Mekanika: Majalah Ilmiah Mekanika

Design Analysis and Structural Prediction of Bus Driver Chair Support: A Study Case using HOQ and FEM

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Keywords:
Driver seat support
Finite element method
Shear force
House of quality
The safety factor

Abstract
The bus driver's comfort is crucial. The location of the driver's seat, which is correlated with the seat support design, is one of the elements supporting his comfort. By considering the safety factor, House of Quality (HOQ), weight, shape, and seat support dimensions, this study intends to ascertain how the characteristics of the bus seat support form after receiving a load or force. Conducting a field visit to gather the necessary data was the initial step in this research. The following stage was to decide on the design criteria based on the collected data. Next, use SolidWork to model the design. Using the Finite Element Method (FEM), this program can investigate design characteristics. The loading simulation under consideration included clutch engagement, bus brake application, and clutch engagement, whether the support was static or stationary. The validation with two supporting journals was then run as the following step to validate the findings. According to the study's findings, the constant chair support fulfills the typical value, whereas Support 1 was the most fracture-prone. The outcomes of Supports 2 and 3 demonstrated that the support strength was weak since it was subjected to an unequal load.

1 Introduction

The safety of land transportation is one of the important topics to study. Many factors must be considered because of economic interests and people's lives. As an illustration, in 2019, 116,411 land transportation accidents occurred in Indonesia [1]. This figure is predicted to continue to increase until 2035 as the number of vehicles in operation increases [2]. This increase in the number of cars can be suppressed by optimizing existing modes of mass transportation. It is anticipated that the number of private vehicle users will decline, along with the accident rate. Buses are one of the mass forms of transportation that have the potential to be developed in Indonesia because it is cheap, accessible, and tend to be more environmentally friendly. BPS-Statistic Indonesia defines a bus as a motor vehicle with more than eight passenger seats weighing more than 3,500 kg. Currently, there are thousands of buses (0.17% of the total active vehicles in Indonesia) operating with thousands of passengers who must be carried around every day [1,3]. Therefore, the safety of this mode of transportation needs to be carefully calculated.

https://dx.doi.org/10.20961/mekanika.v22i1.44371

Revised 17 March 2023; received in revised version 20 March 2023; Accepted 21 March 2023
Available Online 31 March 2023

2579-3144

There are so many aspects that affect the level of bus safety for passengers. The bus's technical performance and human error influence some of these aspects. Poor bus performance, such as brake damage, structural failure, or engine damage, can impact passenger safety. The human error factor is a driver who is not focused on working or experiences fatigue when driving. Along with the times, the technology installed in bus transportation has also been updated. This update aims to improve the comfort and safety of bus passengers when traveling. Many aspects must be updated, including the driver's seating position. The driver's role plays a crucial part on a bus. The comfort of the passengers will be harmed regardless of how well-maintained the bus is if the driver is not at ease. Positioning the driver's seat and its design and long-term comfort can influence that person's comfort. Because the driver's ability to focus on driving will be impaired by fatigue, this will also put the passengers in danger. Due to their inability to focus on the road conditions while tired, drivers are a significant factor in many accidents [4-6]. One of the critical elements in the bus driver's seat comfort while operating the vehicle is the layout of the driver's room. This part pertains to the ergonomic element, namely the arranging position in vehicle design, specifically the link between humans and their work environment, the instruments they use at work, and other factors related to work safety, efficiency, and effectiveness [7]. The driver room layout differs between buses. They started with the style and design of the driver's seat, legroom, backrest inclination, and seat support.

The Quality Function Deployment (QFD) approach was used in prior studies to redesign chairs [8,9]. By taking anthropometric measurements (adjusted for body shape) and analyzing how much value the added value had on the chair redesign for the user, the study was conducted regarding the quality of the chair and comfort. Many aspects still need to be modernized based on the outdated bus seat design, particularly those that deal with seat support. This research involved revamping the support to create a driver's seat support that is both safer and more comfortable for bus drivers considering safety factors and House of Quality (HOQ) [10-12]. The Finite Element Method (FEM) is used to implement Quality Function Deployment (QFD) form to simulate different loading scenarios in this study. In addition, selecting materials is one of the considerations that must be considered. The material used must be appropriate because even if the design is good, but the material is wrong, the risk of failure will remain high.

2 Literature Review

Previous research on chair design optimization using FEM has been presented by [13]. The results showed that a good chair design must be robust in accepting loading and have a relatively small mass. The seat must be able to evenly distribute the load to each of its fulcrums. The safety factor must adjust to the maximum load the chair can handle. Due to frequent limitations, proper seat balance will maintain the seat's lifespan. Concerning the bus structure, the smaller the seated mass, the lighter the load the chassis will receive [14-16]. The part that connects the seat with the chassis is called support. This part can be further optimized to obtain the most suitable shape and size. Stress analysis using FEM makes it possible to see the voltage distribution in this support part. Simulation can be carried out in various conditions that affect the loading scenario. This method is considered more time efficient when compared to using the experiential method directly [17].

