An Applied Mechanics Approach to Designing a Variable-Height Dock Leveler at Kuwait Port

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ABSTRACT

A dock leveler is a crucial platform used at loading docks to bridge the gap between a truck bed and the dock surface, which facilitates the safe and efficient transfer of goods using forklifts. The purpose of this study is to design a PNIS dock leveler that optimizes cost efficiency while enhancing operational performance. The proposed design offers a robust and effective solution tailored for implementation at Shuwaikh Port in Kuwait. A comprehensive analysis of the system is conducted using ANSYS for design simulation under various operational conditions and SolidWorks for precise design modeling. The analysis confirms that the ASTM A36 structure, with a yield strength of 250 MPa, ensures a robust and reliable design. The findings indicate that the improved structure minimizes deflection to 3.28 mm and stress to 218.23 MPa while maintaining a sufficient factor of safety, effectively addressing previous design limitations and enhancing overall performance.

Keywords-PNIS; dock leveler; automation; ANSYS; SolidWorks; modeling; height adjustment

I. INTRODUCTION

A. *Solid Mechanics and Structural Consideration*

Solid mechanics is one of the principal engineering fields concerned with the deformation of materials in response to applied forces and stress. It is critical in the performance and design of mechanical structures, such as dock levelers, which undergo repeated unloading and loading cycles. The operation and strength of dock levelers rely on their ability to resist varying forces while being stable and long-lasting. Several principles of solid mechanics are particularly relevant to dock leveler design:

- Stress and Strain Analysis: Mechanical stresses are encountered by dock levelers due to the weight of forklifts, pallet jacks, and cargo. Stress distribution needs to be understood to prevent excessive deformation and potential structural failure [1].

- Deflection and Flexibility: Dock levelers must be designed to accept differences in truck height without compromising structure stability. Too much deflection would compromise safety [2].
- Material Selection: Materials play a direct role in determining the strength, durability, and performance of dock levelers.

B. Dock Leveler Overview

Dock levelers are crucial mechanisms that create safe and effective loading and unloading procedures by bridging the distance or height gap between a truck, a ship or a trailer bed and a loading dock [3, 4]. The primary job of such mechanisms is to ensure efficient and safe material transfer with minimum manual work. Forklifts and pallet jacks may not perform their intended tasks easily in the absence of a dock leveler [5]. This is since different trucks have different height dimensions with respect to the warehouse or loading dock surface. This variation in height for various scenarios is addressed by dock levelers. Moreover, dock levelers play a vital role in several industries, including manufacturing, distribution, and warehousing as they simplify operations, and boost productivity [6]. By offering a safe environment for loading tasks, not only do they enhance productivity, but also reduce the risk of accidents. Limiting the accidents, cutting downtime, and expediting the loading and unloading processes, increases operational efficiency. These advantages are translated for companies into increased throughput, lower operating costs, and better safety measures.

II. BACKGROUND AND METHODOLOGY

This study proposes a Platform with Non-Identical Stiffeners (PNIS) dock leveler as an innovative solution. The proposed design is intended to enhance productivity in high-traffic logistics environments, such as Shuwaikh Port in Kuwait. It ensures seamless operation and improved reliability. The design addresses the limitations of existing dock levelers, which often struggle to tackle the demands of high-volume logistics hubs, where durability, fast operation, and flexibility are critical.

A. Limitations of Existing Dock Levelers

To highlight the need for an improved design, Table I summarizes the limitations in addition to the advantages of four common dock leveler types, namely mechanical, air-powered, hydraulic, and vertical systems.

B. The Proposed Solution: Platform with Non-Identical Stiffener Dock Leveler

PNIS Dock Leveler offers an optimized balance of cost, performance, and flexibility, which address the key limitations of existing dock levelers. This design integrates non-identical stiffeners, which enhance structural integrity while reducing weight and material costs. These stiffeners aid in distributing the load effectively [11]. Additionally, it is designed to accommodate both hydraulic and pneumatic systems, providing short operational times, increased reliability, and high load-carrying capacity. This adaptability allows the system to function using either mechanism independently. Nevertheless, while the dual-system adaptability is grounded in solid engineering principles, it has yet to be tested in real-world conditions.

TABLE I. COMPARISON OF EXISTING DOCK LEVELER TYPES, THEIR ADVANTAGES, AND LIMITATIONS

Dock leveler type	Advantages	Limitations
Mechanical	• Low initial cost. • Energy-efficient	• Labor-intensive. • High wear and tear Costly long-term maintenance [7]
Air-Powered	• Smoother operation • Lower maintenance • Durable for high-volume applications [8]	• Higher upfront cost • Dependent on compressed air supply
Hydraulic	• Reliable for heavy loads • Precise control • Quick operation [9]	• Higher installation and maintenance cost • Space
Vertical	• Compact • Improves hygiene • Reduces energy loss [10]	• Limited application • Typically more expensive

The key advantages of the proposed solution include:

- Enhanced load-bearing capacity with optimized stiffener placement.
- Reduced long-term maintenance costs due to improved structural efficiency.
- Smoother height adjustments, ensuring seamless functionality.
- Adaptability to different operational requirements through flexible system configurations.

Furthermore, this solution aligns with a variety of standards, including Kuwait, OSHA, and ANSI standards [12-14] for port operations and infrastructure, ensuring regulatory compliance while setting a new benchmark for cost-effective and high-performance dock levelers.

1) Economic Viability

The PNIS dock leveler offers significant economic advantages over conventional models. Hydraulic dock levelers typically range from $4,500 to $10,000 per unit, depending on capacity and features [15]. By optimizing material usage with non-identical stiffeners, the PNIS design could reduce manufacturing costs by approximately 10–15%. With improved structural efficiency and corrosion-resistant coatings, the PNIS dock leveler is projected to reduce maintenance expenses by about 20–25%.

C. Validation Approach

The PNIS dock leveler undergoes rigorous validation to ensure its reliability and efficiency under real-world conditions. The following methodologies are implemented to model the structure and simulate its behavior, when loaded.

1) 3D Modeling

SolidWorks is used for precise 3D modeling and visualization, allowing an in-depth assessment of the design structure.

2) Design Simulation

ANSYS is employed to simulate static loading conditions, and evaluate stress distribution, deflection, and factors of safety under various operational scenarios.

