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Reducing Cattle Stress During Transport: Structural Design And Analysis Of A Ramp-Gate System

Sandip S. Patil,
Reserach scholar, Matoshri College of Engineering & Research Center, Nashik (Mahatashtra) India, Affiliated to Savitribai Phule Pune University. sandipspatil85@gmail.com

Jayant H. Bhangale,
Professor and Head of Mechanical, Matoshri College of Engineering & Research Center, Nashik (Mahatashtra) India, Affiliated to Savitribai Phule Pune University, bhangale100@gmail.com

Abstract

The transportation of cattle in India often relies on regular goods carrier vehicles that lack specialized adjustments for loading and unloading. Typically, cattle are loaded using mud ramps or concrete bases available at markets and dairies. However, in remote locations such as farms or roadside emergencies, loading becomes a significant challenge, leading to stress and potential injury to the animals. To address this issue, a modular cattle transport ramp is designed, which functions both as a loading platform and a secure safety door for the vehicle. This case study presents the design and structural analysis of a cattle transport vehicle ramp with a maintaining sloping angle as per the 31inch base carriage clearance, intended to function as a closing safety door. The ramp is designed with a width of 5.5 ft and a length of 6.6 ft, constructed using a 3mm checkered plate welded onto a 40mm metal pipe frame. The structural integrity of the ramp is analyzed through load distribution calculations, deflection testing, finite element analysis and physical stress parameter like pulse rate and respiration rate are analysis to ensure safe and effective performance and validation through Finite Element Analysis (FEA) and compliance with IS 14904 standards and Indian Road Transport Authority. Key design considerations include weight-bearing capacity for two cattle (approx. 1000 kg), non-slip surface for enhanced grip, and easy integration with the vehicle aiming to ensure the ramp's safety and reliability during cattle loading and transport. Performance testing demonstrates that the analyzed deflection is less than 4mm in loading, loading time by 30% and reduces approximate 70% cattle stresses as compared to traditional methods. Graphical validation through stress-strain analysis and deflection graphs confirms its structural stability under dynamic loading conditions. This study establishes a functional and efficient solution for cattle transport, ensuring safer handling and reduced risks for both handlers and animals. Future improvements may include hydraulic assist mechanisms for enhanced usability.

INTRODUCTION

Cattle transportation in India presents significant logistical and welfare challenges, particularly in rural and remote areas where dedicated infrastructure is lacking. Most livestock are transported using general-purpose vehicles that are not equipped with appropriate loading and unloading mechanisms, often resulting in animal injuries, stress, and handling difficulties (Patil & Bhangale, 2025). These challenges become more critical during emergencies, where fixed loading bays or holding areas are unavailable, highlighting the need for mobile and adaptable solutions.

Animal welfare during transport is directly influenced by how animals are handled during loading and unloading—a process that is inherently stressful but can be mitigated with appropriate equipment and training. According to Eniolorunda (2009), minimizing transportation-related stress requires not just regulatory compliance but also the availability of specialized vehicles, safe loading areas, and properly designed holding facilities. Grandin (2008) further emphasizes that handling equipment must be tailored to specific livestock species, ensuring that factors such as ramp gradient, surface texture, and handler behavior support animal comfort and safety. The absence of such provisions can result in avoidable injuries and operational inefficiencies.

The duration of the loading and unloading process is significantly influenced by the method employed, the availability of suitable infrastructure, and the experience level of the transporter(Huertas, 2018). In the Indian context, affordability and accessibility limit the adoption of specialized transport vehicles, particularly among smallholder farmers who form the majority of the livestock sector (Patil & Bhangale, 2022). This underscores the urgent need for modular, affordable, and easy-to-integrate transport solutions that suit the rural Indian context. Minimizing stress during transportation requires vehicles used for cattle transport to incorporate special adjustments that offer adequate support and ensure safe handling throughout the journey (Uetake, K., 2008).

