



Loading Analysis of Electric Rail Car Body Spreader Redesign Using Finite Element Analysis Method

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Abstract. This study aims to analyze the structural performance of a redesigned adjustable spreader for Electric Train (KRL) carbodies under a maximum static operational load of 40 tons. The research employs the Finite Element Analysis (FEA) method using ANSYS Workbench 2024 R2 to evaluate three alternative cross-sectional profiles, namely hollow square, hollow rectangular, and hollow round, fabricated from SS400 steel. The analysis focuses on Von Mises stress, total deformation, and safety factor to determine the most reliable and efficient design configuration. The simulation results at the maximum 4000 mm span indicate that all redesigned profiles are structurally safe, with maximum Von Mises stresses ranging from 107 to 110 MPa, which remains well below the material yield strength of 205–245 MPa. Among the evaluated variations, the hollow square profile demonstrates the most optimal mechanical performance, exhibiting the lowest total deformation of 0.076663 mm and the highest safety factor of 3.011. Furthermore, this profile offers superior fabrication efficiency due to its flat surfaces, effectively resolving vulnerabilities and rigidity issues in the existing design.

Keywords: Adjustable Spreader; Electric Train; Finite Element Analysis; Hollow Square; SS400 Steel.

1. INTRODUCTION

The rapid urbanization in Indonesia has positioned the *Kereta Rel Listrik* (KRL) or Electric Train as a pivotal mass transit solution, particularly in the Jabodetabek region, to mitigate urban congestion and enhance commuter mobility. To meet the escalating passenger demand, PT Kereta Api Indonesia (KAI) has targeted the deployment of 11 new KRL sets by mid-2026, supported by national policies aiming to increase the modal share of rail transport by 2030 (Sahara et al., 2023). This ambitious expansion necessitates a significant surge in the manufacturing and retrofitting of critical railway components, notably the carbody and bogie assemblies, thereby demanding highly efficient and reliable production support systems.

In the manufacturing process, the spreader carbody serves as an essential lifting apparatus designed to distribute heavy loads evenly and prevent structural deformation during the hoisting of train bodies. However, the existing spreader designs utilized in railway manufacturing facilities face significant structural and operational challenges. Structurally, the main beams are prone to bending deformation, and weld joints frequently experience fatigue failure due to repeated cyclic loading during operations. Operationally, current designs lack versatility, as they are typically customized for a single train model, rendering them inflexible

and inefficient in a dynamic production environment that requires adaptable lifting mechanisms (Maswar, 2017; Nikkardar et al., 2025; Simonetto et al., 2025; Suryawan et al., 2025).

To address these limitations, the redesign of an adjustable spreader is imperative to accommodate varying train lengths and load configurations. Despite the critical nature of this equipment, there is a notable research gap in Indonesian academic literature regarding the structural optimization of railway lifting spreaders. Existing finite element analysis (FEA) studies in the local railway context predominantly focus on components such as wheelsets, traction rods, or brake discs, leaving the mechanical behavior and safety optimization of spreader carbody underexplored (Apriliani et al., 2023; Ilyasa et al., 2024; Muflikhun et al., 2023). Bridging this gap is crucial for developing a robust, adjustable lifting solution that enhances both safety factors and production throughput.

To systematically evaluate and optimize the spreader design, this study employs a computational approach integrating Computer-Aided Design (CAD) and Finite Element Analysis (FEA). The redesigned adjustable spreader models are developed using Autodesk Inventor, ensuring precise geometric representation based on actual carbody dimensions. Subsequently, the structural integrity of these models is validated through static structural simulations in ANSYS Workbench. The analysis specifically evaluates key mechanical responses under a maximum operational load of 40 tons, focusing on Von Mises stress distribution, total deformation, and the resulting safety factor to ensure compliance with stringent engineering standards.

Consequently, the primary objective of this research is to determine the most optimal cross-sectional profile (e.g., hollow square, hollow rectangular, or hollow round) for the redesigned adjustable spreader that yields the highest safety factor and structural rigidity. By comparing the simulated performance of these alternative designs against the existing model, this study aims to provide a theoretically sound and practically viable redesign. Ultimately, the findings are expected to offer tangible benefits to the railway manufacturing industry by minimizing the risk of structural failure during lifting operations, streamlining fabrication processes, and supporting the broader goal of efficient and safe KRL production.