D. Material Selection

Manufacturing any piece of structure requires that critical consideration be given to the material being used. Ensuring safety, affordability, quality, durability, and many other characteristics critically depends on material selection [16]. This occurs since different materials possess distinctive properties that limit their applications. Considering the demanding conditions that dock levelers often encounter, it has been concluded, through intensive literature research [17-19], that steel is employed for such applications. Steel can resist heavy loads that are subjected frequently (Dynamic loads) due to its strength and durability. This makes it suitable for dock levelers as they handle the weight of the goods and forklift truck, which is driven on dock leveler's platform. Another reason is that such a material can easily be fabricated and assembled into complex shapes or structures [20]. Furthermore, it is a cost-effective type of material compared to other materials with similar strength and durability. This is since there is a wide variety of grades, allowing for the selection of the most economical option that meets the requirements of the application.

To adopt the possible material, four options were taken into consideration. These options include ASTM A36, ASTM A572, ASTM A992, and ASTM A588, and were selected because of their various strengths, affordability, availability and compatibility with the design's structural requirements. ASTM A36 is a typical carbon steel with acceptable weldability [21]. On the other hand, ASTM A572 offers greater strength and better structural performance [22]. Also, ASTM A992 is a structural steel shape specification that provides a good mix of strength and formability [23]. Finally, ASTM A588 has improved weather resistance, making it a viable option for outdoor applications and extreme weather conditions [24].

To select the most proper option, a decision-making tool, such as the Decision-Making Matrix (DMM) has been considered. The criteria for the evaluation of the options' appropriateness included weldability, cost-effectiveness, yield strength, young's modulus, weather resistance, density and availability. Following the use of DMM, ASTM A36 was identified as the material of choice. Table II lists several properties of ASTM A36.

TABLE II. ASTM A36 PROPERTIES [25]

Property	Tensile strength (MPa)	Yield strength (MPa)	Density (kg/m^3)	Young's modulus (GPa)
Value	450	250	7850	210

1) Environemntal Degredeation and Fatigue

Given the environmental conditions at Kuwait Port, where the platform will be exposed to saltwater, moisture, and high humidity, the corrosion resistance of ASTM A36 steel could be a concern for its long-term durability. To improve performance in these harsh conditions, galvanization (coating the steel with zinc) can provide strong protection against corrosion [26]. In addition, epoxy or polyurethane coatings can offer extra durability, helping reduce the need for frequent maintenance and extend the platform's lifespan.

In addition to the environmental effects, fatigue is also an important factor to consider for the platform's long-term performance. The repeated movement of forklifts over the platform subjects it to cyclic loading, which over time can lead to the initiation and growth of micro-cracks in the material [27]. These small cracks, if left unaddressed, can gradually propagate and compromise the structural integrity of the platform [27]. Regular inspections and maintenance, along with considering reinforcements in high-stress areas, can help mitigate fatigue-related issues and ensure continued safe operation [28].

III. APPROACH AND EXECUTION OF THE METHODOLOGY

A. Modeling

The design structure was created and modeled thoroughly by using SolidWorks. The main parts of the system are presented through the Bill of Materials (BOM) in Figure 1.

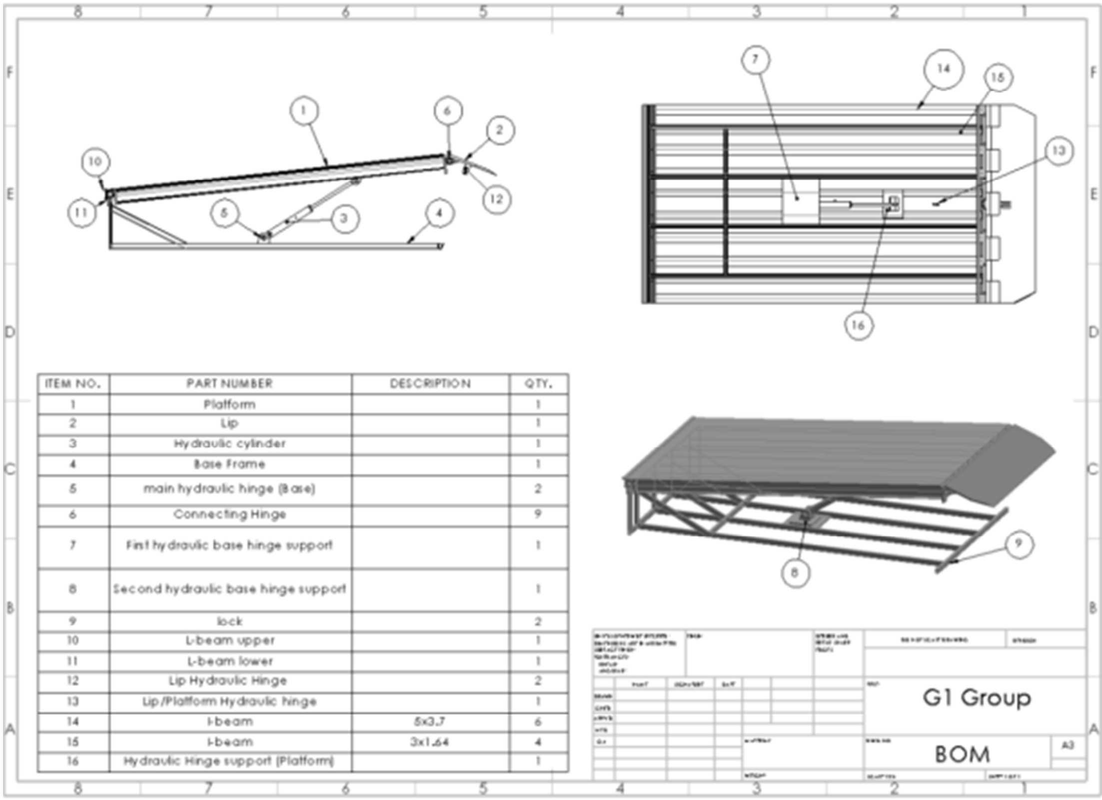
All parts shown in Figure 1 are manufactured by using the selected material ASTM A36. BOM provides an outline of every component used to model the dock leveler. The main sub-assembly engineering drawing of the base frame is provided in Figure 2 to highlight the general dimensions of the design. The overall length is 3000 m, whereas the width is 1800 mm.

