

Research Paper

Experimental Stress Analysis on Frame Structure of A 70-Passengers Electric Bus

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Abstract

Structural strength testing of buses using static vertical load has not previously been explored to validate the structural integrity of bus frames. In this study, the static vertical load method was employed to validate the structural strength of the Universitas of Indonesia electric bus, which utilizes two different materials SS400 for the lower frame and Aluminum Alloy 6061 for the upper frame. Finite Element Analysis (FEA) was conducted to identify critical areas on both the lower and upper frames. The stress values in the simulation were also obtained at the same location as the strain gauge placements in the experiment. Experimental vertical load testing was carried out by incrementally applying a load of 1000 kg up to the equivalent of 70 passengers, with an additional dynamic coefficient of 30% resulting in a maximum load of 6850 kg. Strain measurements were taken using 20 strain gauges on the lower frame and 8 on the upper frame. The experimental result showed the highest stress occurred at strain gauge no. 9 on the lower frame, measuring 78.10 MPa, and 15.32 MPa on the upper frame under 6850 kg load. The comparison between the simulation and experimental results reveals an 18% deviation. Nevertheless, both methods indicate the same critical area of the structure. The stress distribution indicated that the central deck area of the lower frame, where passengers sit and stand, experienced the highest loads. On the upper frame, significant stress was observed in the area where the air conditioning system is mounted. These findings demonstrate that static vertical load testing can be effectively used to validate the structural strength and stress distribution of electric buses, particularly in areas subject to concentrated loading.

Keywords: Vertical load; Finite element analysis; Strain gauge; Bus frame; Electric bus

1. Introduction

We now live in an era of globalization, where the demand for fast and convenient transportation is critical to supporting daily activities [1]. This has led to a significant increase in the use of private vehicle and public transport [2]. Among mass transportation systems, buses are widely utilized due to their versatility in serving both intercity and urban commuter routes. However,

exhaust emission from vehicles including buses have raised serious concern, as they are among the largest contributors to carbon dioxide (CO₂) [3], [4]. Ninety seven percent of transportation in Indonesia relies on fossil fuels [5]. As a result, the development of electric vehicles (EVs) as an alternative power source continues to grow [6]. EVs are highly sought after due to their zero pollution and exhaust emissions, making them environmentally friendly.



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However, electric vehicles also have several drawbacks, such as battery lifespan, long charging times, and inadequate supporting infrastructure. Another significant disadvantage is the weight of EVs, several components, including the battery pack, electric motor, powertrain and other supporting systems, contribute to their heavy weight [7]. Compared to fossil-fuelled buses, an electrical bus equipped with an electric motor and battery pack weighs approximately 2-3 tons more [8].

The chassis of EVs must be designed to support loads, distribute stresses, and withstand shocks and torsional forces to ensure safety and operational reliability [9], [10]. The University of Indonesia has launched a low-deck electric bus intended for urban and campus commuter use, facilitating easy boarding and alighting, particularly for passengers with special needs. This electric bus features a newly developed chassis platform specifically designed for EVs, unlike previous generation that relied on converted conventional bus frames. Additionally, prior research has explored electric bus chassis development using reverse engineering methods [11]. In developing a dedicated electric bus chassis platform, rigorous testing both simulation-based and experimental is essential. Software-based analysis can evaluate static loads on the bus chassis and identify critical stress points [12], [13]. Simulations help determine maximum stress and deflection levels in the chassis structure [14]. Experimental testing is then conducted to validate simulation results, verify assumption, and confirm real world performance. This can involve applying actual loads to the electric bus and measuring structural integrity [15]. Finite element analysis (FEA) is employed to assess the chassis strength and predict its maximum load-bearing capacity [16]. Kurdi dan Rahman [17] utilized FEA to analyse stress distribution on chassis frame. Bus structural strength is further verified through rollover test in accordance with UN-ECE Regulation No. 66, ensuring passenger compartments avoid plastic deformation during collisions, thus preventing passenger injuries [18], [19]. Rong Yang *et al.* [20] applied static simulation analysis to evaluate structural strength of hydrogen city bus under horizontal bending. Mihardi *et al.* [21] applied rollover testing to

evaluate structural improvements for enhanced passenger safety during impacts. The authors note that direct experimental validation of the bus structural strength has not yet been conducted. Previous studies [22], [23], [24], [25] have primarily focus on assessing the strength of the bus superstructure, with particular emphasis on rollover test to evaluate its structural integrity. However, research on the lower frame or substructure remains limited, where current understanding is primarily based on simulation result with scarce experimental validation. Therefore, this study performs an experimental static vertical load test under a full-load condition (equivalent to 70 passengers) with an additional 30% overload to validate the bus frame's strength.

2. Methodology

2.1. Test Specimen

The test specimen utilizes the University of Indonesia's electric bus, shown in Figure 1, which was jointly developed with a domestic bus manufacturer. The electric bus is fully equipped with a battery pack, drive motor, and other essential components, including air conditioning and passenger seating.

The structure of electric bus are constructed using SS400 structural steel for the lower frame and Aluminum Alloy 6061 for the upper frame. The mechanical properties of SS400 and Aluminum Alloy 6061 are provided in Table 1 and Table 2, respectively.

