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DESIGN AND FINITE ELEMENT ANALYSIS OF A HYDRAULIC MOBILE ELEVATING WORK PLATFORM

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Abstract: Mobile Elevating Work Platforms (MEWPs) can provide speed and flexibility, especially in areas such as painting, maintenance, cleaning, and warehouse operations, which require overhead access. This study presents the design and finite element analysis (FEA) of a novel hydraulic MEWP that enables both vertical and horizontal movement, enhancing operational flexibility and personnel safety compared to conventional systems. The main frame of the platform is designed to be movable and foldable, with stabilization legs that secure it in place during operation. The platform design includes a vertically movable section on the main frame and a horizontally movable suspension section attached to this part. Analyses were performed under maximum loading conditions. For the structural analysis, boundary conditions and material properties were defined based on the maximum total load to be supported by the system, excluding the cabin section of the platform. Based on the analysis results, the maximum stress on the platform was measured at 54.8 MPa, while the highest displacement observed in the structure was 15.8 mm at the sling section. Considering the working and loading conditions, the safety factor of the designed mobile lifting system was found to be 4.4, and it was concluded that the system offers a viable solution in terms of functionality.

Keywords: Lifting system, Mechanical design, Finite element analysis, Mobile elevating work platform, MEWP

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1. Introduction

Mobile Elevating Work Platforms (MEWPs) for personnel lifting are essential tools in various industries, providing safe and efficient means for workers to reach elevated areas. Recent findings regarding the design, safety, usability, and technological advancements associated with these platforms are investigated. MEWPs can be categorized into three primary types based on their design, functionality, and application: scissor lifts, boom lifts, and mast lifts. Each category addresses specific operational needs and contributes to enhancing safety, usability, and productivity.

Scissor lifts utilize a crisscrossing mechanism to enable vertical lifting, offering stable and elevated access over a broad area. They are particularly useful in environments such as warehouses and construction sites, where equipment assembly and material handling at height are common tasks (Ermiş et al., 2021). Scissor lifts come in various models, including manual, electric, and hydraulic versions, catering to different operational requirements and load capacities (Kart et al., 2023). Advanced designs often incorporate features like automatic deployment of support arms and dynamic response to improve stability in windy conditions, as demonstrated by Jack et al. (2021), Bošnjak et al. (2009) and Augustyn et al. (2023). The safety and usability aspects of scissor lifts have been extensively studied. Pan et al. (2012) highlighted the importance of fall-arrest systems, revealing that many fatal injuries occur within the operational range of these platforms. Similarly, Pan et al. (2017) evaluated postural sway and impact forces during the ingress and egress of scissor lifts, providing data-driven recommendations to enhance operational safety. Recent innovations focus on improving maneuverability and ergonomics. Kart et al. (2023) proposed a hydraulic walking power steering-controlled scissor lift platform, specifically designed for confined spaces in industrial applications. This design combines enhanced safety features with ease of use, aligning with ergonomic principles.

Boom lifts are versatile platforms categorized into two main types: articulated and telescopic. Articulated boom lifts feature joints that allow the platform to navigate around obstacles, making them ideal for complex work environments like urban construction sites (Hu et al., 2017). Telescopic boom lifts, on the other hand, extend straight up and are better suited for tasks requiring high vertical reach without lateral movement (Li et al., 2022). The integration of advanced technologies in boom lifts has further enhanced their functionality. Jia et al. (2012) explored adaptive neural network control for boom lift arms, demonstrating improved precision and responsiveness. This integration of artificial intelligence contributes significantly to safer and more efficient operations.

Mast lifts are compact platforms designed primarily for indoor use, where tight maneuvering is required. They often feature a vertical mast that can extend upwards, with a platform that can be raised and lowered. They are often employed in tasks like electrical work or warehouse maintenance (Li et al., 2022). Electric motors, pneumatic or hydraulic systems power these platforms. They are suitable for a wide range of tasks, from maintenance work to installation of fixtures in high spaces. Studies have shown that the structural integrity of the mast and its connections plays a significant role in maintaining stability during operation.

In this study, the design and finite element analysis (FEA) of a hydraulic MEWP were conducted. While the MEWP design shows similarities with mast lift systems, it incorporates notable differences. The lifting mechanism consists of supported dual-sided slides instead of a vertically oriented mast. This configuration allows the simultaneous lifting of two personnel instead of one, resulting in a more rigid structure. Additionally, the inclusion of auxiliary ladders enhances the design, making it a multifunctional product tailored for specialized applications. The study presents the components, mobility features, and characteristics of the designed system. The system's behaviour under maximum load conditions was analyzed through simulations and subsequently validated through experimental testing of the manufactured product.