B. Simulation

1) Cases to Consider

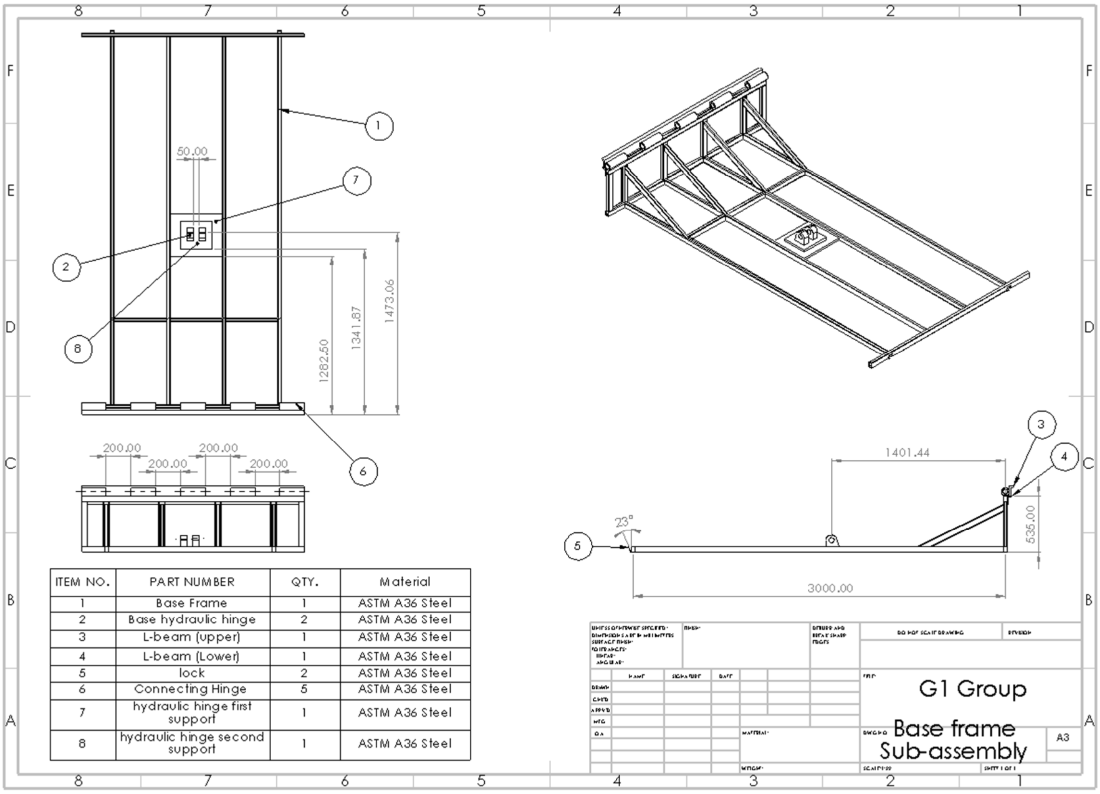
To run the simulation, two cases are considered: one case considers a forklift driven on the center of the platform, and the second case considers the forklift traveling on only one side, due to symmetry, as shown in Figure 3. In addition to the two cases of the forklift paths, the dock leveler has 3 different positions to be considered for each case, as depicted in Figure 4.

Forklift is aimed at having a maximum load of 10 tons handled by the dock leveler. This load is a combination of the load of the cargo and the forklift, which is estimated to weigh 4 tons. This gives a total weight of 10 tons. To be familiar with the various existing forklifts and investigate their specifications, In Table III, 3 forklift models are compared [29].



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Platform		1
2	Lip		1
3	Hydraulic cylinder		1
4	Base Frame		1
5	main hydraulic hinge (Base)		2
6	Connecting Hinge		9
7	First hydraulic base hinge support		1
8	Second hydraulic base hinge support		1
9	lock		2
10	L-beam upper		1
11	L-beam lower		1
12	Lip Hydraulic Hinge		2
13	Lip/Platform Hydraulic hinge		1
14	I-beam	5x3.7	6
15	I-beam	3x1.64	4
16	Hydraulic Hinge support (Platform)		1

Fig. 1. BOM for system components.



ITEM NO.	PART NUMBER	QTY.	Material
1	Base Frame	1	ASTM A36 Steel
2	Base hydraulic hinge	2	ASTM A36 Steel
3	L-beam (upper)	1	ASTM A36 Steel
4	L-beam (Lower)	1	ASTM A36 Steel
5	lock	2	ASTM A36 Steel
6	Connecting Hinge	5	ASTM A36 Steel
7	hydraulic hinge first support	1	ASTM A36 Steel
8	hydraulic hinge second support	1	ASTM A36 Steel

Fig. 2. Main sub-assembly engineering drawing of the base frame showing general dimensions.

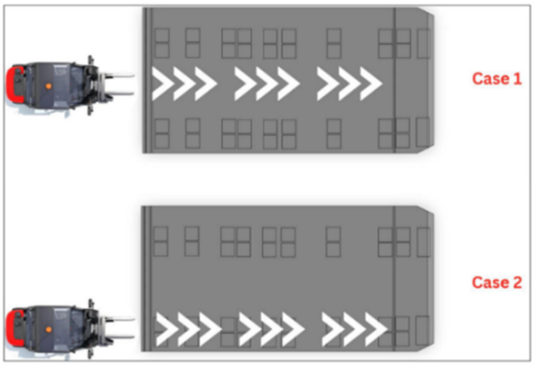


Fig. 3. Simulation cases with forklift at the center and one side of the platform.

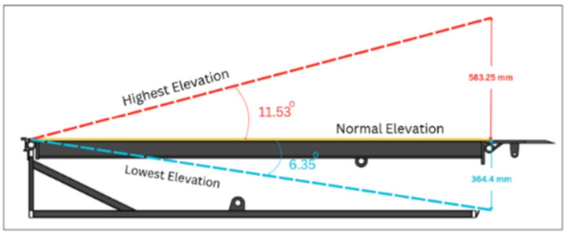


Fig. 4. Three different dock leveler positions for forklift path cases.

2) *Forklift Specifications and Intednded Loads*

As evidenced in Table III, much of the weight on the platform is contributed by the forklift's front axle with the remainder being supported by the rear axle. Moreover, the tires, on average, produce a square print with dimensions of 170 mm x 170 mm. This print also represents the area on which the load is applied on the platform, as demonstrated in Figure 5.