The chair's shape should adjust to the posture of the human body. In this case, anthropometry is needed so that the chair's design can comfort its users [8,18]. A design that does not offer comfort will make the user tired quickly. A static seat with a bus driver's seat has a different function. In stationary seats, the only consideration is the force of gravity. However, the seats on the driver's bus receive more complex loadings affected by the acceleration and deceleration of the vehicle. The angle of application modifies this complicated force. An adjustable seat configuration is more advisable, changing the individual driver. More specific research utilizing interview data from heterogeneous sources is essential.

3 Research Methods

3.1 Materials and design

This research was conducted at PT Selamet Trans Abadi, Pati, Central Java - Indonesia. The first step taken was to collect data through field observations. The observations, HOQ, and the Voice of Customer (VOC) questionnaire showed that the chair support on the bus needed to be redesigned. Several design variations were then created using SolidWorks 2019 Student Version software. The material used in this study was adjusted to the actual conditions, namely American Iron and Steel Institute (AISI) 1020, shown in Table 1.

Table 1. Mechanical properties of AISI 1020 [19]

Material	Tensile Strength	Yield Strength	Elastic Modulus	Shear Modulus	Elongation
AISI 1020	420 MPa	350 MPa	205 GPa	80 GPa	36.5%

3.2 Methods

The method used in this study had been validated using a benchmarking procedure with previous research [20]. The variations of the chair supports were selected based on the survey results. These results were used to see the user's response to the seat support form during testing to see which support was better. After obtaining the actual shape dimension data, proceed with a simulation using the SolidWorks 2019 Student Version application. The simulation began with modelling. The first step when making a model was to sketch the supports using the sketch mode. Then, after the sketch was complete, it was refined using methods on features such as extrude and shell to shape the graphic into the actual shape of the support.

Furthermore, input settings were carried out, and we were in this phase, and what was done was starting to add a simulation mode to SolidWorks. This mode will be used for running the simulation. The boundary condition applied was to give a clamp on one side and then a force on the other, adjusted to the actual state. This study discussed the support of using a pinch pedestal. The clamp support was to bolt the holes on the supports to the base or walls in the bus's interior. So, the fixed geometry setting was chosen on the SolidWorks in the lower bolt hole, intending that the simulation resembled the actual conditions where the seat supports were bolted to the bus's interior. The load on the supports of the upper seat frame and the driver was also carried out. The giving of this burden was divided into three types. The first was the static load scenario, in which loading happened as soon as the driver was seated. From top to bottom, loading condition (F) occurred in the direction of the pedestal. The second condition was the load when stepping on the clutch. The pressure exerted on five trials averaged 30 kg, converted to 294.2 N. These results were obtained by placing the scale on the clutch and then stepping on the grip to determine how much force was needed to make the clutch shift the transmission gears. The third condition was the load when applying the brakes, where when you step on the brake pedal, there was a force that pushed the chair with a backward force and a forward force. The result was a decrease in speed resulting in a pull from behind. This study gave a bus boundary condition with a 60 km/hour rate, then brakes within 100 m to a speed of 0 km/hour [14,16]. After the simulation with various loads, validation was followed by an analysis of the results and conclusions. Verification and validation were done by comparing the simulation results from two settings to produce research objects.

4 Results and Discussion

A good driver seat design could provide comfort for the wearer but still had solid technical specifications that accepted the loading. Stress analysis using FEM had been taken to test whether the product design met the engineering requirements. The simulation was carried out by providing loading as described in the research parameters. The bus driver's seat support simulation results will be displayed in graphs and tables. The discussion is carried out by observing contour figures and comparing existing values.

4.1 Static load condition

Data can be obtained from testing static load conditions arranged in Table 2 and Figure 1. The relationship between the loading weight and stress on each support had been identified.

Table 2. Stress results in static condition

Type	Weight (kg)	Stress Result (MPa)
Uniform	70	22.67
	95	30.79
	120	38.87
Support 1	70	60.35
	95	81.9
	120	103.5
Support 2	70	18.9
	95	25.7
	120	32.5
Support 3	70	5.3
	95	7.24
	120	9.1