2. Materials and Methods

The design of MEWPs is a complex process that integrates various engineering principles, safety standards, and user requirements. One of the primary considerations in the design of MEWPs is the structural integrity and safety under operational conditions. Researches underscore the necessity of rigorous testing and analysis in the design phase to ensure that MEWPs can withstand environmental stresses. FEA has become a cornerstone in this field. In the conducted studies, research has been carried out on the mechanical properties of mobile lifting systems using FEA to evaluate structural safety, assess issues such as tilting and manual decoupling, and validate design optimization (Uludamar and Tuccar, 2017; Karagulle et al., 2022; Huang et al., 2023; Zhang et al., 2023). Findings underscore the importance of detailed stress and deformation analyses for ensuring the reliability of mast lifts in industrial applications. Safety remains a paramount concern in MEWP operations. Updated guidelines emphasize the importance of proper training and adherence to safety protocols to minimize injury risks. Pan et al. (2017) provided foundational research on fall-arrest systems and ergonomic ingress/egress procedures, influencing industry standards. Innovations such as real-time monitoring systems and tactile sensors have significantly enhanced MEWP operations. He et al. (2023) introduced tactile mobile manipulators, showcasing the potential for autonomous operation in warehouses. These platforms use advanced sensors to interact with objects, improving load-handling efficiency. Jia et al. (2012) and Fang et al. (2023) highlighted the role of adaptive and fast luffing control systems in boom lifts, while Ouyang (2024) demonstrated the application of pulse width modulation (PWM) technology in lifting platform control systems, enabling dynamic speed adjustments for enhanced safety.

As the demand for safe and efficient lifting solutions grows, research will continue to focus on structural design, automation, advanced materials, and integrated safety systems. Areas such as AI-driven control systems, real-time structural monitoring, and ergonomic designs are expected to dominate future developments. These advancements aim to not only meet but exceed industry standards for safety and efficiency (Kennedy et al. 2020). MEWPs for personnel lifting highlight the critical importance of safety, usability, technological innovation, and training. Through continuous innovation and rigorous safety analyses, these platforms are evolving to address the growing demands of modern workplaces while ensuring the highest safety standards. Figure 1 shows the various types of industrial MEWPs.

2.1. Design of the Hydraulic Mobile Elevating Work Platform

Accurate positioning is critically important for efficiency and quality in processes such as painting, manufacturing, and maintenance. The developed system is designed to ensure personnel safety in high-risk areas and enable precise positioning. Most studies in the industry have focused on developing products for areas with access difficulties on planar surfaces. However, unlike previous studies, this research aims to design a mobile access platform capable of precise positioning in both the horizontal and vertical axes. A hydraulic telescopic cylinder has been utilized for the elevation of the designed MEWP. Additionally, to facilitate easy access for personnel working at height, an extra telescopic cylinder has been integrated to provide horizontal extension. The movement of the system on the ground is controlled by motors mounted on the wheels, allowing seamless access to the desired work areas and enabling personnel to be directed to the work site using suspension ropes. The system is operated via a control panel located on the command unit. Unlike the single telescopic lifting mechanisms commonly found in mast lifts, the proposed system features a lifting mechanism supported on both sides. This design choice enhances rigidity and safety while allowing two personnel to work simultaneously, ensuring a more stable and secure working environment. Figure 2 shows the closed and extended positions of the developed system.

Figure 1. a) Articulating boom lift (Anonymous, 2025a), b) Scissor-lift (Anonymous, 2025b) c) Vertical mast lift (Anonymous, 2025c), d) Pneumatic vertical lift (Anonymous, 2025d), e) Telescopic boom lift (Anonymous, 2025e), f) Telescopic maintenance lift (Anonymous, 2025f).