TABLE III. COMPARISON OF SPECIFICATIONS FOR THREE FORKLIFT MODELS.

Company	**Weight (kg)**		**Dimensions (mm)**		**Tire dimensions (mm)**
	Front axle	**Rear axle**	**Wheelbase**	**Overall width**	**Front / Rear**
Toyota	9520	1990	2080	1320	167.6 / 167.6
Mitsubishi	8990	1953	1850	1400	167.6 / 167.6
Komatsu	8504	2060	1800	1350	167.6 / 167.6
Mean value	9004.7	2001	1910	1357	170 / 170

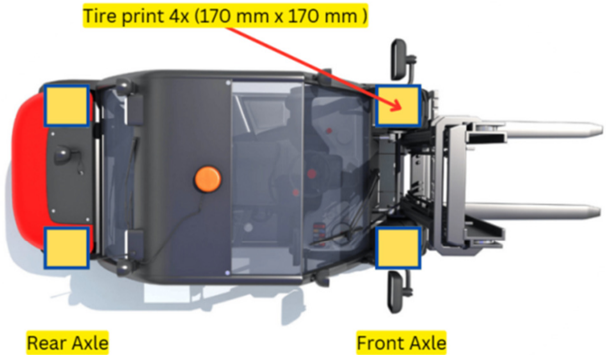


Fig. 5. Load application area on the platform with dimensions of 170 mm × 170 mm.

3) *ANSYS Setup*

Due to the complexity associated with the dynamic analysis, static structural analysis is used to simulate the model, considering 5 different stages of load. These stages cover all the possible positions of the forklifts, and are portrayed in Figure 6.

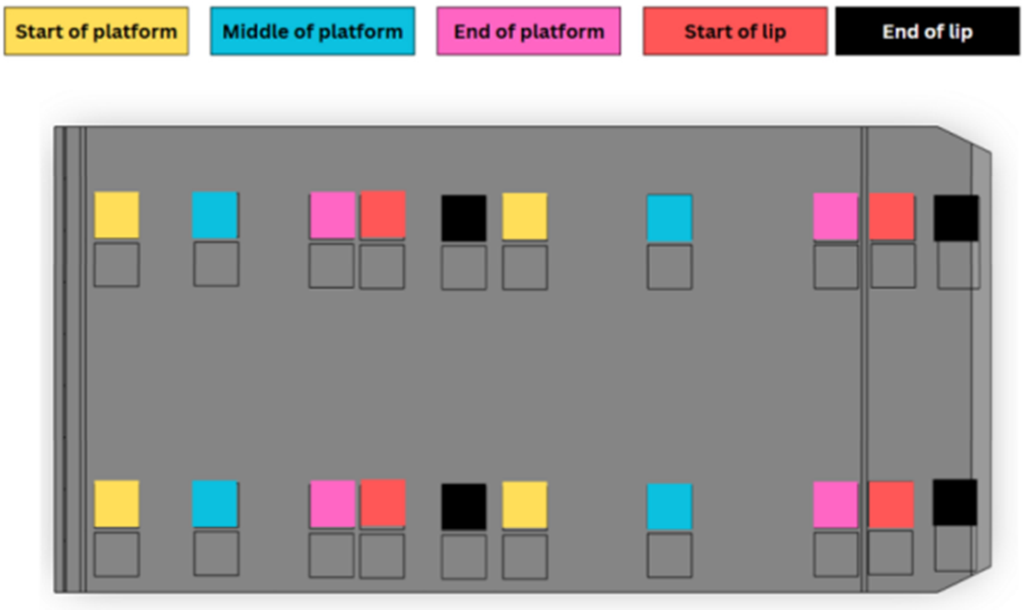


Fig. 6. Load stages representing possible forklift positions in the static structural analysis.

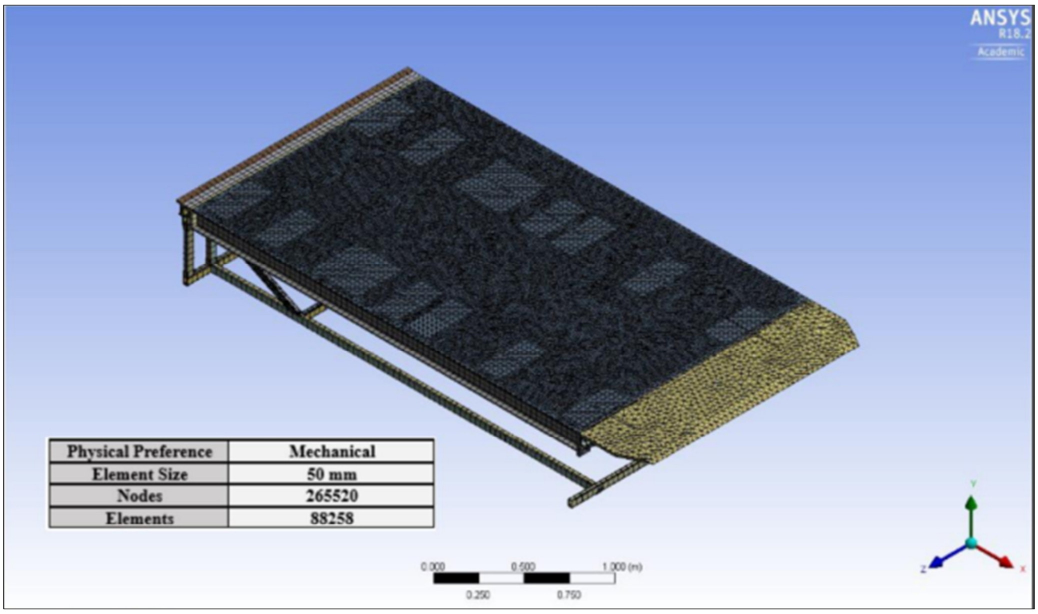


Fig. 7. Mesh details of the design model.