2. THEORETICAL STUDY

The Electric Train (*Kereta Rel Listrik* or KRL) functions as a critical mass transit system engineered to withstand substantial axial, radial, and vertical loads throughout its operational lifecycle (Sugianto et al., 2023). The carbody serves as the primary structural framework, integrating the roof, side walls, end walls, and underframe to maintain geometric

integrity and passenger safety. Given the considerable mass of KRL units, specialized lifting apparatuses are indispensable during manufacturing, assembly, and retrofitting processes to prevent permanent deformation or structural damage. The spreader bar is a fundamental lifting device designed to distribute vertical loads evenly across multiple attachment points, thereby minimizing stress concentration and safeguarding the structural geometry of the lifted component (Habib & Shamsu, 2025; Suryawan et al., 2025).

Despite its critical function, conventional spreader designs in railway manufacturing facilities often exhibit structural and operational limitations. Existing models are typically rigid and customized for a single train configuration, lacking the adaptability required for dynamic production environments. Furthermore, these rigid designs are prone to main beam bending and weld joint fatigue under repetitive cyclic loading, which compromises both lifting safety and operational efficiency (Suryawan et al., 2025). To address these deficiencies, an adjustable (telescopic) spreader redesign is proposed to accommodate varying carbody lengths and load distributions. This modular approach enhances production flexibility, reduces the need for multiple custom lifting tools, and aligns with contemporary engineering standards that prioritize reusable and certified below-the-hook lifting devices (Kusuma et al., 2025).

The redesign process initiates with precise 3D geometric modeling using Computer-Aided Design (CAD) software, which enables accurate dimensional control, virtual prototyping, and seamless data transfer for numerical simulation (Budi & Sukmono, 2023). The structural performance of the proposed adjustable spreader is subsequently validated through Finite Element Analysis (FEA) in ANSYS Workbench, applying the static structural module to replicate real-world lifting conditions (Hasibuan, 2024). The simulation utilizes SS400 structural steel, a low-carbon alloy selected for its favorable strength-to-weight ratio, excellent weldability, and mechanical properties that comply with JIS G3101 standards (Fahmi et al., 2023).

Performance evaluation relies on three primary FEA outputs: Von Mises stress distribution to predict material yielding, total deformation to quantify structural rigidity under a 40-ton operational load, and the safety factor ratio to ensure adequate margins against fatigue and dynamic shock loads. By systematically comparing these parameters across hollow square, hollow rectangular, and hollow round cross-sectional profiles, the framework provides a rigorous basis for selecting the most structurally efficient and fabrication-friendly spreader design (Habib & Shamsu, 2025; Ilyasa et al., 2024).

3. RESEARCH METHODS

This study employs a quantitative, computational research design utilizing Finite Element Analysis (FEA) to evaluate and optimize the structural performance of a redesigned adjustable spreader for Electric Train (KRL) carbodies. The research is conducted using a Lenovo LOQ workstation, with Autodesk Inventor Professional 2024 employed for precise 3D geometric modeling of the spreader variations, which include hollow square, hollow rectangular, hollow round, and the existing baseline design. The structural material is defined as SS400 steel conforming to the JIS G3101 standard. The study manipulates the independent variable of cross-sectional profile design, while measuring the dependent variables of Von Mises stress distribution, total deformation, and safety factor. To ensure the validity of the comparative analysis, controlled variables are strictly maintained, including a static operational load of 40 tons (400 kN), a consistent mesh element size of 5 mm, and uniform boundary conditions across all simulations.

The methodological procedure follows a systematic FEA workflow within ANSYS Workbench 2024 R2, encompassing pre-processing, solution, and post-processing phases. During pre-processing, the 3D CAD models are imported, assigned SS400 material properties, and discretized. Boundary conditions are applied by setting fixed supports on the upper padeyes and distributing the 40-ton load across the designated lifting points. The static structural solver then computes the mechanical responses, which are extracted during post-processing to evaluate stress concentrations, displacement magnitudes, and safety margins. Finally, the simulation outputs are compiled and analyzed using descriptive statistics to comparatively assess the structural efficiency, rigidity, and safety compliance of each redesigned spreader profile against the existing model, ensuring the proposed design meets the minimum safety factor requirement of 3.0.

4. RESULTS AND DISCUSSION

Results

Geometric Modeling and Simulation Setup

The initial phase of this research involved the precise three-dimensional geometric modeling of the adjustable spreader using Autodesk Inventor software. Three distinct cross-sectional profiles were systematically designed to evaluate their structural performance under heavy lifting conditions in railway manufacturing. These profiles included hollow square, hollow rectangular, and hollow round configurations to determine the most optimal shape for load distribution. The telescopic mechanism was also seamlessly integrated into the models to

accommodate varying carbody lengths up to a maximum of 4000 mm. This comprehensive digital prototyping ensured that all geometric variables were strictly controlled before numerical simulation.