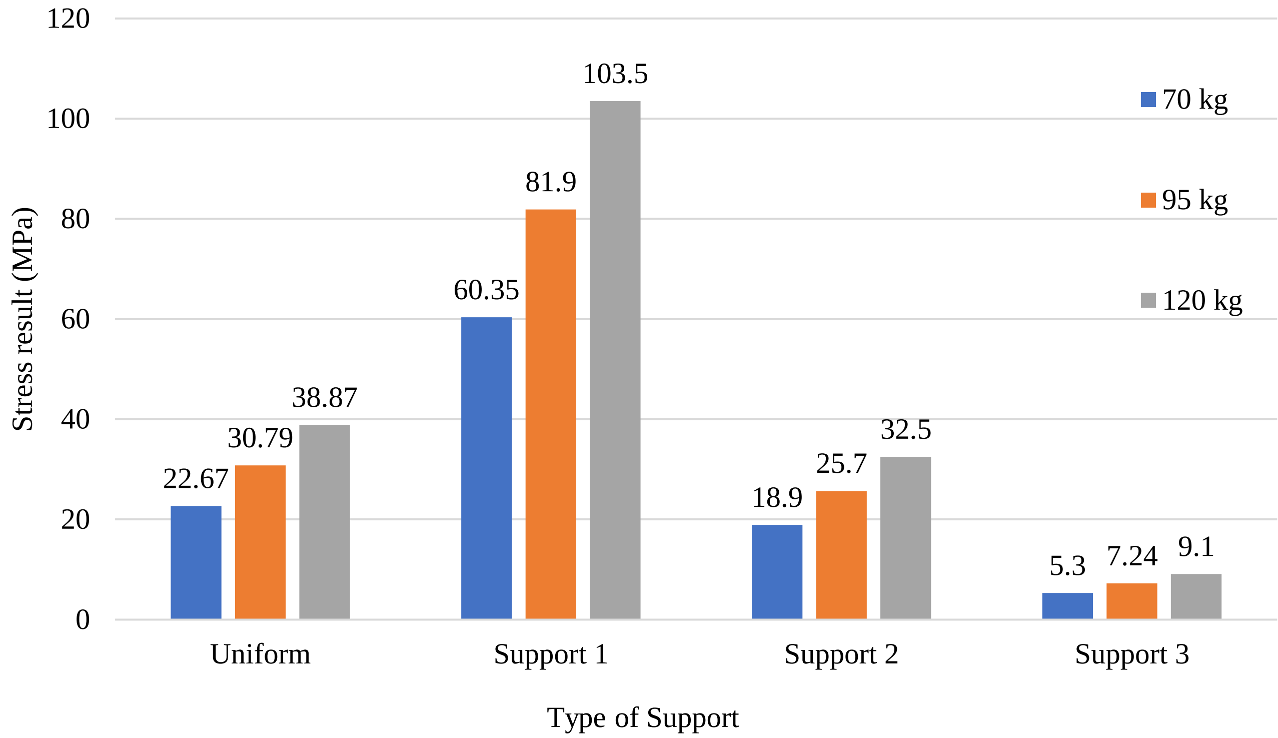


Figure 1. Simulation results in static load condition

Figure 1 shows that for all loads, both 70 kg, 95 kg, and 120 kg, the three of them showed that the result of Support 1 had the highest stress among other supports. Whereas for all loads, the tension of Support 3 showed the smallest number. The pressure on Support 1 was due to the bolt holes attached to the wall. This phenomenon caused the load to be held more by the supports, the seats, and the bus driver. As for other supports, the bolt holes were attached to the floor. Support 3 was the best because of the three loads, and support three still had the lowest tension. This result was due to the design of Support 3, which can distribute the stress more evenly than the other supports.

These results also illustrated that the four supports can still accept the load without fractures or fractures in the chair supports. The standard value expected of support that can withstand the load or input stress was taken from the three lowest data in the 45 MPa. Thus, the four supports still met the Factor of Safety (FOS), where the resulting von mises stress was not more than the yield strength so that the support's shape, the support's position, and the load applied to the supports can affect the stress simulation resulting in the SolidWorks 2019 program.

4.2 Condition when stepping on the clutch

Based on the results of testing the load conditions when stepping on the clutch, data can be obtained, which were then arranged in Table 3, then in Figure 2 shows the previously generated data in graphical form.

Table 3. Stress results when stepping on the clutch

Type	Weight (kg)	Stress Result (MPa)
Uniform	70	19.15
	95	27.26
	120	35.35
Support 1	70	60.6
	95	82.16
	120	103.7
Support 2	70	33.4
	95	39.8
	120	46.2
Support 3	70	9.77
	95	11.1
	120	12.4

Table 3 shows the support characteristics due to gear displacement. Support 1 experienced the maximum stress when compared to other types of support. However, this stress value was still in the elastic area. This phenomenon means that this condition was relatively safe if the load imposed was relatively stable at a certain period. What needed to be watched out for was the influence of the fatigue phenomenon on the material. The design used soft AISI 1020 material, where the risk of fatigue failure was still possible. Support 3 showed the best performance, where the stress that appeared tended to be the least when compared to other types. This small stress value was estimated to be below the material fatigue limit, so it was predicted that the design will not fail under normal conditions. The human error factor was interesting to consider because each driver had their style when driving a bus. Inexperienced drivers may shorten the life of components due to mistakes when moving gears.

