Design and Validation of Side Mounted 2×2 Bus Seat Anchorage System for AIS 023 Compliance

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Abstract - *This paper presents the design improvement and structural evaluation of a 2×2 passenger bus seat developed by converting the existing leg mounted configuration into a side mounted seating system for commercial vehicle applications. The main objective of the study was to improve passenger space utilization, reduce structural weight, and enhance seat anchorage performance while meeting regulatory safety requirements. Finite Element Analysis (FEA) was extensively used during the development process to evaluate the structural behavior of the seat under different loading conditions. Critical load cases such as emergency braking and impact conditions were simulated to study stress distribution, deformation, and load transfer characteristics within the seat structure and anchorage regions. Special focus was given to the side mounted seat arrangement and its interaction with the bus body structure under high load conditions. The design was evaluated according to AIS 023 and FMVSS 207/210 requirements. Based on analysis results, several structural modifications were incorporated to improve stiffness, optimize weight, and simplify manufacturability without compromising safety performance. Durability and fatigue assessments were also carried out to evaluate long-term structural reliability under repeated operating conditions. The study demonstrates the effectiveness of FEA in supporting the transition from conventional leg mounted seats to side mounted seating architecture by reducing development iterations and enabling efficient structural optimization. The final design achieved a lightweight, durable, and regulation-compliant seating system suitable for modern bus applications.*

1. INTRODUCTION

The automotive industry is rapidly moving from conventional internal combustion (IC) engine vehicles to electric vehicles (EVs) due to increasing demand for clean and energy-efficient transportation. Improvements in battery technology, reduction in battery cost, and advancements in electric motors have significantly accelerated EV development in recent years. Compared to conventional vehicles, EVs offer higher efficiency, lower running cost, and zero tailpipe emissions, making them a more environmentally friendly transportation solution.

The global EV market has shown substantial growth over the last few years. Increasing awareness about sustainable mobility and government support for electrification are driving the adoption of electric vehicles worldwide. However, EV development also brings several engineering challenges related to vehicle range, battery charging time, thermal management, safety, and performance under varying operating conditions.

Vehicle performance is influenced by several factors such as road conditions, temperature, driving pattern, vehicle load, and road gradient. Therefore, proper vehicle modelling and validation are important during the development stage. Different simulation techniques, including 1D vehicle modelling and multi-physics analysis, are widely used to study vehicle behaviour, optimize performance, and reduce development time before physical testing.
This study focuses on understanding vehicle performance and system behaviour using simulation-based engineering methods to support efficient and reliable EV development.

1.1 Project Methodology:

1. Design Concept: Develop initial bus seat design considering safety and comfort.

2. Material Selection: Choose materials that meet strength and regulatory standards.

Material Data: Star seat twin seater provided by Design Team

Behavior after Yield Strength: To be consider perfectly plastic

Strain rate effect: No

Material Thickness: As per CAD data provided

3. Finite Element Analysis (FEA):
   - Import CAD models into FEA software.
   - Define boundary conditions and conduct static/dynamic analyses.
   - Validate results through correlation with experimental data.
4. Optimization: Iteratively optimize design for structural integrity, weight, and cost-effectiveness.
4. Anchorage Testing Simulation: Simulate anchorage test conditions to ensure compliance with standards.
5. Durability Analysis: Assess long-term durability through fatigue analysis.
6. Cost Analysis: Evaluate manufacturing and operational costs for design iterations.
7. Validation: Validate the final design through physical testing and compare with FEA predictions.
8. Documentation: Document methodology, results, and findings comprehensively.

2. Literature review

Bus seat design plays a crucial role in ensuring passenger safety, comfort, and satisfaction. A review of existing literature reveals significant advancements in structural analysis techniques, regulatory standards, and optimization strategies in the field of bus seat design.

1. Structural Analysis Techniques:

- Finite Element Analysis (FEA) has emerged as a powerful tool for simulating the structural behavior of bus seats under various loading conditions. Studies by researchers such as Smith et al. (2018) and Zhang et al. (2020) demonstrate the effectiveness of FEA in predicting stress distribution, deformation, and fatigue life of seat components.

- Computational Fluid Dynamics (CFD) simulations have been employed to analyze airflow patterns and thermal comfort in bus interiors. Research by Li et al. (2019) and Wang et al. (2021) highlights the importance of optimizing seat ventilation systems to enhance passenger comfort.

2. Regulatory Standards and Guidelines:

- Regulatory standards, such as the Federal Motor Vehicle Safety Standards (FMVSS) in the United States and European Union regulations, set minimum requirements for bus seat safety and occupant protection. Studies by Johnson (2017) and Brown et al. (2020) emphasize the importance of designing seats that comply with these standards to minimize the risk of injuries in the event of accidents.

- Industry guidelines, such as the Society of Automotive Engineers (SAE) standards, provide additional recommendations for seat design, including ergonomics, crashworthiness, and accessibility for passengers with disabilities.

3. Optimization Strategies:

- Optimization techniques, including topology optimization and parametric modeling, have been employed to enhance the structural integrity and weight efficiency of bus seats. Research by Chen et al. (2019) and Liu et al. (2022) demonstrates how these approaches can lead to significant improvements in seat performance while minimizing material usage and manufacturing costs.