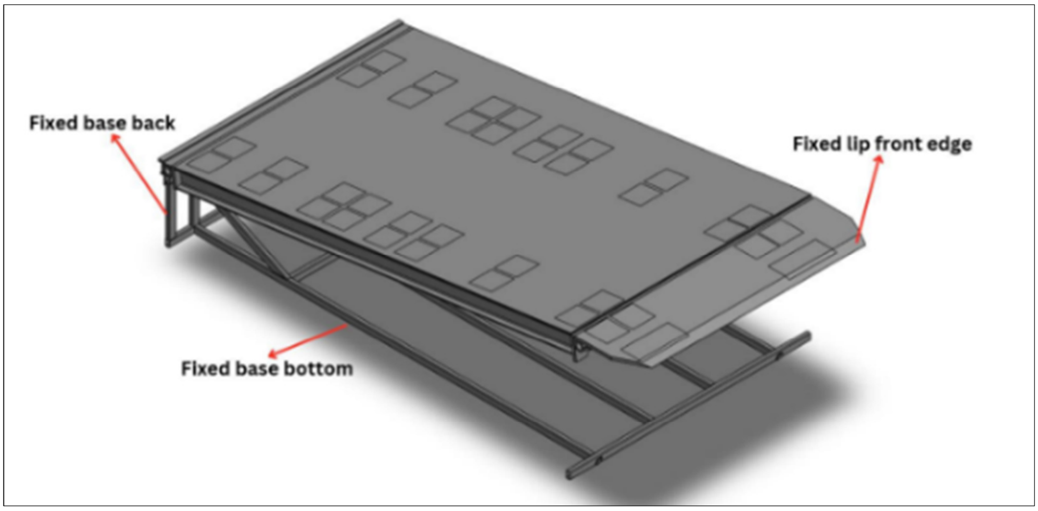


Fig. 8. Applied boundary conditions for the simulation.

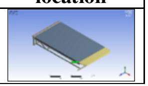
Each color represents the prints of the rear and front tires of the forklift. The distance between each pair of tires is 1910 mm, based on Table III. The mesh information and the necessary boundary conditions are presented in Figures 7 and 8, respectively.

Figure 7 displays the mesh generated by ANSYS for the PNIS dock leveler, with 265520 nodes and 88258. The chosen element size of 50 mm ensures a good balance between structural analysis accuracy and computational efficiency. Based on Figure 8, the back and bottom of the base structure are fixed to replicate the actual installation conditions, where the platform is rigidly attached to the supporting structure. The front-bottom edge of the lip is to rest firmly on the bed of the truck. It is assumed that the truck's suspension system behaves as rigid, minimizing movement during loading and unloading.

4) Sensitivity Analysis

The purpose of this sensitivity study is to assess how different mesh sizes, nodes, and elements affect the model's accuracy and computational speed. The analysis's findings are summarized in Table IV.

TABLE IV. SENSITIVITY ANALYSIS

Size	No. nodes	No. elements	Von-Mises stress (MPa)	Probe location
Coarse	265531	88241	39.57	
Medium	296282	97173	36.92	
Fine	448550	134474	40.94	

The mesh sensitivity analysis has been performed using three different mesh densities: coarse, medium, and fine. The Von-Mises stress results showed a variation of 6.7% between the coarse and medium meshes, and 11.0% between the medium and fine meshes. Since the variation between the coarse and medium meshes was relatively small, further refinement was considered unlikely to significantly impact the results. Convergence was achieved when the stress values showed minimal changes (less than approximately 11%). As a result, the coarse mesh was selected for subsequent analysis, providing a good balance between accuracy and computational efficiency.

IV. RESULTS

To ensure a comprehensive evaluation of the platform's performance under various operating scenarios, several simulations must be considered. This includes simulating the load stages, illustrated in Figure 6, for case 1 and 2 while considering the extreme elevations of the dock leveler, presented in Figure 4. The results of total deformation, Von Mises stress, and factors of safety are tabulated next. These criteria are critical indicators of structural integrity and operational safety under expected loading conditions.

A. Deformation Results

Table V summarizes the obtained deformation results. According to the guidelines set out by the Royal Academy of Engineering, the cantilever beam's maximum displacement for about 3000 mm overall length can be 13 mm without causing any issues [30]. As a result, the design tests are safe as the highest deformation is 3.27 mm, which is smaller than the standard limit (13 mm). This maximum deflection occurs when the forklift is in the middle of the platform travelling to the side at highest elevation. Figure 9 illustrates this case, as simulated in ANSYS.

TABLE V. SUMMARY OF PLATFORM TOTAL DEFORMATION RESULTS (mm)

Position	**Normal elevation (centre - side)**	**Highest elevation (centre - side)**	**Lowest elevation (centre - side)**
Start of platform	2.45–3.07	2.43–3.07	0.65–0.7
Middle of platform	2.4–3.25	2.49–3.27	0.67–0.54
End of platform	1.97–2.85	2.38–3.02	0.42–0.23
Start of lip	1.80–2.67	1.83–2.72	0.41–0.22
End of lip	1.33–1.56	1.37–1.63	0.17–0.16

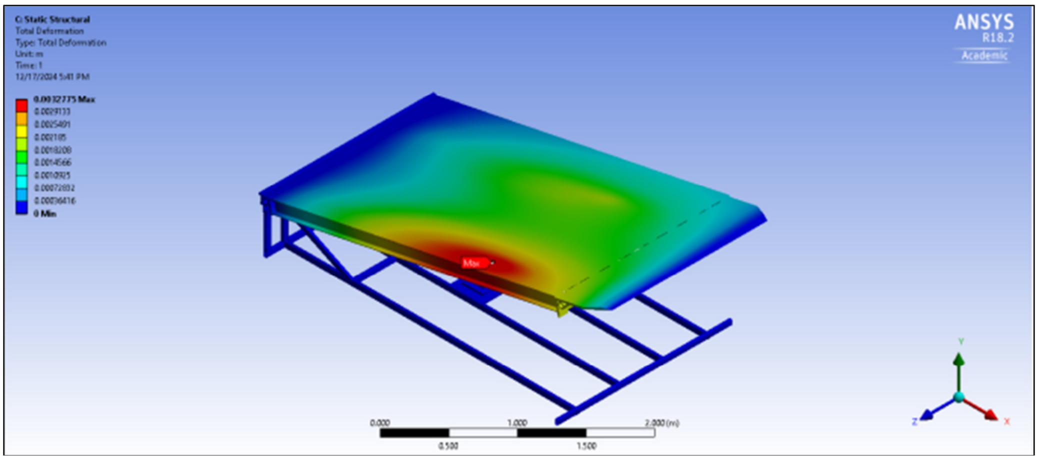


Fig. 9. Simulation of maximum deflection case in ANSYS.