Ramp structures used for loading and unloading cattle must be designed with both animal and handler safety in mind. A poorly designed ramp can lead to accidents, delayed operations, and increased animal resistance, resulting in stress and injury. Reports indicate that approximately 6% of cattle in India are injured or die during transport due to inadequate infrastructure, poor ventilation, and overloading (Byard, 2025; Patil & Bhangale, 2025). Accidental damage caused by improper transport practices often leads to severe injuries or fatalities among animals and, in rare cases, can also threaten human safety (Byard, 2025). Human handlers are exposed to increased risk when inadequate or unsafe equipment is used for managing large animals.

The issues of cattle transportation safety highlighted by the present study proposes the development of a structurally sound, modular ramp that can be integrated with standard goods carrier vehicles. The ramp is designed to serve a dual purpose: as a sloped loading platform and as a secure rear gate during transit. Structural validation has been conducted using Finite Element Analysis (FEA) to evaluate parameters such as load-bearing capacity, deformation, and stress concentration under realistic operational conditions. Additionally, physiological stress indicators such as pulse rate and respiratory rate have been considered to assess the impact on animal well-being during loading and unloading operations.

This research contributes to the fields of rural livestock transportation, mobile veterinary applications, and animal welfare engineering. By offering a field-ready, animal-friendly, and structurally sound solution, the research aims to enhance livestock transport practices in regions lacking fixed infrastructure. The proposed ramp system contributes to safer animal handling, supports mobile veterinary care, and aligns with national animal welfare standards.

Traditional Methods of Cattle Loading and Unloading in India and Proposed Ramp Innovation

Handling large animals such as cattle involves significant physical and safety challenges, necessitating the use of appropriate equipment and infrastructure that can ensure both handler protection and ease of operation. Facilities that promote comfort, control, and operational efficiency during animal movement are essential. Within this framework, a well-designed loading ramp is a critical component for ensuring the safe and humane transfer of livestock (Health and Safety Authority, 2011).

In the Indian context, cattle loading and unloading practices remain largely informal and region-specific. Traditional methods often lack standardization, structural safety, and animal welfare considerations. Commonly observed techniques include:

Manual Loading by Force or Lifting

Cattle are often coerced or manually lifted into transport vehicles using ropes and human labor. This method frequently results in animal distress and physical trauma, particularly musculoskeletal injuries caused by slipping or resistance behavior as shown in figure 1. The lack of mechanical support poses serious risks to both animals and handlers.

Figure 1: Unloading without any support.

Fixed Concrete Ramps

Fixed concrete ramps are often constructed at organized livestock markets or dairies as shown in figure 2. While they provide a somewhat stable solution, they are immobile and hence not useful in decentralized or emergency scenarios such as roadside rescues, rural farms, or grazing fields. The process of loading and unloading cattle is often time-consuming and heavily reliant on the skill of the driver or handler. The duration can be significantly influenced by the method used, the availability of proper facilities, and the experience of the transporter (Huertas,2018).

Figure 2: Cement Ramp in Cattle Market

Temporary Mud Ramps

In rural and under-resourced areas, mud or soil mounds are often used to create makeshift loading ramps as shown in figure 3. These structures are inherently unstable, especially during wet conditions, and lack consistent gradient control. They are prone to collapsing under the weight of the animals, thereby increasing the likelihood of injuries.

Figure 3: Temporary Mud Ramp at Dairy

These traditional practices not only hinder efficient operations but also fail to align with recognized animal welfare standards. They present logistical complications during emergency response scenarios and for handlers operating in the field without access to permanent infrastructure.

Development of a Vehicle-Mounted Modular Ramp

Recognizing the limitations of traditional loading methods, this study proposes the development of a vehicle-mounted, modular ramp tailored for Indian cattle transport conditions. In accordance with the recommendations of Grandin (2008, 2024), the ramp is designed to suit species-specific requirements by incorporating proper slope, surface texture, and ergonomic considerations. Structural integrity and stress distribution have been assessed using Finite Element Analysis (FEA), with a focus on deformation and load-bearing behavior under real-world conditions (Asker, 2012).