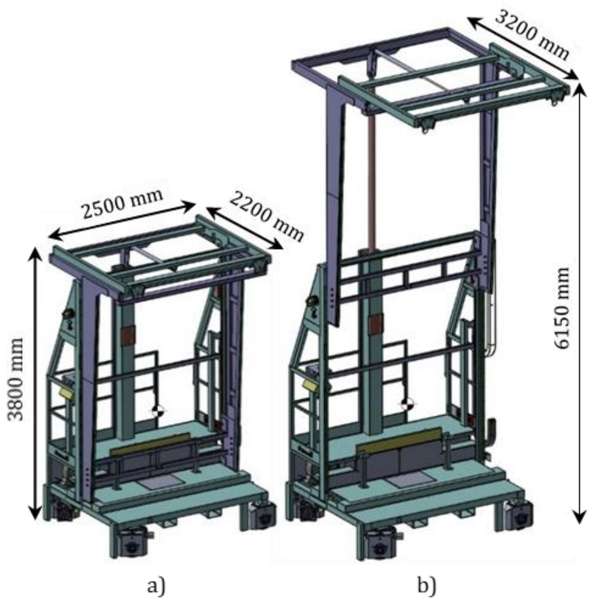


Figure 2. Positions of the developed system: a) Closed, b) Extended

2.2. Structural Analyses of the MEWP

Detailed 3D models were created using SolidWorks CAD software. Assembly and motion analyses were conducted to ensure compatibility between components. Simulations under various conditions were performed to identify potential issues in advance. Safety, functionality, durability, and ease of use were prioritized. A modular structure was preferred to facilitate maintenance and repair. The development of a secure and robust mobile access platform was achieved, enhancing operational flexibility and efficiency. The working conditions in which personnel are on the system are illustrated in Figure 3. As can be seen from the figure, two personnel are suspended by ropes on the system and are working on the work piece. This scenario also represents the maximum loading condition of the system.

Defining boundary conditions in FEA is a critical aspect that significantly influences the accuracy and reliability of the simulation results. Boundary conditions dictate how the model interacts with its environment, and improper definitions can lead to erroneous results, misinterpretations, and potentially unsafe designs. One of the primary reasons for the importance of boundary conditions is their role in accurately representing physical constraints and interactions.

During the development of the finite element model, quadrilateral, triangular, hexahedral, and tetrahedral elements were utilized. The modeling process primarily focused on the use of quadrilateral and hexahedral elements. Triangular and tetrahedral elements were incorporated strategically to define nodal points according to the geometries of the components while maintaining element quality. Quadrilateral and hexahedral elements provide higher solution accuracy compared to triangular and tetrahedral elements. They offer a more precise representation of stress and deformation distributions, particularly in critical regions. Furthermore, models constructed using quadrilateral and hexahedral elements exhibit greater computational efficiency, leading to reduced solution times compared to those composed of triangular and tetrahedral elements. Therefore, special attention was given to maximizing the use of quadrilateral and hexahedral elements in the modeling process. The FEA model of the system is presented in Figure 4.

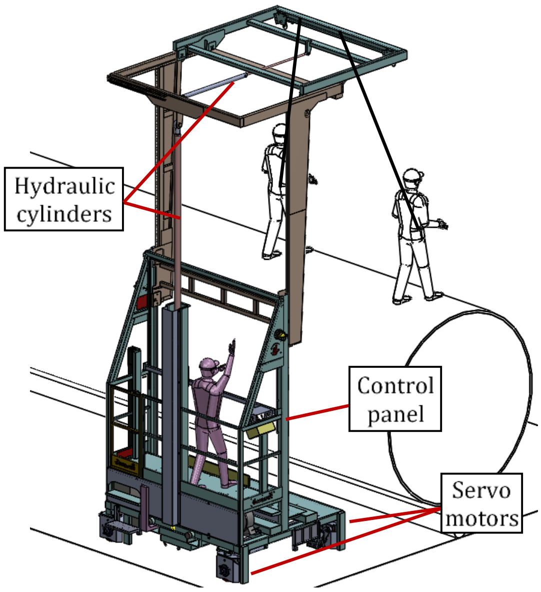


Figure 3. MEWP components and working conditions of the personnel.