Table 1. Mechanical properties of SS400 structural steel [22], [23]

Properties	Value
Ultimate tensile strength (σ_u)	400 MPa
Yield strength (σ_y)	245 MPa
Modulus of elasticity (E)	210 GPa
Possion's ratio (ν)	0.33
Density (ρ)	7,800 kg/m ³

Table 2. Mechanical properties of aluminum alloy 6061 [24]

Properties	Value
Ultimate tensile strength (σ_u)	320 MPa
Yield strength (σ_y)	276 MPa
Modulus of elasticity (E)	68.9 GPa
Possion's ratio (ν)	0.33
Density (ρ)	2,700 kg/m ³



Figure 1. Low deck electric bus

2.2. Experimental Test Equipment

The equipment used in the experimental testing is listed in [Table 3](#), which includes TML-FLAB-5-11 and TML-FLAB-5-23 strain gauge connected to a TML-TDS 540 data logger via sensor cables, as illustrated in [Figure 2](#). Strain gauge FLAB-5-11 with red backing color is used for mild steel measurement and strain gauge FLAB-5-23 with green backing color is used for aluminum measurement. Both strain gauges have gauge length 5 mm, backing color length is 10 mm, 120 ohm resistance and operating temperature is -196 to 150 °C.

2.3. Static Vertical Load

The vertical load test simulates the structural function of the bus as a transport vehicle for both passengers and cargo. This test evaluates the frame's ability to withstand the weight of passengers and cargo loads [\[25\]](#). Stress measurements on the bus structure were conducted using strain gauges installed at multiple location on both the lower and the upper frame. A total of 28 strain gauge measurement

points were distributed as 8 measurement points on the upper frame (made of Alumium Alloy 6061) as shown in [Figure 3](#). Twenty measurement points on the lower frame (constructed from SS400 Sstructural Steel), illustrated in [Figure 4](#). Since the bus was already equipped with components such as the battery pack, electric motor, passenger seats, windows and air conditioning, the simulation initial stress reading (tare load) were accounted for stress values included the baseline structural load before additional test weight applied. In determining the strain gauge location, consideration was given to structural areas where significant loads are applied. Specifically, the gauges were positioned in areas influenced by the weight of on board equipment and passenger

Table 3. Experimental test equipment

No	Equipment	Specification	Quantity
1	Data logger	TML-TDS 540	1 Unit
2	Strain gauge	TML FLAB-5-11	20 Pcs
3	Strain gauge	TML-FLAB-5-23	8 Pcs
4	Sandbags	50kg	140 Bags
5	Cable		28 Pcs