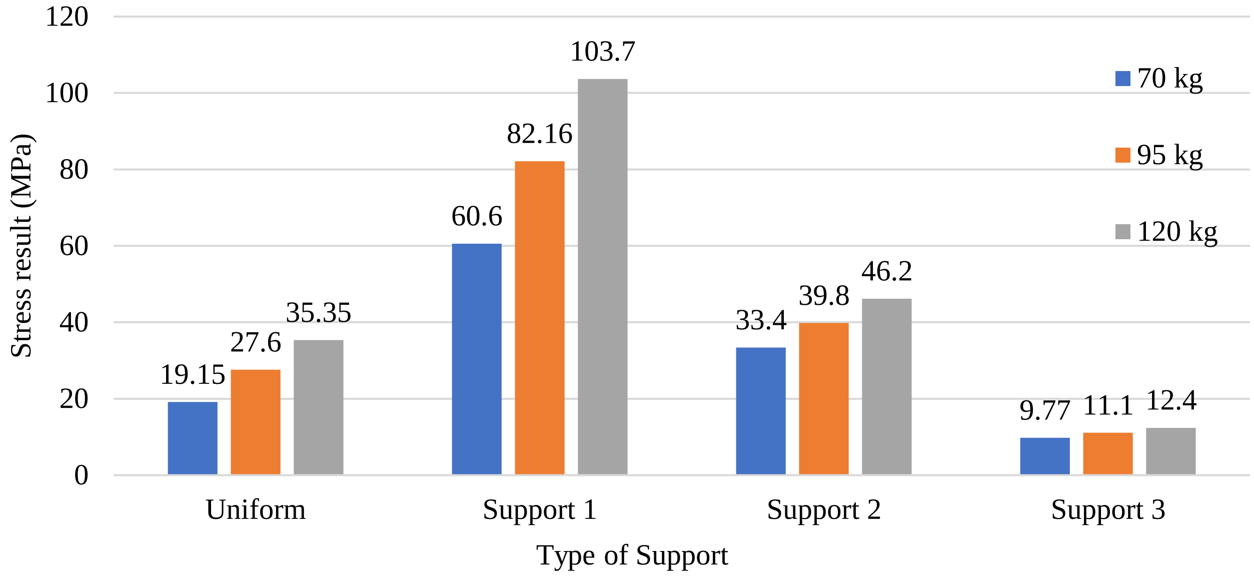


Figure 2. Simulation results in stepping on the clutch condition

Uniform and Support 2 had almost the same characteristics. The range of stress experienced by these two types of support was relatively small. Both kinds of support showed maximum stress at a load of 120 kg. However, the stress that arose was much smaller when compared to type Support 1. The uniform type, Support 2 and Support 3 had pretty good performance and were worth considering.

4.3 The condition when applying the brakes

Data can be obtained from testing static load conditions, which are then arranged in Table 4, then Figure 3 shows the results in graphical form.

Table 4. Stress results when applying the brakes

Type	Weight (kg)	Stress Result (MPa)
Uniform	70	24.03
	95	32.98
	120	41.9
Support 1	70	60.9
	95	82.9
	120	105
Support 2	70	22.16
	95	30.64
	120	39.1
Support 3	70	5.77
	95	7.95
	120	10.21