Following the design phase, the geometric models were exported and imported into ANSYS Workbench for finite element analysis. The structural material was strictly defined as SS400 steel, conforming to the JIS G3101 standard for general structural applications in heavy industry. A uniform mesh size of 5 mm was applied across all models to ensure computational accuracy and consistency during the solving process. This discretization process effectively divided the complex geometries into manageable finite elements for precise numerical calculation. The selection of this specific mesh density guaranteed that stress concentrations would be accurately captured without excessive computational cost.

The simulation setup required the precise definition of boundary conditions to replicate real-world lifting scenarios encountered in the workshop. Fixed supports were applied to the upper padeyes to accurately simulate the rigid connection points with the overhead crane hooks. Subsequently, a static operational load of 40 tons was distributed across the designated lower lifting points to mimic the weight of the carbody. These controlled conditions ensured that the comparative analysis between the different profiles remained scientifically valid and highly reproducible. The strict adherence to these boundary parameters provided a reliable foundation for evaluating the true structural capabilities of each design.

Structural Stress Distribution Analysis

The finite element analysis yielded critical data regarding the von Mises stress distribution across the redesigned spreader structures at the maximum span. For the 4000 mm width configuration, the hollow square profile exhibited the lowest maximum stress at an impressive 107.18 MPa. The hollow rectangular profile followed closely with a maximum stress of 107.35 MPa, indicating a highly efficient and uniform load distribution. Conversely, the hollow round profile recorded the highest stress value among the alternatives at 110.88 MPa due to its circular geometry. These stress concentrations were predominantly localized around the critical lifting lugs and the telescopic transition zones of the assembly.

Despite these localized peaks, all recorded stress values remained significantly below the yield strength of the SS400 material used in the simulation. The yield strength of this specific steel grade ranges between 205 MPa and 245 MPa depending on the exact thickness of the plate. Consequently, the structures operated entirely within the elastic deformation region, preventing any permanent plastic failure during the lifting operation. This substantial margin between the working stress and the yield point confirms the fundamental structural integrity of

the redesigned apparatus. The ability to maintain elastic behavior under such heavy loads is paramount for ensuring long-term durability in industrial applications.

Table 1. Simulation results of spreader with a width of 4000 mm.

No.	Design	Spreader Width	Deformation	Von Misses
1.	Existing	3529 mm	0.23008 Max	227.92 Max
2.	Hollow Square Profile	4000 mm	0.076663 Max	107.18 Max
3.	Hollow Rectangular Profile	4000 mm	0.093269 Max	107.35 Max
4.	Hollow Round Profile	4000 mm	0.096319 Max	110.88 Max

The presented data comprehensively summarizes the structural responses of all four spreader configurations at the maximum 4000 mm span width. It clearly illustrates the drastic reduction in stress and deformation achieved by the three redesigned profiles compared to the unsafe existing model. Notably, the existing design failed to meet safety standards with a factor below 1.0, highlighting the urgent necessity for the proposed geometric redesign. These quantitative results provide a definitive baseline for selecting the most efficient cross-sectional geometry for heavy-duty railway manufacturing applications. The data unequivocally demonstrates that the hollow square configuration offers the most balanced mechanical performance across all evaluated parameters.

Evaluation of Structural Rigidity and Deformation

Structural rigidity was rigorously evaluated by measuring the total deformation of each spreader profile under the applied 40-ton load. The hollow square profile demonstrated superior stiffness, recording the minimum total deformation of 0.076663 mm at the maximum 4000 mm span. The hollow rectangular profile exhibited slightly higher flexibility with a maximum deformation of 0.093269 mm, reflecting its specific moment of inertia. Meanwhile, the hollow round profile showed the greatest displacement at 0.096319 mm, reflecting its relatively lower bending resistance in this specific telescopic configuration. Maintaining these minimal deflections is absolutely crucial for preserving the geometric stability and balance of the lifted carbody.

The minimal deformation values observed across all redesigned profiles highlight their exceptional structural rigidity and resistance to bending moments. Maintaining deflection well below the 0.1 mm threshold is critical for preventing dangerous alterations to the center of gravity during lifting. Excessive bending during overhead crane operations could severely compromise load balance and introduce catastrophic safety hazards in the workshop. Therefore, the high stiffness of these designs ensures safe, predictable, and smooth maneuverability throughout the entire lifting sequence. Furthermore, the telescopic adjustment mechanism maintained its structural integrity without exhibiting any localized buckling during the simulation phase.