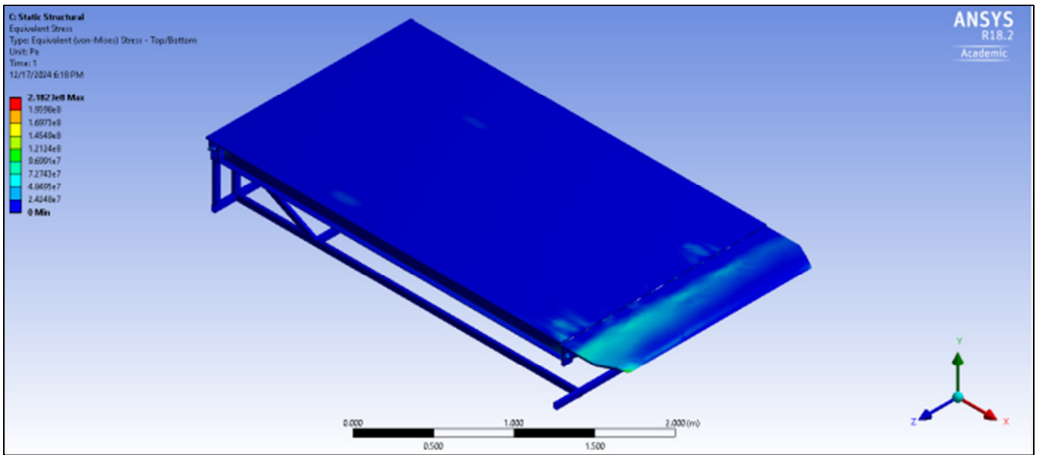


Fig. 10. Simulation of highest stress condition.

B. Stress Results

Table VI summarizes the stress results. The highest stress value observed is 218.23 MPa. This is below the yield strength of the design material, which is 250 MPa according to ASTM A36, as indicated in Table II. This highest stress of 218.23 MPa occurs when the forklift is at the end of platform and travelling to the side at normal elevation. This condition is better simulated in Figure 10. This high stress value is achieved due to the stress concentration, contributed by the sharp edges at the area where the platform meets the lip.

TABLE VI. SUMMARY OF STRESS ANALYSIS RESULTS (MPA)

Position	Normal elevation (centre - side)	Highest elevation (centre - side)	Lowest elevation (centre - side)
Start of platform	103.59 – 131	99.87 – 114.35	91.47 – 215
Middle of platform	136.46 – 139.86	132.91 – 135.55	107 – 203
End of platform	145.66 – 218.23	167.1 – 215.34	111 – 99.95
Start of lip	130 – 150	129.39 – 152.08	117 – 105.3
End of lip	72.72 – 78.93	74.03 – 81.75	66.1 – 65.4

C. Factor of Safety Results

Table VII provides the factor of safety results for each scenario, corresponding to Tables V and VI.

TABLE VII. FACTOR OF SAFETY RESULTS

Position	Normal elevation (centre - side)	Highest elevation (centre - side)	Lowest elevation (centre - side)
Start of platform	2.4–1.9	2.5–2.18	2.73–1.18
Middle of platform	1.83–1.78	1.8–1.84	2.3–1.24
End of platform	1.71–1.15	1.4–1.16	2.25–2.5
Start of lip	1.9 –1.67	1.93–1.64	2.1–2.37
End of lip	3.43–3.16	3.37–3.05	3.78–3.82
Mean	2.26–1.93	2.23–1.97	2.63–2.22

The minimum factor of safety observed is 1.15, which occurs when the forklift is positioned at the end of the platform. While this value is relatively low, it is considered acceptable for most typical loading scenarios. Extreme loads or other factors, such as dynamic loading, are unlikely to occur frequently in day-to-day operations, and the platform is designed to perform safely under standard conditions.

However, to ensure that the platform remains reliable over its full-service life, especially in cases of repeated or extreme loading, reinforcing certain structural elements would be beneficial. Increasing the thickness of load-bearing parts, adding more support beams, or opting for a stronger material could help raise the factor of safety and improve the platform's durability under heavy or cyclic loads. Additionally, introducing features, namely shock absorbers or load limiters, could further shield the platform from unexpected dynamic impacts.

D. Result Representation

This section provides a graphic visualization of the simulation results. The horizontal axis of Figures 11-14 represents the location of the forklift, whereas the vertical axis may represent stress or deflection. Figures 11 and 12 compare the platform deflection and stress, respectively, for case 1, considering the various elevations.

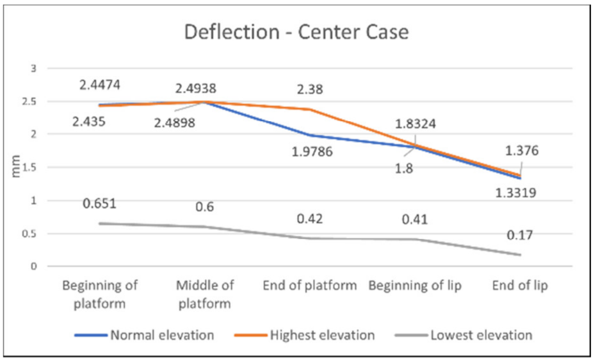


Fig. 11. Platform deflection for case 1 at various elevations.

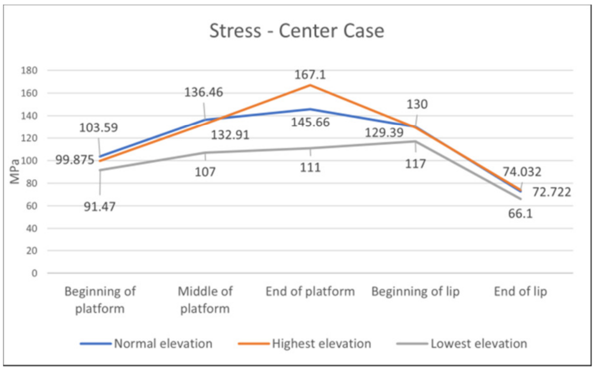


Fig. 12. Platform stress for case 1 at various elevations.