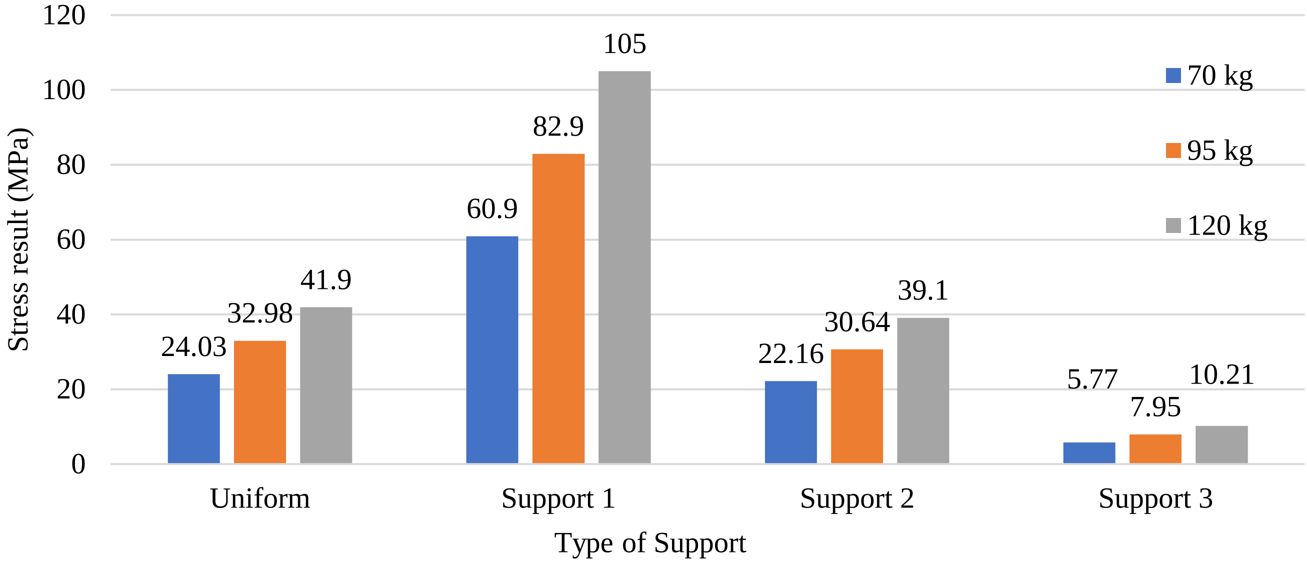


Figure 3. Simulation results in applying brakes condition

Based on the results shown in Figure 3, the increase in each support tended to be more consistent compared to when under static load conditions and stepping on the clutch. This phenomenon was because the direction of the load given when applying the brakes tended to be more evenly distributed. When the driver applied the brakes, there was an inertial loading from the back. As can be seen, the supports can still hold the chair's weight when it was simultaneously loaded from the front, rear, and above. Another factor that affected was the shape of the support, which in testing the Support 2, experienced a drastic increase. This condition was due to the body of Support 2, which made it possible that if the loading was not balanced, the load received by the supports will be more significant so that the stress results from the simulation will experience a drastic increase.

4.4 Factor of safety

A bus is a superstructure that combines a wide variety of more superficial structures. The safety factor is one of the benchmarks for the strength of the design in receiving a load. Each section will give a different response. Concerning stress, each nodal will have an additional value depending on the magnitude of the force compared to the cross-sectional area. Safety factors will form contours because the distribution will be diverse.

In comparison, the minimum distribution value of each design variation will be selected as its performance benchmark. The suggested safety factor varies depending on the circumstance. A safety factor of at least two is deemed adequate for static loads, but a much higher recommendation is needed for dynamic and impact loads. At least a minimum safety factor of two to five is required to prevent the impact load from causing failures in the structure. The simulation of the safety factor described in the parameters can be used as a graph. Figure 4 demonstrates how the contour of Support 2 was almost identical to the constant support marketed generally. Due to its large size and shape compared to the other three supports, Support 3 had the highest safety factor. Support 1 had the lowest yield because the position of the clamp support was on the wall and not on the bus floor, so the authorization's weight will also affect the stress result. All types of support were safe in the face of existing static loads. However, the conditions will be very different when there was a load impact or repeated load. Support 1 will experience a relatively dangerous catastrophic failure.