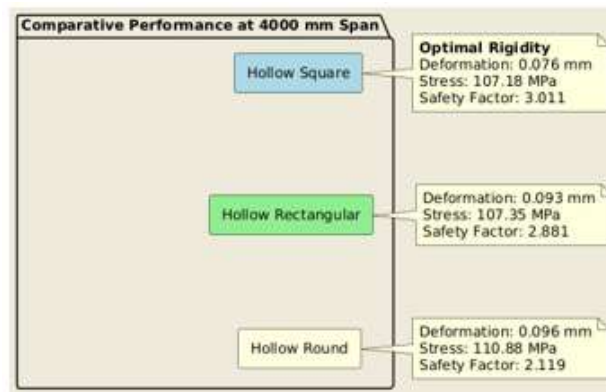


Figure 1. Comparative Performance at 4000 mm Span.

The generated visual diagram provides a clear comparative overview of the mechanical performance metrics for each profile at the 4000 mm span. It highlights the hollow square profile as the optimal choice, balancing the lowest deformation with the highest safety factor among the alternatives. The visual contrast effectively communicates the magnitude of improvement in structural stiffness achieved through the proposed geometric modifications. This graphical output serves as a rapid reference tool for engineering stakeholders to understand the superiority of the flat-sided profiles. Ultimately, the diagram reinforces the numerical findings regarding the enhanced load-bearing efficiency of the hollow square design.

Safety Factor and Operational Reliability

The safety factor serves as the ultimate metric for evaluating the operational reliability and shock-load resistance of the heavy lifting apparatus. At the maximum 4000 mm span, the hollow square profile achieved the highest safety factor of 3.011, successfully meeting the stringent industrial requirement. The hollow rectangular profile provided a robust safety margin of 2.881, ensuring adequate protection against dynamic lifting forces and minor shock loads. In contrast, the hollow round profile yielded the lowest safety factor of 2.1195, which, while technically safe, offers less buffer for unexpected operational shocks. These high safety margins confirm that the redesigned spreaders can easily withstand the dynamic forces inherent in overhead crane operations.

Beyond pure structural metrics, the geometric profiles significantly influence the practical fabrication and field application of the adjustable spreader. The flat surfaces of the hollow square and hollow rectangular profiles greatly simplify the cutting, alignment, and welding processes during manufacturing. These manufacturing advantages reduce production time and ensure higher precision when attaching critical components like padeyes and stiffener plates to the main beam. Consequently, the hollow square profile emerges as the most optimal choice, perfectly balancing maximum structural safety with superior fabrication efficiency.

This practical advantage ensures that the theoretical benefits of the design can be seamlessly translated into physical workshop applications.

Table 2. Simulation results of spreader with a width of 3750 mm.

No.	Design	Spreader Width	Deformation	Von Misses
1.	Existing	3529 mm	0.23008 Max	227.92 Max
2.	Hollow Square Profile	3750 mm	0.053545 Max	93.598 Max
3.	Hollow Rectangular Profile	3750 mm	0.069715 Max	93.706 Max
4.	Hollow Round Profile	3750 mm	0.062617 Max	98.247 Max

This dataset details the mechanical responses of the spreader designs when evaluated at an intermediate span width of 3750 mm. The results indicate a proportional increase in stress and deformation compared to the shorter span, yet all redesigned profiles remain well within safe operational limits. The hollow square profile continues to dominate in terms of minimal deformation, while the hollow rectangular profile exhibits a highly competitive safety factor. These intermediate findings reinforce the conclusion that the proposed geometric modifications consistently enhance structural reliability across varying operational dimensions. The consistency of these results across multiple span widths validates the robustness of the redesigned adjustable mechanism.

Discussion

The structural integrity of the redesigned adjustable spreader was successfully validated, as all three proposed cross-sectional profiles maintained Von Mises stresses between 107 MPa and 110 MPa under a maximum 40-ton load. These values remain significantly below the yield strength of the SS400 material (205–245 MPa), confirming that the structures operate entirely within the elastic deformation region. This finding aligns with the broader imperative to enhance railway manufacturing efficiency, as highlighted by Fathoni et al (2025) and Zahari & McLellan (2024), who noted the urgent need for robust production support systems to meet the escalating demand for new KRL units in Indonesia. Furthermore, this outcome strongly supports the work of Fathoni et al (2025), Ilyasa et al (2024), Pitjarnit et al (2024), and Firmansyah et al., (2026), who utilized Finite Element Analysis (FEA) to redesign a locomotive traction rod. Similar to their findings, the current study demonstrates that targeted structural redesigns in railway components can drastically reduce stress concentrations and eliminate the risk of plastic failure during heavy operational loads.