The proposed design features a multifunctional, frame-integrated ramp constructed from 40 mm square steel pipe and overlaid with a 3 mm checkered plate, offering both durability and a slip-resistant surface. With dimensions of 5.5 feet in width and 6.6 feet in length, the ramp accommodates the comfortable and safe loading of two adult cattle. Its slope is optimized based on an average goods carrier vehicle height of 31 inches, ensuring a gentle incline that minimizes animal stress and physical strain.

This ramp serves a dual purpose: it functions as a robust loading platform when deployed and as a foldable rear safety door when stowed. The integration into the vehicle chassis removes the need for external support or fixed infrastructure. Its rigid construction ensures durability under repeated use, while the folding mechanism allows for compact storage and ease of transportation.

The modular ramp system represents a scalable and field-adaptable solution aimed at improving animal welfare, enhancing operational safety, and addressing the infrastructural challenges faced in rural cattle transportation across India.

Design Considerations for the Cattle Transport Ramp

The design of a cattle transport ramp must address the critical balance between structural integrity, animal safety, and ease of operation. To ensure that the proposed ramp meets these multifaceted requirements, a systematic design process was followed, illustrated in the design stage flowchart as shown in Figure 4.

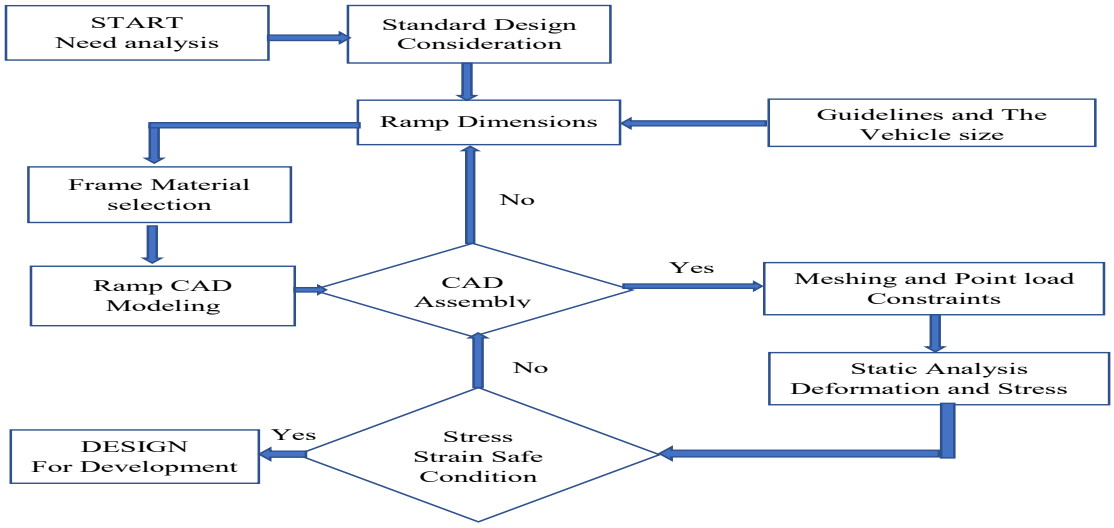

Figure 4: Design Stage Flowchart

The primary design considerations are elaborated as follows:

Structural Strength and Load-Bearing Capacity

The ramp is engineered to withstand a dynamic load of approximately 1000 kg, equivalent to the combined weight of two adult cattle. Key structural design features include:

- Selection of materials with a high strength-to-weight ratio, optimizing both durability and portability.
- Implementation of welded joints and reinforcement ribs to ensure structural stability and limit deformation under live load conditions.
- Design validation through finite element analysis (FEA) to assess stress distribution and maximum deflection parameters during operation.