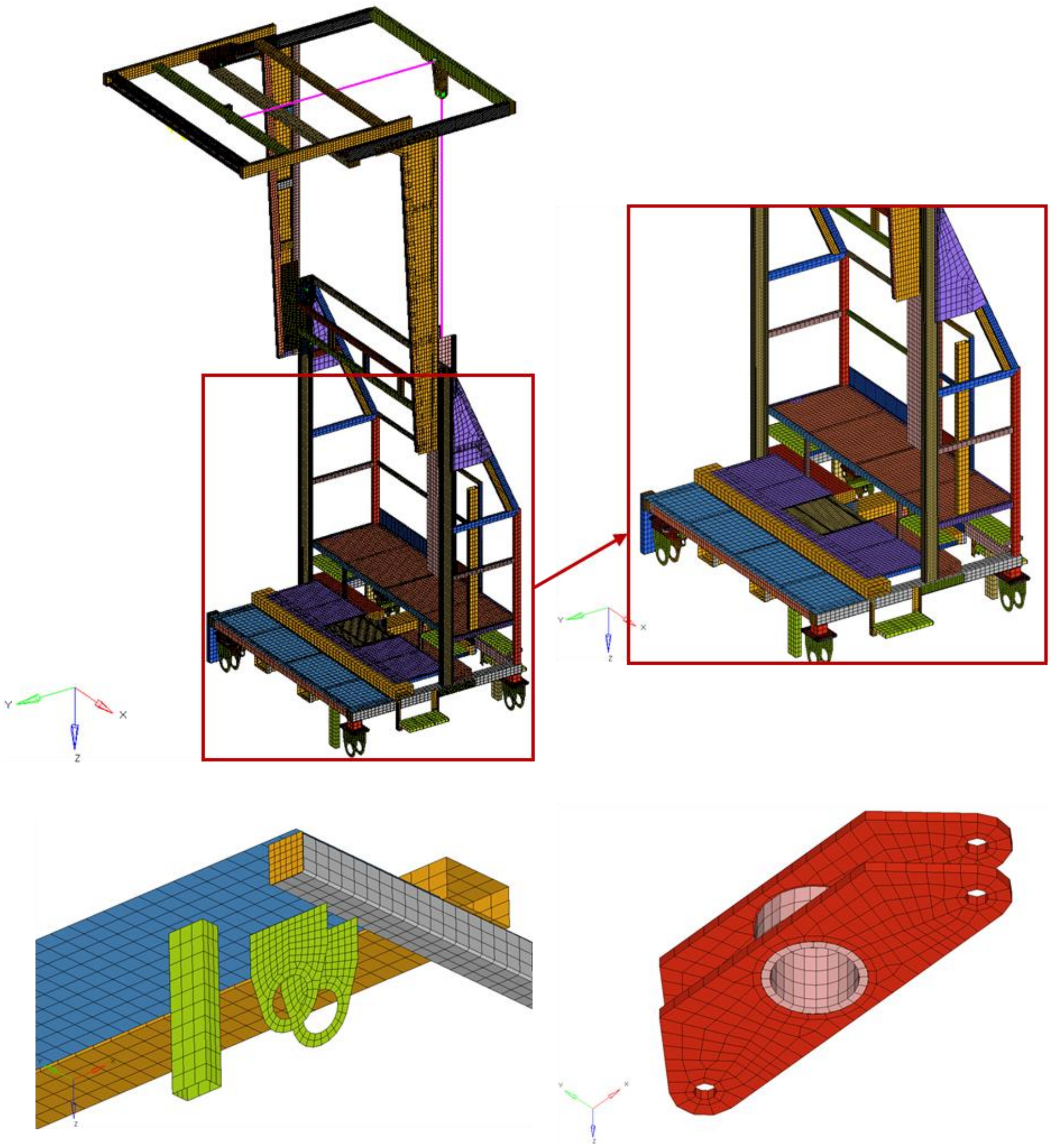


Figure 4. FEA model of the system.

In the MEWP, solid components were modeled using three-dimensional elements, while sheet metal parts were modeled using two-dimensional elements. 2D elements are used in modeling structures that are predominantly planar, such as thin plates, shells, and membrane structures. They are commonly applied in plane stress and plane strain problems. 2D elements can be quadrilateral (four-node bilinear) or triangular (three-node linear). The shape functions for a linear triangular element are given by equation 1. A is the area of the triangle, a_i, b_i, c_i are coefficients derived from the nodal coordinates. The strain-displacement matrix B for a triangular element is indicated in equation 2. The constants b_i and c_i are calculated using the nodal coordinates (x_i, y_i) of the element as in equation 3 (Cook et al., 2002; Zienkiewicz et al., 2013).

$$N_i = \frac{1}{2A}(a_i + b_i x + c_i y), \ i = 1, 2, 3 \quad (1)$$

$$B = \frac{1}{2A}\begin{bmatrix} b_1 & 0 & b_2 & 0 & b_3 & 0 \\ 0 & c_1 & 0 & c_2 & 0 & c_3 \\ c_1 & b_1 & c_2 & b_2 & c_3 & b_3 \end{bmatrix} \quad (2)$$

$$\begin{pmatrix} b_1 = y_2 - y_3, \ b_2 = y_3 - y_1, \ b_3 = y_1 - y_2 \\ c_1 = x_3 - x_2, \ c_2 = x_1 - x_3, \ c_3 = x_2 - x_1 \end{pmatrix} \quad (3)$$

