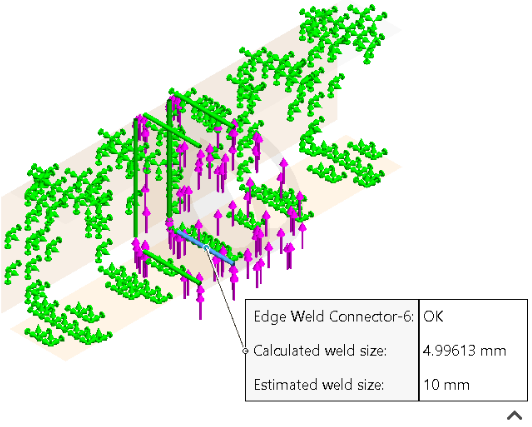
WELDMENT CHECK PLOT

To evaluate the structural strength of the welded connection between the lifting point and the I-beam, an Edge Weld Size Plot was generated using SolidWorks Simulation. This plot provides data on weld size (leg length) and weld throat thickness, h along the weld seam. The throat thickness is especially critical as it directly influences the shear strength of the weld. The pad eyes serve as critical lifting, transferring the applied load directly into the container frame. The welds connecting the pad eye to the container structure are subjected to high localized stresses due to the lifting forces, especially at the curved regions and sides where bending and tension are combined. Fillet welds are used for these connections due to their ability to distribute load across the throat of the weld and provide sufficient strength.

Based on the simulation results, the highest stress concentrations are found around the curved regions and sides of the pad eyes. However, these stresses remain well below the yield strength of the materials used, indicating that all welds are performing safely within design limits. As shown in Figure 10, each pad eye is attached to the container frame using multiple edge weld connectors. These connectors are numbered and strategically positioned to handle the directional forces during lifting. They play a critical role in maintaining the strength and stability of the entire lifting system.

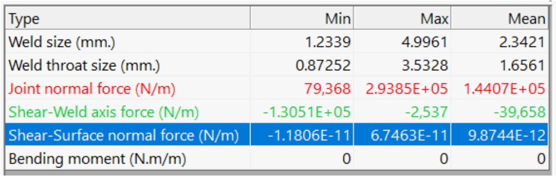
To ensure compliance with welding safety requirements, the weld configuration and performance are designed in accordance with internationally recognized standards. ASME B30.20 and AWS D1.1 emphasize critical aspects such as proper throat thickness, weld length, and fatigue resistance for lifting components. Meanwhile, ISO 3874 outlines handling and lifting requirements for intermodal containers, including the expected loading conditions, and lifting attachment criteria.

Edge weld connectors are critical elements used to simulate weld joints in structural assemblies, especially for lifting components such as container pad eyes. In this project, edge weld connectors were applied at pad eye locations on the I-beam container frame to represent fillet welds. The welding details are shown in Figure 11. Figure 12 shows the weldment size plot.



Edge Weld Connector-6:	OK
Calculated weld size:	4.99613 mm
Estimated weld size:	10 mm

FIGURE 10. Multi-edge weld connectors



Type	Min	Max	Mean
Weld size (mm.)	1.2339	4.9961	2.3421
Weld throat size (mm.)	0.87252	3.5328	1.6561
Joint normal force (N/m)	79,368	2.9385E+05	1.4407E+05
Shear-Weld axis force (N/m)	-1.3051E+05	-2,537	-39,658
Shear-Surface normal force (N/m)	-1.1806E-11	6.7463E-11	9.8744E-12
Bending moment (N.m/m)	0	0	0

FIGURE 11. Weldment details

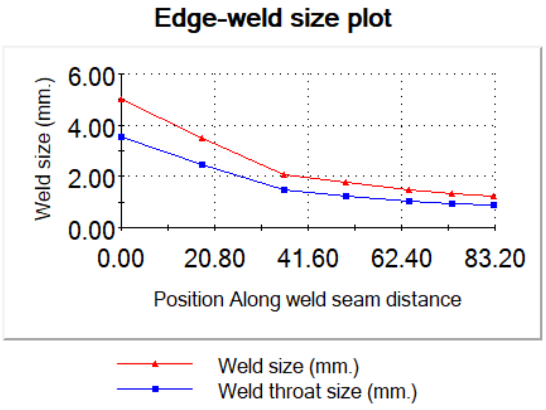


FIGURE 12. Weldment size plot

By analyzing each edge weld connector individually (Table 3), the required weld size was calculated based on force distribution from the lifting scenario. This approach provides an efficient verification of weld strength and optimizing weld layout. This approach also ensures that the design complies with international safety standards. Table 3 summarizes the calculated weld sizes (in mm) for each connector based on the simulation results

TABLE 3. Weld check

Lift lug	Edge	Weld size (mm)
1	1	1.26
	2	4.97
	3	3.40
	4	1.25
	5	3.43
	6	5.00

According to ASME BTH-1, lifting structures exposed to dynamic or fatigue loading conditions such as repetitive lifting of containers may require even higher safety factors depending on design category and use case. The decision to adopt an FOS of 5.0 ensures that the design remains robust, even in offshore or high-risk industrial environments.

Furthermore, weld design and quality are in line with AWS D1.1, which governs structural welding for steel. Although AWS D1.1 does not specify an FOS, it requires welds to transmit the design load including safety factors from applicable codes. In addition, ISO 5817 supports the assessment of weld quality by setting acceptance criteria for imperfections, ensuring the reliability of welded joints under operational conditions.

Lastly, the container structure and lifting point follow the guidelines in ISO 3874, which governs the lifting and securing of ISO containers. By adhering to proper loading paths, lifting angles, and weld evaluation practices, the overall design meets international safety standards for containers.

CONCLUSION

The simulation results showed that the von Mises stresses remained well below the yield strength of both structural steel S275 and alloy steel, confirming that the structure operates within safe elastic limits. The maximum stress recorded was 57.94 MPa, significantly lower than the material yield limits. Additionally, the displacement and strain results were minimal, further confirming that the container frame maintains high stiffness and structural stability under lifting loads.

A Factor of Safety (FOS) of 4.1 was maintained across all critical weld joints, complying with international standards such as ASME B30.20 and ISO 3874, and exceeding the minimum required safety factor of 3.0. Analysis of the edge weld connectors revealed that not all welds share the load equally. Certain connectors, particularly those at high-stress regions, carried most of the lifting load, with weld size requirements up to 4.9 mm. Overall, the weld design, material selection, and connector configuration demonstrate mechanical robustness, supported by both simulation results and manual calculations that validate the weld sizing. This confirms that the design meets the safety, reliability, and standard compliance requirements for lifting operations in industrial and offshore settings.

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DECLARATION OF COMPETING INTEREST

None.

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