Slope and Dimensions

One of the most important welfare-related factors during cattle handling is the incline of the loading ramp, which directly affects stress levels in animals during ascent and descent. Warriss (1991) highlights the physiological and behavioral impact of steep gradients on livestock. To address this:

- The ramp is designed to maintain an optimal slope angle, carefully aligned with the average height of a goods vehicle carriage (approximately 31 inches). The design layout of ramp is shown in Figure 5.
- Dimensions are selected to balance safety and comfort, with a length of 6.6 ft and width of 5.5 ft, ensuring adequate space for animals to move without risk of slipping or crowding.
- The non-slip checkered plate surface further supports secure footing during movement, even under wet or muddy conditions.

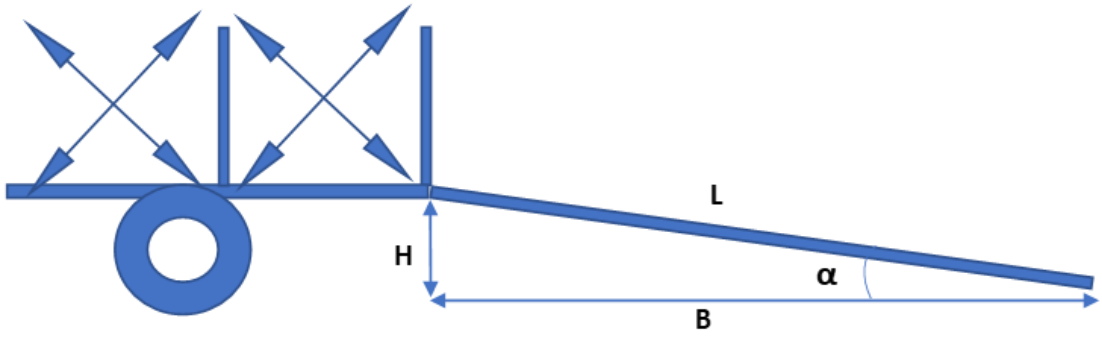

Figure 5: Ramp Dimensional Consideration as per the vehicle mounting

Surface Design and Functional Configuration

The surface texture of the ramp is a critical factor influencing animal safety and movement efficiency. To minimize the risk of slips and falls during loading and unloading, especially under adverse field conditions:

- A 3 mm checkered steel plate is used as the ramp surface, offering superior traction and resistance to slipping.

- The non-slip texture is particularly beneficial in wet or muddy environments, where conventional flat surfaces may become hazardous for cattle movement.

This surface design contributes directly to improved animal welfare, reduced handling stress, and safer operational practices during transportation. Figure 6 shows the loading conditions for the ramp at 4000N load on slop of 25 degree.

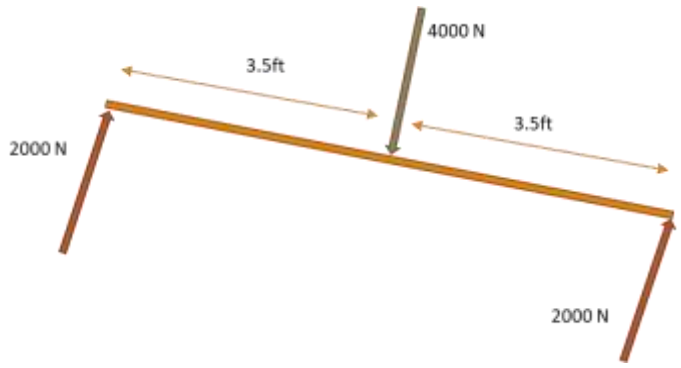

Figure 6: Central Loading conditions

Cattle transportation safety depends heavily on the structural behavior of the ramp under load. This study focuses on a ramp inclined at a 25-degree slope, a configuration selected to maintain a balance between animal comfort and mechanical stability.

The ramp is multifunctional in nature, serving both as a loading platform and a rear safety gate for the vehicle. Given this dual function, the ramp's design underwent detailed finite element analysis (FEA) to assess its structural performance under centralized loading conditions. Key analysis parameters included stress distribution, deflection behavior, and load transfer efficiency.