The shape functions for a bilinear quadrilateral element in natural coordinates (ξ, η) are given in equation 4 (Bathe, 2014).

$$N_i = \frac{1}{4}(1 + \xi_i \xi)(1 + \eta_i \eta), i = 1, 2, 3, 4 \quad (4)$$

The strain-displacement matrix B is derived using the Jacobian matrix J as shown in equation 5.

$$B = J^{-1}\frac{\partial N}{\partial(\xi, \eta)} \quad (5)$$

3D elements are necessary for problems requiring a full three-dimensional representation, such as solid mechanics applications. 3D elements are used for solid body analysis and can take the form of tetrahedral (four-node) or hexahedral (eight-node) elements. The shape functions for a linear tetrahedral element are given in equation 6. V is the volume of tetrahedron and a_i, b_i, c_i, d_i are coefficients derived from the nodal coordinates. The strain-displacement matrix B for a tetrahedral element is given in equation 7. The constants b_i, c_i and d_i are calculated using the nodal coordinates (x_i, y_i, z_i) of the element as in equation 8 (Zienkiewicz et al., 2013) (b_2, c_2 and d_2 can be calculated with similar equations).

$$N_i = \frac{1}{6V}(a_i + b_i x + c_i y + d_i z), \ i = 1, 2, 3, 4 \quad (6)$$

$$B = \frac{1}{6V}\begin{bmatrix} b_1 & 0 & 0 & b_2 & 0 & 0 & b_3 & 0 & 0 & b_4 & 0 & 0 \\ 0 & c_1 & 0 & 0 & c_2 & 0 & 0 & c_3 & 0 & 0 & c_4 & 0 \\ 0 & 0 & d_1 & 0 & 0 & d_2 & 0 & 0 & d_3 & 0 & 0 & d_4 \\ c_1 & b_1 & 0 & c_2 & b_2 & 0 & c_3 & b_3 & 0 & c_4 & b_4 & 0 \\ 0 & d_1 & c_1 & 0 & d_2 & c_2 & 0 & d_3 & c_3 & 0 & d_4 & c_4 \\ d_1 & 0 & b_1 & d_2 & 0 & b_2 & d_3 & 0 & b_3 & d_4 & 0 & b_4 \end{bmatrix} \quad (7)$$

$$\begin{pmatrix} b_1 = (y_2 z_3 - y_3 z_2) + (y_3 z_4 - y_4 z_3) + (y_4 z_2 - y_2 z_4) \\ c_1 = (z_2 x_3 - z_3 x_2) + (z_3 x_4 - z_4 x_3) + (z_4 x_2 - z_2 x_4) \\ d_1 = (x_2 y_3 - x_3 y_2) + (x_3 y_4 - x_4 y_3) + (x_4 y_2 - x_2 y_4) \end{pmatrix} \quad (8)$$

The shape function for a trilinear hexahedral element in natural coordinates (ξ, η, ζ) are given in equation 9. The strain-displacement matrix B is derived using the Jacobian matrix J as shown in equation 10 (Bathe, 2014; Hughes, 2000).

$$N_i = \frac{1}{8}(1 + \xi_i \xi)(1 + \eta_i \eta)(1 + \zeta_i \zeta), \ i = 1, 2, \ldots, 8 \quad (9)$$

$$B = J^{-1}\frac{\partial N}{\partial(\xi, \eta, \zeta)} \quad (10)$$

The entire MEWP structure was subjected to a standard gravitational acceleration of 9.8 m/s^2. St-37 steel, suitable for general purpose use, economical, and easily machinable, is preferred in many industrial applications. St-37 is a low carbon structural steel with good weldability. Due to the relatively low loads in the designed system, St-37 steel was deemed appropriate for all components. The material used has an elastic modulus of 210 GPa, a Poisson's ratio of 0.3, and a density of 7850 kg/m^3.

Constraints were applied to model the movements of the wheels attached to the MEWP, considering a total of six degrees of freedom: three translational and three rotational axes. Linear axes were constrained according to standard vehicle dynamics. In the analysis, the most challenging operating conditions were considered, with a total load of 300 kg, simulating two persons suspended in the middle of the structure and one person weighing 150 kg (Figure 5-a). The constrained freedoms in the linear axis are indicated in Figure 5-b, while all degrees of freedom in rotation were left unrestricted.