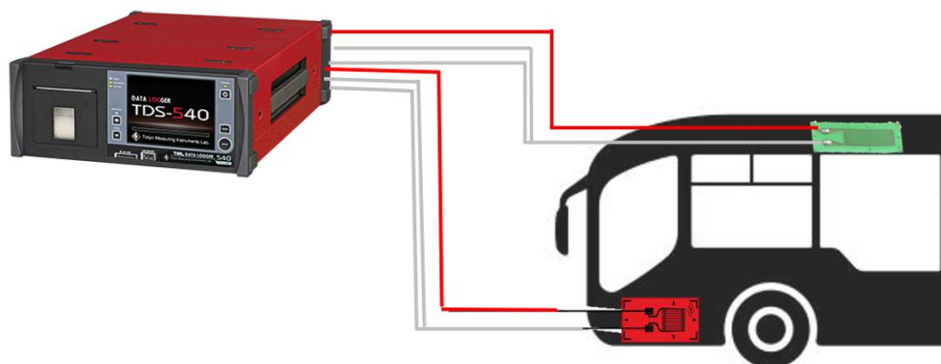


Figure 2. Experimental test schematic diagram

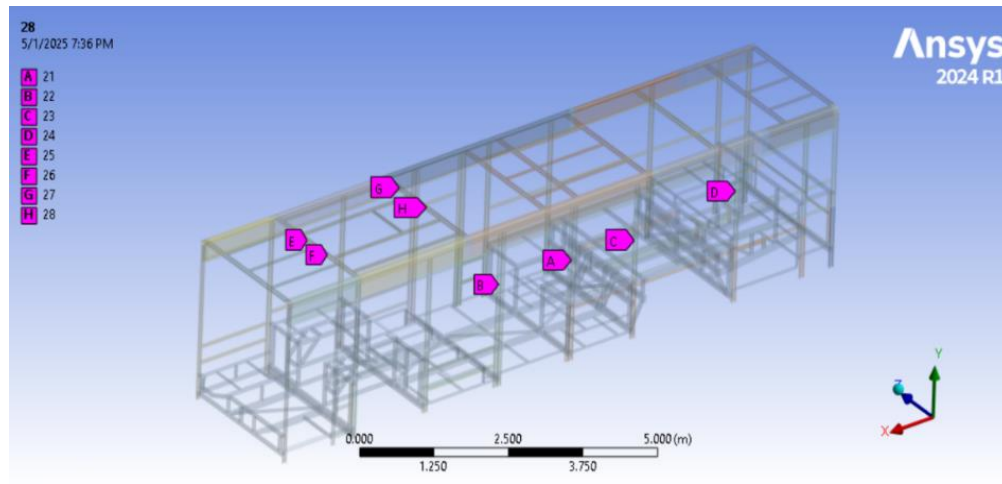


Figure 3. Installation point of strain gauge on aluminum alloy 6061 upper frame

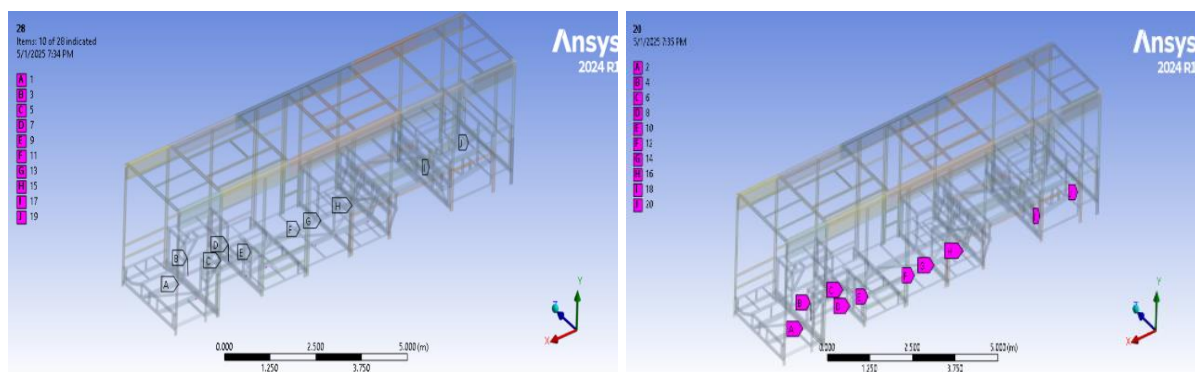


Figure 4. Installation point of strain gauge on SS400 structural steel lower frame

distribution, including both sitting and standing positions. This approach ensure that the measured strains accurately reflect the most critical operation load condition of the structure.

Before proceeding with installation, it is essential to ensure that the strain gauges are in standard condition. This verification was performed by measuring the resistance of each strain gauge, as shown in Figure 5. The installation process can be carried out after all strain gauges were confirmed to meet the required standard.

Prior to strain gauge installation on predetermined measurement points, the target surface must undergo through cleaning to ensure optimal adhesion. This preparation process involves surface degreasing to remove oil dust and contaminants using acetone. Surface abrasion to create a uniform bonding surface then final cleaning with cleaning agents to ensure proper adhesion. This meticulous preparation is critical as it directly affects measurement accuracy by ensuring complete bonding between strain gauge and substrate, eliminating potential consistent strain transfer from structure to sensor. The



Figure 5. Resistance measurement

cleaned surface must pass visual inspection slippage or signal interference and maintaining under proper lighting before proceeding with strain gauge application. Figure 6 demonstrate the approved surface condition achieved through this preparation process. After all the strain gauges are installed, all values of strain gauge on data logger are set to zero (zero setting).

The experimental setup utilized single-type strain gauges for stress measurement. For this configuration, stress can be calculated using fundamental Eq. (1):

$$\sigma = E \cdot \varepsilon \quad (1)$$

where σ = Stress (MPa); E = Modulus of elasticity of the material (GPa); ε = Strain ($\mu\text{m}/\text{m}$).

The vertical load applied to the bus consist of passenger weight and luggage weight. The maximum number of passengers is 70 people, with an average passenger weight of 70 kg and luggage weight of 5 kg per passanger as shown in Figure 7. According to regulation of Minister of

Transportation number KM 41 of 2010 , the total vertical load is calculated by multiplying the combined weight of passengers and luggage by dynamic coefficient of 1.3 [25], [26]. The vertical load calculation can be seen in Eq. (2) :

$$F_v = k \cdot m \cdot g \quad (2)$$

where F_v = Vertical load; k = 1.3 (dynamic coefficient); m = Total weight of passengers and luggage (Kg); g = Gravitational acceleration (m/s^2).

Therefore, the total load applied to the bus is following Eq. (3).

$$F_v = 1.3 \times (75 \times 70) \times 9.8$$

$$F_v = 66,885 \text{ N} \quad (3)$$

The load application was conducted using multiple 50 kg sandbags. The loading was applied incrementally in stages of 1000 kg (20 sandbags) each. The sandbags were distributed evenly across the bus seats and floor area as shown in Figure 8.