Based on Figure 11, the maximum deflection occurs when the forklift is in the middle of the platform. This is reasoned by the fact that the platform is hinged at its back, and the lip rests on the bed of the truck, allowing the largest deflection to accommodate centrally. Furthermore, in Figure 12, the maximum stress is observed when the forklift is at the end of the platform. This can be explained by the fact that the end of the platform acts as a stress concentration point. The sharp 90-degree angle at the platform's edge, where the lip begins, creates a zone where stress is more concentrated. As the results indicate, the design is safe and well-equipped to handle the stress at the platform's edge. Despite the higher stress concentration in that area, the materials chosen are strong enough to manage it, ensuring that the platform remains reliable and durable over time.

On the other hand, Figures 13 and 14 equally compare the platform deflection and stress for case 2 at normal, highest, and lowest elevations of the dock leveler. The same conclusions made for Figures 11 and 12 can be drawn for Figures 13 and 14.

Clearly, the deformation results when the platform is at the lowest elevation are less than the ones encountered at normal and highest elevations for both center and side cases. This is reasoned by the fact that at lowest elevation, the front cover of the platform is prevented from further downward motion by having it fixed at two points in contact with the locks, as illustrated in Figure 15.

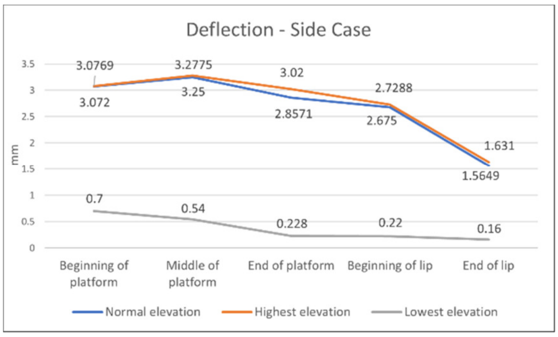


Fig. 13. Platform deflection for case 2 at various elevations.

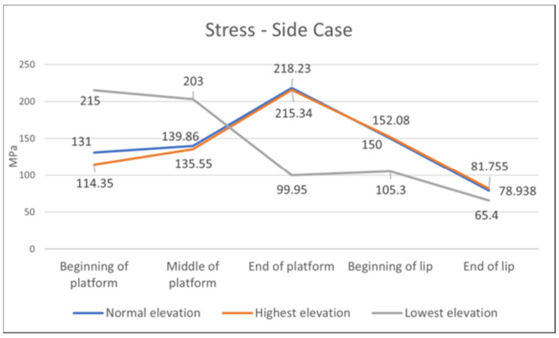


Fig. 14. Platform stress for case 2 at various elevations.

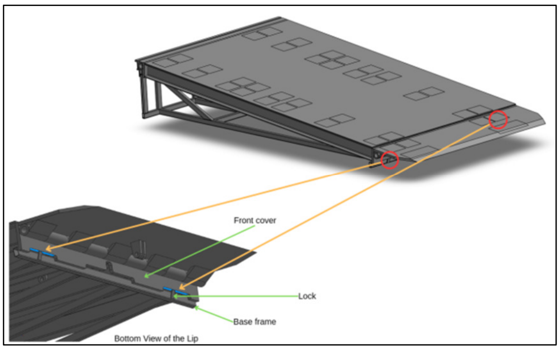


Fig. 15. Platform at lowest elevation, showing the front cover fixed by the locks.

It is also important to note that the whole weight of the platform, including the front cover, is not supported by the locks alone, which are welded to the front face of the base frame. However, a hydraulic system is used to hold most of the weight. Otherwise, the likelihood of lock collapse is high. Locks are intended to secure the system in a stored position for stability during use and transport.

V. DISCUSSION

To evaluate the robustness of the paper's design, a comparative analysis with existing solutions in the Gulf region, such as Shuwaikh Port's design and a leading model from Mega Industrial Equipment, has been conducted. This comparison underscores the superior features and advantages of this paper's work over current alternatives, as presented in Table VIII.

TABLE VIII. DESIGN COMPARISON WITH SHUWAIKH PORT'S DESIGN AND MEGA INDUSTRIAL EQUIMENT'S MODEL

Feature	Shuwaikh port design [31]	Mega industrial equipment [32]	Paper's design
Type	SPL	Hydraulic	PNIS
Lip angle	7.5°	10°	15°
Material	S355J0 Steel	ST-52 steel	ASTM A36
Safety features	Panic-stop activation safety supports	Standard safety locks	Automatic safety locks, motion sensors
Lip length	350 mm	400 mm	479 mm
Special features	Open lip hinge anti-slip coating	Reinforced lip anti slip surface	Reinforced platform, LED lighting system
Technical specifications	Dynamic capacity: 6-8 tons frame installation	Dynamic capacity: 10 tons, heavy duty frame	Dynamic capacity: 10 tons (Max) Heavy duty construction
Control box	User-friendly with extended possibilities	Push-button control	Touchscreen control panel remote operation capabilities
Warranty	Lifetime on the lip open hinge	3-year warranty	5-year warranty on all components
Compliance	EN 1398 directive	EN 1398	OSHA-ANSI Kuwait standards
Platform length	3000 mm	2400 mm	3000 mm
Working range above the dock	280 mm	400 mm	583.25 mm
Working range below the dock	295 mm	320 mm	364.4 mm
Platform width	2000 mm	1800 mm	1800 mm
Frame height	585 mm	550 mm	535 mm
Additional features	Toe protector yellow-black marking below dock control	Weather resistant coating	Overload protection, weatherproof design automated safety locks

The proposed design significantly outperforms both Shuwaikh Port's dock leveler and Mega Industrial Equipment's model in several key areas. By increasing the lip angle from 7.5° (Shuwaikh Port) to 15°, this article's design accommodates a wider range of vehicle configurations and docking heights. The extended lip length of 479 mm, compared to Shuwaikh Port's 350 mm, enhances platform reach and stability, reducing misalignment risks and improving operational efficiency. Utilizing/Based on ASTM A36, steel further strengthens structural durability, offering superior strength and weldability over the materials used in existing systems.

Safety is a paramount focus in the proposed design, which integrates advanced features, such as automatic safety locks, motion sensors, and overload protection, features absent in Mega Industrial Equipment's model and only partially present in Shuwaikh Port's system. These proactive safety mechanisms actively monitor operational conditions, significantly minimizing accident risks. The weatherproof design ensures reliable performance even in harsh environmental conditions, and automated safety locks provide an extra layer of security by preventing unintended platform movement during operation [33-35].