3. Results and Discussion

The system's durability has been rigorously tested under the maximum loads and most challenging conditions. For this purpose, a total load of 300 kg was applied to the component where the personnel ropes are attached. It is undesirable for the system to be excessively overdesigned or to fall below safety limits. According to the Machinery Safety Regulation (2006/42/EC), All metallic components that constitute a sling and are used in conjunction with it must have a working coefficient that ensures an adequate level of safety; as a general rule, this coefficient is equal to 4.

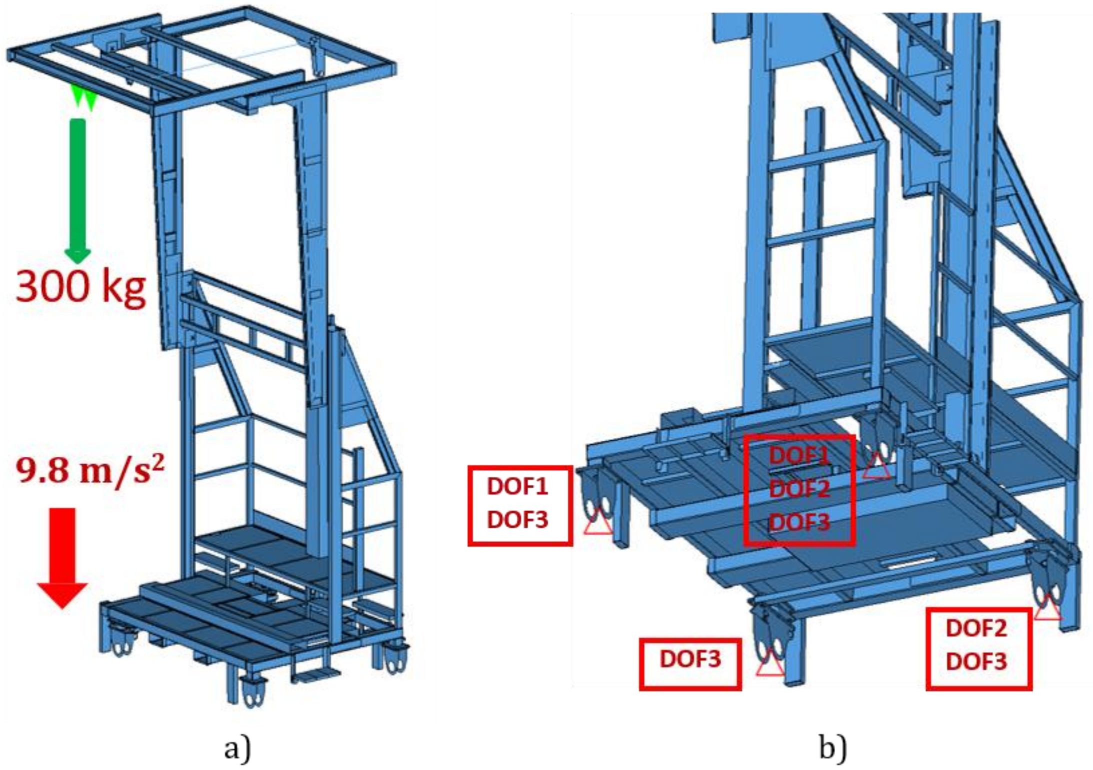


Figure 5. a) Boundary conditions-loading, b) degree of freedom for movement of MEWP.

An overly safe system leads to unnecessary material usage and increased costs, while a system with a low safety factor may compromise worker safety. Therefore, finite element analyses were repeated to ensure a minimum safety factor of 4, and material optimization was performed on the system components. In figure 6, the displacement results are presented.

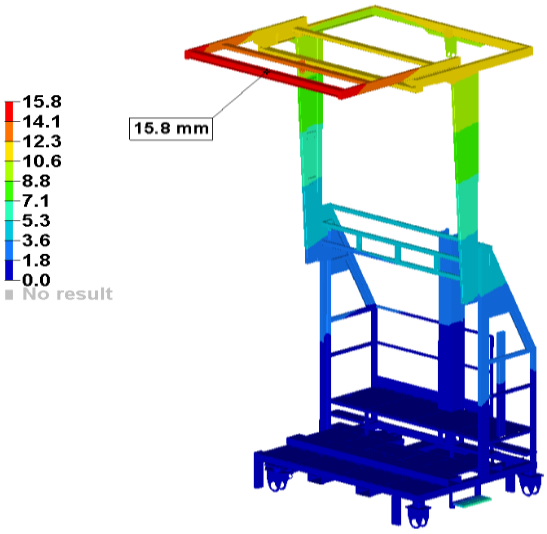


Figure 6. Displacement results for the system

The maximum stress value was observed in the profile located in the subframe section of the structure. A mesh convergence study was conducted specifically for this profile. As indicated in the Table 1 and visual representations in Figure 7, despite increasing the number of elements and reducing the mesh size, the difference in observed stress values decreased. When comparing mesh sizes, the difference in stress values was found to be less than 1%. The stress values obtained from the analysis were computed according to the Von Mises criterion.