Figure 6. (a) Strain gauge on lower frame; (b) Strain gauge on upper frame

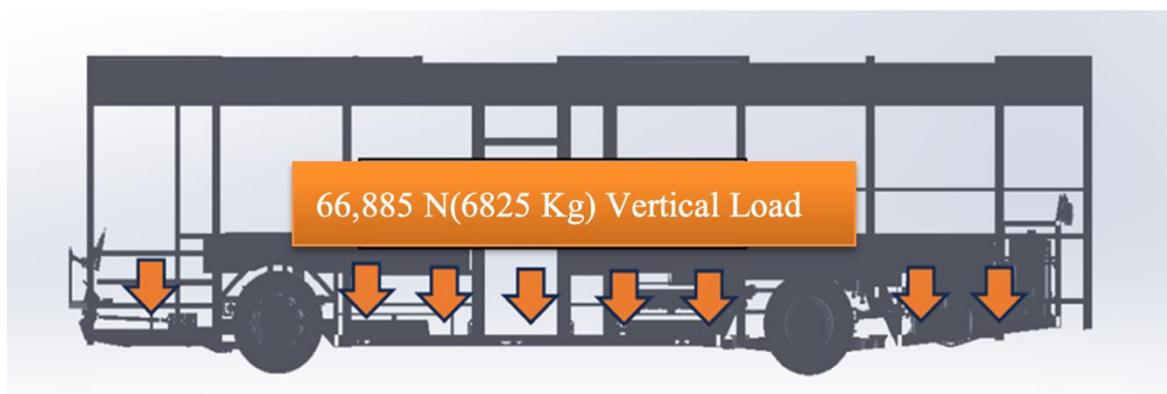


Figure 7. Vertical load



Figure 8. Load applied on the bus's floor and seats

3. Results and Discussion

3.1. Design Analysis

For comprehensive experimental testing of the electric bus structural strength, critical stress points must first be identified. The FEA model was constrained at the wheel contact points, while all translational degrees of freedom at these points were fixed to simulate actual support conditions [27]. The applied loads were distributed across the passenger seat mounts, roof structure and equipment mounting locations in order to capture operational loading as shown in [Figure 9](#).

The finite element analysis simulation result presented in [Figure 10](#) demonstrates the equivalent stress under full load condition of 5250 kg (51450 N), revealing that the maximum stress of 117.8 MPa occurs in the lower frame near the battery compartment and driver's seat area, representing 48% of the SS400 material's yield strength 245 MPa from [Table 1](#), while the upper frame structure experiences peak stress of 79.8 MPa at the air conditioning system mounting points, corresponding to just 28% of the Aluminum Alloy 6061 yield strength 276 MPa from [Table 2](#).

The finite element analysis results reveal that under 30% overload condition as shown in [Figure 11](#), the stress on the lower frame increased to 236 MPa while the upper frame experienced a reduced stress level of 43.69 MPa. This represents a 49.9% stress increase for the lower frame but 54%

stress reduction for the upper frame structure due to effective load redistribution. Importantly, both values remain well below the yield strength of their respective material, 245 MPa for the SS400 and 276 MPa for the Aluminum Alloy 6061. The stress concentration primarily observed in the structure as expected, particularly near high-load areas.

The simulation is also conducted at specific points on the lower and upper frame, as shown in [Figure 3](#) and [Figure 4](#). Strain gauges no. 1 to 20 were installed on the lower frame made of SS400, while strain gauges no 21 to 28 were placed on the upper frame made of aluminum alloy 6061. The resulting stress values at full load and 30% overload are presented in [Table 4](#).

3.2. Vertical Load Result

The experiment was conducted by incrementally loading sandbags into the bus, with each step adding 1000 kg, up to the full load of 5250 kg. An additional 30% load was then applied, resulting in a total load of 6825 kg. The strain gauges reading was recorded using data logger, as shown in [Figure 12](#). Value of the strain gauges are read in micro strain ($\mu\epsilon$). Based on the working principle of strain gauge, which measure resistance change caused by deformation, when the material is subjected to compression, its length decreases, resulting in a negative strain value.