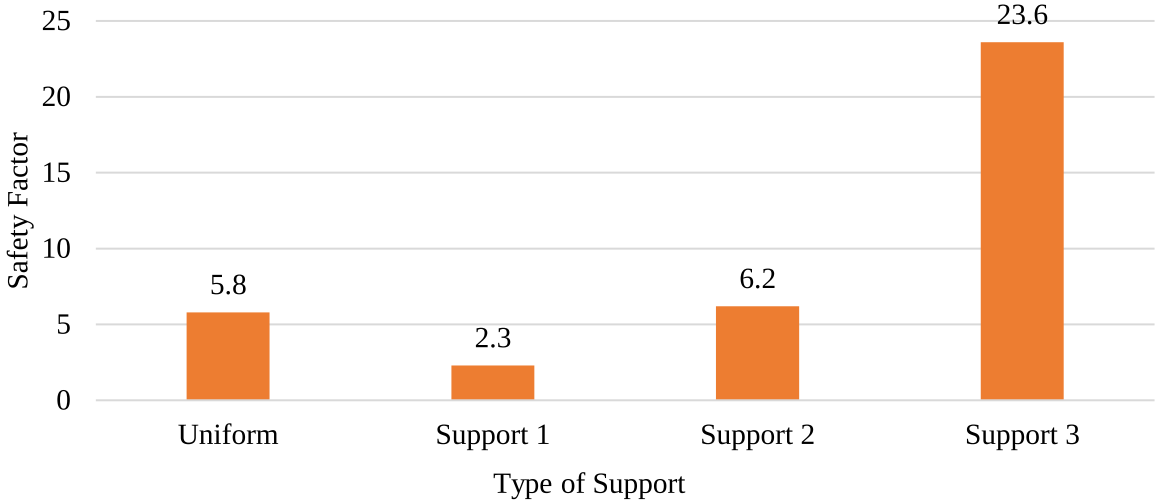
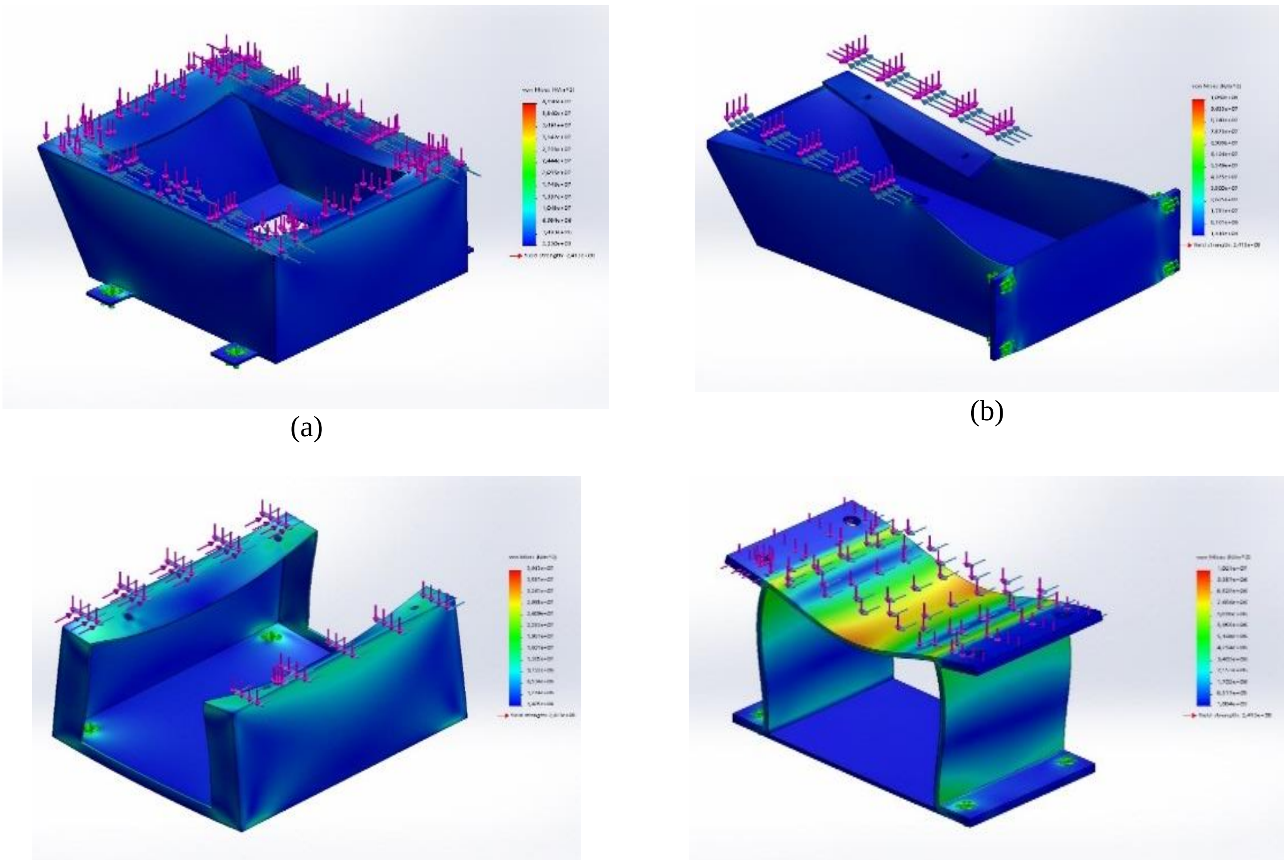


Figure 4. Simulation result: Safety factor

4.5 Von – Mises stress result

Figure 5 shows the von mises stress on the supports resulting from the simulation. These results were of high value in certain sections due to differences in the dimensions of the supports, so the resulting stress points varied. Figure 5 describes how each support distributed the incoming stress. The blue color description explains that the support part received the least stress. The interest in red represents the part of the support with the highest value stress. The difference between most components that bear the heaviest loads, mainly the bolt holes to the bus body, may be noticed more by expanding Figure 7.



(a) (b)

(c) (d)

Figure 5. Von – Mises stress results on support: (a) Uniform, (b) Support 1, (c) Support 2, and (d) Support 3

In uniform supports, the bolt holes were subjected to internal tension when bolted to the bus floor. Then support one showed the same stress when bolted to the bus wall. As a consequence of Support 2, when it was run against the floor, the pressure was more even in the bolt-hole area and less reached the critical point compared to constant support and Support 1. This condition occurred due to the bolt holes on the support plate affixed to the bus floor. Ladder 3 differed from the previous three supports in terms of its features. According to the simulation results, pedestal 3 was under significantly less stress. Besides, it had similarities with Support 2, with a few critical points around the bolt holes. This fact showed that in the actual conditions, as shown in Figure 6, the bolt holes will experience corrosion faster because they were the clamp support of the seat supports, which were the first to withstand the load when driving in any condition and position.