This case study therefore integrates considerations of surface engineering, geometry, and structural analysis to propose a comprehensive and field-deployable solution for cattle transport in rural and emergency scenarios.

Structural Design and Analytical Calculations

To ensure the safety and effectiveness of the cattle loading ramp, a comprehensive structural design and analysis was conducted. The ramp is intended to function both as a modular loading platform and a rear-mounted safety door, integrated directly into the vehicle chassis. The design emphasizes strength, stability, and usability under field conditions.

Material Selection and Ramp Plate Design

A 5 mm thick mild steel (MS) chequered plate was selected for the ramp surface, offering high durability and a non-slip texture essential for safe cattle movement, particularly under wet or muddy conditions. This material also provides sufficient stiffness under live load conditions, minimizing deformation.

To evaluate the ramp's performance under bending loads, standard beam theory was applied using the bending stress formula:

For ramp design We considered 5mm MS chequered plate

$\sigma = \frac{My}{I}$
Where:
σ = Bending stress
M = Bending moment
y = Distance from the neutral axis to the outermost fiber
I = Moment of inertia
For a rectangular cross-section, the moment of inertia I is given by:

$I = \frac{bh^3}{12}$
Where:
b = Width of the section
h = Calculated Thickness of the plate = 4.76 mm
A factor of safety (FOS) of 2 was considered during design to ensure robustness under field conditions. Two reinforcing cross frames were integrated beneath the ramp to distribute the load evenly and enhance support. According to finite element analysis (FEA) results, the maximum deflection was observed to be less than 5 mm, well within the acceptable limit.

Ramp Length Calculation Based on Vehicle Height

The ramp length was determined based on the vertical clearance of the vehicle and a desired incline angle of 25 degrees, which balances comfort for cattle and structural safety.

Using trigonometric principles, the ramp length L was calculated as:

$$L = \frac{H}{Sin\ \alpha}$$

Where:

L = Required length of the ramp

H = Vertical height from the ground to the carriage = 33 inches

α= Ramp angle (25°)

$L = \frac{33}{Sin\ 25} = 78.08 inch$ =6.51ft

This calculated length ensures a gentle incline that reduces physical strain on cattle during loading and unloading.

Gentle ramp inclinations are recommended for cattle loading as they help reduce stress and lower the risk of injury during movement. Studies highlight that non-slip surfaces and proper lighting in loading areas are essential to ensure animal safety and reduce stress during handling and transport, as recommended by animal welfare and loading guidelines (OIE, 2021) (Grandin, T., 2024). The resulting ramp length was approximately 78.08 inches (1983mm), which ensures a manageable incline for cattle movement. These outcomes validate the ramp's viability as a robust, safe, and animal-friendly solution for field deployment in cattle transportation systems. As stress from loading and unloading animals during transportation is unavoidable, it becomes crucial to minimize the combined impact of various stressors. Minimising stress during animal transport requires specialised vehicles, safe loading areas, proper holding facilities, and adherence to regulations (Eniolorunda O, 2009)

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Structural Design Principles:

- Stress and deflection analysis calculations form the core of structural ramp design, ensuring that the ramp can safely withstand the dynamic loads imposed during cattle loading and unloading. These principles, enable accurate estimation of internal stresses and deformations under various loading conditions, which is critical for structural safety and functionality. Additionally, Finite Element Analysis (FEA) plays a vital role in modern design validation by simulating complex real-world loading scenarios, identifying high-stress regions, and optimizing material usage. FEA allows engineers to visualize and address critical stress concentrations, improving the overall reliability and safety of transport systems like modular cattle ramps.