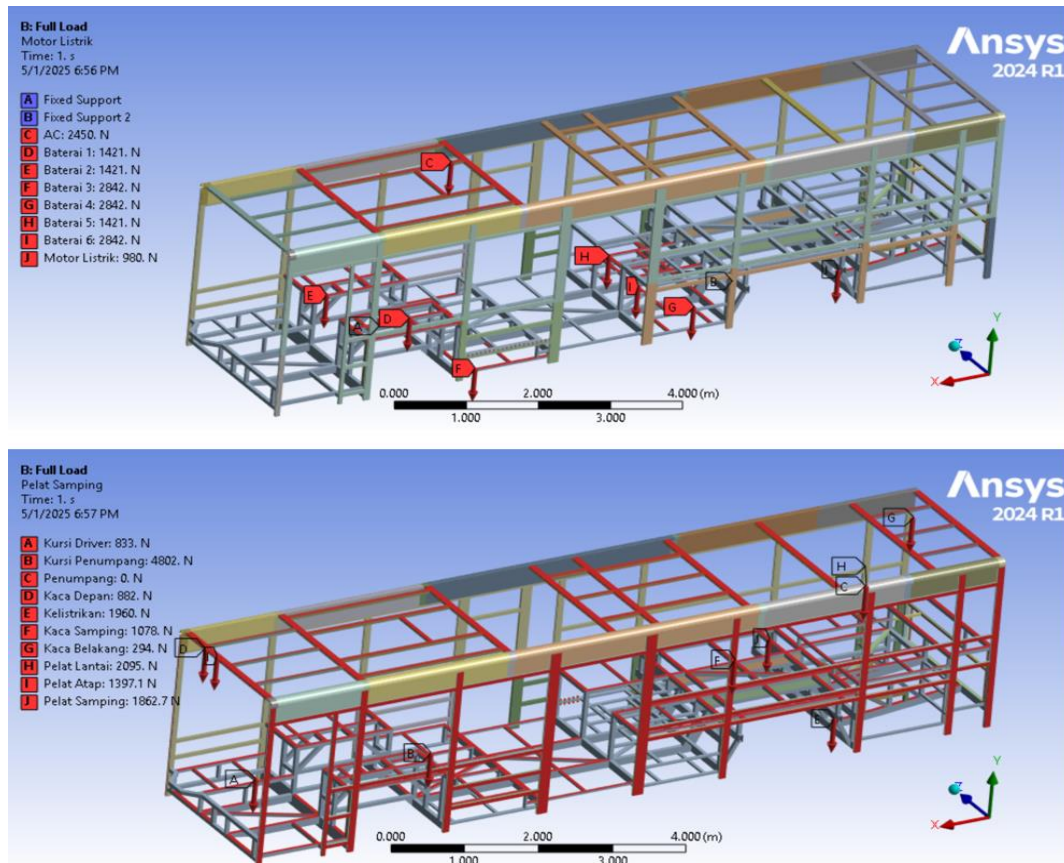


Figure 9. Load distribution and fix support

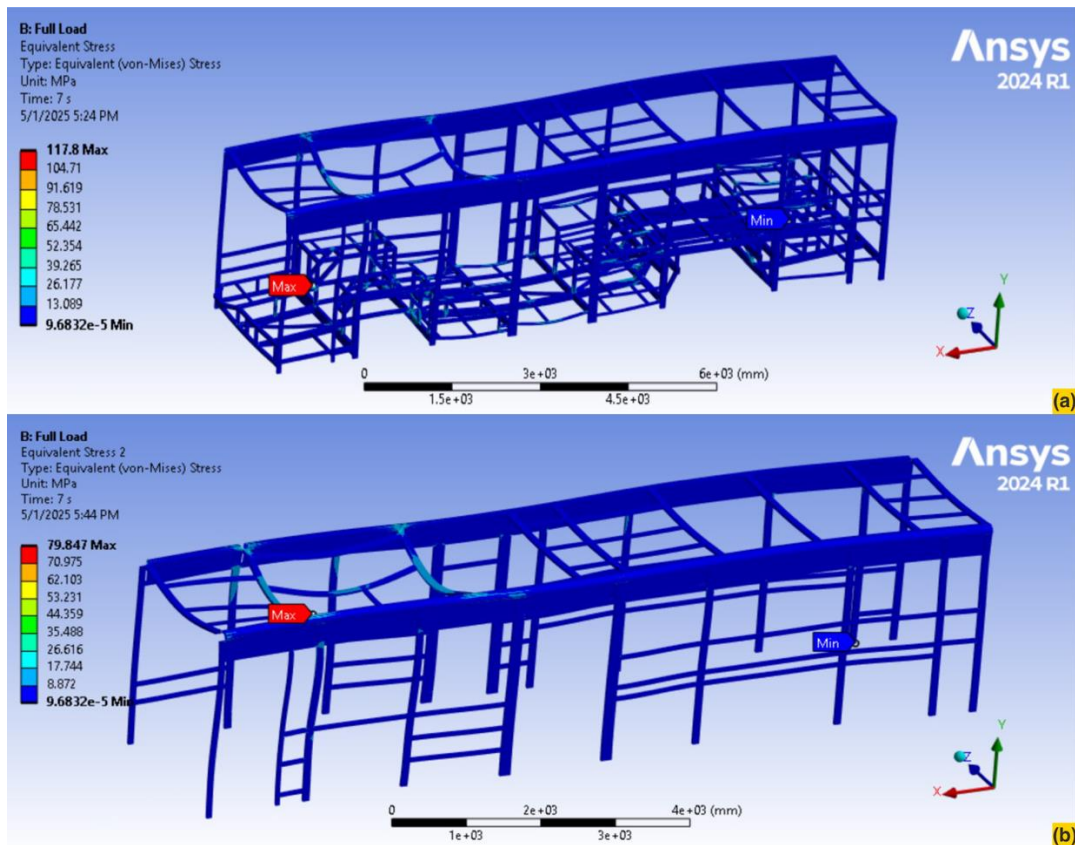


Figure 10. (a) Result of full load equivalent stress on lower frame; (b) Result of full load equivalent stress on upper frame