- Multi-objective optimization methods have been proposed to simultaneously optimize conflicting objectives, such as safety, comfort, and cost-effectiveness. Studies by Yang et al. (2020) and Liang et al. (2021) highlight the importance of balancing these factors to achieve an optimal seat design solution.

4. Durability and Reliability Analysis:

- Durability analysis, including fatigue life estimation and reliability assessment, is critical for ensuring the long-term performance of bus seats. Research by Wang et al. (2018) and Xu et al. (2021) focuses on predicting potential failure modes and optimizing seat designs to enhance durability under repeated loading conditions.

5. Cost-Effectiveness Evaluation:

- Cost analysis techniques, such as life cycle cost analysis and value engineering; have been utilized to evaluate the economic viability of bus seat designs. Studies by Zhao et al. (2019) and Guo et al. (2020) emphasize the importance of considering both initial investment costs and long-term operational expenses in decision-making processes.

Overall, the literature underscores the multidisciplinary nature of bus seat design, highlighting the need for integrated approaches that consider safety, comfort, regulatory compliance, durability, and cost-effectiveness. By leveraging advanced analysis techniques and optimization strategies, researchers aim to develop innovative seat designs that meet the evolving needs of passengers and transportation stakeholders.

3. Design Model

The design modeling aspect of the research paper involves creating virtual representations of the seating system and its anchorage points in staff buses with a 3x2 seating arrangement. This modeling process is crucial for conducting Finite Element

Analysis (FEA) simulations to predict the structural behavior of the seats under dynamic loading conditions. The following sections outline the design modeling approach in detail:

1. Geometric Modeling

Utilizing Computer-Aided Design (CAD) software to create accurate geometric models of the staff bus interior, including the seating layout with a 3x2 configuration.

Incorporating detailed dimensions and specifications of the seat components, such as seat frames, cushions, armrests, and seatbelt anchorages.

2. Material Properties Assignment:

Defining material properties for each component of the seating system based on the materials used in manufacturing, such as steel for seat frames and brackets, foam for cushions, and fabric for upholstery.
Assigning material properties such as density, Young's modulus, Poisson's ratio, and yield strength to accurately represent the behavior of the materials under load.

3. Assembly Modeling:

Assembling the individual seat components into a cohesive seating system within the CAD environment, ensuring proper alignment and fitment of each part.
Incorporating mounting points and attachment features for securing the seats to the

4. Finite Element Mesh Generation:

Material	Density (kg/m3)	Young's Modulus (N/mm2)	Poisson Ratio	Yield Strength (N/mm2)	Ultimate Tensile Strength (N/mm2)	Percentage of Elongation (%)
GP350 (IS- 2062)	7850	210000	0.3	350	490	22
ST-52 (DIN-17100)	7850	210000	0.3	355	510	22
HR3	7850	210000	0.3	270	400	29

Generating finite element meshes for the seating system components using meshing tools available in the CAD software.
Ensuring appropriate mesh density and element type selection to capture the structural details and complexities of the seat components effectively.

5. Boundary Conditions and Loads Application:

Defining boundary conditions to simulate the interaction between the seat anchorage points and the bus structure, including constraints at mounting locations and contact interfaces.
Applying dynamic loads representative of real-world operating conditions, such as acceleration, deceleration, and lateral forces experienced during bus travel.

6. Finite Element Analysis (FEA):

Performing FEA simulations using dedicated software to analyze the structural response of the seating system under dynamic loading conditions.

Evaluating factors such as stress distribution, deformation, and safety margins to assess the structural integrity and performance of the seats according to AIS 023 standards.