Figure 6. The actual condition of the support bolt hole after years of use

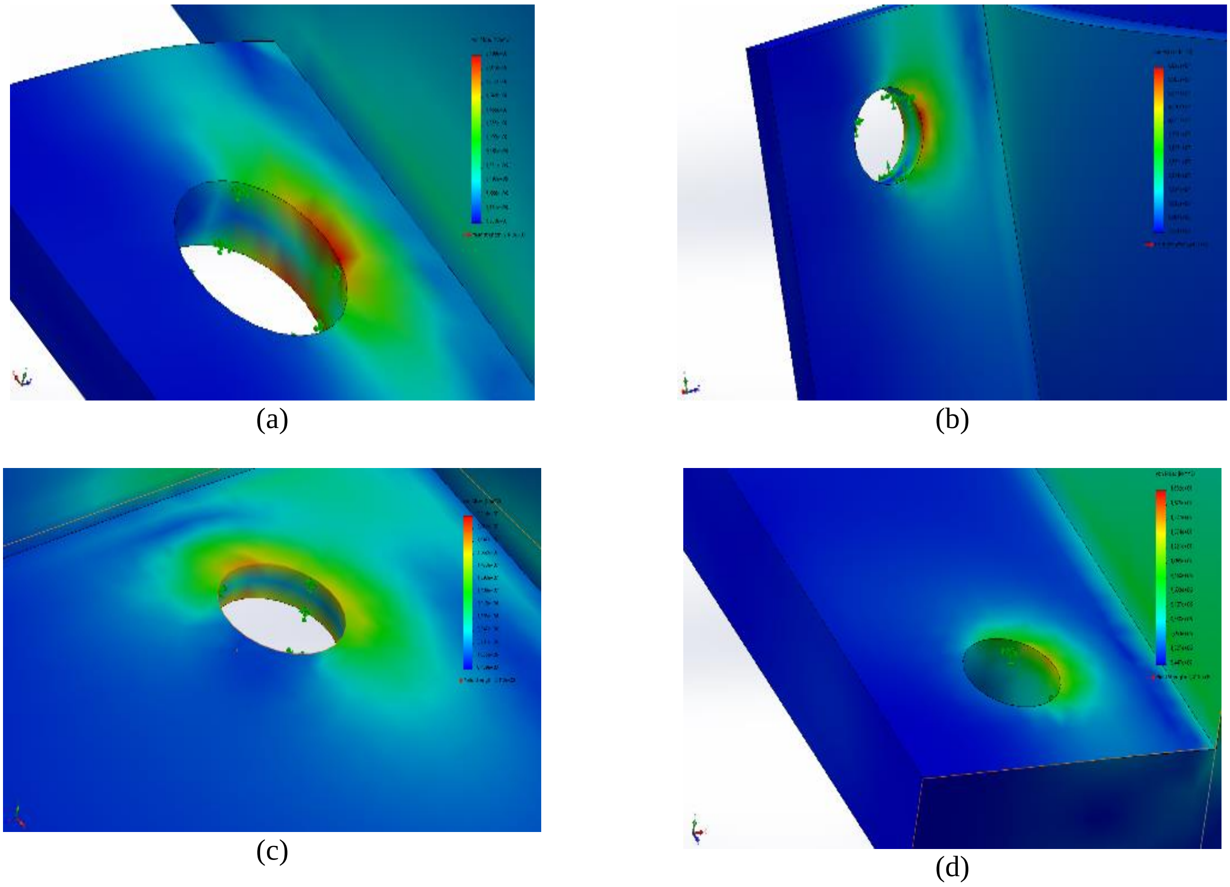


Figure 7. Magnification of the bolt hole of each support: (a) Uniform, (b) Support 1, (c) Support 2, and (d) Support 3

The stress distribution in bolt holes shown in Figure 7 can be observed. This hole was directly intersected with the bolt, which was assumed to be fixed support. The corner had a contour of red color, indicating the occurrence of a stress concentration. The characteristic of fixed support was that it can channel forces from various directions. This type of fulcrum made the structure rigid so that the area closest to the pedestal will receive both the action and the reaction forces. The contours of the blue color represent areas that did not experience stress at all. This part will have the most extended life compared to where the stress concentration occurs.