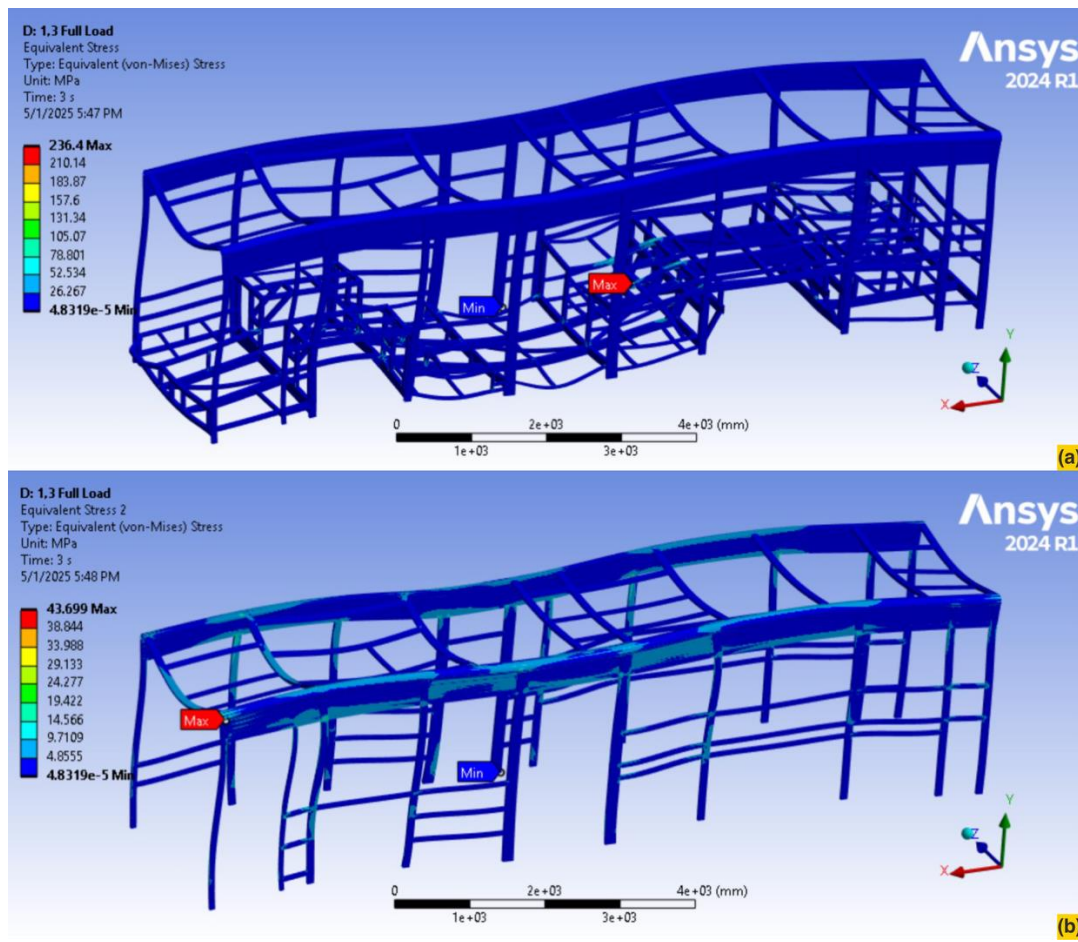


Figure 11. (a). Result of 30% overload equivalent stress on lower frame; (b) Result of 30% overload equivalent stress on upper frame

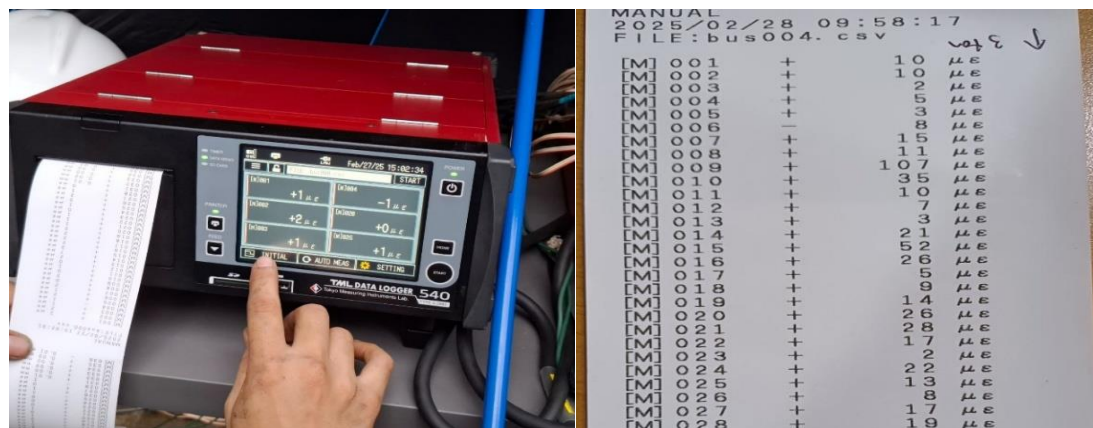


Figure 12. Acquisition of strain gauge readings via data logger

Conversely, when the material is subjected to tension, its length increases, producing a positive strain value.

The change in strain gauge readings is then converted into stress values using Eq. (1), by multiplying the strain gauge value with the modulus of elasticity. The modulus elasticity values are provided in Table 1 and Table 2. For SS 400 material is 271 GPa or 271,000 MPa while for

Aluminum Alloy 6061 is 68.9 GPa or 68,900 MPa. The variations in strain gauge readings can be found in Table 5.

The resulting stress values need to be added to the stress values obtained during the tare load condition. The stress values under the tare load can be found in Table 6, while the total stress experienced by each strain gauge is presented in Table 7.