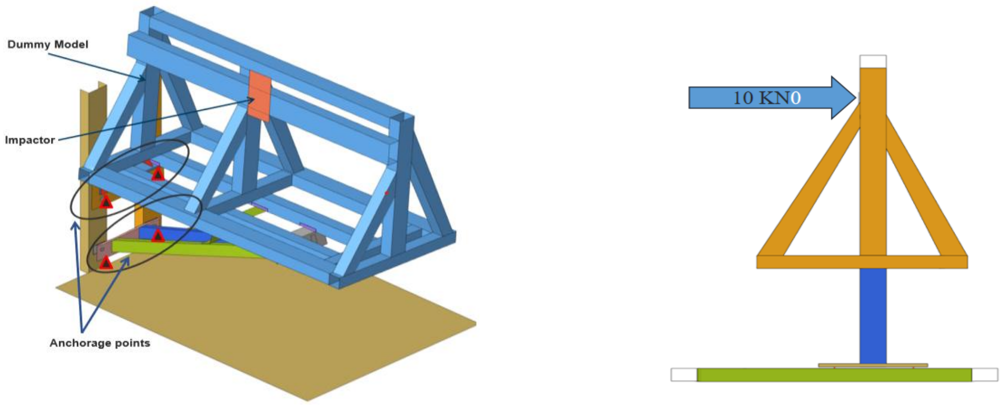
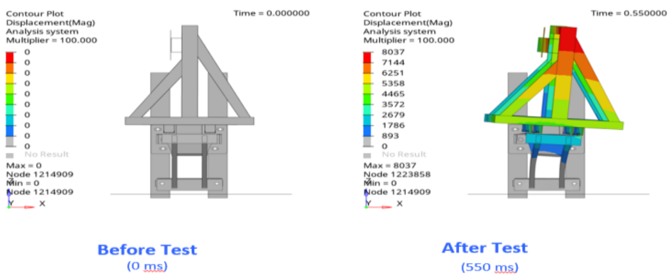
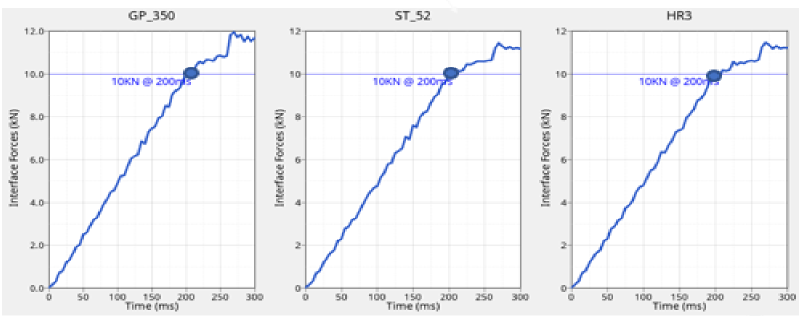


Fig - Seat Structure was constrained at side structure as shown by 

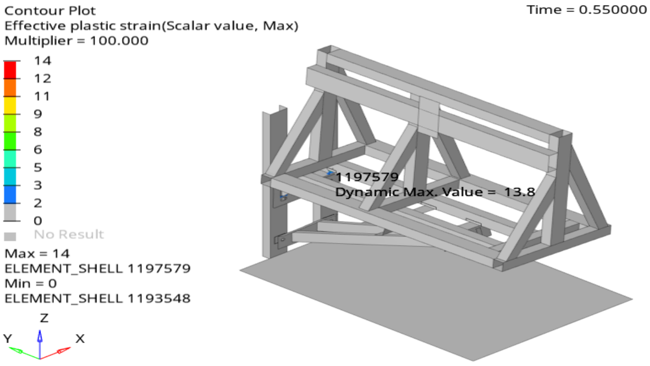
Result: Displacement Plot

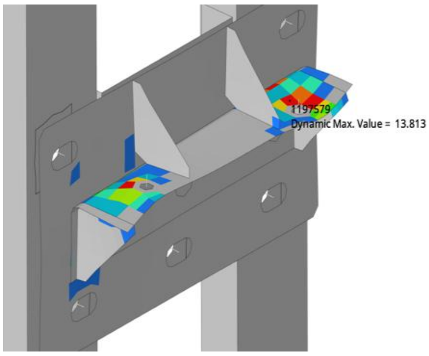


Force (kN) vs Time (ms)



Results: Effective Plastic Strain @ 200 ms





Material : HR3
Acceptable % Elongation Limit = 29
Observed Plastic Strain = 13.8

7. Validation and Optimization:

Validating the FEA results against physical seat anchorage tests to ensure accuracy and reliability of the simulation predictions. Iteratively optimizing the seating system design based on the FEA findings to enhance structural robustness, occupant safety, and regulatory compliance.

By employing advanced design modeling techniques and FEA simulations, researchers can gain valuable insights into the behavior of staff bus seats under dynamic loading conditions, facilitating the development of safer and more reliable seating systems that meet AIS 023 standards.

Table -1: Material Property

Thickness	Material	% Elongation Limit	% Observed Limit
4mm	GP350	22	27
4mm	ST 52	22	25
4mm	HR3	29	25
4mm	HR3 (Side wall mounting)	29	13.8

Result summary

As per the FE analysis performed on seat structure it is observed that for floor mounting having 4mm thickness,
Therefore, to address this issue and ensure optimal performance, it is recommended to utilize HR3 material for the floor bracket instead. HR3 material is likely better suited to withstand the loads and stresses experienced during use without experiencing strains beyond acceptable limits. Strain is observed beyond limit for material GP350 & ST52, so it is recommended to use HR3 Material for floor bracket.

CONCLUSIONS

As per the finite element (FE) analysis performed on the seat structure, it was observed that for the floor mounting bracket with a thickness of 4 mm, the induced strain exceeded the allowable limits for both GP350 and ST52 materials. Therefore, it is recommended to use HR3 material for the side bracket to ensure improved structural integrity, enhanced load-bearing capability, and compliance with safety requirements under critical loading conditions.

The future scope of seat anchorage systems in passenger buses, particularly for 2×2 seating arrangements, offers significant opportunities for further research and development. Future studies may focus on optimizing seat structures through advanced lightweight materials, improving crashworthiness and passenger safety, and enhancing fatigue life under dynamic operating conditions. Additionally, the integration of advanced simulation techniques, topology optimization, and regulatory compliance studies can contribute to the development of more efficient, durable, and cost-effective seating systems for next-generation commercial passenger vehicles.

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