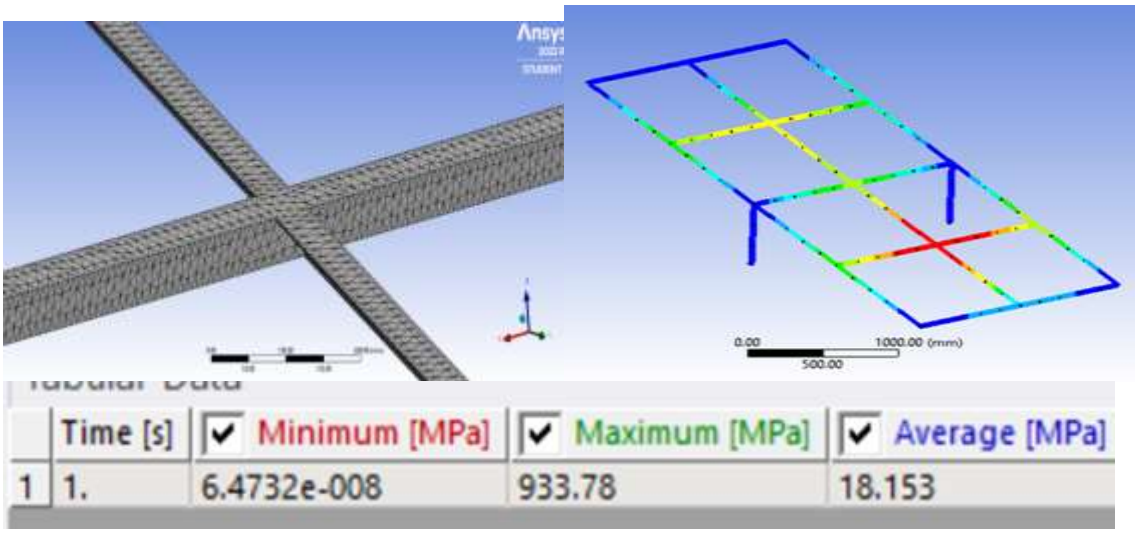

Figure 7: Ramp Structural Analysis

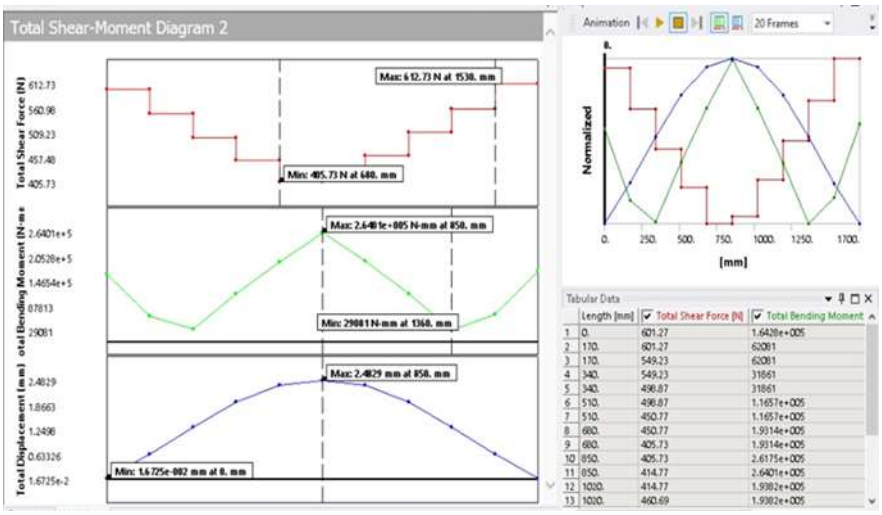

Figure 8: Total Deformation and Moment as per the structure

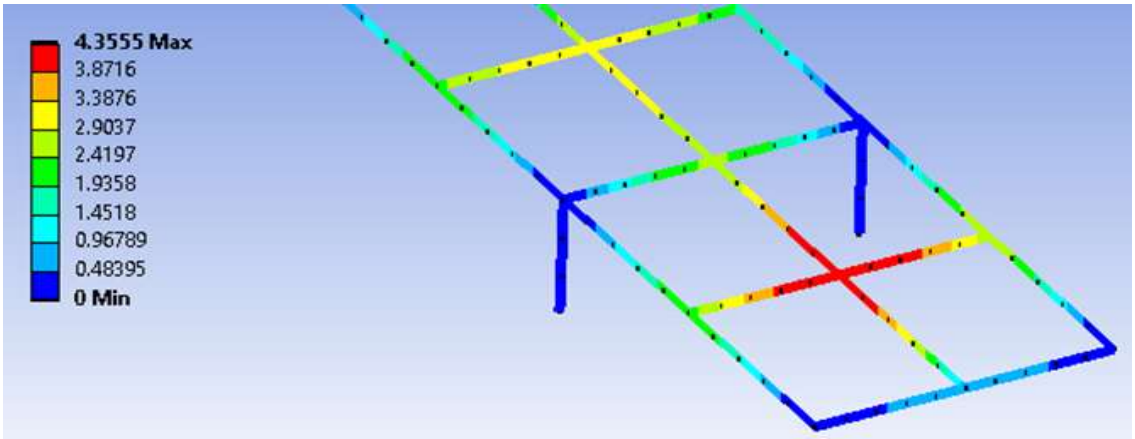

Figure 9: Deformation impact on Ramp Structure

- In this research, the ramp frame is constructed using S275N structural steel, a non-alloy, weldable, fine-grain steel normalized for general structural applications. This material was selected for its excellent mechanical properties and reliable performance under load-bearing conditions, particularly its good weldability and guaranteed strength values, which are essential in modular livestock transport structures. The density of S275N ranges between 7.8×10^3 to 7.9×10^3 kg/m³, providing a robust yet manageable mass for vehicle-mounted ramps. The material cost, estimated at 78–80 INR/kg, also makes it economically viable for