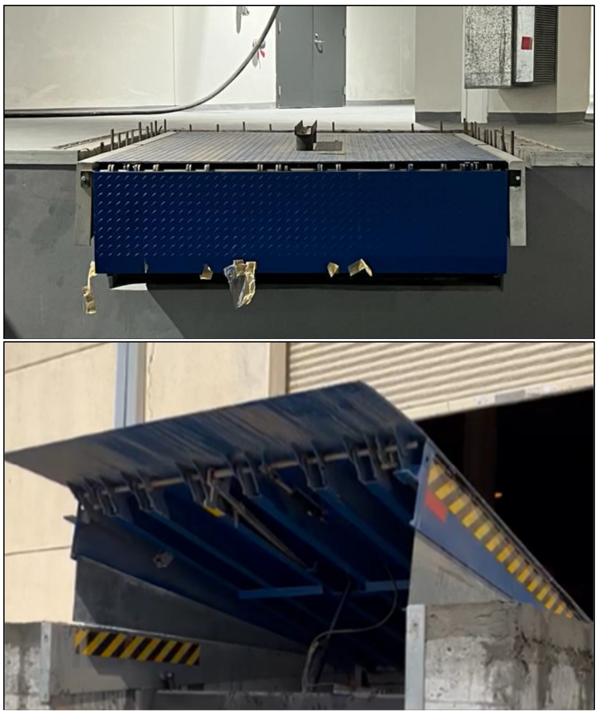


Fig. 16. Dock leveler adopted at Shuwaikh port.

The paper's design also introduces a technologically advanced control system, featuring a touchscreen control panel with remote operation capabilities. This innovation surpasses the standard user-friendly control boxes used in both Shuwaikh Port's and Mega Industrial Equipment's designs, offering a more intuitive and responsive interface. Remote adjustments and monitoring reduce manual intervention, allowing for quicker and more precise operational control [36-38].

From a performance perspective, this article's design boasts a maximum dynamic capacity of 10 tons, exceeding Shuwaikh Port's 6–8-ton range and aligning with Mega Industrial Equipment's highest-capacity model. The working range above the dock is significantly greater at 583.25 mm (compared to the 280 mm for Shuwaikh Port and 400 mm for Mega Industrial Equipment), while the below-dock working range extends to 364.4 mm, surpassing both competitors. These improvements provide greater flexibility for loading and unloading operations, making the system more adaptable to various industrial requirements [39].

Fig. 17. Dock leveler manufactured by Mega Industrial Equipment.

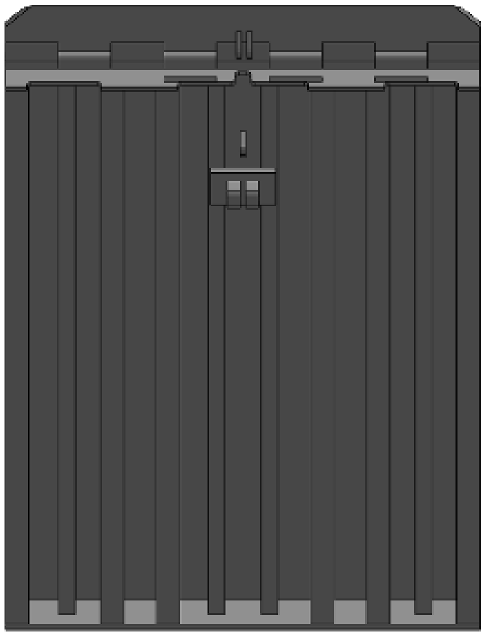


Fig. 18. Bottom view of the PNIS dock leveler, highlighting non-identical I-beam stiffeners for load distribution.

Finally, the compliance with multiple international safety and operational standards, including OSHA, ANSI, and Kuwait Standards, further underscores the robustness of the system [12-14]. In contrast, Shuwaikh Port's design and Mega Industrial Equipment adhere only to the EN 1398 Directive compliance standard [40]. With additional features, such as overload protection, weatherproof construction, and automated safety mechanisms, this paper's design not only meets, but also exceeds current industry expectations, positioning it as the most advanced and reliable dock leveler solution available. However, although the proposed dock leveler demonstrates superior performance over existing solutions, a comprehensive implementation strategy remains under development, with initial deployment being planned to undergo pilot testing in Kuwait and potentially across the Gulf region to evaluate real-world performance and support broader adoption.

Figure 16 shows the typical dock leveler used at Shuwaikh Port, whereas Figure 17 presents the Mega Industrial Equipment' s model. The bottom view highlighting the non-identical stiffeners of PNIS Dock Leveler supporting the platform is presented in Figure 18. These stiffeners are of I-beam type.

VI. CONCLUSION

To achieve the objective of a durable, cost-effective dock leveler for Shuwaikh Port, the focus was on simplifying the structure using non-identical stiffeners. This choice reduced manufacturing complexity while maintaining the necessary strength to handle a maximum load of 10 tons. Through ANSYS simulations, the design's safety and functionality were validated. The results revealed a minimal deflection of 3.28 mm, acceptable stress levels of 218.23 MPa, and a factor of safety of 1.15. This solution not only meets the required operational standards, but also outperforms both the existing models at Shuwaikh Port and Mega Industrial Equipment's designs in terms of durability, cost-efficiency, and overall performance.

Moving ahead, further research should concentrate on the actual use and verification of the enhanced dock leveler design in practical industrial environments involving pilot testing. Thorough inspection and performance assessment will be required to verify its durability, dependability, and effectiveness. Considering the assumptions made in terms of boundary conditions and symmetry, further validation will be required to meet various scenarios of operation. Exploring the potential for modification and adaptation of the design to satisfy unique industry needs and operational procedures will also be important. Furthermore, future research can explore the use of Artificial Intelligence (AI) to enhance and validate the dock leveler design beyond traditional simulations. AI-powered predictive maintenance systems can analyze real-time sensor data to detect early signs of wear, reducing unexpected failures. Computer vision technology can monitor loading operations, identifying unsafe practices and inefficiencies to improve safety and workflow. Additionally, AI-driven adaptive control systems could enable the dock leveler to automatically adjust to different truck sizes and heights using real-time sensor data, ensuring optimal performance and longevity.

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