Table 1. Mesh convergences values

Mesh Size	Stress Value	Total Elements	Difference (%)
20 mm	46.8 MPa	2304	-
15 mm	48.8 MPa	2544	4.2
10 mm	54.1 MPa	2976	9.8
9 mm	54.7 MPa	3294	1.1
8 mm	54.8 MPa	3748	0.2

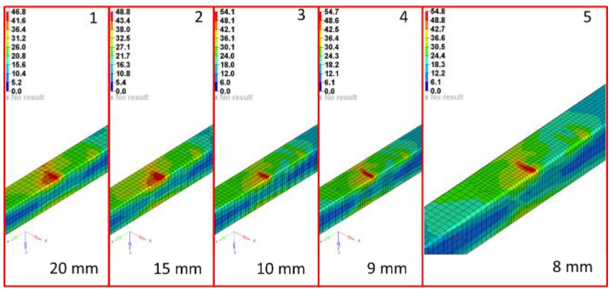


Figure 7. Mesh convergences stress values

The results of the optimized system are presented in Figure 8. The highest Von Mises stress observed in the structure was recorded as 54.8 MPa at the location indicated in the Figure 8. The filtering applied in the right figure includes only values above 40 MPa. The maximum displacement observed in the structure was recorded as 15.8 mm at the region where the workers' ropes are suspended.

According to the structural static analysis results, the maximum displacement in the system is 15.8 mm, while the maximum stress is 54.8 MPa, which provides a safety factor of 4.4 relative to the yield strength of St-37 material (235 MPa). The maximum displacement value does not impact the operational functionality of the system. After achieving the optimum system design, the production phase has commenced. Additionally, in the final design, a ladder was added to the left side of the MEWP. This ladder is an optional component and does not impact the analysis results. Figure 9 displays the solid model of the finalized system and its manufactured version. The produced system was subjected to loads at the suspension points, and the results obtained were consistent with the analysis outcomes. Additionally, the hydraulic systems and servo motors of the system were controlled to test its precise positioning. All conducted tests confirmed that the manufactured system aligns with the analysis and design results.