widespread use in developing regions. Proper welding techniques and appropriate material selection are critical for maintaining the ramp's structural integrity and ensuring long-term durability. A 5 mm checkered plate surface is applied to enhance traction, minimizing the risk of slipping during cattle loading and unloading, which is crucial for animal safety.

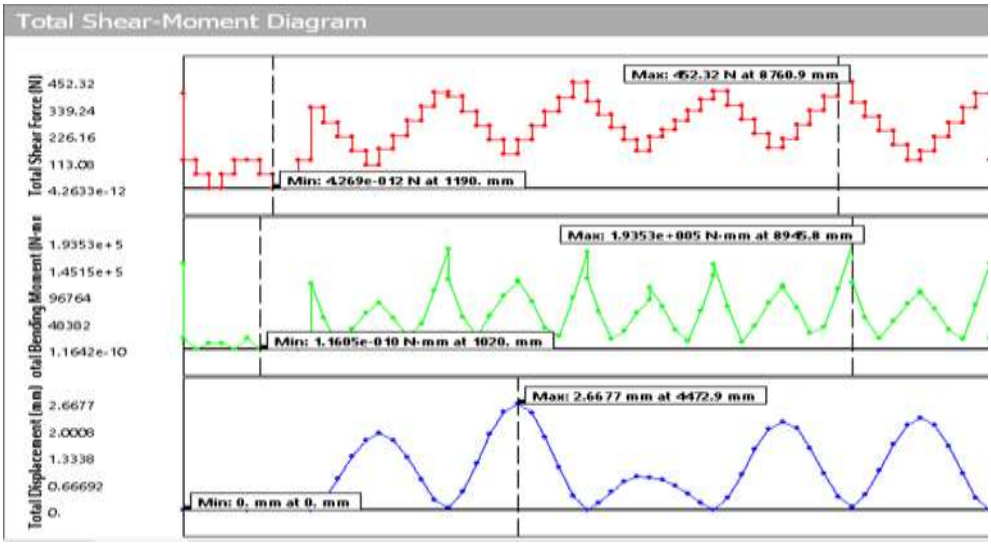

Figure 10: Total Shear Moment

DISCUSSION

The finite element analysis (FEA) of the fabricated sloping ramp frame, modeled in ANSYS, provides critical insights into its structural performance during loading and unloading operations of cattle. The ramp structure

is subject to static loads simulating the live weight of cattle up to 1000 kg during entry and exit, with boundary conditions simulating fixed supports at the vehicle attachment points and free load application along the ramp surface.