Table 4. Strain gauge simulation stress result

Load	(N)	66885
	(kg)	6825
Strain Gauge 1 (MPa)		4.88
Strain Gauge 2 (MPa)		4.91
Strain Gauge 3 (MPa)		7.33
Strain Gauge 4 (MPa)		2.10
Strain Gauge 5 (MPa)		25.27
Strain Gauge 6 (MPa)		3.13
Strain Gauge 7 (MPa)		22.12
Strain Gauge 8 (MPa)		17.25
Strain Gauge 9 (MPa)		27.11
Strain Gauge 10 (MPa)		25.27
Strain Gauge 11 (MPa)		20.10
Strain Gauge 12 (MPa)		21.34
Strain Gauge 13 (MPa)		21.20
Strain Gauge 14 (MPa)		21.55
Strain Gauge 15 (MPa)		23.21
Strain Gauge 16 (MPa)		23.24
Strain Gauge 17 (MPa)		5.17
Strain Gauge 18 (MPa)		5.20
Strain Gauge 19 (MPa)		0.64
Strain Gauge 20 (MPa)		0.53
Strain Gauge 21 (MPa)		3.50
Strain Gauge 22 (MPa)		3.38
Strain Gauge 23 (MPa)		5.30
Strain Gauge 24 (MPa)		4.31
Strain Gauge 25 (MPa)		6.66
Strain Gauge 26 (MPa)		6.56
Strain Gauge 27 (MPa)		3.65
Strain Gauge 28 (MPa)		4.25

Table 5. Strain gauge values reading

Load	(N)	66885
	(kg)	6825
Strain Gauge No.	$\mu\epsilon$	
1	34.00	
2	26.00	
3	11.00	
4	6.00	
5	-11.00	
6	-82.00	
7	-17.00	
8	-27.00	
9	362.00	
10	118.00	
11	124.00	
12	112.00	
13	14.00	
14	30.00	
15	103.00	
16	8.00	
17	14.00	
18	13.00	
19	15.00	
20	161.00	
21	49.00	
22	41.00	
23	-2.00	
24	18.00	
25	-17.00	
26	3.00	
27	13.00	
28	35.00	

Table 6. Simulation stress values on tare load

Strain Gauge No	Stress (MPa)
1	2.28
2	2.72
3	4.58
4	1.86
5	7.91
6	1.16
7	5.26
8	4.00
9	2.08
10	1.53
11	3.31
12	3.71
13	5.79
14	6.23
15	5.45
16	5.51
17	2.37
18	2.49
19	0.39
20	0.39
21	0.28
22	1.10
23	1.80
24	1.83
25	13.97
26	13.46
27	8.81
28	12.90

Table 7. Actual total stress values on strain gauge

Load	(N)	66885
	(kg)	6825
Strain Gauge No.	Stress (Mpa)	
1	9.42	
2	8.18	
3	6.89	
4	3.12	
5	5.60	
6	-16.06	
7	1.69	
8	-1.67	
9	78.10	
10	26.31	
11	29.35	
12	27.23	
13	8.73	
14	12.53	
15	27.08	
16	7.19	
17	5.31	
18	5.22	
19	3.54	
20	34.20	
21	3.66	
22	3.92	
23	1.66	
24	3.07	
25	12.80	
26	13.66	
27	9.70	
28	15.32	

The highest stress value under 30% overload condition equivalent to a load of 6825 kg for SS400 material was recorded at central frame area on strain gauge no. 9, with stress value is 78.10 MPa. This value remains well below the yield strength of material of SS400, which is 245 MPa, representing approximately 31.87% of the yield strength. The location of this strain gauge corresponds to the passenger seating area and standing space, as illustrated in Figure 13.

The highest stress on Aluminum alloy was observed at strain gauge no. 28, with a value of 15.32 MPa. This is also significantly below its yield strength of 276 MPa, accounting for only about 5.5% of the yield strength. Strain gauge no. 28 is positioned in the area designated for the air conditioning system, as shown in Figure 14.

A comparison between the simulation results and experimental measurements revealed a deviation of 18.6%. The deviation is most likely due to the load being concentrated in central aisle during testing which affected the stress values measured. Despite this difference, both approaches showed consistent identification of high stress areas, demonstrating good agreement in predicting critical stress zones. These findings confirm the reliability of the simulation while emphasizing of experimental validation. A visual comparison of simulation and experimental results are illustrated in Figure 15.

Based on Figure 15, it can be observed that several parts of the bus exhibit higher stress or

greater changes in strain gauge readings compared to others. In the lower frame made of ss400 material, stress concentrations are found at strain gauge no. 9, 10, 11, 12, 13, 14, 15, and 20. Strain gauge no. 9, 10, 11, 12, 13 and 14 are located in the central area of the bus, which accommodates six seats and standing space for 10-15 passengers, as shown in Figure 16. Other areas with high stress values are strain gauge no. 15 and 20, where strain gauge no. 15 is located near differential and battery pack, while strain gauge no. 20 corresponds to inverter and electrical system area. The simulation results also indicate that the lower frame areas with higher stress concentrations are located on the central area of the bus, as represented by strain gauge number 5, 7, 11, 12, 13, 14, 15, and 16.

The stress distribution on the upper frame made of Aluminum Alloy 6061 is observed at strain gauges no. 25, 26, and 28. Strain gauge no. 25, 26 and 28 correspond to the air conditioning system installation area, as shown in Figure 17.