4.6 Driver response based on HOQ data

The best way to find out the needs of drivers was to conduct an interview. Ergonomic and anthropometric assessments for each individual showed different results. The data obtained was then processed so that it can be interpreted objectively. Based on the questionnaire distributed to several drivers about how the driver thought about each support, the following is the driver's response in the form of a graph in Figure 8.

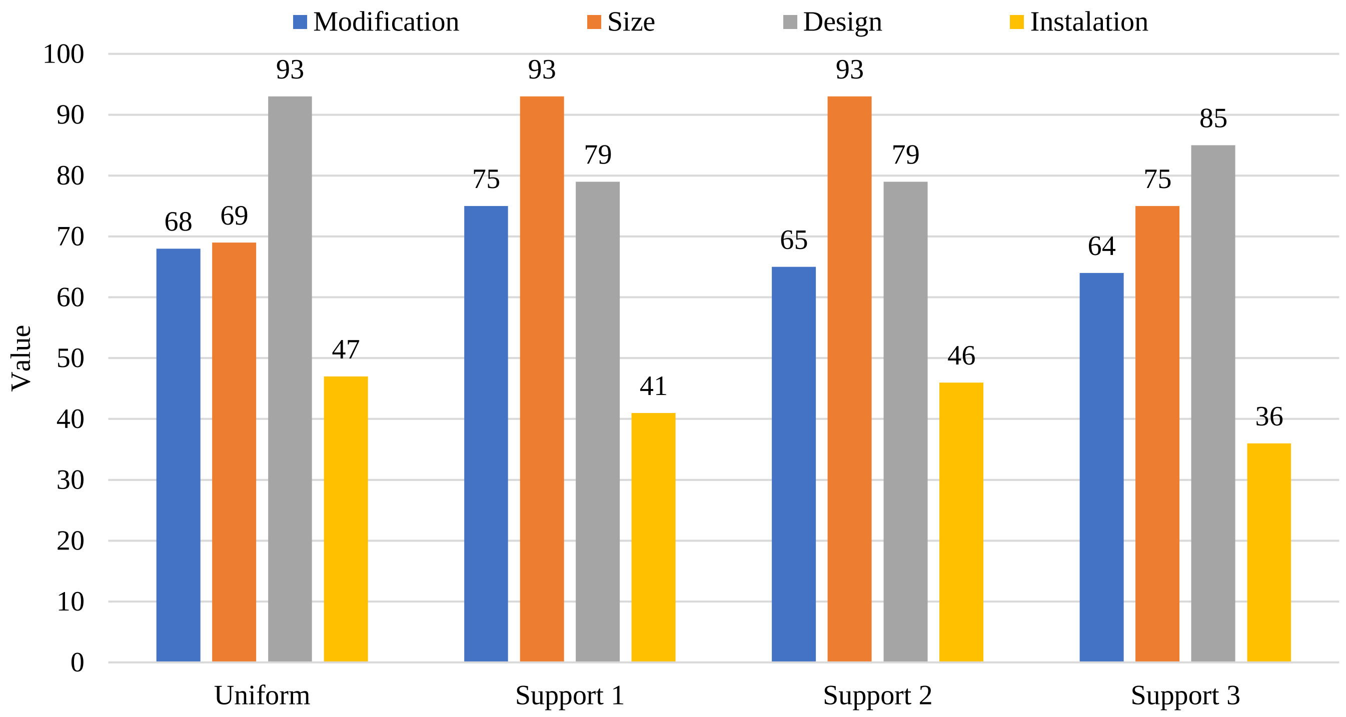


Figure 8. Importance of measuring HOQ value

According to the interviews with drivers, the most critical aspect of chair support design was the ease of installation and little change in the initial setup. These aspects included production standards, support strength, and support comfort. Aspects of size and design were not too crucial for drivers, so the priority of drivers from seat support was the safety and comfort of seat support in helping the performance of driving a bus. A poor design will quickly tire the driver, so they are not focused on working.

5 Conclusions

Based on studies conducted on the characteristics of the supports, it can be determined that:

1. Three types of testing with constant support produced the most consistent findings. As shown by the lowest value was lower than the average. These findings indicated that the uniform supports had complied with the required standard values.

2. Support 1 on three different test types demonstrated that the results were most susceptible to fracturing. The bolt holes' location on the bus wall was significantly higher than the range value.
3. Because the supports were not evenly loaded, Supports 2 and 3 on three different types of testing displayed a sharp increase in stress.
4. Despite the findings of stable pressure showing that support was the best for spreading or distributing stress, constant support was still the best support to utilize.

6 Acknowledgment

This work was supported by the RKAT PTNBH Universitas Sebelas Maret Year 2021, under the Community Service Scheme of “Pengabdian Kepada Masyarakat Hibah Grup Riset" (PKM HGR-UNS), with the grant/contract no. 261/UN27.22/HK.07.00/2021. The authors gratefully acknowledge the support.

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