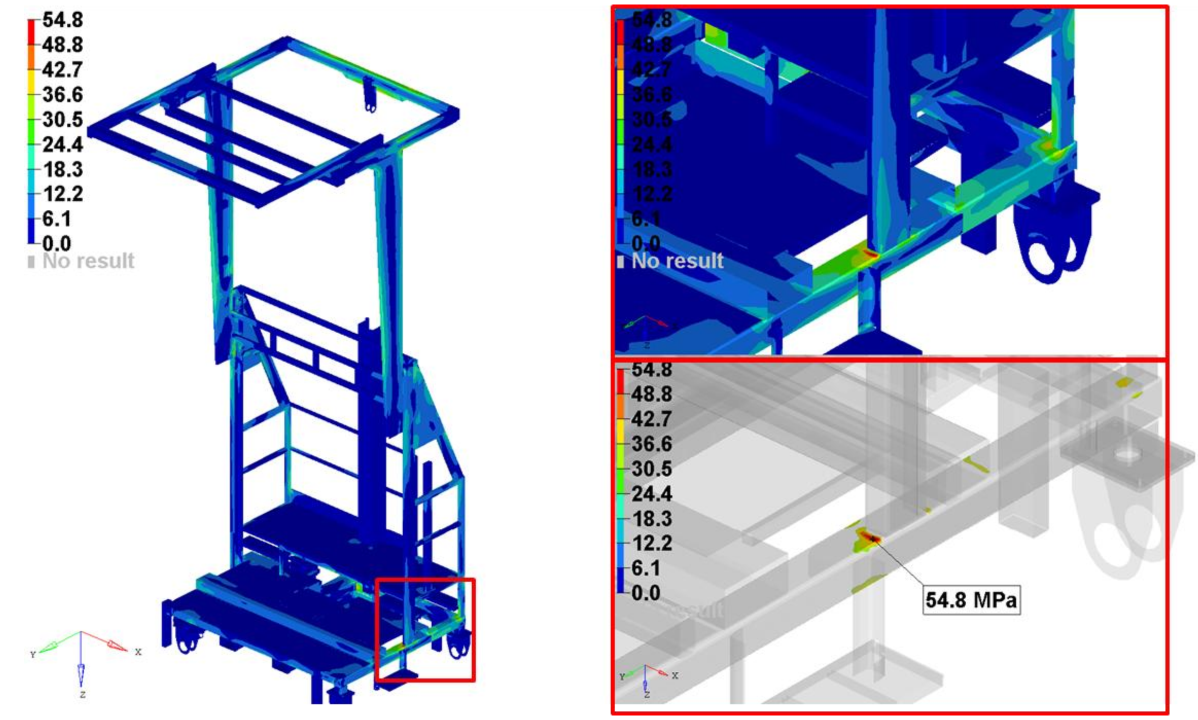
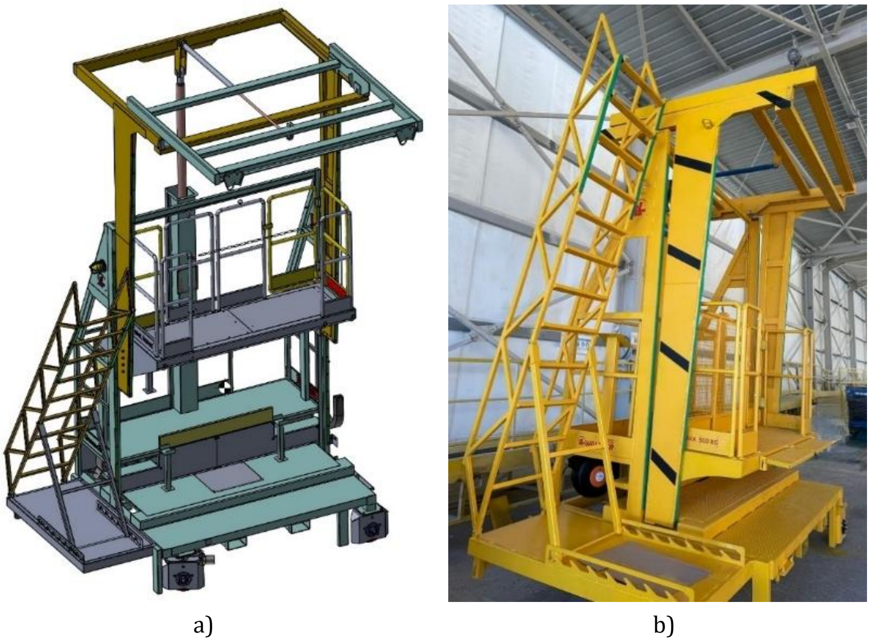


Figure 8. Stress analysis results of the system.



a) b)

Figure 9. a) Final 3-D design of the system, b) Produced system.

5. Conclusion

This study focused on the design, analysis, and testing of a hydraulic Mobile Elevating Work Platform (MEWP) capable of precise vertical and horizontal positioning. The platform was designed to ensure personnel safety and operational efficiency in high-risk environments, incorporating a dual-sided lifting mechanism that allows two personnel to work simultaneously. FEA was employed to evaluate the structural integrity of the system under maximum loading conditions, with a total load of 300 kg applied to simulate real-world operational scenarios. The analysis revealed a maximum Von Mises stress of 54.8 MPa and a maximum displacement of 15.8 mm, resulting in a safety factor of 4.4 relative to the yield strength of the St-37 steel used in the design.

These results confirm that the system meets stringent safety requirements while maintaining structural stability. The integration of hydraulic telescopic cylinders for vertical and horizontal movement, along with a modular design, enhances the platform's functionality and ease of maintenance. Experimental testing of the manufactured system validated the FEA results, demonstrating consistent performance under load and precise positioning capabilities. The addition of an optional ladder further improves accessibility without compromising the system's structural integrity. This research contributes to the advancement of MEWP technology by addressing the need for safer, more efficient, and versatile lifting solutions in industrial applications. The findings of this study provide a robust foundation for the development of next-generation MEWPs, ensuring they meet the evolving demands of modern workplaces while prioritizing worker safety and operational efficiency.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	O.G.	O.B.S.	T.G.	S.D.	M.S.
C	20	20	20	20	20
D	20	20	20	20	20
S	-	-	-	-	100
DCP	20	30	30	20	-
DAI	30	30	30	10	-
L	10	10	10	10	60
W	20	10	10	10	50
CR	20	20	20	20	20
SR	20	20	20	20	20
PM	25	25	25	25	-
FA	25	25	25	25	-

C=Concept, D=design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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