4. Conclusion

The experimental results on the lower frame made of SS400 material indicate that highest stress occurs in the central area of the bus, which corresponds to the passenger seating and standing area, as well as the placement of the battery pack, drivetrain and battery management system. Similarly, the simulation result also show that the maximum stress is concentrated in the

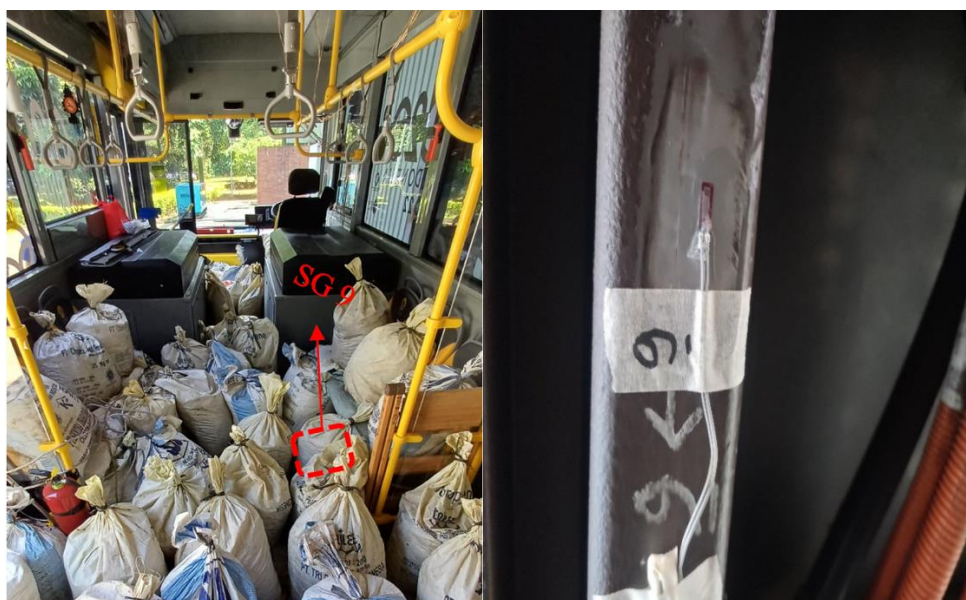


Figure 13. Strain gauge no. 9 location



Figure 14. Strain gauge no. 28 location

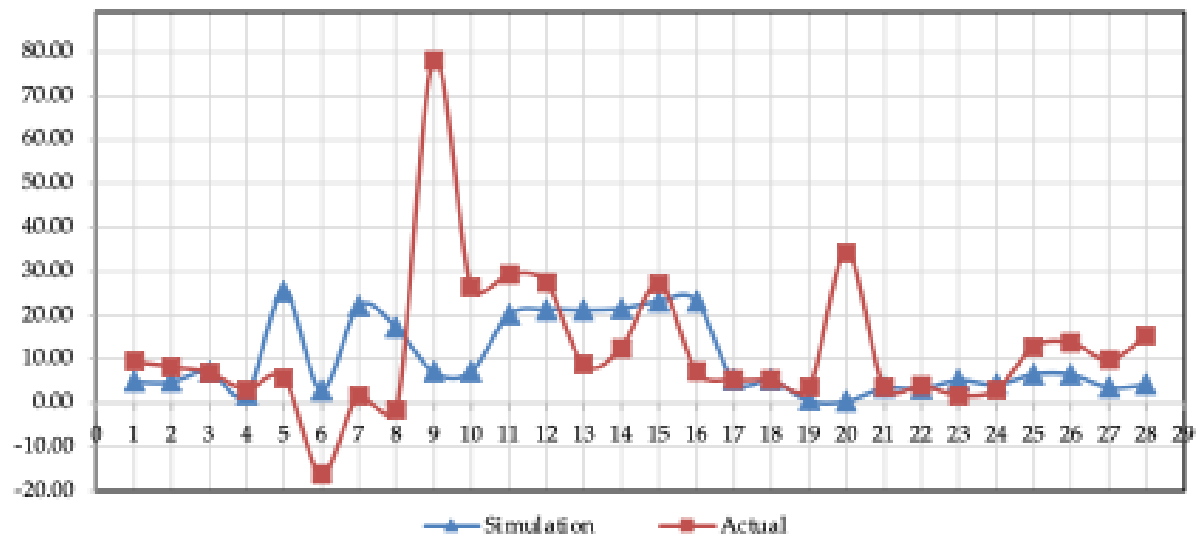


Figure 15. Simulation and actual stress value at 30% overload (6850 kg)



Figure 16. Strain gauge at central deck



Figure 17. Strain gauge at air conditioning system

same central area. For the upper frame, constructed from Aluminum Alloy, both experimental and simulation result consistently identify the critical area at the location of air conditioning system.

These findings demonstrate that the vertical load testing method can effectively be used to evaluate critical stress regions of the bus structure. This method may serve as an alternative approach for structural strength assessment and optimization of the bus frame. Although a dynamic load coefficient of 30% of the full load was included to approximate stresses during real operating conditions, full scale dynamic testing is still required to validate the structural strength and fatigue resistance under operating conditions. Furthermore, static vertical load testing may be conducted at preliminary stage, prior to the installation of additional equipment, to assess the structural integrity of the bus.

Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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Competing interests

The authors declare no competing interest.

Additional information

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