The maximum von Mises stress observed in the structure was 933.7 MPa as shown in figure 7, localized near the junctions of the welded cross-pipes and at the fixed base plate. These zones correspond to areas of stress concentration due to geometric discontinuities and load transmission. The stress levels remained within the material's yield strength S275N or mild steel, confirming structural safety under anticipated usage.

The total deformation after loading as shown in figure 9 observed 4.355mm, with maximum deflection occurring at the mid-span of the ramp a typical result for simply supported sloping structures. This indicates that the ramp flexes predictably under load without causing permanent deformation or instability.

Bending moment analysis shows peak moments 1.9353 e^5 Nmm along the central length of the ramp's cross-link members. Figure 8 and figure 10 shows the bending moment and total shear stresses observed in loading condition. These moments are induced by concentrated cattle weight during motion, particularly when weight is transferred from one hoof to the next. The cross-link pipes contribute to distributing loads evenly across the ramp, enhancing stiffness and resistance to buckling or bending.

The mesh refinement study confirmed the accuracy of results with a final element size of 0.33 mm, ensuring convergence in critical stress and displacement regions. The structural simulation included contact elements to represent joint behavior and friction effects, improving the fidelity of the real-world loading scenario.

Furthermore, the sloping configuration introduces non-uniform vertical and horizontal reaction forces. As cattle ascend or descend, load components create additional shear forces which are well handled by the frame's rectangular section geometry (40 mm × 40 mm pipes) and welded checkered plate. The telescopic and collapsible design showed structural adequacy under load, although fatigue analysis is recommended for long-term performance validation.

CONCLUSION

This case study demonstrates the design and analysis of a 25-degree sloping ramp for cattle transport. The FEA results provide a more realistic picture of the stress and deformation than simplified hand calculations. The results will be compared to the material properties to ensure the ramp is safe. Further design iterations may be necessary to optimize the frame structure and reduce stress concentrations. Future work could include fatigue analysis and experimental testing.

The FEA simulation using ANSYS confirms that the fabricated frame, designed as a sloping ramp for cattle loading/unloading, performs reliably under expected operational loads. Key conclusions include:

- The maximum stress levels are within the allowable limit of the chosen steel grade (S275N/MS), ensuring no risk of yielding or fracture under static cattle loading.
- The maximum deformation up to 4.75mm and 4.33mm calculated and analyzed respectively remains within acceptable bounds, indicating good load distribution and effective support from cross-members and side frames.
- Bending moment peaks 1.9353 e^5 Nmm occur mid-span, affirming the design's structural efficiency and the importance of cross-link support.
- Stress concentrations at welded joints suggest reinforcing gusset plates or increased pipe wall thickness in future designs.

- The sloping configuration considered 25 degree does not significantly compromise stability when properly supported at the base and rigidly fixed to the vehicle chassis.
- The telescopic and collapsible mechanism shows promise for field operation, offering ease of storage without loss in structural strength.

Overall, the study validates the design from a structural safety and usability perspective. For future work, dynamic analysis (accounting for sudden animal movements), fatigue life estimation, and physical prototype testing are recommended for robust performance validation.

DECLARATIONS

Authors' contributions

Sandip Subhashrao Patil : Writing - Original draft, Project Administration, Methodology, Investigation, Formal Analysis, Data curation, Conceptualization, Visualization, Validation.

Jayant Hemchandra Bhangale : Writing - Review & editing, Writing - Original draft, Supervision, Project Administration, Methodology ,Resources, Formal Analysis, Conceptualization.

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Competing interests

The authors declare that they have no competing interests

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