The viability of the adjustable (telescopic) mechanism in accommodating varying carbody widths up to 4000 mm without compromising structural safety is a critical achievement of this research. This result directly corroborates the findings of Li & Dong (2024), who designed a telescopic spreader bar for heavy industrial applications. While Suryawan et al. reported a higher maximum Von Mises stress (314.04 MPa) due to different material

specifications (ASTM A992) and loading conditions, both studies conclusively prove that telescopic mechanisms are structurally viable when geometric transitions are properly simulated. The current study expands on this by demonstrating that an adjustable spreader specifically tailored for KRL carriages can safely distribute massive vertical loads while eliminating the operational inflexibility inherent in rigid, single-model lifting tools.

Regarding structural rigidity, the hollow square profile emerged as the optimal design, recording the lowest total deformation of 0.076663 mm at the maximum 4000 mm span. This superior stiffness is attributed to its favorable moment of inertia, which effectively resists bending moments at the mid-span. This geometric optimization resonates with the research conducted by Kusuma et al (2025), who analyzed an 80-ton spreader bar for pressure vessel lifting. Kusuma et al. emphasized that specific geometric configurations are paramount for minimizing deflection and strain under extreme loads. The current study validates this principle within the context of railway manufacturing, proving that flat-sided profiles (square and rectangular) provide better resistance to vertical bending compared to the hollow round profile, which exhibited the highest deformation (0.096319 mm) due to its lower bending stiffness in this specific telescopic configuration.

The operational reliability of the redesigned spreader is further evidenced by its safety factor performance. The hollow square profile achieved a minimum safety factor of 3.011, successfully meeting the stringent requirement of ≥ 3.0 for lifting equipment subjected to dynamic or shock loads. This robust safety margin is crucial for compensating for real-world variables such as crane acceleration, sling angle variations, and minor load imbalances. This finding strongly aligns with the validated workflow for below-the-hook lifting devices proposed by Latif et al (2026) and Thomas & Thomas (2025), which stresses that FEA must demonstrate a substantial safety buffer to ensure operational reliability before physical deployment. In stark contrast, the existing rigid spreader design yielded a safety factor of only 0.914, highlighting its imminent risk of catastrophic failure and underscoring the critical necessity of the proposed redesign.

Beyond numerical performance, the practical implications of the chosen geometry significantly influence fabrication efficiency. The hollow square and hollow rectangular profiles offer distinct manufacturing advantages, as their flat surfaces simplify the precise alignment, cutting, and welding of critical components such as pad eyes and stiffener plates. This practical benefit is supported by Budi & Sukmono (2023), who highlighted that integrating precise Computer-Aided Design (CAD) modeling with FEA not only guarantees structural safety but also streamlines the overall manufacturing process by identifying and

resolving design flaws prior to physical prototyping. Consequently, the hollow square profile represents the most holistic solution for the railway workshop, perfectly balancing peak mechanical performance, operational safety, and manufacturing efficiency.

5. CONCLUSION

The Finite Element Analysis (FEA) of the redesigned adjustable spreader for KRL carbodies demonstrates that all three proposed cross-sectional profiles (hollow square, hollow rectangular, and hollow round) are structurally safe under a maximum static operational load of 40 tons at a 4000 mm span. The maximum Von Mises stress recorded across all redesigned models ranged from 107 MPa to 110 MPa, remaining well below the yield strength of the SS400 material (205–245 MPa). Among the evaluated variations, the hollow square profile exhibited the most optimal mechanical performance, achieving the lowest total deformation of 0.076663 mm and the highest safety factor of 3.011. This confirms that the hollow square design provides superior bending stiffness and an adequate safety margin to withstand operational shock loads, effectively resolving the structural vulnerabilities and rigidity issues present in the existing spreader model.

Beyond structural integrity, the implementation of the adjustable (telescopic) mechanism significantly enhances operational flexibility, allowing the apparatus to accommodate varying KRL carbody lengths without compromising lifting safety. From a manufacturing perspective, the hollow square and hollow rectangular profiles offer distinct practical advantages over the hollow round design. Their flat surface geometries greatly simplify the fabrication process, ensuring higher precision during the cutting, alignment, and welding of critical structural components such as pad eyes and stiffener plates. Consequently, the hollow square profile emerges as the most highly recommended design, as it perfectly balances maximum structural reliability, compliance with industrial safety standards, and high fabrication efficiency for railway manufacturing workshops.

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